Speculations on Consciousness

Contents

Note: To look up references, see the Consciousness Bibliography, listing 10,000 books and articles, with full journal and author names, available in text and PDF file formats at http://www.outline-of-knowledge.info/Consciousness_Bibliography/index.html.

CONS>Consciousness>Speculations

consciousness speculations

Biological sciences, computer sciences, mathematics, physical sciences, and psychology can contribute ideas about sensations, conscious observers, and mental space {consciousness, speculations} {speculations, consciousness}.

dimensionless neuron outputs

Neuron inputs and outputs do not use units, and so they are dimensionless, allowing neuron inputs and outputs to add {dimensionless neuron outputs}. Perceptual input and output are about information, which has no physical units [Shannon, 1948].

factoring and neurons

Factoring can separate wholes into separate parts with no remainders {factoring and neurons}. Neuron-series-array arrays can check factors to make regions consistent and complete.

factorable

Dividing factorable numbers by correct factors leaves no remainder and results in one dividend, with no addition. For example, 15 is factorable, because 3 * 5 = 15, and 3 and 5 are unique and prime. Dividing factorable polynomials by correct factors leaves no remainder.

remainder

Dividing factorable numbers by incorrect factors leaves incorrect-factor fractions (remainder) that add to dividend. For example, 10/3 = 3 + 1/3. Dividing factorable polynomials by incorrect factors leaves remainders.

logarithms

Dividing factorable numbers by all correct prime factors equals one. For example, 8 has three factors 2, 2, and 2, and 8/(2*2*2) = 2^3 / 2^3 = 1. Logarithm of 1 is 0. For example, log(2^3) / log(2) = log(2^2), log(2^2) / log(2) = log(2^1), log(2^1) / log(2) = log(1) = 0. Alternatively, log(2^3) = 3 and log(2) = 1, so 3 - 1 - 1 - 1 = 0.

Dividing factorable numbers by incorrect factors does not equal one. For example, dividing 8 by 3 makes 2 + 2/3. Logarithm is not zero. For example, log(8) - log(3) is not zero.

harmonic ratios and neurons

Ratios are more harmonic if numerator and denominator have smaller integers {harmonic ratios and neurons}. The most-harmonic ratios are 1:1 and 2:1. The second-most harmonic ratios are 3/2, 4/3, 5/3, 5/4, and 6/5.

Adding 1 to 1, for duplication, makes 2/1 ratio. Dividing 1 by 2, for splitting, makes 1/2 ratio. Repeated doubling and splitting can make all whole-number ratios. Because they can add and divide, neuron assemblies can build harmonic ratios.

Opponent-process output is a ratio with range from 1 to 2. Therefore, high end to low end has ratio 2/1. Middle to low end has ratio 1.5 = 3/2. Middle, of low end to middle, to low end has ratio 1.25 = 5/4. Middle, of middle to high end, to low end has ratio 1.33 = 4/3. Continuing makes ratios 6/5, 7/6, 8/7, 9/8, and so on, including 15/8, 7/4, 5/3, and 7/5. Opponent-process harmonic ratios can indicate categories.

line length

Line lengths have ratios. Geometric figures with sides in harmonic ratios have symmetries and high information. Geometric figures with sides in non-harmonic ratios have few symmetries and low information.

CONS>Consciousness>Speculations>Observer

semi-observer

The first observer {pre-observer} {semi-observer} had no space, no time, no intensity, and no quality. Semi-observer had semi-space and semi-qualities. Semi-observer had semi-feelings of self-awareness. It was like objectless meditation, blindsight, and attention without awareness.

vector space and observer

Vector space can model observer and observations as integrated system {vector space and observer}. Coordinate origin is observer. Vector termini are observations.

CONS>Consciousness>Speculations>Observer>Biology

body motions and observer

Head and body rotate around centers. Vestibular, kinesthetic, and visual feedback makes motor centers into perceptual centers, which define observation point {body motions and observer}.

circuit flows and observer

Brain is large and complex and can have internal circuit flows, one of which represents observer {circuit flows and observer}. Loops allow reverberations, feedback, and feedforward, to maintain processes. Observer and observed circuit flows interact.

origins of self

Sensory and central neurons have electrochemical processes, have associative memories, and control motor neurons. Ganglia use neuromodulators, have procedural memories, and use statistical and vector processes to control motor-neuron sets. Brains are ganglia sets that use statistical and tensor processes to coordinate body, head, and limb motions. Vertebrate brains have perceptions and declarative memories and use nested processes [Hofstadter, 2007]. Self began with a central perception and behavior process {origins of self} that nests and controls other brain processes.

Algorithms can distinguish inside-body stimuli, as self, and outside-body stimuli, as non-self. Tightening muscles actively compresses, to affect proprioception receptors that define body points. During movements or under pressure, body surfaces passively extend, to affect touch receptors that define external-space points.

resonating wave and observer

Brain can have resonating waves, one of which can represent observer {resonating wave and observer} {self-wave}.

CONS>Consciousness>Speculations>Observer>Psychology

frames and observer

Sensations occur in contexts (frames), which indicate spatial relations. One context is observer {frames and observer}.

knowing and having meaning

Knowing {knowing, meaning} can be recognition or association.

property

Properties are about something measurable, such as location, time, intensity, or sense quality. Objects and events have properties. Properties have relative values. Perception measures property values while keeping property natures or types abstract and separate. Sensation measures values but also assigns property types and natures, so colors, sounds, and so on, have meaning.

category

Categories are object or event groups. Category objects share at least one property value. People can group objects and events to make categories (association). People can put objects or events into (previously memorized) categories (recognition). Categories have subcategories and supercategories.

meaning

Meaning {meaning, knowing} requires knowing something about property, not just property values. For example, meaning requires knowing something about red, not just intensity value.

meaning: value relations

Perception builds property-value series from repeated situations. Property-value sequences can reveal functions, such as $x = x + 1$, and other relations. Value changes (gradients or flows) and value-change changes (accelerations or forces) can have relations and reveal property-value functions. By remembering and comparing property values, brain can find property meaning by transforming to new properties that can be parameters, by associating properties to make categories, and by recognizing category members.

symbol grounding

Symbol systems give meaning to symbols. Property systems give meaning to property types. Symbols have grounding when they associate with spatial or temporal patterns. Property types have grounding when they have spatial or temporal patterns. Property types depend on symbol systems with grounding.

self and first sensation

Perhaps, sense qualities derive incoming-stimuli receiving point, to define observing self {self and first sensation}. However, behavior is not sense qualities, and self seems complex.

CONS>Consciousness>Speculations>Sensation

intensity and space and sensations

Sense qualities require intensity, space, and time {intensity and space and sensations}.

intensity fluctuation type and sensations

Light-wave amplitude has frequency. Sound-wave amplitude has frequency. Touch involves vibrations with frequencies. Smell and taste involve molecule collisions that cause molecule vibrations. For all senses, stimulus intensity fluctuates. Different senses have different vibration types. Perhaps, sense qualities are intensity-fluctuation types {intensity fluctuation type and sensations}. Intensity fluctuation involves frequency modulation and/or amplitude modulation.

self-observable sensations

People can observe sensations but not physical stimuli. Sensations have observers. Sensations are self-observable {self-observable sensations}.

sensation parameters

Sense functions have three parameters {sensation parameters}, making a function family. Different senses have different subfamilies. Within a sense, sense qualities have the same function with different parameter values.

sensation parameters: intensity

Intensity goes from zero to pain. Vision and other senses add receptor inputs to find intensity, and then compare adjacent intensities to find relative intensity. Intensity involves time, distance, momentum, and energy, which are never negative.

sensation parameters: non-opposing quality

Non-opposing quality goes from zero/low through middle to high maximum. Examples are frequency, concentration, polarity, shape, density, and absolute temperature, which are never negative. Light, sound, and vibrations have frequency. Molecules have shape, concentration, and polarity. Materials have temperature and density.

sensation parameters: opposing quality

Opposing quality can go from negative to zero to positive. Examples are charge and spin. Opposing quality can go from below to neutral to above. Examples are acidity and cool to neutral to warm temperatures, as well as compression to equilibrium to tension. Opposing quality can go from left to symmetric to right. Examples are handedness and parity. For opposing qualities, range ends are opposites.

sensations

Sensations always have intensity and have at least one opposing quality and at least one non-opposing quality. Senses combine sensation parameters to make sensations.

stimulus matching and sensations

Sensations evolve to become best matches to physical information {stimulus matching and sensations}. Brain analyzes inputs to find categories and relations and then synthesizes abstract variables to replace physical variables to make output model the input stream. Output and input integrate to make a unified whole.

time and sensations

Physical processes use gravitational and/or electromagnetic forces and so very short times. Mental processes are about information flows and have arbitrary times. Low-level mental processes occur over 20-millisecond to 200-millisecond intervals {time and sensations}. High-level mental processes occur over hours. 20-millisecond and longer times allow neuron-assembly activity-pattern integration and expression as sensations.

tingle

Neuron-assembly activity patterns evolved to become tingles {tingle} {pre-qualities} {semi-qualities}, which later differentiated to become sense qualities. All sensations share an underlying vibrational state.

predecessor

Physical quantities have real-number amounts and have units, such as volts or frequencies, which may have directions. Physical quantities occur at one time and place. Physical intensities use only energy, area, direction, and time. Nerve impulses and neuron-assembly activity patterns involve physical quantities. Sense systems use neuron-assembly activity patterns.

tingles

At first, all senses had only intensities. Evolution then began to work on neuron-assembly activity patterns to make kinetic effects and overall oscillations. These abstract vibrations are tingles. Tingles are non-local. Tingles have intensities. Tingles are the beginnings of sense qualities. Tingles are vibrations of new abstract physiological variables that combine physical quantities. Different senses have different vibration types. Within a sense, different sense qualities have the same vibration type but different frequencies and harmonic ratios.

Tingles derive from neuron transient vibrations after stimuli. Neuron assemblies can combine inputs to make microphonic neuron signals [Saul and Davis, 1932], with frequencies up to 800 Hz.

Semi-qualities are undifferentiated sense qualities and have semi-feeling and semi-meaning. Tingles are between neuron physiology and sense qualities. Like neuron signals, tingles can vary in wavelength, frequency, frequency range, frequency distribution, amplitude, amplitude change rate, amplitude acceleration, intensity, phase, persistence after stimulus, direction, rotation, orientation, pitch, roll, yaw, and wobble. Waves can have different forms, such as longitudinal, transverse, polarized, spherical, and ellipsoidal. Like sense qualities, tingle semi-qualities have semi-time, semi-space, and semi-intensity.

antecessor

As tingles evolved, they differentiated into sense qualities with intensities. Sensations have no real-number amounts and have no units. Rather, sensations have relative amounts and sense qualities. Sensations combine intensity amount and unit into a post-tingle. Tingle frequency, spatial extent, and amplitude differentiated to make different sense types. Within a sense type, post-tingles vary and make sense qualities, such as red.

CONS>Consciousness>Speculations>Sensation>Biology

animals and sensations

Animals are Pre-Cambrian invertebrates, Cambrian invertebrates, chordates, vertebrates, fish, lobe-finned fish, freshwater lobe-finned fish, amphibians, reptiles, mammals, primates, Old World monkeys, apes, Home erectus, and Homo sapiens, in order of evolution. Many people believe that mammals have consciousness and sense qualities {animals and sensations}. However, mammal brain parts and functions are similar to other-vertebrate brain parts and functions, so mammals seem to have nothing fundamentally new in brain.

behavior and perception

Perception is like behavior in that input triggers output {behavior and perception}. Coordinated switches trigger muscle movements, gland outputs, and perceptions. Perception and behavior have feedback, looping, and exchanging. Muscles, glands, and nerves work together, as do sense receptors and brain. Behavior and perception use whole brain and body.

energy flow and sense intensity

Sense receptors measure kinetic-energy flow onto their receptive-field area {energy flow and sense intensity}. For example, taste receptors measure salt concentration as salt-to-receptor binding per second, which transfers kinetic energy per second. Kinetic energy flow transforms to potential-energy change. Membrane-potential changes and molecule-potential-energy changes continually transfer stimulus energy to new neurons. Neuron coding represents neuron potential-energy and kinetic-energy transfers. Electrochemical flows are like kinetic energy, and electrochemical states are like potential energy {electrochemical potential and kinetic energy}. Electric circuits have resistances, capacitances, and inductances, and pipes have constrictions and standpipes.

CONS>Consciousness>Speculations>Sensation>Biology>Brain

brain evolution and first sensation

Perhaps, sense qualities arose in humans or mammals from new brain regions or functions {brain evolution and first sensation}. However, human and mammal brain regions and functions are similar to other-vertebrate brain regions and functions, so humans and mammals seem to have nothing fundamentally new in brain.

brain region duplication and multisense qualities

After sense-region duplication, original region performs original function, so duplicated region can evolve to perform new functions, such as receive from another sense and integrate two senses {brain region duplication and multisense qualities}.

color processing

Vision processing {color processing} represents color brightness, hue, and saturation.

photoreceptors

Rods have photopigment with maximum sensitivity at bluish-green 498 nm, to measure light intensity. Cone types have maximum sensitivity at one wavelength and lower sensitivities at other wavelengths.

Non-primate mammals have cones with photopigments with maximum sensitivity at indigo 424 nm to 437 nm (short-wavelength receptor) and yellow-green 555 nm to 564 nm (long-wavelength receptor). Non-primate mammals can distinguish colors over the same light-frequency range as primates. Because they have only one color dimension, they may or may not see subjective colors.

Primates have cones with photopigments with maximum sensitivity at indigo 437 nm (short-wavelength receptor), green 534 nm (middle-wavelength receptor), and yellow-green 564 nm (long-wavelength receptor). Because they have two color dimensions, they may see subjective colors.

neurons

ON-center and OFF-center neurons calculate cone-input sum, which represents intensity, or ratio, which represents light frequency. The first opponent-process ratio was for yellowness and blueness. The second opponent-process ratio was for redness and greenness.

Later processing categorizes colors. Perhaps, whiteness can change to light yellowness, and blackness can change into dark blueness. Perhaps, yellowness split into darker orangeness and lighter greenness, which mixes blueness and yellowness. Perhaps, orangeness becomes redness.

labeled lines and topographic maps

Visual-tract axons carry color-blob opponent-process information from retina to lateral-geniculate-nucleus and primary-visual-cortex topographic maps. Senses have labeled lines because their neurons follow sense-specific pathways and have physiological specializations.

color lightness

The lightness color parameter relates directly to the difference between brightness and short-wavelength-receptor output: M + L - S. In order of increasing color lightness, black causes no response. Blue has small M-receptor and L-receptor outputs and large S-receptor output. Red has middle M-receptor and L-receptor outputs and small S-receptor output. Green has large M-receptor and L-receptor outputs and medium S-receptor output. Yellow has large M-receptor and L-receptor outputs and medium-small S-receptor output. White has very large M-receptor and L-receptor outputs and medium S-receptor output. Therefore, subjective color lightness relates directly to the blue-yellow opponent process.

color temperature

The temperature (warmth and coolness) color parameter relates directly to difference of long-wavelength-receptor and middle-wavelength-receptor outputs: L - M [Hardin, 1988]. In order of increasing color temperature, blue has small L-receptor and medium-small M-receptor outputs. Green has medium L-receptor and large M-receptor outputs. Black causes no response. White has very large L-receptor and M-receptor outputs. Yellow has large L-receptor and large M-receptor outputs. Red has large L-receptor and medium M-receptor outputs. Therefore, subjective color temperature relates directly to the red-green opponent process.

brightness, lightness, temperature

If black has brightness 0, and if blue, red, and green have maximum brightness 1, then brightness ranges from 0 to 3. Magenta adds blue and red to make 2. Cyan adds blue and green to make 2. Yellow adds red and green to make 2. White adds blue, red, and green to make 3.

