DOMAINS OF FREEDOM

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Domains of Investigation — main contents of the website

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B. Contests (sports and games)

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C. Engineered organisms

I. Eyes that look at objects (Gazer)

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2. Constructions start with a primal model of stimulus and response.
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4. VE movers are models of muscles and illustrate the "kit of parts" method.
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 "Gazer" model, operations of a quadnet device in a sensorial body control reflexive visual movements.

Overview: engineered organisms mimic primitive movements of animals

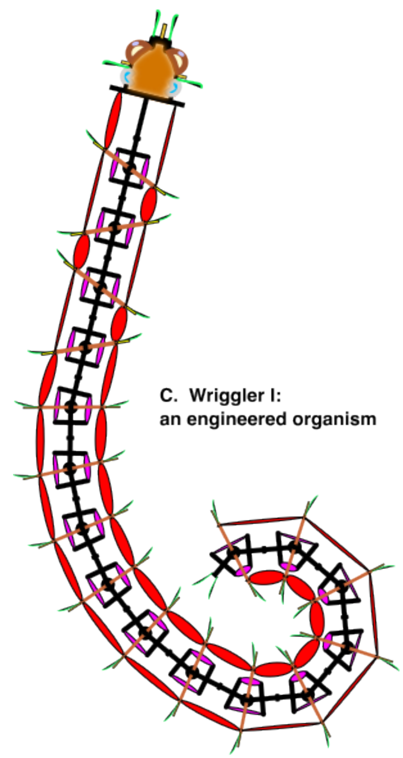
The figure below shows the initial design for an engineered organism "Wriggler I." Movements of engineered organisms aim to resemble movements of animals. In anticipated designs, multiple kinds of movement occur simultaneously. Simultaneous movements are sometimes independent of each other, sometimes coordinated and sometimes synchronized. The body of the organism produces movements spontaneously; movements are driven by scripts in the head; and movements respond to momentary bodily and sensory influences.

Distant goals of construction include engineered organisms that exercise freedom according to the principle of Shimmering Sensitivity, as discussed in the website part B (contests). In anticipated designs, an exercise of freedom involves multiple interconnected layers of activity with processes synchronized so that critical moments occur together in multiple layers in a unified way.

This construction approach begins with the body of an organism, which moves prior to and independently of any brain or mind. In anticipated later stages, brain or mind can intervene and take control, enlarging repertoires of movements.

Reflexes operate in the lowest, foundational layer of construction. A reflex is constituted by a stimulus and a response. Examples include "wiping reflexes" of a headless frog whose limbs target and rub at a drop of acid on the skin. (See website part A, §2). Higher layers lead to itching and scratching that can be controlled by a mind.

Itching and scratching manifest a principle of “location selection.” In this form of action, a stimulus can appear at any location in a sensorial field and trigger responsive movements targeting that location.

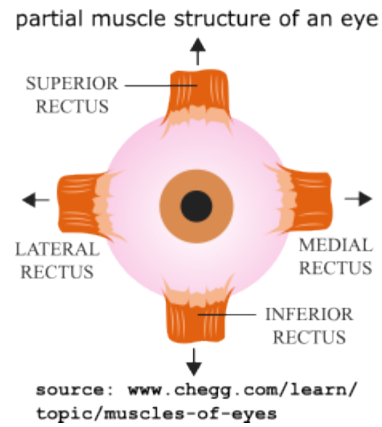


I suggest that when an object appears in the visual field, eyes can reflexively aim their gaze at the object. In other words, eyes look at objects "on their own" prior to processing of images. Objects can be located or mapped in head-centered space by means of the signals that produce reflexive muscular movements of eyes. Such muscle-based mappings may be sufficient to guide the organism in certain movements of approach or avoidance. A spatial foundation defined by reflexive movements supports image-processing functions like memory and recognition.

Eyes that look at objects (Gazer)

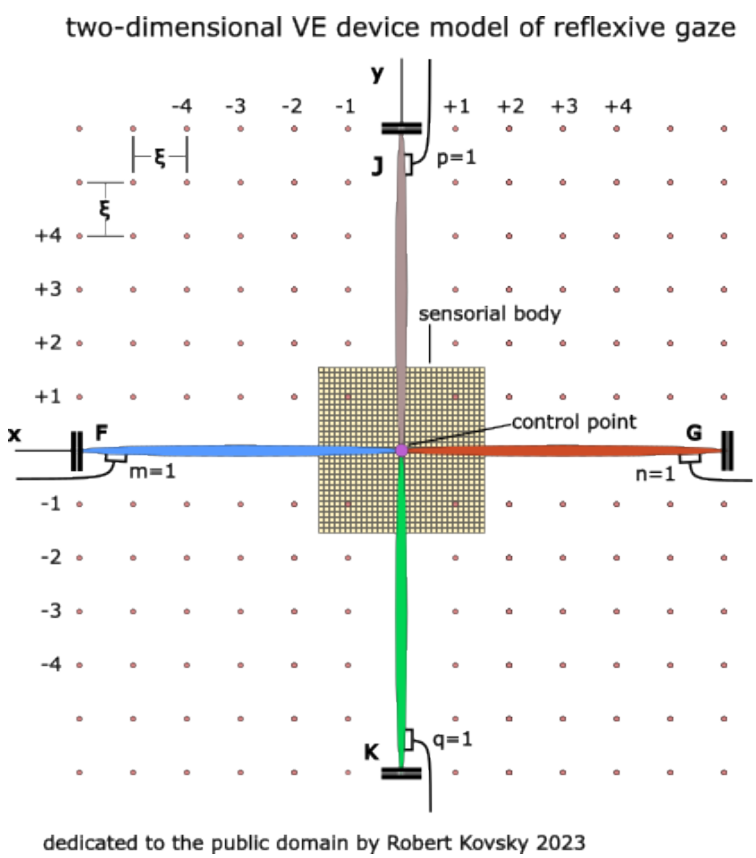
1. This course of construction concludes with Virtual Energy (VE) device models of reflexive gaze.

Constructions proceed step by step and lead to final VE models that demonstrate a principle of "stimulus and response" — the appearance of an object in the visual field is a "stimulus" and the "responses" are eye movements that direct the gaze at that object.

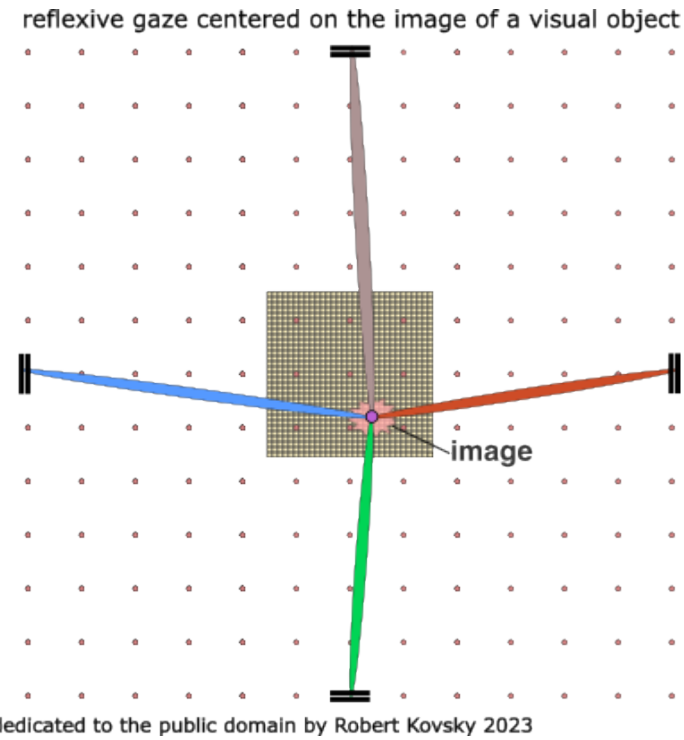


The adjacent figure shows four "rectus" muscles that partially control movements of a human eye, rotating the eyeball to the left or right, or up or down. As a result of such movements, the gaze is aimed in a particular direction, often at an object in the visual field.

In a device model of reflexive gaze shown below, four different-colored "movers" resemble rectus muscles. Labelled **F**, **G**, **J** and **K**, 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.



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 figures incorporate a systematic deformation. In a more accurate version (like one constructed below), sensor elements in the sensorial body would 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.

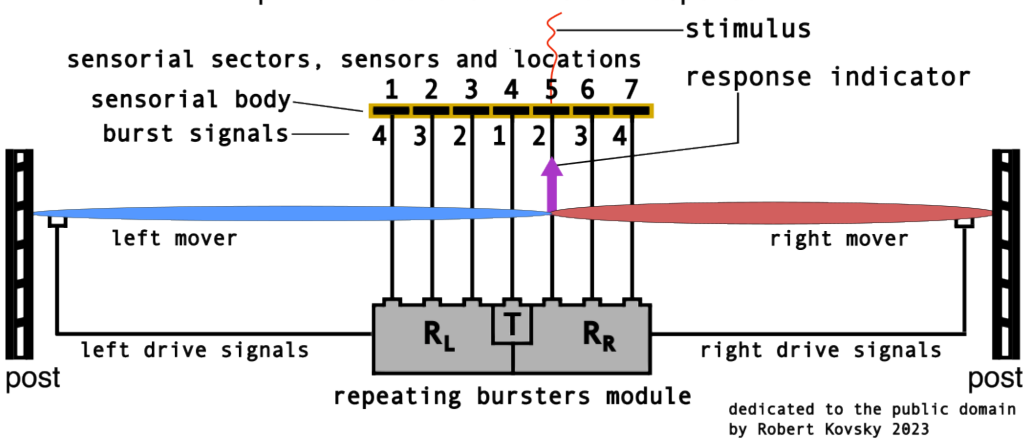
This project proceeds by a series of stages starting with a "primal model." Development of movers occurs during the first stages. Then attention shifts to development of the sensorial body and control devices. These constructions emphasize functions of device parts and modules.

Further constructions are set forth in the companion project: *A formal Virtual Energy model for Gazer device designs*, which includes VE definitions for operations of devices and modules used herein.

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 model produces seven positions/locations.

The "sensorial body" will be developed below into a collective device resembling an integrated circuit in which individual elements in an array are based in a 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 "sensorial sectors" at "locations" numbered "1" through "7." A "stimulus" targets a single sensorial sector and triggers its "sensor" to transmit a "burst signal" to the "repeating bursters module," which produces drive signals.



