

DOMAINS OF FREEDOM

www.quadnets.com

Domains of Investigation — main contents of the website

- A. Movements and feelings of animal bodies (actual life)
 - B. Contests (sports and games)
 - C. Engineered organisms (eyes that look at objects)
 - D. Music practice and performance
 - E. Practices of bodily consciousness
-

C. Engineered organisms mimic primitive movements of animals.

Eyes that look at objects: models of visual movements and sensory control

1. The final constructions: device models of reflexive gaze
2. Constructions start with a primal model of stimulus and response.
3. The primal model is adapted for use with a rotating joint.
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5. Four movers operate in a VE model of gaze-directing movements of eyes.
6. Bundled movers produce denser repertoires of movements.
7. In a fast simple design, a quadnet device in a sensorial body controls movements of reflexive-gaze models.

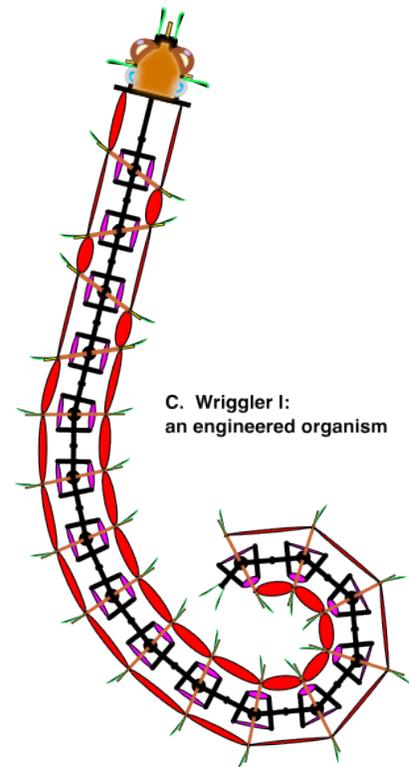
Overview: engineered organisms mimic primitive movements of animals

The figure below shows the initial design for an engineered organism "Wriggler I." Movements of engineered organisms are intended to resemble movements of animals. Multiple kinds of movements occur simultaneously and respond to momentary bodily and sensory influences.

Distant goals include engineered organisms that exercise freedom according to the principle of Shimmering Sensitivity, as discussed in part B of the website (contests).

Constructions in this project mimic certain reflexes in the form of stimulus and response, e.g., "wiping reflexes" of headless frogs aimed at a drop of acid on the skin and even suggesting itching and scratching. (See part A of the website). A stimulus can appear at any location in a sensorial field and trigger responsive movements targeting that location.

I suggest that: when an object appears in the visual field, eyes reflexively aim their gaze at the object. In other words, eyes look at objects "on their own." Locations of objects in head-centered space can be mapped by means of reflexive muscular movements of eyes and the signals that produce the movements. Such muscle-based mappings may be sufficient for purposes of approach and/or avoidance.



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Projects are constructed in imaginary Virtual Energy domains using "kits of parts," where the parts are "energy conversion devices" that run on "Virtual Energy." The approach resembles that of electrical circuit designs.

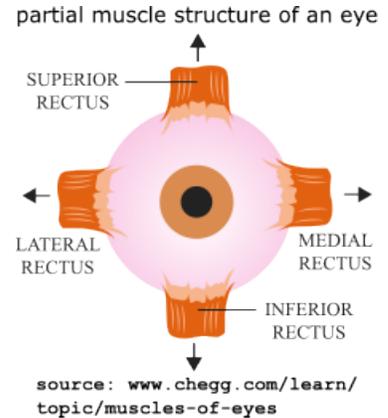
Virtual Energy (VE) is an abstract invention used to model a presumed "actual energy" that occurs in nature, with concepts similar to those used to describe and sometimes to control movements of steam engines, audio loudspeakers and animal bodies. In steam engines, energy in chemical bonds in fuel is converted into heat energy stored in steam; then heat energy in steam is converted into work. Electro-mechanical energy conversions occur in audio loudspeakers. In animal bodies, energy in chemical bonds in sugar delivered through the bloodstream is converted into forceful movements of muscles and electro-chemical signals in nerves and brains. VE designs aim to model or mimic energy conversions in animal bodies using simple imaginary constructions.

Eyes that look at objects: models of visual movements and sensory control

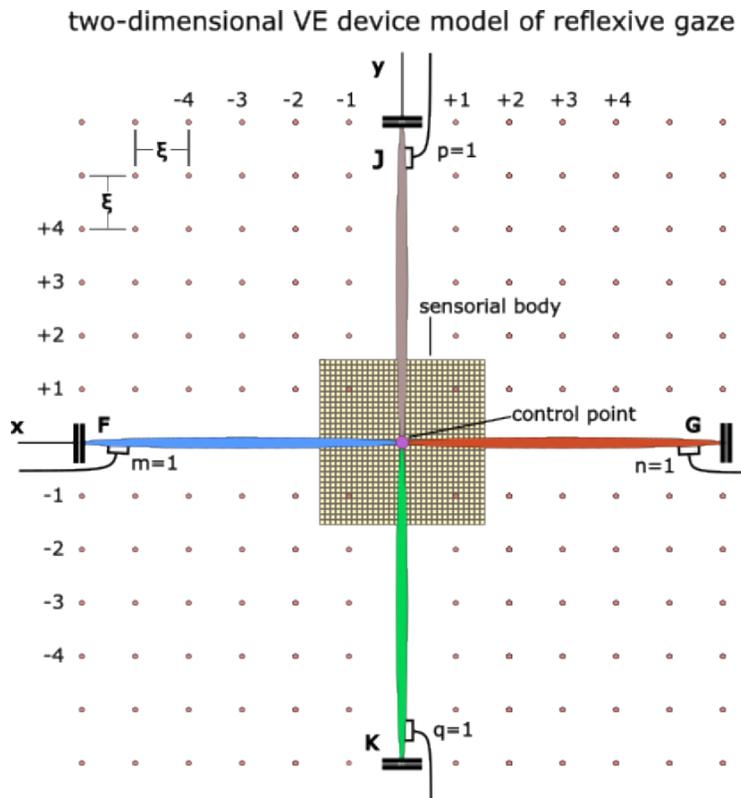
1. The final constructions: device models of reflexive gaze

The adjacent figure shows four "rectus" muscles that partially control movements of a human eye, rotating the eyeball to the left or right, or up or down. As a result of such movements, the gaze is aimed in a particular direction, often at an object in the visual field.

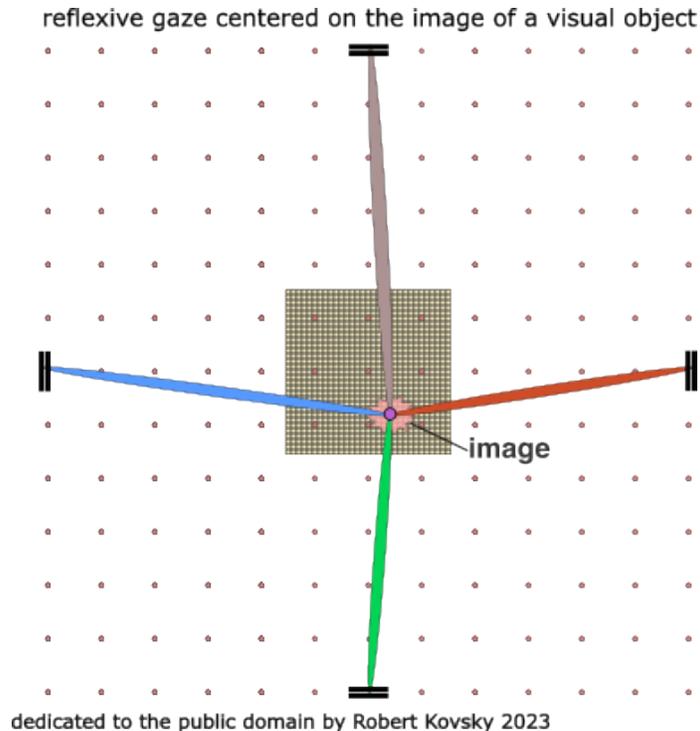
VE models of reflexive gaze follow a principle of "stimulus and response" — the appearance of an object in the visual field is a "stimulus" and eye movements that direct the gaze at that object are "responses."



In a device model of reflexive gaze shown below, four different-colored "movers" resemble rectus muscles. Movers produce variable contractile forces and have variable lengths. The fixed "sensorial body" resembles a retina in an eye. Movers shift the position of the mobile "control point," shown in a resting position at the center of the sensorial body. Movers **F** and **G** control the position of the control point by pulling to the left and right, movers **J** and **K** by pulling up and down.



The figure below shows the model in the gazing position that is investigated in the final designs in this project. First, as a stimulus, an "image" of an object appeared on the sensorial body; then, responsive changes in mover forces shifted the control point to a position close to the center of the object-image.



In the model, the control point moves and the sensorial body is fixed. In an eye, both the aiming pupil at the front center of the eye and the retina at the rear are parts of the eyeball and both the pupil and the retina move. However, movements in the model are readily shown to correspond to those of an eyeball, with adjustments as needed.

The figure incorporates a systematic deformation. In a more accurate version (like one constructed below), sensor elements in the sensorial body have curved edges and compressed dimensions, rather than the square elements in the figure. The deformation is readily correctible and simpler square elements are used here.

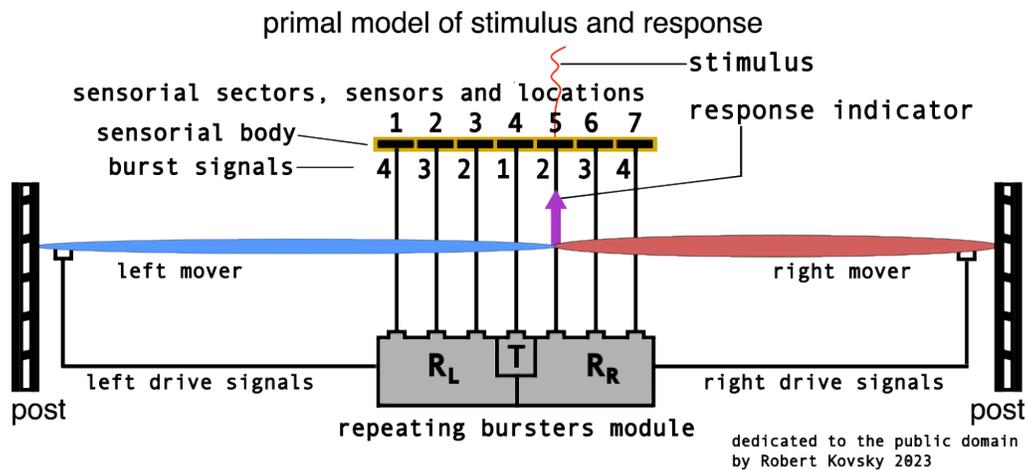
This project proceeds by a series of stages starting with a "primal model." Development of movers occurs during the first stages. Then attention shifts to development of the sensorial body, sensors and additional control devices. These constructions emphasize functions of device parts and modules.

Further constructions are to be set forth in a separate project (in preparation): a formal Virtual Energy (VE) model, including VE definitions for operations of devices and modules used in this project.

2. Constructions start with a primal model of stimulus and response.

In the primal model of stimulus and response shown below, muscle-like left and right "movers" operate in opposition to each other and with variable forces set by "drive signals." Each mover is connected to a fixed "post" at one end and to a shared mobile "response indicator" at the other end. A change in drive signals produces a change in position of the response indicator. Positions are steady between changes. A steady position of the response indicator matches the location of the most recent stimulus.

The "sensorial body" will be developed below into a collective device resembling an integrated circuit in which individual elements are laid over a common uniform substrate. Individual devices in the sensorial body are subject to collective control, e.g., being turned on and off. In this first version, the sensorial body contains seven "sensorial sectors" at "locations" numbered "1" through "7." A "stimulus" targets a single sensorial sector and triggers the "sensor" therein to transmit a "burst signal" to the "repeating bursters module," which controls drive signals.



Inside a mover are multiple *force fiber devices*, each producing forceful *twitches*. Twitches of force fiber devices resemble twitches of muscle fibers in animals that exert contractile force. In a *duet*, two force fiber devices produce two sets of alternating and overlapping twitches that add up to *steady forces*. Details in the formal VE model will resemble designs in Wiggler projects.