If blue, red, and green have lightness 1, 2, and 3, respectively, lightness ranges from 0 to 6. Magenta adds blue and red to make 3. Violet adds blue and half red to make 3. Orange adds red and half green to make 3.5. Cyan adds blue and green to make 4. Chartreuse adds half red and green to make 4. Yellow adds red and green to make 5. White adds blue, red, and green to make 6. Blue and yellow, red and cyan, and green and magenta add blue, green, and red to make white 6.

If blue, green, and red have temperature -2, 0, and 2, respectively, temperature ranges from -2 to +2. Cyan averages blue and green to make -1. Magenta averages blue and red to make 0. White averages blue, red, and green to make 0. Blue and yellow, red and cyan, and green and magenta average blue, green, and red to make white 0. Chartreuse averages half red and green to make 0.5. Yellow averages red and green to make 1. Violet averages blue and half red to make 1. Orange averages red and half green to make 1.5.

If brightness is first coordinate, lightness is second coordinate, and temperature is third coordinate, blue is (1,1,-2), red is (1,2,2), and green is (1,3,0). Magenta is (2,3,0). Cyan is (2,4,-1). Yellow is (2,5,1). White is (3,6,0). Black is (0,0,0). Darkest gray is (0.5,1.0,0.0). Dark gray is (1,2,0). Gray is (1.5,3.0,0.0). Light gray is (2,4,0). Lightest gray is (2.5,5.0,0.0).

brightness and blackness

The brightness color property depends on the brightness color parameter, which sums long-wavelength-receptor and middle-wavelength-receptor outputs: L + M. Black has low brightness. Blue wavelength is far from L and M maximum-sensitivity wavelengths, so blue is dim. Red wavelength is closer to L and M maximum-sensitivity wavelengths, so red has average brightness. Green wavelength is close to L and M maximum-sensitivity wavelengths, so green is bright. White adds green, red, and blue and is brightest.

saturation and whiteness

Colors can have whiteness. White adds to primary colors linearly and equally. Any color mixture has red, green, and blue. In any color mixture, red, green, or blue has the lowest brightness, and the other two colors have at least that brightness. Therefore, whiteness is three times the lowest-brightness-primary-color brightness. Subtracting lowest-brightness-primary-color brightness from the other two primary-color brightnesses, and then adding the two results defines hue brightness. Saturation is hue brightness divided by total brightness. Unsaturation is whiteness divided by total brightness. Hue brightness and whiteness add to 100%. Vision processing compares adjacent and overall brightnesses to adjust brightness and so saturation.

hue

Three photoreceptor types and two opponent processes determine color categories [Krauskopf et al., 1982]. Two color-blob-neuron opponent processes detect red-green and blue-yellow ranges [Livingstone and Hubel, 1984].

Retina unit areas have one Long-wavelength, one Middle-wavelength, and one Short-wavelength cone. See Figure 1. Any-wavelength light excites all cones. Retina opponent processes calculate L - M and L + M - S. See Figure 2.

Comparing opponent processes, using thresholds to separate continuous frequency-intensity spectra into discrete categories, selects three color-categories. If both opponent-process ranges can be from -1 to +1, blue is (-1,-1), green is (0,0), and red is (+1,+1), where the first value is the L - M range, and the second value is the L + M - S range.

Comparing opponent processes selects four color-categories. Blue is (-1,0), green is (0,+1), yellow is (+1,+1), and red is (+1,0). See Figure 2.

Adding the black-gray-white sense process selects the red, yellow, green, blue, black, gray, and white color categories. See Figure 3.

Vision processing subtracts the smallest primary-color brightness from the other two primary-color brightnesses, and then adds the two results to find hue brightness. Vision processing compares adjacent and overall hue brightnesses to adjust local hue.

opponency pairs

Brightness opponency pairs with darkness opponency. Yellow-blue opponency pairs with blue-yellow opponency. Red-green opponency pairs with green-red opponency. Brain compares opponency pairs for verification and discrimination.

color constancy

Visual-area-V4 neurons account for background illumination, which reflects differentially from local areas, to make color constancy. Spreading excitation, lateral inhibition, and object and object-relation knowledge help make color constancy.

location

A separate visual system finds color spatial locations. The location system finds visual angle (space direction) and distance.

color and location integration

Location system and color system information integrate to specify contrast, color, orientation, shape, location, distance, and time.

Figure 1

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                     Color Wavelengths (in nanometers)
350       400       450       500       550       600       650       700
|----*----|----S----|----*----|----*M---|-L--*----|----*----|----*----|----*
MMMMMMVVVVVVVVVIIIIBBBBBBBCCCCCCCCGGGGGGGCCCYYYYOOOOOORRRRRRRRRRRRRRRRRRRMM
  M         V    I    B       C       G   C   Y     O             R        M
           410  435  460     500 520 540 560 580   610           680