Inside a mover, multiple ***force fiber devices*** produce forceful ***twitches*** that collectively exert a steady force. Twitches of force fiber devices resemble twitches of muscle fibers in animals. During a twitch, a fiber produces a contractile force. In steady mover designs, multiple overlapping twitches add up to ***steady forces***. Details are set forth in the formal VE model.

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. Several pulses in rapid succession make up a ***pulse burst***. ***Bursters*** in the control module (components labeled "R") generate pulse bursts that are sent as drive signals to movers. In the bursters module, timing of operations is controlled in the component labeled "T." 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

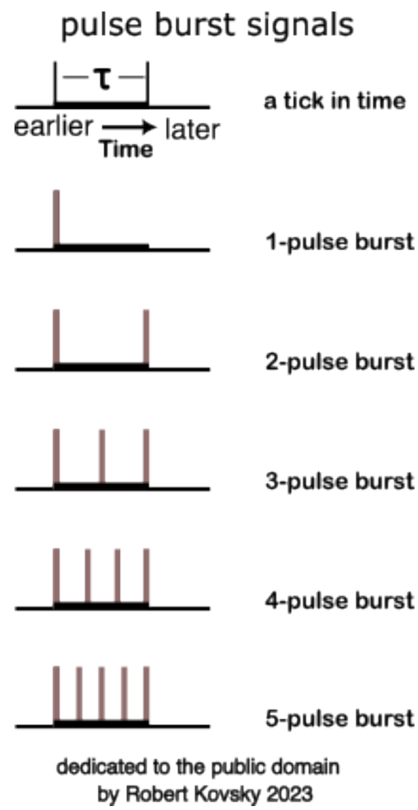
Models of movements and sensations are built from twitches and pulses — and from groups of twitches and pulses.

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

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 feature suited to a particular design, e.g., $\tau = 0.1$ second or $\tau = 0.01$ 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.

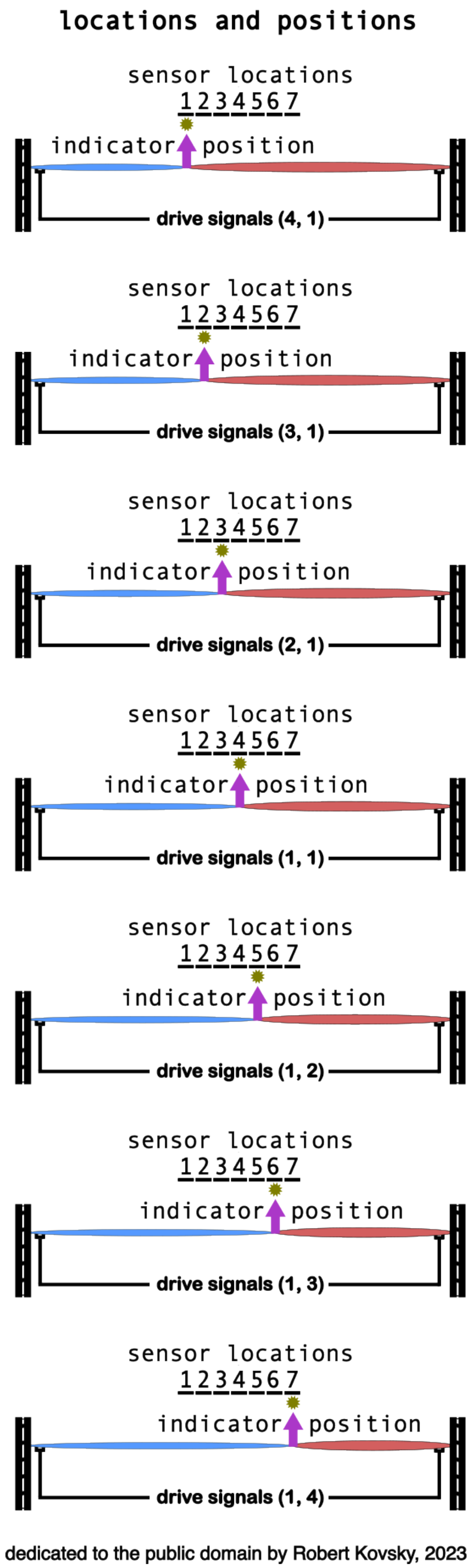
These definitions of pulse bursts are constructed for easy production and handling by devices. The different pulse burst sizes produce different forces in a mover, with more pulses producing a stronger force.



Pulses travel on ***projections*** between VE devices, shown in the primal model (1) as lines for burst signals from sensors to the bursters module and (2) as drive signal lines from bursters to movers. In idealized VE designs, a pulse lasts for only an instant, resembling an idealized electrical impulse. 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.

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 controlled by the Master Clock, devices maintain repetitive action patterns or schemata (plural).

repertoire and elements of the primal model



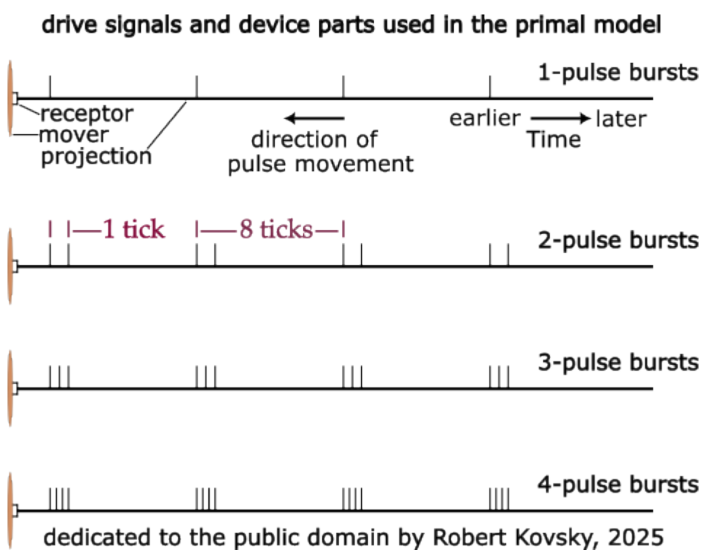
The figures on the left show the sensor locations and indicator positions of the primal model, along with the drive signals that produce the positions. Positions and locations coincide and have a simple one-to-one relationship.

The figures below show drive signals and device parts used in the primal model:

(1) a mover that produces contractile forces;

(2) a projection that carries pulse bursts; and

(3) a receptor that connects the projection to the mover.



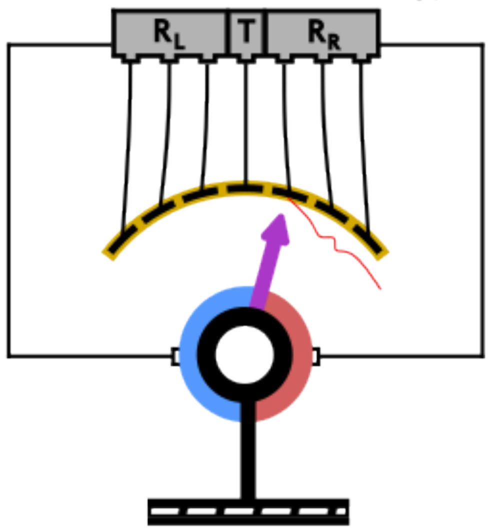
In the figures, pulses travel from right to left. Also shown are ***charts*** of pulse signals: a projection serves as a time line for representation of signals, with "earlier" signals to the left and "later" signals to the right.

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.

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. In the figure, the joint is shown as a black circle wrapped in blue and red movers, which 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°.

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

The figures below show the seven steady positions of the rotating joint version of the primal 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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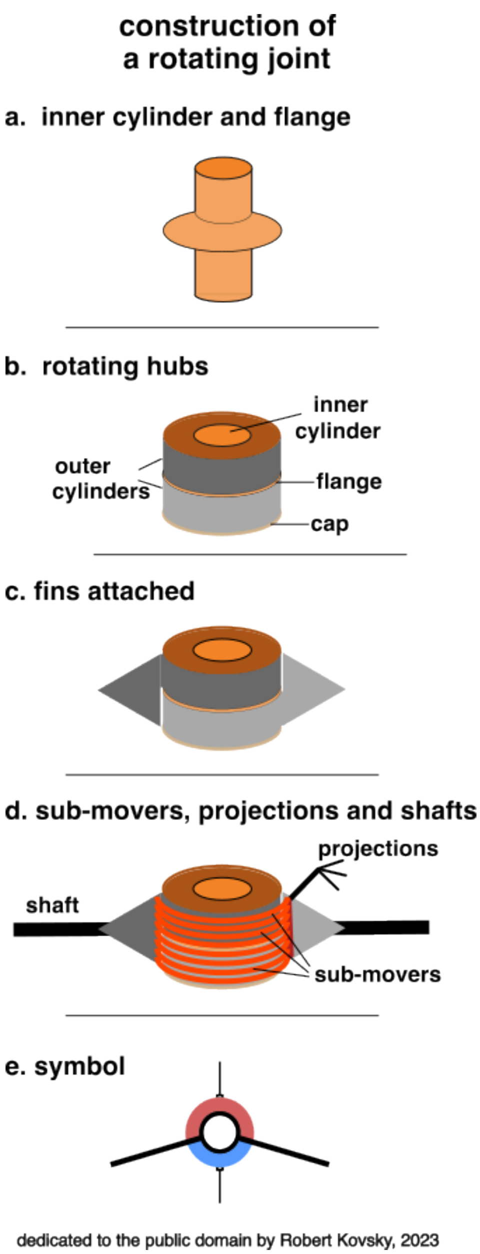
Correspondences between linear and circular models are maintained in subsequent constructions. Thus, two-dimensional (flat) movements constructed later in this project correspond to rotations of a spherical eyeball.

In this approach, a construction starts with a foundation based in permanent 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.



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 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. VE movers are models of muscles and illustrate the "kit of parts" method.

Detailed definitions of movers are part of the formal VE model. For purposes here, a ***steady mover*** is a Virtual Energy force production device that operates according to force equation "Formula (1)" stated below. Initial designs of movers are crude or "coarse." As developed in § 6, ***bundles of sub-movers*** produce "fine" gradations and larger repertoires of steady forces.

Constructions apply a method of "kits of VE parts." To start, VE designs use individual VE devices (parts) that are controlled by pulses on projections. Such parts have defined operating characteristics and features. VE designs resemble electrical circuit designs ("schematic diagrams") made of components selected from "kits of electrical parts." Later investigations focus on VE currents flowing in sensorial bodies (resembling integrated circuits) that contain many device parts.

One basic kit of electrical parts has various kinds of "resistors," 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." A kit of resistors is classified according to certain specifications: (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%). For use in an electrical circuit, a resistor is completely defined by stating its specifications.