Elemental *signals* are made of *pulses* generated by VE control devices, such as the repeating bursters module. In idealized designs, a pulse is a uniform packet of Virtual Energy. In the bursters module, timing of operations is controlled in the part labeled "T." Bursters in the control module (labeled "R") generate short *pulse bursts* that are sent as drive signals to movers. Repetitive streams of pulse bursts in drive signals produce repetitive streams of twitches that result in steady forces.

More about pulses, pulse bursts and timing of repetitive operations

Constructions of movements and sensations start with twitches and pulses.

In early designs, there is a single underlying *flow of time* that is generated and controlled by devices. Initially, a "Master Clock" sets the beat that controls all operations. Development starts with primitive concepts where unified time moves continuously at a fixed rate from earlier to later. In more complex arrangements, independent modules have various modes and rates of time.

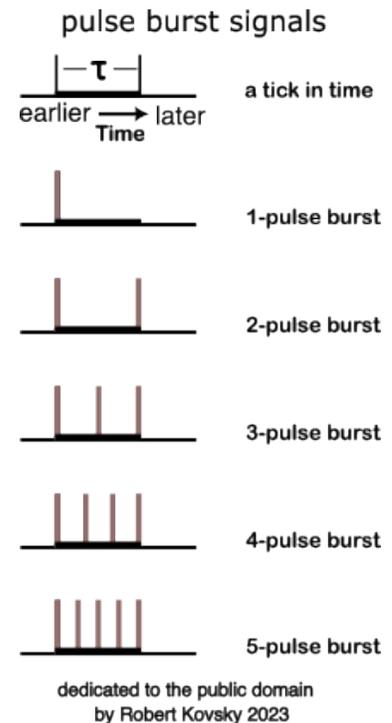
Pulses travel on *projections* between VE devices, shown in the primal model as lines for burst signals from sensors to the bursters module and as drive signal lines from bursters to movers. In idealized VE designs, a pulse lasts for only an instant. Pulses, like electrical signals, travel *instantaneously* from the origin to the destination. Pulses on projections also resemble signals on nerves, namely action potentials (traveling energy spikes), with a constant shape and one-way travel.

The adjacent figures show the pulse burst signals used in this project. The top figure shows a time element, called a "tick." The duration of a tick – " τ " – is a design feature and can be variable. Constructions start with a "slow tick," e.g., $\tau = 0.1$ second. A "fast tick" is also used, e.g., $\tau = 0.01$ second.

A pulse burst signal lasts for exactly one tick, including both the first and last instants of the tick. A pulse starts the tick and defines the first instant of the burst signal. If more than one pulse is in the burst, the final pulse occurs at the last instant of the tick. Any additional pulses are spread evenly throughout the tick.

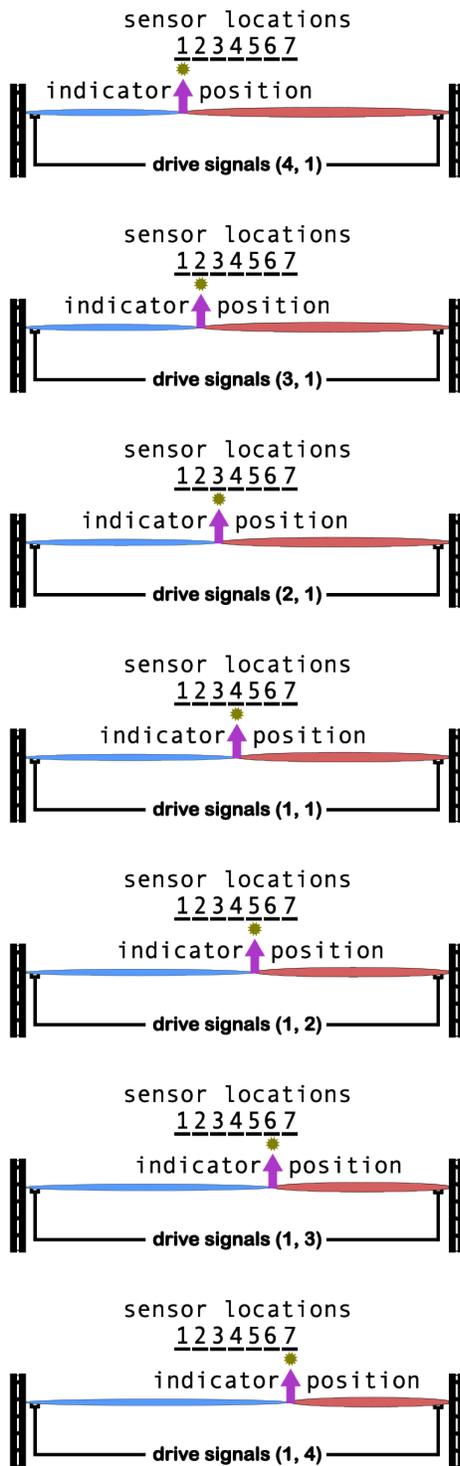
These definitions of pulse bursts are constructed for easy production and handling by devices. The different pulse burst sizes produce different forces in a mover, with more pulses producing a stronger force.

Devices in this project operate in cycles, with 8 ticks in a cyclical period. Each device has an action pattern – a *schema* – that is tethered to the 8-tick cycle. Through operations synchronized by the Master Clock, devices can maintain coordinated repetitive action patterns or *schemata* (plural).



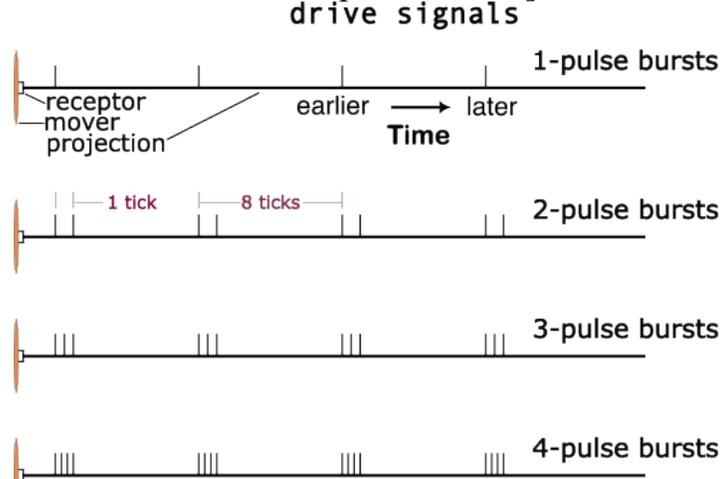
repertoire and elements of the primal model

locations and positions



The figures on the left show the sensor locations and indicator positions of the primal model, along with the drive signals that produce the positions. Positions and locations coincide and have a simple one-to-one relationship.

The figures below show repetitive drive signals used in the primal model. The first figure also names parts of the design: (1) *movers* that produce contractile forces; (2) *projections* that carries pulse bursts (each burst sets the force for the next mover cycle); and (3) *receptors* that connect projections to movers. [The primal model does not use 5-pulse bursts.]



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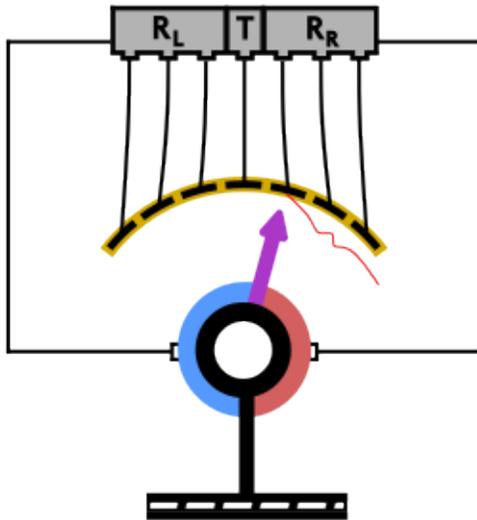
The figures above incorporate *charts* of pulse signals: a projection also serves as a time line for representation of signals, with "earlier" signals to the left and "later" signals to the right. Linear "Time" matches a measure of space in the chart. Each pulse burst fills one tick. Eight ticks intervene between successive pulse bursts. An 8-tick cycle governs operations of twitching movers and pulsating bursters.

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3. The primal model is adapted for use with a rotating joint.

VE designs are readily adaptable to new situations by means of deformations and other modifications.

primal model adapted to a rotating joint



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The adjacent image shows a modified version of the primal model — re-organized around a rotating joint, which is shown as a black circle wrapped in blue and red movers. Here, movers have shapes defined as arcs of a circle. One end of each mover is attached to the shared post and fixture and the arcs of the two opposing movers add up to a whole circle. The indicator arrow moves in a range of motion of 90° or one quarter of a circle.

Other than the rotating joint and the different shapes of the movers and of the sensorial body, there is not much difference between the original primal model and the rotating joint version. Operations of sensors and the control unit are identical in the two versions, as are sensorial signals and drive signals.

The figures below show the seven steady positions of the rotating joint model, along with the drive signals. These correspond directly to the seven indicator positions of the linear version.

steady positions in the repertoire of the primal rotating joint



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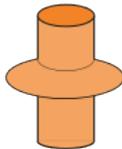
Correspondences between linear and circular models are maintained in subsequent constructions. Thus, two-dimensional (flat) movements constructed later in this project correspond to rotations of a spherical eyeball.

A construction in this project starts with a particular situation based in hardware features such as the posts in the primal model or the rotating joint in the circular model. Hardware features enable and constrain movements of movers much like a skeleton and joints enable and constrain movements of muscles.

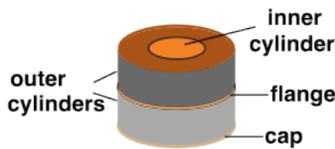
Hardware features of a rotating joint are shown in the figures below.

construction of a rotating joint

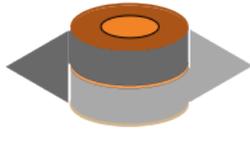
a. inner cylinder and flange



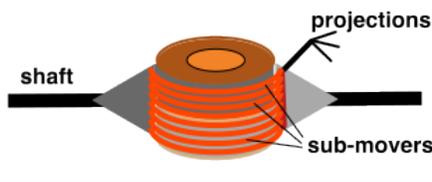
b. rotating hubs



c. fins attached



d. sub-movers, projections and shafts



e. symbol



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As shown in Fig. a, the core of the rotating joint is a rigid piece of plastic, metal etc. in the shape of an *inner cylinder* encircled around the midpoint by a disc or *flange*. In idealized designs, the flange provides a rigid frictionless surface that supports movements of hubs rotating around the core.

Rotating hubs are shown in Fig. b as outer cylinders that rotate freely and without friction around the inner cylinder. Hubs rotate independently, separated by the flange. A cap secures the lower hub. A cap might also fit over the top of the joint.

Fins are thin plates made of the same rigid material as the hubs; they are incorporated in the hubs, as shown in Fig. c. Fins limit the range of motion of the hubs but do not interfere with movements in that range.

Sub-movers are attached to the fins in Fig. d. Each sub-mover runs from one fin to the other fin, serving to pull the two fins towards each other and thus rotating the joint. A sub-mover rests on an outer cylinder but slides easily on its surface. Multiple sub-movers operate synchronously, distributing forces over the fin.

Another set of sub-movers is attached to the other sides of the fins (they are "hidden" in Fig. d) and the two sets of sub-movers operate in opposition.

As shown in Fig. d, *shafts* and *projections* round out the construction. The design is represented in Fig. e by an iconic symbol.

4. Movers make up a "kit of parts" that are used in constructions

Detailed definitions of movers are part of the formal VE model. For purposes here, a *mover* is a Virtual Energy force production device. Movers aim to mimic animal muscles. Elemental movers are *force fiber devices* that produce contractile twitches. *Holding twitches* are designed to work in combination and to maintain steady forces. Another device produces *saccadic twitches*, where strong forces are concentrated at the start of each twitch.

Combinations of force fiber devices make up *collective movers*, e.g., *bundles* of multiple force fibers that twitch synchronously or in sequence and bundles of duets that produce finer gradations and larger repertoires of steady forces (see § 6 below).

Constructions apply a method of "kits of VE parts." To start, VE designs use VE devices (parts) that are connected by projections; and parts have defined operating characteristics and features. The approach resembles that of electrical circuit designers and engineers who use copper wires to hook up components they have selected from "kits of electrical parts." Later investigations focus on *VE currents* flowing in *sensorial bodies* (perhaps resembling integrated circuits).