    | B     l     u     e   | G  r  e  e  n  | R       e       d       |

      Receptor Maximum-Sensitivity Wavelengths (in nanometers)
               424                    530   560
    380         S                        540
                430                    M                       660
                430                          L                           720
```

Color wavelengths range from 380 nm to 720 nm: Magenta, Violet, Indigo, Blue, Cyan, Green, Chartreuse, Yellow, Orange, and Red. Wavelengths under color letters indicate center of color range.

Blues predominate from 380 nm to 500 nm.
Blue-greens are from 460 nm to 545 nm.
Greens predominate from 500 nm to 590 nm.
Green-reds are from 545 nm to 630 nm.
Reds predominate from 590 nm to 720 nm.
Red-blues are from 630 nm to 460 nm.

S, M, and L are the short-wavelength, middle-wavelength, and long-wavelength photoreceptors. Photoreceptor spectral curves approximate a normal distribution, with maximum sensitivity at 424 nm, 530 nm, and 560 nm, respectively.

Short-wavelength range is 380 nm to 540 nm.
Middle-wavelength range is 430 nm to 660 nm.
Long-wavelength range is 430 nm to 720 nm.

Figure 2
Example: Color vs. Cone Activity

	Maximum-Sensitivity Wavelength for Receptors		
	Short	Medium	Long
Color	424	530	560
358	0	0	0
392	6	1	0
426	10	3	1
460 blue	9	7	4
494	7	9	7
528 green	2	10	9
562 green	1	9	10
596	0	7	9
630 red	0	4	7
664 red	0	1	4
698 red	0	0	1
732	0	0	0

Example: Color vs. Color-Opponent Activity

	540(green)	501(cyan)			
Color	L - M	L + M - S	L + M	-1 to +1	-1, 0, +1
358*magenta	0	0	0		(+1,-1)
392 violet	-1	-5	1		(0,-1)
426 indigo	-2	-6	4		(-1,-1)
460 blue	-3	2	11	(-1,-1)	(-1, 0)
494 cyan	-2	9	16		(-1,+1)
528 green	-1	17	19	(0, 0)	(0,+1)
562 green	1	18	19		(0,+1)
596 yellow	2	16	16		(+1,+1)
630 orange	3	11	11		(+1,+1)
664 red	3	5	5	(+1,+1)	(+1, 0)
698 crimson	1	1	1		(0, 0)
732*magenta	0	0	0		(+1,-1)

L-M	**L+M-S** -1	0	+1
-1	indigo	blue	cyan
0	violet	crimson	green
+1	magenta	red	yellow

Threshold for	**L - M**	**(L + M) - S**
red (not from blue to green)	$+1 > x > 0$	$+1 > y > 0$
green (not from red to blue)	$-1 < x < 1$	$-1 < y < +1$
blue (not from red to green)	$-1 < x < 0$	$-1 < y < 0$

Cone pairs are symmetric around their mean, and so color pairs are just opposites, with no phenomenal color.

A cone triple makes colors asymmetric and so able to have different perceptual colors.

Figure 3
Example: Color vs. Cone Activity

		Maximum-Sensitivity Wavelength for Receptors		
		Short	Medium	Long
Color		424	530	560
crimson	(.75 red + .25 blue)	2	1	3
magenta	(.50 red + .50 blue)	4	0	2
violet	(.25 red + .75 blue)	6	1	1
blue	(1 blue)	6	2	0
turquoise	(.75 blue + .25 green)	5	3	1
cyan	(.50 blue + .50 green)	4	4	2
spring	(.25 blue + .75 green)	3	5	3
green	(1 green)	2	6	4
chartreuse	(.25 red + .75 green)	1	5	5
yellow	(.50 red + .50 green)	0	4	6
orange	(.75 red + .25 green)	0	3	5
red	(1 red)	0	2	4

Example: Color vs. Color-Opponent Activity

Color		L-M	L+M-S	L+M	M-L+L+M	Combined
crimson (1)		2	0	2	0	2
magenta (2)		1	-1	1	0	2
violet (3)		0	-2	0	0	2
blue (4)		-1	-3	1	2	2
turquoise (5)		-2	-2	2	4	2
cyan (6)	(.75 blue + .25 yellow)	-3	-1	3	6	2
spring (1)		-2	0	4	6	2
green (2)	(.5 blue + .5 yellow)	-1	1	5	6	2
chartreuse (3)	(.5 yellow + .5 green)	0	2	6	6	2
yellow (4)		1	3	5	4	2
orange (5)	(.5 red + .5 yellow)	2	2	4	2	2
red (6)		3	1	3	0	2

Numbers in parentheses show complementary colors.
L-M has maximum at red and minimum at cyan.
L+M has maximum at chartreuse and minimum at violet.
M-L and L+M have maximum at green and minimum at magenta.
L+M-S has maximum at yellow and minimum at blue.

Opponencies make color categories: blue, green, yellow, and red.
Other colors mix these colors.

S-L-M and L-M and (L-M and L+M) have no maxima or minima.

Combining opponencies makes white, because red, green, and blue mix equally. Combining opponencies makes black, because cyan, magenta, and yellow mix equally. Grays mix black and white.

continuity and sensations

Television-screen electron guns excite phosphors that shine until beam returns, so picture persists. Sensory-motor processing exchanges information and interconnects neurons faster than neuron signals decay, making spaces, times, intensities, and sense qualities continuous {continuity and sensations}.

high-level processing and sensations

Low-level processing determines high-level processing, and high-level processing sends feedback to low-level processing. However, high-level-processing feedback is not noticeable, because it causes only secondary effects, has complex features, is statistical, uses whole brain, and takes much longer times {high-level processing and sensations}.

invariants and sensations

Holding all variables, except one, constant can find the derivative with respect to the non-constant variable. Unchanging partial differentials are invariants. Neuron-assembly processing can detect perceptual invariants {invariants and sensations}. Invariants persist and so can become memories.

perception change and first sensation

Perhaps, brain compared before-and-after or adjacent perceptions, and perception changes caused first sensation {perception change and first sensation}. Perhaps, brain compared perception and memory, and sense qualities arose from spatial-gradients, temporal-gradients, differences, or errors. For example, people can realize that motion does not have expected effect. Error can cause punishment or can lower reward. Perhaps, brain detected position differences, and sense qualities arose as movement perception. Perhaps, sense qualities arose as perceptual-process modification, distinction, realization, notice, feeling, or comparison. However, changes, differences, gradients, and errors use same units as original quantities and so are not new things.

probability and sensations

Conscious sense qualities have largest combination number and so highest-probability state {probability and sensations}.

response internalization and first sensation

Stimuli tend to cause muscular or glandular responses. Perhaps, sense qualities arose as responses became notes, marks, or signals {response internalization and first sensation}. Alternatively, brain processes can inhibit tendencies or internal signals. However, behavior is not sense qualities.

statistics and sensations

Sensory-motor processes use many parallel processes and storage registers and are statistical {statistics and sensations}. Because many points contribute to results, narrowing to one distribution and average, resolution can be high.

synchronization and arousal

Synchronizing neuron signals increases intensity by causing simultaneous arrival. Synchronous alpha waves cause arousal {synchronization and arousal}.

CONS>Consciousness>Speculations>Sensation>Biology>Brain>Topographic Map

circuit flows and sensations

Topographic maps can have neuron circuits [Gutkin et al., 2003]. Circuit-flow waves and local patterns can represent objects and sense qualities {circuit flows and sensations}. Vibrations, accelerations, jolts, eddies, vortexes, turbulence, and streamlining, with varying dimension, frequency, phase, and amplitude, can represent sense intensities and qualities. Different senses have different flow patterns.

Intensity is kinetic energy flow per area in flow longitudinal direction.

Liquid flows have lateral-pressure patterns, liquid pools have transverse waves from wind and forces, and moving charges have transverse magnetic fields. Sense-quality information is in two transverse potential energy (not distance) coordinates. Circuit flows have cross-sectional shapes, like random stereograms hold stereoscopic patterns.

Reticular-formation input starts and sustains circuit flows. Topographic-map circuit elements control, analyze, and modulate flows, using stimuli, feedback, feedforward, or hormones.

neuron-array output ratios and sensations

Sense qualities are topographic-map local neuron-activity patterns [Schiffman, 2000] {neuron-array output ratios and sensations}.

registers and sensations

Topographic maps have variable-size three-dimensional registers that hold objects with sense qualities {registers and sensations}. Registers work together to represent motions.

topographic-map displays and sensations

Topographic-map neurons can be Off, On, or in between, like a black-and-white TV screen {topographic-map displays and sensations}. Topographic-map neuron activities can make geometric patterns, such as lines, circles, and ellipsoids. Changing neuron activities can make movements, flows, vibrations, orbits, spins, and waves.

CONS>Consciousness>Speculations>Sensation>Biology>Neuron

coding and sensations

Neuron electrochemical processes cause axon impulse instantaneous frequency, average frequency, and frequency changes, and synapse neurotransmitter-packet release rate {coding and sensations}. Impulses and packets are discrete and make digital code. Summing, averaging, synaptic transmission, transmitter binding, feedback, neuron interactions, and neurohormones blur digital code to make essentially analog code.

stimulus energy and receptors

Stimuli transfer kinetic energy to receptors, which require a minimum (threshold) energy to respond. Light photons collide with, and transfer kinetic energy to, retinal photoreceptors {stimulus energy and receptors}. Photons have energy E that depends on electric-field frequency f: $E = h * f$, where h is Planck constant. Blue-light-photon-energy to red-light-photon-energy ratio is approximately 1.75. Photoreceptors have maximum-sensitivity wavelength and respond less to higher and lower wavelengths.

thresholds as category boundaries

To cause one nerve impulse, neuron input must make neuron membrane potential higher than threshold potential. Below threshold, neuron axon has no impulse, equivalent to 0. Above threshold, neuron axon has one impulse, equivalent to 1. Neuron thresholds split instantaneous input-value range into two output opposites, to make intensity categories {thresholds as category boundaries}. Thresholds convert analog signals to digital signals. Neuron series with increasing thresholds can indicate increasing accumulations/intensities and so categories. Thresholds are the lowest level of meaning: yes or no, present or not, true or false.

neurochemical waves and sensations

After receiving sufficient stimulus input, axon-impulse-frequency and synapse-neurotransmitter-packet-release rates typically increase from baseline level, peak, then decrease to baseline, making one wave {neurochemical waves and sensations}, which has 2-millisecond to 20-millisecond time interval. Because they involve few axon impulses, single waves cannot have amplitude or frequency modulation. Neuron-assemblies have coordinated waves that make neuron-assembly activity patterns, to code stimulus intensity, quality, and location.

CONS>Consciousness>Speculations>Sensation>Chemistry

biochemicals and sensations

Hallucinogens distort mental space and sense qualities. Perhaps, normal biochemicals make undistorted mental space and sense qualities {biochemicals and sensations}.

chemical reactions and sensations

Perhaps, stimuli are like reactants, and perceptions are like products {chemical reactions and sensations}.

CONS>Consciousness>Speculations>Sensation>Computer Science

filtering and sensations

Filtering removes values outside a frequency and/or intensity range. Filtering defines a category by specifying boundaries {filtering and sensations}. Neuron assemblies use thresholds to establish boundaries and make categories.

information processing and sensations

Computers and brains have readers that input data and algorithms, processors that use data and algorithms to make output data, and writers that output data. Computers and brains process information in circuits, transfer information over channels, and store information in structures. Perhaps, mind is dynamic information in brain structures {information processing and sensations}.

operating system and sensations

Computer operating systems control basic functions, such as file manipulation, gathering input, and sending output. Perhaps, minds are like operating systems {operating system and sensations}.

simultaneous mutual interactions and sensations

Analog computers receive continuous voltages or currents and output continuous voltages or currents, so feedback and feedforward simultaneously affect output and input. Simultaneous mutual interaction requires system governors to prevent stops or exponential increases.

Serial digital computers have clocks that step through algorithms in discrete isolated operations that wait for specific input and deliver specific output. Parallel digital computers use clocks and software to deliver inputs and use outputs when appropriate. Digital neural networks step through network layers, so inputs from one layer affect next layer.

Two neurons can exchange information in both directions. One neuron can send excitation directly to other neuron. Other neuron can send excitation directly to third neuron, which sends inhibition directly to first neuron. Brain electrochemical signaling continuously goes through many interconnected circuits simultaneously, so inputs continually affect outputs, and outputs continually affect inputs, unifying and nesting sensation and action and causing continual recursion {simultaneous mutual interactions and sensations}. Perhaps, mind requires simultaneous mutual interactions.

CONS>Consciousness>Speculations>Sensation>Computer Science>Coding

analog coding and sensations

Analog coding is continuous and tracks physical processes directly. Digital coding prevents degradation and other errors and makes categories. Brain uses digital processing for axon impulses and neurotransmitter packets. Perhaps, mind uses analog processing to make continuous sensations {analog coding and sensations}.

code types and sensations

Current computers can code numbers and so code sense intensities but cannot code types and meanings and so cannot represent sense qualities {code types and sensations}.

coded messages and meaning

Perhaps, brain is like ink, and mind is like message {coded messages and meaning}.

CONS>Consciousness>Speculations>Sensation>Computer Science>Files

data structures and sensations

Computers and brains use data structures, such as files, tables, arrays, and displays. Files have elements, such as bytes, numbers, strings, dates, times, and booleans, separated by tabs, commas, and/or spaces. Files can have rows, with fixed or variable column numbers. Perhaps, mind uses three-dimensional displays {data structures and sensations}.

file access and sensations

Computers open and close files to read or write data. Perhaps, brain opens and closes files {file access and sensations}. Opening files is like awakening and becoming conscious, by accessing memory. Closing files is like sleeping, by blocking memory.

structure files and sensations

To describe object collections, structure files list object types and relative coordinates and distances. For example, to describe molecules, chemical structure files list atoms and relative coordinates and distances [Dalby et al., 1992]. Brains can use structure files to describe visual displays {structure files and sensations}.

CONS>Consciousness>Speculations>Sensation>Computer Science>Language

programming languages and sensations

Computer-processor programs use binary code. Assembly languages express hardware operations in simple grammar. Human-readable programming languages have sentence-like statements. Programming languages can emphasize procedures that manipulate objects or objects that have procedures. BASIC and C are procedure oriented. Java and C++ are object oriented. High-level code translates unambiguously into low-level code, and vice versa. Brain uses low-level code and/or procedure-oriented programming languages. Perhaps, mind uses object-oriented programming {programming languages and sensations} to represent geometric objects and perform geometric operations.

CONS>Consciousness>Speculations>Sensation>Computer Science>Vision

ray tracing and sensations

Ray tracing {ray tracing and sensations} tests light-source and surface-reflection light rays, to see where they land on object-depth-indexed two-dimensional-surface displays. Ray tracing indexes object locations, directions, and distances, as well as shapes, overlaps, shadows, light sources (emissions), absorptions, reflections, refractions, opaqueness, translucency, transparency, and color variations [Glassner, 1989].