The kit of parts of steady movers has the following specifications: hardware features, e.g., structure of attachment points; force equation; schema (action pattern of operations); maximum length L_0; elemental force F_1; and dissipation factor j. In a full design, a mover contains a certain-sized Virtual Energy Store (VES) and specified VE operations, which are set forth in the formal VE model. Such specifications and operations completely define a steady mover, at least until further development.

A kit of steady mover parts would include various elemental forces and various sizes of maximum mover length, perhaps ranging from a fraction of an inch or centimeter to many inches or centimeters. Movers in the kit could, e.g., raise a limb or an eyelid.

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

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

The mover's elemental force F_1 and dissipation factor j are fixed during operations. The ***pulse number n*** refers to a stream of repetitive or steady pulse burst signals: n = 1, 2, 3, 4 or 5.

The momentary length L of a mover changes during operations under the influence of drive signals and external forces. $\Delta L = L_0 - L$ denotes the momentary ***shortening*** of the mover. 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 certain 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

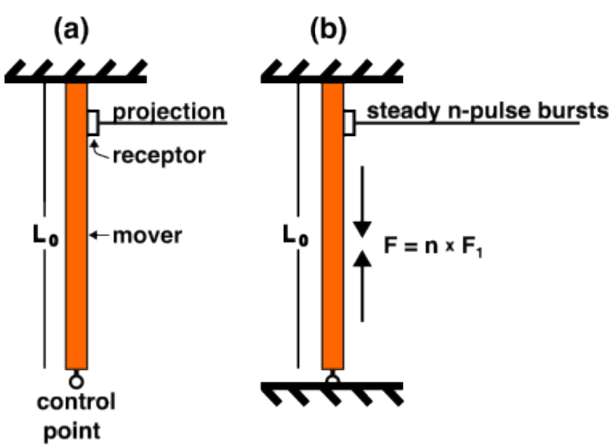


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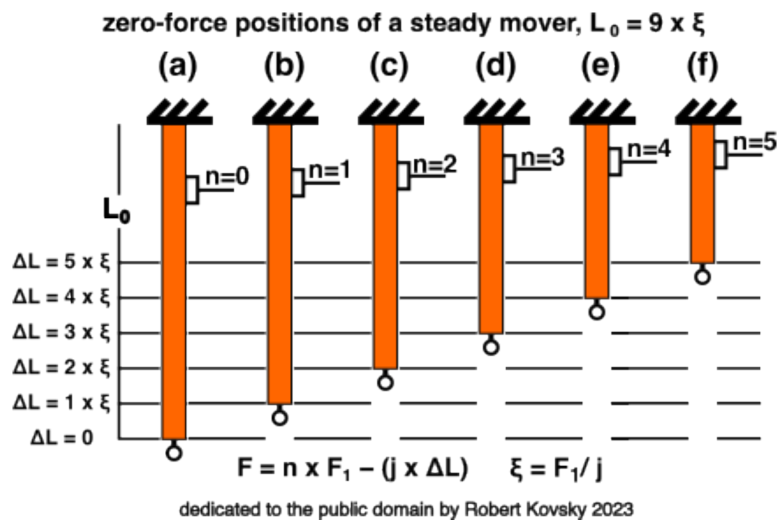
Fig. (a) shows parts of a steady mover in a relaxed condition. The mover is attached to an immovable fixture at the top end while the bottom end has a "control point" that is unattached and stationary. In Fig. (a), there is no drive input, the mover is passive and $L = L_0$.

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 causes production of a steady contractile force. In this arrangement, the set or ***repertoire*** of forces is:
$\{F_1, 2F_1, 3F_1, 4F_1, 5F_1\}$ corresponding to $\{1, 2, 3, 4, 5\}$ pulses in each burst.

The mover in the figures below has a length specification $L_0 = 9\times\xi$ where $\xi = F_1/j$.

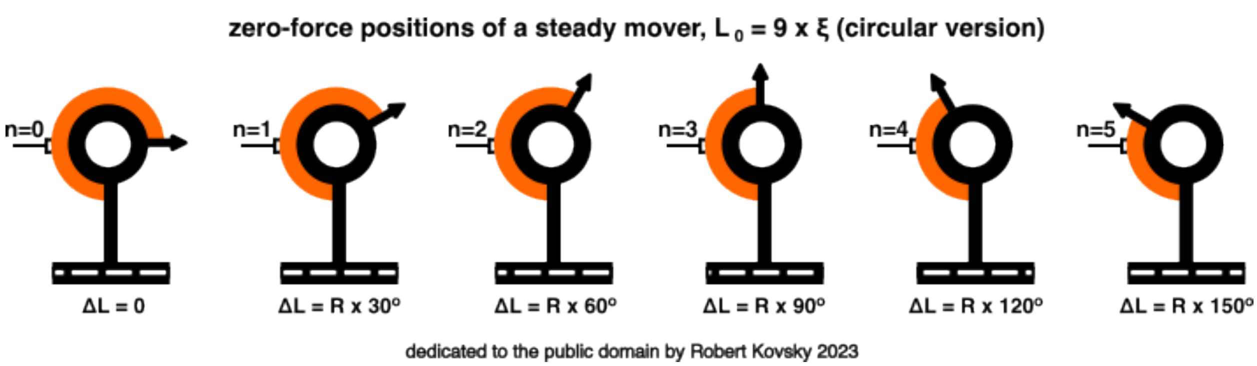
Fig. (a) is the same as the prior Fig. (a); n=0 denotes an absence of a drive signal.

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 F_1 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.



A set or repertoire of steady mover positions defines a space in terms of ξ.

A maximum length $L_0 = 9\times\xi$ is also suitable for circular arrangements. Below, a mover is an arc of a circle with a radius R. The arc of the n=0 mover extends over 270°. $\Delta L = R\times n\times 30°$ 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 a further construction of ***symmetrical 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 a feature of 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.

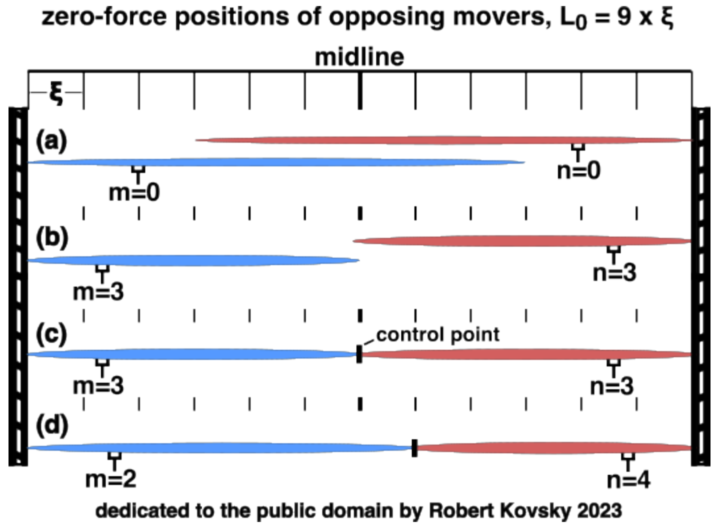


Fig. (d) shows another zero-force position, where m=2 and n=4. The repertoire of zero-force positions in this design is: (m,n) ε {(5,1), (4,2) (3,3), (2,4), 1,5)}.

The figures below show ***tense movers***: an internal tension can impose or oppose an external force. In the figures, external forces 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.)

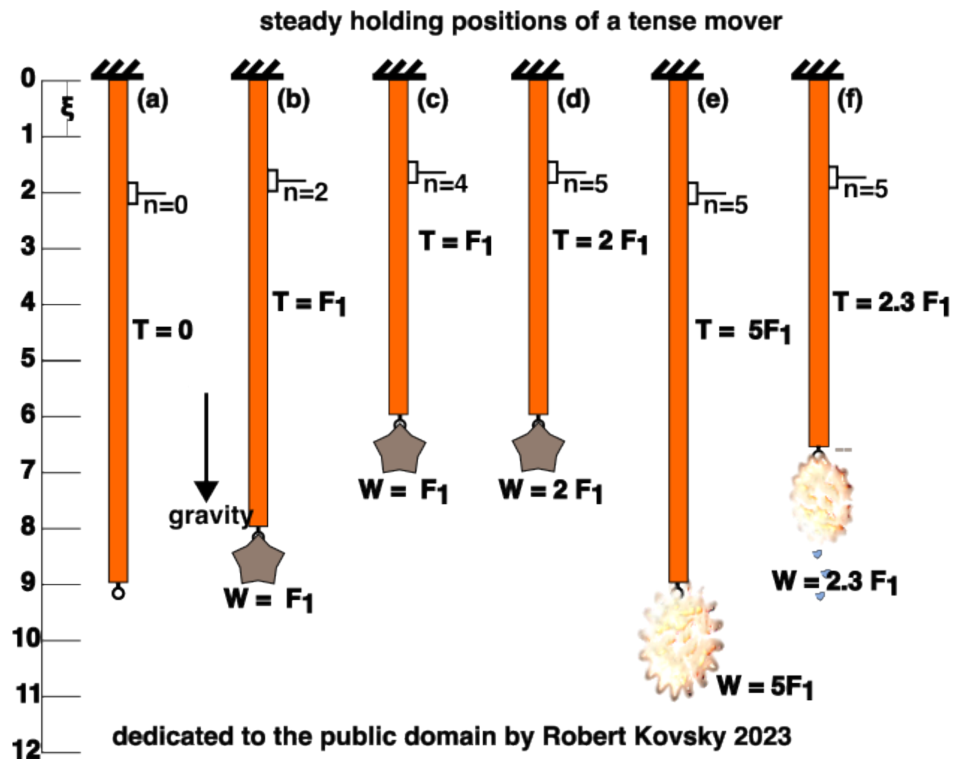


Fig. (a) starts with the prior zero-force position of a single mover with drive signal n = 0. The weight of the mover is disregarded.

