Elemental Constructions in Virtual Energy Domains: Forces and Balances, Movements and Measures, Forms and Feelings, Action and Images, Constraints and Freedom

SUMMARY

In imaginary Virtual Energy (VE) domains, designs for proposed devices are progressively developed with goals of producing actions that resemble those produced by sensory-motor systems of animals. Such designs also resemble schematic diagrams for electronics devices. A primal element in VE designs is a force fiber device that produces distinct contractions similar to twitches of an animal muscle fiber. To start, a duet construction uses two force fiber devices and two bursting devices that model neurons and that control alternating twitches of fibers: a duet holds a weight in balance and moves a weight. In constructions aiming to model muscular movements of animal eyes, opposing duets produce a spectrum of balancing points and perform spatial measurements. Development leads to quartets and octets, controllable force devices that can be organized in large numbers in ensembles attached like muscles to body parts. Stretch sensors, another class of devices, detect variations in lengths and positions of force devices and body parts; pressure sensors similarly detect forces based in internal and external bodies. Incremental signals from sensors directly involved in movements – suggestive of bodily feelings of a person – are combined with large-scale driving signals that can have remote origins – suggestive of forms of action. A layer of devices involved in such actions locates a sensation in a field of sensors, mimicking movements of limbs that scratch itches on skin surfaces or eyeball movements that direct the visual gaze. Other layers of devices, called image layers, generate patterns that resemble those occurring in the action layer but that can be changed without involvement of force devices. Some system operations begin with a change in an image layer, e.g., in a form, and then transform that change into action. Other system operations respond to peripheral changes in the sensory-motor layer and then transform those changes into changes of a pattern in an image layer, resembling, e.g., a limiting pain in one limb that modifies a balanced movement, causing first a limp and then alterations in gait and movements on both sides.

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6. The duet with added storage burster device is further modified so that the class of substitution input signals is extended to all Σ-forms.

C. Repertoires of quasi-static movements that are produced by four force fiber devices illustrate primal operational principles of VE constructions.

1. Two independent, confluent duets with disparate sizes of force fiber devices add and interweave large and small forces quasi-statically.

2. Two opposing duets produce a spectrum of balancing positions.

3. A quartet of force fiber devices produces a repertoire of quasi-static movements, classified as doubled movements and cycling movements.

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D. An octet force device, built from doubled self-cycling quartets with substitution and adjustment inputs, is a motor unit suitable for use in larger constructions.

(Provisional Outline for Subsequent Stages)

II. Elemental signal generators, sensor devices and control devices are incorporated with motor units in sensory-motor constructions.

   A. The class of pulser devices illustrates foundational principles of Virtual Energy.

      1. VE Principles both resemble and differ from those of Conserved Energy.

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   B. The primal timing device, developed from the primal pulser device, is used in controllable units that model generation of sensations.

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IV. Locational motor systems operate on a field of sensors.

   A. Opposing force devices and an array of sensory devices operate in a one-dimensional system with linear force-space relations that are coordinated by means of collective operations of a body of uniform devices, called an ensemble.

   B. Linearly organized, two-dimensional force-space relations of multiple moving parts of a system are coordinated by device ensembles called Quad Nets.

V. An additional system of bursting devices, making up an image layer, generates patterns that closely resemble patterns generated by the motor system in the previously-constructed action layer, but that can be independently varied without involvement of force devices. New operations control interactions between patterns in the action layer and patterns in image layers.

APPENDIX: Provisional Goals of Constructions

Anticipated modules operate in diverse domains

Anticipated models of tubular organisms (worms) operate in natural domains

I. Elemental Signals in Virtual Energy (VE) domains.

A. A VE signal consists of pulses that move on a projection between devices.

Constructions in Virtual Energy (VE) domains resemble spatial constructions of plane geometry and temporal constructions of musical compositions. In VE domains, proposed ***devices produce movements***. As elements of construction, movements of VE pulses (and pulse bursts) on projections, illustrated in Fig. 1 below, resemble geometrical points (and lines) or musical notes (and chords). Forceful contractions that resemble twitches of animal muscle fibers make up another elemental class of VE movements. Operational movements occur within devices.

As in geometry and music, there is a family of Virtual Energy domains. Elemental constructions in this project occur in the ***primal VE domain*** that does not influence operations of devices. This ***stage 1*** project is the first in an anticipated series. Anticipated collective ***ensembles*** of devices called ***modules*** resemble biological tissues and organs, with interactive controls resembling hormones. Anticipated constructions of worm models, ***engineered organisms*** that operate in natural domains, guide and motivate elemental constructions in this project. (See Appendix.)

Fig. 1 shows movements of pulses in three elemental constructions in the primal VE domain. Each signal consists of a ***pulse*** or ***pulses*** (shown as vertical strokes); and each pulse travels on a ***projection*** that extends ***from*** a pulse-generating device ***onto*** a force device or onto a timing device. In initial elemental designs, all pulses are "the same" (except for timing and location) and each pulse carries one unit of Virtual Energy, symbolized as "!" and defined as "one bang."

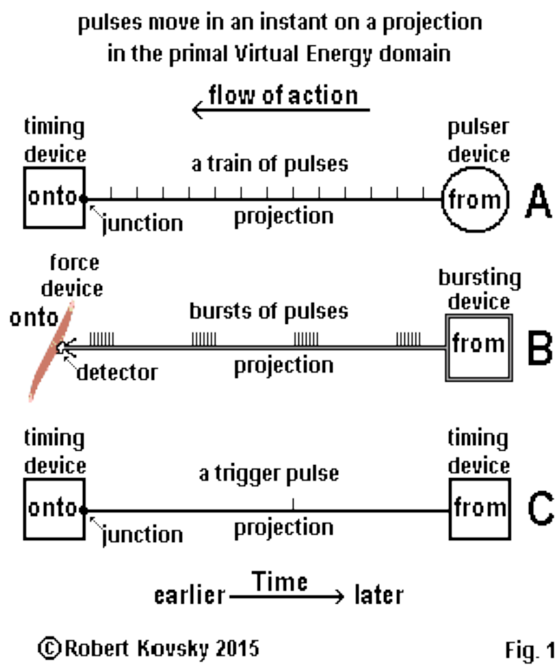


Fig. 1

A — a pulser device generates and sends a ***pulse train*** signal onto a timing device;

B — a bursting device generates and sends a ***pulse burst*** signal onto a force device;

C — a timing device generates and sends a ***trigger pulse*** onto another timing device.

The projection from the bursting device attaches to the force device via a ***detector***. Projections from the pulser and the "from" timing device attach to "onto" timing devices via ***junctions***. A detector operates with a burst of pulses while a junction operates with individual pulses.

In the flow of action of Fig. 1, pulses move from right to left; the corresponding flow of time from left to right is used to show periods of time between pulses, like on a mathematical graph.

In the primal VE domain, each pulse is discharged by a first device, travels on a projection, and arrives at a second device, all in a particular ***instant***. As a practical definition, an instant is a period of time very much shorter than any other operational period of time. Electrical signals are similarly instantaneous. In tracking events in the primal VE domain, time spent in movements of pulses is treated as null. Between any two pulses in a VE signal is a period of ***silence***.

B. Sensory signals are based on steady trains of pulses.

Pulsers, timing devices and bursting devices – and their respective signals – are combined in constructions. The simpler pulser and timing device signals start with ***steady pulse trains***.

1. Steady trains of pulses are generated by a pulser device and by two coupled timing devices.

Fig. 2 shows two very simple device constructions that generate steady pulse trains. First, a pulser device generates a steady pulse train on an output projection. "Steady" means that there is a fixed period of time between pulses, denoted by τ_0. Functionally, the device resembles a clock. Steady pulse generation with a fixed period τ_0 is the only function of the pulser device shown in Fig. 2. The steady pulse train contains a steady flow of Virtual Energy and resembles a steady musical tone, e.g., a violinist's A=440 Hz.

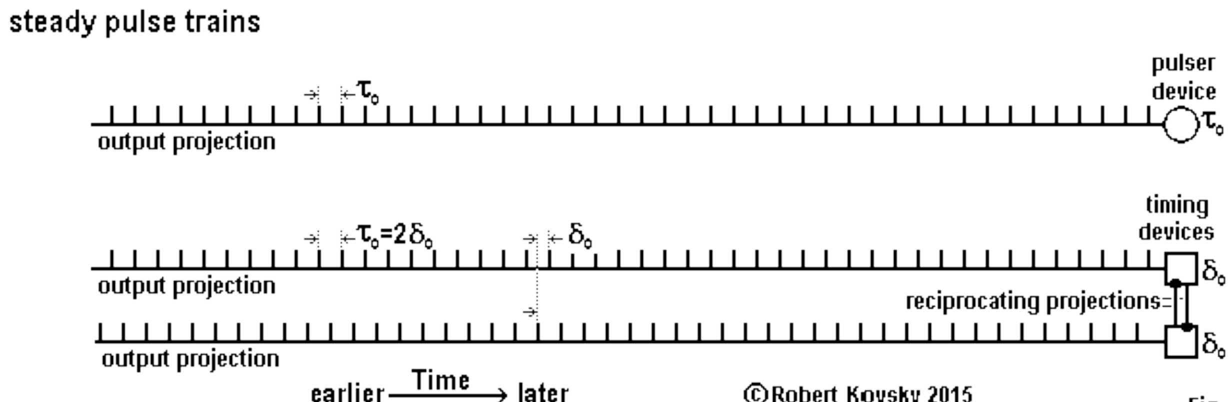


Fig. 2

Second, two identical timing devices are connected by reciprocating projections and junctions; each timing device generates a steady pulse train on an output projection. The two output trains are "the same" except for a half-cycle displacement.

Operations of the coupled pair illustrate timing device principles. The arrival of a pulse at the junction of a timing device at instant t_0 triggers activity of the device that leads to discharge of output pulses on both the output and the reciprocating projections at instant $t=t_0+\delta_0$. The ***response period*** δ_0 specifies the amount of time between arrival of a pulse at a timing device and discharge of pulses.

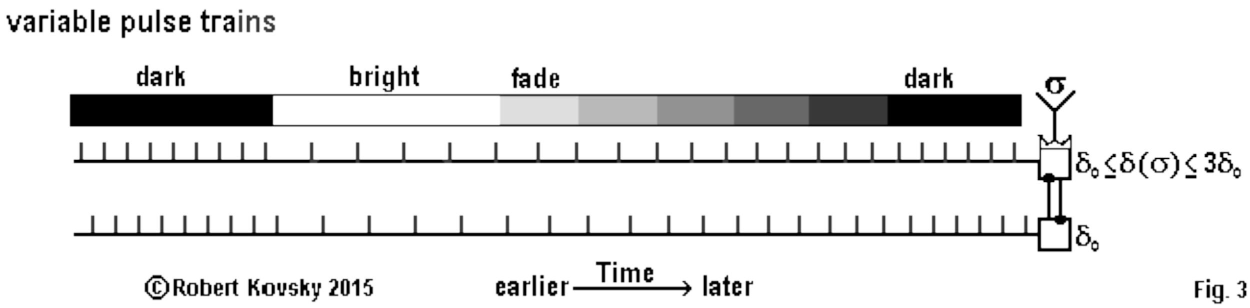
The two timing devices in the signal generator trigger each other repetitively. Each device discharges pulses once every $2\delta_0$; thus, the period between pulses in the trains is $\tau_0=2\delta_0$, which stays "the same" or "remains steady" while the signal generator is operating properly. Assuming a value of $\delta_0 = 0.01$ sec, the coupled pair generates pulses at the rate of 50 per sec.

Operations of the coupled timing device design in Fig. 2 resemble those of an electronics multivibrator.

2. A variable train of pulses is generated by a timing device couple that responds to light intensity, which is thereby measured.

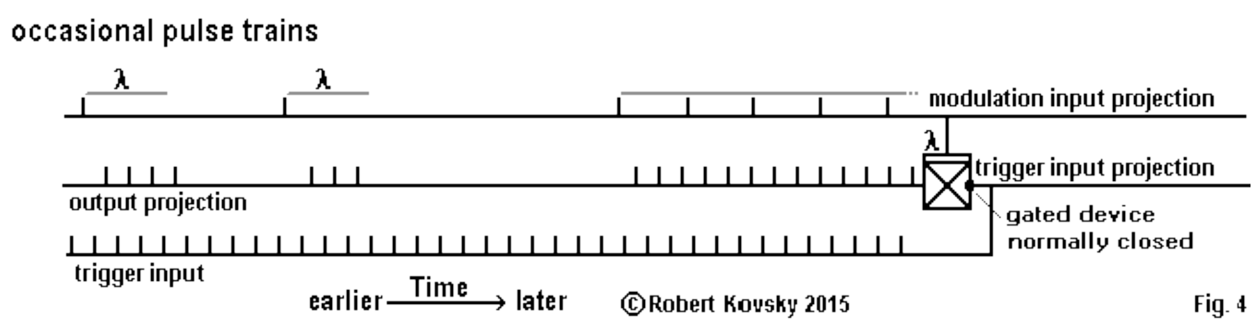
Variable pulse trains, as shown in Fig. 3, are generated by a light-modulated signal generator, based on and developed from the previous steady pulse generator design. The upper timing device has a response period δ that varies between δ_0 and $3\delta_0$, depending on the intensity (σ) of light incident on a light sensor. The lower timing device is unmodified from the previous design.

In the absence of light, when conditions at the light sensor are "dark," the response period in the upper device is the same as for the steady case above. That is, $\delta=\delta_0$ and periods between pulses are again $\tau_0=2\delta_0$. When light at the sensor reaches a certain high level called "bright," the response period in the upper device slows to $\delta=3\delta_0$; and the period between pulses increases to $\tau_1=(\delta_0+3\delta_0)=2\tau_0$. When light intensity is greater than dark but less than bright, pulse periods vary with intensity: brighter light generates slower pulsing. In Fig. 3, periods between pulses range between $\tau_0=2\delta_0$ and $\tau_1=4\delta_0$. The period measures the brightness of the light.



3. An occasional train of pulses is generated by a gated timing device.

A third class of pulse train patterns, the ***occasional pulse train***, is generated on the output projection of a ***gate normally closed timing device*** shown in Fig. 4. Operations of gated timing devices resemble those of electrical relays, vacuum-tube triodes and point-junction transistors. The gate controls whether a pulse arriving on the ***trigger input projection*** will produce a pulse on the output projection. "Normal" operations occur when the ***modulation input projection*** is silent. The gate in this device is normally closed and trigger input pulses are normally blocked. The gate is opened by the "occasional" arrival of a pulse on the modulation input projection; and the gate is opened for a specific amount of time by such a modulation pulse, the ***modulation period λ***. While the gate is open, arriving trigger input pulses produce output pulses after a delay δ_0, as with the original timing device discussed above (Fig. 2). If modulation pulses arrive more rapidly than once every λ, the gate stays open.