vector graphics and sensations

Vector graphics {vector graphics and sensations} [Foley et al., 1994] represents scenes using geometric-figure descriptors, such as "circle", which have parameters, such as "color", "radius", and "center", which have values, such as "black" or "2". Descriptors have positions relative to other descriptors or to the display.

Vector graphics represents images using mathematical formulas for volumes, surfaces, and curves (including boundaries) that have parameters, coordinates, orientations, colors, opacities, shading, and surface textures. For example, circle information includes radius, center point, line style, line color, fill style, and fill color. Vector graphics includes translation, rotation, reflection, inversion, scaling, stretching, and skewing. Vector graphics uses logical and set operations and so can extrapolate and interpolate, including filling in.

CONS>Consciousness>Speculations>Sensation>Mathematics

complex number analogy

Complex-number real-number part indicates physical measurement. Imaginary-number part, and interactions between real and imaginary numbers, account for factors affecting solutions or processes. Complex-number multiplication is commutative: $(a + b*i) * (c + d*i) = (c + d*i) * (a + b*i)$. Other complex-number operations can be non-commutative, so complex-number operations can represent all physical interactions. Complex-number functions and series can represent physical states or processes, because they can model translations, rotations, reflections, inversions, and waves, including interference, superposition, resonance, and entanglement. Complex-number operations make complex numbers, not new number types, and so can model physical situations, because physical interactions make only existing physical properties, not new ones.

Perhaps, brain is like real numbers, and mind is like imaginary numbers {complex number analogy}. Like real and imaginary numbers, brain and mind are separate and independent but can interact.

duals and sensations

In networks, links and nodes are duals. In two-dimensional projective geometry, points and lines are duals. In three-dimensional projective geometry, planes and points are duals. In three-dimensional space, lines bound surfaces, and surfaces bound lines, so mathematical theorems about lines have corresponding mathematical theorems about surfaces. On n-manifolds, p-forms and (n-p)-forms are duals, so 1-form (covariant tensor, linear function of coordinates, or manifold gradient) and vector field (contravariant tensor, function, or manifold) are duals, and they interact to make scalar products. For vectors, tangent vectors have covector duals. Perhaps, mind and brain are duals, and phenomena and manifolds are duals {duals and sensations}.

principal components and perception

From intensity and intensity-change comparisons, brain can build variables that are optimal for describing sensations {principal components, perception}. Different senses have different principal components. Within a sense, different qualities have the same principal components but with different values. Principal components are the same for everybody.

spherical harmonics and sensations

Indefinite spherical harmonics build to make indefinite Fourier three-dimensional waves that model/simulate sensations {spherical harmonics and sensations}.

CONS>Consciousness>Speculations>Sensation>Mathematics>Color

algebra and color

Algebras have elements, such as integers. Algebras have operations on elements, such as addition. Integer additions result in integers. Integer addition commutes: 13 + 27 = 40 = 27 + 13. Integer addition is associative: (13 + 27) + 5 = 45 = 13 + (27 + 5). Integer identity element adds to integers to make the same integer: 13 + 0 = 13, and 0 + 0 = 0. Integer inverse elements add to integers to make zero: 13 + -13 = 0, and 0 + 0 = 0. Finite or infinite tables can show operation results for all element pairs.

If elements are colors and operation is additive color mixing, adding two colors makes color, by wavelength-space vector addition, following Grassmann's laws {algebra and color}. Order of adding two colors does not matter, so color addition is commutative. Sequence of adding three colors does not matter, so color addition is associative. Colors have complementary additive-inverse colors, and adding both colors makes white, so color addition has inverses. Adding black, white, or gray to color does not change color hue but does change saturation, so black, white, or gray are like identity elements. Unlike integer addition, adding color to itself makes same color.

distributive property

Identity, inverse, commutation, and association work whether colors come from light sources or reflect from pigments. Colors from light sources and colors from pigment reflections can mix. If reflected color mixes with mixture of two source colors, or if reflected color mixes with each of two source colors and then mixtures combine, same color results, like the distributive property.

harmonic ratios and color

Tone and color frequencies and wavelengths have harmonic ratios {harmonic ratios, color}.

harmonics

Harmonic ratios have small integers in numerator and denominator. In increasing order of denominator, harmonic ratios are 1:1, 2:1, 3:2, 4:3, 5:3, 5:4, and so on.

color wavelengths

The purest red color is at light wavelength 683 nm, with orange at 608 nm, yellow at 583 nm, green at 543 nm, cyan at 500 nm, blue at 463 nm, and violet at 408 nm. Magenta can be at 380 nm or 760 nm.

color wavelength ratios

Color wavelength ratio for red/yellow, 683/583 = 1.17, and green/blue, 543/463 = 1.17, is 7/6 = 1.17 or 6/5 = 1.20. Color wavelength ratio for red/green, 683/543 = 1.26, and yellow/blue, 583/463 = 1.26, is 5/4 = 1.25. Color wavelength ratio for red/blue, 683/463 = 1.48, is 3/2 = 1.5. Color wavelength ratio for yellow/green, 583/543 = 1.07, is 13/12 = 1.085. Color wavelength ratio for red/violet, 683/408 = 1.67, and magenta/indigo, 725/435 = 1.67, is 5/3 = 1.67. See Figure 1.

color frequency ratios

Color frequency ratio for yellow/red, 518/436 = 1.19, and blue/green, 652/556 = 1.17, is 7/6 or 6/5. Color frequency ratio for green/red, 556/436 = 1.28, and blue/yellow, 652/518 = 1.26, is 5/4. Color frequency ratio for blue/red, 652/436 = 1.50, is 3/2. Color frequency ratio for green/yellow, 556/518 = 1.07, is 13/12. Color frequency ratio for violet/red, 740/436 = 1.70, and indigo/magenta, 694/420 = 1.66, is 5/3.

additive complementary colors

Additive complementary color pairs have same wavelength ratio, 4/3 = 1.33. Red/cyan is 683/500 = 1.37 to 650/500 = 1.30. Yellow/blue is 583/463 = 1.26 to 583/435 = 1.34. Chartreuse/indigo is 560/435 = 1.29 to 560/408 = 1.37. Magenta/green is 722/543 = 1.33.

Additive complementary-color triples have three color-pairs, whose average wavelength ratio is also 4/3. For three additive complementary colors, ratios are red/blue, 683/463 = 1.48, red/green, 683/543 = 1.26, and green/blue, 543/463

= 1.17. Arithmetic average is (1.5 + 1.25 + 1.2)/3 = 1.32. Geometric average is (1.5 * 1.25 * 1.2)^0.333 = 1.32. For three subtractive complementary colors, ratios are magenta/cyan, 722/500 = 1.45, magenta/yellow, 722/583 = 1.24, and yellow/cyan, 583/500 = 1.17. Average wavelength ratio is 4/3.

Three complementary colors have same relative values: red = 1.5, green = 1.2, and blue = 1, or magenta = 1.5, yellow = 1.2, and cyan = 1.

subtractive complementary colors

Because mixing darkens and blues colors, subtractive complementary color pairs have increasing wavelength ratios. Red/green is 683/543 = 1.26. Orange/blue is 608/463 = 1.31. Yellow/indigo is 583/435 = 1.34. Chartreuse/violet is 560/408 = 1.37.

color wavelength ratios starting at red

Starting with red at 1/1 = 683/683, orange is 8/7 = ~683/608, yellow is 7/6 = ~683/583, green is 5/4 = ~683/543, cyan is 4/3 = ~683/500, blue is 3/2 = ~683/463, violet is 5/3 = ~683/408, and magenta is 7/4 = ~683/380.

color wavelength ratios starting at green

Magenta is 2/3 = ~380/543. Violet is 3/4 = ~408/543. Blue is 5/6 = ~463/543. Cyan is 8/9 = ~500/543. Green is 1/1 = 543/543. Yellow is 17/16 = ~583/543. Orange is 9/8 = ~608/543. Red is 5/4 = ~683/543. Magenta is 4/3 = 720/543.

color wavelength ratios starting at red

Starting with red at 1/1 = 683/683, orange is 8/7 = ~683/608, yellow is 7/6 = ~683/583, green is 5/4 = ~683/543, cyan is 4/3 = ~683/500, blue is 3/2 = ~683/463, violet is 5/3 = ~683/408, and magenta is 7/4 = ~683/380.

color wavelength ratios starting and ending at magenta

On color circles, complementary colors are opposites. Complementary-color pairs have same wavelength ratio, so cyan/red = blue/yellow = magenta/green. Colors separated by same angle have same wavelength ratio, so yellow/red = green/yellow = cyan/green = blue/cyan = magenta/blue = red/magenta. Example color circle has red = 32, yellow = 16, green = 8, cyan = 4, blue = 2, and magenta = 1 and 64. Put into octave as exponentials, red = 2^0.83, yellow = 2^0.67, green = 2^0.5, cyan = 2^0.33, blue = 2^0.17, and magenta = 2^0 and 2^1. Put into octave, magenta = 2/1, red = 9/5, yellow = 8/5, green = 7/5, cyan = 5/4, blue = 9/8, and magenta = 1/1. Complementary colors have ratio 1.412 = ~7/5. Neighboring colors have ratio 1.125 = 9/8. Example wavelengths with these ratios are magenta = 750 nm, red = 668 nm, yellow = 595 nm, green = 531 nm, cyan = 473 nm, blue = 421 nm, and magenta = 375 nm, close to actual color wavelengths.

color harmonic ratios

Color frequency categories are at harmonic ratios: 48 Hz for red, 60 Hz for green, and 72 Hz for blue. 60/48 = 1.25 = 5/4. 72/48 = 1.5 = 3/2. 72/60 = 1.2 = 6/5. See Figure 2. Color-pair wavelength ratios have harmonic relations. Red/magenta = 7/4. Red/violet and magenta/indigo = 5/3. Red/blue = 3/2. Complementary colors red/cyan, yellow/blue, chartreuse/indigo, and magenta/green = 4/3. Red/green and yellow/blue = 5/4. Red/yellow and green/blue = 6/5 or 7/6. Red/orange = 8/7. Green/cyan = 9/8. Yellow/green = 13/12. See Figure 3.

Red, green, and blue add to make white. Magenta, cyan, and yellow add to make black. For red, green, and blue, and for magenta, cyan, and yellow, average of the three color-pair wavelength ratios is 4/3.

Looking at only primary colors red, green, and blue, color-pair wavelength ratios are red/blue 3/2, red/green 6/5, and green/blue 5/4. Red:green:blue relations have 6:5:4 ratios.

Looking at wavelength differences rather than wavelength ratios, magenta, red, orange, yellow, green, cyan, blue, and violet have approximately equal wavelength differences between adjacent colors. See Figure 2. Setting wavelength difference equal to one, color wavelengths form series 8, 7, 6, 5, 4, 3, 2, and 1. See Figure 3.

Assuming colors are like tones, colors can fit into one octave. Primary colors red, green, and blue, and complementary colors cyan, magenta, and yellow, respectively, are equally spaced in octave from 2^0 to 2^1. Magenta, red, yellow, green, cyan, blue, and magenta form series 6, 5, 4, 3, 2, 1, and 0. Magenta = 2^1, red = 2^0.83, yellow = 2^0.67, green = 2^0.5, cyan = 2^0.33, blue = 2^0.17, and magenta = 2^0. Adjacent colors have ratio 2^0.17 = 1.125 = 9/8. All complementary colors have the same ratio, 2^0.5. All complementary-color triples, such as red/green/blue, average 2^0.5. White, gray, and black have average color-pair wavelength ratio 2^0.5. In this arrangement, color-pair ratios are red/magenta ~ 9/5, yellow/magenta ~ 8/5, green/magenta ~ 7/5, cyan/magenta ~ 5/4, and blue/magenta ~ 9/8. See Figure 3. In this arrangement, whites, grays, and blacks are farthest from being octaves and so have dissonance. Other colors have smaller integer ratios and so more consonance. Color categories are at harmonic ratios.

multiple harmonics

One pair has two or three categories, like tone intervals or red/green or red/green/blue. Two pairs make six or seven categories, like octave whole tones or main spectrum colors. Three pairs make 12 categories, like octave half tones or major spectrum colors. Four pairs make 24 categories, like octave quarter tones or major and minor spectrum colors.

summary

Using physical-color wavelengths, wavelength ratios are red/magenta = 7/4, red/violet = magenta/indigo = 5/3, red/blue = 3/2, red/cyan = yellow/blue= chartreuse/indigo = magenta/green = 4/3, red/green = yellow/blue = 5/4, red/yellow = green/blue = 6/5 or 7/6, red/orange = 8/7, green/cyan = 9/8, and yellow/green = 13/12.

Additive complementary-color pairs, such as red/cyan, yellow/blue, chartreuse/indigo, and magenta/green, have same 4/3 wavelength-ratio.

For red, green, and blue additive complementary colors, average of the three wavelength ratios, red/blue, red/green, and green/blue, is 4/3. For magenta, cyan, and yellow subtractive complementary colors, average of the three wavelength ratios, magenta/cyan, magenta/yellow, and yellow/cyan, is 4/3.

These intervals are harmonic musical tones in an octave: C, E, and G in the key of C. Blue and red make a major fifth interval. Blue and green make a minor third interval. Green and red make a major third interval.

Figure 1

Color Wavelength Ratios

	/red	/ora	/yel	/cha	/gre	/cya	/blu	/ind	/vio	/mag
730 magenta										2
683 red/	1	**1.12**	**1.17**	1.22	**1.26**	1.37	**1.48**	1.57	**1.67**	**1.87**
608 orange/		1	1.04	1.09	**1.12**	1.22	**1.31**	1.40	**1.49**	**1.67**
583 yellow/			1	1.04	1.07	1.17	**1.26**	1.34	**1.43**	**1.60**
560 chartreuse/				1	1.03	1.12	1.21	1.29	1.37	1.53
543 green/					1	1.09	**1.17**	**1.25**	**1.33**	**1.49**
500 cyan						1	1.08	1.15	1.23	1.37
463 blue/							1	1.06	**1.13**	**1.27**
435 indigo/								1	1.07	1.20
408 violet/									1	1.12
365 magenta										1

Colors and Frequency Ratios

Color	Ratio	Color Tone	
magenta	0.94 = 15/16	B	
red	1.00 = 1/1	C	= 2^0.00
orange	1.12 = 9/8	D	= 2^0.17
yellow	1.20 = 6/5	D#	= 2^0.25
green	1.25 = 5/4	E	= 2^0.33
cyan	1.33 = 4/3	F	= 2^0.42
blue	1.50 = 3/2	G	= 2^0.58
violet	1.67 = 5/3	A	= 2^0.75
magenta	1.88 = 15/8	B	= 2^0.92

Figure 2

Colors distribute approximately equally by wavelength across the visible spectrum.

Color	Wavelength (nm)	Difference (nm)
Magenta		
Violet	410	40
Blue	460	50
Cyan	500	40
Green	540	40
Yellow	580	40
Orange	610	30
Red	650	40
Magenta		40
		320

Colors distribute approximately equally around green, by wavelength.

Color	Wavelength (nm)	Difference (nm)
Magenta	380	−160
Violet	410	−130
Blue	460	−80
Cyan	500	−40
Green	540	0
Yellow	580	+40
Orange	610	+70
Red	660	+120
Magenta	700	+160

Equal-wavelength separations make a series of small-integer (harmonic) ratios.

Color	Multiples	Ratios
Magenta	0	0
Violet	40	1
Blue	80	2
Cyan	120	3
Green	160	4
Yellow	200	5
Orange	240	6
Red	280	7
Magenta	320	8

Figure 3

Fit into an octave, color wavelengths have small-integer (harmonic) ratios.

Color	Tone	Logarithm	Ratio	Numeric Ratio
Magenta	C	2^0.00	1/1	1.00
Violet	C#	2^0.06	13/12	1.09
Indigo	D	2^0.13	9/8 or 8/7	1.13 or 1.14
Blue	D#	2^0.19	7/6	1.17
Turquoise	E	2^0.25	6/5	1.20
Turquoise	E	2^0.32	5/4	1.25
Cyan	F	2^0.38	4/3	1.33
Spring	F	2^0.44	11/8	1.38
Green	F#	2^0.50	17/12	1.42
Chartreuse	G	2^0.56	3/2	1.50
Chartreuse	G	2^0.63	19/12	1.58
Yellow	A	2^0.69	13/8	1.63
Orange	A	2^0.75	5/3	1.67
Vermilion	A#	2^0.82	7/4	1.75
Red	B	2^0.88	11/6	1.83
Crimson	B	2^0.94	23/12 or 15/8	1.92
Magenta	C	2^1.00	2/1	2.00

mathematical group and color

Mathematical groups have elements, such as triangles. Operations map group elements to the same or another element. For example, if element is equilateral triangle, rotations around center by 120 degrees result in same element. Finite or infinite tables can show operation results for all elements.

If elements are colors and operation is additive color mixing, adding two colors makes color, by wavelength-space vector addition, following Grassmann's laws {mathematical group and color}. Adding black, white, or gray to color does not change color hue but changes color saturation, so color addition is not a single operation.

vectors and colors

Because they cannot be negative but can complement each other, color qualities are vectors {vectors and colors}. Color vectors have three components: hue, saturation, and brightness, or red, green, and blue.

CONS>Consciousness>Speculations>Sensation>Mathematics>Information

information compression and sensations