In Fig. (b), 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 at $\Delta L = \xi$: $F = 2\times F_1 - j\times\xi = F_1$, which suffices to hold the weight at that position. ***Tension* T** = F_1 is held throughout the mover from the weight up to the fixture. **T** opposes the gravitational force and holds the weight steady,

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

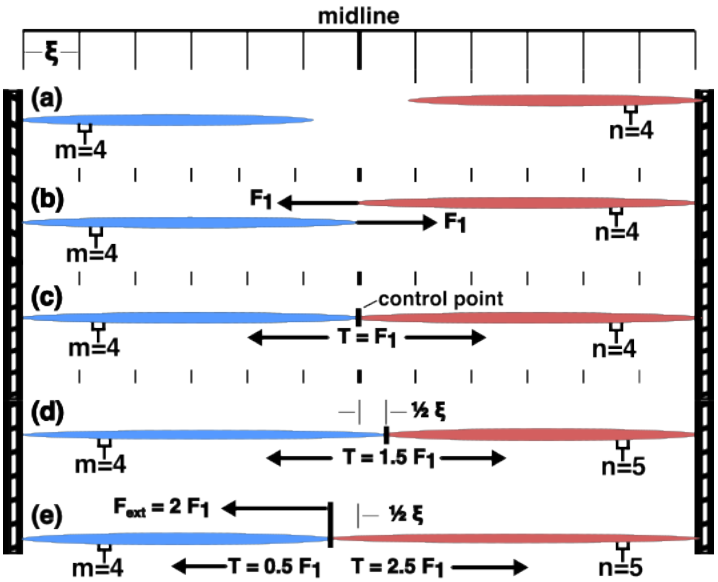
$L = [(9–n) + (W/F_1)] \times \xi$. Two such examples are shown in Fig. (c) and Fig (d).

In Figs. (e) and (f), the paradigm is extended to include slow movements. A piece of ice with weight $5F_1$ is attached to the control point. A drive signal of 5-pulse bursts holds the weight at maximum length. As ice melts, its weight declines; while drive signals remain constant, the length of the mover shortens, e.g., as shown in Fig. (f) where $W = 2.3F_1$ and $\Delta L = 2.7\times\xi$.

Next, tension is 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 tension in a mover 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 the control point and both movers by ½ξ. The added F_1 in the right mover is shared with the left mover, adding $0.5F_1$ to both tensions.

steady, tense positions of opposing movers



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In Fig. (e), the control point in Fig. (d) is subject to an external force $F_{ext} = -2F_1$ (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 produce zero forces at multiple positions while a spring produces a zero force only at a single position; movers dissipate energy while a spring conserves energy; springs both push and pull while movers only pull.

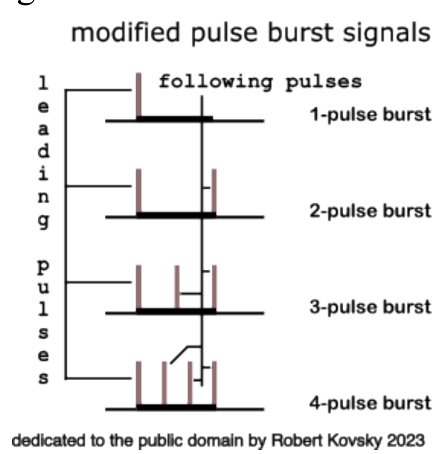
Previous examples are readily extended to a set of steady positions (with no external forces) that are arranged around midline and that are identified by the drive signals that produce them: (5,1) at 2ξ left of midline; (5,2) at 1½ξ left of midline, (5,3) at 1ξ left of midline, (5,4) at ½ξ left of midline, (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 ½ξ 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°, 15°, 30°, 45°, 60°}.

The foregoing opposing movers model has parallels with the primal model, e.g., in duplicates of held positions. Chief differences between the two models involve drive signals. The opposing movers model produces an extreme position with drive signals (5,1) that does not appear in the primal model; and midline signals (1,1) in the primal model can't be used in the opposing movers model. The strongest signals appear at the center in one model and at the edges in the other.

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. When phasic forces are absent on both sides, tonic forces hold the control point at midline.

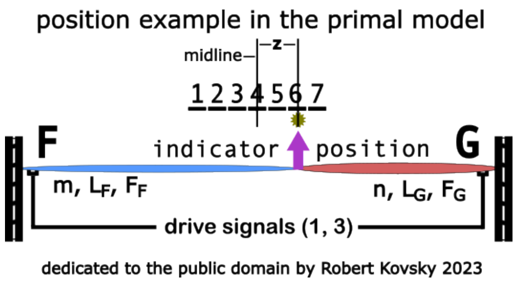
For the primal model, the tonic force is $4F_1$. A mover can produce as much as $7F_1$, with $3F_1$ as the maximum phasic force. That is, for these movers, the $n\times F_1$ term in Formula (1) is in the set $\{4\times F_1, 5\times F_1, 6\times F_1, 7\times F_1\}$. Positions produced by modified movers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



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. That is, 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.

Apply Formula (1) to modified mover F_G 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.

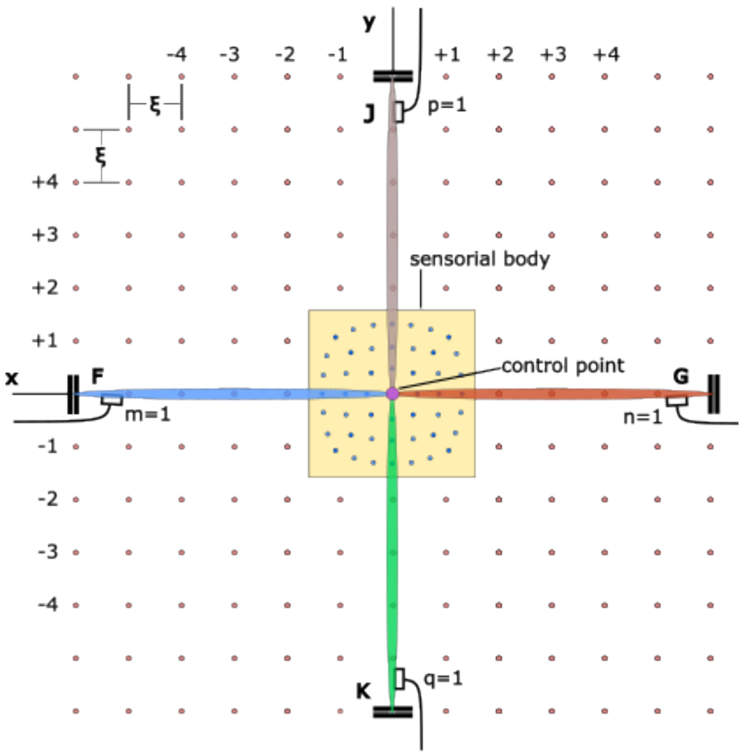
$F_F = 4\times F_1 - j\times(3\xi - z) = 6\times F_1 - j\times(3\xi + z) = F_G$.

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 ½ξ.

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

The primal model is developed into a two-dimensional VE device model shown below, where the control point is pulled by movers **F**, **G**, **J** and **K** into a set of positions shown as blue dots in an array on the sensorial body. Movements of the model are intended to mimic certain movements of human eyes produced by rectus muscles shown below.

two-dimensional VE device model of reflexive gaze



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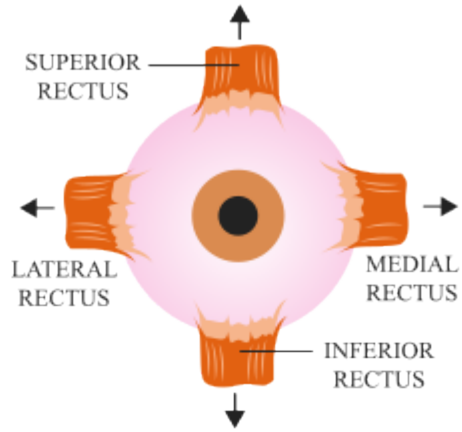
partial muscle structure of an eye



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

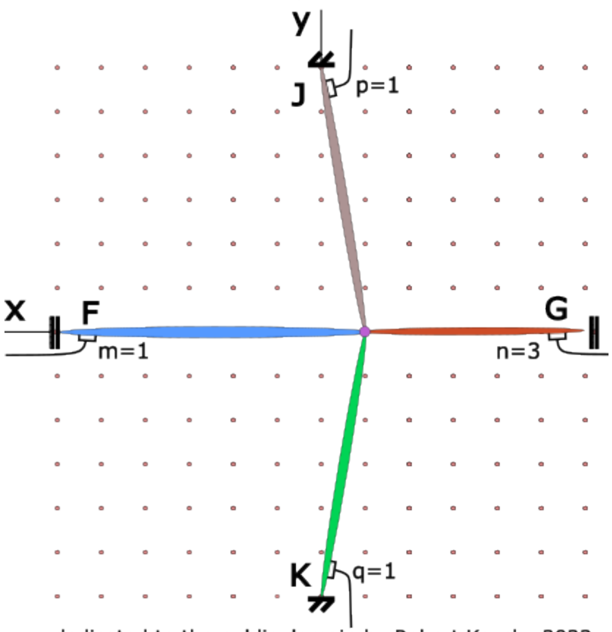
The fixed sensorial body resembles a rudimentary retina. As in the primal model, stimulus of a single specific sensor in the sensorial body causes the control point to move to and hold a position directly corresponding to the location of the sensor. The movement of the model resembles movements of an 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 ξ between grid points, where $\xi = F_1/j$ is based on specifications of movers. 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 researcher holds the control point at a specific position and specific steady drive signals are applied, the ***steady position i***s the unique position where the control point does not move when released.

A position vector z = (x, y) is assigned to the control point and referenced to the grid. In the example below, the control point is held at position z = (ξ, 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. Hence, this position is not steady.

VE device held in position z = (ξ, 0)
and driven by signals [(1,3), (1,1)]



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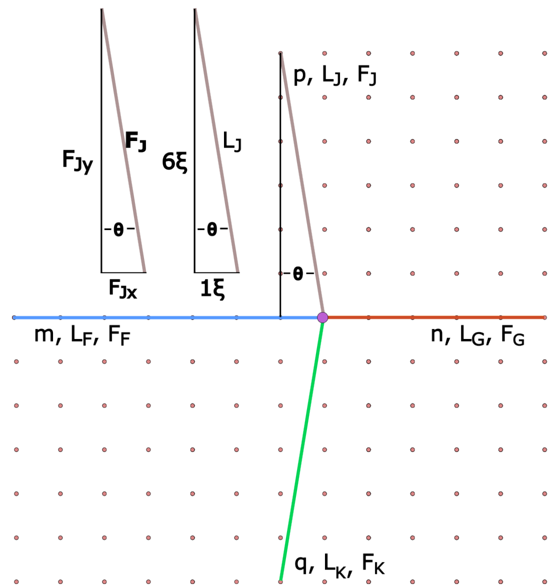
free-body diagram of VE device with
signals [(1,3), (1,1)], position z=(ξ, 0)



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Principles of Statics taught in engineering lead to a "free-body diagram" in which forces correspond to line segments in similar triangles, as shown above. In the main central diagram, mover **J** is described by its drive signal p, its length L_J, its force F_J and the angle θ_J it makes with the y-axis.