An example of an electrical kit of parts is one with various kinds of "resistors." Resistors are used to control flows of electrical currents. A typical resistor has two conducting wires sticking out from a small unit of manufactured material that has a suitable "electrical resistance." Resistors are classified according to certain specifications, namely: (1) the material constitution (e.g., whether made of carbon composition or metal film or wirewound); (2) power rating (e.g., ¼ watt, ½ watt, 25 watt); (3) resistance (e.g., 100 ohm, 68 kilohm, 2.2 megohm); and (4) precision (e.g., tolerating discrepancies in the resistance of 20%, 10%, 5%). A resistor is completely defined by stating its specifications.

Similar specifications for a kit of parts of movers are: constitution (hardware features), force equation, schema (action pattern of operations), maximum length L_0 , elemental force F_1 and dissipation factor j . In a full design, such a device contains a certain-sized Virtual Energy Store (VES) and specified VE operations, but discussion of these specifications can be deferred.

The initial *steady mover* has two holding force fiber devices, which make up a duet. During a cycle, one force fiber device, the *leader*, twitches immediately in response to a pulse burst signal. Meanwhile, the second force fiber device, the *follower*, is resting; but it then continues the twitch started by the leader — while the leader is resting and becoming ready to twitch again. Alternating twitches overlap and add up to a steady force that can be set by means of the drive signal.

A full kit of steady mover parts would include various elemental forces (F_i) and various sizes of maximum mover length L_0 , perhaps ranging from a fraction of an inch or centimeter to many inches or centimeters. The momentary length L of a mover changes during operations under the influence of drive signals and external forces. The elemental force F_1 and the dissipation factor j of a mover are fixed during operations. Movers in such a kit could, e.g., move a limb or an eyelid.

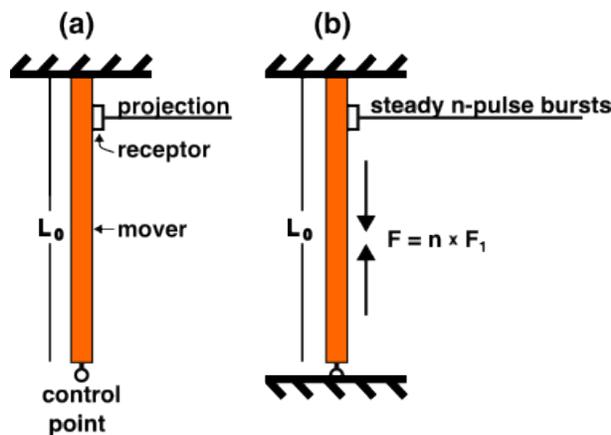
The following Formula 1 defines the **contractile force** F produced by a steady mover that is being driven by a repetitive stream of pulse bursts with n pulses each:

$$\text{Formula 1: } F = n \times F_1 - j \times \Delta L.$$

As noted above, the elemental force F_1 and dissipation factor j are specifications of a specific mover and are fixed during operations. The **pulse number** n refers to pulse burst signals; n belongs to a set of integers, e. g., $\{1, 2, 3, 4, 5\}$. The term ΔL denotes the momentary **shortening** of the mover: $\Delta L = L_0 - L$ (maximum length minus momentary length). As stated in Formula 1, the force diminishes when the mover contracts or shortens from its maximum length, even while the pulse number stays constant. In a shortened mover, energy that might have gone into twitches is lost or dissipated.

Figures below show operations of a steady mover. This is the first step in a course of construction that has some features different from the primal model, e.g., use of 5-pulse burst signals.

parts of a steady mover and and force production rule



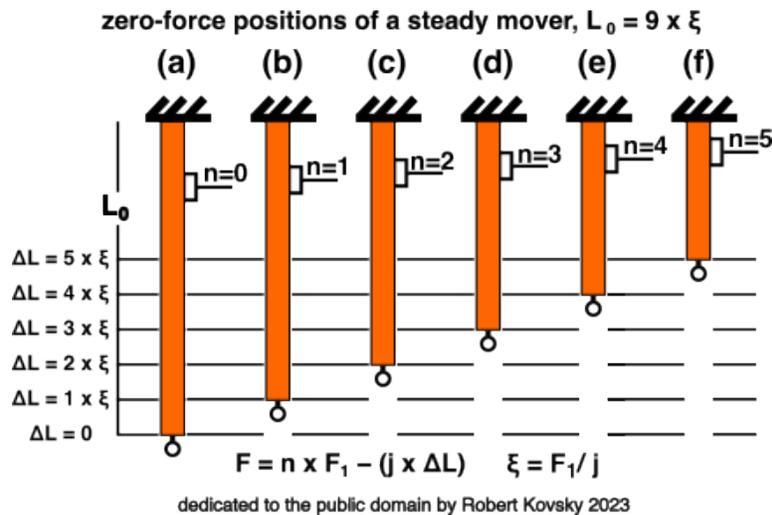
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Fig. (a) shows parts of a steady mover in a relaxed condition. The mover is attached to an immovable fixture at the top end while the bottom end has a "control point" that can be used in various ways. In Fig. (a), there is no drive input, the mover is passive and the control point is mobile but steady.

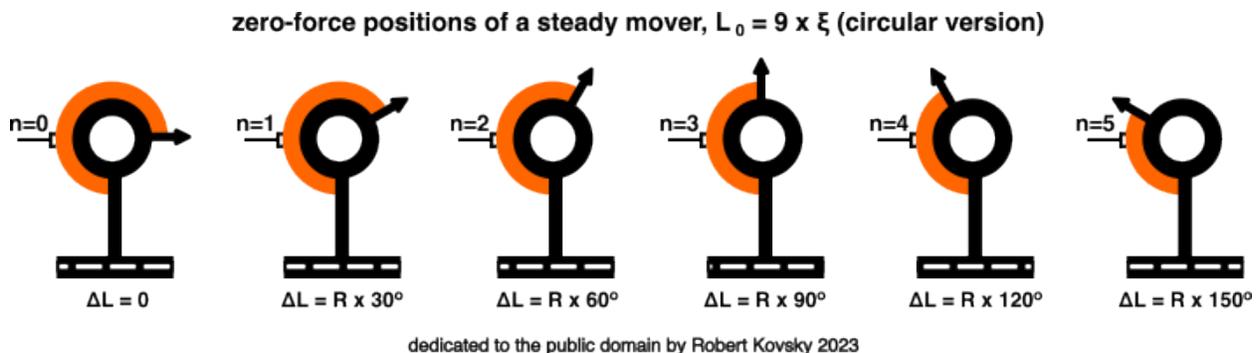
Fig. (b) shows the control point attached to a fixture; thus, the mover is maintained at its maximum length. A steady stream of pulse bursts maintains a steady contractile force. Because $\Delta L=0$, the set or **repertoire** of forces is:

$F_1, 2F_1, 3F_1, 4F_1$ and $5F_1$, corresponding to 1, 2, 3, 4 or 5 pulses in each burst.

Fig. (a) below is a copy of the mobile mover from the prior Fig. (a); $n=0$ denotes an absence of a drive signal. Next, as shown in Fig. (b), a drive signal $n=1$ is applied, along with a guiding hand that slows and controls the movement. The contractile force shortens the mover. As the mover shortens, the force diminishes. Referring to Formula (1) (also shown below the figures), when the shortening reaches a certain point — when $j \times \Delta L = F_1$ — the force falls to 0 and the mover comes to rest as indicated in Fig. (b). That is, a steady **zero-force position** is maintained with pulse bursts $n=1$ and shortening $\Delta L = F_1/j$. A **full mover step** is equal to F_1/j , which is called " ξ ." Successive increases in n lead to successive increases in ΔL . $\Delta L = n \times \xi$ identifies the zero-force positions of the mover.



The mover shown in the above figures has a maximum length of $9 \times \xi$. That length is suitable for both linear and circular arrangements, as shown below. In the circular version, the mover is an arc of a circle with a radius R . The $n=0$ mover extends over 270° . $\Delta L = R \times n \times 30^\circ$ identifies the zero-force positions of the mover. A step of 30° in the circular version corresponds to a step of ξ in the linear version.

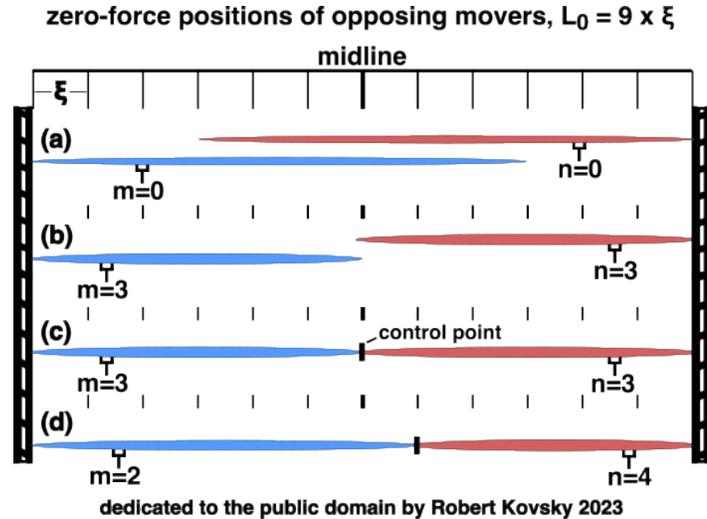


The figures below show the construction of opposing movers in zero-force positions. To distinguish the two drive signals, the left mover is driven by a stream of bursts with pulse number "m" and the right mover is driven by a stream of bursts with pulse number "n."

In Fig. (a), movers are full-length and drive signals are absent. Midline is defined by symmetry.

In Fig. (b), movers maintain symmetrical zero-force positions at midline with $m = n = 3$.

The movers are joined with a mutual control point in Fig. (c). The control point can hold tension – although no tension is present here.



Another zero-force position is shown in Fig. (d), where $m=2$ and $n=4$. The full set of zero-force positions in this design is: $(m,n) \in \{(5,1), (4,2), (3,3), (2,4), (1,5)\}$.

The figures below show *tense movers*, in which forces and tensions are produced by gravity acting on weights. (Gravity is useful for this set of figures but is otherwise absent from the imaginary domain of this project.) A tense mover carries an internal tension that can impose or oppose an external force.

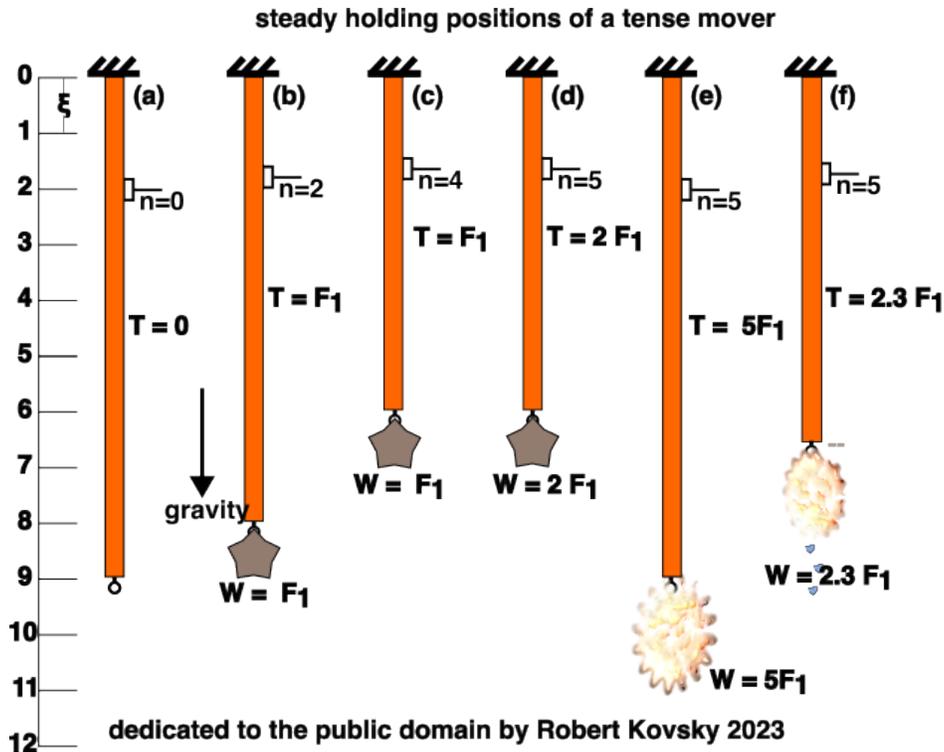


Fig. (a) starts with the prior zero-force position of a single mover with drive signal $n = 0$. The weight of the mover is disregarded.