Perhaps, sense qualities are compressed intensity-frequency spectra {information compression and sensations}.

negative information

Sense information includes negative information {negative information}, such as not blue.

CONS>Consciousness>Speculations>Sensation>Physics

acceleration pattern and sensations

Perhaps, sense qualities depend on acceleration patterns {acceleration pattern and sensations} and are about flow vibrations, jolts, eddies, vortexes, streamlining, and turbulence.

motions

Translations, vibrations, rotations, reflections, inversions, and transitions can have accelerations. Vibrations, rotations, and transitions have acceleration changes.

accelerations

Forces include tensions, compressions, and torsions. Photon and molecule interactions transfer energy and cause forces, accelerations, and acceleration changes. Materials resist tension, compression, and torsion and reduce initial acceleration to zero acceleration. Accelerations have location, duration, maximum, minimum, and change rate.

jolt types

Acceleration changes (jolts) are vectors, with magnitude and direction, and have different types.

Acceleration can be zero (with no net force), so jolt is zero. Acceleration can be constant positive (due to constant positive force), so jolt is zero. Acceleration can be constant negative (due to constant negative force), so jolt is zero.

Acceleration can increase at constant rate (due to constant positive force change), so jolt is constant positive. Acceleration can decrease at constant rate (due to constant negative force change), so jolt is constant negative.

Acceleration can increase at increasing rate (due to increasing positive force change), so jolt is increasing positive (until resisting force makes it constant positive). Acceleration can decrease at increasing rate (due to increasing negative force change), so jolt is increasing negative (until resisting force makes it constant negative). Acceleration can increase at decreasing rate (due to decreasing positive force change), so jolt is decreasing positive (until it becomes constant). Acceleration can decrease at decreasing rate (due to decreasing negative force change), so jolt is decreasing negative (until it becomes constant).

Acceleration can oscillate between increase and decrease, so jolt oscillates.

collisions

Before inelastic collisions, colliding-object deceleration is zero, and velocity is maximum: kinetic energy = 0.5 * mass * velocity^2. In inelastic collisions, colliding-object deceleration quickly reaches maximum, and velocity starts to decrease: Force = mass * acceleration = k * (S - x) = -k * S, where k is material's resistance factor, x is distance traveled in material, and S is distance at which object stops. After inelastic-collision process ends, colliding-object deceleration and velocity decrease to zero: F = k * (S - x) = 0.

vibrations

At vibration equilibrium point, molecule acceleration is zero, and velocity is maximum. Then, velocity decreases, and deceleration increases. At maximum displacement, velocity is zero, and deceleration is maximum. Then, velocity increases, and acceleration increases, in opposite direction. At equilibrium point, acceleration is zero, and velocity is maximum, in opposite direction. Jolts depend on wave frequency and amplitude.

receptor acceleration patterns

Energy transfer causes receptor-molecule change. Molecule atoms accelerate, change energy to potential energy as they decelerate, and then stop moving. Then, molecule transfers energy to signal molecule, and receptor molecule returns to resting state. Signal molecules go to other cell receptors, making a cell signaling system. Neurotransmitters, neurohormones, and neuroregulators go to receptors on other cells and sustain the code. Receptors, signal molecules, and later molecules have vibrations and so acceleration changes.

dimension and sensations

String theory has extra spatial dimensions. Universe may have hidden spatial or temporal dimensions. Perhaps, mind is in hidden dimensions, and experience is orthogonal to normal space-time {dimension and sensations}. However, physical activity must affect mind, so mind does not involve extra spatial or temporal dimensions.

electromagnetism and sensations

Electromagnetism can relate to sense qualities {electromagnetism, sensations}.

electromagnetic induction

Changing electric fields induce magnetism, and changing magnetic fields induce electric force. Perhaps, brain induces mind. For example, brain particles cause mind waves.

fire

Fire is electromagnetic radiation from excited electrons in oxidation reactions. Perhaps, brain has reactions whose secondary effects make mind. Burning is like unconsciousness, and fire is like consciousness.

magnetism

Though net electric charge is zero, electric-charge relativistic motions make observable net electric charge perpendicular to motion, creating magnetism. Perhaps, mind depends on active "charges" whose relative motions and interactions create net effects, but whose static states are not observable.

hidden variable and sensations

Physical and mental descriptions use variables. Variables can be measurable and have units. Variables can be ratios with no units. Variables can be not measurable and have no values or units. Perhaps, brain is about measurable variables, but mind involves hidden immeasurable variables {hidden variable and sensations}. Properties that combine other properties can seem ineffable. For example, words can sound the same when used as nouns or verbs, but actually have subtle noun-marker or verb-marker sound features.

quantum mechanics and sensations

Matter and energy properties are discrete. For example, energy has quanta. Matter and energy are both particle and wave. Waves allow probabilistic physical events and transitions without intermediate states. Particle waves are infinite and allow action at distance and non-local effects. Quantum-mechanical mathematical waves simultaneously represent multiple points and energies, and string-theory moving strings simultaneously represent multiple points. Perhaps, sense qualities are brain-activity quantum-mechanical effects {quantum mechanics and sensations}.

mathematical waves

Perhaps, mind and consciousness involve mathematical waves, similar to quantum-mechanical waves. Infinite waves have no definite position and fill space, accounting for sensory field. Waves can have wave packets, accounting for sensations.

complementarity

Quantum-mechanical waves and particles describe event positions and energies (complementarity). Forces are particle exchanges, and energies depend on wave superpositions. Perhaps, brain and mind have complementarity. Brain uses particle motions, and mind uses abstract waves.

electronic transition

Electrons orbiting atomic nuclei move to other orbits with no intermediate stages. Quantum-mechanical waves change frequency with no intermediate frequencies. Perhaps, mind is like quantum-mechanical waves or is intermediate to physical interactions.

virtual particle

Quantum-mechanical particle interactions and wave energy transformations can create particle pairs that exist for less than one quantum time unit. For example, spontaneous energy fluctuations create virtual particle pairs in space vacuum. Interaction cannot create single particles, because one particle cannot conserve momentum. Instruments cannot observe virtual particles, because they recombine rapidly to return vacuum energy to more-probable state. Though they have short existence, virtual particles can interact with real particles. Perhaps, mind is like virtual particles, which can affect brain but have no direct measure.

orbitals

Electron orbitals have one resonating wave, with frequency, amplitude, inertia, and moment. Perhaps, sense qualities are resonating wave packets in three-dimensional orbitals. Orbital amplitude represents intensity. However, orbitals cannot model colors, because colors also have saturation.

spins

Particles have spin, with frequency, amplitude, inertia, and moment. Perhaps, sense qualities are particles with spins. However, spins cannot model colors, because primary-color spins cannot interact or sum to make secondary-color spins.

relativity and sensations

General relativity shows that masses and energies change space shape, and changed space alters particle motions through space. Perhaps, brain is like masses and energies, and mind is like space {relativity and sensations}. Brain masses affect mind space, and mind space affects brain masses.

right-left symmetry and sensations

Universe has right and left forms, and most physical laws have parity. Perhaps, universe has another right-left-like asymmetry that causes reality to have two sides, physical and mental {right-left symmetry and sensations}. Mind can look behind reality. For example, surfaces have two sides, and back can affect front and vice versa. Mental reality is entirely physical but is complementary to physical reality.

subphysical processes

Particle and object collisions, gravitation, and electromagnetism are relatively strong (primary) forces. Perhaps, mental forces and energies are very weak (secondary) forces and energies {subphysical processes}.

superphysical processes

Superphysical processes transcend physical forces by extending them {superphysical processes}. Perhaps, mental forces and energies are superphysical.

CONS>Consciousness>Speculations>Sensation>Physics>Energy

energy and sensations

Perhaps, sense qualities are energies, and their intensities are energy densities {energy and sensations}. Perhaps, perceptual surfaces have types of kinetic and/or potential energy.

Physical forces have one dimension, because they are interactions between particles. Vectors represent forces. Physical energies have no dimensions, because they are integrals of forces over distances. Scalars represent energies. Physical energies can flow, so intensities have one dimension. Vectors represent intensities. Perhaps, sensations have more than one dimension, because they combine properties.

heat and temperature and sensations

Heat, an extensive quantity, makes temperature, an intensive quantity. Perhaps, brain energy makes mind intensity {heat and temperature and sensations}.

potential energy and sensations

Potential energies are scalars and have type, amount, radial distance, azimuth, and elevation. Sensations are not vectors, because sense qualities do not have direction or flow. Like potential energies, sensations are in fields. Sensations have azimuth, elevation, and radial distance. Perhaps, sensations are like non-physical potential energies {potential energy and sensations}.

CONS>Consciousness>Speculations>Sensation>Physics>Interaction

interaction and sensations

Independent things add. Same objects and properties can add. Summing or subtracting two same-type quantities results in values with same unit. Integration involves summation. Summations make extensive quantities.

Interacting objects and properties multiply. Same or different objects and properties can multiply. Multiplying or dividing two quantities results in values with different unit. Differentiation involves division. Divisions make intensive quantities.

Two masses or two charges interact to make gravitational or electric force. Multiplying same units can make intensive quantities: (4 kg) * (6 kg) / (2 meters)^2 = 6 N of force. Multiplying 4 newtons of force and 5 meters of distance makes 20 newton-meters, 20 joules of energy. Multiplying different units can make extensive quantities. Multiplying 4 coulombs and 5 kilograms makes 20 coulomb-kilograms. However, combining charge and mass has no physical meaning, because charge and mass do not interact. Multiplying can make extensive or intensive quantities.

Only continuous quantities can interact. Discrete quantities cannot affect each other. For example, 4 oranges times 5 bananas results in 20 banana-oranges, which do not exist. Multiplying 4 oranges and 5 oranges results in 20 orange-oranges, which do not exist.

New things arise from physical or mathematical interactions. Perhaps, sense qualities arise from physical or mathematical interaction mechanisms {interaction and sensations}. Neurons use no units.

joining and sensations

Joining existing things can produce something new {joining and sensations}. Joining alters or destroys existing objects.

new force or energy

Physics is still discovering new physical forces and energies, with unknown properties. Perhaps, mind has new physical forces, energies, and fields {new force or energy}. However, mind does not measurably affect physical world.

splitting and sensations

Splitting existing things can produce something new {splitting and sensations}. Making something from physical void or vacuum requires splitting. Void can split into opposites: point and anti-point, pole and anti-pole, left spin and right spin, and ON mark and OFF mark. Splitting can destroy existing properties.

CONS>Consciousness>Speculations>Sensation>Physics>Phase

crystals and sensations

Perhaps, colors are like crystals, with different symmetries and harmonics {crystals and sensations}.

particles and sensations

Perhaps, sense qualities result from kinetics and dynamics of many abstract particles, which make phases {particles and sensations}.

phases and sensations

Solid, liquid, and gas phases depend on material, temperature, and pressure. Within a sense type, sense qualities are like phases {phases and sensations}. Perhaps, red, green, and blue are different phases. Complementary colors mix phases, like at double points. Color mixtures that result in white, gray, and black are at triple points.

CONS>Consciousness>Speculations>Sensation>Physics>Wave

phosphorescence and sensations

Brain is like phosphors, which phosphoresce for seconds after stimulation {phosphorescence and sensations}. Long times allow neuron activities to integrate.

waves and sensations

Oscillations can be longitudinal along one dimension, such as chemical-bond-length oscillations. Oscillations can be transverse along two dimensions, such as chemical-bond-angle oscillations. Violin-string points oscillate transversely across resting-string line. Plane waves, such as in vibrating guitar strings, can rotate around travel-direction axis, like helices, in three dimensions. Electromagnetic-wave points have transverse electric-field oscillation and transverse perpendicular magnetic-field oscillation. Electromagnetic waves also travel, so they have three dimensions and can rotate around travel direction. Electrons in electronic orbitals can oscillate in three dimensions.

Waves spread over space. Perhaps, mind is like waves {waves and sensations}. However, waves cannot model colors, because primary-color waves cannot interact or sum to make secondary-color waves.

wave modulation

Television and radio signals have basic frequencies. To carry information about music or scenes, basic-wave amplitude or frequency can vary with signal intensity and frequency. Flow modulation can carry information. Perhaps, mind is modulated brain waves or flows.

frequency transitions

Waves change frequency in one cycle, with no intermediate stages. Mind transitions between mental states with no intermediate states.

CONS>Consciousness>Speculations>Sensation>Psychology

attention and first sensation

People can attend to new or contrasting stimuli without full awareness {attention and first sensation} [Berns et al., 1997] [Debner and Jacoby, 1994] [Hardcastle, 2003] [He et al., 1996] [Lamme, 2003] [McCormick, 1997] [Merikle and Joordens, 1997] [Posner, 1994] [Robertson, 2003] [Tsuchiya and Koch, 2007].

blindsight and first sensation

Cortical disease or injury can result in minimal experience {blindsight and first sensation}, such as blindsight, in which people are only aware of object or surface presence, existence, or motion [Azzopardi and Cowey, 1997] [Barbur et al., 1993] [Güzeldere et al., 2000] [Holt, 1999] [Kolb and Braun, 1995] [Sanders et al., 1974].

labeling and sensations

Sensations label perceptions {labeling and sensations}, to provide meaning for perceptions. For example, the color red is a label for a feature, and "red" and "green" name features. Using a symbol, label, index, reference, or name defines a category, feature, or variable type. Applying a label groups objects, events, relations, or ideas. Indexing helps memory and recall.

