Engineered Organisms: A formal Virtual Energy model

I. Purposes of the formal Virtual Energy model

The formal Virtual Energy (VE) model serves purposes of technology development and investigations of freedom exercised by animal bodies.

II. Preliminary concepts

1. The formal Virtual Energy model is a mental construction that combines aspects of atomic models and thermodynamic models.
2. An imaginary substance called Virtual Energy (VE) is constructed from shared features of H_2O, electrical charge and Conserved Energy.
3. Subsequent layers of construction occur in a VE domain that is similar to a circuit diagram domain. The VE domain features a plenum of sources of VE, deformable space and hierarchical time.
4 Elements of initial constructions are imaginary bodies ("VE devices") that carry flows of VE and convert VE between forms, producing pulsational signals and muscle-like twitches. In later constructions, a body contains many individual cells occupied by device modules and operating collectively.
5. Methods of construction include ideals, presumptive bodily properties, primal devices, kits of parts and provisional principles.

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I. Purposes of the model

> The formal Virtual Energy (VE) model serves purposes of technology development and investigations of freedom exercised by animal bodies.

This project has multiple aspects. In one aspect, VE models resemble theories of mathematical physics that have primitive concepts, definitions based on the primitives, axioms such as physical laws, and goals of proved theorems. [See C. Truesdell, *Rational Thermodynamics* (2d. ed. 1984) at 63-64.] VE models are intended to lead to new technologies. In another aspect, VE constructions aim to mimic natural phenomena of bodily freedom exercised by people and animals.

Diffculties arise because exercises of freedom are not readily investigated by methods of science. Exercises of freedom often involve "feelings" that are vague, momentary and indescribable. During exercises of bodily freedom, a choice of the next movement may turn on subconscious feelings that differ in multiple ways from person to person. In sports contests, happenstance events are often influential.

Notwithstanding difficulties, investigations of freedom on the homepage of the website show pathways of progress. Exercises of freedom can be closely examined during repetitive cycles of movement in a fixed, restricted environment, especially during habitual movements and programs of practice.

Analysis of layered constructions of freedom can overcome difficulties of "vagueness." Vagueness in a concept of freedom resembles vagueness in the concept of "heap" that was investigated by ancient Greek philosophers in "the paradox of *sorites* (heap)" Twenty grains of wheat do not make a "heap." Twenty grains do not turn into a heap by the addition of one more grain, so twenty-one grains of wheat do not make a heap. The same argument applies over and over, for maybe a million times. One million grains of wheat do not make a heap and neither do a million-and-one.

Such an incremental construction ignores practical meanings of the word "heap," which are collective meanings that depend on the situation. A heap of wheat in a home kitchen would not qualify as a heap of wheat at an industrial flour mill. Whatever the situation, the collective content of the heap is measured by a unit, such as a cup or a ton, that contains grains too many to number.

I suggest that vagueness in a concept of freedom arises from a collective character like the collective character of a heap. The collective character in freedom is more complex because the elements are ***disparate*** — with different individual natures as in "muscular movements" and "bodily feelings" — rather than identical natures like grains of wheat.

In sum, in an animal body, a multitude of parts produce collective and integrated movements, feelings and sensations that succeed in achieving the purposes of the animal, such as seizing prey or threading a needle. Such collective and integrated movements are investigated through projects of construction in parts A and E on the website.

The heap in part A can be viewed in six layers, three layers in the body alone and then three more layers that develop mental control. (1) The lowest layer includes "wiping reflexes" produced by the spine of a headless frog, extended to itching and scratching of a human being. Movements of limbs target a stimulus that appears in a sensorial field embedded in the surface of the body. Accurate wiping occurs on the first attempt in various bodily orientations and despite impediments imposed by researchers. A primal psychological function is identified, namely "location selection," a refexive combination of sensation and movement that also occurs, I suggest, when an eye reflexively gazes at an object in a landscape.

Although there might be reluctance to ascribe "freedom" to wiping reflexes of headless frogs, substantial reasons support their position at the start of construction. Wiping reflexes raise serious questions suggesting the need for new approaches and present a simple problem.

Wiping reflexes plus a bodily feeling leads to itching and scratching that I experience in my own body. The bodily feeling has potential for incorporation in more complex kinds of action. Construction methods that add additional layers lead to more satisfying examples with awareness of feelings and consciousness. For example, an itch can trigger a memory in the mind: "nurse says do not scratch." Refraining from scratching is a rudimentary example of "free will," e.g., a mental command to perform or halt a bodily movement. "Holding your breath until you can't anymore" is an example of free will — and of its limitations.

(2) Next in the part A construction, a wiping reflex develops into repetitive productions of movements and feelings in cyclical patterns.   Jean Piaget observed rudimentary cycles in movements of newborn infants. "He sucks for the sake of sucking." Repetitive movements are used during locomotion and simple tasks.

(3) Next, one repetitive series of movements is followed by another similar series, and then by a third, etc. — as when drying off after a bath or brushing the teeth.

Brushing the teeth involves linkages between series of movements, generating a sequence of movements. A frequently-repeated sequence of movements is called a ***habit***. In my habitual toothbrushing, I start by brushing the outsides of teeth in the lower jaw; next, I brush the insides of those teeth. Movement then shifts to the upper jaw, first outside then inside.   Ordinarily, such linkages occur without mental involvement; my mind may be otherwise occupied in planning my day.

For further development, a map of different kinds of movement-control is provided by the anatomy of the human nervous system. I locate bodily control over habitual linkages and sequences of movements like toothbrushing in the cerebellum, "the hindbrain," which "resides" close to the brain stem and spinal cord. I locate mental control in the cerebrum, "the forebrain," whose operations are more "remote" from the spine. I suggest that movements have ***residential*** and/or ***remote*** origins.

I define "awareness" as self-imagery of the body in its surroundings, which includes body-maps of feelings based in the spine and on spatial locations of objects in the external environment; awareness is generated in the brain stem and cerebellum. I define "consciousness" as directed at images of objects (e.g., bodies, sights, sounds, ideas) often external but also including images of internal feelings; consciousness is cerebral and includes body-maps of feelings and movements.

In my approach, different movements and images are based in different combinations of parts of the nervous system. Parts can operate independently; operations of parts can also be combined, coordinated, synchronized or integrated through means of interconnected body-maps. Brain parts in the central region, e.g., thalamus and basal ganglia, can control complex collective activity, including whole-person movements and feelings. People can invent new combinations and new activities, especially when assisted by new technologies.

In the construction of part A, habits are grounded in physical properties of body parts, such as joints and muscles. Concepts of physical properties are familiar from studies of physical materials in engineering and biology. In VE models, physical properties of device parts and bodies are of fundamental importance.

I suggest that development of mental control in actual life is dependent on bodily foundations maintained as reflexes and habits. In the part A construction, mental control is added to bodily foundations in three layers: (4) sensorial cues, (5) external commands and (6) choices. Cues replace habitual linkages in the toothbrushing model with mental commands triggered by external sensory events, e.g., a visual cue or an audible cue. In a routine controlled by cues, such as peeling, slicing and dicing a carrot, the order of repetitive movements is fixed; the timings are subject to events such as bodily interactions with the task.

When external commands control movements, there are many possible next movements but only one next movement is actually performed. An external authority utters a command that selects the next movement. Perhaps a coach trains a martial artist by commanding movements in an order that cannot be predicted by the athlete, who is expected to respond to commands "as if by reflex."

In the final construction in part A ("choosing a dinner from a menu"), the result is similar to that of a command, namely, a particular movement is selected from multiple possible movements, but the process of getting there is more complex, involving multiple possibilities in the mind of the person who then makes the selection on the basis of taste, price, social influences, theories of nutrition, etc. Instead of an immediate response as in cues and commands, a period of deliberation may occur. Such a choice clearly involves an exercise of freedom.

"Freedom of choice" is a major topic on the website, re-appearing, e.g., in games and music. "Selective eating" is a specific freedom of choice that is exercised throughout the animal kingdom, e.g., by birds and domestic pets. Eating according to tastes and appetites is of major daily importance to many human beings.

Retrospectively, looking back from the final example of choosing from a menu, prior steps also involve freedom. A martial artist following commands from a coach is perfecting high-level skills that require concentration during execution. Conscious attention is required to prepare food in the kitchen efficiently and safely. Habitual movements in toothbrushing may may not require conscious attention but the body is exercising freedom on an ongoing basis by adjusting the pressure of the bristles and the direction of the strokes. Even in the lowest layer of itching and scratching, free will can intervene and halt a movement.

Jean Piaget viewed his own psychological constructions retrospectively in *Play, Dreams and Imitation in Childhood* (1946) at 6-8. Referring to his first book on early infancy [*Origins of Intelligence in Children* (1936)] ("*OI*"), he wrote:

> …when we studied the beginnings of intelligence [in *OI*], we were forced to go back as far as the reflex in order to trace the course of the assimilating activity which finally leads to the construction of adapted schemas, for it is only by a principle of functional continuity that the indefinite variety of structures can be explained.

Applying a similar approach to the psychology of imitation, he found a reflexive precursor of imitation in observations ("OBS 1") of his own infant in a nursery, where crying by one child occurred simultaneously with crying by others.

> On the very night after his birth, T was wakened by the babies in the nearby cots and began to cry in chorus with them. …it is possible that the crying occurred as a result of its repetition, owing to a kind of reflex analogous to that we saw in the case of suction [in *OI*], but in this case with intensification of the sound through the help of the ear. … in this [] case, the crying of the other babies would increase the vocal reflex through confusion with his own crying.

More development had occurred by the second month, as noted in "OBS 2":

> Three times in succession, the crying of L. (four years old) started him crying also. Such a reaction appeared to be quite distinct from those in OBS 1. As soon as L. stopped crying, he too stopped. It therefore seemed to be a clear case of contagion and no longer a mere starting off of a reflex by an appropriate stimulus.

I suggest that, from a retrospective perspective, collective freedoms of a musical band (part D) might be seen to originate in audio-vocal reflexes of infants that develop into contagious crying and imitation.

In the approach in part E (practices of bodily consciousness), layers in "the heap" are investigated with final aims of conscious awareness of whole-body freedom exercised during improvisational dance movements. First, yoga practices develop conscious mental control, training the body to relax (*savasana*) and focussing on stationary positions of joints and muscles, breath practices and related feelings in a context of bodily immobility (*asana* and *pranayama*).

Next, using methods of Buddha and Feldenkrais, mental control is detached while consciousness is maintained. The mind observes while breath and slow movements occur on their own and generate imagery. In final steps, mental control and detachment are combined in larger movements of qigong exercises and nataraja yoga. Qigong exercises follow routines while nataraja yoga incorporates improvisation.

Feldenkrais exercises investigate movements that are ***easy*** — slow, light and reversible. When the whole body is stationary and certain body parts prepare to move, the body on its own maintains equipotential positions, which can change ***easily*** into any one of multiple movements. When the whole body is moving, movements themselves are equipotential and the body or the mind can select particular further movements out of multiple possibilities.

For example, a ping pong player may be in a position of stationary readiness after completing a stroke, awaiting the next stroke of the opponent. Then, the player's movements start with a pelvic reflex triggered by visual images of the opponent; and movements progress into thrusting the active shoulder and arm towards the approaching ball while the whole body is in motion; and, finally, the player produces fine movements of arm, wrist and hand that select and execute a particular stroke, e.g., a drive or a flip.

Investigations in parts A and E suggest a construction path for development of engineered organisms that exercise freedom in ways that mimic exercises by animals and persons. "Development" means that any particular design is part of a larger course of construction; any course of construction is part of a larger program of growth that proceeds by means of conceptual extensions and innovations.

Virtual Energy device models for reflexive gaze operate without feelings or freedom; a goal is to construct "something like" a locational reflex by means of visual signals and movements like an eye.   A foundation is provided by a set of 7 sensor in 7 positions in a line and then by 49 sensors in 49 positions in a square array that is also deformable to adjust to physical requirements. Such positions are equipotential in the sense that the control point can be shifted with equal ease between different positions, giving a loose or practical meaning to the word "equal," without trying to imply exact equivalence.

Reflexive Virtual Energy models appear to operate mechanistically although the principles are thermodynamic rather than mechanical. A mechanistic gazing layer in an eye model can serve as a foundation for additional layers that have different functions, e.g., selecting a moving image for attention. Sensors that stimulate the first layer also stimulate the additional layers. All the layers are contained in a unitary body with collective control, e.g., a single beat drives all the devices.

Eye models can be incorporated in Wriggler models that also produce locomotion, with the whole system designed to follow a source of light. Eye parts and locomotion parts each have maps and maps can be interconnected in multiple and changing ways. Anticipated developments include synchronization of separate modules, leading to coordination of images and movements. Applied to models of eyes, chief goals include fast and easy control over the direction of the gaze, providing a continuing stream of images that influence changes in movements of the body. This is a construction path that leads towards freedom.

Overall guidance for development of freedom in engineered organisms is provided by development of freedom in evolution of animals, driven by life-and-death demands of predation. Predators and prey have common needs of more freedom and they compete in their exercises of freedom. In this context, more freedom includes larger repertoires of movements, faster movements, faster selections of movements and more precisely targeted movements. Development of such freedoms in animals appears to occur simultaneously in the muscular-skeletal system and the nervous system, based on physical properties and functions of animal bodies.

II. Preliminary concepts

1. The formal Virtual Energy model is a mental construction that combines aspects of atomic models and thermodynamic models.

Virtual Energy (VE) models, like models of mechanics (Newton's mechanics, statistical mechanics, quantum mechanics), are used to construct positions and movements of imaginary elements in imaginary domains, e.g., as represented in a diagram on a chalkboard. Imaginary events are intended to resemble actual events involving material bodies, e.g., in a laboratory or in technology.

VE models lack the universal concepts used in mechanics. Universal concepts such as gravity, elementary particles and random chance are presumed to apply in all situations and at all times. Specific applications only provide useful examples. Concepts in VE models, on the other hand, are tethered to specific applications and situations — even while a researcher seeks to extend models to new situations.

I suggest that methods of specific models work better for investigations of feelings and freedom. Universal concepts imply commitments to uniformity, predictability and eternal, comprehensive Laws of Physics. As discussed in the free-will puzzles project, such commitments tend to derogate movements of animal bodies that involve feelings; and they exclude freedom.

In *Rational Thermodynamics* at 424, Truesdell observes that similar commitments in physics "reflect a failure to come to grips with the real complications of nature. Beyond the easiest and long-mastered special cases, nature is too intricate for any inclusive theory." These observations are also pertinent to theories about movements and feelings of animal bodies.

Truesdell compares two methods used by mathematical physicists to investigate flows of fluids. First are continuum methods originating with Claude Navier and George Stokes where a fluid is modeled as a deformable body with idealized properties (e.g., linear relation between velocity and viscosity). Second are statistical and kinetic methods originating with James Clerk Maxwell and Ludwig Boltzmann where "the type of material ... [is] ... a moderately rarefied monatomic gas" in which "the molecules are mathematical points" and "all collisions are binary even though the intermolecular forces may extend to ∞." (Truesdell at 383, writing about another topic.)

Truesdell continues at 424: "Different models have different uses; they emphasize different *aspects* of nature, often at the expense of leaving others altogether aside. Such is clearly the case in the kinetic and simple theories of fluids. One leaves out bulk viscosity, the other some effects of non-homogeneity … Each leaves out much more, not the same for either. Each has its virtues…"

Truesdell also notes: "A good deal of misunderstanding seems to arise from the differences in psychic motivation. Researchers in statistical or kinetic theories are inclined to claim a kind of universality for their own results and hence to presume in others like aspirations to empire. Modern continuum mechanics has been, from its start in 1945, frankly a theory of models. No one, as far as I know, has *ever* claimed any universal truth for the theory of simple materials."

Here, basic models are ***atomic*** and ***thermodynamic***. Atomic models of H_2O and electrical charge employ tiny identical units. Conserved Energy and Virtual Energy are thermodynamic models. All models are constructed in mental domains but each construction has unique features that are adapted to its subject-matter.

An atomic model is constructed by means of "a certain mode of thought, suited to certain subject-matters: that in which an array of primitive elements is subject to specified principles of combination which generate determinate relations between complexes of those elements. This combinatorial mode of thought [] yields a certain kind of novelty in the domain at issue [] and proceeds in a bottom-up style …" (Colin McGinn, *Problems in Philosophy* (1993) at 18.)

In *Rational Thermodynamics* at 353-54, Truesdell applies a combinatorial mode of thought to ordinary chemistry defined in terms of "exchanges of mass among the constituents of a mixture" — that is, a mixture of specific materials such as chemical reagents.

> In ordinary chemistry, the exchanges of mass are restricted to a special kind, according to the laws of "chemical reaction". In such reactions the constituents combine and disassociate only in definite proportions. These proportions are commonly explained by saying that each substance consists of "molecules" and that each molecule is composed of a certain whole number of "atoms" of a few specified kinds. … In the reactions, molecules are created or destroyed, but the atoms are permanent in number and nature. The terms "atom" and "molecule" are merely convenient for visualizing the rules of definite combination and need not be thought as denoting corpuscles, nor need we limit the interpretation to strictly "chemical" changes. All that needs to be assumed is that each constituent is made up by combination in fixed proportions from certain individually indestructible constituents. Nevertheless, the terms "atomic" and "molecular are so familiar that I occasionally use them in describing the pure phenomenology of reactions.

In contrast to the uniformity of atomic models, thermodynamics models manifest various modes of thought suited to specific subject matters. In about 1970, some statements of thermodynamicists were collected and published, including:

> "It is amazing to note the conflicting opinions expressed by eminent scientists."
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> "We all seem to have a different, a private congenial way of justifying the First Law, etc., and argue about the rationale in each separate formalism."
>
> "Thermodynamics is something which develops, which expands, which grows, and it has the capability of growing, and this kind of growing is just like the house that Jack built, by patching on and patching over and mending, and so this is the reason, I believe – the historical reason – why there are so many differences in deriving thermodynamic properties."
>
> "The motivation for choosing a point of departure for a derivation is evidently subject to more ambiguity than the technicalities of the derivation. Motivation is tied up with psychological and philosophical factors, and these are nowadays not considered *bona fide* topics for public discussion."
>
> "I hesitate to use the terms 'first law' and 'second law', because there are almost as many 'first laws' as there are thermodynamicists, and I have been told by these people for so many years that I disobey their laws that now I prefer to exult in my criminal status."
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> [References are included in *A Patchwork of Limits: Physics Viewed From an Indirect Approach* (2000) at 18-19, available on the website.]

The Feynman Lectures on Physics, Vol. I (1963) develops atomic models for most of the book. Then, Chapter 44 on "The Laws of Thermodynamics" starts:

> So far we have been discussing the properties of matter from the atomic point of view, trying to understand roughly what will happen if we suppose that things are made of atoms obeying certain laws. However, there are a number of relationships among the properties of substances which can be worked out without consideration of the detailed structure of the materials. The determination of the relationships among the various properties of materials without knowing their internal structure is *thermodynamics,* Historically, thermodynamics was developed before an understanding of the internal structure of matter was achieved. (Page 44-1.)