C. Signals that drive forceful movements are based on bursts of pulses.

1. Pulse bursts are defined within a Ψ-form.

In this project, ***bursts of pulses*** are defined by ***Ψ−forms***, which are based on an ***organizational period of time*** of duration Ψ. The number of pulses in a burst sets the strength of a forceful twitch produced by a force fiber device. Fig. 5 illustrates a Ψ−form for a pulse burst.

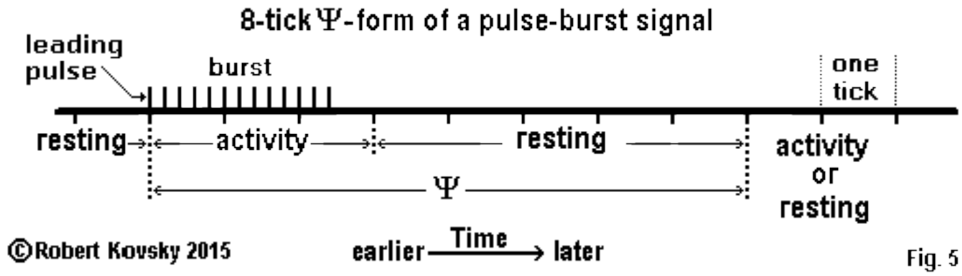


Fig. 5

A pulse burst contains an integral number of pulses that have been generated at a uniform rate by a bursting device, as discussed below. Pulses in a burst are all "the same" except for timing. The first pulse in a burst, called the ***leading pulse***, references the start of both the pulse burst and the Ψ−form to a specific instant.

In elemental constructions, a fixed period of time, a ***tick***, is used to impose synchronicity of operations. The duration of one tick is denoted as "t". Anticipated modules will use ticks with variable durations. A useful duration is 1 t = 0.1 sec: then, a twitch of a force fiber device defined as 5 ticks long will last 1/2 sec, close to twitch durations of some animal muscle fibers.

The Ψ−form in Fig. 5 is divided into 8 uniform ticks. Ψ−forms with 16 ticks are used below. In designs herein, pulses in a burst are generated at the rate of 5 per tick. Let ι (Greek iota) denote the period of time between successive pulses in a burst. If 1 t = 0.1 sec, ι = 20 milliseconds (ms).

A pulse burst is contained in a period within Ψ called the ***activity period*** that commences with the leading pulse and that is three ticks long. The activity period is three ticks long regardless of the number of pulses in the pulse burst. In this Ψ−form, the number of pulses in a burst or ***pulse number*** varies from 1 to 15. In Fig. 5, the burst has a pulse number of 13, denoted n=13.

After the activity period comes the ***resting period***, a period of silence that is 5 ticks long in this Ψ−form. The activity period and resting period together make up the Ψ=8 ticks of this Ψ−form. Depending on whether bursts in 8-tick Ψ−forms are generated every 8 ticks or at longer intervals, a Ψ period may be followed by the activity period of the next Ψ-form or by more resting.

Adaptable ***code forms*** for Ψ-forms employ strings of symbols. To start, each symbol denotes one tick. One code form for an 8-tick pulse-burst signal is: `SaSrrrrr`, where "S" stands for "signal activity tick," "r" stands for "resting tick" and variable "a" tracks distinct pulse numbers. Another code has the form: `jkmrrrrr`; j, k or m denote pulses in separate ticks and the total pulse number in the burst n = j+k+m; e.g., `553rrrrr` codes the Ψ−form for the burst in Fig. 5.

Ψ-forms and ticks are incorporated in operations of devices by rules of construction. Strict rules are used in elemental constructions. In anticipated modules and organisms, operations will have additional controls; as a result, imposed synchronicity, strict Ψ-forms and rigid rules may be relaxed for purposes of achieving finer precision, smoother movements and larger repertoires.

2. Σ-forms organize stiff, bound, half-bound and sparse patterns of pulse bursts defined in Ψ-forms.

Ψ-forms are usefully organized by introduction of classes of Σ-forms called ***stiff***, ***bound***, ***half-bound*** and ***sparse***. The classification of Σ-forms resembles the classification of pulse trains introduced above in connection with Figs. 2, 3 and 4 (steady, variable and occasional pulse trains) but there are also differences. Definitions here are stated for 8-tick Ψ–forms but are also applicable with slight modifications to 16-tick Ψ–forms used later.

In a stiff Σ-form, the period between leading pulses in successive bursts is always 8 ticks. In other words, Ψ-forms are tightly packed, head to tail, as in the example shown below.

SaSrrrrrSbSrrrrrScSrrrrrSdSrrrrrSeSrrrrrSfSrrrrrSgSrrrrrShSrrrrr

In a bound 8-tick Σ-form, the period between leading pulses in successive bursts is between 8 ticks and 16 ticks; the range includes endpoints. Resting ticks in excess of the 8 ticks of the stiff form are shown in the example below, using a code notation of boldface **rrr** for any excess.

SaSrrrrr**rrrr**SbSrrrrr**rrr**ScSrrrrr**r**SdSrrrrrSeSrrrrr**rr**SfSrrrrr**rrr**SgS

In a half-bound 8-tick Σ-form (not shown), the period between leading pulses in successive bursts can be any duration equal to or greater than 8 ticks. In one approach, the half-bound 8-tick Σ-form is the most general 8-tick Σ-form and other 8-tick Σ-forms are members or subclasses of the class of half-bound Σ-forms. In another approach, the approach taken here, the stiff Σ-form is the point of origin for development of Σ-forms. Synchronized operations start with stiff Σ-forms.

In a sparse 8-tick Σ-form, the period between leading pulses in successive bursts can be any size greater than 16 ticks. In elemental constructions, such a period is equal to or greater than 17 ticks. The class of half-bound Σ-forms is equal to the union of the class of bound Σ-forms and the class of sparse Σ-forms. In the illustrative sparse Σ-form shown below, resting ticks in excess of 8 ticks are shown in boldface **rrr**, as in the bound Σ-form. Resting ticks in excess of 16 ticks appear in each Ψ-form and are shown using both underlined and boldface, e.g., **<u>rrr</u>.**

SaSrrrrr**rrrrrrrr<u>rr</u>**SbSrrrrr**rrrrrrrr<u>rrrr</u>**ScSrrrrr**rrrrrrrr<u>rrrrrr</u>**SdSr

Sparse Σ-forms are used in constructions that produce "holding patterns" of forces that are only occasionally changed, like holding a coin in the hand while walking. Another way to produce holding patterns is with a stiff Σ-form with bursts that maintain a fixed number of pulses except for occasional changes. Such "holding patterns" are called "quasi-static."

Quasi-static constructions are foundational in this project. Their chief advantage is that they avoid difficulties arising from the "momentum of a moving material body." The limitation is necessary for initial imaginary constructions. In this project, development of devices starts from a quasi-static foundation but aims for control of bodily momenta. Other courses of construction in other projects may follow different approaches.

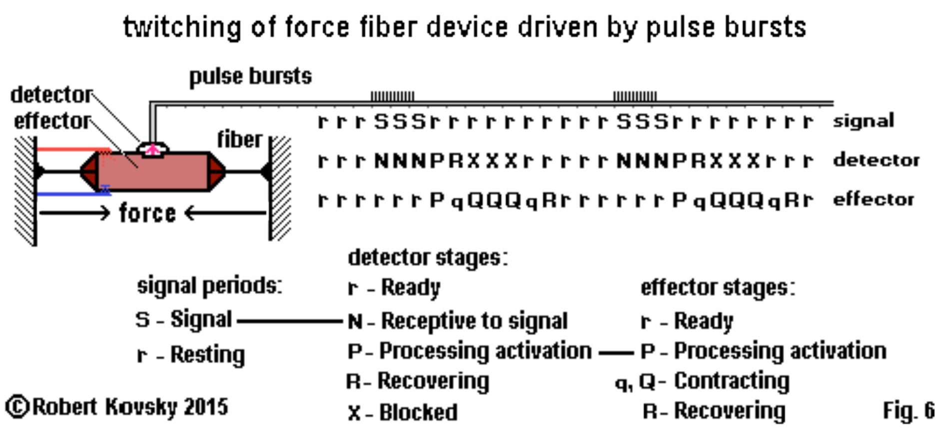
II. Muscle-like movements are constructed from ensembles of elemental twitches.

A. A force fiber device produces elemental twitches.

1. In a rigidly affixed and fully extended force fiber device, pulse bursts in Ψ-forms drive forceful twitches, operating with a linear variation.

A foundational movement in this project is a ***twitch produced by a force fiber device***. As shown in Fig. 6, a force fiber device has two chief parts: (1) a signal ***detector*** which receives pulse burst signals; and (2) an ***effector***, which produces forceful contractile twitches and which can thus perform mechanical work, e.g., lifting a weight. Fig. 6 shows an ***affixed fiber*** attached to rigid supports at maximum length. An affixed effector contracts isometrically even though actual movement is impossible. Initial definitions apply to a rigidly affixed and fully extended force fiber device. Then rigid constraints are relaxed for development of actual movements.

Arrival at the detector of the leading pulse of a burst starts the detector Ψ–form: the detector ***notices*** the burst for three ticks, denoted by "N" in its Ψ–form. The leading pulse also leads to one tick of joint ***processing*** in detector and effector, coded by "P," which includes ***triggering*** of a forceful ***contraction*** of the effector, coded by "q" and "Q." The period of contraction starts at tick 2 (coded q) in the Ψ–form of the effector, with a force strength that starts at a minimum and that ramps up to the specified level as shown in the following Fig. 7. After a steady force for the next three ticks, marked Q, the strength level ramps down during effector tick 6, again marked q. On average, ramping q is half the force of steady Q. The tired effector ***recovers*** during its tick 7, activity coded by "R." Then it waits for a new contraction while in a ***ready*** condition coded by "r." When the effector is not contracting – during ticks P, R and r in the effector – the fiber has a minimal tautness. A tired detector recovers (R) after processing a burst but continues to be blocked (XXX) from receiving a new burst until expiration of the 8-tick detector Ψ–form.