Label meaning can depend on relation to body parts. Many means more than number of fingers. Large means larger than body. Right means nearer to right arm than left arm. Up means nearer to head than feet. Complex labels, such as elephant or victory, combine simple labels.

marking and first sensation

Perhaps, sense qualities arose as marking {marking and first sensation}. Markers provide reference signs, such as indexes, to which other signs can relate. For example, consciousness can mark figure and not ground. Marking has no units, such as length units. However, marking is only information bits and so is not a new thing.

musical instrument analogy and first sensation

Like music from instruments, brain produces mind {musical instrument analogy and first sensation}.

synthesis and first sensation

Analysis finds differences, parts, and functions. Synthesis finds similarities, wholes, and goals. After neuron-assembly information analysis, brain synthesizes intensity and frequency to make first sensation {synthesis and first sensation}.

CONS>Consciousness>Speculations>Sensation>Psychology>Sense

sense properties and first sensation

Sense properties relate to first sensation {sense properties and first sensation}. Sensations require duration, location, intensity, and quality.

intensity

Intensity alone cannot make sensation. Something or nothing, on or off, yes or no, true or false, or 0 or 1 has no type. Thresholds make switches, with no units. Intensity is only information bits and so is not a new thing. Intensity at spatial location has no type. Intensity for duration has no type.

intensity type

Intensity type alone, without intensity, spatial, or temporal information, has no amount. Intensity-type in space, without time or intensity, has no amount. Intensity type at space location for duration has no amount. Intensity type for duration has no amount. Intensity and intensity-type, without temporal or spatial information, has amount and type.

time

Before and after, time flow, or cycles in time, without space, intensity, or intensity type, has no type.

position

Space location alone, without intensity, intensity-type, or temporal information, has no type.

space

Perhaps, sense qualities arose as nearness or farness, right or left, or up or down in space. Space location for duration has no type.

surface

Perhaps, first sensations indicate only surface presence, existence, or motion, with no phenomenal quality, intensity, or pattern, purely mathematical, spatial, and geometric.

hearing properties

Tones can be harsh or smooth, be sharp or flat, and have acute or gradual onset and offset {hearing properties}. Tone pairs can have consonance or dissonance and major or minor intervals.

Physically, sound waves have frequencies with intensities. Frequencies have ratios, so sounds have harmonics, such as octaves, fifths, thirds, fourths, sixths, and sevenths. Physiologically, sounds are independent and unmixed (analytic) and have loudness and tone. Hearing perceptual processes [Kaas and Hackett, 2000] compare adjacent and harmonic frequency intensities to find loudness and tone. Relative sound intensity determines loudness. Loudness ranges from painful to whisper. People can distinguish 100 loudness levels. Sound frequency determines tone. Tones have width, deepness, shrillness, and thickness. High frequencies are narrow, shallow, shrill, and thin. Low frequencies are wide, deep, dull, and thick. People can distinguish 10 octave levels and 12 (or 24) harmonic levels, so people can distinguish 120 tones.

pain and pleasure

Pain can be high-amplitude pain, acute pain, or dull pain. Pleasure can be high-amplitude pleasure, acute pleasure, dull pleasure, or orgasm {pain properties} {pleasure properties}.

Physically, pains have inelastic distortions. Physiologically, people feel dull or acute pain. Pain perceptual processes [Chapman and Nakamura, 1999] compare nociceptor inputs. Inelastic distortion determines pain, which can be acute or dull. People can distinguish 10 pain levels.

smell properties

Odors are sweet, putrid, cool, hot, sharp, and flat {smell properties} {odor properties}. Odors can be sweet, like fruit, or putrid, like goat or sweat. Odors can be cool, like menthol, or hot, like heavy perfume. Odors can be sharp and harsh, like vinegar or acid, or flat and smooth, like ether or ester. Aromatic, camphorous, ether, minty, musky, and sweet are similar. Camphor, resin, aromatic, musk, mint, pear, flower, fragrant, pungent, fruit, and sweets are similar. Goaty, nauseating, putrid, and sulphurous are similar. Smoky/burnt and spicy/pungent are similar. Putrid or nauseating, foul or sulfur, vinegar or acrid, smoke, garlic, and goat are similar. Acidic and vinegary are similar. Acidic and fruity are similar. Vegetable smells are similar. Animal smells are similar.

Physically, air-borne chemicals have concentrations, sizes, shapes, and sites and attach to nasal-passage chemical receptors. Physiologically, smells are strong or weak fruity, flowery, sweet, malty, earthy, savory, grassy, acrid, putrid, minty, smoky, pungent, camphorous, musky, urinous, rubbery, tobaccoey, woody, spermous, nutty, fishy, rotten, and medicinal. Smell detects aldehyde smells first, floral smells second, and lingering musky, sweet spicy, and woody smells later. Smells are mild-pungent (flat-sharp) and sweet-putrid. Foul, sulfurous, acidic, acrid, and putrid are pungent and putrid. Pungent, burnt, and spicy are pungent and neutral. Mint, ether, and resin are pungent and sweet. Flowery and fruity are mild and sweet. Musk is mild and neutral. (Mild cannot be putrid.) Smells can be cool, like menthol, or hot, like heavy perfume. Cool and hot mix mild-pungent and sweet-putrid. Smell perceptual processes [Firestein, 2001] [Laurent et al., 2001] compare alcohols (fruity), ethers in concave and trough-shaped sites (ethereal and flowery), esters as chains (sweet), aldehydes (malty), dioxacyclopentanes (earthy, moldy, and potatoey), furanones (savory spice), hexenals and alkene aldehydes (grassy and herby), smallest positively charged carboxylic acids (acrid or vinegary), larger positively charged carboxylic acids as chains (putrid and sweaty and rancid), oxygen-containing-side-group benzene rings in V-shaped sites (minty), polycyclic aromatic hydrocarbons and phenols (burnt and smoky), negatively charged aryls as compact (spicy and pungent), multiple benzene rings in small concave sites (camphorous), multiple-benzene-ring ketones in large concave sites (musky), steroid ketones (urinous), isoprenes (rubber), carotenoids (tobacco), sesquiterpenes (woody), aromatic amines (spermous), alkyl pyrazines (nutty), three-single-bond monoamines (fishy), sulfur compounds (foul and sulfurous and rotten), methyl sulfides (savory), and halogens (pharmaceutical and medicinal). Concentration determines odor intensity, which can range from faint to harsh. People can distinguish 10 intensity levels. Molecule atoms and bonds determine odor shape, size, and site. Sites can be alcohol, ether, ester, aldehyde, ketone, acid, aryl, isoprene, amine, sulfur, and halogen. Shape can be chain, oblong, or ball, with sharp, medium, or smooth shape edges. People can distinguish 1000 odors.

taste properties

Tastes are salty, sweet, sour, and bitter {taste properties} {flavor properties}. Sour acid and salt are similar. Bitter and salt are similar. Sweet and salt are similar. Sour (acid) and bitter (base) are opposites. Sweet (neutral) and sour (acid) are opposites. Salt and sweet are opposites.

Physically, water-borne chemicals have concentrations, sizes, shapes, sites, acidity, and polarity and attach to tongue chemical receptors. Physiologically, tastes are acid, salt, base, sugar, and savory. Taste has sweetness-saltiness and sourness-saltiness-bitterness. Taste perceptual processes [Kadohisa et al., 2005] [Pritchard and Norgren, 2004] [Rolls and Scott, 2003] compare sugar, acid, base, salt, and umami receptor inputs to find intensity, acidity, and polarity. Acid-salt-base and salt-sweet opponent processes share salt. Concentration determines taste intensity. People can distinguish 10 intensity levels. Molecule atoms and bonds and electric charge determine taste acidity, which can be acidic, neutral, or basic. People can distinguish 3 acidity levels. Molecule atoms and bonds and molecule-electron properties determine taste polarity, which can be polar, half polar, or nonpolar. People can distinguish 3 polarity levels. Polar and acid define sour. Polar and neutral define salt. Polar and base define bitter. Nonpolar and neutral define sweet. Between sour and salt defines umami-glutamate. (Nonpolar cannot be acid or base.)

temperature properties

Temperature can be warm or cool {temperature properties}.

Physically, temperatures have random motions. Physiologically, people feel cool or warm. Temperature perceptual processes compare thermoreceptor inputs. Heat flow determines temperature, which ranges from cold to warm to pain. People can distinguish 10 temperature levels.

touch properties

Touches can be acute or smooth, steady or vibrating, and light or heavy {touch properties}.

Physically, touches have transverse motions and pressures (compression, tension, and torsion) that displace surface areas. Physiologically, people feel hardness, elasticity, surface texture, motion, smooth surface texture, rough surface texture, tickle, sharp touch, and tingle. Touch perceptual processes [Bolanowski et al., 1998] [Hollins, 2002] [Johnson, 2002] compare free nerve ending (smooth or rough surface texture), hair cell (motion), Meissner corpuscle (vibration), Merkel cell (light compression and vibration), pacinian corpuscle (deep compression and vibration), palisade cell (light compression), and Ruffini endorgan (slip, stretch, and vibration) inputs to find compression-tension and vibration. Pressure compression and tension determine hardness, elasticity, surface texture, motion, smooth surface texture, rough surface texture, tickle, sharp touch, and tingle. People can distinguish 10 compression-tension levels. Stimulus intensity and frequency determines vibration. People can distinguish 10 motion levels.

CONS>Consciousness>Speculations>Sensation>Psychology>Sense>Vision

color parameters

Colors have brightness, lightness, and temperature {color parameters}. Brightness defines the order black-white, blue/darkest_gray-yellow/lightest_gray, and red/dark_gray-green/light_gray. Color lightness (unsaturability, transparency, sparseness) defines the order black-white, blue-yellow, and red-green. Color temperature (texture, noisiness) defines the order blue-red, cyan-yellow, and green-magenta-black-white-gray.

A coolness-warmth axis and a perpendicular darkness-lightness axis define a color wheel. Blue, green, and red are on the circumference, with equal arcs between them. Coolness-warmth runs from blue -1 through green 0 then red +1, where -1 is cool and +1 is warm. Darkness-lightness runs from blue -1 through red 0 then green +1, where -1 is dark and +1 is light, in the opposite direction around the color circle. Dark and cool make blue (-1,-1). Light and neither warmth nor coolness make green (+1,0). Neither dark nor light and warm make red (0,+1).

Brightness is perpendicular to the color wheel, and the three axes define color space.

color properties

Color has brightness, hue, and saturation {color properties}. Color properties come from black-white, red-green, and blue-yellow opponent processes.

hue

Hue depends on electromagnetic-wave frequency [Krauskopf et al., 1982]. Fundamental color categories are white, gray, black, blue, green, yellow, orange, brown, red, pink, and purple [Kay and Regier, 2003]. White, gray, and black mix red, green, and blue. Brown is dark orange. Pink mixes red and white. Purple mixes red and blue. See Figure 1.

Alternatively, colors have six categories: white, black, red, yellow, green, and blue. Blue and red have no green or yellow. All other colors mix main colors. Purple mixes red and blue. Cyan mixes green and blue. Chartreuse mixes yellow and green. Orange mixes red and yellow. Pink mixes red and white. Brown mixes orange and black.

brightness and blackness

Color brightness depends on electromagnetic-wave intensity [Krauskopf et al., 1982]. Darkness is the opposite of brightness and is the same as added blackness. Colors can add black, and white can add black. Black adds to colors linearly and equally. See Figure 2. At all brightness levels, white looks lightest, yellow looks next lightest, green looks next lightest, red looks next lightest, blue looks darker, and black looks darkest.

White surroundings blacken color. Complementary-color surroundings enhance color. Black surroundings whiten color.

saturation and whiteness

Color saturation depends on electromagnetic-wave frequency distribution [Krauskopf et al., 1982]. Colors can add white, and black can add white. White adds to colors linearly and equally. Complete saturation means no added white. Lower saturation means more white. No saturation means all white. Less saturation makes colors look lighter. See Figure 3. Black looks most saturated. At all saturation levels, blue looks next most saturated, red looks somewhat saturated, and green looks less saturated. White looks least saturated.

transparency and opacity

Color transparency depends on source or reflector electromagnetic-wave density. Opaqueness means maximum color density, with no background coming through. Transparency means zero color density, with all background coming through. See Figure 4. With a white background, opacity is the same as saturation, and transparency is the same as no saturation, so colors are the same as in Figure 3. With a black background, opacity is the same as lightness, and transparency is the same as darkness, so colors are the same in Figures 2 and 4. Blue looks most opaque, and green looks least opaque.

color strength

For all color brightnesses, when both colors have equal brightness, black suppresses one color more {color strength}. Red is stronger than blue, because frequency is lower and wavelength is higher. Blue is stronger than green, because frequency is lower and wavelength is higher. Green is stronger than red, because frequency is lower and wavelength is higher. See Figure 6. Less blue needs to balance green and red, so blue is darker than red and green. Less red needs to balance green, so red is darker than green.

For all color brightnesses, when stronger color is 32 bits lower, weaker color can appear. See Figure 6.

Relative color strengths are the same no matter the computer-display color profile, contrast level, or brightness level.

mixtures

Blue is most dark, opaque, saturated, and cool. Red is less dark, opaque, and saturated and most warm. Green is least dark, opaque, and saturated and neither cool nor warm. See Figure 5, which displays the primary colors, their 1:1 mixtures plus CYMK mixtures, and their 2:1 mixtures.

Magenta mixes blue and red. In its group, it is most dark, opaque, saturated, and neither cool nor warm. Cyan mixes blue and green and so is less dark, opaque, and saturated and most cool. Yellow mixes red and green and so is least dark, opaque, and saturated and most warm. Because they add colors, magenta, cyan, and yellow do not directly compare to blue, green, and red.

Violet mixes blue and some red. In its group, it is most dark, opaque, and saturated and slightly cool. Purple mixes red and some blue and so is less dark, opaque, and saturated and is slightly warm. Turquoise mixes blue and some green and so is less dark, opaque, and saturated and is slightly cool. Orange mixes red and some green and so is less dark, opaque, and saturated and is warm. Spring green mixes green and some blue and so is less dark, opaque, and saturated and is neither warm nor cool. Chartreuse mixes green and some red and so is least dark, opaque, and saturated and is neither warm nor cool. Because they add colors differently, these six colors do not directly compare to magenta, cyan, and yellow or to blue, green, and red.

Mixing blue and yellow, green and magenta, or red and cyan makes white, gray, or black, because blue, green, and red then have ratios 1:1:1. White is lightest, because it adds blue, green, and red. Gray is in middle, because it mixes blue, green, and red. Black is darkest, because it subtracts blue, green, and red.

Figure 1