In Fig. (b), with drive signal $n=2$, the *weight* W produces a gravitational force of F_1 and the mover shortens by ξ . That is, applying Formula (1) above: $F = 2 \times F_1 - j \times \xi = F_1$, which suffices to hold the weight at that position. As indicated in Fig. (b), a tension $T = F_1$ is held throughout the mover from the weight up to the fixture.

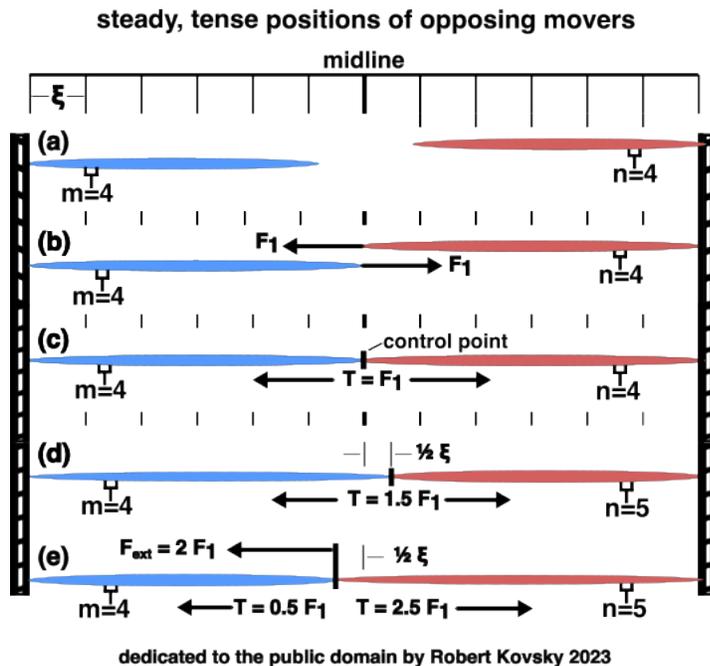
With further examples, a general equation emerges for the length L of a single steady mover ($L_0 = 9 \times \xi$) that is driven by n -pulse bursts and that is holding a weight W at a steady position, namely:

$$L = [(9-n) + (W/F_1)] \times \xi. \text{ Two such examples are shown in Fig. (c) and Fig (d).}$$

In Fig. (e), a piece of ice with weight $5F_1$ is attached to the control point. A drive signal of 5-pulse bursts is required to hold the weight at the maximum length. As the piece of ice melts, its weight declines; while drive signals remain constant, the length of the mover shortens, as shown, e.g., in Fig. (f), where $\Delta L = 2.7 \times \xi$.

Tension is now incorporated in opposing movers, as shown in the figures below. In Fig. (a), individual movers are shown in zero-force positions with 4-pulse bursts driving both movers. Next, in Fig. (b), a constant stretching force F_1 is applied to each mover, similar to the force of gravity in prior figures. Each mover stretches 1ξ , at which point the internal force or tension equals F_1 , balancing the external force. In Fig. (c), the two movers are joined with a mutual control point that holds tension, $T = F_1$, which extends through the two movers to the posts.

In Fig. (d), the drive signal to the right mover is increased to 5-pulse bursts. The stronger right mover shifts each mover by $\frac{1}{2}\xi$, a total shift of 1ξ . The added F_1 in the right mover is shared with the left mover, adding $0.5F_1$ to both internal tensions.



In Fig. (e), the control point in Fig. (d) is subject to an external force $F_{\text{ext}} = -2F_1$ (directed left). A new steady position is reached, with a step of 1ξ to the left from the position in Fig. (d). Internal tensions in Fig. (e) include a jump of $2F_1$ across the control point. Together, the movers pull to the right with a net force of $2F_1$ that balances the external force.

Suppose that the control point is held at a certain position and certain drive signals are applied and then the control point is released. The control point does not move when it is in the unique steady position produced by such drive signals. Otherwise, the control point will move to that unique steady position. In this project, movements are slow, with negligible momentum.

Certain features of movers resemble those of a simple "spring" or harmonic oscillator (SHO) that is described by Hooke's Law $F = -k \times \Delta x$. For example, both operate with linear balancing forces. Differences include: movers dissipate energy while a simple spring conserves energy; movers produce zero forces at multiple positions while a spring produces a zero force only at a single position; springs both push and pull while movers only pull.

Previous examples are readily extended to a set of steady positions (with no external forces) that are arranged around midline and that are identified by the drive signals that produce them: (5,1) at 2ξ left of midline; (5,2) at $1\frac{1}{2}\xi$ left of midline, (5,3) at 1ξ left of midline, (5,4) at $\frac{1}{2}\xi$ left of midline, (5,5) at midline — and mirror positions for drive signals (4,5), (3,5), (2,5) and (1,5).

A similar set of steady positions is produced by the circular version. A shift of $\frac{1}{2}\xi$ in the linear version corresponds to a shift of 15° in the circular version. With the same set of drive signals as those in the linear version, steady positions in the circular version make up a set of deflections from midline: $\{0^\circ, 15^\circ, 30^\circ, 45^\circ, 60^\circ\}$.

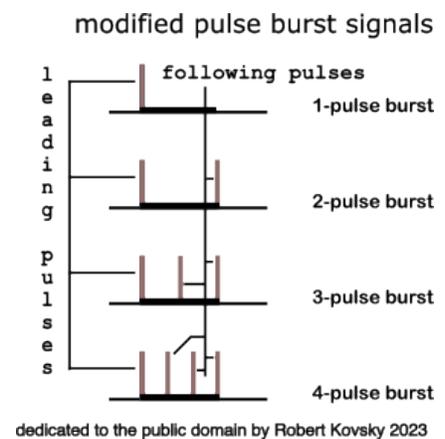
The foregoing opposing movers model has parallels with the primal model, chiefly in duplicates of held positions. The opposing movers model produces extreme positions (e.g., using drive signals (5,1)) that do not appear in the primal model. Chief differences between the two models involve drive signals. In the primal model, drive signals (1,1) produce the midline position. In the opposing movers model, at least (3,3) is needed to produce the midline position and drive signals (1,1) have no use.

To change the opposing movers model into the primal model, modifications are incorporated in both mover design and drive signals. First, the modified mover produces two kinds of forces: (1) **tonic forces** that are the same for every twitch and (2) variable **phasic forces** that are set by pulse bursts. Processes of force production are otherwise the same for the two kinds of forces. The total force produced by the mover is the sum of the tonic and phasic forces.

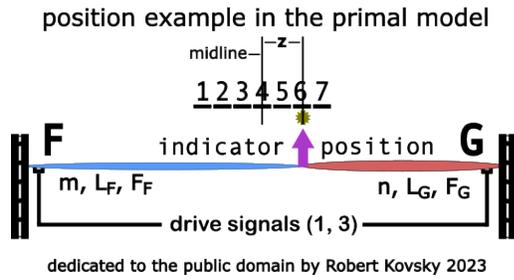
For designs in this project, the tonic force is $4F_1$. A mover can produce as much as $7F_1$, with $3F_1$ as the maximum phasic force. That is, for these movers, the $n \times F_1$ term in Formula (1) is in the set $\{4 \times F_1, 5 \times F_1, 6 \times F_1, 7 \times F_1\}$. Positions produced by modified movers are like those produced by prior movers.

Next: in modified drive signals, the **leading pulse** in a pulse burst is the first pulse. The leading pulse performs timing functions, e.g., starting a device. Additional pulses, if any, are called **following pulses** and make up the content of the burst. Chiefly, following pulses add phasic forces of 1, 2 or 3 F_1 to the tonic force of $4F_1$ in the next upcoming twitch.

Let $k \times F_1$ denote the tonic force. Then, disregarding the leading pulse, $(n - 1) \times F_1$ denotes the phasic force. If $k = 4$, the force produced by a full-length mover ($\Delta L = 0$) is $F = (k + n - 1) \times F_1 = (3 + n) \times F_1$.



An exemplary position in the primal model illustrates the foregoing principles.



Mover F on the left is driven by signal m , has a momentary length L_F and produces a momentary force or tension F_F . Mover G on the right is driven by signal n , has a momentary length L_G and a momentary force F_G . **Position vector** z denotes the momentary distance from midline to the position indicator.

Recall Formula (1) for the previously-discussed mover with tonic force $4F_1$.

$F_G = (3+n) \times F_1 - j \times \Delta L_G$ and $n = 3$. A similar expression holds for F_F and $m=1$.

Also, for both movers: $\Delta L = L_0 - L$ and $L_0 = 9\xi$. As before, $F_1 = j \times \xi$. At the midline position, each mover has a length of 6ξ .

By inspection, $L_F = 6\xi + z$; and $L_G = 6\xi - z$.

$\Delta L_F = 9\xi - (6\xi + z) = 3\xi - z$; and $\Delta L_G = 3\xi + z$.

At the indicated steady position, $F_F = F_G$, $3+m=4$ and $3+n=6$.

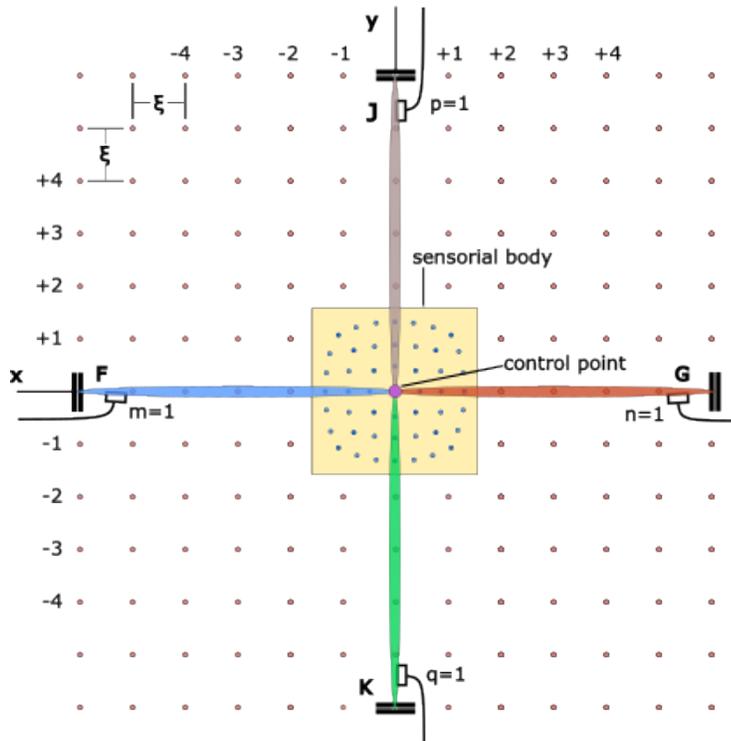
$F_F = 4 \times F_1 - j \times (3\xi - z) = 6 \times F_1 - j \times (3\xi + z) = F_G$.

Hence, $z = \xi$, which means that the indicator position is held steady at 2 steps to the right of midline with a step length of $\frac{1}{2}\xi$.

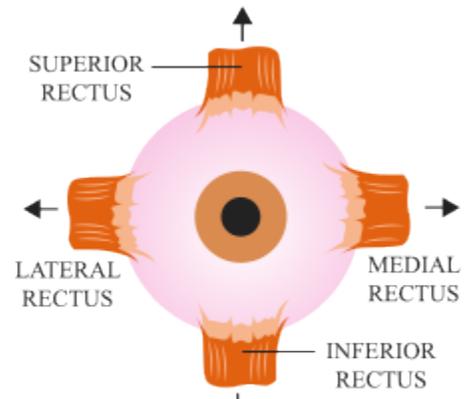
5. Four movers operate in a VE model of gaze-directing movements of eyes.