Essential Ψ–forms for operations of the force fiber device are set forth in the ***operational chart*** below. The pivot of the action is the processing tick P, which is shared in detector and effector. The `combined:` code shows the flow of action in the elemental force fiber device.

```
operational chart for the elemental force fiber device in Fig. 6
signal:    SSS
detector:  NNNPRXXX
effector:     PqQQQqR
combined:  NNNPqQQQqR
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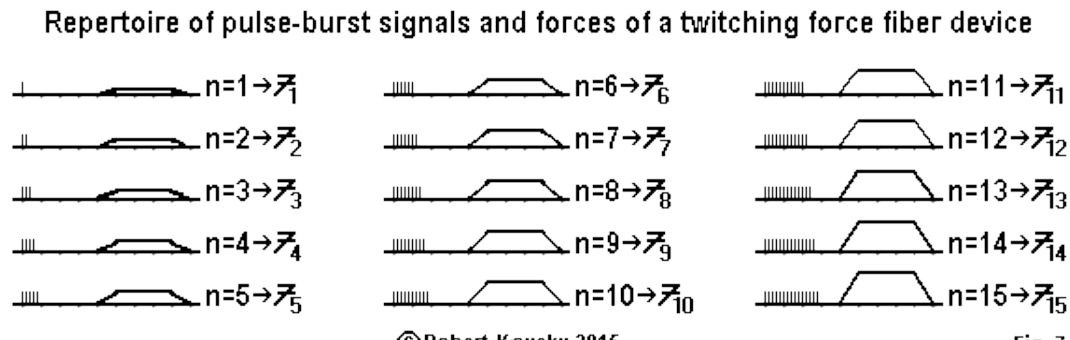


Fig. 7

Fig. 7 states a "look-up table" for an affixed and fully extended force fiber device that produces a repertoire of forceful twitches from a repertoire of pulse busts. Strength levels of forces are specified as $\mathcal{F}_n = n\mathcal{F}_1$, where n is the number of pulses in the burst and $\mathcal{F}_1$ denotes the strength level produced by the smallest burst where n=1. E.g., $\mathcal{F}_8$ denotes a force twice the size of $\mathcal{F}_4$. Force strength increases during the first tick from minimal tautness to the level specified by the pulse number. During the fifth tick, the force strength decreases to minimal tautness in a way that equals and reverses the increase during the first tick of the twitch. Miniature constructions require symmetrized rises and falls; the linear ramp form used here is a simple symmetrical form.

The finely graded strength repertoire of the force fiber device is different from an "all or nothing" response that is said to be characteristic of animal muscle fibers. It is possible to adapt the force fiber device to an "all or nothing" model. Suppose that a force fiber device is made up of 15 parallel "mini-fibers," each producing a twitch force $\mathcal{F}_1$ and all convergent in direction, so that the pulls of n mini-fibers add up to a total force of $n\mathcal{F}_1$. Each specific mini-fiber has an all-or-nothing response to a pulse burst that contains ***at least*** a specific number of pulses. Mini-fiber 1 responds when the pulse burst has 1 ***or more*** pulses. Mini-fiber 2 responds when the pulse burst has 2 or more pulses. And so forth. Mini-fiber 15 responds only when the pulse burst has 15 pulses. Mini-fiber 1 twitches after every burst. Mini-fiber 15 rarely twitches. The resulting force repertoire is identical to that of the force fiber device but with all-or-nothing units.

Another way to construct a repertoire of twitches is with variable durations. A twitch might extend over two ticks, three ticks, four ticks, five ticks or six ticks. Adapting the q-Q-q code, the twitches of various durations might be coded as: qq qQq qQQq qQQQq qQQQQq. When forces are summed, q+q=Q. Twitch forces have summed volumes of 1Q, 2Q, 3Q, 4Q and 5Q.

A repertoire of twitches that combines two sub-repertoires might be produced by ten mini-fibers with possible durations of twitches of 1Q, 2Q, 3Q, 4Q or 5Q. In a device that produces the repertoire, the three-tick activity period of a pulse burst is divided into a two-tick part that specifies the number of mini-fibers and a one-tick part that specifies the duration of the twitch.

In all the foregoing variant forms, more pulses in a burst means a greater volume of force produced over the period of the twitch. Constructions using the force fiber device design set forth in Fig. 7 have advantages of simplicity that come with a repertoire of twitches of uniform duration and linearly graded force strength.

2. A mobile force fiber device incorporates variations in the force of a twitch that depend on fiber length and movement.

A rigidly-affixed fully-extended force fiber device can neither move nor perform work on an external object, no matter how much Virtual Energy it is consuming. Modifications develop the force fiber device for such productive activity. Modifications are based on well-know facts about a typical muscle producing voluntary movements: when such a muscle shortens, it exerts less tension; and the tension further decreases as the speed of shortening increases.

Developing the definition of the elemental force fiber device, the expression for the twitch strength level $\mathcal{F}$ becomes the ***primal twitch strength expression***: $\mathcal{F} = n\mathcal{F}_1 - j(\ell_1 - \ell_x) - A|(d\ell_x/dt)|$. The fiber length ℓ_x varies between a minimum ℓ_0 and a maximum ℓ_1; ℓ_1 is the length of the fully extended device discussed above. For an affixed holding force at maximum length, as in the initial definition, $(d\ell_x/dt)=0$ and $\ell_x=\ell_1$; then, the new $\mathcal{F}$ reduces to the previous $\mathcal{F}= n\mathcal{F}_1$.

"Primal" means that the foregoing expression is the point of origin for development of force devices in this project. Other twitch strength expressions can be stated and used in different device designs; then, different kinds of devices might be combined for greater versatility.

The $j(\ell_1 - \ell_x)$ term in the strength expression states a reduction in the force of a twitch of a contracted device as a result of operational dissipation. The $A|(d\ell_x/dt)|$ term is a dissipative ***damper*** similar to the dashpot that is part of the harmonic oscillator paradigm of mechanics or to friction that slows movement of a rigid body in a viscous fluid: reduction of force strength resulting from movement of a force fiber is proportional to speed of movement, with the same effect whether movement is shortening or lengthening.

In this project, a course of construction begins with simple initial designs that are maximally constrained; and it then develops through additions of new devices and more complex systems. During the course of construction, movements are defined in a progressive way. The project starts with ***quasi-static movements***, which resemble ***positioning movements*** of animals (e.g., standing or holding a weight). One line of development is directed towards ***working movements***, which resemble ***sustained tension movements*** of animals (e.g., walking steadily or lifting a weight). Another line of development is directed towards ***saccadic movements*** which resemble ***ballistic movements*** of animals (e.g., jumping or throwing a weight). Important classes of saccadic movements are produced by sets of opposing muscles that control eyeball movements and finger movements in persons. Such movements can be quick and precise, finding a single actual location in a field containing many possible locations. Constructions in this project are similarly directed towards locating a sensation in a field of sensors, like scratching an itch.

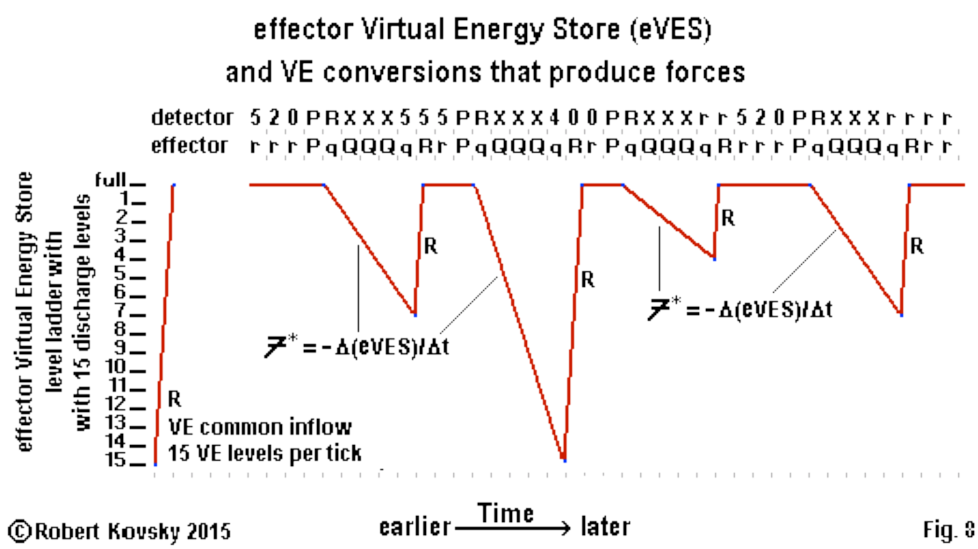
The course of construction herein, based on quasi-static movements, leaves the damper term A somewhat in the background but still operative. With limitations on movements, e.g., based in opposing force devices, and with a sufficiently large A, a moving body part or external object eases into a new position of balance rather than bouncing up and down before coming to rest. During quasi-static movements, a damper term ensures smooth performance. During working movements, limiting effects of dampers can be partially overcome or controlled by adjustments of devices that aim to minimize VE consumption. During saccadic movements, damper terms limit speeds and help to protect devices from out-of-range movements or self-damaging actions.

3. Operations of the elemental force fiber device exemplify classes of devices that store, transfer and convert Virtual Energy.

An energy concept serves multiple functions. In the elemental force fiber device, VE serves ***storage functions***, ***conversion functions*** and ***transfer functions***. Storage is a conservative function. Conversions are dissipative in general but some classes have conservative limit points. Transfers can be conservative or dissipative (resembling elastic or inelastic collisions). As shown in Fig. 8, the force fiber device has an ***effector Virtual Energy Store*** (eVES) that holds VE like a conserved substance. The eVES is divided into 15 discharge levels to match the set of pulse bursts; stored VE is converted to a force with a strength level set by the discharge level. On discharge, during q ticks and Q ticks, conversion of eVES produces a steady ***raw force*** $\mathcal{F}^*$ that is then reduced through dissipation to produce the final ramped twitch force $\mathcal{F}$. The eVES model thus serves to organize the repertoire of twitches stated as a "look-up" table in Fig. 7.

In dissipative transfer operations during N ticks in the detector, each pulse in an arriving burst pushes the ***n indicator point*** in the eVES ***level ladder*** down one step. During the P tick, corresponding discharge points are set in the effector, marked by blue dots in VES traces.

As shown in Fig. 8, during 5 q and Q ticks, the effector converts stored VE into a transient force or twitch. The eVES level decreases from "full" to the level set by the pulse burst. The raw force of the twitch is defined as $\mathcal{F}^* = -[\Delta(\text{eVES})/\Delta t]$. Here, the length of a twitch is specified by $\Delta t=5$ ticks for all twitches. Hence, it is possible to define the size of Δ(eVES) according to that of the arriving pulse burst. E.g., a pulse burst with a pulse number of 7 (appearing twice in Fig. 8) sets the discharge level to 7. The corresponding discharge of eVES is also at level 7. The raw force varies in a direct and linear way with the discharge level: doubling the discharge level means doubling the raw force. Dissipation reduces the raw force during the first or "start-up" tick and during the final or "run-down" tick to produce the ramping shapes shown in Fig. 7. Dissipation further reduces the force of a contracted device (as specified by j) and of a moving device (as specified by A) as previously discussed.



The ratio between the eVES stored in a force fiber effector and the VE unit in a pulse is variable; the ratio depends on the working size of the force fiber. Using rough figures, the eVES of a tiny force fiber device might hold 1,000 bangs (measured in pulses) while the eVES of a large device might hold 1,000,000 bangs. A pulse burst is like pressing a particular key on a pipe organ; actual tones depend on the combination of organ pipes that are sounded, controlled by "stops," as well as by airflow delivered to the pipes, controlled by a pedal. The organist uses much the same finger force all the time; "energy" in actual tones also depends on other factors.

In the force fiber device, VE comes from an external source (electricity or other flow resembling flow of sugar in blood) and restores the Store during the first tick after completion of a twitch, denoted as "R" in the effector Ψ-form (Fig. 8). Even if the eVES has been completely depleted during a twitch, enough Virtual Energy arrives in 1 R tick to restore it to a "full" condition. Once the eVES is full, additional VE inflow is turned off or dissipated.

The force fiber device twitches in response to an input burst. Each twitch is distinct from other twitches and is responsive to a single burst. Each pulse burst is processed the same as every other pulse burst and the force level can even change between opposite extremes between twitches, although such changes are avoided herein. If, e.g., pulse bursts arrive in a stiff Σ-form, action is described by the following code, omitting "r" and "X" ticks for purposes of simplicity:

```
det:  NaNPR   NbNPR   NcNPR   NdNPR
eff:      PqQaQqR PqQbQqR PqQcQqR PqQdQqR
```

The eVES resembles the Internal Energy that Rudolf Clausius (1822-1888) invented for his Conserved Energy thermodynamics. eVES is a pivotal kind of Virtual Energy like Internal Energy is a pivotal kind of Conserved Energy, serving in each case as a bodily locus for energy conversions that produce mechanical work. In VE constructions, the body that holds the eVES accomplishes such conversions in an obscure way, much like the obscurity of Internal Energy conversions of steam heat to mechanical work in Clausius' thermodynamics. Thus, in a common formulation of the "First Law of Thermodynamics" ($dU = \delta Q - pdV$), an ambiguous pairing of two kinds of differentials ("δ" and "d") obscures the obscurity. [See Truesdell, *Rational Thermodynamics* (2d ed.), Historical Introit at 12 ("internal energy is just as obscure [as entropy] – perhaps even more so") and the sarcastic discussion in Lecture 1 of equation 1.3 ($TdS \geq \delta Q$).]

There are further similarities and overlaps between CE principles and Virtual Energy (VE) principles — and also important differences. Both describe activities of material bodies by means of operations that store, convert and transfer such "energy." In both cases, definitions are crafted for purposes of facilitating larger constructions. In both cases, energy is first defined as a capacity or potential to perform mechanical work. A VES is one kind of capacity or potential and Internal Energy is another kind of capacity or potential; thus, compare $\mathcal{F}^* = -[\Delta(\text{eVES})/\Delta t]$ to $F = -[dU/dx]$ in classical mechanics, where U is an energy potential.

As to chief distinguishing features: (1) Dissipations are essential for VE operations and a continual inflow of VE is required while CE operations typically involve processes where energy is maintained as a state. (2) Pulsational VE operations are fundamentally "jumpy," in contrast to static CE forms; quasi-static and steady-state VE operations that resemble CE state operations are important but simple special cases. (3) VE operations involve ***flows*** of Virtual Energy, in contrast to ***quantities*** of Conserved Energy. But see Truesdell, Lecture 1 above, which uses rates and flows such as "working" and "heating" instead of more common state variables "work" and "heat." (4) Conservative Energy presumes a reality in which numerical sums have hegemonic control ("Die Energie der Welt ist Konstant") while Virtual Energy avoids such presumptions.

B. A ***duet*** uses two force fiber devices driven by two bursting devices to hold and move a weight quasi-statically.

1. Two force fiber devices operating as a duet are driven by reciprocating and repeating bursting devices to produce steady forces that hold a weight.

Fig. 9 shows two force fiber devices, a and b, coupled together in a ***duet***, the first in a series of ***ensembles***. The two force fiber devices share physical connections that carry forces; they produce alternating forces that combine to hold a mobile weight W steady inside a supporting and constraining cylinder. The only possible movements of the weight are up and down; the only forces are provided by gravity and by the duet. In initial constructions, forces are in balance.

Fig. 9 also shows two ***repeating bursting devices***, A and B, that are connected reciprocally and that generate pulse bursts in a stiff Σ-form on reciprocating and output projections, similar to steady pulse trains shown in Fig. 2. Each repeating bursting device or "burster," denoted by "R," has a detector and a body that resemble the detector and the effector of a force fiber device.

The duet is designed to produce a steady but variable force **F**. Duet fibers share a variable length, denoted by ℓ_x. The quantity $\ell_1 - \ell_x$ ranges between $\ell_1 - \ell_x = 0$ at $\ell_x = \ell_1$ (full extension) and $\ell_1 - \ell_x = L$ at $\ell_x = \ell_0$ (full contraction). L defines the range of motion (ROM). The strength of **F** is equal to that of $\mathcal{F}$, the central twitch strength. A steady **F** is "patched" together from alternating twitches; a successor twitch ramps up just as a predecessor twitch ramps down. As to momentary force, q+q = Q = $\mathcal{F}$ = **F**. In Fig. 9, gray ramps appear below the blue line that is tracing a steady **F**.

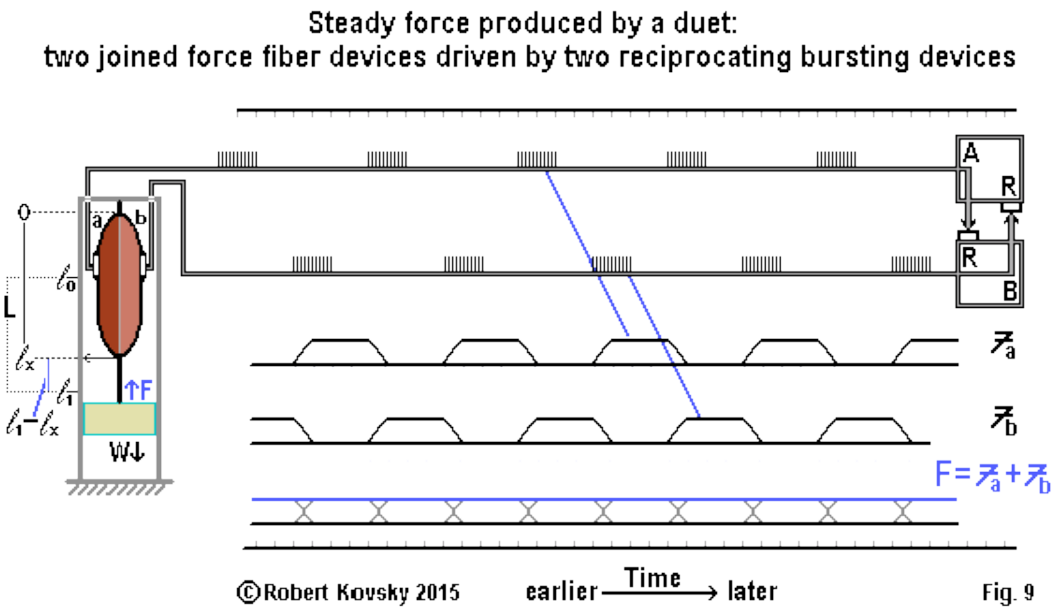


Fig. 9

Ψ-forms of parts of force fibers during duet operations are represented below in code (omitting R, X and r), along with net force **F** :

```
a-det:  NNNP      NNNP      NNNP      NNNP      NNNP
a-eff:      PqQQQq   PqQQQq   PqQQQq   PqQQQq   PqQQ
Net F:  FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
b-eff:           PqQQQq   PqQQQq   PqQQQq   PqQQQq
b-det:       NNNP      NNNP      NNNP      NNNP      NNNP
```

Ψ-forms for parts of the repeating bursting device are defined by the operational chart below that resembles that for the force fiber device. Discharge is denoted by `OOO`. While a burster body is discharging, it's detector is blocked (`RXXX`) from noticing an input signal. Blockages become important in some later constructions; in other charts, they may be omitted.