The Feynman Lectures discusses a particular "comparison [that] shows the advantages and disadvantages of thermodynamics over kinetic theory."

The final conclusion is:

> When knowledge is weak and the structure is complicated, thermodynamic relations are really the most powerful. When the situation is very simple and theoretical analysis can be made, then it is better to try to get more information from theoretical analysis.

Powerful thermodynamic relations include ***activation energies*** that relate the rate of a chemical reaction to the temperature of the body or environment. Many reactions go faster when the temperature is hotter; an activation energy expresses this relation mathematically. Activation energies are used in metallurgy and biochemistry. Svante Arrhenius (1859-1929) constructed the original activation energy by extending experimentally-based thermodynamics methods. Similar activation energies were later constructed using statistical methods.

In the domain of engineered organisms, the subject-matter for models is "interactive muscular movements and feelings of animal bodies." Applying Feynman's criterion, "knowledge is weak and the structure is complicated." Therefore, Virtual Energy models are constructed along the general lines of thermodynamics with atomic forms incorporated in various aspects such as devices, pulses, timings, twitches and stationary positions.

2. An imaginary substance called Virtual Energy (VE) is constructed from shared features of H_2O, electrical charge and Conserved Energy.

__Summary__. In scientific concepts of H_2O, electrical charge and Conserved Energy, a ***substance*** is defined in terms of multiple ***forms***, ranges of ***quantities*** and spatial ***locations***. ***Changes*** in forms, quantities and locations are constrained by ***conservation laws***.

Features of scientific concepts are modified when they are reconstructed as VE. Notwithstanding aims of imitating animal life, VE constructions are mental inventions and independent of natural phenomena. Scientific conservation laws are replaced by variable ***dissipation principles*** in which conservation may be an idealized endpoint in a range. Lacking a comprehensive definition, VE concepts are restricted to specific bodies of devices and may incorporate processes dependent on whole-body principles such as synchronization.

a. meanings of "energy"

We presume that there is "something" called "energy" that pervades our own bodies — and everything else in the immensities of external surroundings, a "something" that reaches by means of a food supply from the radiance of the sun to the beating of my heart and the thoughts of my brain.

In scientific models, such "energy" is presumed to be quantifiable under all circumstances and in each submicroscopic volume. Such presumptions lead to substantial progress in acquisition of knowledge but also restrict investigations, excluding events where "energy" is not so quantifiable, such as practices of bodily consciousness that involve feelings of *prana* or qi.

In this VE model, VE is quantified initially but I do not presume that VE is quantifiable or locatable submicroscopically under all circumstances. I anticipate that, during critical moments of Shimmering Sensitivity, VE is ***unquantified*** and ***unlocalized*** within a VE distribution that can extend over multiple modules, each containing collective devices. A shimmering distribution condenses to form a specific actual distribution like water vapor condenses to form a snowflake.

In scientific models, further restrictions are imposed by "conservation laws." A conservation law restricts investigations to situations in which a focal quantity remains constant while other aspects of the situation change. A ***universal conservation law*** presumes conservation of the focal quantity over the entire universe and over everything in it. In contrast, in the VE domain, some device processes are constrained by specific ***local principles of conservation and/or dissipation***. Local conservation principles may serve as endpoints of local dissipation principles — the pont where dissipation diminishes to zero.

An overall view of "energy" suitable for an initial VE model was set forth in *The Phenomenon of Man* (1955, 1959 English transl.) by Teilhard de Chardin. I have revised his statements by substituting “body” for his “atom” and “change(s)” for his "transformations" and “synthesis.” A few of his words are omitted as unnecessary distractions. (The original version is quoted in the Paradigms project.)

> …Energy is the measure of that which passes from one body to another in the course of their changes. A unifying power, then, but also, because the body appears to become enriched or exhausted in the course of the exchange, the expression of structure.
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> …Though never found in a state of purity, but always more or less corpuscular (even in light), energy nowadays represents for science the most primitive form of universal stuff. Hence we find our minds instinctively tending to represent energy as a kind of homogeneous, primordial flux in which all that has shape in the world is but a series of fleeting ‘vortices.’ From this point of view, the universe would find its stability and final unity *at the end of its decomposition….*
>
> Let us keep the proofs and indisputable measurements of physics. But let us not become bound to the perspective of the final equilibrium that they seem to suggest. …(pp. 42-43.)
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>
> *First Principle*. During changes of a physico-chemical type, we do not detect any measurable appearance of new energy. …
>
> *Second Principle.* In every physico-chemical change, adds thermodynamics, a fraction of the available energy is irrevocably lost in the form of heat. Doubtless it is possible to retain this degraded fraction symbolically in equations so as to express that in the operations of matter nothing is lost any more than anything is created, but that is merely a mathematical trick. As a matter of fact, something is finally burned in the course of every change to pay for that change. (pp. 50-51.)

I presume that ***actual energy*** passes through animal bodies and produces movements, feelings and other imagery. I presume that actual energy is beyond our capacity to understand but that we can construct useful models with concepts such as Conserved Energy and Virtual Energy. The VE model aims at investigating freedom and is based on exercises of freedom that I observe in muscular movements and bodily feelings, as discussed above in part I of this project.

b. Features of VE are adapted from scientific models of H_2O, electrical charge and Conserved Energy.

Constructed definition. For purposes here, Virtual Energy (VE) is a ***substance*** that is described by multiple ***forms***, variable ***quantities*** and variable ***locations*** in bodies, starting with ***VE devices***. VE devices are interconnected and assemblies of devices, called ***modules***, perform useful functions. Such performances involve ***changes*** in forms, quantities and locations of VE in devices. Devices hold VE, transport VE and change VE from one form to another. VE processes in specific devices are constrained by various principles of dissipation and conservation.

Steps in the construction.

i. Substance, form, quantity, location and distribution

ii. Changes in form; constraints imposed by conservation principles

iii. Changes in locations and distributions (flows or transport)

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i. Substance, form, quantity, location and distribution

Three separate domains are investigated and common principles are identified and adapted for use in VE constructions. Constructions have successive step.

H_2O. The symbols "H_2O" are based on the atomic-molecular model and label all forms of the ***material substance*** "water," reserving the word "water" for the liquid form. ***Form*** is a primitive concept. Solid forms of H_2O are ice and snow; gaseous forms are vapor and steam. In this first step of construction, each ***body*** of H_2O has such a ***form*** and it is kept fixed. Changes in form occur in the next step.

The ***quantity*** of H_2O in a body is measured as a certain number of molecules. In ideal measurements, each cup of water or pound of ice has a definite number of molecules. Quantities (numbers of molecules) are added like arithmetic numbers.

To start, the number of molecules is fixed and the body is described by a definite volume of space. Inside the body, molecules may be fixed or vibrating or mobile. At each moment, each molecule has a specific ***location*** described by a tiny (submicroscopic) volume; and molecules are ***distributed*** in space with a specific number of molecules located in any specific tiny volume of the body.

Electrical charges. Features of H_2O (substance, form, quantity, location and distribution) can be adapted to electrical charges. However, electricity has additional features that have led to many innovations. (1) There are two kinds of electrical charges. (2) In static arrangements, two charges of the same kind repel each other forcefully. Two charges of different kinds attract each other with a force equal to that produced by charges of the same kind but in the opposite direction. (3) Moving charges (electrical currents) in wires produce new forces that are more complicated than forces produced in static arrangements.

A standard chemical atom contains a certain number of positive electrical charges, held in ***material particles*** called ***protons***, and the same number and strength of negative electrical charges, held in particles called ***electrons***. A combinatorial mode of thought declares that all materials are made of protons, electrons, etc.

Protons and electrons have the same "invariant" quantity of charge but distinguished by "postive" and "negative." Charges of particles in a combination of charges can be added like arithmetic numbers; sums of positive and negative charges cancel each other with a result that may have no net charge ("body is electrically neutral") — or a very small net charge. Forces produced by charges follow the same rules of addition and cancellation as charges.

Separated charges and canceled charges serve as forms of electrical charge. Energy is required to separate charges and is sometimes nearly recoverable when separated charges are allowed to cancel. Separted charges attract each other.

In static arrangements, each charge is presumed to be confined to a specific location or submicroscopic volume of space so that it can be summed up by a mathematical expression of integration. Definitions for distributions of static charges follow the format used for H_2O. Fluid models of electricity were popular during early years of research. Flows and currents of charges resemble flows and currents of liquid water, with adaptations for two kinds of charges. Electrical voltage resembles hydraulic pressure.

Further details of natural phenomena of charges are more complex. Electrons are light and mobile, in continuous motion even when confined; in contrast, protons are heavy and require an external force to produce movement. While protons are bound in fixed forms, electrons can go through many changes in form.

In standard chemical atoms, inner electrons are confined relatively close to the nucleus. Outer electrons participate in chemical bonds, e.g., ionic, covalent, hydrogen or metallic. Free electrons travel inside vacuum tubes. Postive and negative ions travel in electrified aqueous solutions. Biologists investigate movements of electronic charges inside living animal bodies.

Conserved Energy. Conserved Energy is a constructed general concept that unifies a large number of concepts based on different physical phenomena. (See T. H. Kuhn, *The Essential Tension*, "Energy Conservation as an Example of Simultaneous Discovery" (1956).) The unification depends on a Conservation Law – the First Law of Thermodynamics. The unification identifies common features in phenomena of very different kinds, e.g., energy involved in moving bodies, high-altitude lakes, steam engines, chemical reactions, electrical devices.

The First Law declares that a single quantity controls conversions between such different phenomena. Like a quantity of H_2O measured in molecules, there is a single "positive" energy that is completely represented by a real number and a dimension. There are ergs in a swim stroke of a fish, ergs in a train moving on a track, ergs in a gallon of gasoline, ergs in a lightning flash and ergs in a nuclear explosion. Numbers of ergs are arithmetic quantities that obey rules of addition.

Concepts of quantity, location and distribution of Conserved Energy resemble those of H_2O and electrical charges. Inside a body, such energy resembles both liquid water and electronic charge in free mobility and readily-changing quantities, forms and distributions. Thermodynamic potentials are constructed that resemble electrical potentials (voltages) and hydraulic pressures; and all drive flows.

I suggest that the First Law restricts domains of exact application of energy principles to specific kinds of situations identified as "quasi-static," "equilibrium" and "reversible" in various paradigms of construction, all of which support a "state function of entropy." These methods achieve success within restricted domains — which have little apparent connection to movements and feelings of animal bodies.

Some researchers extend applications of Conserved Energy to "steady-state," "non-equilibrium" and "irreversible" domains, often relying on principles of "minimum entropy production," resembling conservation principles and allowing for certain additional variations. (E.g., Katchalsky & Curran, *Nonequilibirum Thermodynamics in Biophysics* (1965).)   Such extensions provide useful guides for certain phenomena, e.g., passage of molecules through a cell membrane. Their usefulness does not extend to bodily feelings and related movements of animals.

VE devices.   Virtual Energy is a construction that starts with Conserved Energy (CE), including features of substance, form, quantity, location and distribution. The Virtual Energy Store (VES) in the body of a VE device serves functions like those of Internal Energy (U) invented by Rudolf Clausius as part of classical thermodynamics. VE conversions and transports resemble those of H_2O, electrical charge and CE.

Then, during particular constructions, features of CE are removed or modified. New features are added by means of physical principles imputed to bodies. These include definitions of operational time periods of devices and synchronized discharges of pulses in a collective VE device, resembling synchronized ticking of identical mechanical clocks on a table. Introduction of new principles imputed to bodies is of chief importance in this project that is aimed at investigating freedom as a physical principle applicable to classes of bodies.

Certain aspects of VE differ markedly from those of Conserved Energy. In the VE domain, ideal conservation laws are modified in various ways to incorporate dissipation principles. Waste heat is "washed away" rather than interpreted in terms of "entropy." Pulses on projections, VE flows in bodies and changes of form inside bodies do not qualify as a general kind of "information." Instead, each signal, each flow and each change may have individual characteristics that depend on the devices involved.

ii. Changes in form; constraints imposed by conservation principles

Conservation laws and principles constrain changes involving substances, including changes in location and form. Pursuant to a conservation principle, a focal quantity (such as a quantity of molecules, atoms, electrical charges or ergs) remains constant while other quantities undergo changes. Applied here to changes in form, the constant focal quantity connects beginning forms with ending forms.

H_2O. On a first level of investigation, forms of H_2O are solid, liquid and vapor. A change in form occurs when a body of H_2O is confined in a closed chamber and heated or cooled. Liquid water boils to become steam or freezes to become solid ice. Ice melts to become liquid or sublimates to become vapor. Vapor condenses to become liquid water or solid ice or snow. The quantity of H_2O (the number of molecules) in the closed chamber remains constant during each such change.

On a deeper level of investigation that includes chemical reactions, H_2O is not always conserved. New H_2O appears when a carbohydrate fuel (sugar or gasoline) is burned. Such a chemical reaction combines the carbohydrate with O_2 from the atmosphere and produces H_2O and CO_2. Conversely, photosynthesis in plants combines H_2O and atmospheric CO_2 and produces carbohydrate and O_2 — so H_2O is "lost." In a chemical reaction, what is conserved is the number of atoms of each kind, e.g., carbon, oxygen and hydrogen.

Electrical charge. The law of invariance or conservation of charge is said to be inviolable in all ordinary situations of actual life. However, facts are more complicated because of the cancellation feature that operates when opposing charges are added together. In a body, the number of cancelled charges is huge compared to the number of separated charges; but any useful activity depends on separated charges. It is for this reason that a storage battery appears to produce "new" electrons when it is connected in a circuit. In semiconductors, mobile electrons float free of particular positive ions; the number of mobile electrons varies with the temperature so "new" electrons appear when the temperature rises or, conversely, electrons "disappear" when the temperature falls.

Conserved Energy. The Law of Conservation of Energy is a pillar of the modern scientific view but it clashes with facts of actual life. Every animal body continually produces "waste heat" that first passes into the environment and eventually radiates into empty space. Inanimate bodies also radiate energy into empty space. Facts of waste heat and radiation are often ignored in paradigms of energy conservation.

Energy in living bodies on Earth originates from radiation that has streamed from the Sun and been converted by plants. Energy from the Earth is continually streaming into space. Compared to streams of radiation from the Sun and Earth, only miniscule quantities of energy are conserved in storage in living bodies. An "energy conservation law" that applies to energy streaming from a star must include ways to expand the sphere of application at the speed of light.

Simple energy conservation (movements are permanent) occurs in nature in only a few specific situations, such as planetary orbits and chemical bonds. On Earth, technology creates new situations where energy can be said to be "conserved."

Notwithstanding its shortcomings, Conserved Energy has proved to be a useful principle for technology. It fits methods of human intelligence and can grow through adaptations. It applies to many phenomena involving inanimate bodies. I suggest that it can be modified into forms of Virtual Energy that may be useful for investigating movements and feelings of animal bodies.

Virtual Energy. The character of VE is opportunistic and may incorporate, with modifications, any of the various methods and principles discussed above. "Primal" VE conversions begin with idealized paradigms resembling CE conversions. Initial slow, restricted conversions are first steps in a course of development that leads to fast, highly dissipative conversions.

iii. Changes in locations and distributions of VE (flows or transport)

It is apparent in common experience that, during certain changes in location, that is, during ***transport***, the quantity of material in a body remains constant, e.g., liquid water in a jug, earth in a wheelbarrow, a piece of clothing or a container of foodstuff. No new material appears without a source. Perhaps a small quantity of material is lost in transit, but during ideal movements, the loss is reduced to zero.

Scientific models develop concepts of transport that are based on common experience. In *Thermal Physics* (1965) at 108, Philip M. Morse uses a uniform definition for flows of matter (n), entropy (S) and internal energy (U) and discusses a situation involving a screen D and what happens when "one of the 'fluids,' S or U or n, flows through D."

VE flows embody concepts of fluidity based on flows of water, electrical current and heat. Extensions of timing device constructions below are suggested by diffusion paradigms in physics that are applied to materials, electricity and Conserved Energy. The extension leads to potential-driven processes, resembling flows of water in pipes under pressure, flows of electricty driven by voltage difference and flows of heat in thermodynamic paradigms.

3. Subsequent layers of construction occur in a VE domain that is similar to a circuit diagram domain. The VE domain features a plenum of sources of VE, deformable space and hierarchical time.

a. plenum of sources of VE

As a foundation for all further constructions in this project, a general Virtual Energy domain is defined in imagination. A chief function of the general VE domain is to provide sources of the VE that is required by all VE devices.

Electrical engineering provides methods suitable for adaptation called ***pegboards, breadboards*** and ***printed circuit boards***. These provide domains for assembly of circuits of electrical and electronic components. An old-fashioned pegboard was a sheet of woody material with holes drilled in a rectangular pattern, e.g., two inches between holes in both directions. A ***power supply*** was attached, connected to a source of electricity and delivering currents at specific voltages needed for the project. The researcher first attached electrical and electronics components to the pegboard by means of bolts in holes and then connected wires from the power supply to the parts. The researcher also connected wires between parts.

A later breadboard has a rectangular pattern of attachment points similar to a pegboard, plus an internal power distribution network that delivers power sources to each attachment point. External wiring requirements are reduced. Other improvements include plastic materials and smaller spacings more suited to modern electronics.

In putting together a printed circuit board (PCB), automated methods replace the attaching and connecting of the researcher. The domain of construction is a techological material perhaps the size of a playing card. Before anything is attached, an engineer's final design for the circuit is embodied in properties and features of the material body such as holes and tabs. Then, connecting wires are laid down as thin strips of metal. Finally, parts are attached, including devices that access and control power flow through the wires, devices designed to interact with external influences, integrated circuits and "chips," resistors, capacitors, etc.

Similar to an electronics domain on a breadboard, the general VE domain has power access at every point. Likewise, animals have circulatory systems that carry fuel, oxygen and other nutrients to every living cell. In such cases, a ***plenum*** of energy sources is accessible through foundational functioning of the system. Accordingly, plenary energy sources are incorporated in the general VE domain.

An ***energy economy*** is progressively constructed as part of the project. A chief economic principle is minimization of energy expenditures while maintaining successful performance of functions. If actual engineered organisms were to be designed to acquire from their environment all the energy necessary to sustain their imitation of life, strict economies would have to be imposed. Guidance for development is suggested by minimal energy principles in physics. Animal bodies also minimize net energy expenditures, such as when "taking a shortcut." Acquisition of food and something like an energy economy appear to be chief driving motivations behind movements of non-human animals.

In the VE economy, the basic unit is the ***bang***, denoted by the symbol "!." A one-bang pulse traveling on a projection is a formal definition of Virtual Energy.

b. deformable space

A useful feature of constructions in VE domains is ***deformable space***, meaning that parts in a design can be easily re-arranged by local squeezing, stretching or bending of spatial dimensions. Deformable space is based on an operating feature of VE designs, namely, the instantaneous transport of a pulse on a projection. Regardless of the length of the projection, the "zero" time of transit is the same.

The instantaneous passage of a pulse on a projection resembles the instantaneous passage of an electrical signal in a copper wire or the instantaneous movement of water under pressure in a pipe when a valve is opened. The focal substance fills the inside of the body of the transport device; and pushing and movement occur everywhere all at once, or, perhaps more precisely, except for transit time of signals travelling at speeds comparable to that of light.