The primal model is developed into the two-dimensional VE device model shown below, where the "control point" is pulled by movers into a set of positions shown as blue dots. Movements of the model are intended to mimic certain movements of human eyes produced by the "rectus muscles" shown below. Four identical movers (F, G, J and K) correspond to four rectus muscles in the eye. The "sensorial body" of the VE device model resembles a rudimentary retina.

two-dimensional VE device model of reflexive gaze



partial muscle structure of an eye



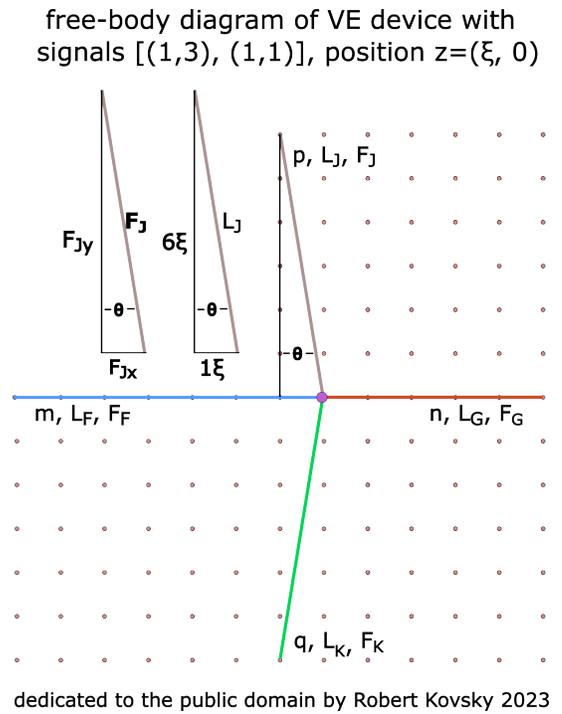
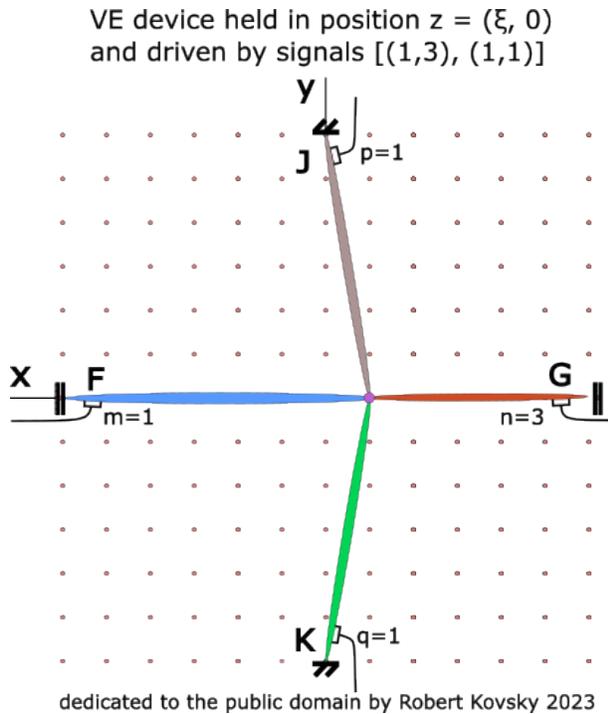
source: www.chegg.com/learn/topic/muscles-of-eyes

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As in the primal model, stimulus of a single specific sensor in the sensorial body causes the control point to move to and hold a position directly corresponding to the location of the sensor. The movement of the model resembles movement of an eye directing the gaze at an object whose image appears on the retina. A spherical version developed from the rotating joint model would more closely resemble an eye. Flat versions are sufficient for purposes here.

The device model is laid out on a grid with a spacing $\frac{1}{2}\xi$ between grid points that are referenced to "x" and "y" axes, where $\xi = F_1/j$, based on specifications of movers. Slightly transparent movers in the figure disclose points of reference. The sensorial body is attached to the grid. Drive signals for the model take the form $[(m,n), (p,q)]$ where m denotes the drive signal to mover F; n the drive signal to mover G; p the drive signal to mover J; and q the drive signal to mover K.

Methods used for two opposing movers are extended to calculate steady positions of the two-dimensional model. If the control point is held by external forces at a specific position and specific drive signals are applied, the steady position is the unique position where the control point does not move when released. A position vector $z = (x, y)$ is referenced to the grid. In the example below, the control point is held at position $z = (\xi, 0)$. Drive signals are $[(1,3), (1,1)]$. At this position, F and G are in balance while J and K produce substantial forces to the left.



Principles of Statics taught in engineering lead to a "free-body diagram" in which forces correspond to line segments in triangles, as shown above. In the diagram, a mover is described by its drive signal (m, n, p or q), its length L , its force F and the angle θ it makes with the x-axis or y-axis.

In insets in the free-body diagram, the spatial triangle defined by $L_J, 1\xi$ and 6ξ corresponds to force F_J along mover J and its x and y force components, F_{Jx} and F_{Jy} . With the forces shown, F_y components of F_J and F_K are in opposite directions and in balance, with J pulling up and K pulling down. The F_x components of F_J and F_K are additive, each pulling the control point towards the left.

In calculating the net force to the left, the angle θ plays the central role:
 $\theta = \arctan(1\xi/6\xi) = 9.462^\circ$. $L_J = 6\xi/\cos(\theta) = 6.083\times\xi$. (This is also $\sqrt{37}\times\xi$, applying the Pythagorean theorem.) Hence $F_J = 4F_1 - j\times(9\xi - 6.083\xi) = 1.083F_1$.
 $F_{Jx} = F_J\times\sin(\theta) = .178\times F_1$, pulling to the left. F_{Kx} is the same, totaling $.356F_1$ pulling to the left.

Trial-and-error investigations lead to the position vector $z = (0.85\xi, 0)$. In this position, $\theta = 8.063^\circ$, $L_J = 6.060\xi$ and $F_J = 1.060F_1$. Hence $F_{Jx} = F_J \times \sin(\theta) = .149F_1$. F_{Jx} and F_{Kx} pull with a net force $.298F_1$ towards the left.

F_G and F_F produce a net pull towards the right:

$$F_G - F_F = [6F_1 - j \times (9\xi - 5.15\xi)] - [4F_1 - j \times (9\xi - 6.85\xi)] = .300F_1.$$

The imbalance in $F_G - F_F$ almost exactly counters the pulls from F_J and F_K . Hence $z = (0.85\xi, 0)$ is close to the steady position of the two-dimensional VE device model when it is operating with drive signals $[(1,3), (1,1)]$.

Along the x-axis:

Drive signals $[(1,2), (1,1)]$ produce a steady position close to $z = (.46\xi, 0)$;
 drive signals $[(1,4), (1,1)]$ produce a steady position close to $z = (1.27\xi, 0)$.

Symmetry principles simplify calculation of positions on the diagonal where the position vector has the form $z = (y,y)$. The figure below shows the free-body diagram applicable to the VE device when drive signals are $[(1,3), (3,1)]$. In this position, movers F and K have equal drive signals, equal lengths and equal forces; $\theta_F = \theta_K$. Likewise, as to movers J and G, $p = n$, $L_J = L_G$, $F_J = F_G$ and $\theta_J = \theta_G$.

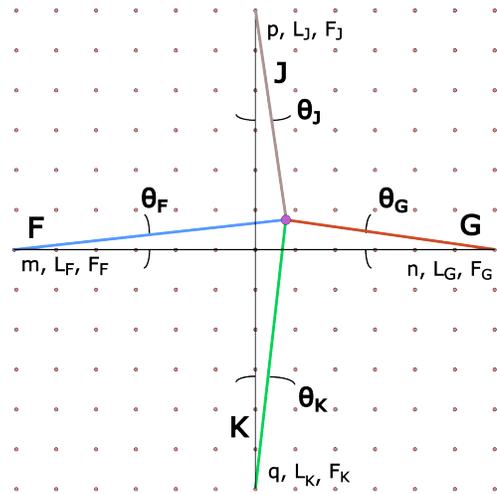
The position in the adjacent figure $[z = (0.75\xi, 0.75\xi)]$ is close to the steady position produced by the device with drive signals $[(1,3), (3,1)]$.

The other positions on the diagonal are:

drive signals $[(1,2), (2,1)]$;
 position z close to $(0.38\xi, 0.38\xi)$.

drive signals $[(1,4), (4,1)]$;
 position z close to $(1.03\xi, 1.03\xi)$.

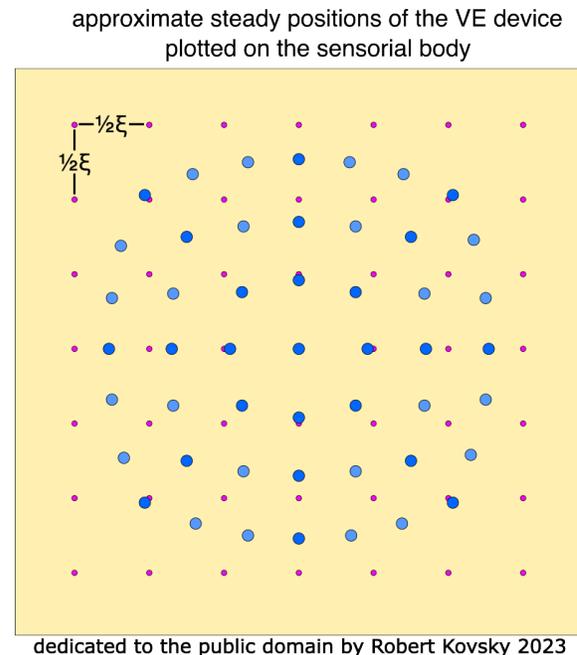
free-body diagram when drive signals are $[(1,3), (3,1)]$ and position is $z = (0.75\xi, 0.75\xi)$



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The adjacent figure shows all 49 steady positions produced by the 2-dimensional VE device model, plotted on the same grid as before.

Markers with the darker blue color lie along axes and diagonals on positions calculated above. The lighter blue color indicates approximated positions.



A new stage of development now commences that focuses on the *sensorial body* of the device model. In this approach, certain *material properties* are imputed to the sensorial body. For example, a whole sensorial body might maintain either-or conditions of "off" and "on" and might be easily switched between "off" and "on."

Another example is *entrainment* or physical synchronization of ticking.

Entrainment occurs in unison ticking of identical mechanical clocks that are standing together on a table. A foundation for entrainment is imputed to the table and can also be imputed to repetitively pulsing bodies that contain VE devices. As developed below, synchronization of individual VE devices in a collective quadnet device is based on such bodily entrainments.

Another material property called *migration* is imputed to the sensorial body of the two-dimensional device model of reflexive gaze. During migration, a sensor in the sensorial body moves inside the body to a location that corresponds directly to the position of the control point that the sensor stimulates.

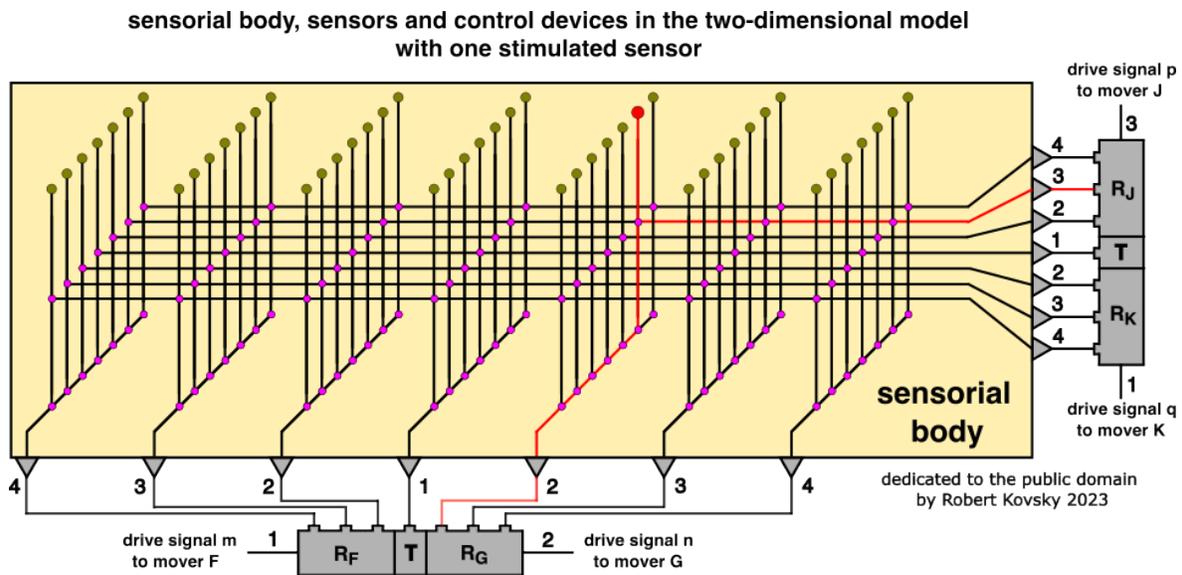
Positions produced by movers are definitive; migrating sensors adjust locations to mark those positions. If one mover should slightly weaken so as to change the steady positions, affected sensors will migrate to new locations. Presumptively, the range of migration is limited, e.g., to one ξ from the original location.