```
operational chart for the repeating bursting device "R"
signal:    SSS
detector:  NNNPRXXX
body:         POOOR
```

Similar to the `combined` form for a force fiber device, a combined Ψ-form shows the flow of action in the R device.

```
R-comb: NNNPOOOR
```

As shown in Fig. 9, the burster output signal is split or ***ramified***; and identical signals are sent over both an output projection and a reciprocating projection. In neurons, ramification occurs from the axon; VE device designs also ramify from the body. The output signal remains singular.

Bodies of bursters operate with Ψ–forms where `OaO` denotes generation of a pulse burst. A burster output burst lasts three ticks in contrast to a force fiber twitch that lasts five ticks. As in the force fiber device, the pivotal processing tick P is shared in the detector and in the body of a bursting device. In the operational chart for the duet below, prior code lines for operations of force fiber devices a and b are copied but re-arranged. In the simple duet of Fig. 9, the strength of twitches is fixed and all movements are at level "a." In the first action in the chart, highlighted by the arrangement of lines, the body of burster A discharges a signal `OaO`, which is noticed as `NaN` by both the detector of burster B and the detector of force fiber device a.

```
operational chart for the Fig. 14 duet
A-body: OaOR   POaOR   POaOR   POaOR   POaOR   POaOR
B-body:    POaOR   POaOR   PoaOR   POaOR   POaOR
B-det:  NaNPR   NaNPR   NaNPR   NaNPR   NaNPR   NaNPR
A-det:      NaNPR   NaNPR   NaNPR   NaNPR   NaNPR

a-det:  NaNPR   NaNPR   NNaPR   NaNPR   NaNPR   NaNPR
b-det:  _   NaNPR   NaNPR   NaNPR   NaNPR   NaNPR
a-eff:  __ PqQaQqR PqQaQqR PqQaQqR PqQaQqR PqQaQqR PqQ
b-eff:  ______ PqQaQqR PqQaQqR PqQaQqR PqQaQqR PqQaQqR
Net F:  _____FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
```

An R device operates with alternating movements of the detector (**`NNN`**) and the body (**`OOO`**). An **`OaO`** output from one reciprocating burster becomes an **`NaN`** input onto the other reciprocating burster. The matching symmetry can be represented by a ***condensed code*** where every symbol stands for 4 ticks. Condensed code is used only for burster operations. In the duet of Fig. 14, the size of the burst (pulse number) is fixed and coded by "Z."

```
condensed code for bursters in the prior operational chart __
A-body: Z Z Z Z Z Z
B-body:  Z Z Z Z Z
B-det:  Z Z Z Z Z Z
A-det:   Z Z Z Z Z
```

2. VE operations of the repeating burster device ("burster") are based on those of the force fiber device, with significant modifications.

Fig. 10 shows the burster Virtual Energy Store (bVES) of the repeating bursting device, along with operations that generate output pulse bursts. Output bursts "repeat" input pulse bursts: output n=input n. For purposes of illustration, pulse bursts arriving at the detector in Fig. 10 are the same as those arriving at the force fiber detector in Fig 8, rather than repeating signals.

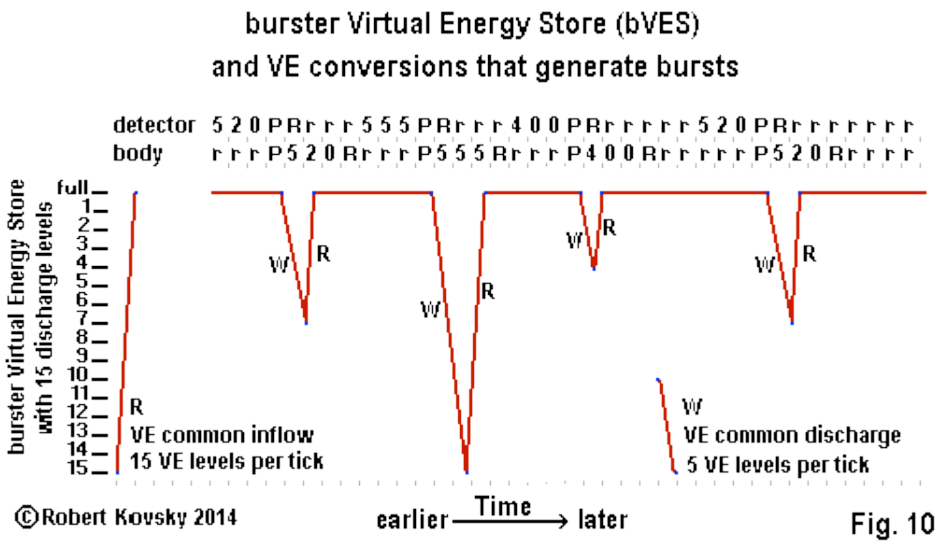


Fig. 10

Comparison of bVES operations in Fig. 10 with eVES operations in Fig. 8 shows that, in both devices: during 3 initial N ticks, an incoming signal sets the level of discharge of VE from a VES; processing occurs during a 4th P tick; output begins at the start of the 5th tick. Refill of VES in the two devices has a single form, although volumes of VE in bursters are much smaller than those in force fiber devices that control weights.

A major difference involves the way VE discharges are converted to forces or to pulses, as the case may be. In the force fiber device, a VE discharge occurs over a fixed period of time (5 ticks) and the rate of discharge [Δ(eVES)/Δt] varies according to the discharge level. In the burster device, bVES discharge occurs at a fixed rate and the period of discharge varies. While discharge is occurring, pulses are generated at the rate of 5 per tick. In Fig. 10, discharge, denoted by W, takes less than 1 tick for the 400 burst and a full three ticks for the 555 burst.

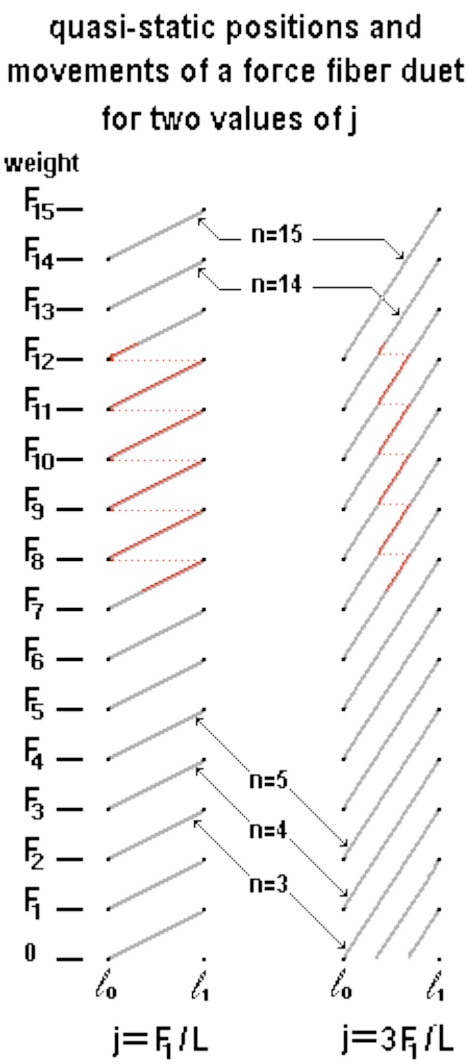
Another difference involves timing of VE discharges. In the force fiber device, VE discharge starts exactly "on the tick" – that is, at the beginning of the first q tick. The raw force ratio Δ(eVES)/Δt reaches full value immediately. The burster device has a more demanding job: the leading output pulse must appear exactly on the tick. Hence, VE discharge must start prior to the start of the first O tick, indeed, one iota or "ι" prior to that tick. In other words, in order to have a leading pulse ready at the commencement of the first output tick, VE discharge must begin at 0.8 of the way through the prior P tick. It is assumed that, in the primal VE domain, what can be accomplished in 1 tick can also be accomplished in 0.8 ticks.

(Within anticipated modules, adjacent ensembles and layers of devices have connections in the nature of "gap junctions" as well as through far-reaching projections; a "trigger wave" of VE that passes through layers of gap junctions is used to control collective modular discharges. Trigger pulses, introduced below, are to be developed into trigger waves in such modular constructions.)

3. Force fiber duets driven by reciprocating and repeating bursters have repertoires of quasi-static positions and movements.

The quasi-static twitch force expression for the force fiber device [$\mathcal{F}$=n$\mathcal{F}_1$–j(ℓ_1–ℓ_x)] has a special case where j=F_1/(ℓ_1–ℓ_0); or, in other words, where j= F_1/L and L=(ℓ_1–ℓ_0). Then F=F_1[n–(ℓ_1–ℓ_x)/L], where n, the pulse number, is an integer; and (ℓ_1–ℓ_x)/L is a real number between 0 and 1.

For the j= F_1/L case shown in the left panel of Fig. 11, a duet can hold any specific weight between 0 and 15F_1 by means of repeating bursts with a unique number of pulses and a unique fiber length – except for weights that are exact integral multiples of F_1 and such weights are held at two positions, one position at length ℓ_0 with a specific pulse number, n_s, the other at length ℓ_1 with pulse number n_s–1. Sizes of weights that are held by specific pulse numbers and fiber lengths for the j= F_1/L case are shown as gray traces in the left panel of Fig. 11.



©Robert Kovsky 2015 Fig. 11

Suppose that a j= F_1/L duet driven by pulse bursts with n=15 is holding a block of ice with a weight W=15F_1 at position ℓ_1. If ice slowly melts and water drips off, the contractile force (15F_1) exceeds the weight of the ice block, fibers contract and the force diminishes until balance is reached. As the ice bloc progressively shrinks; lengths of duet fibers progressively contract and the course of movements follows the top left gray line in Fig. 11. When the weight of the ice block shrinks to the equivalent of 14F_1 (or F_{14}), the fiber lengths have contracted to ℓ_0.

Suppose that the ice bloc duet has fully contracted and holds the weight W=14F_1 at position ℓ_0. Next, suppose that the pulse number is reduced to 14 pulses per burst. Then, the contractile force, reduced by the j term, drops to 13F_1; and the ice block falls. As it falls, contractile forces increase and the damper slows movement — the system “eases” into a balanced position close to ℓ_1. If ice further melts, the cycle repeats but with lower pulse numbers. Part of the course of such movements is shown in red in the left panel of Fig. 11.

In the right panel, Fig. 11 shows the case where j = 3F_1/L. In such case, a weight less than 13F_1 or F_{13} can be held at three positions with a spread of pulse numbers, except at endpoints where it can be held at four positions. A course of movements of a melting ice bloc is shown in red for the j= 3F_1/L case, which resembles the course of movements in the j= F_1/L case.

In the j= 3F_1/L case, operations can lead to a large variety of courses of movements, depending on timing of pulse-burst reductions. In the particular course of movements shown in red in Fig. 11, such a reduction occurs at the 2/3 point of contraction. When the pulse number is reduced by

1, the fibers lengthen to the 1/3 point of contraction. A different course of movements would put the point of reduction at full contraction (as in the j= F_1/L case), and reduce the pulse number by 3, leading to a movement from full contraction to full extension. In all such cases, the driving rate is that of weight reduction from melting ice. Comparing the two red-lined courses of action: in the j= $3F_1/L$ case, there is less up and down movement. A design principle is suggested: more dissipation provides more control and a larger repertoire.

Fig. 12 shows operations of a force fiber duet when j = $15F_1/L$. (A value of j higher than $15F_1/L$ results in a reduction in the range of motion.) In operations with such j, repeating bursts with a pulse number of 15 hold and carry the exemplary ice bloc, starting at an original weight equal to $15F_1$, as it drips down to the last drop, with a course of movements that has a single slow rise from ℓ_1 to ℓ_0, as outlined by the red trace in Fig. 12.

A smaller fixed weight can be held at several positions by pulse bursts that have a range of pulse numbers. In Fig. 12, the blue trace shows positions and movements of a constant weight W_c equal to a force level between F_7 and F_8. Steady positions of W_c have a linear variance with respect to the pulse number, the higher the pulse number, the more contraction and the further the position from ℓ_1.

Hence, it is possible, within a reduced range of activity, to lift or, alternatively, to lower W_c in a quasi-static fashion by integral increments or decrements of pulse number in successive steps. Each step begins and ends in a steady position along the blue trace. In other words, for quasi-static movements, after an incremental change in pulse number, the weight must come to rest before the pulse number is changed again.

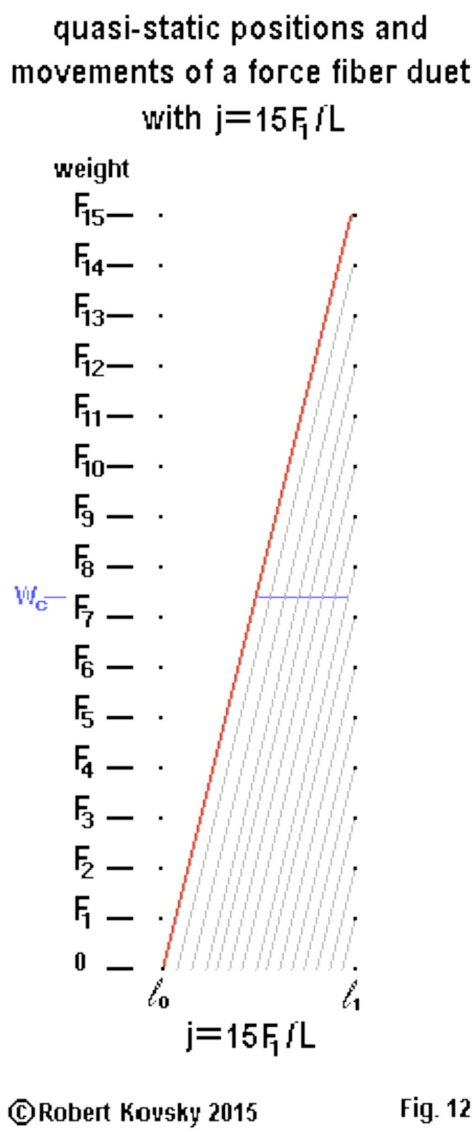


Fig. 12

4. The duet design is modified for non-reciprocating operations so that an input signal in a stiff Σ-form produces quasi-static movements.

In the original duet design of Fig. 9, a stiff pattern of pulse bursts is generated by reciprocating bursters. As shown in Fig. 13, a similar result can be obtained if repeating bursters are driven by a stiff external signal of bursts in 8-tick Ψ-forms, processed without reciprocating activity. Other than the removal of one projection between the bursters and a new detector for the incoming signal, the circuit and operations are unchanged from the reciprocating case of Fig. 9.

an input signal of pulse bursts in a stiff Σ-form
produces steady holding in a duet with modified bursters

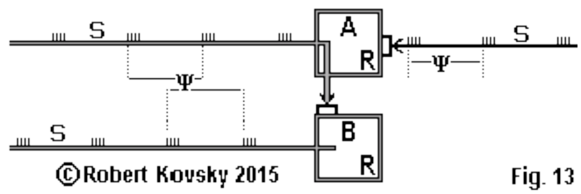


Fig. 13

Previously-discussed operational charts for the duet are adapted to the design in Fig. 13, leading to the chart below. Both original coding and condensed coding are included.