In contrast, passage of a remote nerve signal inside a large animal body requires a substantial period of time. Designs with long travel times for signals may require modifications when adapted from designs with instantaneous signals. It is presumed at this stage of development that needed modifications can be invented and that concerns about travel times can be deferred.

c. hierarchical time

VE devices operate in time structures defined by a researcher for specific purposes. Here, the time structure starts with a "lab clock" that follows a national standard and has a hierarchical character that is shown in the following table. In anticipated designs, multiple modules generate independent time structures.

The following table lists time periods used in current VE projects along with names and signs. Examples are tethered to convenient values that guide major device designs. Different values may be useful in future innovations.

Table of time periods in VE projects

name	sign	values	device designs
instantaneous		0 sec.	projections, channels
fast switch	α	0.001 sec.	pulse width, minimum change period, junctions
slow switch	δ	0.01 sec.	receptors, timing devices
tick	t	0.1 sec.	movers (force devices), bursters that drive movers
beat		0.4 sec.	4 ticks — used to synchronize movers and bursters operating collectively in a body
schema		various; e.g., 0.8 sec.	action form defined in terms of operational ticks, e.g., 8 ticks in a mover schema NPqQQQqR that controls each twitch of a force fiber device.

A principle of design is to include ***margins of silence*** sufficient to prevent successive operations from interfering with each other. One operation in a device is clearly finished before the next operation commences. For example, a pulse has a width in time of α; to maintain a margin of silence, a minimum period of 2α intervenes between the start times of two succeeding pulses. Presumptively, the device restores its energy and condition during the intervening α. Based on the convenient value in the time hierarchy ($\alpha = 1/1000^{th}$ of a second), the maximum rate of pulse production and transport in this approach is 500 pulses per second.

In VE designs, energy and pulse rates are closely connected. VE constructions use "low-level methods" and "high-level methods," with "low-level" movers and bursters generally using low pulse rates and economizing on energy and with "high-level" timing devices bodies requiring high energy supplies to operate at high rates and achieve fast responses to stimuli.

A low-level ***base rate guidance*** would limit the maximum flow to 50 pulses per second. The base rate guidance corresponds to a minimum period between pulses of 0.01 second, denoted by δ in the table, along with an equal margin of silence.

"High-level" timing devices and bodies are highly dissipative and a base rate guidance of more than 100!/sec. appears to be needed. Innovations such as banks of device can provide pulse rates higher than 50 pulses per second, at least in short bursts.

4. Elements of initial constructions are imaginary bodies ("VE devices") that carry flows of VE and convert VE between forms, producing pulsational signals and muscle-like twitches. In later constructions, a body contains many individual cells occupied by device modules and operating collectively.

VE principles are defined for specific kinds of ***devices***, which are elements of construction. Individual VE conversion devices — pulsers, timing devices, movers, bursters — share uniform features: a ***body*** defined inside an ***envelope***, which isolates the body from its surroundings except for quantified ***inflows*** of source VE and pulse signals and quantified ***outflows*** of pulse signals and forceful twitches, along with waste heat dissipations, quantified or not. The body contains a ***Virtual Energy Store*** (***VES***), which serves as a locus for changes in form of VE: e.g., VE inflows are stored in the VES and stored VE changes into pulses or twitches.

Simple transport devices — projections, channels, receptors, junctions — carry ***flows of VE*** that change locations and distributions of VE.

At any moment, a device body maintains a specific ***condition***, e.g., a charging condition, a holding condition, a discharging condition. Changes in condition are caused by internal processes and external events. An example of changes caused by internal process: VE flows into a primal pulser that is in a "charging condition" until a certain quantity of VE (a "bang") is accumulated in the body and then the body changes condition and discharges the bang of VE as a pulse on a projection. The pulser repetitively "fills and spills;" it goes "beep-beep-beep." As an example of an external event: a timing device is in a "ready condition" and discharge occurs when a "trigger pulse" arrives from another device.

A sequence of conditions is a ***schema*** or action pattern. First one condition, then the next condition. Each device follows a schema specific to its operations. When a device has more than one schema, such schemata are called ***modes of operation***. Changes of mode are caused, e.g., by internal processes and external events. A module is following only one schema at a particular moment.

Collective devices are made of cells, where each cell contains operational ***modules*** made of devices, performing functions and sharing a ***modular body*** or a ***sensorial body***. Operations of such bodies may involve ***physical properties*** such as synchronized operations. Individual devices in a collective body may share envelopes and transfer VE through interconnecting junctions. ***Distributions*** of VE occur inside collective modular and sensorial bodies.

Such definitions restrict VE to specific devices and operations. Uniform definitions simplify and clarify constructions, serving many of the same functions as universal laws but with reduced burdens of theory and justification.

VE device constructions resemble circuits made of electrical and electronic devices. Nineteenth-century electrical inventions included batteries, cables, switches, capacitors, resistors and coils in relays and motors; these have parallels in VE constructions. Operations of many electrical devices can be interpreted by means of energy principles. In twentieth-century electronics inventions such as vacuum tubes and semiconductors, energy required to maintain background capacities for operations is often greater than energy involved in specific operational processes and energy interpretations have lesser usefulness.

Similar to electrical devices, "low-level" VE operations of pulsers, bursters and movers involve direct energy conversions and invoke conservative ideals. In contrast, like electronics devices, "high-level" operations of timing devices involve indirect influences and produce streams of dissipation.

Different kinds of parallels are suggested by thermodynamic heat engines, whose principles apply, e.g., to steam engines and internal combustion engines. Production of work is the chief purpose of such engines. Operations of heat engines require a closed chamber in which defined energy conversions occur.

5. Methods of construction include ideals, presumptive bodily properties, primal devices, kits of parts and provisional principles.

   a. Ideals

Ancient Greek geometry was a chief source of mathematics and science; its influence extends into modern science. Geometry incorporates numerous ideals, including a point that has no dimensions and a line that has only one dimension. Angles in geometry are exact, e.g., in triangles with exact angles of 30°, 60° and 90°. Similar ideals continue in modern astrophysics where huge stars and planets are modeled by geometrical points. Many scientific models presume an environment of perfectly empty space. Physical materials like metals are modeled by ideal mathematical formulae.

The formal VE model adapts methods of ideals. In contrast to geometry, VE constructions occur in time rather than space. Like a dimensionless point, a VE pulse travels instantaneously from a discharging device to a receiving device. In definitions of operations of devices, periods of time are presumed to manifest mathematical exactitude. Strict time structures are imposed by presumptive physical properties of material bodies, e.g., entrainment and finality.

Ideal constructions have advantages that outweigh their disregard of nature. Ideals facilitate large-scale mental constructions such as geometry; and they support large-scale investigations into properties of materials such as metal alloys. Ideals are features of mental disciplines that can be shared by a community. They suggest innovations that sometimes turn out to have practical value.

Energy conservation is another ideal borrowed from scientific traditions. Ideal energy conservation in VE constructions includes conservation during VE storage, during changes in form and during changes in location. In the primal pulser design, a certain quantum of VE (a "bang") is stored in the Virtual Energy Store (VES) of the device; this VE is converted into the same-sized pulse of VE that travels without loss instantaneously on a projection to another device.

Such ideals can be adapted to accommodate actual devices. If a fraction of energy in an actual device is lost during storage, conversion or transport, contrary to ideal designs, possible solutions are to provide a bigger VES or to provide more energy at the start of operations and/or higher rates of energy supply during operations. In a VE domain, sources of energy are ample for all such needs.

b. Presumptive physical properties (synchronized, entrained, finality).

The VE model does not suggest a "theory" or "explanation" for conversions and transports of VE, such as explanatory theories of "information" or "quantum mechanics." Rather, VE principles are axioms of construction that are invented for particular purposes. Additional VE principles include properties of bodies that are invented or presumed or imputed to bodies of devices. In this project, presumptive physical properties include synchronization, entrainment and finality.

First, suppose that a large number of uniform VE pulsers are independently pulsating at the same rate; each device is isolated from all the other devices and there is no causal connection between devices. In such a situation, there is no basis for synchronization or temporal relations or correlations between pulses.

Next, suppose that the same pulsers share a common body of material inside of which forces can move. Perhaps devices are arranged on the surface of a wooden table or perhaps devices are all suspended in a bowl of goo. Now the devices gradually shift their activity patterns so that all devices pulsate at the same moment. Such pulsations are ***synchronized***.

Such synchronized processes have been observed naturally in pendulum clocks, musical metronomes and neurons in brains. Similarities extend to synchronized movements in musical bands, choirs and dance troupes. Such natural phenomena provide justification for a bodily principle of synchronization in VE designs.

In VE designs, synchronized operations of devices provide useful ideals that simplify some designs and suggest innovations in others. Synchronized operations presumptively arise from a physical property of bodies that is shared by the individual devices and the common larger material of the body.

Next, the principle of synchronization is extended to state a more general principle of ***entrainment***. Entrainment means that movements of different parts of a body occur in a fixed repetitive pattern, often at different times. Movements of water molecules in a wave are entrained. Movements of a beating heart are entrained. When a person drums their fingers on a table, entrained finger movements strike the table in a definite, repetitive pattern.

Examples of entrainment in music include repeated rhythmic series of tones, e.g., the opening theme of Beethoven's Fifth Symphony. The four tones in the theme are not synchronized but they are bound together in a specific memorable pattern.

In VE designs, entrainment means that classes of devices in a collective body perform like a well-rehearsed choir, with voices in blocs of unified tones and with unified starting and ending. Multiple blocs of voices can be involved in many different patterns.

Ideal entrainment is further extended to state a principle of ***finality***. Finality means that a device movement or output has a pre-determined specific moment of ending. The device "meets a deadline" by ending on that moment with precision. Collective devices meet collective deadlines that are set by entrained operations.

Principles of finality in VE devices resemble "equifinality" in theories of motor control based on work of Nikolai Alexandrovich Bernstein (1896-1966). Bernstein observed professional blacksmiths who aimed hammers at a piece of metal on an anvil. The head of the hammer followed a well-defined repetitive trajectory but movements of the blacksmiths' arms and other body parts were more scattered. Many different intermediary movements led to "the same" final results. Aiming for a specific final position in space resembles aiming to meet a deadline in time.

c. Primal devices, kits of parts and provisional principles

Methods discussed above are combined in primal devices. Primal devices in this project include: projection, primal pulser, primal timing device, primal repeating burster and the force fiber device used in constructions of muscle-like movers. Primal devices are ideal mental constructions restricted to a device body and used to produce exactly repetitive cycles.

The foregoing primal devices share common features based on VE — chiefly the VE concept, the VE domain and the definitional one-bang pulse. Notwithstanding shared features, each primal device is defined independently of other devices. Each primal device starts a course of development that is independent of those of other devices. Features may be adaptable from one course of device development to another course for purposes of smoother coordination. For example, different signals share common time elements and pulse bursts that drive muscle-like movers can interconvert with pulse trains produced by sensory devices.

A ***kit of parts*** is the result of a line of development from a primal device, e.g., kits of parts of pulsers, timing devices, movers and bursters. Kits of VE parts resemble kits of electrical signal generators, switches, resistors and relays.

Principles of VE operations are ***provisional***: there is an expectation that changes, extensions and modifications will be introduced. Following a maxim of opportunism, shortcomings in present constructions may suggest innovations and further development.

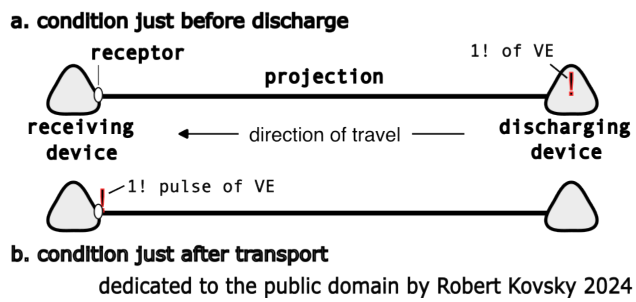
III. Device definitions, applications and extensions

6. Projections, receptors, channels and junctions carry flows of VE.

Fig. 1 shows the first construction in the VE domain: the discharge of a ***pulse*** from a ***discharging device***, transport of the pulse on a ***projection*** and arrival of the pulse at the ***receptor*** of a ***receiving device***. Each pulse contains one unit of VE called a ***bang*** and symbolized by "!". Discharge and transport all occur in an ***instant***. An "instant" is the shortest period of time in VE constructions, idealized as 0 and resembling a point in geometry. Doubling or tripling the duration of an instant would not change anything.

I am not able to show an instant of discharge and transport in a single figure, so Fig. 1 does so indirectly with two figures. Fig 1(a) shows conditions of devices at the last instant prior to discharge: the store in the discharging device holds 1! of VE, ready for discharge. Fig 1(b) shows conditions of devices just after a pulse carrying 1! of VE has traveled to the receptor of the receiving device.

Fig. 1: discharge and transport of a pulse on a projection



The projection is the primal device for transport of VE. Such transport is one-directional. All projections operate identically; a transport operation carries one pulse of VE from an origin device to a destination device. The design is intended to mimic the movement of an action potential on a nerve.

The transport of a pulse on a projection is conservative, meaning that one bang of VE is discharged and one bang of VE arrives at the receptor. It is presumed that the projection requires a VE source to operate and that an unidentified quantity of VE from this source is dissipated during transport.

In Fig. 1, an abstract version of a receptor conveys incoming VE pulses from the projection to the receiving device. While all projections are identical, different receptors connect projections to different devices, e.g., timing devices and bursters. A particular receptor may be a simple connection or it may have multiple modes and incorporate control features, e.g., the receptor is active (working) in one mode and inactive (blocked) in another mode.

The VE concept set forth in § 3 is applied to the design for discharge and transport of a pulse on a projection. An underlying substance of VE is described as: a single quantity (one bang); two forms (starting in storage inside a device and ending as a pulse on a projection arriving at a receptor); two locations (the two devices); and an action-structure or schema of changes (discharge, transport; first Fig. 1.a, then Fig. 1.b). The VE substance is conserved during the changes.

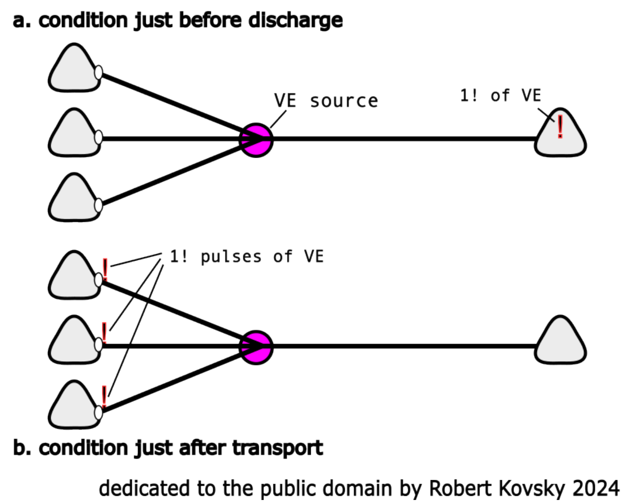
Considering the two kinds of models described in § 2, changes in form, also called conversions, are thermodynamic features. Distinct devices and identical one-bang units used in transport and processing operations provide atomic simplicity.

Chief ideals are instantaneous pulse discharge and instantaneous pulse transport. In more advanced models, instantaneous pulse discharge is replaced by an extended discharge period and a specified pulse width. Instantaneous pulse transport stands thoughout as an endpoint in the hierarchy of time.

As shown in Fig. 2, ideal ***branching projections*** are used in VE designs. At a branch point, an incoming projection splits into two or more outgoing projections. Each outgoing projection carries a full signal. Similar to Fig. 1, Fig. 2 shows conditions "just before discharge" and "just after transport"

A single projection carries a 1! pulse into the branch point and three outgoing projections each carry a 1! pulse. The whole transport occurs instantaneously. The branch point has a VE source, accessed through the VE plenum, preserving the principle that "no new VE appears" during such pulse multiplication. The VE source is shown as a reddish circle in Fig. 2.

Fig. 2: branching projections, pulse multiplication



Advanced constructions involve collective devices that operate inside bodies where transport of VE occurs in ***channels*** that resemble projections and in ***junctions*** that resemble receptors. A channel has added features: (1) a channel can carry VE in quantities other than 1! pulses, e.g., a continuous stream; (2) channels can merge; VE from many originating devices in a collective body is channeled into a single receptive device. A junction connects two VE devices that share part of their envelopes. Junctions can operate in one direction or in both directions. Like receptors, junctions can incorporate control features, e.g., open or closed.

7. Pulsers

a. the primal pulser device

The ***primal pulser device*** shown below in Fig. 3 is the "seed" or point of origin of devices that change the form of VE. In the primal pulser device, source VE changes into VE stored in the device body; then stored VE changes into pulses. One aim is to mimic activity of a very simple neuron.

As discussed above, VE devices operate in defined forms of constructed time. Such a **Time (t)** is shown in Fig. 3, running from "earlier" to "later." Such time applies to operations of device parts (shown in Fig. 3(a)) and to the momentary quantity of Virtual Energy [$\mathcal{V}(t)$] in the ***Virtual Energy Store*** (VES) (Fig. 3(b)).

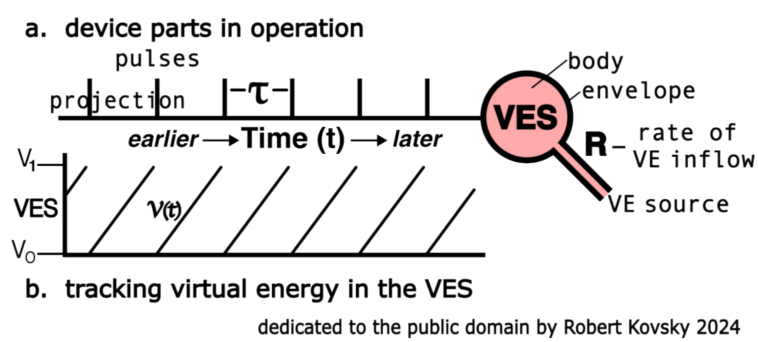
The chief parts of the primal pulser device are the ***projection*** that carries pulses away from the pulser, the ***body*** that holds the VES and the ***VE source*** that provides VE at a rate R. An ***envelope*** isolates the body from its environment except for a specific VE inflow (**R**) and a specific VE outflow (pulses on the projection).

As discussed above, a projection has an independent VE source for its operations. The projection in Fig. 3(a) also serves as a time line in a graph-like depiction or ***chart*** tracking the production of pulses. The pulse chart in Fig. 3(a) has the same time line as the graph in Fig. 3(b) that tracks the quantity of VE in the VES, denoted by $\mathcal{V}(t)$. The lowest level of VE in the VES is $\mathcal{V}(t) = V_0$.

Here, R is constant. In the body, VE flows in at rate R and is changed into stored VE denoted by $\mathcal{V}(t)$. $d[\mathcal{V}(t)]/dt = R$.

$\mathcal{V}(t)$ increases until $\mathcal{V}(t) = V_1$, where $V_1 - V_0 = 1!$. Then 1! of VE in the VES changes without loss into a pulse on the projection and $\mathcal{V}(t)$ falls to V_0.