Adjacent to mover **J** in the diagram, the spatial triangle defined by L_J, 1ξ and 6ξ corresponds to the force triangle formed by F_J along mover J and its x and y components, F_{Jx} and F_{jy}. F_y components of F_J and F_K are in balance. F_x components of F_J and F_K are additive, both pulling the control point to the left.

In calculating the net force to the left, the angle θ plays a central role:
$\theta = \arctan(1\xi/6\xi) = 9.462°$. $L_J = 6\xi/\cos(\theta) = 6.083\times\xi$. (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 the control point to the left. F_{Kx} is the same, totaling $.356F_1$ pulling to the left.

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

In this position, 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 pull to the right from $F_G - F_F$ almost exactly balances the pulls to the left from F_J and F_K. Hence z = (0.85ξ, 0) approximates 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 = (.46ξ, 0);
drive signals [(1,4), (1,1)] produce a steady position close to z = (1.27ξ, 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 $\theta_J = \theta_G$.

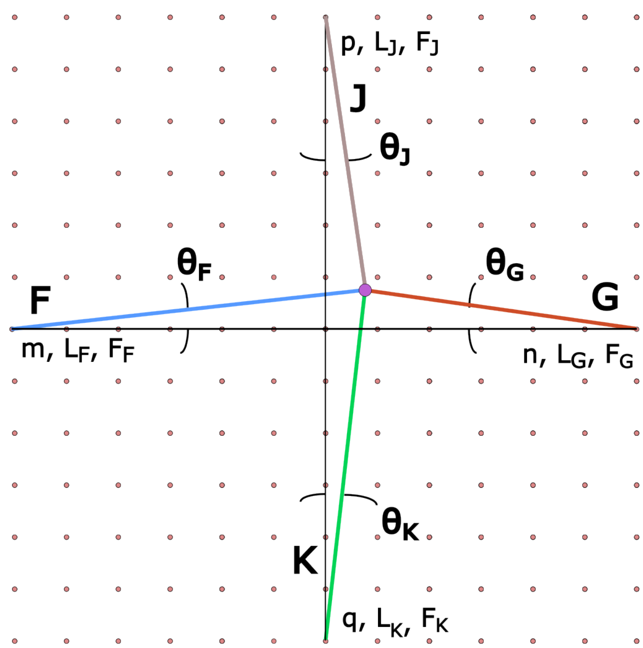
The position of the control point in the adjacent figure z = (0.75ξ, 0.75ξ)] is close to the steady position produced by the device with drive signals [(1,3), (3,1)].

The other positions of the control point on the diagonal are:

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

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

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



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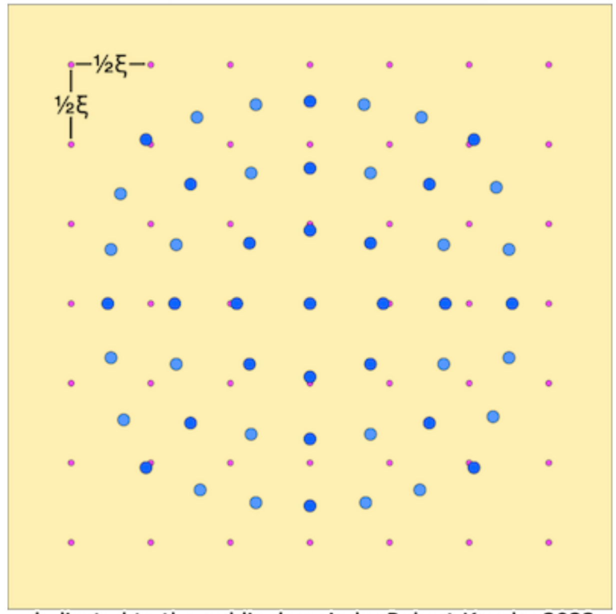
The adjacent figure shows all 49 steady positions produced by the 2-dimensional VE device model, plotted on the same grid as before.

Markers on axes and diagonals are positioned according to calculations above. Other markers were visually approximated.

approximate steady positions of the VE device plotted on the sensorial body



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A new stage of development now commences that focuses on the sensorial body.

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."

An important material property is physical ***synchronization***, which is observed, e.g., in unison ticking of identical mechanical clocks standing together on a table. In the concluding design of this project, synchronization of VE devices is a feature of collective quadnet operations which control the beat or tempo of operations.

Another material property called ***migration*** is imputed to sensors in the sensorial body. During migration, a sensor moves inside the body to a location that corresponds directly to the position of the control point that the sensor stimulates. In other words, the separation between the sensor and the mover position is reduced to a minimum.

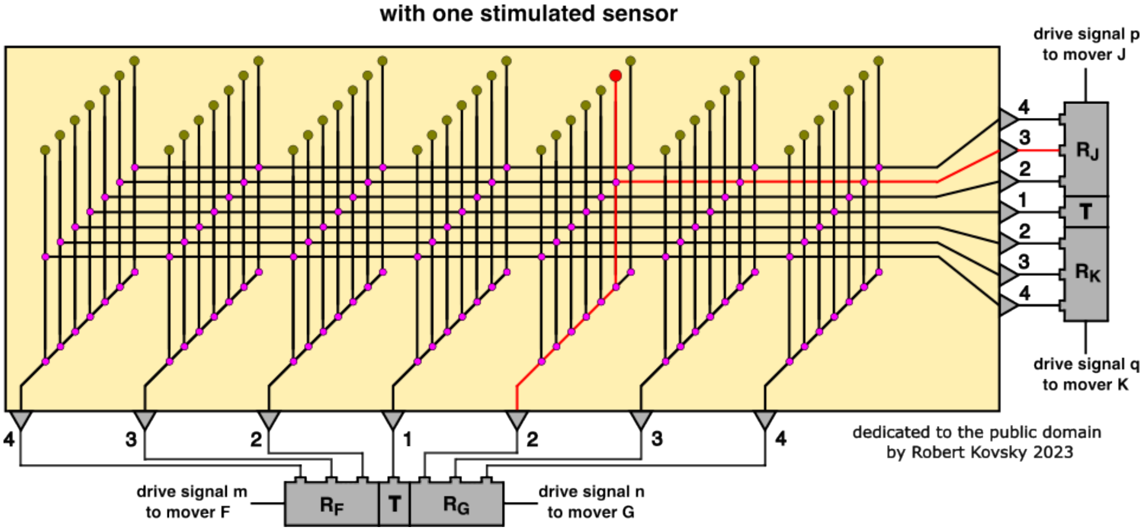
In this approach, positions produced by movers are definitive and sensors adjust their locations to mark those positions. If one mover should weaken slightly, affected sensors will migrate to locations that track new positions. It might be imagined that, before use, sensors are somewhat misplaced in the sensorial body from positions defined by movers. Then, during a "break-in period," each sensor migrates to a location close to the mover position produced by stimulation of that sensor.

The figure below shows sensors, VE distribution network and control devices in the sensorial body of the two-dimensional model. Stimulation of a sensor in the top layer of dots results in drive signals that position the control point at that sensor. In the examplen, values for drive signals [(F,G),(J,K)] are [(1,2),(3,1)].

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 a VE pulse to trigger the discharge of a pulse burst signal to the targeted burster.

Operations of the two burster module systems (F-G and J-K) are (1) independent of each other and (2) employ identical designs. Burster modules and drive signals are the same as in the primal model.

sensors, sensorial body and control devices in the two-dimensional model with one stimulated sensor



Inside the sensorial body, lines represent a new feature of devices called ***channels***. Channels in a body carry flows of Virtual Energy that are similar to flows of VE in projections between devices: flows are instantaneous and are maintained by the body without loss. In this design, a flow starts at a sensor and ends up at two timing devices. Channels have capacities that projections lack. (1) VE from multiple channels can flow into a common channel. (2) In a projection, VE moves in an integral number of uniform pulses; in a channel, VE can move in a continuous range of quantities.

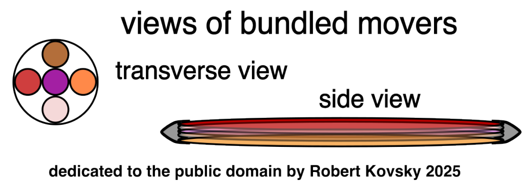
A capacity for maintaining flows of VE in networks of channels is imputed to the sensorial body. Small devices (pink dots in the figure) have independent sources of VE and, e.g., generate a VE flow in a horizontal channel when there is a flow in a vertical channel. Absent such a device, channels that appear to cross in the figure are not connected.

6. Bundled movers produce denser repertoires of movements.

In this step, the primal model is developed into a "bundled mover model." A ***bundled mover*** is made of ***five identical sub-movers***. Each sub-mover has an elemental force $0.2F_1$. Other than the smaller elemental force, sub-movers operate the same as the original steady movers. During operations, sub-movers are driven synchronously by independent drive signals from separate bursters. The resulting force is an arithmetic sum of the separate sub-forces.

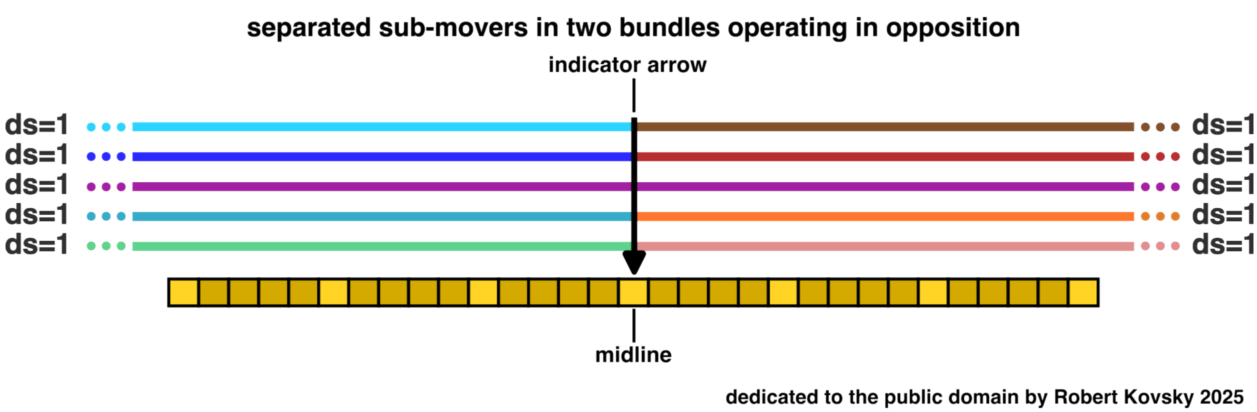
When all sub-movers in a bundled mover are driven with the same signals, the resulting position is also a position of the primal model. When sub-movers in a bundled mover are driven with different signals, the sum of forces has an intermediate value between two values of the primal model; and then the control point moves to an intermediate position.