```
operational chart for modified duet driven by stiff Σ-form
Signal: SaS     SbS     ScS     SdS     |  Z Y X W
A-det:  NaNPR   NbNPR   NcNPR   NdNPR   |  Z Y X W
A-body:    POaOR   PObOR   POcOR   POdO |   Z Y X W
B-det:     NaNPR   NbNPR   NcNPR   NdN  |   Z Y X W
B-body:        POaOR   PObOR   POcOR    |    Z Y X

a-det:  ____NaNPR   NbNPR   NcNPR   NdN |
b-det:  ________NaNPR   NbNPR   NcNPR   |
a-eff:  ______ PqQaQqR PqQbQqR PqQcQqR  |
b-eff:  __________ PqQaQqR PqQbQqR PqQc |
Net F:  _________FFFFFFF*GGGGGGG*HHHHHH |
```

Four ticks after an input burst arrives at the detector of burster A, A generates duplicate bursts onto force device a and onto burster B. Another four ticks later, burster B generates another duplicate output burst onto force device b. Synchronously, the stiff input signal is delivering a new burst onto the detector of burster A, leading to A's next output burst, which, in turn, causes force device a to start twitching just as the prior twitch in force device b is ramping down.

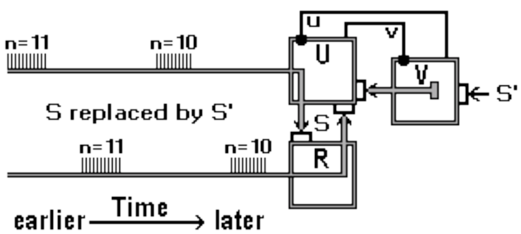
Operations begin with steady holding, maintained by a fixed pulse number in the input signal stream. In addition, it is now possible to produce quasi-static movements by changing the input pulse number by 1. Bursts with the new pulse number are delivered repetitively until the weight comes fully to rest at the new position. In the operational chart, net force G may be identical to net force F or incrementally different from net force F; and, similarly, H may be identical to or incrementally different from G. "*" denotes a possible transitional force.

The Fig. 13 design provides for minimally jerky changes built from a duet of twitches. During a change, stronger twitchings replace weaker twitchings. Steady holding is interrupted, but then restored. Symmetry is lost and regained, ready to be lost again. More elements organized in ensembles and with arrays of attachments and balancing operations can smooth the jerky character of movements built from twitches but that character can never be eliminated.

5. A design with a new storage burster device produces both steady forces and quasi-static changes driven by a substitution signal in a sparse Σ-form.

In Fig. 14 a new burst `S′` replaces an `S` burst that is being repeated. Reciprocating bursters U and R operate with `S` until `S′` arrives. The duet operates continuously "on its own" with a steady force; and the force is also occasionally changed. Quasi-static changes are incremental.

Substitution of a burst in a duet via a sparse Σ-form



©Robert Kovsky 2015 Fig. 14

R in Fig. 14 is the same as in Fig. 9. U is a modified version of R that coordinates with the new storage burster V. When `S′` arrives, V stores the setting for `S′` – then, at just the right moment, V sends an `S′` burst to U and `S′` replaces `S`. Single ***trigger pulses*** travel between U and V over projections labeled u and v and perform "just the right moment" functions.

Operations of V are based on those of a repeating burster R. A modification introduces a delay between processing P and discharge of the output burst. Such a delay varies between 0 and 7 ticks, where operations with a delay of 0 are the same as for the R device. Delays are managed to perform "just the right moment" functions.

In elemental designs, a "master clock" imposes system-wide ticking. Thus `S′` arrives at V aligned as to tick edges but without regard to duet Ψ-forms, called an ***asynchronous*** arrival.

For clarity, codes for Ψ-forms below use two symbolic spaces per tick, with a repetition of symbols as needed. A new `S′` burst starts the Ψ-form of the V detector and its noticing `N′`. At the start of the third `N′` tick, V discharges a u pulse. Trigger pulses always occur at the start of a tick. During the fourth tick, joint processing in detector and body prepare for discharge. Meanwhile, the device is "waiting" for a v pulse, as denoted by a vertical stroke "|." Arrival of the v pulse triggers a burst discharge on the next tick.

```
operational chart for the V storage burster device
Signal:   S’S’S’
V-det:    N’N’N’PPRRXXXXXX
V-body:         P|O’O’O’RR
V-u-out:      u
V-v-in:         |v
```

The flow of action has a wait denoted by "|". `V-comb: N’N’u_P|v_O’O’O’RR`

The | in the combined Ψ-form represents eight possible Ψ-forms ("__" also denotes "waiting"):

`V-comb0: N’N’u_vPO’O’O’RR` (v arrives on the 4th tick; P and v unite, as in an R device)
`V-comb1: N’N’u_PPv O’O’O’RR` (v arrives on the 5th tick)
`V-comb2: N’N’u_PP__v O’O’O’RR` (v arrives on the 6th tick)
`V-comb3: N’N’u_PP____v O’O’O’RR` (v arrives on the 7th tick)
`V-comb4: N’N’u_PP______v O’O’O’RR` (v arrives on the 8th tick)
`V-comb5: N’N’u_PP________v O’O’O’RR` (v arrives on the 9th tick)
`V-comb6: N’N’u_PP__________v O’O’O’RR` (v arrives on the 10th tick)
`V-comb7: N’N’u_PP____________v O’O’O’RR` (v arrives on the 11th tick)

In the `V-comb0:` form, the functions of preparation (P) and triggering (v) are combined, as in the simple repeating R burster. The v pulse arrives at the start of the fourth tick; the device both prepares for discharge and also triggers the discharge to start on the next tick. In other `V-combk:` forms, the functions are distinguished and the trigger function is provided externally by a pulse that may arrive at various times; meanwhile Virtual Energy is stored in the bVES in a conserved condition and ready to generate pulses when discharged.

Operations of the modified repeating burster U are shown in the chart below. During repetitive operations before burst substitution, U receives the `S` burst from R, as shown by `NNNNNN` on the `U-detR:` line. During a substitution, U receives a new burst, `N’N’N’`, not from R, but from V. To perform the substitution, U must (1) signal V to send the new burst and (2) close off receipt of the old burst from R. U performs the first task by sending a v pulse to the V device at the start of the 8^{th} tick in the U detector. Such a pulse, as shown previously, will trigger the discharge of the new burst from V one tick later, at “just the right moment” when U is ready to receive it. The U device is alerted to send the v pulse by the arrival of a u pulse at any time within 8 ticks prior to the start of the 7^{th} tick in the U detector. A U device that receives a u pulse before the start of the 7^{th} tick has at least one full tick to generate the discharge of the v pulse. The “8 ticks prior to” make up a window denoted by hyphens on the `U-u-in:` line in the operational chart. Each U detector Ψ–form has a window; windows connect via repeating Ψ–forms; and a window is always open. (Only one window is shown in the operational chart.) Whenever a u pulse arrives, it finds a window open and causes discharge of a v pulse on the next available 8^{th} tick.

The second task of the U device is performed by blockage of burst receipt by the `U-detR:` detector, coded by “YY.” “YY” is like “XX” but “YY” appears only occasionally. In other words, while the V-connected detector in U is receiving a (new) burst from V, the R-connected detector in U is being blocked from receiving the (old) burst that R is discharging. In the operational chart below, all “XX” and “YY” are shown.

The U repeating burster has a switching character rather than the simple action flow character of prior devices and the `U-comb:` form is longer than simple flow forms. In the `U-comb:` form, the device discharges a v pulse just after discharging pulse bursts to the force fiber device and the other burster. The v pulse is the pivot of the action.

```
U-comb:  NNNNNNPPOOOOOORRNNNNNNNPPOOOOOOvRN’N’N’PPO’O’O’RR

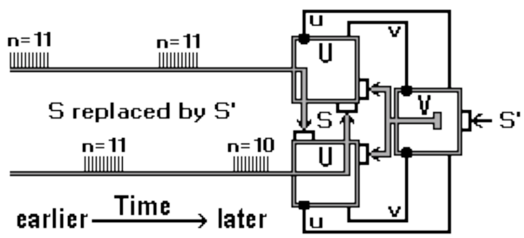
operational chart for the U repeating burster device in Fig. 16
U-u-in:              -------u--------
U-v-out:                               v
U-detV:          XXXXXXXX        XXXXXXXXN’N’N’PPRRXXXXXX
U-detR:  NNNNNNPPRRXXXXXXNNNNNNPPRRXXXXXXYYYYYYYYXXXXXXXX
U-body:        PPOOOOOORR      PPOOOOOORR      PPO’O’O’RR
```

The circuit in Fig. 14 is restricted to substitution bursts arriving via a sparse Σ-form. This is because a cycle of operations in the body of the V device can require up to 13 ticks, namely, `P234567vOOOR`, using the shorter one-symbol-per-tick code, with numerals counting the wait ticks. (At the other end of the range of operations, the shortest cycle in the body of the V device occurs when the v pulse arrives during the P tick and operations revert to `NNNPOOOR`.) The design in Fig. 14 can always handle a signal in the sparse Σ-form, in which at least 17 ticks intervene between pulse bursts; but it is not able to handle more densely packed Σ-forms.

6. The duet with added storage burster device is further modified so that the class of substitution input signals is extended to all Σ-forms.

The restriction to sparse Σ-forms in the design in Fig. 14 is overcome by that in Fig. 15, where substitution bursts can arrive as quickly as once every 8 ticks. A revised version of V operates symmetrically in coordination with two revised U devices that drive force fiber devices. A pulse burst substitution occurs in one or the other of the U devices depending on when the new burst arrives at V and V sends out u pulses. The V device in Fig. 15 is modified from that in Fig. 14 by the addition of a duplicate set of timing pulse connections and output burst projection, which all carry signals just like the first set. The operational chart of the V device is unchanged but the waiting period for arrival of a v pulse is reduced from a range of 0-to-7 ticks to a range of 0-to-3 ticks; the number of possible `V-combk:` forms is reduced from 8 to 4.

Substitution of a burst in a duet via all Σ-forms



©Robert Kovsky 2015 Fig. 15

U devices in Fig. 15 are operationally modified from the U device in Fig. 14 so that the "window period" for the u pulse is reduced to four ticks. In the U device of Fig. 14, a window is always open; in the revised U device of Fig. 15, each window is closed half the time. That is, a new U device is responsive to a u pulse only half the time and is blocked (XX) half the time. Two alternating window periods in the two devices combine to cover the whole 8 ticks of each Ψ–form. These revisions are reflected in the `U-u-in:` line of the operational chart below. Otherwise, operations of U are unchanged from those discussed in connection with Fig. 14.