```
                          Color Wavelengths (in nanometers)
350       400       450       500       550       600       650       700
|----*----|----S----|----*----|----*M---|-L--*----|----*----|----*----|----*
MMMMMVVVVVVVVVIIIIBBBBBBBCCCCCCCCGGGGGGCCCYYYYOOOOOORRRRRRRRRRRRRRRRRMM
  M         V    I    B       C       G   C   Y     O             R        M
           410  435  460     500 520 540 560 580   610           680

     |  B     l     u     e   |  G  r  e  e  n  |  R       e       d      |

      Receptor Maximum-Sensitivity Wavelengths (in nanometers)
              424                    530   560
     380       S                        540
               430                    M                       660
               430                          L                          720
```

Color wavelengths range from 380 nm to 720 nm: Magenta, Violet, Indigo, Blue, Cyan, Green, Chartreuse, Yellow, Orange, and Red. Wavelengths under color letters indicate center of color range.

Blues predominate from 380 nm to 500 nm.

Blue-greens are from 460 nm to 545 nm.

Greens predominate from 500 nm to 590 nm.

Green-reds are from 545 nm to 630 nm.

Reds predominate from 590 nm to 720 nm.

Red-blues are from 630 nm to 460 nm.

S, M, and L are the short-wavelength, middle-wavelength, and long-wavelength photoreceptors. Photoreceptor spectral curves approximate a normal distribution, with maximum sensitivity at 424 nm, 530 nm, and 560 nm, respectively.

Short-wavelength range is 380 nm to 540 nm.

Middle-wavelength range is 430 nm to 660 nm.

Long-wavelength range is   430 nm to 720 nm.

Figure 2

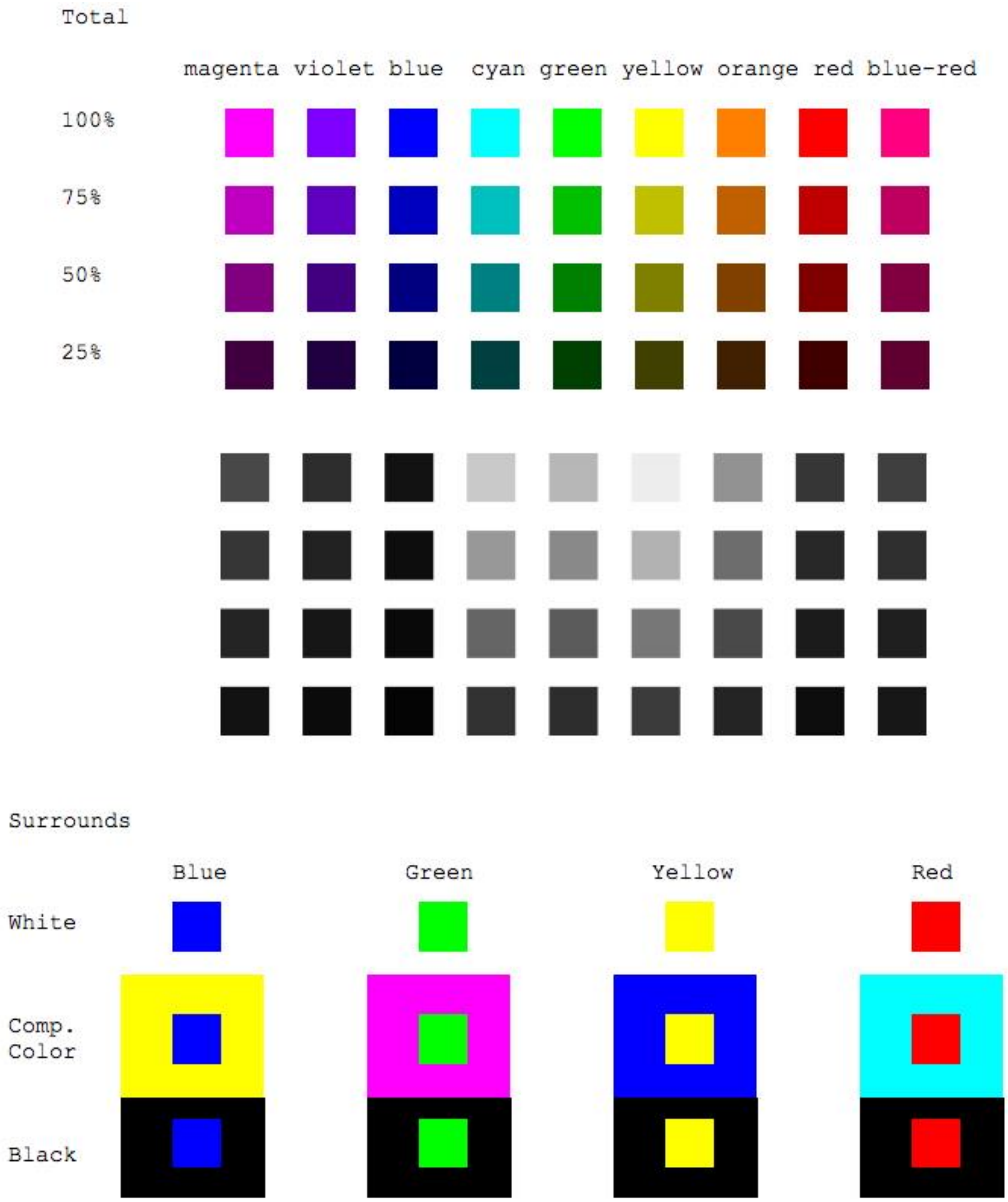

Total
magenta violet blue cyan green yellow orange red blue-red
100%
75%
50%
25%
Surrounds
Blue
Green
Yellow
Red
White
Comp.
Color
Black

Figure 3


Saturation
magenta violet blue cyan green yellow orange red blue-red
100%
50%
25%

Figure 4


Transparency
magenta violet blue cyan green yellow orange red blue-red
0%
50%
75%

Figure 5

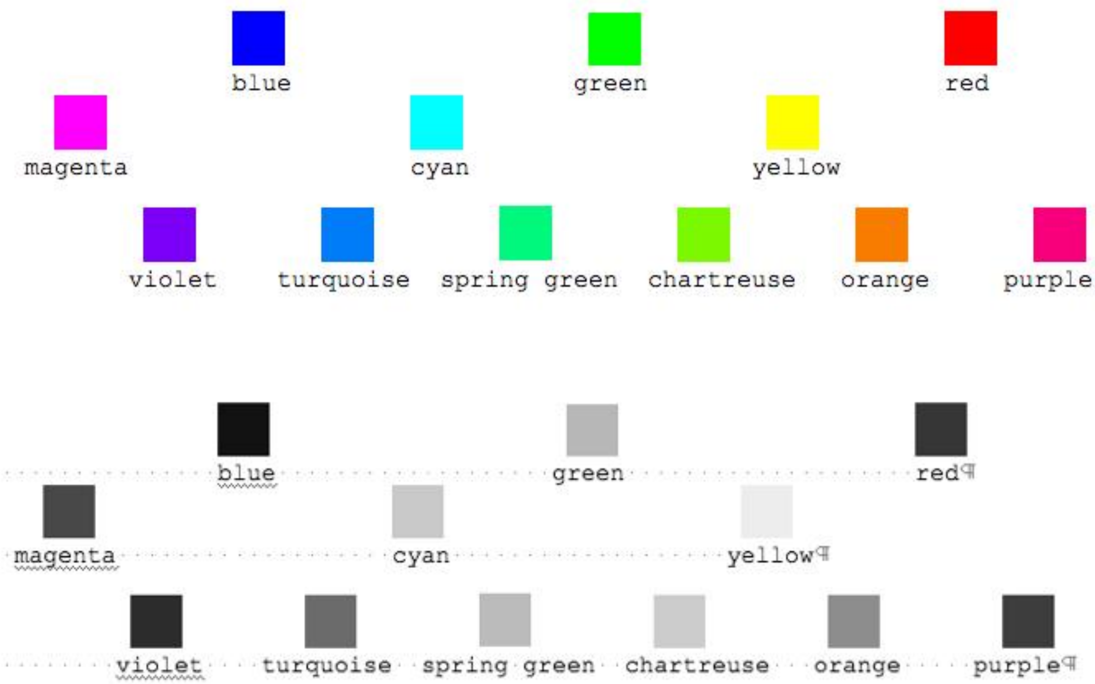
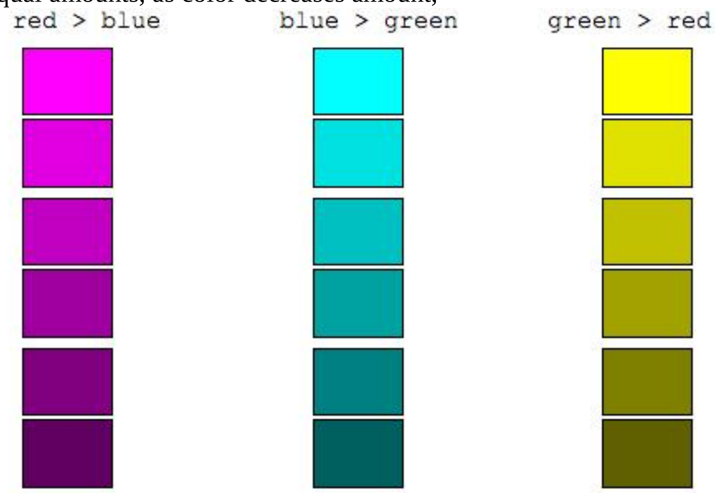
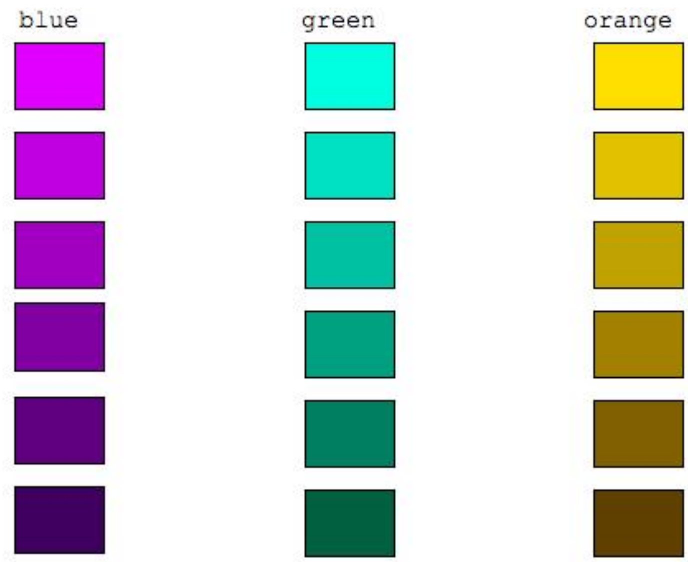

blue
green
red
magenta
cyan
yellow
violet
turquoise
spring green
chartreuse
orange
purple
blue
green
red¶
magenta
cyan
yellow¶
violet
turquoise
spring green
chartreuse
orange
purple¶

Figure 6

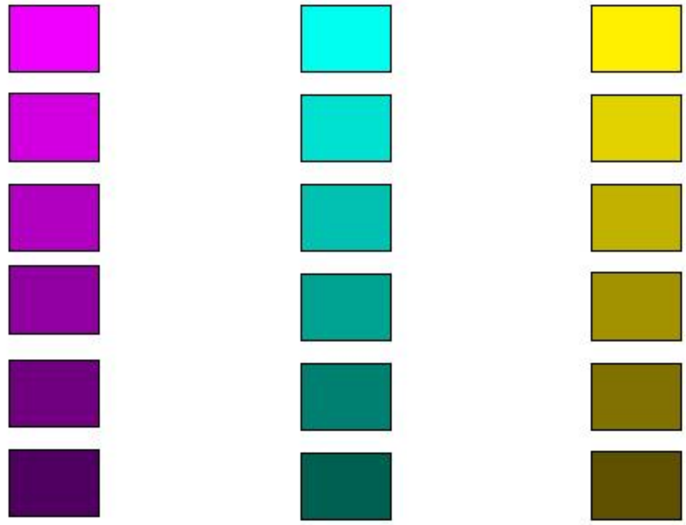
When both colors have equal amounts, as color decreases amount,



When stronger color is 32 bits lower, as color decreases amount,
weaker color can appear:



When stronger color is 16 bits lower, as color decreases amount,
colors balance:



color properties

Physically, light waves have frequencies with intensities. Physiologically, colors are dependent and mixed (synthetic) and have brightness, hue, and saturation. Brightness depends on intensity and ranges from dim to bright. People can distinguish 100 intensity levels. Hue depends on average light frequency and ranges across the color spectrum, from red to violet. People can distinguish 100 hues. Saturation depends on light-frequency distribution and ranges from unsaturated to saturated. People can distinguish 100 saturation levels. Brightness, hue, and saturation define colors. People can distinguish one million colors. Vision perceptual processes also find color temperature and color lightness. Relative light intensities determine brightness. People can distinguish 100 brightness levels. Relative salience and activity determine color temperature, which ranges from cool to warm. People can distinguish 100 color temperatures. Relative transparency determines color lightness, which ranges from dark to light. People can distinguish 100 color lightnesses. Color brightness, temperature, and lightness define colors.

color facts

Colors are insubstantial, cannot change state, have no structure, do not belong to objects or events, and are results not processes {color facts}.

number of colors

Colors range continuously from red to scarlet, vermilion, orange, yellow, chartreuse, green, spring green, cyan, turquoise, blue, indigo, violet, magenta, crimson, and back to red. People can distinguish 150 to 200 main colors and seven million different colors.

discrimination

Humans can discriminate colors better from cyan to orange than from cyan through blues, purples, and reds.

people see same spectrum

Different humans see similar color spectra, with same colors and color sequence. Adults, infants, and animals see similar color spectra. Colorblind people have consistent but incomplete spectra.

purity

For each person, under specific viewing conditions, blue, green, and yellow can appear pure, with no other colors, but red does not appear pure.

location

Colors appear on surfaces.

adjacency

Adjacent colors affect each other and enhance contrast.

metamerism

Identical objects can have different colors. Different spectra can have the same color {metamerism}.

hue

Colors have hue. Colors respond differently as hue changes. Reds and blues change more slowly than greens and yellows.

brightness

Colors have brightness (lightness) or absence of black.

opaqueness

Colors have opaqueness. Transparency means no color.

saturation

Colors have saturation or absence of white. Different hues have different saturability and number of saturation levels.

emotion

Psychologically, red is alerting color. Green is neutral color. Blue is calming color.

depth

Blue objects appear to go farther away and expand, and red objects appear to come closer and contract, because reds appear lighter and blues darker.

Color can have shallow or deep depth. Yellow is shallow. Green is medium deep. Blue and red are deep.

lightness

Dark colors are sad because darker, and light colors are glad because lighter. Yellow is the lightest color, comparable to white. Colors darken from yellow toward red. Red is lighter than blue but darker than green. Colors darken from yellow toward green and blue. Green is lighter than blue, which is comparable to black. Therefore, subjective lightness increases from blue to red to green to yellow. See Figure 1. Lightness relates directly to transparency, unsaturability, and sparseness. Blue is dark, opaque, saturable, and dense. Red is lighter, less opaque, less saturable, and less dense.

Green is light, more transparent, unsaturable, and sparse. Yellow is lightest, most transparent, most unsaturable, and sparsest.

Blue is similar to dark gray. Red is similar to medium gray. Green is similar to gray. Yellow is similar to very light gray. Magenta is similar to gray. Cyan is similar to light gray. See Figure 1.

temperature

Colors can be relatively warm or cool. Blue is coolest, then green, then yellow, and then red [Hardin, 1988]. White, gray, and black, as color mixtures, have no net temperature. Temperature relates directly to sharpness, emotion level, expansion, size, and motion toward observer. Blue is cool, is sharp and crisp, causes calmness, seems to recede, and appears contracting and smaller than red. Green has neutral temperature, is less sharp and less crisp, has neutral emotion, neither recedes nor approaches, and is neither smaller nor larger. Red is warm, is not sharp and not crisp, causes excitement, seems to approach, and appears expanding and larger than blue. See Figure 2. Red and blue are approximately equally far away from green, so green is average. Magenta has neutral temperature, because it averages red and blue. Cyan is somewhat cool, because it averages green and blue. Yellow is somewhat warm, because it averages green and red. Black, grays, and white have neutral temperature, because mixing red, green, and blue makes average temperature.

Warmness-coolness, excitement-calmness, approach-recession, expansion-contraction, and largeness-smallness relate to attention level, so temperature property relates to salience.

change

Colors change with illumination intensity, illumination spectrum, background surface, adjacent surface, distance, and viewing angle.

constancy

Vision tries to keep surface colors constant, by color constancy processes, as illumination brightness and spectra change.

white

White is relatively higher in brightness than adjacent surfaces. High colored-light intensity makes white.

black

Black is relatively lower in brightness than adjacent surfaces. Black is not absence of visual sense qualities but is a color. Low colored-light intensity makes black.

gray

Gray is relatively the same brightness as adjacent surfaces. Increasing gray intensity makes white. Decreasing gray intensity makes black. Increasing black intensity or decreasing white intensity makes gray.

red

Red light is absence of blue and green. Red pigment is absence of green, its subtractive complementary color. Red is alerting color. Red is warm color, not cool color. Red has average lightness. Red mixes with white to make pink. Spectral red blends with spectral cyan to make white. Pigment red blends with pigment green to make black. Spectral red blends with spectral yellow to make orange. Pigment red blends with pigment yellow to make brown. Spectral red blends with spectral blue or violet to make purples. Pigment red blends with pigment blue or violet to make purples. People do not see red as well at farther distances. People do not see red as well at visual periphery. Red has widest color range. Red can fade in intensity to brown then black.

blue

Blue light is absence of red and green. Blue pigment is absence of red and green. Blue is calming color. Blue is cool color, not warm color. Blue is dark color. Blue mixes with white to make pastel blue. Spectral blue blends with spectral yellow to make white. Pigment blue blends with pigment yellow to make black. Spectral blue blends with spectral green to make cyan. Pigment blue blends with pigment green to make dark blue-green. Spectral blue blends with spectral red to make purples. Pigment blue blends with pigment red to make purples. People see blue well at farther distances. People see blue well at visual periphery. Blue has narrow color range.

green

Green light is absence of red and blue. Green pigment is absence of red. Green is neutral color in alertness. Green is cool color. Green is light color. Green mixes with white to make pastel green. Spectral green blends with spectral magenta to make white. Pigment green blends with pigment magenta to make black. Spectral green blends with spectral orange to make yellow. Pigment green blends with pigment orange to make brown. Spectral green blends with spectral blue to make cyan. Pigment green blends with pigment blue to make dark blue-green. People see green OK at farther distances. People do not see green well at visual periphery. Green has wide color range.

yellow

Yellow light is absence of blue. Yellow pigment is absence of indigo or violet. Yellow is neutral color in alertness. Yellow is warm color. Yellow is lightest color. Yellow mixes with white to make pastel yellow. Spectral yellow blends with spectral blue to make white. Pigment yellow blends with pigment blue to make green. Spectral yellow blends with spectral red to make orange. Pigment yellow blends with pigment red to make brown. Olive is dark yellow-green or less saturated yellow. People see yellow OK at farther distances. People do not see yellow well at visual periphery. Yellow has narrow color range.

orange

Spectral orange can mix red and yellow. Pigment orange can mix red and yellow. Orange is slightly alerting color. Orange is warm color. Orange is light color. Orange mixes with white to make pastel orange. Spectral orange blends with spectral blue-green to make white. Pigment orange blends with pigment blue-green to make black. Spectral orange blends with spectral cyan to make yellow. Pigment orange blends with pigment cyan to make brown. Spectral orange blends with spectral red to make light red-orange. Pigment orange blends with pigment red to make dark red-orange. People do not see orange well at farther distances. People do not see orange well at visual periphery. Orange has narrow color range.

violet

Spectral violet can mix blue and red. Pigment violet has red and so is purple. Violet is calming color. Violet is cool color. Violet is dark color. Violet mixes with white to make pastel violet. Spectral violet blends with spectral yellow-green to make white. Pigment violet blends with pigment yellow-green to make black. Spectral violet blends with spectral red to make purples. Pigment violet blends with pigment red to make purples. People see violet well at farther distances. People see violet well at visual periphery. Violet has narrow color range. Violet can fade in intensity to dark purple then black.

brown

Pigment brown can mix red, yellow, and green. Brown is commonest color but is not spectral color. Brown is like dark orange pigment or dark yellow-orange. Brown color depends on contrast and surface texture. Brown is not alerting or calming. Brown is warm color. Brown is dark color. Brown mixes with white to make pastel brown. Pigment brown blends with other pigments to make dark brown or black. People do not see brown well at farther distances. People do not see brown well at visual periphery. Brown has wide color range.

Figure 1
By percent white:

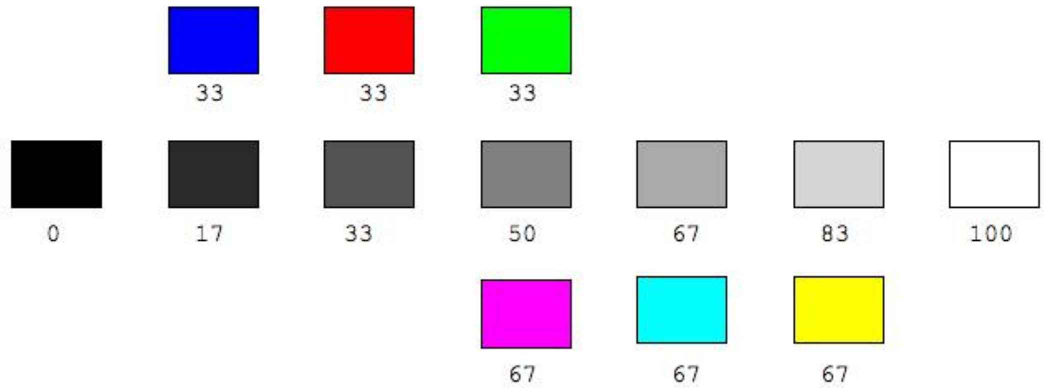
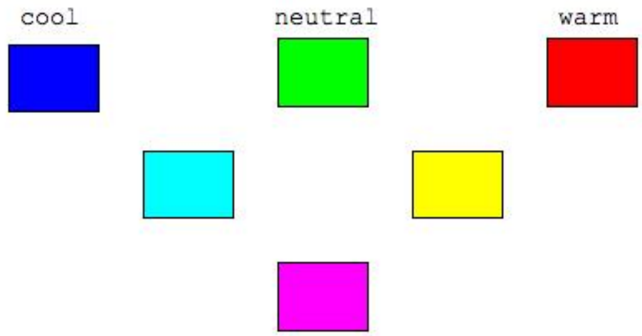


Figure 2



color space with orthogonal vectors

Simple color space can have orthogonal red, green, and blue coordinates {color space with orthogonal vectors}, with unit vectors at (1,0,0) for red, (0,1,0) for green, and (0,0,1) for blue. Adding red, green, and blue coordinates makes the resultant-vector color.

Brightness is resultant-vector length. For example, bright green can have vector (0,9,0), with length 9. Bright green (0,9,0) and bright red (9,0,0) can add to vector (9,9,0), with length 9 * 2^0.5.

Hue is resultant-vector direction. For example, unit red and unit green can add to yellow (1,1,0).

Saturation is resultant-vector angle to the color-space diagonal. For example, unit red, unit green, and unit blue add to white (1,1,1), which is on the diagonal and so has 0% saturation. Unit red and unit blue add to magenta (1,0,1), which is on the farthest plane, with maximum 45-degree angle to the diagonal, and so has 100% saturation.

CONS>Consciousness>Speculations>Space

cross-sections and three-dimensional space

Flow cross-sections have two dimensions and can represent surfaces. Flow cross-sections can represent three dimensions {cross-sections and three-dimensional space}. To represent a squat cylinder, cross-section left region can represent cylinder top layer, middle region can represent cylinder middle layer, and right region can represent cylinder bottom layer. Alternatively, the three regions can interleaf throughout cross-sections, with cross-section points having top-, middle-, and bottom-layer points. Because cross-sections can represent three-dimensions, circuit flows can represent three-dimensional space over time.

layers and three-dimensional space

Because layers can represent two-dimensional images, multiple layers can represent a three-dimensional image {layers and three-dimensional space}. See Figure 1.

One layer can represent a three-dimensional image by skewing. See Figure 2. Left region represents top layer. Middle region represents middle layer. Right region represents bottom layer.

One layer can represent a three-dimensional image by interleafing. See Figure 3. Evenly distributed neuron sets represent top layer, middle layer, and bottom layer.

One topographic-map neuron layer can represent three-dimensional space, and layer series can represent three-dimensional space over time.

Figure 1

Top	Middle	Bottom
010	000	000
111	010	010
010	000	000

Figure 2