The figure shows a "transverse view" of a bundled mover: a central 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.



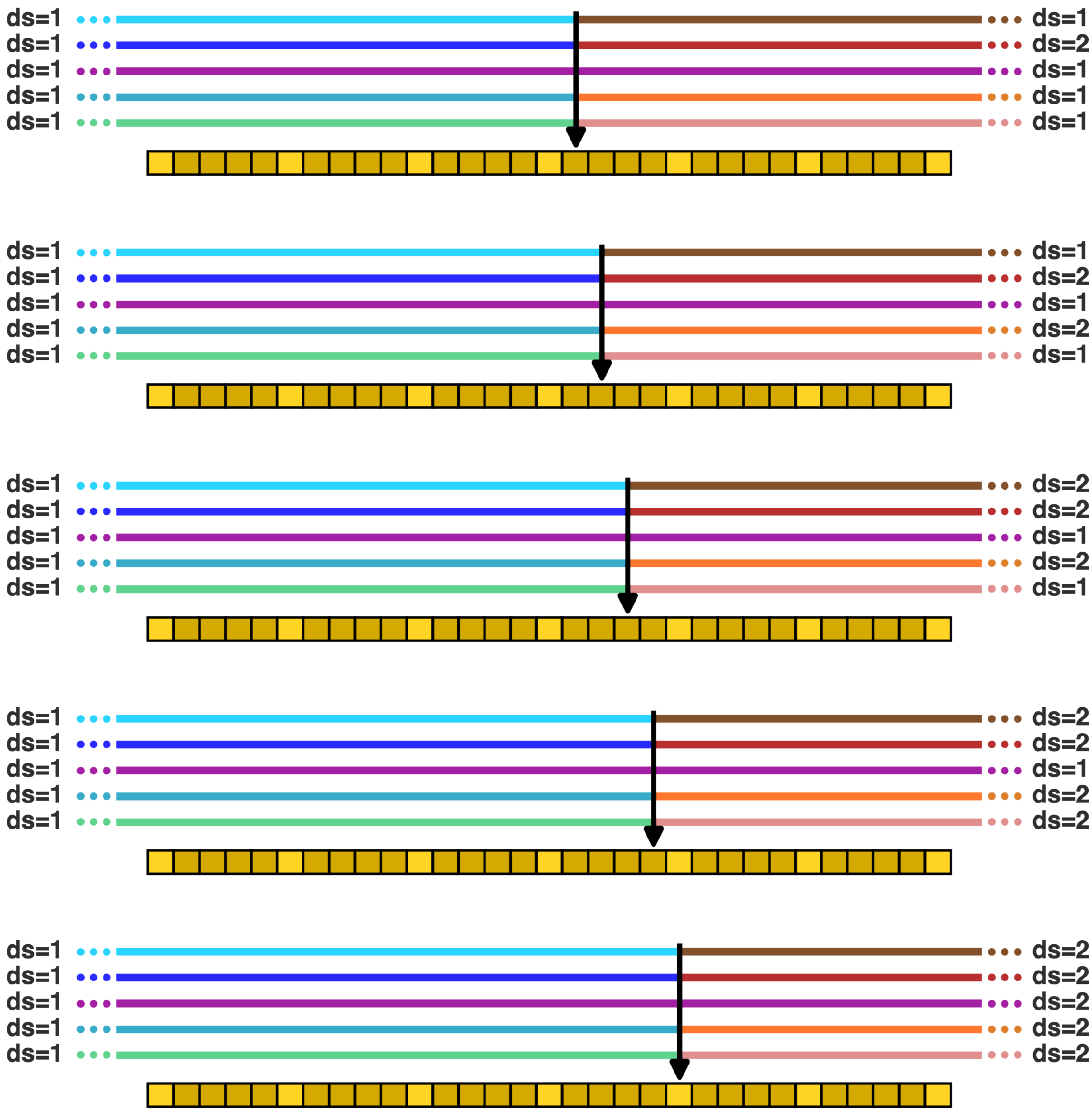
In the figure below, two opposing bundled movers are dis-assembled into sub-movers with separate attachments to the indicator arrow, which is constrained to stand vertically. Each sub-mover has an individual drive signal "ds." The midline position is maintained by drive signals ds=1 arriving at all the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



In figures below, individual drive signals to peripheral sub-movers in the right bundle are increased one by one, resulting in incremental changes in the position of the indicator arrow. In other words, stronger incremental signals are applied to the peripheral sub-movers in an orderly progression. When all peripheral sub-movers have had incremental increases during such a progression, the next step is to send a higher primal signal to all sub-movers; and none receive incremental signals. No incremental drive signal is ever sent to the central sub-mover.

variable drive signals and mover positions in a bundled mover model



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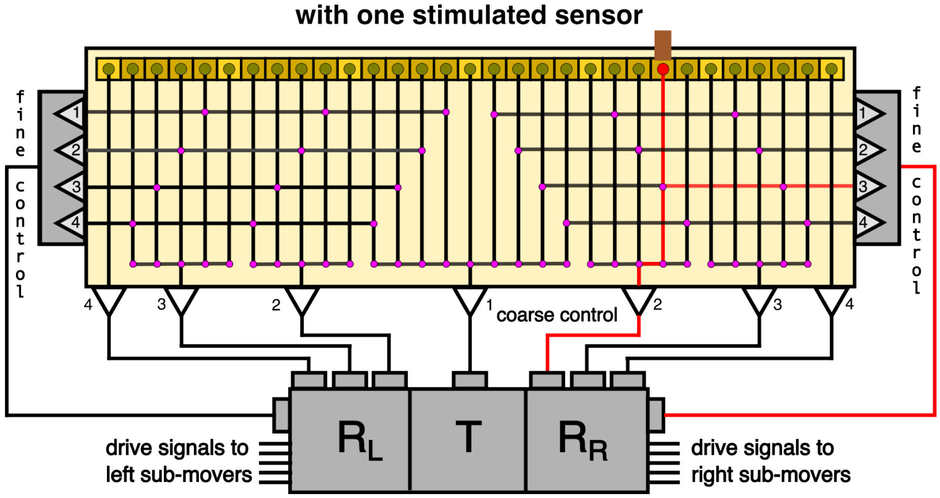
The bundled mover model in the figure below is a development from the primal model. An internal network of channels processes a stimulus to generate drive signals for sub-movers. Vertical channels are connected by devices (pink dots) to horizontal channels so as to direct a VE flow to two timing devices. Sensors, channels and dot devices all operate within the sensorial body, receiving VE through it and subject to its conditions.

The internal network of connected channels in the bundled mover model resembles the network in the two-dimensional model above; and both resemble associative networks in electronics systems.

Timing devices labeled "coarse control" operate along the bottom of the sensorial body like timing devices in the two-dimensional model. All the sub-movers in a bundle receive the same "coarse control" signal.

Two sets of timing devices discharge inside "fine control" modules on the sides of the sensorial body, which control incremental signal increases to sub-movers. The number of pulses appears inside the fine control timing device and equals the number of sub-movers to be incrementally increased. Fine control timing devices drive a burster that is part of the fine control module; only one signal line is needed to carry that burster's output (one pulse burst) to the main burster module.

sensors, channels and control devices in the bundled mover model with one stimulated sensor



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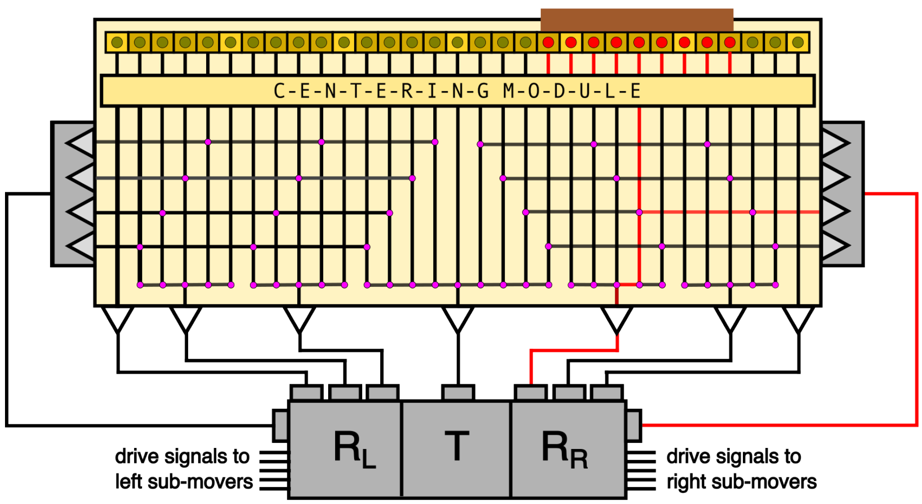
In the example in the figure, drive signals to the right sub-movers produce an intermediate position between two primal positions. All five right sub-movers receive 2 pulses per cycle while three right sub-movers receive an additional pulse. The collective right drive signal is denoted R_R=2-3, following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

In designs up to this point, a stimulus must activate exactly one sensor. There is no capacity to respond to stimulation of multiple sensors.

The figure below shows stimulation of multiple sensors in a ***bloc***. A "centering module" operates between the bloc of stimulated sensors and the VE channel network. The module produces a VE flow in a single channel leading to drive signals (R_L=1-0; R_R=2-3), which position the control point close to the center of the stimulus bloc.