```
U-comb:  NNNNNNPPOOOOOORRNNNNNNPPOOOOOOtRN'N'N'PPO'O'O'RR

operational chart for the U repeating burster device in Fig. 15
U-u-in:  XXXX        XXXXXXXX---u----XXXXXXXX
U-v-out:                               v
U-detV:          XXXXXXXX        XXXXXXXXXN'N'N'PPRRXXXXXX
U-detR:  NNNNNNPPRRXXXXXXNNNNNNPPRRXXXXXXYYYYYYYYXXXXXXXX
U-body:        PPOOOOOORR      PPOOOOOORR      PPO'O'O'RR
```

The Fig. 15 circuit operates properly when a new substitution burst arrives at the V detector no more quickly than once every 8 ticks, as in a stiff Σ-form. In other words, the circuit in Fig. 15 operates with incoming signals in all 8-tick Σ-forms or with an unbounded 8-tick Σ-form. The agility of such a circuit is separate from slower capacities of force fiber devices to impart momentum to weights such as are necessary to bring about an actual movement. Therefore, constructions of movements in this project continue to follow a quasi-static path where difficulties involving momenta of weights are reduced to a size that can be neglected.

C. Constructions of repertoires of quasi-static movements produced by four force fiber devices introduce primal operational principles of VE constructions.

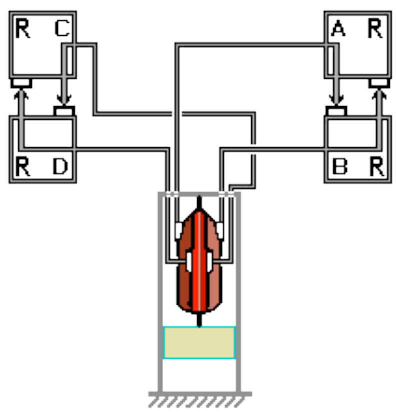
1. Two independent, confluent duets with disparate sizes of force fiber devices add and interweave large and small forces quasi-statically.

Development of ensembles from the initial duet proceeds in a first step with the design shown in Fig. 16, which combines forces of two duets. One duet produces big forces; the other duet produces small forces. Fibers in both duets share a variable length, ℓ_x, the dissipation factor j and the quasi-static twitch force expression, namely $\mathcal{F}=n\mathcal{F}_1-j(\ell_1-\ell_x)$. Forces produced by all four fibers are confluent, pulling at the same point in the same direction.

The combination of two disparate duets in a device ensemble provides for interweaving of forces and the construction of a larger structured repertoire of movements.

As shown in Fig. 16, each pair of force fiber devices is driven by a pair of reciprocating bursting devices. Force fiber devices are big and small but bursting devices are the same size. Bursting device pairs can be independently controlled as to timing intervals and VE storage operations.

two disparate and confluent duets



©Robert Kovsky 2015 Fig. 16

Let r denote the ratio of force strengths of fiber devices: the big force strength equals r times the small force strength at equal pulse numbers and fiber lengths. The steady net force produced by the system at maximum length is $F=(mr+n)F_1$, where m and n are pulse numbers of bursts onto big fibers and small fibers, respectively, r is the force ratio and F_1 is the minimal force (n=1) produced by the small duet acting alone at maximum length. A reduction in force produced by a contracted fiber depends only on ℓ_x. Hence, variations in force strength that depend on fiber length are unchanged from previous designs and it is sufficient to discuss full-length operations

disparate fibers, r=15		
net force	m	n
$59F_1$	3	14
$60F_1$	3	15
$61F_1$	4	1
$62F_1$	4	2

As shown in the adjacent table, a special case occurs when r=15, where the system has many uniformly-spaced small steps in force strength; however, coordinated changes must be made during operations at crossover points. The action somewhat resembles that of an automobile odometer. When r=15, there are 225 distinct force levels that can be maintained. If, on the other hand, r=2, coordinated changes in pulse numbers are in the ratio of 2:1 rather than 15:1; there are 43 distinct force levels and most are heavily redundant.

2. Two opposing duets produce a spectrum of balancing positions.

Fig. 17 shows two equal and opposing duets, each affixed at one end and connected to the other duet at the other end. Outside the Figure, a pair of reciprocating bursters sends signals to the left duet with pulse number m; similarly, an independent pair of reciprocating bursters sends signals with pulse number n to the right duet. The design in Fig. 17 establishes relations between pulse numbers and spatial locations in a spectrum of balancing positions. The design is the first in a series of constructions aiming to mimic movements of eyes of animals.

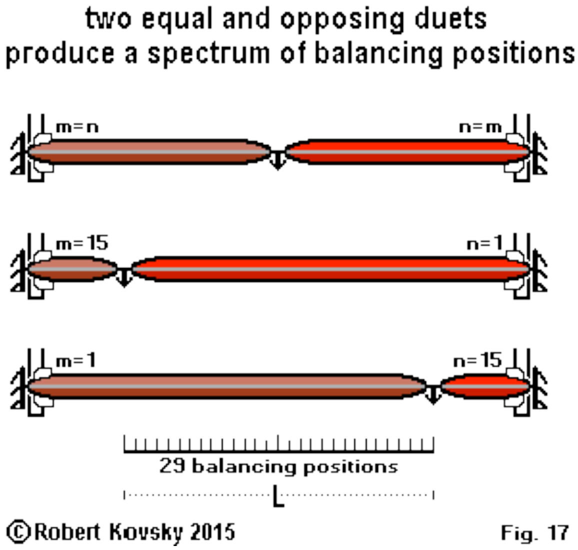


Fig. 17

The top image shows the duets in center-point balancing, where equal pulse bursts are sent to the two duets; that is, m=n. When signals are equal, the indicator arrow is centered. Equal forces and a centered indicator can occur for pulse numbers of any size, from 1 to 15.

The range of motion in Fig. 17 is denoted by L, like L in Fig. 9. An end-of-range position occurs when one duet is driven by bursts with pulse number 1 and the other duet is driven by bursts with pulse number 15. At such limit positions, one duet is fully extended and the other duet is fully contracted.

In this design, fibers at full extension have a length that is 5 times the length of fibers at full contraction. That is, for each force fiber device, $\ell_1 = 5L/4$ and $\ell_0 = L/4$. $L+2\ell_0$ is the distance between points of affixation; and the distance from each such point to the centerpoint is 3L/4.

Let x be measured from the centerpoint, with positive values to the right. Balancing is expressed by: $F_m=F_n$, where $F_m=mF_1 - j(3L/4+x)$ and $F_n= nF_1 - j(3L/4-x)$. For duets to be in balance at extreme positions (e.g., x=L/2), $15F_1-5jL/4 = F_1-jL/4$; or $j=14F_1/L$.

In the $j=14F_1/L$ system, 29 equally spaced balancing positions are defined by $x/L=(n-m)/28$, where $-\frac{1}{2}L \le x \le \frac{1}{2}L$. When n>m, balancing points are on the right-hand side. When m>n, balances are to the left. Except at limits points, multiple pairs of (m,n) hold the balance.

A $j=14F_1/L$ system has a high dissipation, close to the $j=15F_1/L$ system shown in Fig. 12. The effect of high dissipation can be seen if m=1 and n=2. Even though the “raw force” pulling to the right is twice as strong as the “raw force” pulling to the left, dissipation is so high that the displacement to the right is only one part out of 14. In other words, when pulse numbers of bursts to both force fiber devices are low, movements are limited to the center.

Thus, operations of opposing duets in Fig. 17 have limitations at low activations. One approach to such limitations is to run one duet at the highest level (e.g., m=15) and adjust the other duet for a desired position. Which duet is run at highest level depends on whether the balancing point is to the left or right of midline. In this approach, balancing at midline is produced by m=15 and n=15 and by no other pair of pulse numbers. There is a one-to-one matching between pairs of pulse numbers (m,n) of bursts that drive force duets and balancing positions in the spectrum. Every pair has m=15 or n=15 or both m=15 and n=15.

3. A quartet of force fiber devices produces a repertoire of quasi-static movements, classified as doubled movements and cycling movements.

In Fig. 18, a ***quartet*** is made of four identical confluent force fiber devices, bursters A and B (the leading duet) and bursters C and D (the following duet). Operating as an ensemble in certain "modes," the C/D duet follows the A/B duet like burster B follows burster A.

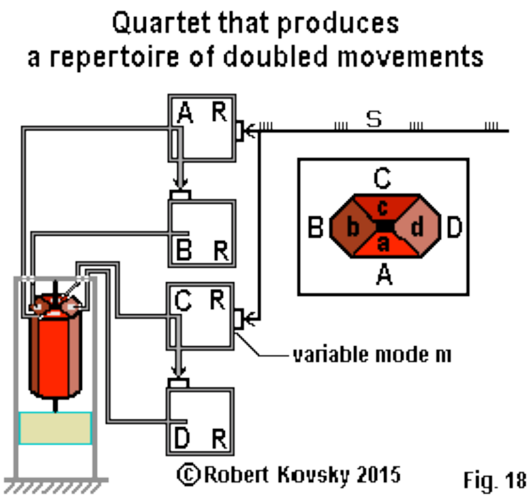


Fig. 18

The inset denotes hookups between force fiber devices and bursting devices that are maintained during development below. The design in Fig. 18, based on that in Fig. 13, is driven by a stiff signal and produces the repertoire of doubled movements listed below. Specific doubled movements correspond to values of "additional delay" (denoted by "m" for "mode") that is a variable operational specification of burster C. Driven by a repetitive input signal S and maintaining a specific fiber length, the Fig. 18 quartet produces a steady but variable force of $F=2F_d$ regardless of mode, where F_d denotes the steady but variable force produced by a duet.

Initial designs are limited to quasi-static changes where the load weight is held at constant length or moved in incremental steps. A code unit, e.g., "qQbQq," includes a variable "b," denoting a variable twitch strength that either remains constant or changes by a single distinct step.

$F=2F_d$ unison doubled movements, m=0

no additional delay

```
qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
q   qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
q   qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
```

$F=2F_d$ staggered doubled movements, m=1

additional delay 1 t

```
qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
q   qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
 qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
Qq   qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
```

$F=2F_d$ alternating doubled movements, m=2

additional delay 2 t

```
qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
q   qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
  qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
_Qq   qQaQq   qQbQq   qQcQq   qQdQq   qQe
```

$F=2F_d$ overlapping doubled movements, m=4

additional delay 4 t

```
qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
q   qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
q   qQaQq   qQbQq   qQcQq   qQdQq   qQeQq
qQ_Qq   qQaQq   qQbQq   qQcQq   qQdQq
```

$F=F_d$ cycling movements

developed below in §§ 4 and 5

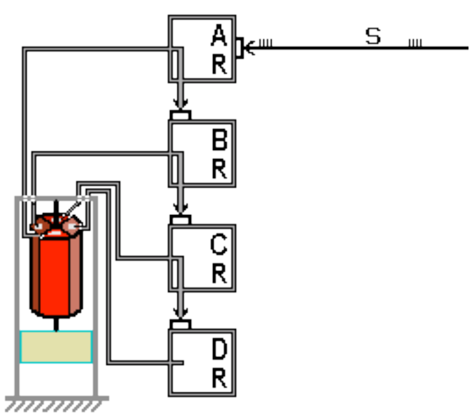
```
qQaQq           qQbQq           qQcQq
    qQaQq           qQbQq           qQcQq
        qQaQq           qQbQq           qQc
q           qQaQq           qQbQq
```

4. Construction of a self-cycling quartet with direct triggering and with a storage burster for a substitution signal develops operations that “run steadily on their own” and that are also subject to changes.

Constructions lead to a self-cycling quartet that “runs on its own” and that also receives two kinds of inputs: (1) a substitution input like those used before; and (2) new adjustment inputs. In designs in Figs. 27 and 28, substitution inputs control large movements according to “forms” that are generated at a distant or “remote” location; adjustment inputs control small changes in ongoing movements guided by something like “bodily feelings” that are generated close to or that “reside” in movements. (William James discussed classes of “remote” and “resident” feelings in *The Principles of Psychology* (1890) (available online), in the chapter on “Will.”)

Fig. 19 shows a cycling quartet driven by 4 bursting devices that produce movements shown in the cycling pattern above labeled $\mathtt{F}=\mathtt{F}_d$. The quartet in Fig. 19, again resembling that in Fig. 13, operates with an input signal in a stiff 16 tick Ψ–form. Following designs use 16 tick Ψ–forms. The stiff 16 tick Ψ–form for an incoming signal `S` has 3 activity ticks and 13 resting ticks.

cycling quartet driven by stiff signal



©Robert Kovsky 2015 Fig. 19

In the ladder of bursting devices in Fig. 19, a pulse burst is passed from A to B to C to D. Resulting twitching forces appear first in force fiber a, then in b, then in c, then in d. While d is still twitching, A sends a new burst to a. In the $\mathtt{F}=\mathtt{F}_d$ pattern, the weight is supported by a single force fiber device 3/4 of the time; during the other 1/4 of the time, weight support is shared and shifting between two adjacent force fiber devices.

In the design in Fig. 19, each burster is a 16-tick repeating bursting device similar to 8-tick devices discussed in connection with Figs. 9 and 10. Force fiber devices are unchanged.

The chart below shows essential Ψ–forms of bursters and force fiber devices operating in the Fig. 19 design with two kinds of code. Modifications introduced below involve device hookups and Ψ–forms of bursters only. In all stages of construction, Ψ–forms of force fiber devices remain the same. That is, when hookup designs are modified, outputs from burster effectors that drive force fibers do not change. Later charts omit unnecessary detail.

```
Ψ-forms of bursters and force fiber devices in Fig. 19
S    SaS             SbS             ScS          | Z   Y   V
A    NaNPOaOR        NbNPObOR        NcNPOcOR     | ZZ  YY  VV
B        NaNPOaOR        NbNPObOR        NcNPOcOR |  ZZ  YY  VV
C            NaNPOaOR        NbNPObOR        NcNP |   ZZ  YY  V
D    O_OR        NaNPOaOR        NbNPObOR         |    ZZ  YY

a       PqQaQqR         PqQbQqR         PqQcQqR   |
b           PqQaQqR         PqQbQqR         PqQcQ |
c    qR         PqQaQqR         PqQbQqR         P |
d    qQ_QqR         PqQaQqR         PqQbQqR       |
```

The self-cycling quartet is introduced in Fig. 20. New device parts that are symbolized in Figures by small rings and called ***connectors*** are used to join pieces of projections.

self-cycling quartet

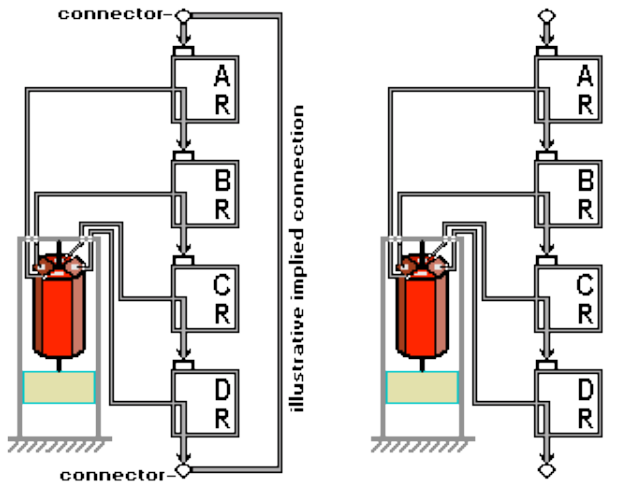


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Fig. 20

First the self-cycling quartet is shown with an "illustrative implied connection" that attaches to connectors which are also attached to projections from and onto bursters. Second, the illustrative implied connection is omitted; passage of pulses from burster D onto burster A are implied by the connectors. Bursts of pulses move from burster D and disappear into the D connector, emerging instantaneously from the connector onto burster A.

.

The self-cycling quartet uses Ψ–forms that closely resemble those of the signal-driven cycling quartet in Fig. 19. The operational chart below shows burster Ψ–forms and flows of action in the self-cycling quartet. Both standard code and condensed code are shown. In the absence of a capacity for receiving input, burst sizes `NaNPOaO` remain fixed and are denoted by Z in condensed code.

```
Ψ-forms and flow of action in the self-cycling quartet (Fig. 20)

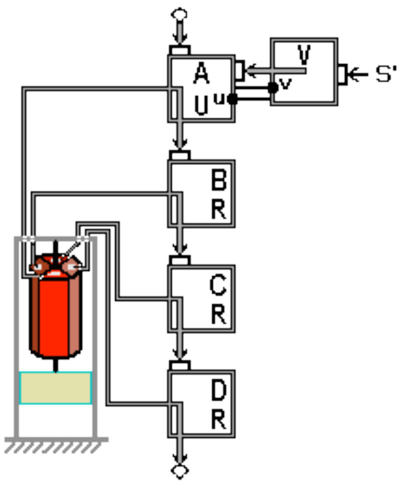
A-detD:   NaNP            NaNP            NaNP      |  Z   Z   Z
A-body:      POaOR           POaOR           POaOR  |   Z   Z   Z

B-detA:       NaNP            NaNP            NaNP  |   Z   Z   Z
B-body:          POaOR           POaOR           P  |    Z   Z

C-detB:           NaNP            NaNP              |    Z   Z
C-body:              POaOR           POaOR          |     Z   Z

D-detC:               NaNP            NaNP          |     Z   Z
D-body:   OaOR           POaOR           POaOR      |      Z   Z
```

self-cycling quartet with
over-riding substitution input



©Robert Kovsky 2015   Fig. 21

In Fig. 21, operations that substitute one burst for another are added to the self-cycling quartet through modifications like those involved in the Fig. 14 design. A 16-tick R burster is replaced by a corresponding U burster with a detector that receives input from storage burster V after V receives an asynchronous input burst through `S′`. As in the prior design, V sends a u pulse to U; in response, U sends a v pulse to V that is timed so that V sends the `S′` burst to U at just the right moment. The system processes `S′` input signals that have at least 16 ticks between leading pulses.

The self-cycling quartet operates "on its own," providing a steady signal that drives force fiber devices repetitively. Alternatively, a new signal can be substituted, changing the level to a new value, that thereafter remains fixed, until a newer substitution burst arrives.

Operational codes and charts for the 16-tick Ψ–forms of U and V set forth in the example below resemble those for the Fig. 14 design but with single-spaced coding. When a new pulse burst SbS arrives through `S′`, V sends a u pulse to U. In response, U sends a v pulse to V on the next 15th tick of the det-U Ψ–form, causing V to send a substitution burst to U at the commencement of the next det-U Ψ–form. The window for arrival of the u pulse closes immediately prior to the 14th tick of the U detector Ψ–form so that U has at least one full tick to prepare to send a v pulse. In the example shown below, the substitution burst could arrive at any of 16 ticks such that the u pulse appears during the "window for u" — and the timings of the v pulse and of substitutions in force devices would be the same for all such arrivals.