Fig. 3: primal pulser device



Activity of the primal pulser continues cyclically as in "beep-beep-beep." Pulses are produced at a constant rate with a ***period*** τ between any two successive pulses. In ideal operations, $R \times \tau = !$. Here, the suggested maximum value of R is 100!/sec. and the suggested minimum value of τ is .01 sec.

The primal pulser resembles the ***Carnot heat engine***, an imaginary device used in thermodynamics to model a steam engine. A body of steam in a steam engine acts like a VES, storing energy. Heat energy from a fire under a boiler is converted into latent heat in steam, then latent heat in steam is converted into work. The function of VE in the VES resembles that of latent heat in steam.

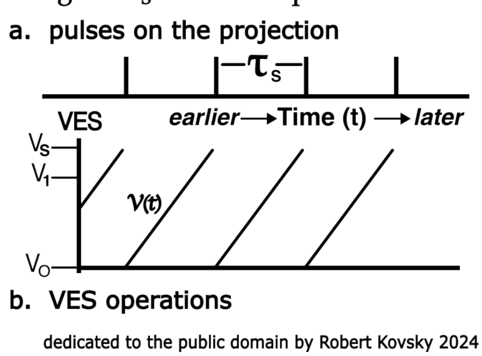
Methods described in part II are applied in the primal pulser. An underlying substance of Virtual Energy has three forms: an incoming stream R; a quantity stored in the VES, $\mathcal{V}$(t); and one-bang pulses on the projection. Changes in form are constrained by a conservation principle.

The pulser design can also be applied to repetitive pulsations of bodies, e.g., as an embodiment of synchronization or entrainment. In the final design of the Gazer project, "Timing functions are relocated to the sensorial body, which generates an ongoing beat that entrains active devices." Centering devices constructed in § 9 below employ drive bodies that generate collective squeezes.

b. dissipative pulsers and the Virtual Energy functional

Pulsers are the first kit of parts. Steps in the development of pulsers are precursors for development of more complex kits of parts.

Fig. 4: V_s-controlled pulser device



Operations of the **V_s-controlled pulser device** are shown in Fig. 2. A modified VES holds more than one bang of VE; and the quantity of VE in the VES, $\mathcal{V}$(t), reaches a higher level than V_1 before the device discharges a pulse. The higher level is denoted by V_s, called the ***discharge point***. $V_s – V_0$ > !.

More time is required for each pulse: τ_s is longer than the τ of the primal pulser.

The quantity of VE in a pulse is still one bang. During each cycle, a quantity of VE, namely $V_s – V_1$, is dissipated or converted into ***waste heat*** inside the VES. In order to deal with this waste heat, an additional feature is added to the envelope of the device, namely, a capacity for passing waste heat into the environment. Waste heat has no significance in current VE constructions.

Next, operations in Fig. 4 develop into the ***VES-controlled pulser device*** based on the ***VES functional***. This "VES functional" also operates in timing devices, bursters and movers. In mathematics, a "functional" is a general form that leads to classes of functions. Here, the VES functional leads to classes of devices.

The construction of a VES-controlled pulser has two steps. The first step, shown in Fig. 5, constructs a new kind of VES with a varying dissipation. As shown in Fig. 6, the second step adds V_s and other features to define an operating device.

In a VES-controlled device, VE that is in storage in the VES is partially converted into waste heat and passes into the environment or is dissipated. The rate of dissipation is proportional to the difference between $\mathcal{V}(t)$ (the momentary quantity of VE in the VES) and V_0 (the lowest quantity of VE in the VES). In symbols:

The rate of dissipation = $D \times [\mathcal{V}(t) - V_0]$, where D is a constant of proportionality. This is a familiar form, originating with Newton's law of cooling.

In Fig. 5, $\mathcal{V}(t)$ tracks the VE level after t_0, the instant of the last pulse discharge.

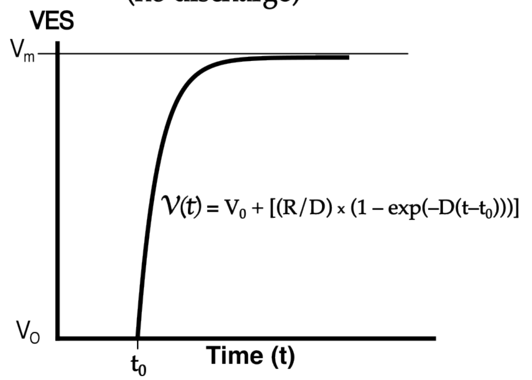
$d[\mathcal{V}(t)]/dt = R - \{D \times [\mathcal{V}(t) - V_0]\}$.

Inflow R increases the quantity of VE in the VES; dissipation decreases that quantity.

Solving the differential equation:

$\mathcal{V}(t) = V_0 + [(R/D) \times (1 - \exp(-D(t - t_0)))]$.
This is the ***VES functional*** shown in Fig. 5.

Fig. 5: VES functional in dissipative VES (no discharge)



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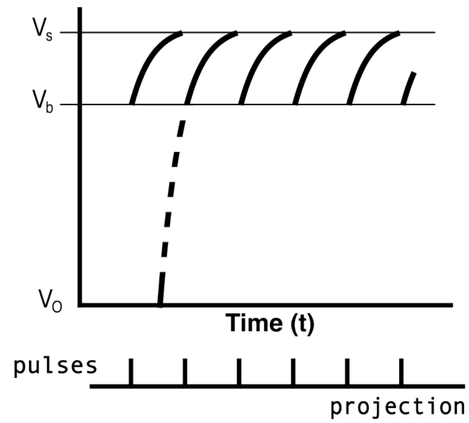
Observe the VES functional at its extremes. Close to $t = t_0$, $d[\mathcal{V}(t)]/dt$ is close to R, as in the primal pulser. At the other end, $\mathcal{V}(t)$ approaches $V_m = V_0 + R/D$.

Fig 6 shows an operating VES-controlled pulser device. The discharge point is set at $V_s < V_m$. When discharge occurs, $\mathcal{V}(t)$ falls to V_b (rather than to V_0 as in the primal pulser). The dashed line shows the omitted segment of the VES functional.

It is required that $V_s - V_b \geq !$. Any excess VE passes as waste heat into the environment.

The device operates cyclically, producing a pulse in each cycle. The period between pulses is determined by values of R and D and by device settings of V_s and V_b.

Fig. 6: VES functional in operating pulser



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A different functional that is useful for analysis of the energy economy is an idealized "minimal time" form where source inflow = R and dissipation is zero while $\mathcal{V}(t) < V_m$; when $\mathcal{V}(t) = V_m$, dissipation switches to take all of R. $\mathcal{V}(t)$ increases at the linear rate R until it reaches V_m and then remains at that level.

c. pulsers with extended discharge periods

VES operations of pulsers with extended discharge periods are shown in Fig. 7. Fig. 7(a) shows operations of a pulser producing a steady stream of single pulses; Fig. 7(b) shows a different device producing a steady stream of pulse bursts.

In these devices, the rate of positive change of VE in the VES is a constant R during the ***charging period*** and the rate of negative change of VE in the VES is a constant W during the ***discharging period***. Through an internal process, the charging condition changes to the discharging condition when $\mathcal{V}(t) = V_s$. Similarly, a discharging condition changes to a charging condition when $\mathcal{V}(t) = V_0$. Principles of finality state that conditions of charging and discharging fit exactly into their assigned time periods. Charging periods and discharging periods alternate; together, they fill the time line.

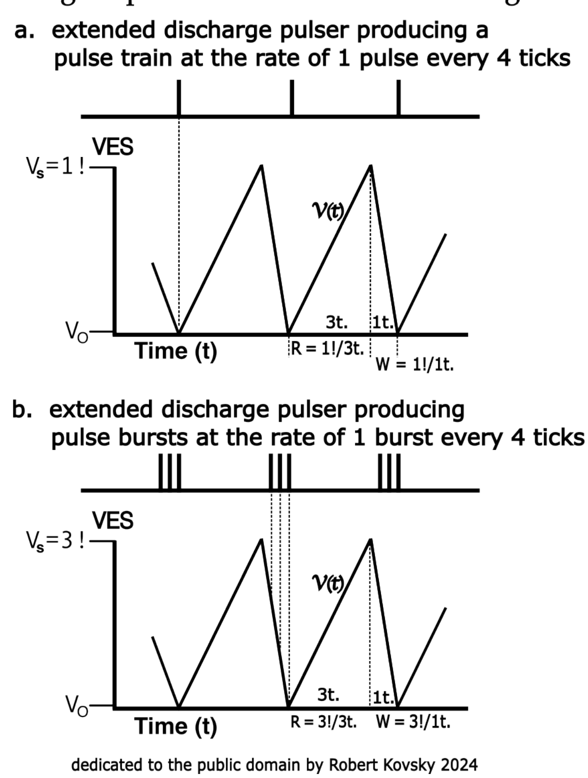
The unit-bang definition of a pulse on a projection imposes a requirement on devices that discharge onto projections: a full bang of VE must be ready for discharge before discharge can occur. A capacity is imputed to the device body of holding VE ready for discharge until a full bang of VE is accumulated.

In Fig. 7(a), the period of R is 3 ticks and the period of W is 1 tick. R is denoted as R = 1!/3t. The discharge process starts when $\mathcal{V}(t)$ reaches V_s. W = 1!/1t. Pulse discharge is delayed until $\mathcal{V}(t) = V_0$. A finality principle states that pulse discharge occurs exactly on the tick.

A pulse burst device is shown in Fig. 7(b), where the scale of VE operations is multiplied by 3. $V_s - V_0 = 3!$. Time stays the same. Thus, R = 3!/3t. and W = 3!/1t.

Discharge of the first pulse in a burst occurs 1/3 tick after the discharge process starts, at the instant $V_s - \mathcal{V}(t) = 1!$ The last pulse is on the tick (finality principle) and the middle pulse fits into place.

Fig. 7: pulsers with extended discharge



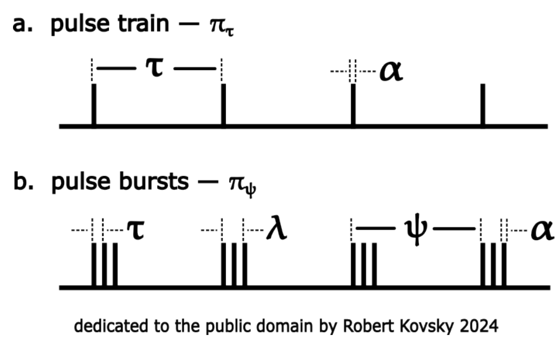
d. ideal pulse patterns

Pulse patterns produced by pulsers with extended discharge periods (Fig. 7) serve as exemplars for ideal pulse patterns shown in Fig. 8.

The pulse pattern in Fig. 8(a) is a succession of pulses with a uniform time period τ between any two pulses. This pattern is called a ***pulse train***, denoted here by π_τ. Timing intervals of length τ partition the time line exactly. As an example, suppose that τ = 4t. The convenient value for this interval is τ = 0.4 sec. It does not matter where in the cycle τ starts; but it is convenient to define the cycle as starting at the instant that pulse discharge starts.

Each pulse in the ideal pulse train extends over a non-zero period of time denoted by α. A convenient value for α is .001 second. An ideal pulse abruptly starts at a sharply-defined instant and abruptly ends after α.

Fig. 8: ideal pulse patterns



A stream of pulse bursts – denoted by π_ψ – is shown in Fig. 8(b). Time period ψ denotes the periodic interval of time between bursts. Each ψ period starts at the instant the device starts discharging the first pulse in a burst and ends at the instant the device starts discharging the first pulse in the next burst. Time required to discharge a pulse (α) is the same as in Fig. 8(a). Time period τ is re-defined as the period between starting instants of successive pulses in a burst. Following the guidance on maximum vales, τ is never less than 0.02 sec., which equals 5! per tick.

Time period λ approximately defines the width of the pulse burst. In Fig. 7(b), λ equals 2/3 tick. The λ period starts at the first instant of discharge of the first pulse and ends at the first instant of discharge of the last pulse. The period of the last pulse – α – is not included in this λ. These definitions facilitate interconversions between sensorial pulse trains and pulse bursts that drive movers.

Various constructions can use various methods to deal with pulse width. Although some care is advisory, as a general principle, slight differences in pulse widths and pulse placements in time appear to play no part in practical results.

e. sensory pulsers and modules

Variable pulse trains are produced by ***sensory pulsers*** in which the rate of output pulses is a measure of an environmental influence, e.g., pressure on the skin or temperature. The final modular design is intended for use in larger constructions. When the environmental influence is absent or weak, the output pulse rate of the module is low. As the influence becomes stronger, the output rate increases.

Operations in these designs are stable. That is, if the researcher introduces a slight temporary disturbance in operations, they return smoothly to the prior values after the disturbance ends, with no change other than a shift in time. It is also possible to modify operations progressively, by small changes. These features resemble quasi-static processes in classical thermodynamics.

Steps in the construction of the sensory module are:

i. pulser with controlled R

ii. pulser with stable self-control

iii. pulser with dissipative sensor

iv. sensory pulser

v. sensory module with direct readout

---

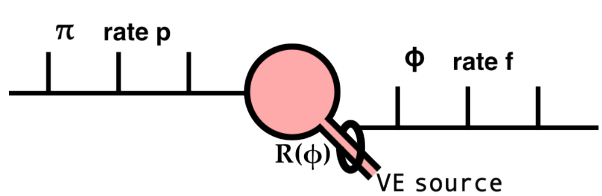
i. pulser with controlled R

An ideal pulse train π is specified by its period τ. The inverse of τ is the ***rate*** of pulse production, namely, a number of pulses per standard time period. Rates can be used when signals are ideal pulse trains but not necessarily for other signals.

In this construction, the defining time period for operations is 3 ticks denoted "3t". The rate of pulse production, "rate p" in Fig. 9, is defined as p pulses in 3t. The rate of VE inflow, R, is also defined for a 3 tick period. In this device, p = R.

In Fig. 9, R is controlled by an input pulse train φ specified by rate f. A ***control function*** R(φ) defines the relation between rate f and R. A simple control function states that arrival of a φ pulse at the device causes the release of a π pulse as output. In other words, p = R = f.

Fig. 9: pulser with controlled R



For purposes of development, let pulse train φ control a ***sphincter*** around the VE inflow tube, constricting the flow as f increases. When f increases, R and p decrease. Here, let R(φ) = 16!/3t. – f and thus f + p = 16!/3t. Rates are real numbers in the interval [1, 15]. This means that the maximum R is 15! in 3t, equal to 50!/sec., within the suggested maximum rate.

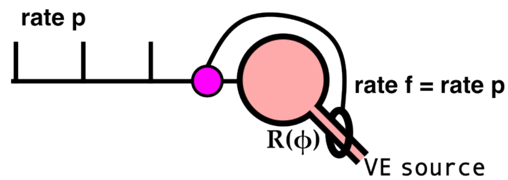
f	5	6	7	8	9	10
p	11	10	9	8	7	6
R	11	10	9	8	7	6

The adjacent table shows results of this control function for some integral values of f, p and R.

ii. pulser with stable self-control

In the Fig. 10 design, a new projection branches from the output projection and drives the sphincter control function introduced in Fig. 9. Referring to the table above, this means that f = p and that both rates are 8!/3t.

Fig. 10: pulser with stable self-control



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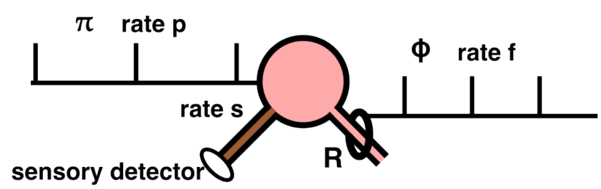
Suppose that a researcher interferes with the branching projection so that f is reduced below 8!/3t. Then p will increase by a corresponding amount. Next suppose that the interference ceases. Faster p and f will tighten the sphincter constriction and thus reduce p. A sufficiently slow response of the sphincter to changes in f will result in a smooth return to 8!/3t. This stabilizing response resembles that of a sufficiently damped harmonic oscillator in mechanics.

iii. pulser with dissipative sensor

The pulser with dissipative sensor (Fig. 11) is another modification of the Fig. 9 design. The device has an outflow of VE from the VES that is dissipated in a ***sensory detector*** at a rate s.

The sensory detector dissipates energy as a measure of an environmental influence, e.g., heat, pressure on the skin. As the influence strengthen, dissipation grows larger and the outflow of VE from the VES also grows larger.

Fig. 11: pulser with dissipative sensor



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R is no longer equal to p; rather a conservation principle requires that: R = p + s. Recall that R= 16!/3t. – f. Hence, f + p + s = 16!/3t.

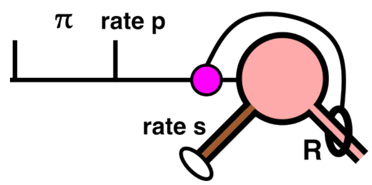
f	5	6	7	8	9	10
p	9	8	7	6	5	4
s	2	2	2	2	2	2
R	11	10	9	8	7	6

The adjacent table shows operations of the pulser with dissipative sensor for some integral values of f, p and R when s=2.

iv. sensory pulser

The sensory pulser in Fig. 12 combines dissipation and self-control. Rate f is set equal to rate p. Referring to the previous table for the case s=2!/3t, when f equals p, both are equal to 7!/3t. Rate p has dropped by 1!/3t. as a result of sensory dissipation. Generally, p = (8! – s/2)/3t. An increase in s is measured as a decrease in p.

Fig. 12: sensory pulser



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v. sensory module with direct readout

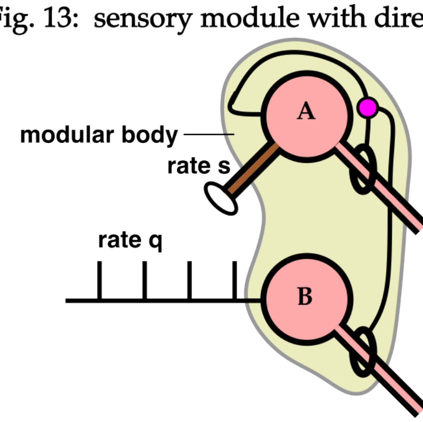
A simple principle of coordination suggests that a stronger sensation should result in a faster rate of pulses in the output of the sensor, leading to a faster and stronger movement. The Fig. 12 design produces a contrary result. The sensory module with direct readout in Fig. 13 produces the desired result.

The module is based in a modular body enclosed in an envelope; it has specified inputs (source VE for each pulser) and specified outputs (sensory dissipation at rate s and pulses at rate q). Modular bodies in more advanced designs can influence operations of VE devices inside the body; however, the modular body in Fig. 13 has no influence. There is no correlation in operations of the two devices A and B. In this first step of development, the modular body is only a package.

Device A in Fig. 13 operates like that in Fig. 12. The p = f input that drives R(φ) in device A also drives an identical R(φ) in device B. But device B has no dissipation and rate q = R(φ) = 16!/3t. – p, much as in Fig. 9. And p = (8! – s/2)/3t. from the previous step.