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



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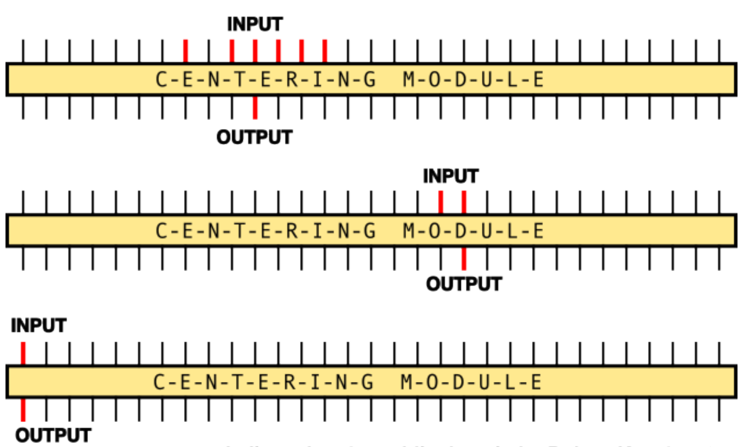
A suitable stimulus bloc is a single group. Additionally, some designs allow for a gap no larger than a single sensory channel. With such an input, the output appears on a single channel that is at or near the center of the stimulated bloc. Examples below illustrate operations of a centering module. The formal VE model includes construction of three progressively faster designs for centering modules.

centering module: examples of input-output relations



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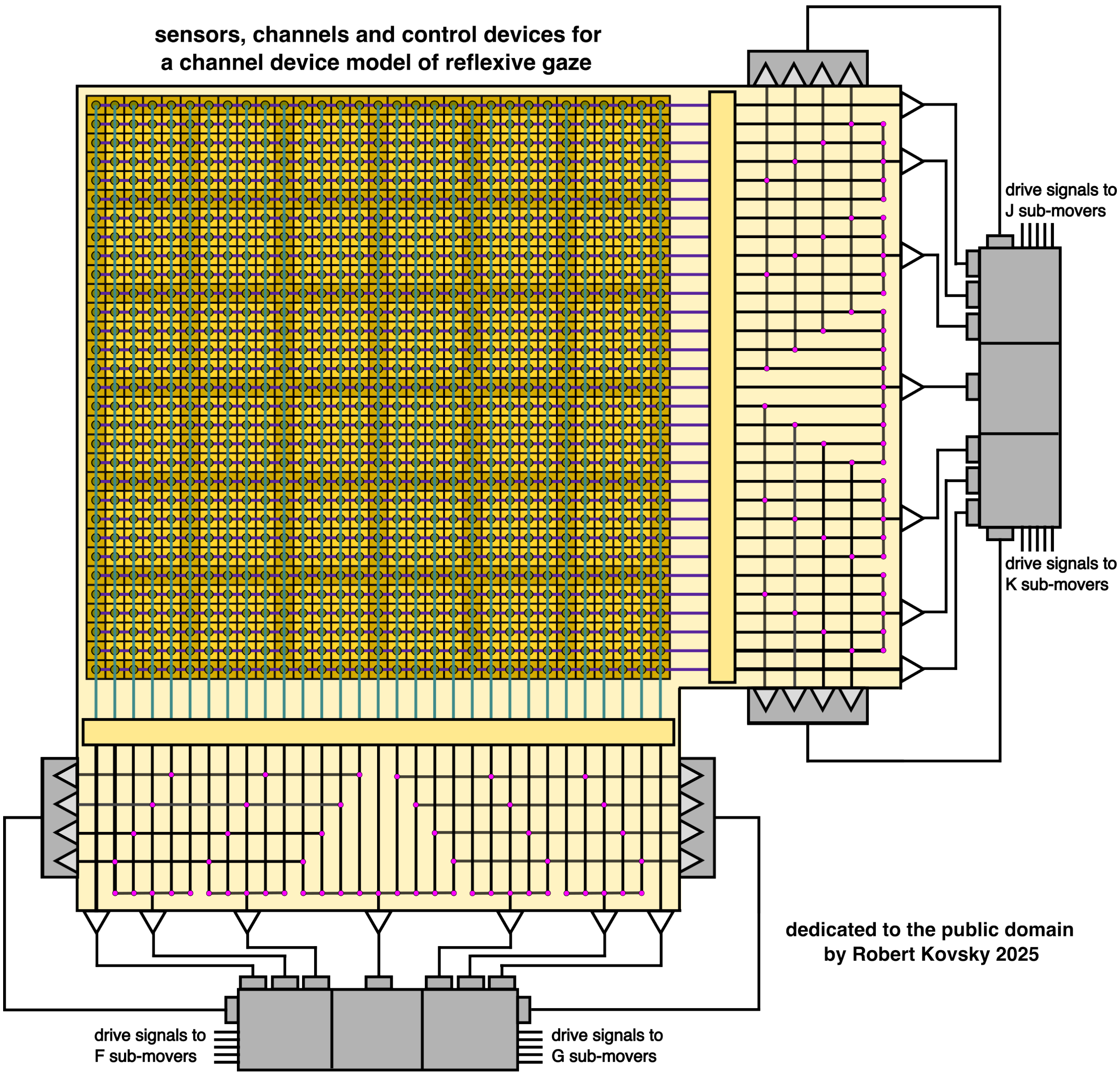
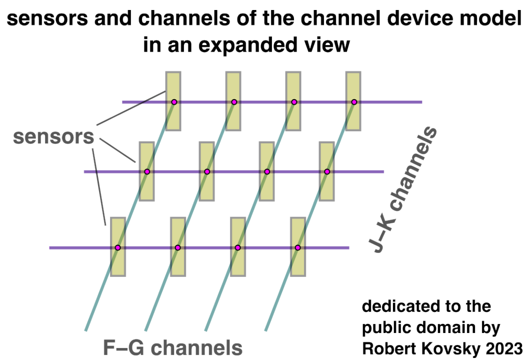
The bundled mover model with centering is readily extended to two dimensions, leading to the ***channel device model of reflexive gaze*** shown below. This model can be used to drive movements of F-G-J-K movers shown above in § 1, according to constructions of §§ 5 and 6.

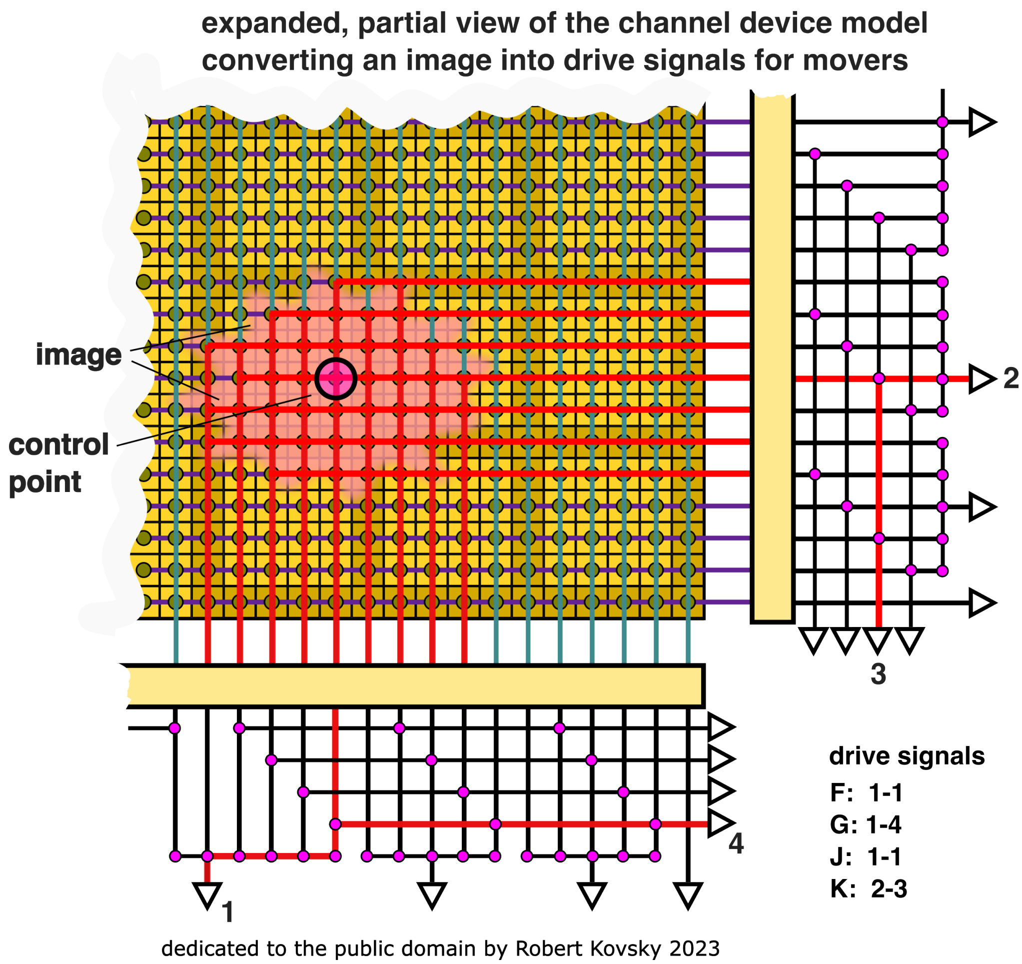
A centering module and channel network are connected to the bottom edge of the sensor bloc; these drive a burster module and control F and G sub-movers. Another identical system is connected to the right edge of the sensor bloc and controls J and K sub-movers. Operations and movements of the two control systems are independent of each other. The two control systems each reproduce the bundled mover model.





The adjacent figure provides a close-up view of operational elements inside the sensor bloc of the channel device model. Prior to stimulation, each sensor has a store of VE that 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 sensor bloc and VE networks of the channel device model while processing the image from §1. The image stimulates sensors, which discharge VE into channels shown in 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.