```
example of operational chart for burst substitution in Fig. 21

S′:                         SbS
V-detS:                     NbNPR
V-body:                                  ObOR
V-u:                          u
V-v:                                    v

U-u:                   --window for u--
U-v:                                    v
U-detV:                                  NbNPR
U-detD:   NaNPR           NaNPR          YYYY            NbNPR
U-body:      POaOR           POaOR          PObOR           PObO

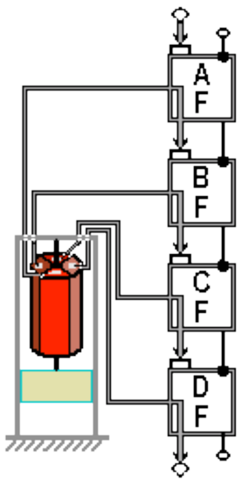
B-det:        NaNPR           NaNPR          NbNPR           NbN
B-body:          POaOR           POaOR          PObOR

C-det:            NaNPR           NaNPR          NbNPR
C-body:              POaOR           POaOR          PObOR

D-det:                NaNPR           NaNPR          NbNPR
D-body:   OaOR           POaOR           POaOR          PObOR
```

A design for a self-cycling quartet with pulse triggers, developed from the design in Fig. 20, is shown in Fig. 22. A set of new projections is added. Each of the new projections carries a trigger pulse that functions like the “u” and “v” timing pulses introduced earlier. In the Fig. 22 design,, trigger pulses accompany activity that occurs without trigger pulses. In anticipated constructions, trigger pulses control timing of discharges and supersede rigid ticking.

self-cycling quartet with triggered discharges



©Robert Kovsky 2015 Fig. 22

The design in Fig. 22 incorporates the connectors introduced in Fig. 20 that imply a connection line. Another pair of connectors imply a connection line that runs between the trigger pulse connector from burster D and the connector onto the junction of burster A.

In this design, burster discharges are triggered by means of trigger pulses that are carried on separate projections. Each burster device F discharges a trigger pulse at the start of the 5th tick in its body (the 8th tick in its detector). A trigger pulse, denoted by “!,” arrives onto the next F device at the commencement of its P tick. The arrival of the trigger pulse initiates discharge starting one tick later. Resulting operations in the Fig. 22 design are indistinguishable from those in the Fig. 20 design.

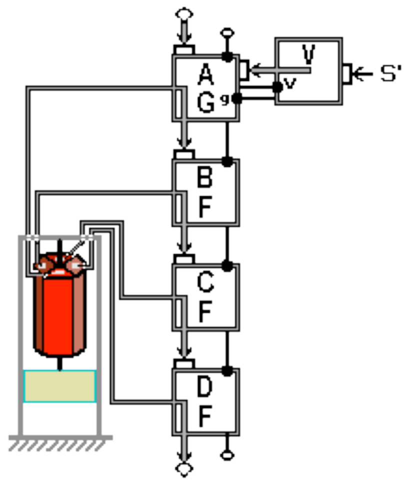
```
Ψ-forms of bursters and flows of action in Fig. 22
At-in:       !               !               !     | !   !   !
A-det:    NNNPRXXX        NNNPRXXX        NNNPRXXX | ZX  ZX  ZX
A-body:      POOOR           POOOR           POOOR |  Z   Z   Z
At-out:          !               !               ! |  !   !   !

Bt-in:           !               !               ! |  !   !   !
B-det:        NNNPRXXX        NNNPRXXX        NNNP |  ZX  ZX  ZX
B-body:          POOOR           POOOR           P |   Z   Z
Bt-out:              !               !             |   !   !

Ct-in:               !               !             |   !   !
C-det:            NNNPRXXX        NNNPRXXX         |   ZX  ZX
C-body:              POOOR           POOOR         |    Z   Z
Ct-out:                  !               !         |    !   !

Dt-in:                   !               !         |    !   !
D-det:                NNNPRXXX        NNNPRXXX     |    ZX  ZX
D-body:                  POOOR           POOOR     |     Z   Z
Dt-out:                      !               !     |     !   !
```

self-cycling quartet with triggered discharges and over-riding subsitution input



©Robert Kovsky 2015 Fig. 23

The design in Fig. 23 combines a self-cycling quartet with triggered discharge shown in Fig. 22 and the Fig. 21 design that operates steadily until changed by over-riding substitution input. Code for operations of the Fig. 23 design combines that of Figs. 21 and 22.

example of operational chart for burst substitution in Fig. 23

```
S’:              SbS
V-detS’:         NbNPR
V-body:                    ObOR
V-u:                   g
V-v:                      v

G-g:      --window for g--
G-v:                      v
G-detV:                    NbNPR
G-t-in:       !               !               !               !
G-detD:    NaNPR           YYYY           NbNPR           NbNPR
G-body:       POaOR           PObOR          PObOR           POb
G-t-out:          !               !              !

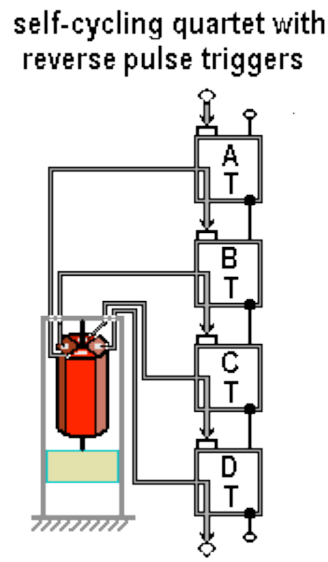
B-t-in:           !               !              !
B-det:         NaNPR           NaNPR          NbNPR           Nb
B-body:           POaOR           PObOR          PObOR
B-t-out:              !               !              !

C-t-in:               !               !              !
C-det:               NaNPR           NaNPR          NbNPR
C-body:               POaOR           PObOR          PObOR
C-t-out:                  !               !              !

D-t-in:                   !               !              !
D-det:                 NaNPR           NaNPR          NbNPR
D-body:    OaOR           POaOR           PObOR          PObOR
D-t-out:      !               !               !              !
```

5. In a self-cycling quartet with reverse triggering, substitution input and additional adjustment inputs, distinct and different operations produce changes identified with “forms” and “feelings.”

A modification of the Fig. 22 design leads to the self-cycling quartet with ***reverse triggering*** of bursters shown in Fig 24. Four identical bursters with reverse triggering are denoted by “T.”



©Robert Kovsky 2015 Fig. 24

In the Fig. 24 design, a pulse burst arriving onto a T burster, e.g., onto `B-det` at the start of the chart below, is processed, as before, by B’s detector and in B’s bVES during four initial ticks.
B discharges a pulse burst onto C during ticks 13-15 of B’s combination Ψ–form (rather than during ticks 5-7):

`T-comb: NNNP1234567!OOOR.`

B discharges a trigger pulse onto A at the start of the 16th tick in the `T-comb:` Ψ–form, producing discharge of the next burst by A onto B. During underscored and numbered ticks 5–11, B can respond to new adjustment signals, as shown in Fig. 26 below.

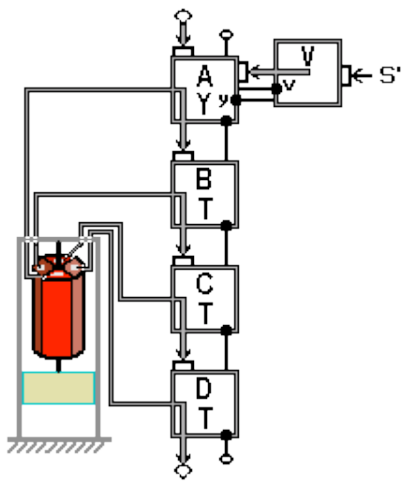
In the self-cycling quartet with reverse triggers, two flows of action operate in opposite directions. One flow of pulse bursts sets force strengths of twitches and the other flow of trigger pulses sets timings of twitches. In movements shown below, pulse burst transfers (OOO→NNN) flow from top to bottom while pulse trigger transfers (!→!) flow from bottom to top. Compare to Fig. 22.

```
Ψ-forms of bursters and flows of action in Fig. 24 _

At-out     !               !               !     | !   !   !   !
A-det   XXXXNNNP        XXXXNNNP        XXXXNNNP | XZ  XZ  XZ  X
A-body  OOOR   P        OOOR   P        OOOR  P  | Z   Z   Z   Z
At-in                  !               !         |    !   !   !
Bt-out                 !               !         |    !   !   !
B-det   NNNP        XXXXNNNP        XXXXNNNP     | Z  XZ  XZ  XZ
B-body     P        OOOR   P        OOOR   P     |    Z   Z   Z
Bt-in              !               !             |   !   !   !
Ct-out             !               !             |   !   !   !
C-det           XXXXNNNP        XXXXNNNP         |   XZ  XZ  XZ
C-body          OOOR   P        OOOR   P         |   Z   Z   Z
Ct-in          !               !               ! |  !   !   !
Dt-out         !               !               ! |  !   !   !
D-det       XXXXNNNP        XXXXNNNP        XXXX |  XZ  XZ  XZ
D-body      OOOR   P        OOOR   P        OOOR |  Z   Z   Z
Dt-in      !               !               !     | !   !   !   !
```

Fig. 25 adapts the Fig. 23 substitution input design for reverse triggering. The chief change from the Fig. 23 design is that the V burster in Fig. 25 sends three substitution bursts to Y rather than a single substitution burst. Triple substitution bursts are necessary because stored settings continue to circulate unless replaced. During each of four P ticks in a 16-tick cycle of the Fig. 25 quartet, three bursters have stored settings and one does not; during the other 12 ticks, two bursters have stored settings and two are involved in burst transfer.

self-cycling quartet with reverse triggering and over-riding subsitution input



©Robert Kovsky 2015 Fig. 25

Operation in the Fig. 25 design resemble those in the Fig. 23 design; there are also important differences. Response of the Fig. 23 design is quicker and sharper than that of Fig. 25.

In the Fig. 25 design, the y and v pulses and 17 output bursts in the chart occur as follows:

```
OaOR OaORyOaOR OaORvOaOR OaOR
OaOR ObOR OaOR OaOR ObOR ObOR
OaOR ObOR ObOR ObOR ObO
```

In the Fig. 23, design, the u and v pulses and 15 output bursts in the chart occur as follows::

```
OaOR OaORgOaOR OaORvOaOR ObOR
ObOR ObOR ObOR ObOR ObOR ObOR
ObOR ObOR Ob
```

<u>example of operational chart for burst substitution in Fig. 25</u>

```
S':          SbS
V-detS":     NbNPR
V-body:                   ObOR            ObOR            ObOR
V-y:             y
V-v:                     v

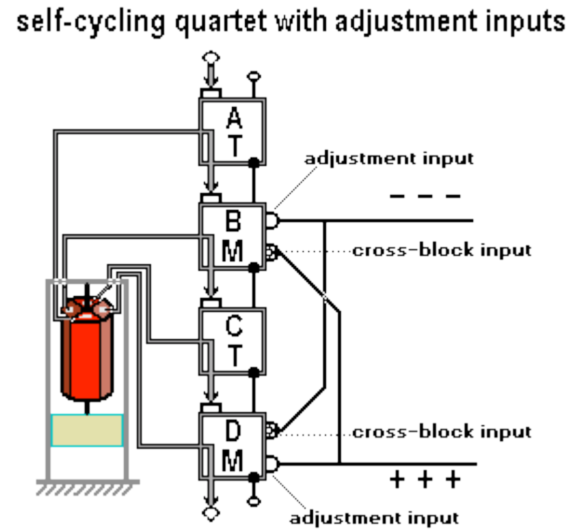
Y-y:     --window for y--
Y-v:                     v
Y-detV:                   NbNPR           NbNPR           NbNPR
Y-t-out: !               !               !               !              !
Y-detD:    NaNPR           YYYY            YYYY            YYYY           NbN
Y-body:  R   P        OaOR   P        ObOR   P        ObOR   P       ObOR
Y-t-in:               !              !               !               !

B-t-out:              !              !               !               !
B-det:   PR           NaNPR           NbNPR           NbNPR           NbNPR
B-body:  P        OaOR   P        OaOR   P        ObOR   P        ObOR   P
B-t-in:           !               !               !               !

C-t-out:          !               !               !               !
C-det:            NaNPR           NaNPR           NbNPR           NbNPR
C-body:       OaOR   P        OaOR   P        OaOR   P        ObOR   P
C-t-in:       !               !               !               !

D-t-out:      !               !               !               !
D-det:        NaNPR           NaNPR           NaNPR           NbNPR
D-body:   OaOR   P        OaOR   P        OaOR   P        OaOR   P        ObO
D-t-in:  !               !               !               !               !
```

In Fig. 26, a ***minus adjustment line*** (denoted by – – –) is attached to burster B in the Fig. 24 design; and a ***plus adjustment line*** (denoted by + + +) is attached to burster D. Adjustment inputs have activation connections, denoted by open symbols, to bursters denoted by "M." Each adjustment line also connects to the other M burster through a cross-blocking connector, denoted by a filled symbol. E.g., when the minus line to B is activated, D is blocked from receiving adjustment input. B's minus adjustment input is also blocked after receiving a signal. Blockage of adjustment inputs for a period after an adjustment (coded by `YYY` in charts) maintains quasi-static constraints. The needed period depends on material properties of the system.



©Robert Kovsky 2015 Fig. 26

Devices can have different kinds of adjustment inputs, e.g., through a timing device junction that processes individual pulses or through a burster detector that processes pulse bursts.

The Fig. 26 design uses a simple input: a pulse train signal on the minus adjustment input of burster B results in a reduction by 1 in the pulse number of bursts discharged onto the force fiber device driven by that burster and onto burster C, such reduction being effected in B's bVES during ticks 5 to 11.

In the condensed code example below, similar to that for the Fig. 25 design, three 16-tick cycles are needed for an input adjustment to become set in all bursters. A circulating burst with pulse number N is replaced by a burst with pulse number M. M=N–1.