The result: q = 8!/3t. + s/2.

Fig. 13: sensory module with direct readout



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8. Timing devices, linear arrays and extensions

Development of timing devices began in 2007 and culminated in 2011 with "An Ear for Pythagorean Harmonics," a .pdf publication, and "Brain Models Built From Timing Devices," a web project; these are accessible on the website. Further deigns have been used in more recent projects.

This construction is smaller in scope than prior projects but it includes new devices and modules for use in the Gazer project. Culminating designs perform functions of "VE centering device" modules used in that project. The concept of Virtual Energy starts as a pulse on a projection and develops into a VE distribution inside a linear array of entrained devices operating within a sensorial body. Departing from timing device principles, final development of "VE centering devices" investigates processes driven by VE potentials that resemble pressures in water flows, voltage differences in electric current flows and sources of heat in thermodynamics.

Steps in this timing device construction are:

a. primal timing device

b. signal generators

c. pulse waves in linear arrays of primal timing devices

d. pulse bursts produced by timing devices during extended discharge periods

e. mode changes in gated devices and two-pulse devices

f. centering modules for Gazer designs are constructed from timing devices

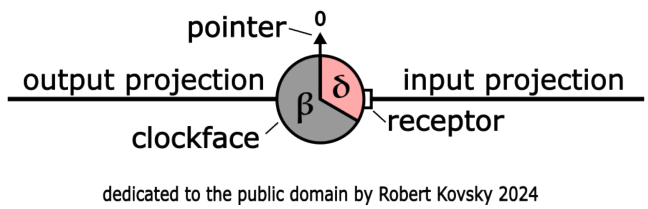
g. centering module designs are extended to distributive processes

h. further extension to potential-driven distributive processes

a. primal timing device

A functional design for the primal timing device is shown in Fig. 14. An input pulse arrives over the input projection, triggers the receptor and starts an internal clock of the device. The action resembles that of a stopwatch in sports, with a pointer moving over a clockface. An exact period of time denoted by "δ" intervenes between the arrival of the input pulse and the discharge by the device of a pulse on the output projection. The VES, which has produced the output pulse, is re-filled with VE during a subsequent exact period of time denoted by "β." Then the device is ready for another response.

Fig. 14: functional design of the primal timing device



A more formal definition begins with the timing device in the ***ready*** condition: the pointer sits unmoving at 0. The arrival of a trigger pulse at the receptor at time t_0 changes the condition to the ***responding condition*** and starts the pointer on its round. At time (t_0 + δ), the pointer has traveled through the δ region of the clockface. Time period δ is called the ***responding period***. On the final instant of the responding period, the device discharges a pulse. After discharge, the device condition changes to the ***restoring condition*** and the cycle continues for an additional time period β, called the ***restoring period***.

As part of the cycle of operations, the receptor is ***inactive*** (blocked) during the (δ + β) period and cannot process an arriving pulse. When time reaches (t_0 + δ + β), the pointer reaches 0 and stops, the receptor becomes active and the device returns to the ready condition.

The form or schema of the cycle is:

ready – responding (including discharge) – restoring – ready.

Fig. 15 shows VES operations of the primal timing device. The active segment of the VES functional in the lower right of Fig. 15 is taken from Fig. 5. The active segment is exaggerated in the vertical direction. For faster operations, V_b would be just below V_r. V_s is just above V_m. $V_s - V_r$ is slightly less than 1 ! and $V_r + 1! > V_s$, resulting in discharge of a pulse after the period δ. V_r marks the return to readiness.

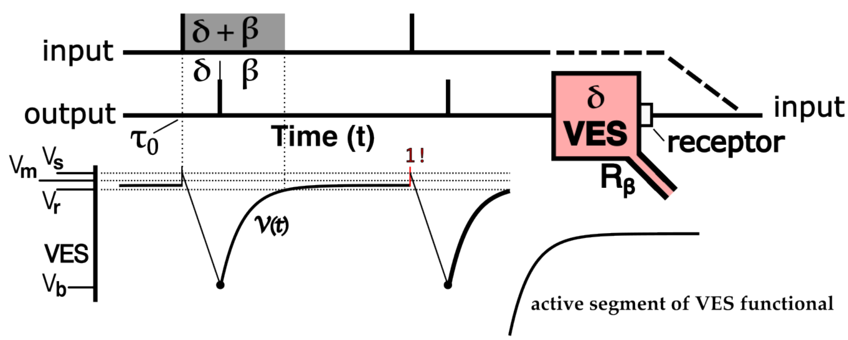
$\mathcal{V}(t)$ approaches V_m from below but does not reach V_m on its own. An input pulse arriving at time τ_0 is converted and added to the VE in the VES, momentarily pushing $\mathcal{V}(t)$ above V_s and starting the discharge process. Applying the finality principle, the discharge process completes at the end of its period δ. At the last instant of the responding period, a pulse is discharged.

The responding period δ is a specification of the timing device. In the primal timing device, δ is conveniently set at 0.01 sec. Later designs define responding periods as 1 tick or 4 ticks.

The restoring period β has different values and functions in various designs.

The receptor in the primal timing device is inactive or blocked during the (δ + β) part of the cycle as denoted in gray in the input line of Fig. 15. At the end of the restoring period, $\mathcal{V}(t) = V_r$ where $(V_s - V_r) < 1!$. The receptor is then unblocked and the device becomes ready to respond when a fresh input pulse arrives.

Fig. 15: VES operations of the primal timing device



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Energy economy in the primal timing device starts with idealized operations where $V_s = V_m$, $V_s - V_r = 1!$ and $V_b = V_r$. A useful benchmark value for β is β = δ. Then, where δ = .01 sec, the maximum production rate of pulses is 50/sec.

In a cycle of idealized economic operations, 1 external pulse is added to the VES and 1 pulse is discharged from the VES. The value of $\mathcal{V}(t)$ moves in a 1! range.

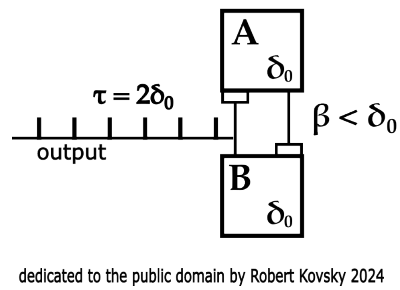
To round out the construction, add to the primal timing device a separate VE reservoir that has its own VE source R and that has no dissipation. While the VES is discharging a pulse, during the responding period δ, fresh VE charges the reservoir. Then, during the restoring period, VE from the reservoir supplements direct VE inflow into the VES. Suppose that, following conservative ideals, R = 100!/sec. During a cycle of 2δ, 2! of VE flows into the reservoir. During the β period, VE from the inflow R and from the reservoir combine to refill the VES. (This is more clearly seen with the "minimal time" form of VES functional discussed in §7(b) above.) These flows can meet the energy demands of the device.

b. signal generators

The signal generator shown in Fig. 16 is built from two interconnected primal timing devices A and B, which discharge onto each other in reciprocating operations and generate an ideal pulse train with a repetitive period $\tau = 2\delta_0$, where δ_0 is the responding period of both devices.

Suppose that device A discharges a pulse that triggers device B at time $t = t_0$. After the responding period δ_0, device B discharges a pulse that triggers device A at time $t = (t_0 + \delta_0)$. A duplicate pulse appears on the branching output projection. The response and discharge of device A requires another δ_0, resulting in arrival of a pulse at device B at time $t = (t_0 + 2\delta_0)$, completing one cycle of signal generation. The next pulse will be produced during the next cycle.

Fig. 16: signal generator built from 2 primal timing devices

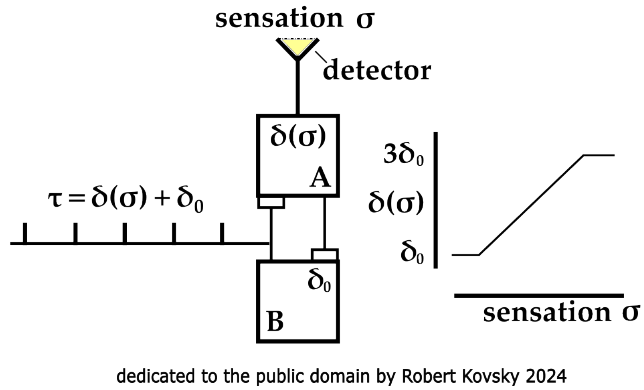


One constraint on operations of this design is that β must be less than δ_0. The VES of a timing device that has just discharged must be restored and ready when the other timing device discharges.

The signal generator in Fig. 17 is a variant of that in Fig. 16. It responds to an increase in a variable sensation σ by increasing the period of the resulting output. A stronger sensation lengthens the responding period of device A, which is denoted by $\delta(\sigma)$. An example is shown in the accompanying graph, with a maximum increase to $\delta(\sigma) = 3\delta_0$.

Suppose that $\delta_0 = 0.01$ sec. and that $\delta(\sigma)$ varies between 0.01 sec and 0.03 sec. The frequency of pulses on the output projection will vary from 50 per sec. when there is no sensation or detection to 25 per sec at maximum detection.

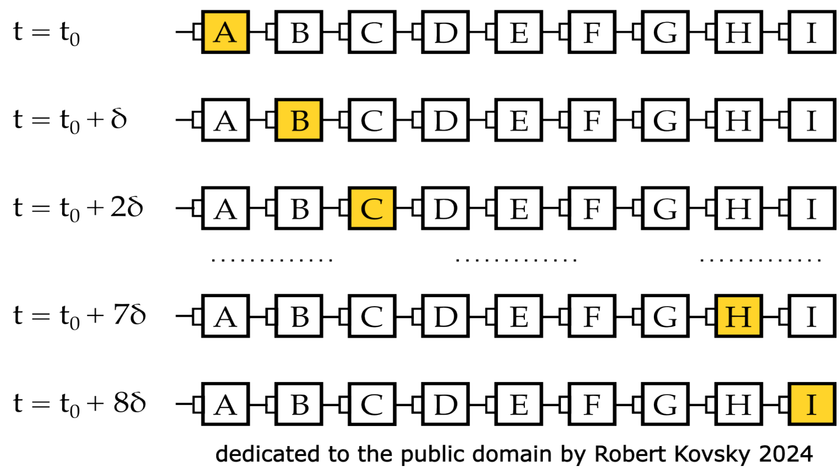
Fig. 17: signal generator that responds to a sensory variation



c. pulse waves in linear arrays of primal timing devices

In Fig. 18, nine identical primal timing devices are connected in a linear array of devices. Triggered in succession with a time step of δ, they produce a wave of pulses. Development of linear arrays culminates in centering device modules.

Fig. 18: a wave of pulsations in a linear array of primal timing devices



At time $t = t_0$, timing device A discharges.

At time $t = t_0 + \delta$, timing device B discharges.

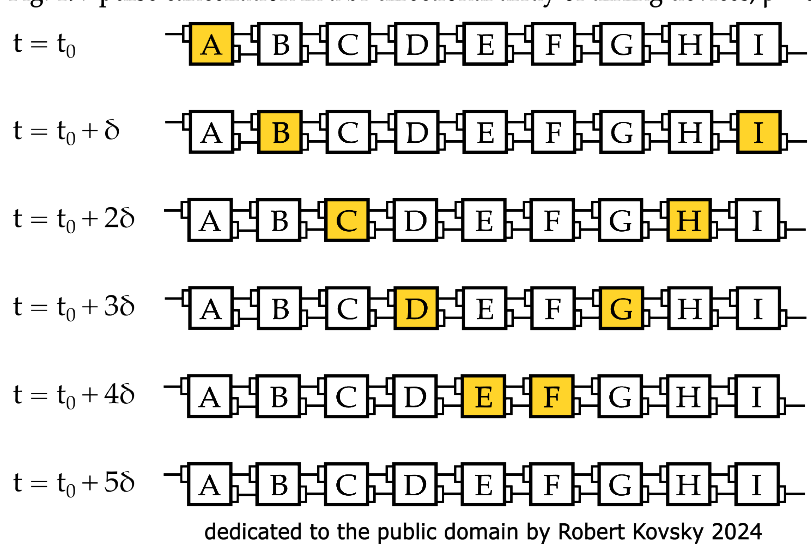
At time $t = t_0 + 2\delta$, timing device C discharges.

…continuing down the line, and so forth…

… until the end.

The array in Fig. 19 performs a new function of pulse cancellation. It resembles the array of Fig. 18, but devices are modified: two projections and two receptors in a device mean that the array is bi-directional. When a device discharges, it produces two pulses, one on each output projection. If a device is ready, it can be triggered through either input projection. The constraint $\beta > \delta$ means that when device A discharges onto device B, device A is not ready when device B discharges. A reciprocating pattern like that in Fig. 16 is excluded.

Fig. 19: pulse cancellation in a bi-directional array of timing devices, $\beta > \delta$



Operations start the same as in Fig. 18. At the $t = t_0 + \delta$ step, a new feature is introduced: a pulse wave starting at the other end of the array. When the two waves meet, further triggering cannot occur because receptors are blocked and because of the constraint $\beta > \delta$. The two pulses cancel each other.

Movements of the two waves in Fig. 19 are synchronized, simplifying the figure. Cancellation also occurs the same when waves are not synchronized.

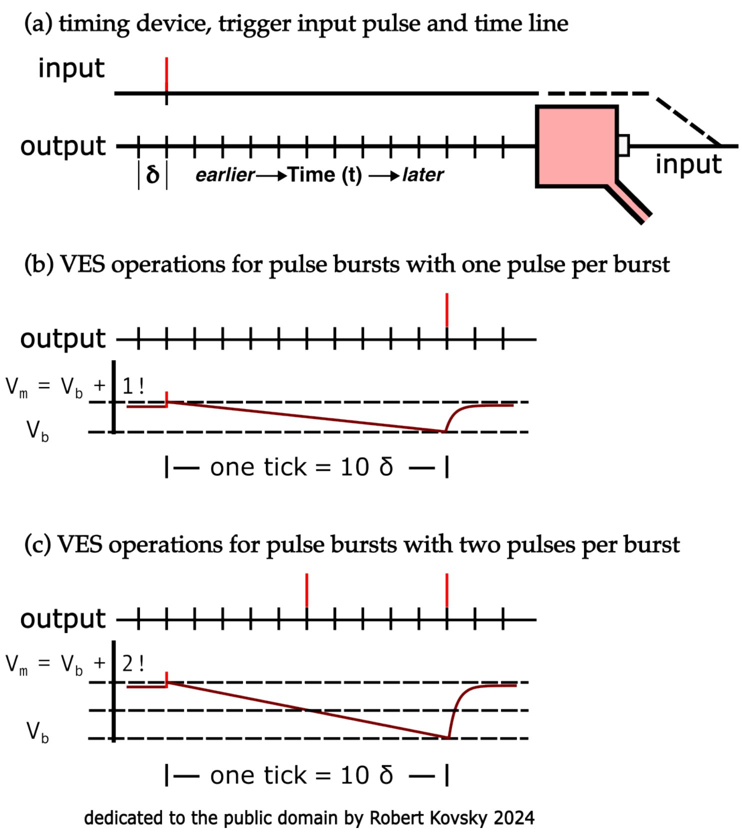
d. pulse bursts produced by timing devices during extended discharge periods

In the Gazer project, certain timing devices denoted by numbered triangles operate at the edges of sensorial bodies and send signals to burster modules. That function is performed by timing device modules constructed below. This construction also defines the class of pulse burst signals used in the Gazer project.

These device modules produce bursts that fill one tick, including both end points. Here, one tick = 10δ and δ is the responding period of the primal timing device. Operations resemble those of pulsers with extended discharge periods. (Fig. 7.) The discharge period for timing devices with extended periods is 1t. or 10δ.

Fig. 20 shows operations of a first group of timing devices with extended discharge periods.

Fig. 20: timing devices that discharge pulse bursts



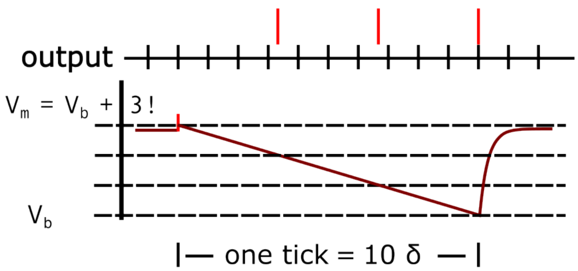
A representative device is shown in Fig. 20(a) with input and output projections and a time line. A trigger input pulse starts operations.

Fig. 20(b) shows the simplest example with a 1-bang VES range and a 1-pulse output burst. The trigger pulse immediately starts the discharge process, which has a period of exactly one tick. The pulse discharge at the end of the tick applies a principle of finality.

In the Fig. 20(c) device, the VES range equals 2!. The first output pulse is discharged 5δ after arrival of the input pulse, when one ! of ready VE has accumulated in the body of the device. The second pulse at the end of the tick again applies a finality principle.

Fig. 21: more timing devices that discharge pulse bursts

(d) VES operations for pulse bursts with three pulses per burst



(e) VES operations for pulse bursts with four pulses per burst

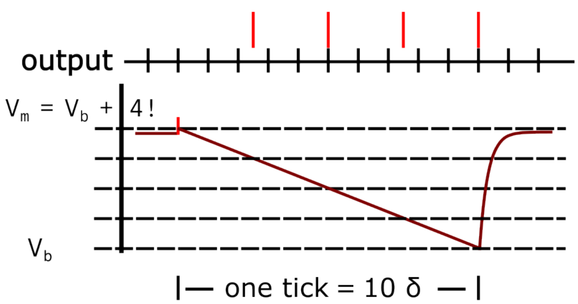


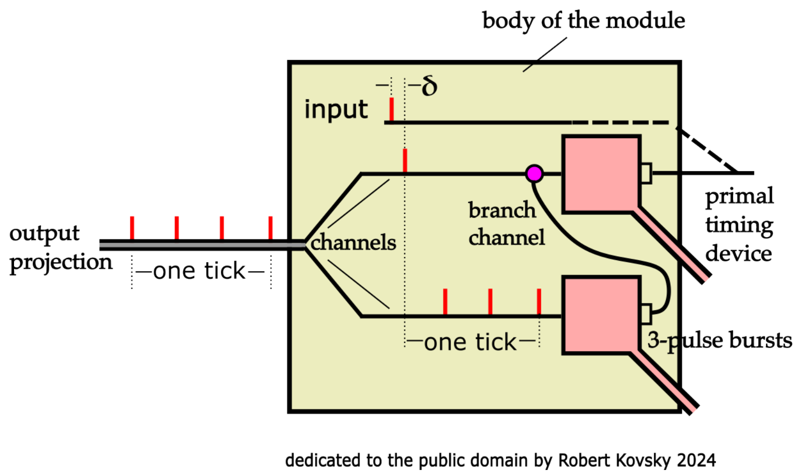
Fig. 21 rounds out the class: a 3-pulse device is shown in Fig. 21(d) and a 4-pulse device is shown in Fig. 21(e).

The bursts share a finality principle for production of the final pulse in the burst.

The discharge period is divided into n sub-periods, where n is the number of pulses in a burst. Each sub-period concludes with the discharge of a pulse.