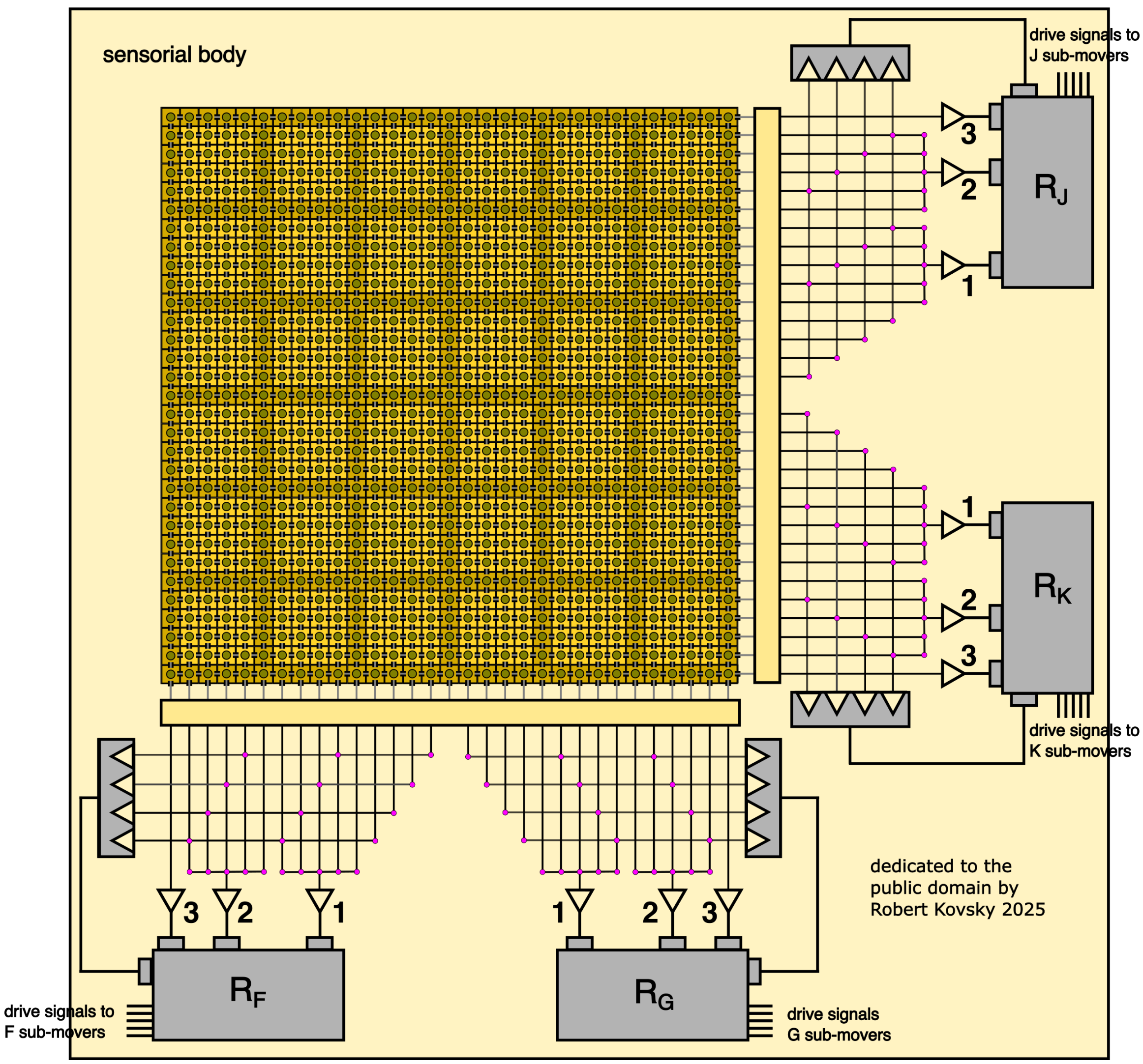


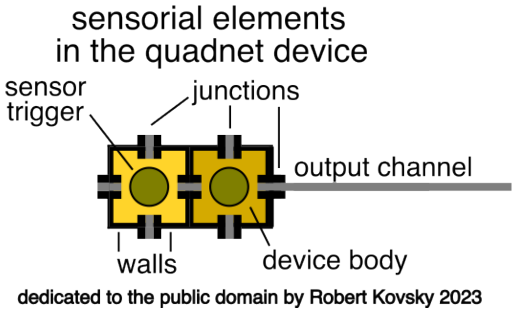
7. In a fast "Gazer" model, operations of a quadnet device in a sensorial body control reflexive visual movements.

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 that move the control point to a position close to the center of the image.

Gazer's operations are faster and simpler than those of the channel device model. A ***quadnet device*** operates inside the sensorial body, which also incorporates centering modules, VE networks and burster modules. Timing functions are relocated to the sensorial body, which generates an ongoing beat that synchronizes active devices. Burst signals are simplified by omission of leading pulses, which controlled timing in prior models. In coarse control timing devices, pulse bursts have 1, 2 or 3 pulses. Operations of fine control modules are unchanged.

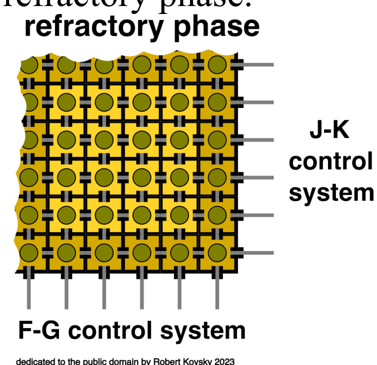
"Gazer," a quadnet device model of reflexive gaze



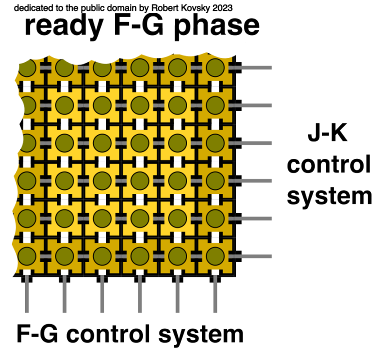


The adjacent figure shows sensorial elements of the quadnet device, which is an array of 961 sensorial elements. Internal ***junctions*** between elemental devices replace the continuous channels of the prior model. At the terminus, a junction directs a VE flow into an output channel in the control network.

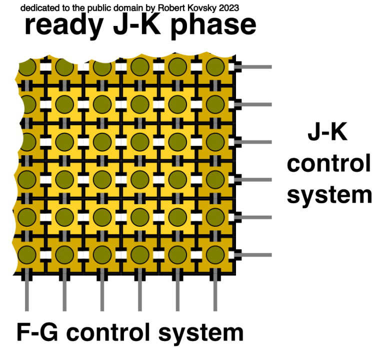
The whole-body quadnet device operates cyclically and sensorial elements collectively pass through a series of conditions or ***phases***. In this context, the word "phase" denotes a whole-body condition. At each moment, the body is in exactly one phase. Changes occur abruptly. The cycle has four steps 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.



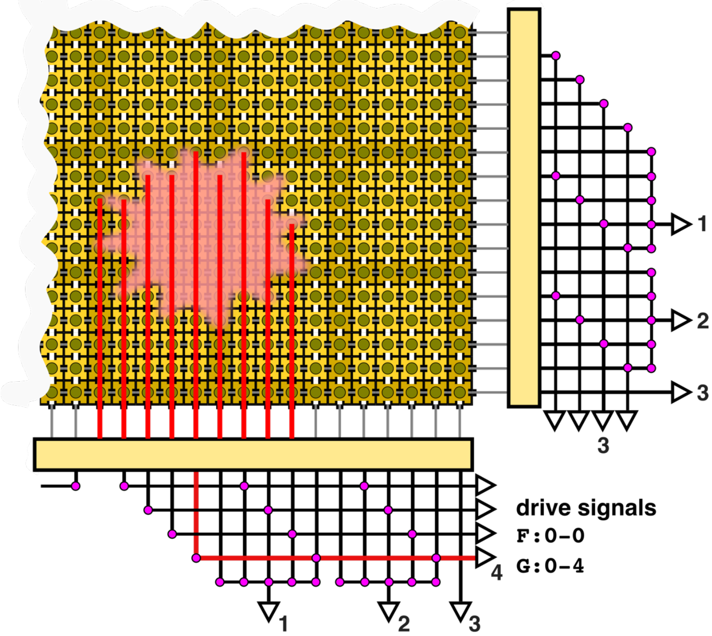
The adjacent figure shows sensory devices in an F-G phase that is ready but not stimulated. Half the junctions are open, making up internal passages for VE that are equivalent to channels and that can direct VE into channels of the F-G control system at the periphery of the quadnet device.



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 again 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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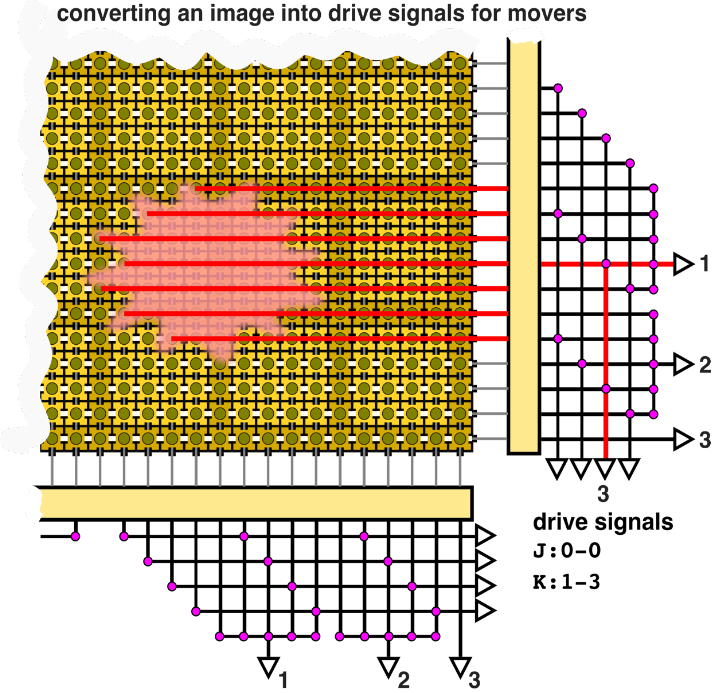
During an active F-G phase, stimulated sensors discharge VE that passes through columns of open junctions into channels of the control system. Only F-G channels are involved. Flows in junctions lead to F and G drive signals, which differ in value from those in the channel device model but which lead 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 with the same visible image as in the prior F-G phase. 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 a single mode of operation called ***streaming***, in which a set of signals generated by stimulation of sensors passes through stages of conversion that lead to drive signals for movers. Each set of sensory signals leads to one set of drive signals, produced in alternating signals to horizontal and vertical 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 stands at the central location.

In contrast, the channel device model 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, the model switches to substitution mode for the next cycle. If no additional sensory signal arrives during the next cycle, the model reverts to holding mode. If an additional sensory signal arrives, substitution continues. Continuous substitution mode in the channel device model produces the same repertoire of steady positions as streaming mode in the quadnet device model, but the channel device model requires many more control devices and longer processing times. Similarly, the primal model and its successors operate in holding and substitution modes. [Holding and substitution modes are thoroughly investigated in the Wriggler I project.]

The quadnet Gazer model completes the course of construction of this project. Initial mover constructions were foundational and later sensory and control constructions have specific features and operations that depend on the mover system. Concepts of VE flow were developed, starting with pulses in projections, followed by VE flows in channels in sensorial bodies and then by VE flows through junctions in a quadnet device. A similar course of construction is undertaken in the formal VE model.

The quadnet Gazer model aims at distant goals of Shimmering Sensitivity: both kinds of processes involve cycles of phase changes in quadnet devices. The Gazer model is suggestive of further developments in that direction. Sensory signals generated in the primary quadnet that leads 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. In anticipated developments, secondary quadnets participate in operations of ***image processing and recognition***, e.g., comparing two images and detecting "same" or "different."

Images prepared with Inkscape 1.2
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