```
Example of Ψ-forms of bursters in Fig. 26

At-out    !   !   !   !   !   !   !   !   !
A-det     XN  XN  XN  XN  XN  XM  XM  XM  XM
A-bod     N   N   N   N   N   N   M   M   M
At-in        !   !   !   !   !   !   !   !
Bt-out       !   !   !   !   !   !   !   !   after B-mod becomes active
B-det        XN  XN  XN  XN  XN  XM  XM  XM  N bursts arrive
B-bod        N   N   M   M   M   M   M   M   M bursts leave
B-mod              --  --  --  YYYYYYYYYYYY  B-mod active for 48 ticks;
Bt-in       !   !   !   !   !   !   !   !    then input is blocked
Ct-out      !   !   !   !   !   !   !   !
C-det       XN  XN  XM  XM  XM  XM   XM  XM
C-bod       N   N   N   M   M   M    M   M
Ct-in      !   !   !   !   !   !    !   !
Dt-out     !   !   !   !   !   !    !   !
D-det      XN  XN  XN  XM  XM  XM   XM  XM
D-bod      N   N   N   N   M   M    M   M
D-mod             YYYYYYYYYYYYYYYYYYYYYYYYY  input is blocked
Dt-in     !   !   !   !   !   !    !   !
```

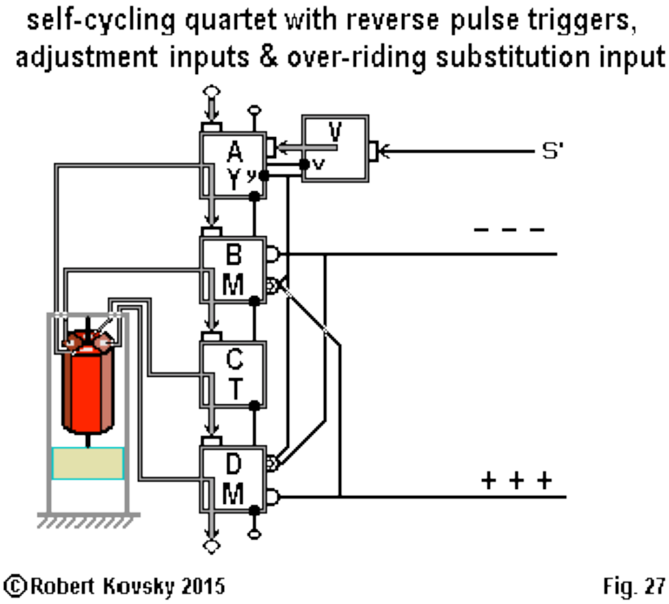


Fig. 27

Previous features are combined in the design for self-cycling quartet with reverse pulse triggers, adjustment inputs and an over-riding substitution input shown in Fig. 27. Foundational activity is steady cycling of a pulse burst with a fixed pulse number. The pulse number can be incremented or decremented by signals on the adjustment inputs.

In other operations, a substitution burst replaces the cycling burst. On arrival of a substitution burst `S'` at V, V sends a y pulse that signals the Y burster and blocks modification inputs on M bursters. Blockage prevents changes in the M bursters while burst substitution is carried out and the weight returns to rest.

One line of development starts with the Fig. 24 design and adds a substitution input to get to the Fig. 25 design. Another line of development starts with the Fig. 24 design and adds adjustment inputs to get to the Fig. 26 design. The substitution input attaches to burster A and adjustment inputs attach to bursters B and D. The two kinds of input operate independently in the Fig. 27 burster circuit and, without cross-blocking, they could conceivably operate at the same time. However, while quasi-static constraints are maintained, combined operations are avoided. Blockages are used to separate the two kinds of changes and maintain quasi-static control.

The quartet design in Fig. 27 leads to the Fig. 28 octet design for a unitary force device and to anticipated constructions involving large numbers of such force devices. Substitution signals and adjustment signals serve distinct functions in anticipated constructions. Substitution signals drive large scale movements according to ***forms*** that can be generated at a remote location and stored until need. Adjustment signals are based in movements and in sensory devices located inside and close to force devices. Adjustment signals may be slight, producing only wobbles. Such signals are said to be resident in movements and to correspond to ***feelings*** that modify a directed movement. Such modifications must occur contemporaneously with the movement.

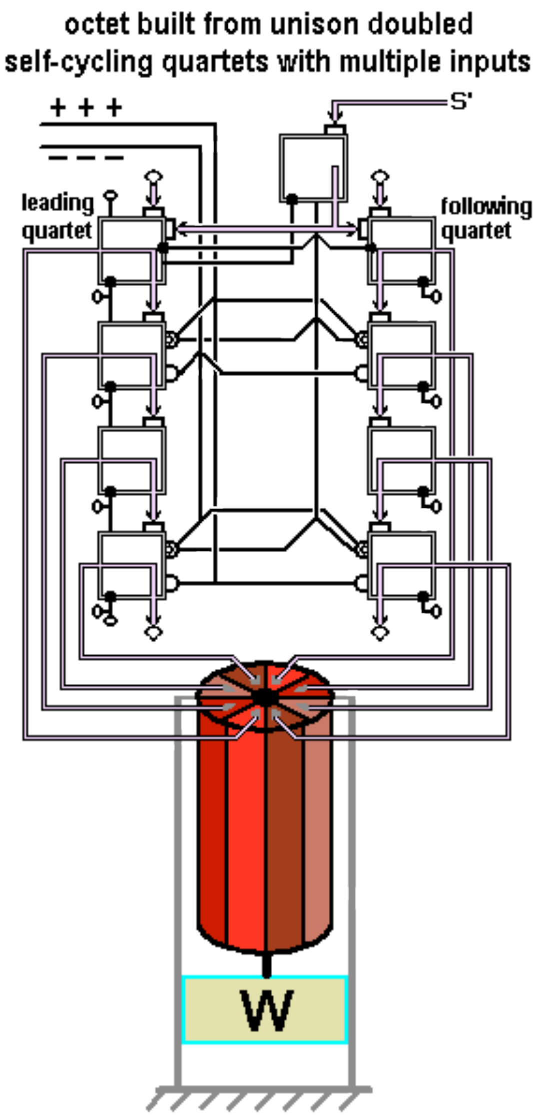
Designs suggest that such correspondences between feelings and movements might also be based in Quad Net devices in which long-range, collective phase changes in materials control switching operations and which I suggest also generate imagery that resembles a person's experiences.

An example of such personal experience is provided by my habitual behavior at the mailbox on my front porch. I do not look into the mailbox but open it and thrust my arm inside. If my hand encounters objects, my fingers close around them and hold them while my arm withdraws. I suggest that the arm motions are based in forms controlled by higher brain parts, such as the cerebellum, while finger motions are based in feelings generated by neurons in spinal vertebra and nearby dorsal root ganglia. Forms are stored and operate when needed while feelings operate immediately.

Hence the Fig. 27 design suggests how remote forms, based on intentions, might be combined with bodily adjustments based in feelings.

D. An ***octet force device***, built from two self-cycling quartets with substitution and adjustment inputs, is a ***motor unit*** suitable for use in larger constructions.

Fig. 28 shows the design for an octet force device that functions as a motor unit component in larger sensory-motor constructions. Supplied with Virtual Energy from a source outside the image, the octet force device operates continuously with cycling bursts of pulses and produces a steady contractile force that, at full extension, ranges from a minimum of $2F_1$ to a maximum of $30F_1$, where the size of steady F_1 is equal to the central twitch strength $\mathcal{F}_1$ of a single force fiber device. Two quartets operate synchronously on opposite sides of the octet and produce more balanced forces than a single quartet. Additional variations are suggested by Fig. 18. A force device with four quartets and 16 force fibers would offer further possibilities for development.



©Robert Kovsky 2015 Fig. 28

The force produced by the octet remains steady until an input signal is supplied. A substitution input signal `S'` replaces the cycling burst with a new burst.

Adjustment input signals denoted by + + + and - - - can increase or decrease the size of a cycling burst. In quasi-static designs, adjustments are limited to a unit change in pulse number; each movement comes to rest before another adjustment starts.

The Fig. 28 octet combines two self-cycling quartets based on the Fig. 27 design. The ***leading quartet*** on the left is an independent version. The ***following quartet*** on the right depends on the leading quartet for timing functions. In the left quartet, trigger pulses travel on projections between bursters; they are also impliedly delivered via connections to corresponding bursters in the right quartet. Right and left bursters are triggered by ramified pulses and discharge synchronously.

Also: only the leading top burster sends a trigger pulse to the storage burster; triggered by that pulse, the storage burster sends a substitution burst to both top bursters.

Arrival of `S'` at the storage burster initiates a course of action, beginning with discharge of a trigger pulse that causes the leading top driver burster to send a trigger pulse back to the storage burster at just the right moment, also causing both top bursters to switch input receptors to the storage burster at the next opportunity. In quasi-static operations, cross-blockages prevent a second change from any input for a specified period that is sufficient for the weight to return to rest.

III. Elemental signal generators, sensor devices and control devices are incorporated with motor units in sensory-motor constructions.

A. The class of ***pulser devices*** illustrates foundational principles of Virtual Energy.

1. VE Principles both resemble and differ from those of Conserved Energy.

According to Laws of Physics, a "real" principle of Energy Conservation is presumed to govern interactions of bodies that range in size from atoms to galaxies. In contrast, Virtual Energy is a constructed concept with initial correspondences to Conserved Energy (CE) but progressively detaching therefrom. From a VE perspective, CE constructions are limited to restricted classes of systems; they also serve as starting points for development of different principles.

A statement of energy principles that applies to both Conserved Energy and Virtual Energy was provided by Teilhard de Chardin in *The Phenomenon of Man* (1955, 1959 English transl.). Although our aims differ, de Chardin and I both look for alternatives to the "modern scientific view." I would substitute "body" for his "atom," omit "the real evolutionary standpoint" and make other minor changes; otherwise, the following extracts from de Chardin's principles are suitable for a statement of Virtual Energy principles that resembles one for Conserved Energy.

> …Energy is the measure of that which passes from one atom to another in the course of their transformations. A unifying power, then, but also, because the atom appears to become enriched or exhausted in the course of the exchange, the expression of structure.
>
> …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.)
>
> *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 'entropised,' lost, that is to say, 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 more than anything is created, but that is merely a mathematical trick. As a matter of fact, from the real evolutionary standpoint, something is finally burned in the course of every synthesis to pay for that synthesis. (pp. 50-51.)

The following course of construction has four layers. The lowest layer contains pulser devices, where Conserved Energy principles and Virtual Energy principles have areas of overlap. Conserved Energy principles describe some timing device operations but they are limited. Bursting devices and force devices, previously discussed, have too much arbitrary dissipation for exact description by Conserved Energy principles. Quad Net devices are even more detached.

APPENDIX: Provisional Goals of Constructions

Anticipated modules operate in diverse domains

A. Virtual objects and action schemata are combined to make up courses of action in Virtual Energy domains.

1. In Piaget's psychology, real objects incorporate features of substance, permanence and participation in causal relations.

2. Virtual Energy in VE Storage is re-constructed as a virtual object with a variable, rather than a permanent, character that combines a steady VE inflow with dissipations and pulsational arrivals and discharges.

3. Action schemata constructions in the primal VE domain both resemble and also differ from similar constructions (e.g., Carnot cycle) in the Conservative Energy domain of classical physics.

4. VE Stores in devices generate pulses during dissipative conversion and Quad Net transformation (selection) schemata.

5. Dissipative VE conversion and transformation schemata are combined with conservative VE storage and transfer schemata to construct courses of action in a general Virtual Energy domain.

B. Collective and disparate modular devices operate together in diverse Virtual Energy domains.

1. A general Virtual Energy device leads to disparate kinds of devices that operate in diverse Virtual Energy domains with variable influential characters.

2. A collection of uniform devices with independent operations, interconnected operations and unison operations makes up an ensemble of devices.

3. Organized ensembles of devices make up modular devices that operate independently, interdependently and collectively in variable domains.

4. Quad Net devices are reconstructed for organization and control of transient assemblies of modules by means of imagery that is generated from memories of prior courses of action.

Anticipated models of tubular organisms (worms) operate in natural domains

A. In a toroidal design for a model of peristalsis, a uniform circular tube of elastic material with a central channel is overlaid with muscle-like rings made up of modularized force devices that are driven by a network of bursting devices to squeeze the elastic material and control movements of objects through the central channel.

B. In designs for models of worms, outer tubular layers of muscle-like materials are joined to an inner peristalsis model by means of muscle-like orifices at ends of tubes. Tubular bodies produce repertoires of movements; orifices, constrained by bodily movements, operate with other movements. An incompressible and viscous (dissipative) fluid fills spaces separating layers of muscle-like materials, as in a coelomate animal. Equipped with sensors (e.g., of pressure, gravity, sound, molecules, light) and distributed networks of bursting devices. ensembles and modules, including networks that resemble cephalic ganglia, models are designed to move purposefully and spontaneously in natural environments in ways that resemble biological worms, e.g., by consuming and gathering plastic debris from ocean waters, by burrowing into earth to trace the source of a pollutant or by performing diagnostic tests while crawling inside a colon or an artery.

1. Models resembling sea anemones with circular and lengthwise muscles produce squish-squash movements while fixed in position on a supporting base.
2. Longitudinal squish-squash movements become a means of locomotion in mobile models that resemble simple bottom-dwelling sea worms.
3. Multiple oblique muscle-like layers produce more complex repertoires of transverse undulatory (wavy) movements of models operating in water.
4. Segmented models that resemble earthworms can also burrow into material media, twist in groping movements and bend into shapes.
5. Worm models with quadnetted layers of sensory-motor device modules have enlarged repertoires of movements — e.g., drilling or joining head to rear and rolling like a wheel — and can use memories to experiment with movements in response to events. The ***whole body*** participates in selections of movements, achieving integrity of movement. The body exercises rudimentary freedoms.

4/29/15