It might be imagined that, before use, sensors are plotted on square grid points with spacings of $\frac{1}{2}\xi$, like grids shown in the figures. Then, during a "break-in period," each sensor migrates to a location directly corresponding to the mover position produced on stimulation of that sensor.

The figure below shows the sensors, VE distribution network and control devices in the sensorial body of the two-dimensional model. In operation (as shown), a stimulus at a sensor (top layer of dots) is converted into drive signals for F-G and J-K movers that position the control point at that sensor. To simplify the design, sensors are shown at locations on a square grid rather than according to previously shown mover positions. Such locations are presumptively adjustable.

New control devices are shown as numbered triangles along edges of the sensorial body. These *timing devices* send pulse burst signals to the burster modules. The number next to a timing device denotes the number of pulses in a burst. During operations, timing devices are ready and waiting, needing only the arrival of VE to trigger the discharge of a pulse burst signal to the targeted burster.

Operations of the peripheral timing devices and burster modules of the two systems (F-G and J-K) are (1) independent of each other and (2) employ identical designs, except for some labels. Burster modules and drive signals are the same as in the primal model.



Inside the sensorial body, lines represent a new material property called *channels*. Channels in a body carry flows of Virtual Energy that are similar to flows of VE in projections between devices, e.g., flows are instantaneous and are maintained by the body without loss. Here, flows start at sensors and end up at timing devices. Channels have a feature that projections lack, namely, VE from multiple channels can flow into a common channel. In a projection, VE moves in an integral number of uniform pulses; in a channel, VE moves in a range of quantities.

A capacity for maintaining flows of VE in networks of channels is imputed to the sensorial body. Small devices (pink dots in the figure) generate a VE flow in a horizontal channel when there is a flow in a vertical channel; these devices have

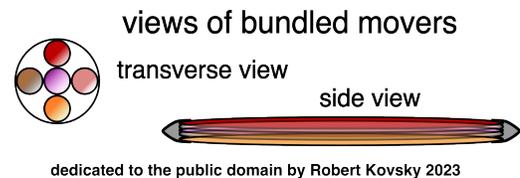
independent sources of VE and thus maintain desired F-G and J-K flows. Absent such a device, channels that appear to cross in the figure are not connected.

6. Bundled movers produce denser repertoires of movements.

In this project, a ***bundled mover*** is made of ***five identical sub-movers***. Each sub-mover has an elemental force of $0.2F_1$. Other than the smaller elemental force, sub-movers operate the same as the original steady movers. Sub-movers are driven synchronously by independent drive signals from separate bursters.

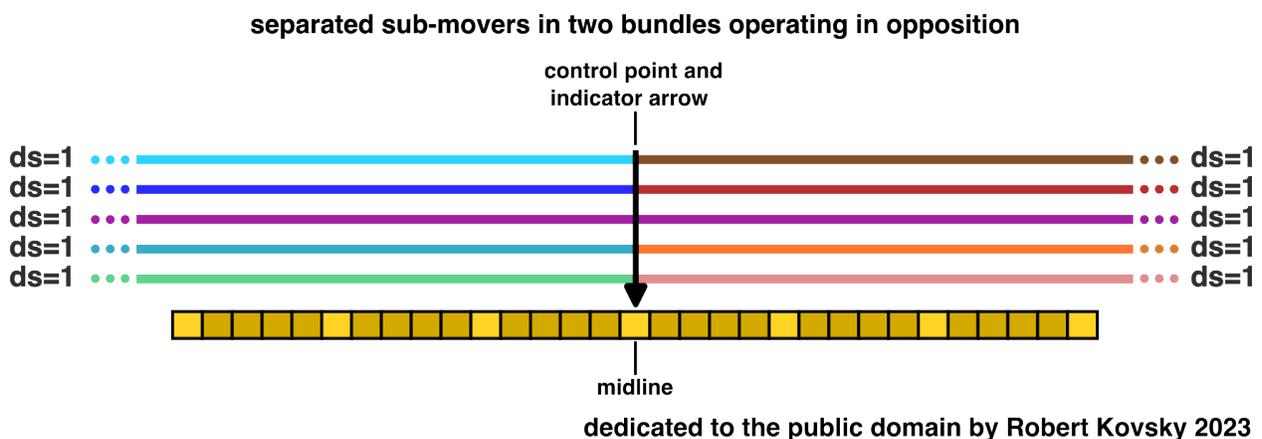
When sub-movers in a bundled mover are driven with different drive signals, the sum of forces may have an intermediate force value (between two prior force values); and then the control point moves to an intermediate position.

The figure shows a "transverse view" of a bundled mover: a central purple sub-mover and four peripheral sub-movers. As shown in the "side view," sub-movers join at two terminal points of attachment to deliver a unified force.

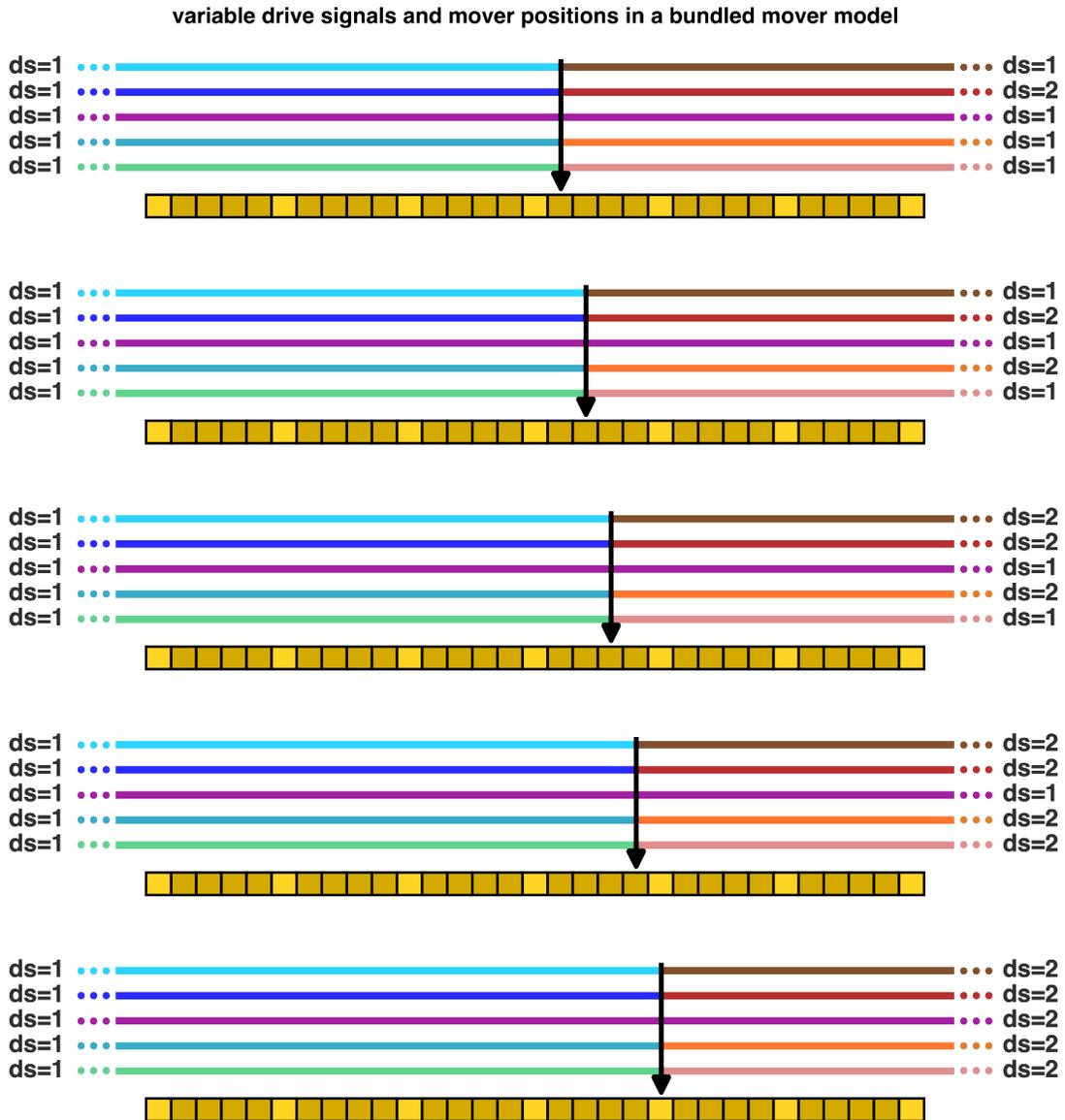


In the figure below, two opposing bundled movers are dis-assembled into sub-movers with separate attachments to the control point and indicator arrow, which is constrained to stand vertically. Each sub-mover has an individual drive signal "ds." The midline position is maintained by drive signals $ds=1$ arriving at all the sub-movers.

The system produces 31 positions, corresponding to 31 sectors in the sensorial body. Seven light-colored sectors are carried over from the primal model. Four dark-colored intermediary sectors divide the space between each successive pair of primal positions.



The figures below show incremental changes in the position of the control point and indicator arrow as individual signals to sub-movers are increased one by one. Incremental signals are applied to the peripheral sub-movers in an orderly progression. The increase in drive signal to the central (purple) sub-mover produces a change in the primal positioning.

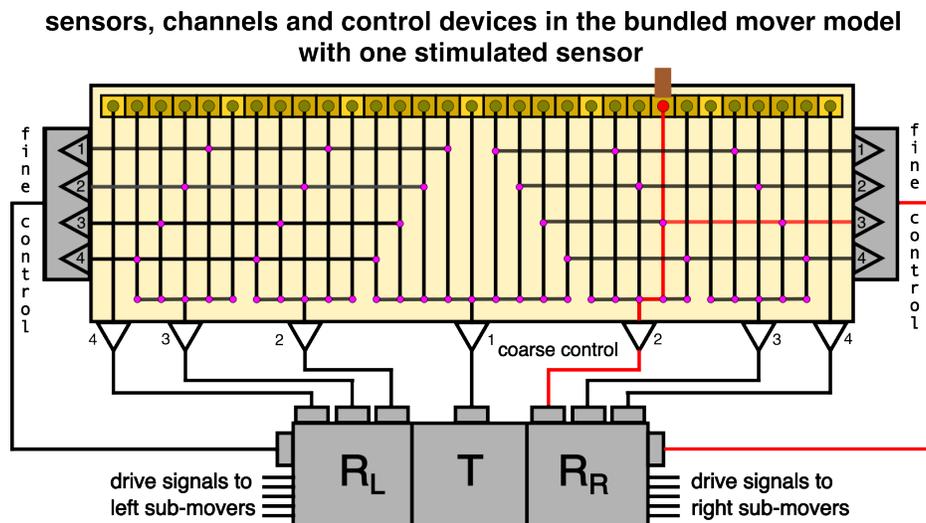


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The figure below shows the channels in the sensorial body of the bundled mover model; these channels are connected so as to direct VE flows to two kinds of timing devices. Pink dots connecting channels are connected to active sources of VE. Sensors, channels and dot devices all operate within the sensorial body, receiving VE through it and subject to its conditions.

One set of timing devices, called "coarse control" devices, operate along the bottom of the sensorial body like the timing devices in the two-dimensional model above. All the sub-movers in a bundle receive the same "coarse control" signal.

The other sets of timing devices operate inside "fine control" modules on the sides of the sensorial body; these timing devices discharge signals inside the module that result in a specific number of sub-movers receiving an incremental signal of one additional pulse. The number of sub-movers to be incrementally increased appears inside the fine control timing device. Fine control timing devices drive a repeating burster that is part of a fine control module; only one signal line is needed to carry that burster's output to a main burster module.