The exemplary timing device module shown in Fig. 22 uses two timing devices operating in a modular body that contributes physical properties to the construction. In the module, a primal timing device and a 3-pulse burst device combine outputs. Internal ***channels*** carry VE instantaneously just like projections. Differing from projections, channels merge and transport VE into the output projection. A branch of the output channel from the primal device carries its signal to the 3-pulse device.

Fig. 22: timing device module that discharges full-tick 4-pulse bursts



An input pulse triggers the primal timing device, which discharges a pulse after a period δ. This pulse appears on the output projection and also starts the tick in the bursting device that produces 3 pulses. Pulses are combined to form a 4-pulse output signal with equal periods that add up to a full tick.

Operations of the module produce a unified signal. Unification is a result of both (1) the branch channel that connects devices and synchronizes timing; and also (2) bodily entrainment of operations. Unification by means of bodily entrainment is maintained when channels are later replaced by junctions. Entrainment in Fig. 22 resembles drumming one's fingers on a table.

Fig. 23: pulse burst signals

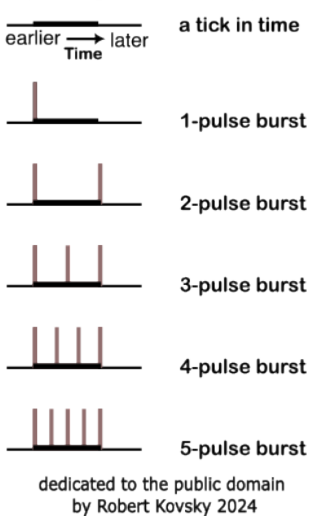


Fig. 23 shows the repertoire of pulse burst signals that are produced by the class of timing device modules using the Fig. 22 design. Bursting devices produce 0, 1, 2, 3 and 4 pulses (depending on the size of the VES), which are unified with the first pulse from the primal timing device.

This is also the repertoire of signals set forth in § 2 of the Gazer project. These pulse burst signals drive movers. Such burst signals are generally produced and processed by VE devices called bursting devices or ***bursters***.

Pulse burst signals can be interconverted with sensorial pulse trains by means of certain burster designs, facilitating coordination of sensations and movements.

e. mode changes in gated devices and two-pulse devices

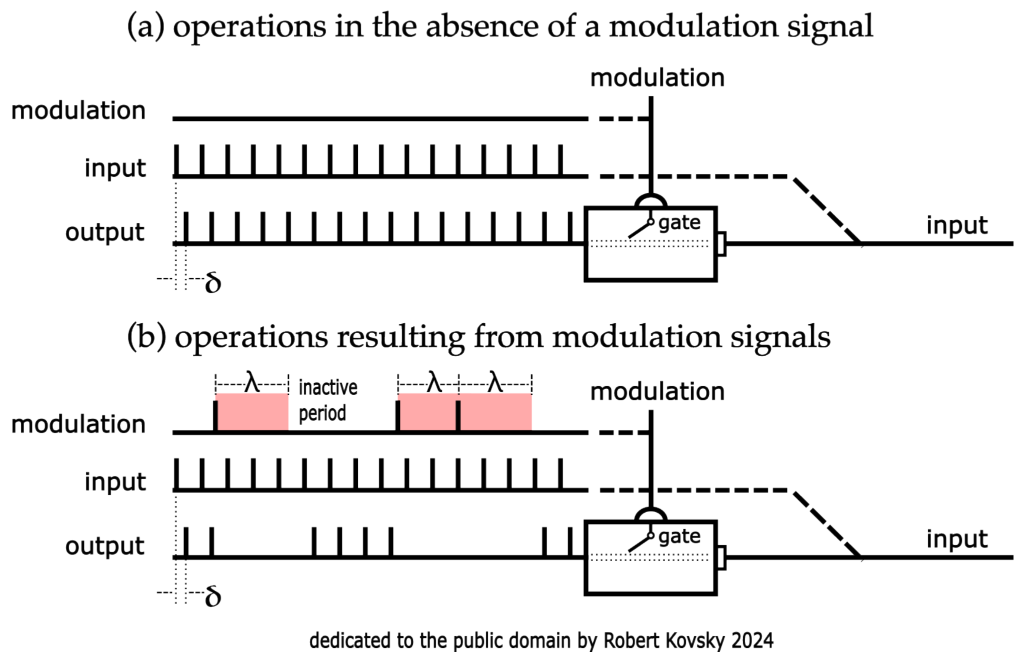
As discussed above in § 5, a schema is a sequence of conditions that defines the operations of a VE device. Many devices have two or more schemata and are switched between schemata by pulse signals or internal operations. Such a device has multiple ***modes*** of operation and the device ***changes modes***. A switch between modes involves changing conditions of receptors or of a device body. E.g., a pulse through one input changes the effects of pulses through another input.

i. gated timing devices

Operations of gated timing devices resemble those of electrical relays and vacuum-tube triodes: a signal passes or does not pass from input to output depending on the presence or absence of a modulation signal. Such devices can be assembled into systems that perform logical operations.

Fig. 24(a) shows operations of a ***normally-active gated timing device*** in the absence of modulation signals — the results are the same as those of a primal timing device, reproducing a pulse stream with a delay δ.

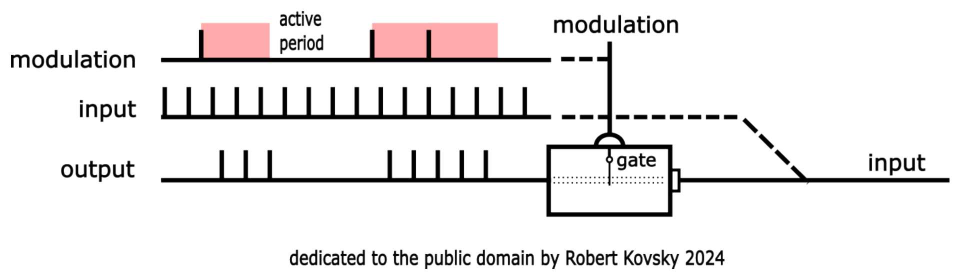
Fig. 24: operations of a normally-active gated timing device



As shown in Fig. 24(b), when a pulse arrives over the modulation projection, the input receptor immediately switches to an inactive condition that lasts for an "inactive period λ." It is as if a gate has closed, blocking processing of pulses. When the inactive period ends, the gate opens and the receptor returns to the normally-active condition. If modulation pulses arrive in a steady stream at a rate greater than 1/λ, the receptor stays blocked in an ongoing way.

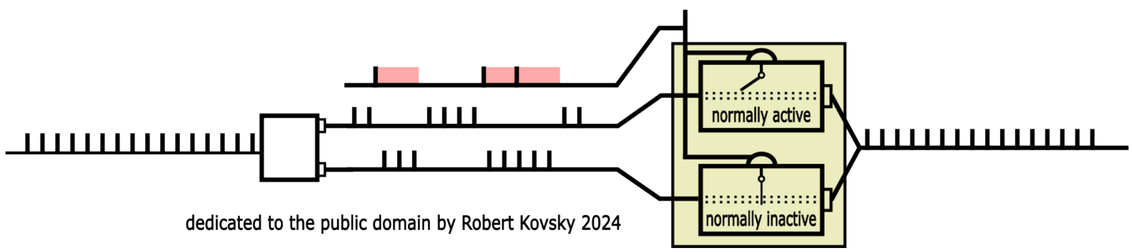
A similar device is shown in Fig. 25, except that the condition of the receptor is normally inactive. The receptor becomes active for a period λ after arrival of a pulse over the modulation projection. Repeated modulation pulses at a sufficiently high rate keep the receptor in an active condition.

Fig. 25: operations of a normally-inactive gated timing device



In Fig. 26, a single depiction shows three stages in the processing of a pulse train. The module has two gated timing devices — one gated device is normally active and the other normally inactive. An input feeds both timing devices equally. A modulation pulse switches both devices simultaneously. Then the two outputs drive a single timing device. The result is splitting and recombining a pulse train.

Fig. 26: timing devices splitting and recombining a pulse train



ii. two-pulse devices

The two-pulse timing device shown in Fig. 27 has two input projections that operate identically. It produces an output pulse when separate pulses on input 1 and input 2 arrive within a time period λ of each other. The device detects (approximately) ***coincident pulses***.

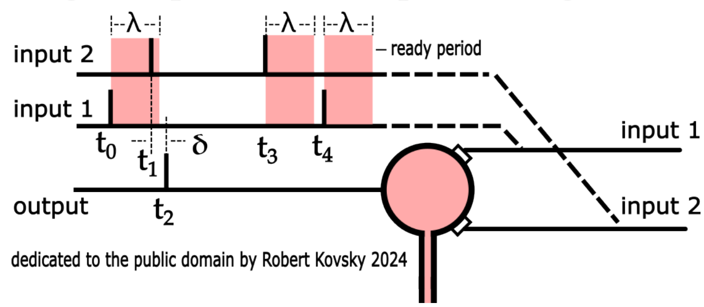
Schemata of the 2-pulse device are developed from the schema of the primal timing device:

primal schema: ready – responding – restoring – ready
2-pulse schemata: unready – ready – unready (mode 1)
unready – ready – responding – restoring – unready (mode 2)

The device is in the ***unready*** condition until an input pulse arrives over one of the input projections; the device then switches to the ***ready*** condition and can respond like a primal timing device for the ***modulation period*** λ. The input receptor that carried the first pulse is blocked during λ.

If a pulse arrives over the other projection during the modulation period, it triggers the response process. After discharging and restoring, the device returns to the unready condition. This cycle of operations is mode 2. If a second pulse does not arrive over the other projection during the modulation period, the device returns to the unready condition without discharging; this is mode 1.

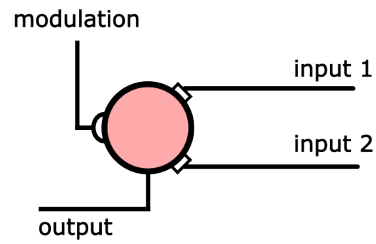
Fig. 27: operations of a 2-pulse timing device



Examples are shown in Fig. 27. The pulse arriving on input 1 at time t_0 changes the condition of the device from unready to ready. The device remains in the ready condition (as shown in pink on the time chart) until a pulse arrives on input 2 at time $t_1 < t_0 + \lambda$, triggering a timing device response and discharge of an output pulse at time $t_2 = (t_1 + \delta)$. Alternatively, while the device is in the ready condition after a first pulse on input 2 at time t_3, a period of time λ passes without any pulse arriving on input 1, at which point the device returns to the unready condition at time $(t_3 + \lambda)$. Then, the next pulse at t_4 over input 1 starts a new ready period.

Fig. 28 shows a further development in which a modulation control is added to the 2-pulse timing device. Modulation control in the 2-pulse device is like that in the normally-inactive gated device. Input receptors in both normally-inactive devices are blocked except for an active period after the arrival of a modulation pulse.

Fig. 28: a normally-inactive 2-pulse timing device



The following list sets forth the distinct schemata of the normally-inactive 2-pulse timing device. Additional pulse patterns can be constructed, e.g., the schema shown around t_3 and t_4 in Fig. 27; such patterns are not in the list but can be constructed from schemata that are on the list. Listed schemata thus serve as "atom-like" elements in "molecular" structures of combination.

1. inactive
2. inactive – M – unready – P – inactive
3. inactive – M – unready – I_1 – ready – P – unready – P – inactive
4. inactive – M – unready – I_1 – ready – I_2 – discharging – P – unready – P – inactive

Schemata in the list include ***linkages*** between successive conditions of the device, namely: M denotes the arrival of a modulation pulse; I_1 denotes the arrival of a first input pulse; I_2 denotes the arrival of a second input pulse; and P denotes a change resulting from internal processing of the device.

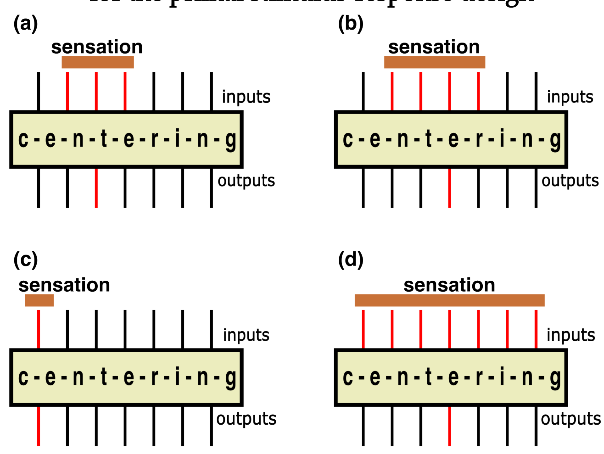
f. centering modules for Gazer designs are constructed from timing devices

In Fig. 29, examples of operations of a centering module apply to a 7-location stimulus signal from §2 of the Gazer project. A "sensation" arrives as input signals in a bloc of projections. Other projections are silent. After processing, a single pulse appears on an output projection at or near the center of the bloc.

The simplest example (Fig. 29(a)) shows one active output projection at the center of the bloc of three active input projections. When an even number of input projections are active (Fig. 29(b)), the active output projection is just off center to one side or the other.

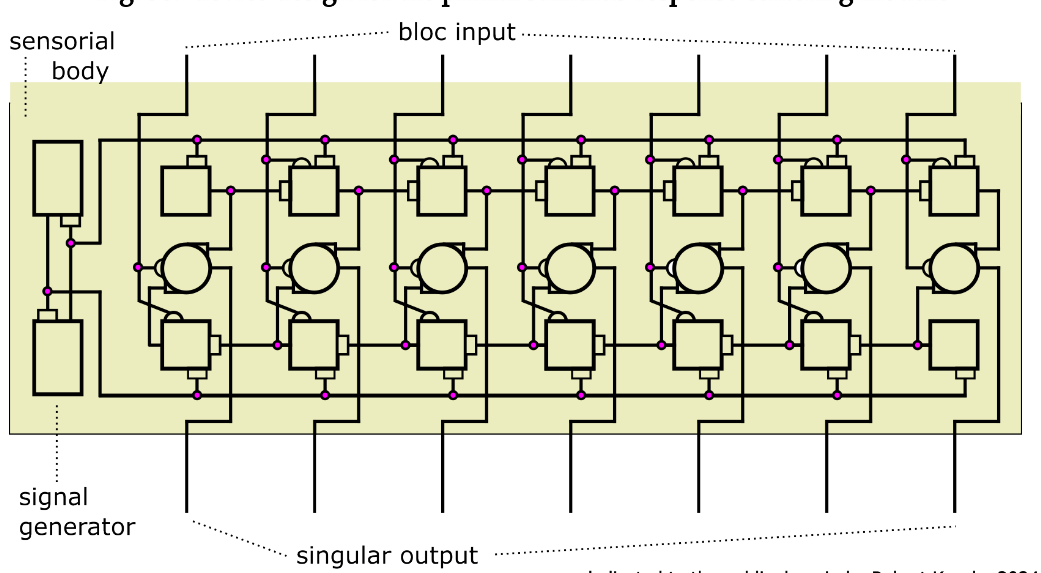
The module produces appropriate results for a single stimulus at an edge of the module (Fig. 29(c)) and for a stimulus that covers the whole module (Fig. 29(d)).

Fig. 29: examples of operations of a centering module for the primal stimulus-response design



In Fig. 30, a device design for the module shows bloc input and singular output. A signal generator on the left discharges pulses ("clicks") in an alternating pattern onto the long horizontal top and bottom projections. The seven operating columns are identical except for a variation at the edges (with simpler inputs from the signal generator). The sensorial body incorporates all the devices in the centering module and may extend to neighboring modules.

Fig. 30: device design for the primal stimulus-response centering module



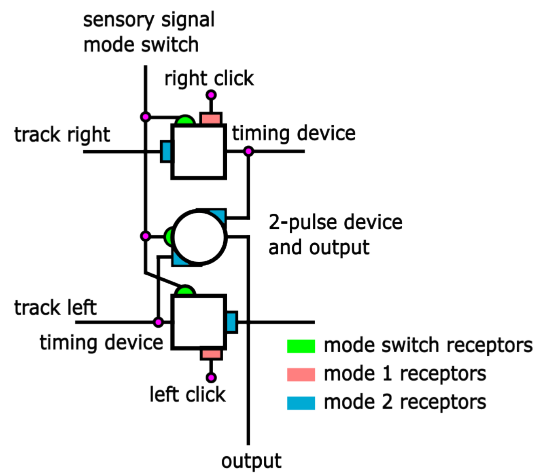
Inside the bloc of devices activated by input pulses, the linear array of timing devices along the tops of the columns (the "right track") carries a wave of pulses to the right like the wave in Fig. 18. The linear array along the bottoms of the columns (the "left track") carries a pulse-wave to the left.

Fig. 31 shows a representative column: it has two-mode timing devices at the top and bottom of the column and a normally-inactive 2-pulse device in the middle. In mode 1, the column connects to click pulses from the signal generator. In mode 2, the column participates in waves along tracks. The modes cannot operate simultaneously. Sensory signals switch modes for columns in the bloc of sensation. That is, a sensory modulation pulse switches modes in the timing devices from mode 1 to mode 2 and activates the 2-pulse device.

Absent a pulse on the sensory signal line, mode 1 receptors on the timing devices are active and mode 2 receptors are blocked; the 2-pulse device is inactive. Timing devices are driven by pulses on the click lines but outputs have no effect.

A mode switch pulse activates mode 2 receptors in the timing devices and blocks mode 1 receptors; it also activates the 2-pulse device, which becomes unready.

Fig. 31: column in centering module



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After arrival of a bloc of sensory signals, the corresponding bloc of columns have switched to mode 2. Unswitched columns remain in mode 1. The bloc of timing devices in mode 2 carries two linear waves similar to the wave shown in Fig. 18.

Devices in the module have the following specifications for time control periods:

signal generator devices:	responding period = δ	restoring period = 0.5δ
2-mode timing devices:	responding period = 2δ	restoring period = 2.5δ
2-pulse device:	ready period = 1.5δ	responding period = δ

Initial conditions of the centering module are shown in Fig. 32.

Fig. 32: activating the centering module

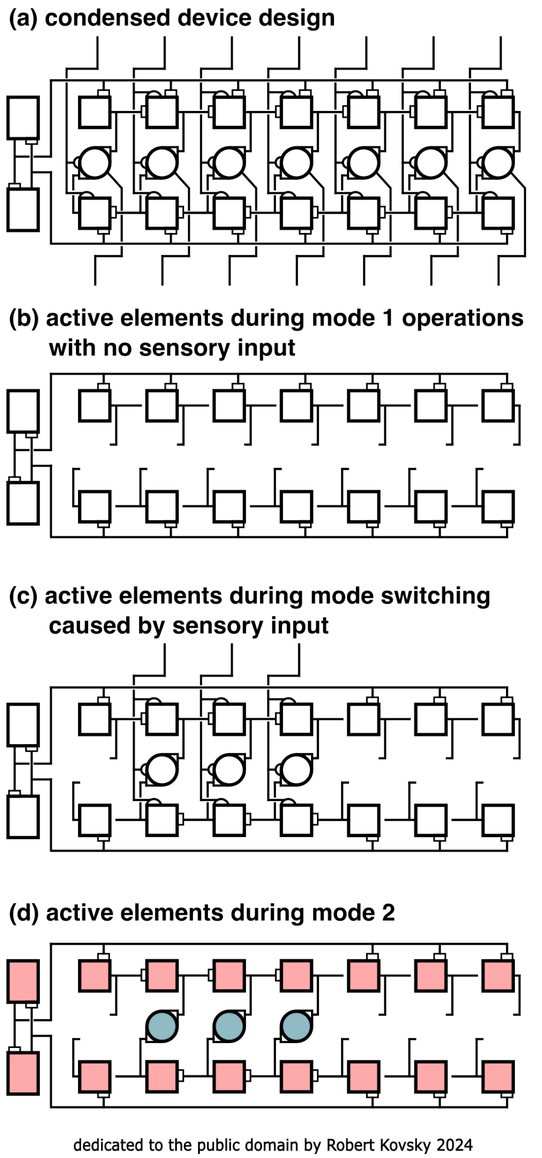

Fig. 32(a) shows a small-scale version of the centering module.

Fig. 32(b) shows devices and receptors that are active during mode 1 operations when there is no sensory input. The timing devices respond to alternating click pulses but their output projections are not connected to active receptors and their discharges have no effect.

Fig. 32(c) shows mode switching, using the example in Fig. 29(a). In timing devices in the switched columns, mode 2 receptors are activated and mode 1 receptors are blocked. Inside the switched bloc, columns are connected along the tracks. The 2-pulse devices are activated in switched columns.

Fig. 32(d) shows activated elements at the outset of mode 2 but prior to operations. The 2-pulse devices are in the unready condition and all the timing devices are in the ready condition.

Fig. 33: operations of the centering module

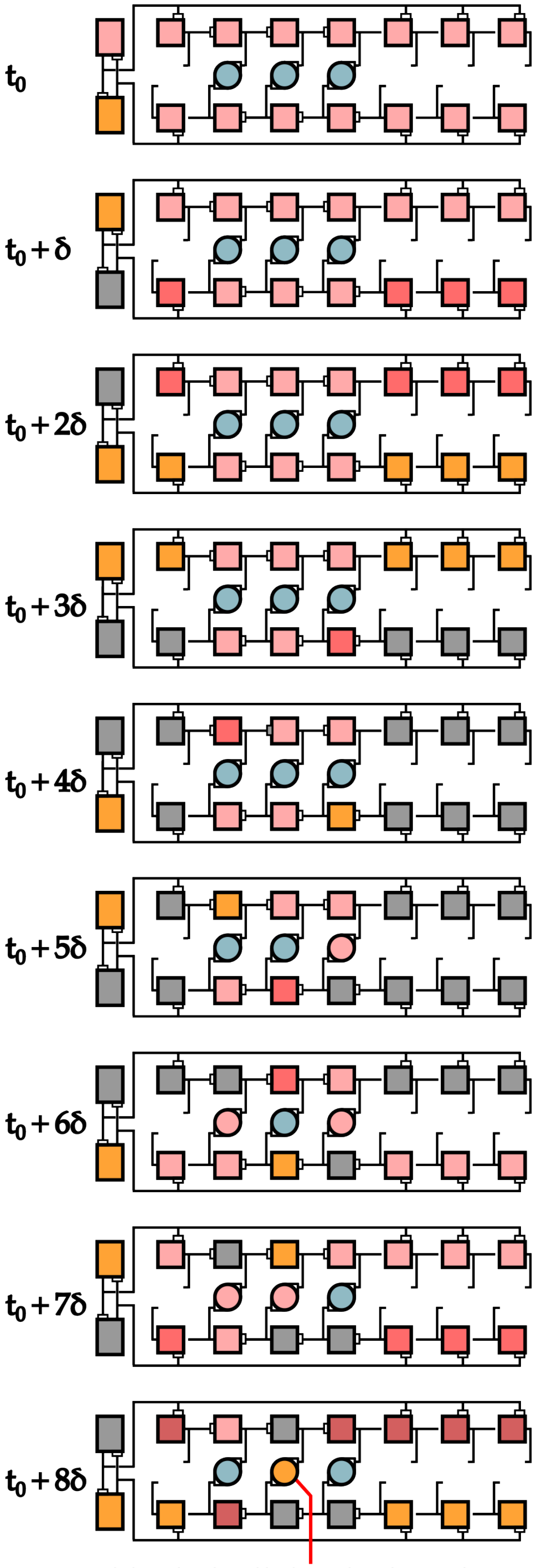

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Fig. 33 shows operations of the centering module for the ongoing example. Operations start with the triggering of a timing device in the signal generator. Conditions of devices are shown at time t_0 "just after" that first trigger.

Operations occur with successive steps of δ. At $t_0 + \delta$, the first click pulse has just arrived at the 4 left track timing devices that are in mode 1, starting their responses.

Fig. 34 lists color codes for conditions of devices. The responding condition of track timing devices has a period of 2δ and two different color codes are used. Both color codes appear after the next step, at $t_0 + 2\delta$.

Fig. 34: conditions of devices in the centering module

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At $t_0 + 3\delta$ and $t_0 + 4\delta$, timing devices at the edges of the switched bloc in mode 2 have just received pulses from mode 1 columns just outside the bloc and have started to respond. During successive steps, pulses advance towards the center of the bloc from each side, first stepping on one track, then on the other. After pulses on the two tracks reach the same column, the 2-pulse device in that column receives two pulses that trigger its discharge. This column is at the center of the switched bloc and will discharge just before $t_0 + 9\delta$, terminating the centering process.

g. centering module designs are extended to distributive processes

The centering module constructed from timing devices incorporates structures and operational schemata that suggest development beyond timing devices. New constructions introduce ***distributions*** in collective devices that are interconnected by ***junctions***, performing centering functions by means different from timing devices. The linear one-dimensional form is a precursor of two-dimensional forms. Two-dimensional forms were used in the Wriggler I project, part II.G.

i. slow speed of the centering module built from timing devices

Speed is a measure of merit in VE device systems and such a measure is readily constructed for the Fig. 30 centering module. For the operations shown in Fig. 33, the ***time required for performance* T** is defined as T = 9δ. This T measure is crude but sufficient for purposes here.

If the bloc of switched devices is enlarged to 5 input projections, operations will require two more steps and T = 11δ. If all seven input projections carry switch signals, T = 13δ. From another perspective, if an operational period of T > 13δ is always provided for performance of the Fig. 30 centering device, performance will be completed during that time period for any size of input bloc.

Analysis for the 7-input centering module can be extended to the full 31-input centering module used in later Gazer projects. The longest time required for performance is that required to center an image that covers the whole linear dimension of 31 inputs, namely, T = 37δ.

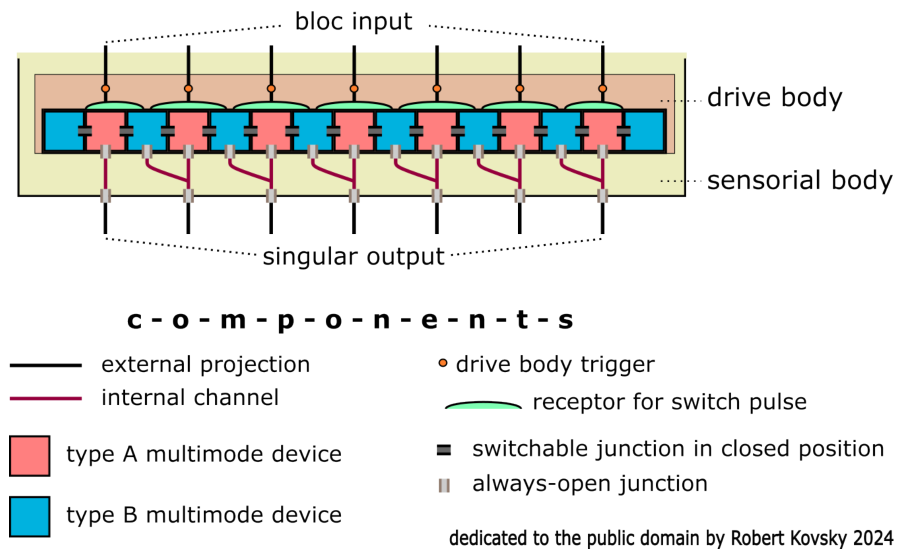
Gazer operations are controlled by a repeating cycle of eight ticks or 80δ. In the large-scale cyclical time structure, a fixed amount of time Δ separates the commencement of distinct functions in a sequence. Performance time for a 31-input centering module appears to fit into a structure where Δ = 40δ. In this time period, the module will always complete performance and become ready for a new stimulus. This is also the performance time of an elemental twitch of a force fiber device. In such a context, a performance time of T < 40δ for centering is substantial but feasible. The system can work; but a lot of time is required for centering and time requirements limit further enlargement of the sensorial field.

ii. faster speed through use of junctions

The hierarchical time structure set forth in §3(c) includes ***junctions*** that transport VE "up to 10 times faster" than timing devices that have projections and receptors. Operations of a faster junction-based centering design shown below in Fig. 35 resemble those of the Fig. 30 design but there are numerous differences.

Looking first at similarities, the Fig. 35 design has the same bloc input projections and singular output as the Fig. 30 design. In both designs, schemata of individual devices are organized in collective cycles. In both kinds of linear arrays, devices have multiple modes; and input pulses cause switches of mode. Unswitched devices feed pulses into both sides of a bloc of switched devices and those pulses step towards each other, meeting at the center and triggering an output pulse.

Fig. 35: centering module with junctions



The Fig. 35 design includes new components. Like projections, ***channels*** transport VE instantaneously. Channels operate internally inside the sensorial body in contrast to projections that extend through deformable space. In addition to the functions of projections, channels can merge, into the output junctions in Fig. 35. (In this design, only one branch channel feeds pulses into a merger at any specific time.) Additionally, channels can carry VE in quantities different from integral VE pulses. (In this design, a movement of VE in a channel is restricted to 1 pulse.)

Another new component is the ***drive body*** that replaces the signal generator shown in Fig. 30. At the start of operations, the drive body is ready and waiting for triggering by any input pulse. After a trigger and a delay for mode switches of devices in the linear array, the drive body produces a repetitive series of ***squeezes*** that continue until operations are terminated. As shown below, a squeeze transfers VE through an open junction from one multimode device to an adjacent device.

The ***multimode devices*** operate in a ***pulsational*** mode and a ***storage/transfer*** mode. In contrast to prior devices, the VES of the multimode device is ***conservative***; it does not dissipate VE and can hold a bang of VE for an indefinite period.

As to the pulsational function, the multimode device has a $\mathcal{V}(t)$ and a V_s like those of prior devices. In the Fig. 35 module, $\mathcal{V}(t)$ is limited to values of 0, 1! and 2!. A convenient value for V_s is $V_s = 1.5!$. When, for a particular device, $\mathcal{V}(t) = 2!$, the device discharges a pulse into its output channel; the pulse travels through the always-open junction that connects the channel to an output projection. Such a discharge completes performance of the centering function; immediately after discharge, the module terminates operations and enters into a restoration period.

As to storage/transfer functions, a type A multimode device has two ***switchable junctions*** that connect it to adjacent type B multimode devices. Switchable junctions are initially closed and are switched between closed and open conditions.

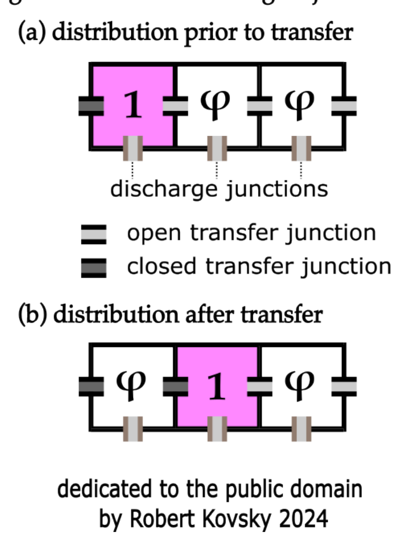
VE in the VES of a multimode device is held at a constant value unless changed. Changes occur during the following operations.

(1) ***Loading*** during the restoration period. In the Fig. 35 module, each multimode device is loaded with 1! of VE. A colored box in the figure denotes 1! in the VES.

(2) ***Clearance*** on command. During clearance, the VE in the VES is dissipated. The VES condition of a device that has been cleared is denoted as $\mathcal{V}(t) = \varphi$ (nil).

(3) ***Transfer*** as a result of a squeeze from the drive body. Transfer in the Fig. 35 module is limited to an arrangement where a loaded device has a single open junction that is connected to a cleared device. A small example is shown in Fig 36.

Fig. 36: VE transfer through a junction



Prior to transfer, the VE arrangement in Fig. 36(a) is denoted as 1φφ. As required for a transfer, the loaded device has one open junction.

After transfer, the VE arrangement is φ1φ. (Fig. 36(b).) The previously-loaded device has been cleared (without dissipation); VE is in the previously-cleared adjacent device; and the junction that carried the transfer has been closed. Closing a junction after transfer is required for a further transfer in the array.

Fig. 36 introduces the concept of ***distributions*** used to specify VE quantities in various device locations in a linear array or other collective module. Quantities of VE in various device locations can be added like arithmetic numbers to define a ***collective VE***. Here, the transfer operation changes the distribution of VE in the array while ***conserving*** the quantity of collective VE.

Fig. 37(a) continues the ongoing example started in Fig. 29(a) and Fig. 32(c). Before switching, multimode devices in the module are in the ready condition, each with 1! of VE. All switchable junctions are in the closed position.

In addition to triggering the drive body, an input pulse causes changes in conditions of multimode devices. A single input pulse changes conditions in a type A multimode device. Two input pulses are required to change conditions in a type B multimode device. (The two inputs must be adjacent in the bloc of input pulses.) As a result, the bloc of switched multimode devices has an odd number of devices and type A timing devices are at the edges inside the bloc.

Also: when a multimode device is switched (Fig. 37(b)), its 1! of stored VE is dissipated, leaving the VES in a cleared condition denoted by φ. Switchable junctions are controlled by switching type A devices and are changed to the open condition when the type A device is switched.

Fig. 37: switching operations in the junction module

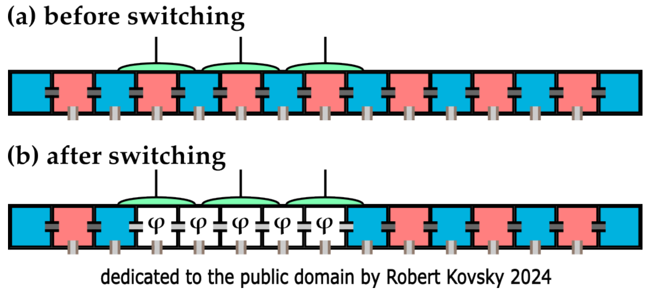
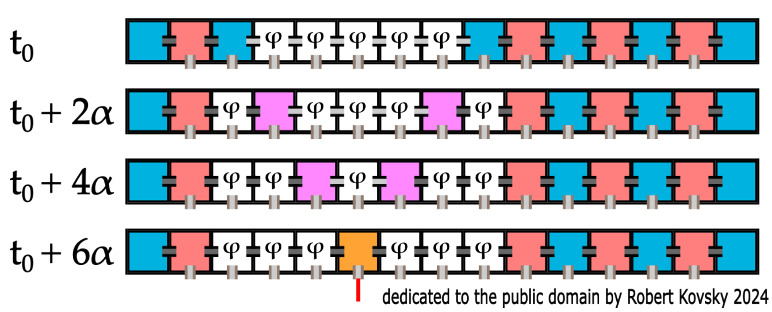


Fig. 38 shows operations of the junction centering module that start after switching and that lead to the culminating discharge onto an output projection. Colored boxes denote devices holding 1! of VE. Device conditions at time t_0 occur just before the first squeeze from the drive body. Squeezes occur every 2α where α is the time required for the transfer through the junction. Each squeeze includes a second α as a margin of silence. The figure at time $t_0 + 2\alpha$ shows conditions after the first squeeze and before the second squeeze. The first squeeze transfers VE between individual devices from outside the switched bloc into the switched bloc.

Fig. 38: internal flow operations in the junction module



Successive squeezes transfer VE inside the switched bloc of devices from both ends towards the center. There is nothing to prevent the final transfers of VE from two adjacent devices into both junctions of the central device. The VES of an individual device operates in a conservative fashion and the VE in the central device is summed to 2!. This quantity exceeds the V_s of the pulsational mode; in this mode, the device discharges a pulse, leading to completion of performance.

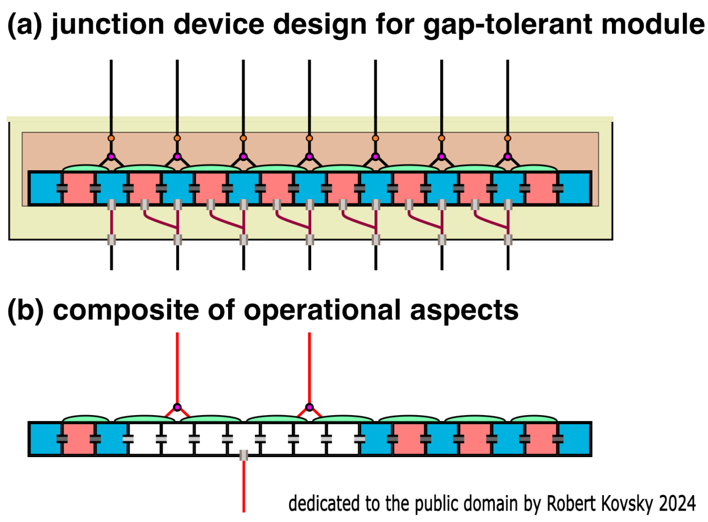
In the Fig. 30 design, a step requires .02 sec. In the Fig. 35 design, a step requires .002 sec. During its most time-consuming function, the junction module operates "up to 10 times faster" than the timing device module.

iii. centering module that tolerates gaps

In the Gazer model, centering devices "require an input with a nearly continuous bloc of stimulated sensors — a single group with no gap larger than a single [input projection]." In other words, centering devices described in Gazer tolerate a gap of one inactive input projection in a bloc of active input projections.

The design in Fig. 39 incorporates a gap-tolerant feature. The chief change from the Fig. 35 design is use of branching input projections; each input pulse activates two receptors. Also, two more timing devices are added to the whole array and to the bloc of switched devices.

Fig. 39: centering module that tolerates gaps



Operations of the gap-tolerant centering module are shown in Fig. 39(b) in a composite figure that superimposes separate steps in the centering process: (1) activation of input projections, with a gap in the bloc of inputs; (2) initial clearances of multimode devices; and (3) final discharge of the multimode device that is located in the center of the switched bloc.

h. extension to potential-driven distributive processes

A course of construction leads to a new method for whole-body centering of signals in a bloc of VE devices. The final design overcomes a shortcoming of prior centering designs, namely, the time-consuming step-by-step march of pulses inwards from both edges of the sensorially-switched bloc — until pulse waves meet at the center.

i. Mathematical models of natural diffusion in material bodies;

ii. A design for diffusion of "potential energy" in a linear array of VE devices or cells resembles a paradigm of heat diffusion in an iron bar;

iii. An alternative VE diffusion model uses VE device detectors that convert potential energy differences between adjacent cells into signals that control inflows of VE from sources or outflows (dissipations);

iv. Additional timing devices – difference devices and balancing units – provide more efficient controls for detector/control models;

v. VE diffusion in a diffusion body resembles that occurring in a line of cells;

vi. The centering function is performed by a new design with a diffusion body, a linear array of VE cells and modules, potential difference detectors between cells and balancing unit controls for VE sources.