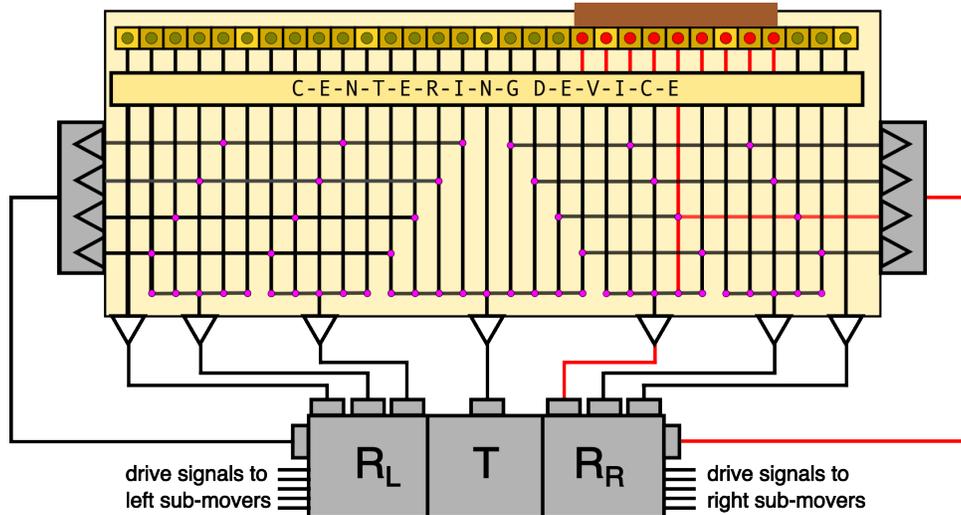


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In the figure, drive signals to the right sub-movers produce an intermediate position between two primal positions. All five right sub-movers receive 2 pulses per cycle while three right sub-movers received an additional pulse. The collective right drive signal is denoted $R_R=2-3$, following the form "coarse-fine." The left collective drive signal $R_L=1-0$. These drive signals hold the control point at the location of the stimulus.

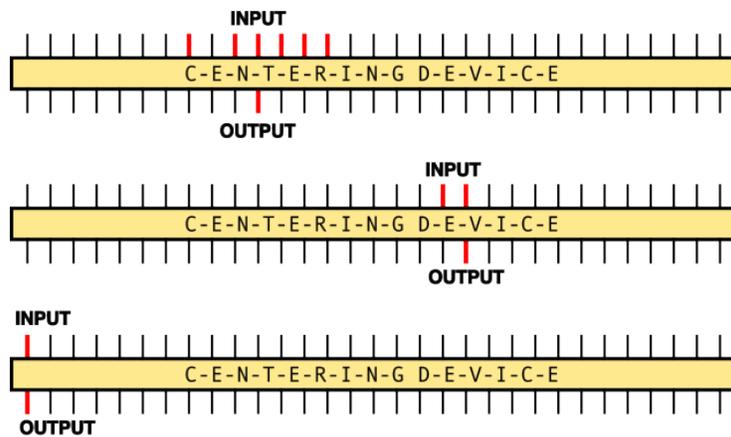
An important restriction on designs up to this point is the operating principle that a stimulus must activate exactly one sensor. There is no capacity for responding to stimulation of multiple sensors. Activation of many sensors by an extended stimulus is shown below, where a "centering device" operates between a bloc of stimulated sensors and the VE channel network. The centering device generates a VE flow in a single vertical channel leading to appropriate drive signals to sub-movers ($R_L=1-0$; $R_R=2-3$) that position the control point near the center of the bloc.

sensors, channels and control devices in the bundled mover model with centering of an extended stimulus



Operations of the centering device require an input with a nearly continuous bloc of stimulated sensors — a single group with no gap larger than a single sensory channel. With such an input, the output appears on a single channel that is at or near the center of the stimulated bloc. Examples below illustrate operations of the centering device. Detailed designs for centering devices are to be included in the formal VE model.

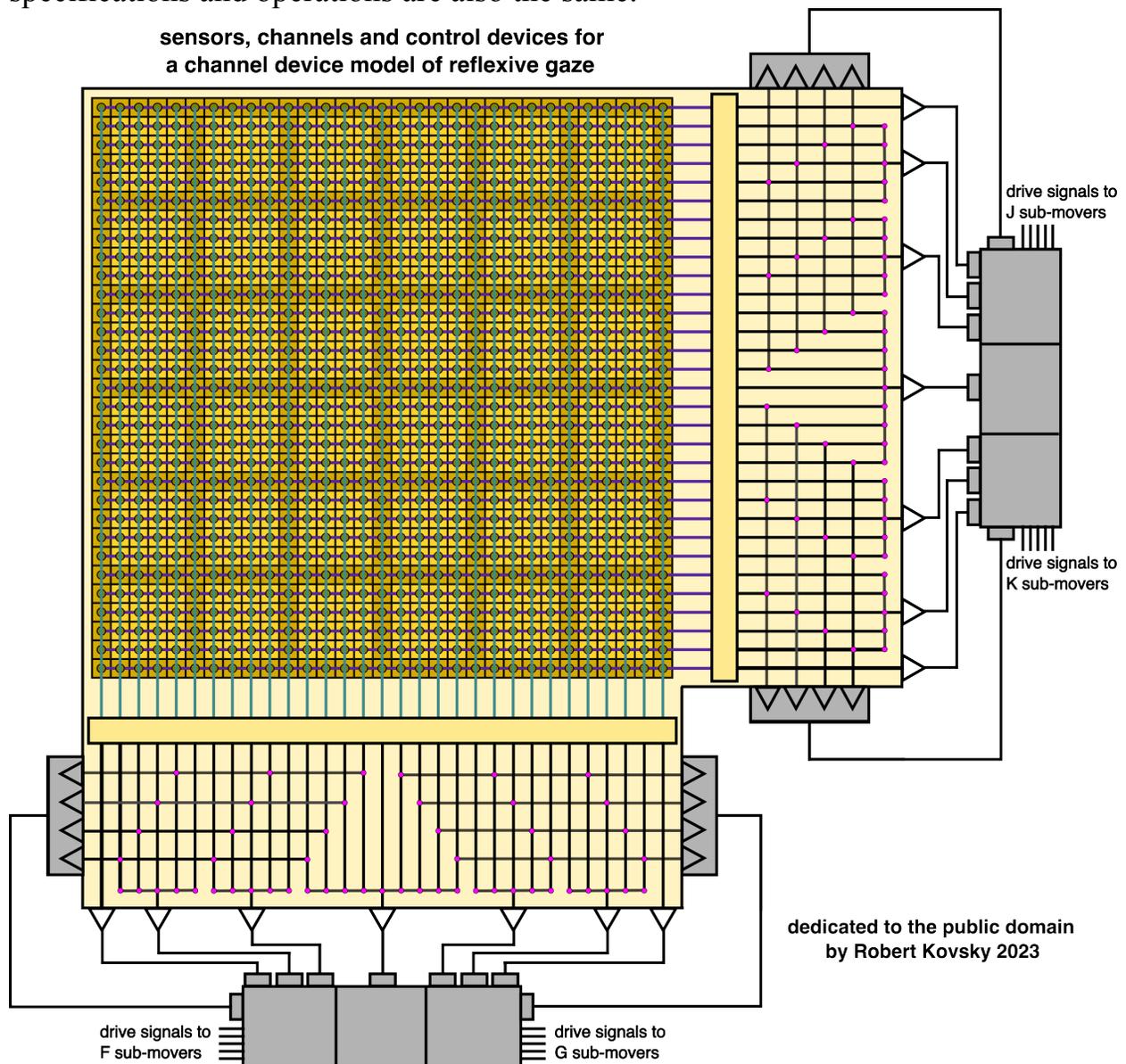
centering device: examples of input-output relations



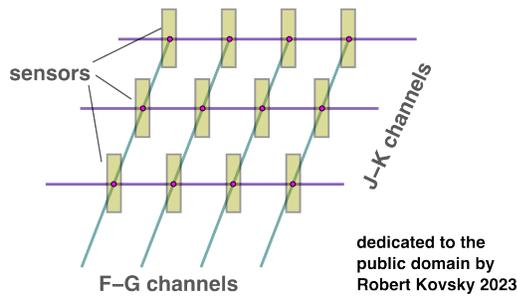
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The bundled mover model with centering is readily extended to two dimensions, leading to the *channel device model* of reflexive gaze shown below. This design is used to drive the movements of F-G-J-K movers and sub-movers shown above in § 1 and constructed in §§ 5 and 6.

A centering device, channel network and repeating burster module are connected to the bottom edge of the sensorial device bloc; these control F and G sub-movers. Corresponding devices are connected to the right edge of the device bloc and control J and K sub-movers. Operations and movements of the two control systems are independent of each other. The two control systems have the same internal devices and connections as those in the bundled mover model. Device specifications and operations are also the same.



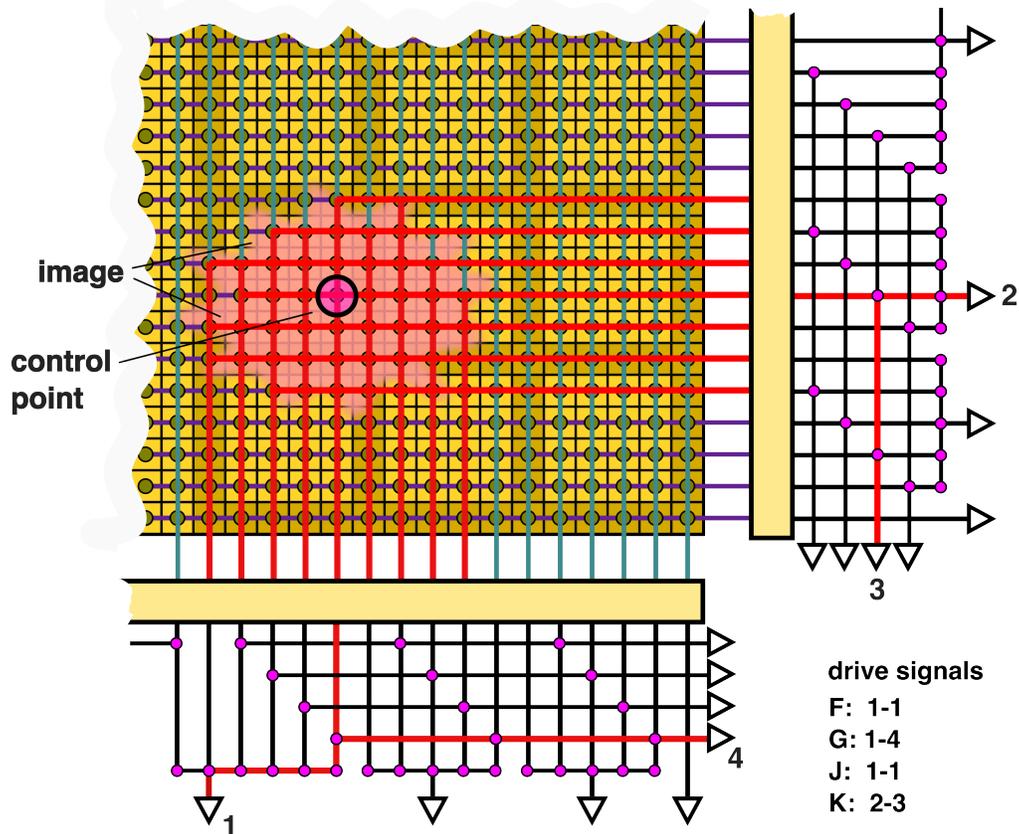
sensors and channels of the channel device model in an expanded view



The adjacent figure provides a close-up view of operational elements inside the sensorial body of the channel device model of reflexive gaze. While the system is in a steady position and without stimulation, each sensor has a source of VE that is not active but is ready and waiting. When a sensor is stimulated, it discharges VE into both the F-G channel and the J-K channel specific to that sensor.

The figure below shows an expanded view of one quadrant of the sensorial body and VE networks of the channel device model while processing the image from § 1. The image stimulates sensors, which discharge VE into channels that are colored red. After centering, resulting drive signals are: F=1-1; G=1-4; J=1-1; K=2-3. These signals move the control point to a position close to the center of the image.

expanded, partial view of the channel device model converting an image into drive signals for movers

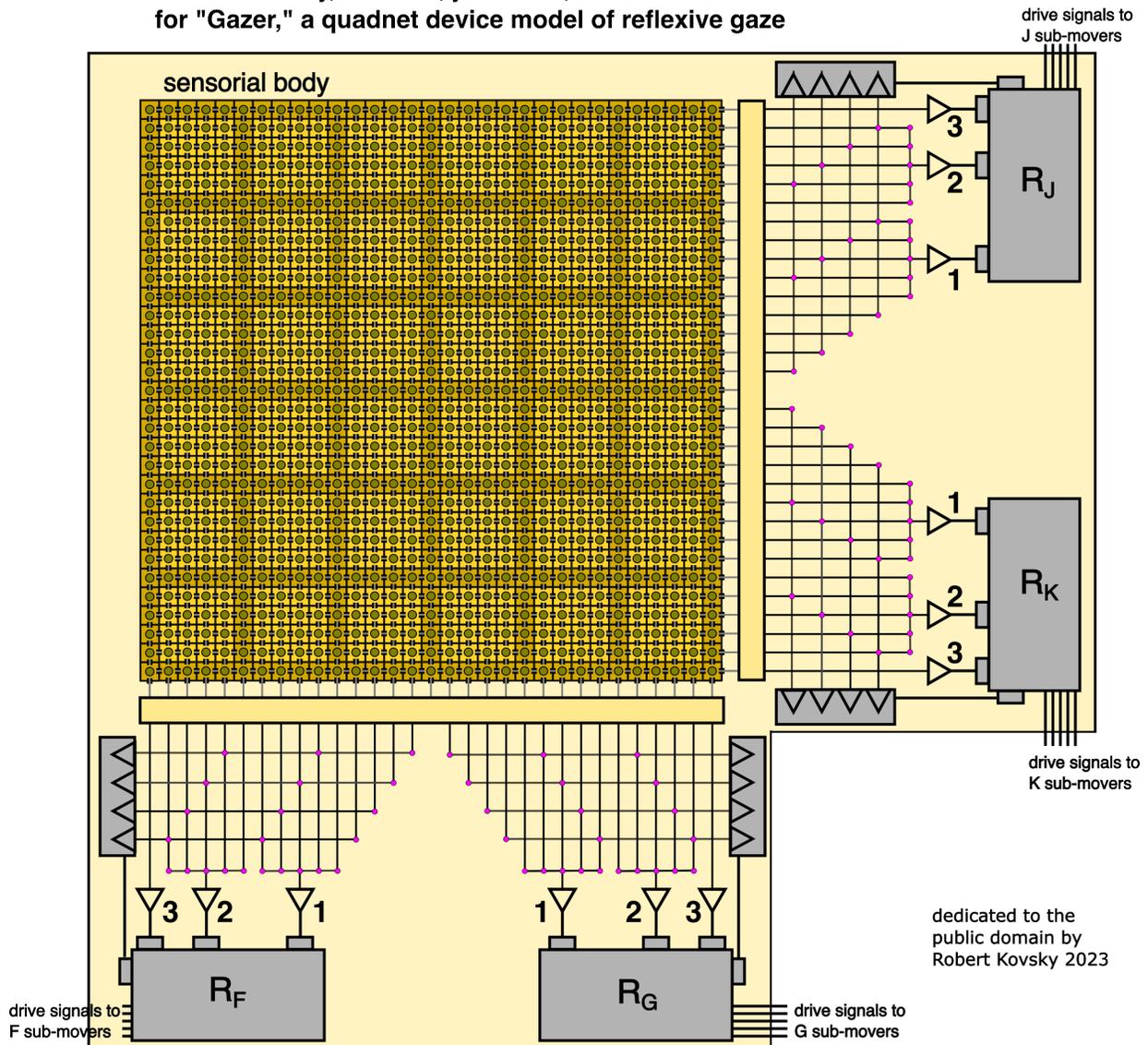


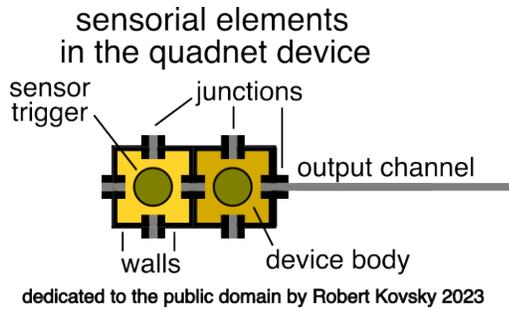
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- In a fast simple design, a quadnet device in a sensorial body controls movements of a reflexive-gaze model.

The figure below shows the final Gazer model. Like the prior channel device model, it converts a compact image that stimulates sensors into drive signals for the mover system such that the control point is moved to and held at a position close to the center of the image. It differs from the channel device model in that operations are faster and simpler. A collective *quadnet device* operates inside the sensorial body and incorporates all the sensory elements. Timing functions are relocated to the enlarged sensorial body, which generates an ongoing beat that entrains devices. In other changes, burst signals are simplified by omission of leading pulses, which controlled timing in prior models. Pulse bursts in the coarse control set have 1, 2 or 3 pulses. Operations of fine controls are unchanged.

**sensorial body, sensors, junctions, channels and control devices
for "Gazer," a quadnet device model of reflexive gaze**





The adjacent figure shows sensorial elements of the quadnet device, which is an array of 961 sensorial elements. Internal *junctions* between elemental devices replace the continuous channels of the prior model. At the terminus, a junction directs a VE flow into an output channel in the control network.

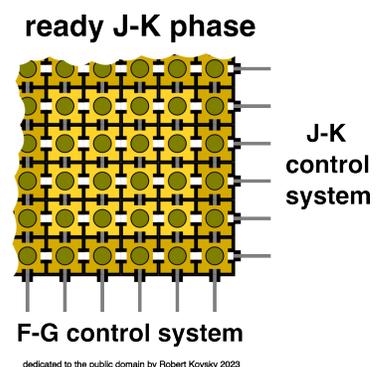
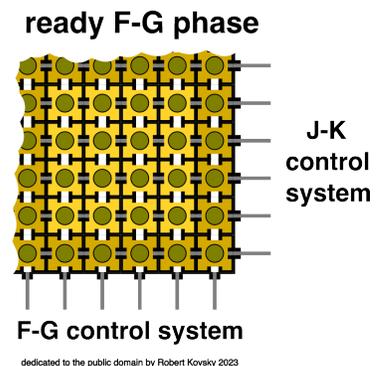
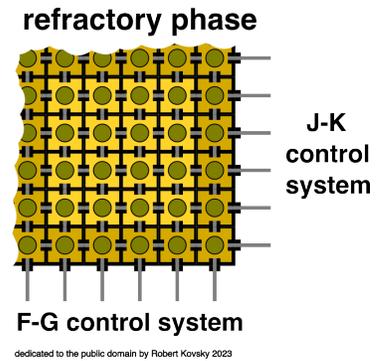
The whole-body quadnet device operates cyclically and sensorial elements collectively pass through a series of conditions or *phases*. In this context, the word "phase" denotes a whole-body condition. At each moment, the body is in exactly one phase. Changes occur abruptly. The cycle has four steps and three phases: (1) F-G phase; (2) refractory phase; (3) J-K phase; and (4) refractory phase.

During the refractory phase, all the junctions are *closed*; no VE passes through a closed junction. Sensory elements are resting.

The quadnet cycle inserts a refractory phase between two active phases. Any depleted VE is restored during a refractory phase.

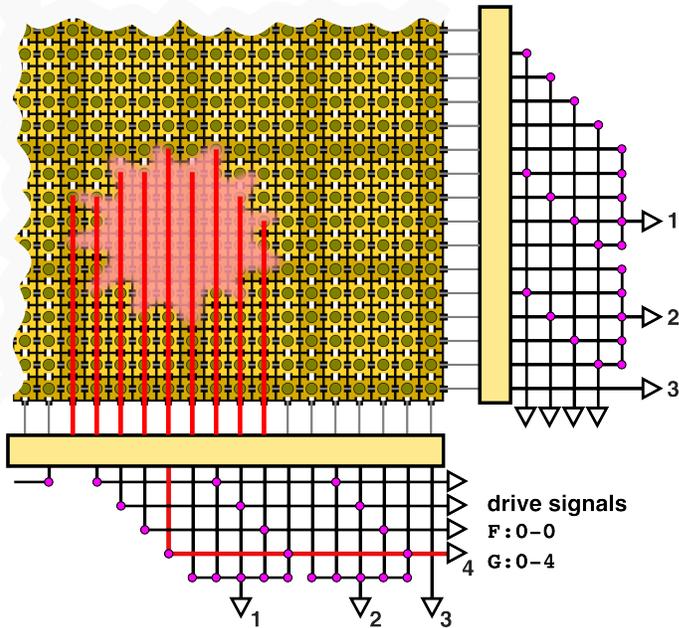
The adjacent figure shows sensory devices in an F-G phase that is ready but not stimulated. Half the junctions are open, making up internal passages for VE that are equivalent to channels and that can direct VE into channels of the F-G control system at the periphery of the quadnet device.

The adjacent figure shows sensory devices in a ready J-K phase, in which open junctions can direct VE into channels of the J-K control system.



In the figures below, the visible image from prior figures has appeared on the sensorial body, stimulating a compact set of sensors in the quadnet device.

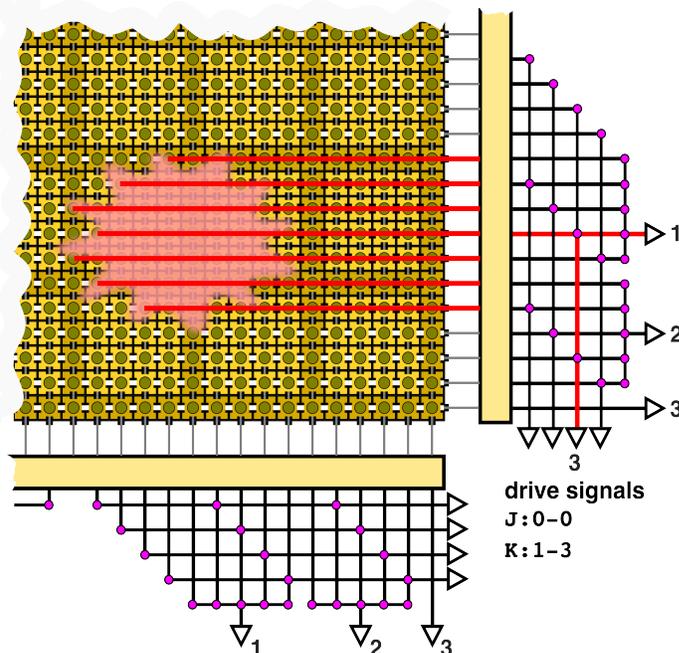
active F-G phase of the Gazer model while it is converting an image into drive signals for movers



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During an active F-G phase, stimulated sensors discharge VE that passes through columns of open junctions into channels of the control system. Only F-G channels are involved. Flows in junctions lead to F and G drive signals, which differ in value from those in the channel device model but which lead to the same resulting movements.

active J-K phase of the Gazer model while it is converting an image into drive signals for movers



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The adjacent figure shows an active J-K phase similar to the prior F-G phase, with the same visible image. In this phase, rows of open junctions direct VE into J-K channels.

It is necessary to isolate the two phases from each other. If all the junctions were open at one time, VE would spread out, even to the edges of the quadnet device; and the resulting gaze would probably not be directed at the object.

The quadnet device model has one mode of operation called *streaming*, in which signals from sensors pass through stages of conversion, resulting in drive signals that are sent to movers. Driven by the beat generated in the sensorial body, the model operates continually; if no image appears, all drive signals have the form 0-0 and the control point is maintained at the central location.

In contrast, the channel device model (like the Wiggler design) has two modes of operation, called *holding* and *substitution*. Holding mode operations are maintained in the absence of new sensory signals. When a new sensory signal arrives, operations switch to substitution mode for the next cycle. If no additional sensory signal arrives, operations revert to holding mode. If an additional sensory signal arrives, substitution can continue. If a continuous stream of signals is provided, substitution mode in the channel device model resembles streaming mode in the quadnet device model, but the channel device model requires intermediary control devices and longer processing times.

The quadnet Gazer model completes the course of construction of this project. Mover constructions are foundational and sensory and control constructions have specific features and operations that depend on the mover system. In later constructions, concepts of VE flow have been developed, starting with pulses in projections, followed by VE flows in channels in sensorial bodies and finishing with VE flows through junctions in a quadnet device.

The quadnet Gazer model aims at distant goals of Shimmering Sensitivity, which also involves a cycle of phase changes in a quadnet device. The Gazer model is suggestive of further developments in that direction. Sensory signals generated in the quadnet device that lead to reflexive gaze can also be connected to different kinds of devices in secondary quadnets. Sensory signals can become more complex, e.g., characterized by a frequency that corresponds to intensity. The secondary quadnets can participate in operations of *image processing*, e.g., comparing two images and detecting "same" and "different." Such developments are anticipated in the formal VE model.

December 2023, amended