----

i. Mathematical models of natural diffusion in material bodies

The leading mathematical model of diffusion was published in 1822 in *The Analytic Theory of Heat* by Jean-Baptiste Joseph Fourier. Fourier's methods apply to movements of heat in solid material bodies such as iron bars and have been foundational for development of major areas of mathematical physics.

Fourier's methods were applied to electrical currents and voltages in metal conductors by George Ohm in 1827 and were also applied to electrical signals in the first (1854) trans-Atlantic telegraph cable designed by William Thompson (Lord Kelvin) and George Stokes. (Paul J.Nahin, *Oliver Heaviside* (2002), Chapter 3.) Fourier's methods were further applied to movements of salt dissolved in water, as reported by Adolf Fick in 1855.

In such models, a substance is distributed with different concentrations (quantities) in different locations. When adjacent locations contain different concentrations of the substance, some substance will be transferred from the location with the higher amount to the location with the lower amount. The transfer is governed by Newton's Law of cooling, mentioned above in § 7(b).

ii. A design for diffusion of "potential energy" in a linear array of VE devices or cells resembles a paradigm of heat diffusion in an iron bar.

The VE diffusion module in Fig. 40(b) adapts common features of diffusion paradigms for H_2O, electrical charge and heat. An interconnected ***linear array of uniform VE devices*** has a collective form of ***cells in a body***; two adjacent cells may have different levels of VE, called ***potential energies*** or V_k; during diffusion, VE moves from one cell with a higher potential energy to an adjacent cell with a lower potential energy in an amount (or at a rate) that is proportional to the difference in potential energies.

Such a diffusion paradigm can be defined either by repetitions (or interations) of step-by-step cycles suitable for computation or by multiple co-existing streams of flow. VE designs in this construction use both iterations and streams.

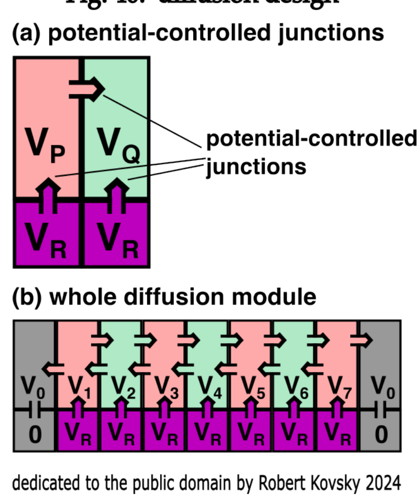
In Fig. 40, the amount of VE held in the VES of a device is interpreted as a ***potential energy*** that can be converted into pulses. Similar potential energy is held in water in a high mountain lake that feeds into a hydroelectric turbine; or as "latent energy" in hot steam in a steam engine; or as the charge held by an electrical storage battery; or in chemical bonds of fuel.

Fig. 40(a) shows two adjacent cells, a pink cell with potential energy V_P and a green cell with potential energy V_Q. Colors identify separate devices, each with its own VES. Each cell is connected to a VE source device V_R through a one-way ***potential-controlled junction***. $V_R > V_P$ and $V_R > V_Q$. To start a diffusion process, VE from the V_R sources is transfered into uncharged cells to set the quantity of VE in a particular cell at the value desired for the particular process, e.g., V_P or V_Q.

A similar potential-controlled junction connects V_P to V_Q. Next in the diffusion process, the V_P -V_Q junction is opened. If V_P is greater than V_Q, VE flows from V_P to V_Q at a rate proportional to $V_P - V_Q$. If V_P is less than V_Q, there is no flow. The flow rate of VE through the V_P -V_Q junction is: $f_{PQ} = F_0 \times (V_P - V_Q)$; $V_P - V_Q \geq 0$ and F_0 is a constant of proportionality.

Fig. 40(b) shows a whole diffusion module. The cells at either end are maintained at $V_0 = 0$; these serve as foci of dissipation. Seven active cells make up a linear array connected via one-way junctions.

Fig. 40: diffusion design



In an iterative design, the ongoing diffusion process consists of two alternating steps. First, potential energy differences between adjacent cells are calculated.

Such differences are in the form $\Delta V = (V_{n+1} - V_n) \geq 0$ and $\Delta V = (V_n - V_{n+1}) \geq 0$. The index n is defined by the set {0, 1, 2, 3, 4, 5, 6, 7) and $n_{7+1} = 0$ and $V_0 = 0$.

In the second step of an iteration, energy transfers $\Delta\mathcal{VE}$ occur through a junction according to the formula $\Delta\mathcal{VE} = G_0 \times \Delta V$ where G_0 is a constant of proportionality. Applying a conservation principle, the quantity of potential energy in each VES changes like a permanent number subject to addition and subtraction. Potential energy subtracted from one VES is added to the other VES.

To connect iterative transfers to stream flows, $G_0 = F_0 \times \Delta\tau$ where $\Delta\tau$ is the fraction of time in a cycle that the V_P -V_Q junction is open during the second step in an iteration. In a streaming process, $\Delta\tau$ extends to cover the whole process.

Next, apply such rules to a process similar to a centering process: cells in a bloc or segment are selected by trigger inputs from an external stimulus; cells that are not selected are set at V = 0. Suppose that the selected bloc is the segment that includes cells 1 through 5 and that the initial potential energy for V_1 through V_5 is set at 27! In an iterative process, let $G_0 = (1/3)$. The following table calculates several steps in the process. If a calculation of a transfer creates a fractional amount, the actual transfer is rounded down to the next lower integer.

cell	0	V_1	V_2	V_3	V_4	V_5	V_6	V_7	0
PE_1 just after stimulus	0	27	27	27	27	27	0	0	0
$transfers_1$	←9	0	0	0	0	9→	0	0	
PE_2	0	18	27	27	27	18	0	0	0
$transfers_2$	←6	←3	0	0	3→	6→	0	0	
PE_3	0	15	24	27	24	15	0	0	0
$transfers_3$	←5	←3	←1	1→	3→	5→	0	0	
PE_4	0	13	22	25	22	13	0	0	0
$transfers_4$	←4	←3	←1	1→	3→	4→	0	0	
PE_5	0	12	20	23	20	12	0	0	0
$transfers_5$	←4	←2	←1	1→	2→	4→	0	0	
PE_6	0	10	19	21	19	10	0	0	0
$transfers_6$	←3	←3	0	0	3→	3→	0	0	
PE_7	0	10	16	21	16	10	0	0	0

The PE_7 VE distribution, like those of standard diffusion paradigms,has a distinct peak at the center of the bloc and symmetrical, moderate declines on the sides.

iii. An alternative VE diffusion model uses VE device detectors that convert energy potential differences between adjacent cells into signals that control inflows of VE from sources or outflows (dissipations);

VE operations that mimic diffusion are shown in Fig. 41. The complete module in Fig. 41(c) functions like the diffusion module in Fig. 40, with seven cells and a distribution of potential energies that undergoes a similar changing pattern. This design uses streaming to track changes.

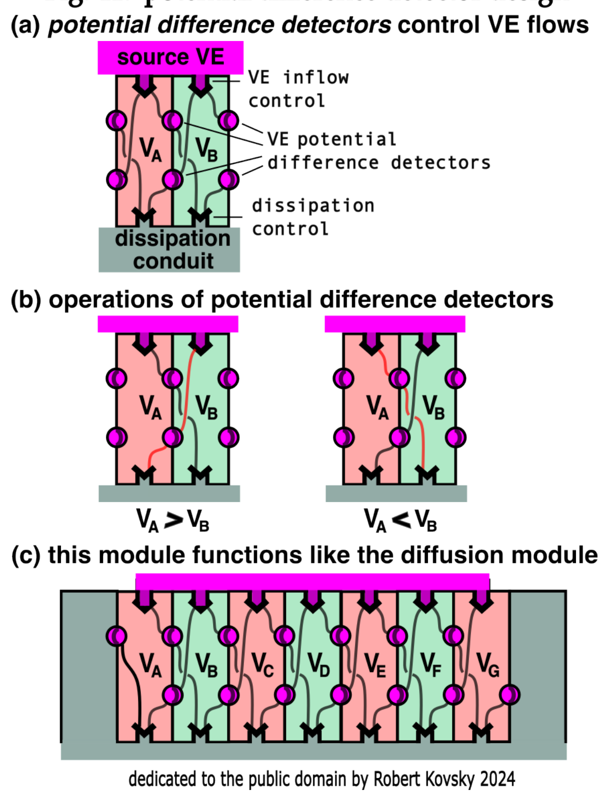
Potential energy differences detectors are embedded in walls between two adjacent cells in a body, detecting a potential difference between the two cells and producing twin flows of pulses onto two projections at a rate that is proportional to the potential difference. Each potential difference detector measures in one direction oly and has its own sufficient source of VE.

Fig. 41(a) identifies potential difference detectors that produce signals that control VE inflow and dissipation (VE outflow). Each potential difference detector is connected to a VE inflow control in one cell and to a dissipation control in the adjacent cell.

Fig. 41(b) shows that if $V_A > V_B$, one detector responds; if $V_A < V_B$, the other detector responds. A response is a twin flow of pulses on two projections.

Suppose that, for each twin pair of pulses, 1! of inflow VE is released from the VE source; and, in the adjacent cell, 1! of VE is dissipated. It is "the same" as if 1! was transferred between the cells. The potential energy difference model functions "the same" as the diffusion model.

Fig. 41: potential difference detector design



iv. Additional timing devices – difference devices and balancing units – provide more efficient controls for detector/control models;

A shortcoming of the potential energy difference detector design is the waste of energy that occurs when VE both comes into a cell because of the potential difference on one side and also leaves the cell because of the potential difference on the other side. Energy is both coming in from a source and also leaving via dissipation, like running an apartment heater and air conditioner at the same time.

Wasted energy can be greatly reduced with a timing device arrangement that uses ***difference devices*** and ***balancing units*** that are constructed from difference devices. Results produced by an improved-efficiency module are "the same" as those of prior modules.

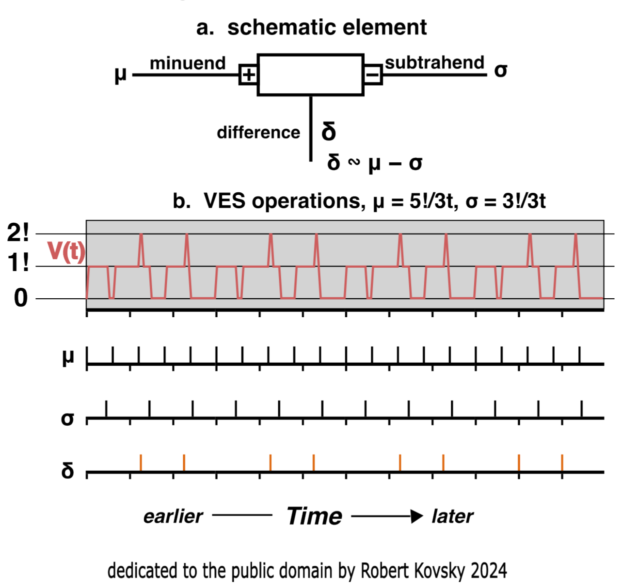
Difference devices

Fig. 42 shows operations of the difference device. In the schematic form, Fig. 42(a), one signal travels over the "minuend" projection and arrives at the "+" receptor of the difference device. Another signal travels over the "subtrahend" projection and arrives at the "–" receptor. To start, suppose that both signals are perfect pulse trains with a pulse rate of μ on the minuend and σ on the subtrahend. In defining operations, it is presumed that $\mu \geq \sigma$. If $\mu \leq \sigma$, there is no output.

The difference device produces a pulse train signal δ over the "difference" projection with an approximate rate of $\delta \approx \mu - \sigma$. The signal is irregular and "gappy," but such irregularities do not interfere with device functions in this project.

In Fig. 42(b), frequencies are: μ = 5!/3t; σ = 3!/3t; and $\delta \approx$ 2!/3t. The chart of VES operations shows momentary changes in **V(t)** — the level of VE in the VES. V(t) ranges between 0 and 2!. If V(t) reaches 2!, a pulse of 1! is discharged over δ and V(t) drops from 2! to 1!. Each pulse arriving over μ raises V(t) by 1!. Each pulse arriving over σ lowers V(t) by 1!. If two opposing pulses arrive close together (not shown), the processes cancel and V(t) stays (or ends up) where it started.

Fig. 42 difference device



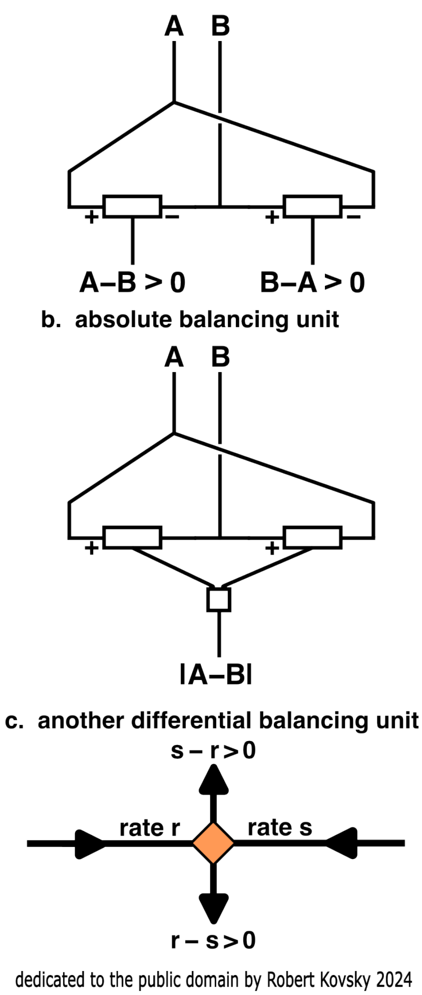
The difference pulse stream is constructed from the minuend pulse stream by removing or "canceling" certain pulses from the minuend stream and allowing the other pulses in the minuend stream to produce output pulses. Usually, a subtrahend pulse "cancels" the next minuend pulse. It may be that a subtrahend pulse arrives close to the same time as a minuend pulse and it is that coincident minuend pulse that is "canceled." Cancellations result in gaps. If there is a question of which minuend pulse is canceled, the difference between the two events is slight, shifting a gap one space forward or back.

balancing units

Fig. 43 shows designs for balancing units.

Fig. 43 balancing units

a. differential balancing unit



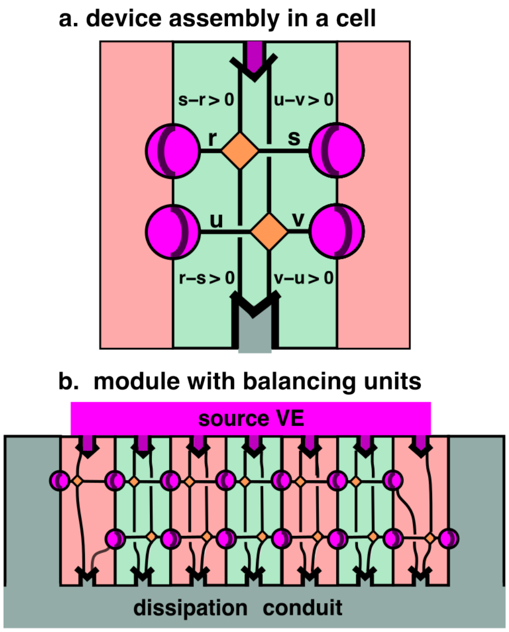
The "balancing unit" in Fig 43(a) is made of two difference devices. A perfect pulse train, A, arrives at the minuend receptor (+) of the first device and the subtrahend receptor (–) of the second device. A second perfect pulse train, B, arrives at the subtrahend receptor (–) of the first device and the minuend receptor (+) of the second device. If A ≠ B, one difference device will produce an output.

In Fig. 43(b), outputs of both difference devices are connected to a primal timing device that produces pulses at a rate equal to the absolute value of A – B.

Fig. 43(c) shows another form for a differential balancing unit that will be used in subsequent constructions. Two pulse streams r and s arrive at the balancing unit, which produces one of two possible resulting streams, depending on which pulse stream has a faster rate. In either case, the irregular pulse rate in the resulting stream is equal to the difference between rates in the two input streams.

Fig. 44 shows a cell and a module that functions much like the previous design, except for "difference calculations," e.g., s–r and r–s, performed by balancing units that operate between potential energy difference detectors and VE controls. The difference calculation eliminates wasteful simultaneous inflow and outflow of VE.

Fig. 44: diffusion module with balancing units



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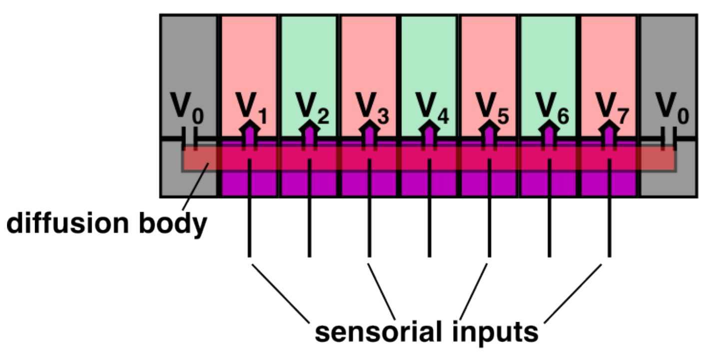
Such waste occurs when VE potential differences between cells have a gradient, e.g., $V_1 > V_2 > V_3$. Such a gradient produces both u and v signals while r and s are silent.

v. VE diffusion in a diffusion body resembles that occurring in a line of cells;

Fig. 45: bodily diffusion of VE in a centering module



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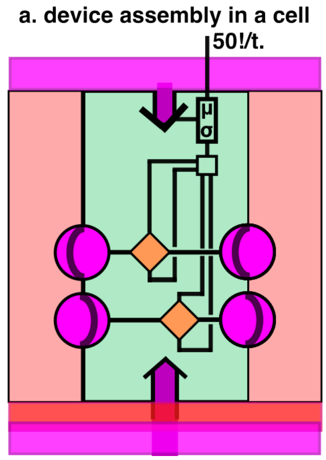
vi. The centering function is performed by a new design with a diffusion body, a linear array of VE cells and modules, potential difference detectors between cells and balancing unit controls for VE sources.

Fig. 46: centering module with concentration process



An advantage of detector/control designs is a capacity for innovative kinds of connections between detectors and flow controls. "Inversed connection," with energy movements contrary to those in a diffusion model, result in a ***concentration process***, building up VE at the high part of an energy profile. Such operational concentrations are suggestive of possible developments in quadnet devices, e.g., as a means to extract features from an image in a visual field, following on the Gazer project.