```
Top/Mid/Bottom
Left/Mid/Right
 010/000/000
 111/010/010
 010/000/000
```

Figure 3

T11	M11	B11	**T12**	M12	B12	T13	M13	B13
T21	M21	B21	**T22**	**M22**	**B22**	**T23**	M23	B23
T31	M31	B31	**T32**	M32	B32	T33	M33	B33
0	0	0	**1**	0	0	0	0	0
1	0	0	**1**	**1**	**1**	**1**	0	0
0	0	0	**1**	0	0	0	0	0

network to space

A network of nodes and links among nodes {network to space} can represent space. Sense processing uses neuron assemblies to represent nodes and links.

semi-space

Two-dimensional surfaces {pre-space} {semi-space} can add relative distance information to represent three-dimensional spaces. Semi-spaces are like two-and-a-half-dimension sketches [Marr, 1982].

Sense, and computer, processing uses intensity variations to find symbolic primitives, such as zero crossings, edges, contours, and blobs; detect boundaries and brightnesses; and represent two dimensions. From the primitives, sense and computer processing finds relative surface distances, depths, contours, and orientations and uses surface shading, orientation, scaling, and texture to find object and observer spatial relations, to simulate three dimensions. Later, sense and computer processing uses memory and global information to integrate the two-dimensional and depths-and-distances descriptions to build a three-dimensional model for object representation, manipulation, and recognition.

stimuli as media

Stimuli can serve as substrates/media on which to display sensations {stimuli as media}. Sense, and perhaps computer, processing can simulate stimulus input streams from physical space.

surface elements and mental space

Mental-space points are surface elements (differential surfaces), which have direction, distance, and orientation {surface elements and mental space}. Surface elements link to make space. Sense, and perhaps computer, processing can make surface elements in space.

CONS>Consciousness>Speculations>Space>Biology

adjacency and mental space

Skin touches objects, and touch receptors receive information about objects adjacent to body {adjacency and mental space}. As body moves around in space, mental space expands by adding adjacency information.

angle-comparison computations calculate distances

Eye-accommodation-muscle feedback to vision depth-calculation processes can calculate distances up to two meters. Using metric depth cues can calculate all distances. Observing objects requires at least two eye fixations, which allow vision processing to calculate two different perceived angles, for two different eye, head, and body positions. Vision and body angle-comparison computations can calculate line, surface, feature, and object distances {angle-comparison computations, distances} {distances, angle-comparison computations}.

two sight-line to surface angles

At first eye fixation on a line or surface point, vision calculates a sight-line to point angle. At second eye fixation on a collinear or co-surface point, vision calculates a different sight-line to point angle, because eye, head, and/or body have rotated. At nearest possible line or surface point, sight-line to point angle is 90 degrees. At farthest possible line or surface point, sight-line to point angle is 0 degrees. Angle decreases linearly with distance. If angle of sight-line to line or surface is more perpendicular, line or surface point is nearer. If angle of sight-line to line or surface is less perpendicular, line or surface point is farther.

Comparing sight-line angles to two collinear or co-surface points can calculate distance. Angle difference varies directly with distance. Larger angle change means object is nearer. Smaller angle change means object is farther.

two visual angles

At first eye fixation on an object edge or contour, object has a retinal visual angle, calculating object relative size. At second eye fixation on a different object edge or contour, object has a different retinal visual angle, because eye, head, and/or body have rotated. If sight-line to object edge or contour angle is 90 degrees, visual angle is maximum. At other angles, visual angle is less. Visual angle decreases linearly with distance. If sight-line to object edge or contour is more perpendicular, visual angle is more. If sight-line to object edge or contour is less perpendicular, visual angle is less.

Comparing first and second visual angles can calculate object distance. Angle difference varies directly with distance. Larger angle change means object is nearer. Smaller angle change means object is farther.

two sight-line to point angles

At first eye fixation on an object point, sight-line to point has an angle. At second eye fixation on the same object point, sight-line to point has a different angle, because eye, head, and/or body have rotated. At nearest possible object point, sight-line to point angle is 90 degrees. At other object points, sight-line to point angle is less. Angle decreases linearly with distance. If sight-line to object point is more perpendicular, object is nearer. If sight-line to object point is less perpendicular, object is farther.

Comparing first and second angles can calculate object distance. Angle difference varies directly with distance. Larger angle change means object is nearer. Smaller angle change means object is farther.

two concave or convex corner angles

The first eye fixation on a concave or convex corner determines its angle. The second eye fixation determines a different angle, because eye, head, and/or body have rotated. Smaller-angle concave corners are farther, and larger-angle concave corners are nearer. Smaller-angle convex corners are nearer, and larger-angle convex corners are farther.

Comparing first and second corner angles can calculate distance. Angle difference varies directly with distance. Larger angle change means object is nearer. Smaller angle change means object is farther. Angles and vertices use the same reasoning as corners.

body angle comparisons

First eye fixation and second eye fixation have two different eye, head, and/or body positions. The kinesthetic system determines their angle sets and sends kinesthetic angle-difference information to association cortex for comparison with the corresponding vision angle-difference information.

integration

Comparing the two sets of angle differences calculates absolute metric distances. Accumulating distance information allows building three-dimensional-space information.

body surface and mental space

Sensations impinge on body surface in repeated patterns at touch receptors. Nervous system occupies three dimensions and has information about receptor locations. From receptor activity patterns, nervous system builds a three-dimensional sensory surface {body surface and mental space}.

carrier waves and mental space

Senses make a global carrier-wave function, and whole brain-and-body has a carrier-wave function {carrier waves and mental space}. Global functions are regular and form coordinate grids, establishing egocentric space. Local disturbances affect global function to indicate location.

convexity and concavity and mental space

Frontal-lobe region derives three-dimensional images from two-dimensional topographic maps by assigning convexity, concavity, and boundary edges [Horn, 1986] to lines and vertices and making convexities and concavities consistent {convexity and concavity and mental space}.

cortical processing and mental space

Primary-visual-cortex topographic map represents scene intensities. After primary visual cortex, cortical topographic-map neurons {cortical processing and mental space} respond to orientations, locations, and distances [Burkhalter and Van Essen, 1986] [DeValois and DeValois, 1975] [Newsome et al., 1989] [Tootell et al., 1997] [Zeki, 1985]. Topographic maps use thresholds to make boundaries and regions. Vision system sends information to motor and other sense systems [Bridgeman et al., 1997] [Owens, 1987]. Topographic maps use movements, angles, and perspective to add distance and depth by interpolation and extrapolation and represent egocentric space. Brain integrates and synthesizes spatial information [Andersen et al., 1997] [Gross and Graziano, 1995] [Olson et al., 1999].

frames and mental space

Nose, cheeks, and eyebrow ridges frame vision scenes. Silent regions frame sounds. Untouched surrounding areas frame pressures. Neutral-temperature regions frame warm or cool areas. Nose touch sensations frame odors. Mouth touch sensations frame tastes. Silent sensors frame active sensors. Sensations have frames that provide context for near and far locations {frames and mental space}.

memory and mental space

Long-term memory recall makes space {memory and mental space}. Short-term memory builds space modifications. Awaking activates memory, which activates space. Perception and recall occur on space background. Memory is stronger than perception, because people can remember images and override perceptions.

motions and mental space

Retinal regions can receive repeated light-pattern series that correlate with motion {motions and mental space}. For example, when moving toward light source, as visual horizon lowers, source appears lower in visual field. When moving away, source appears higher in visual field. When turning, rotations are around sense organ.

When people move, other objects do not move. Correlated movements belong to body region, and correlated non-movements belong to other region. Moving establishes a boundary between adjacent moving and non-moving regions. Moving is inside region, and non-moving is outside region. In and out make a space axis. When finger slides across surface, or feet walk across ground, touch correlates with vision moving/non-moving boundary.

motor feedback and space

Brain senses, moves, senses, moves, and so on, to have feedback, so brain processes are multisensory and sensorimotor. Visual-motor and touch-motor feedback loops interact to locate surfaces {motor feedback and space}, also using kinesthetic and vestibular systems. Vertical gaze center near midbrain oculomotor nucleus detects up and down motions [Pelphrey et al., 2003] [Tomasello et al., 1999]. Horizontal gaze center near pons abducens nucleus detects right-to-left and left-to-right motions [Löwel and Singer, 1992].

multimodal neurons and mental space

Midbrain tectum and cuneiform nucleus have multimodal neurons, whose axons envelop reticular thalamic nucleus and other thalamic nuclei to map three-dimensional space {multimodal neurons and mental space}.

multiple neurons for multiple space points

To experience multiple space points simultaneously, neuron assemblies have 200-millisecond intervals in which events are simultaneous {multiple neurons for multiple space points}.

topographic map continuum

Topographic-map neurons, dendrites, axons, and synapses are so numerous that overlapping forms a continuum {topographic map continuum}. Perhaps, the continuum carries analog signals and geometric figures, like TV screens, and models continuous space.

CONS>Consciousness>Speculations>Space>Biology>Boundaries

analog to digital conversion and mental space

Neuron thresholds reduce instantaneous below-threshold input to 0 and set instantaneous above-threshold input to 1. Thresholds differentiate regions by establishing boundaries {analog to digital conversion and mental space}.

boundary and mental space

Brain can compare outgoing (inner) and incoming (outer) signals, which differ. Inner signals have loops and loop patterns and include memories and imaginings. Outer signals have non-looping patterns and include stimuli. Nervous system builds a boundary {boundary and mental space} between inner (self) and outer (other). Boundary is at nervous-system edges. Waking and dreaming rebuild the boundary.

inequalities and boundaries

To trigger a neuron impulse, membrane potential, caused by input neuron impulses, must be greater than neuron threshold potential. Neuron threshold potentials establish inequalities. Lower potential has no effect. Higher potentials cause one impulse. (Higher potentials over time cause higher impulse rate.) Inequalities establish boundaries {inequalities and boundaries}. At space boundaries, one region has response above threshold, and adjacent region has response below threshold. (Neuron thresholds can change.)

lateral inhibition and spatial regions

Adjacent neurons can inhibit central neuron. Such lateral inhibition reduces central-neuron activity. Lateral inhibition can contract regions {lateral inhibition and spatial regions}. Lateral inhibition can move boundaries inwards. Lateral inhibition can suppress and eliminate boundaries. Spreading activation and lateral inhibition can join or separate regions.

spreading activation and spatial regions

Central neuron can excite adjacent neurons. Such spreading activation increases adjacent-neuron activity. Spreading activation can expand regions {spreading activation and spatial regions} {spreading excitation and spatial regions}. Spreading activation can move boundaries outwards. Spreading activation can establish and emphasize boundaries. Spreading activation and lateral inhibition can join or separate regions.

CONS>Consciousness>Speculations>Space>Biology>Coordinates

coordinate transformation and allocentric space

People see objects in space as external and stationary (allocentric) [Rizzolatti et al., 1997] [Velmans, 1993]. Cerebellum and forebrain anticipate, coordinate, and compensate for movements.

Frontal-lobe topographic maps can represent egocentric space [Olson et al., 1999], with vertical, right-left, and front-back directions. Coordinate-origin egocenter is in head center, on a line passing through nosebridge. Space points have directions and distances from egocenter. All points make vector space.

As body, head, or eyes move, egocentric space moves, spatial axes move, and point coordinates and geometric figures transform linearly to new coordinate values [Shepard and Metzler, 1971]. Transformations are translation, rotation, reflection, inversion, and scaling (zooming). Motor processing uses tensor transform functions to describe changes from former to current output-vector field [Pellionisz and Llinás, 1982]. To maintain stationary allocentric space, so point coordinates do not change when body moves, visual processing must cancel egocentric spatial-axis coordinate transformations {coordinate transformation and allocentric space}. Visual processing inverts motor-system tensors to transform egocentric coordinate systems in opposite directions from body movements [Pouget and Sejnowski, 1997]. Topographic maps can describe tensors that transform from egocentric to allocentric space. Topographic maps can represent allocentric space.

example

Translating and rotating make spatial axes change direction. After movement, new axes relate to old axes by coordinate transformations. For example, two-dimensional vector (0,1) can translate on y-axis to make vector (0,0), rotate both axes to make vector (1,0), or reflect y-axis to make vector (0,-1). Coordinate transformations do not change dimension number.

stationary space

Perception typically maintains an absolute spatial reference frame. Stationary space allows optimum feature tracking during object and/or body motions. Moving reference frames make all motions three-dimensional, but stationary space makes many movements one-dimensional or two-dimensional.

gravity and vertical direction

Gravity exerts vertical force on feet and body. Nervous system analyzes this distributed information and defines vertical axis in space {gravity and vertical direction}.

ground and mental space

Foot motions stop at ground. Touch and kinesthetic receptors repeatedly record this information. Nervous system analyzes this distributed information and defines a horizontal plane in space {ground and mental space}. Ground nearest to eye has sight-line perpendicular to ground. Farther-away ground points have sight-lines at smaller angles. All objects are on or vertically above ground.

invariants and coordinate axes

Vision observes moving and stationary points in space with varying brightnesses and colors. Nervous system analyzes this information to detect perceptual invariants. For space, invariant points are stationary reference points. Invariant lines are stationary coordinate axes {invariants and coordinate axes}: vertical, horizontal right-left, and horizontal near-far. Because invariants stay constant over many situations, invariants can be grounds for meaning.

motions and touches

Nervous system correlates body motions and touch and kinesthetic receptors to extract reference points and three-dimensional space {motions and touches}. Repeated body movements define perception metrics. Such ratios build standard length, angle, time, and mass units that model physical-space lengths, angles, times, and masses. As body, head, and eyes move, they trace geometric structures and motions.

tracking

During body movements, neuron activations follow trajectories across topographic maps. Brain can track moving stimuli. Brain can study before and after effects by tracking stimuli.

stimuli and motions

Stimuli can trigger attention and orientation, and so body moves or turns toward or away. Different stimulus intensities cause different moving or turning rates.

distance

Because distance equals rate times time, motion provides information about distances. Brain can track locations over time. Brain can use interpolation and extrapolation.

horizontal directions and motions

Moving toward or away from stimuli maximizes visual flow and light-intensity gradient, and establishes forward-backward direction. Moving perpendicular to sight-line to stimuli minimizes visual flow and light-intensity gradient, and establishes left-right direction.

vertical direction and motion

Body raising and lowering can indicate vertical direction.

orientation columns and direction

Vision topographic maps have orientation macrocolumns, which align and link orientations to detect line directions and establish all spatial directions {orientation columns and direction} [Blasdel, 1992].

pole and dimension

As body moves in a straight line, visual flow and light-intensity gradient establish one forward point (pole). Eye to forward point defines the forward-backward spatial dimension {pole and dimension}.

rotation centers and mental space

Body and body parts rotate around balance or equilibrium points {rotation centers and mental space}. Kinesthetic receptors send information to brain, which defines those reference points and builds three-dimensional space.

tensors and mental space

Topographic-map series can store matrices and so represent tensors {tensors and mental space}. Motor processing uses tensor transform functions to describe changes from former to current output-vector field [Pellionisz and Llinás, 1982]. Tensors can linearly transform coordinates from one coordinate system to another. Output vectors are linear input-vector and spatial-axis-vector functions. Motor-system topographic maps send vector-field output-vector spatial pattern to motor neurons. Muscles move body, head, and eye to specific space locations, or for specific distances or times. Current output-vector field differs from preceding output-vector field by a coordinate transformation.

topographic maps and coordinate axes

Topographic-map-neuron types have regular horizontal, vertical, and diagonal spacings, at different small, medium, and large distances. Neuron grids make a spatial network of nodes and links. Neuron grids allow measuring distances and angles and using coordinates. Topographic-map neuron grids have up/down, left/right, and near/far axes {topographic maps and coordinate axes}. Topographic-map spatial axes intersect to establish a coordinate origin and make a coordinate system, so points, lines, and regions have spatial coordinates.

Sensory topographic maps can have lattices of superficial pyramidal cells, whose non-myelinated non-branched axons travel horizontally 0.4 to 0.9 millimeters to synapse in clusters on next superficial pyramidal cells. The skipping pattern aids macrocolumn neuron-excitation synchronization [Calvin, 1995].

topographic maps and distances

Topographic maps have neurons specific for space locations {topographic maps and distances}. Locations involve space direction and distance. If 100 neurons are for radial distance one unit, to have same visual acuity 400 neurons must be for radial distance two units. To have less acuity, 100 neurons can be for radial distance two units.

vestibular system and direction

Vestibular-system saccule, utricle, and semicircular canals detect gravity, body accelerations, and head rotations. From that information, nervous system establishes vertical direction and two horizontal directions {vestibular system and direction}.

vision and direction

Animal eyes are right and left, not above and below, and establish a horizontal plane that visual brain regions maintain {vision and direction}. Vision processing can detect vertical lines and determine height and angle above horizontal plane. Body has right and left as well as front and back, and visual brain regions maintain right, left, front, and back in the horizontal plane.

CONS>Consciousness>Speculations>Space>Computer Science

models for three dimensions from two dimensions

Models can build three dimensions from two-dimensional images {models for three dimensions from two dimensions}. Stacks of two-dimensional layers can model three-dimensional space. Rotation of one two-dimensional layer can sweep out three-dimensional space.

reading and writing and mental space

Mental space has no reading or writing {reading and writing and mental space}, because output becomes input and input becomes output simultaneously and in parallel.

CONS>Consciousness>Speculations>Space>Computer Science>Algorithm

segmentation and mental space

Region boundaries have high contrast. Surfaces have coarser or finer and other texture types. Textures depend on surface slant, surface tilt, object size, object motion, shape constancy, surface smoothness, and reflectance. Segmentation algorithms {segmentation and mental space} separate observed regions by contrast and surface texture. Contrast and steep texture gradients define large domains. Subdomains have different surface textures.

self-calibration and mental space

Camera algorithms can use epipolar transform and absolute conic image in Kruppa equation to find standard metric and relative distances and positions {self-calibration and mental space}.

shape from shading and mental space

Vision processing can find convexities, concavities, and boundary edges. Later vision processing makes these consistent to build three-dimensional space {shape from shading and mental space}.

structure from motion and mental space

Motions cause disparities and disparity rates that can reveal structure {structure from motion and mental space}. Bundle-adjustment algorithm can find three-dimensional scene structure and eye trajectories. First, projective reconstruction can construct the projected structure, and then Euclidean upgrading can find actual shape. Affine projective reconstruction uses Tomasi-Kanade factorization.

synthesis algorithms

Synthesis algorithms {synthesis algorithms} compare vectors and coordinates to build images and space.

vision algorithms and space

Vision algorithms can use fiducials as reference points for calibration to make space coordinates {vision algorithms and space}.

CONS>Consciousness>Speculations>Space>Mathematics

continuity and mental space

Continuous surfaces have no gaps and no overlaps. Phenomenal space seems continuous {continuity and mental space}.

cross products and mental space

Two vectors define one plane or surface. Two vectors can multiply to make a vector perpendicular to both vectors. Perhaps, mental space gets the distance dimension from cross products {cross products and mental space}.

derivatives and mental space

Derivatives indicate changes, gradients, and directions at space and time points. Second derivatives indicate gradient and direction changes and so apply to curves. Perhaps, brain calculates derivatives to find directions and surfaces, and their curvatures, and so build mental space {derivatives and mental space}.

generators and mental space

Brain not only represents space, but also generates/constructs space {generators and mental space}. From an origin, each space direction has a function that indicates distance and color. Functions extend from origin, in brain, into space, outside body, so there is no action at a distance. Space is nonphysical abstract vector space.

mathematics and mental space

Mathematical ideas can relate to mental space {mathematics and mental space}. Neuron assemblies can represent mathematical objects and mathematical operations.

number

Over a one-millisecond interval, neurons have (1) or do not have (0) an impulse, so neuron series can represent binary numbers. Over a one-second interval, one neuron's series of 0s and 1s can represent a binary number with 1000 digits.

Over a one-second interval, single-neuron axon-impulse number or released-neurotransmitter-packet number can represent a whole number. Neurons have impulse frequencies up to 800 Hz, so one neuron can represent numbers from, say, 1 to 800.

Neuron series can use positional notation to represent larger numbers. For example, one neuron can represent numbers from 0 to 99, and the other can represent numbers from 0000 to 9900, so neuron pairs can represent numbers from 0 to 9999.

number: integer

In neuron series, one neuron can represent sign, so neuron series can represent integers.

number: rational

In neuron series, one neuron can represent decimal point, so neuron series can represent rational numbers.

number: real

Real numbers have rational-number approximations, so neuron series can represent real numbers.

number: imaginary

In neuron series, one neuron can represent square root of -1, so neuron series can represent imaginary numbers.

number: complex

Complex numbers add real number and imaginary number, so two neuron series can represent complex numbers.

ratio

Neurons can compare receptive-field center input to surround input to measure stimulus-intensity ratio. Opponent processes compare inputs from two neurons to find ratio. Ratios are dimensionless, because dividing cancels units.

ratio: metrics

Comparing current and memorized ratios builds standard relative lengths, angles, and other measurement units (standardized metrics).

addition

To add two numbers, neuron series can receive input from two neuron series that represent numbers. To subtract, one input is negative.

Single neurons can accumulate membrane potential or neurotransmitter over time to represent simple summation.

addition: tables

If tables are available, arithmetic operations can use table lookup. First number is in first column, second is in second column, and answer is in third column. Neuron arrays can store number tables. Using indexes allows table lookup.

multiplication

To multiply two numbers, neuron series can receive input from two neuron series that represent numbers.

multiplication: amplification

Single neurons can amplify input. Cell body priming can cause inputs to dendrites to make more membrane voltage. Axon gating near synapse can cause synapse to release more neurotransmitter. Amplification is like multiplication.

multiplication: logarithm

Neuron series can store bases and exponents, so three neuron series can represent exponentials and logarithms. Neuron-series sets can add logarithms to perform multiplications. Logarithms are smaller than original number. For example, if number is 100, logarithm is 2: 100 = 10^2.

multiplication: power and root

Powers are multiplication series: a^3 = a*a*a. Roots are multiples of reciprocals: a^0.5 = (1/a) * (1/a). Neuron-series sets can repeat multiplications and divisions to find powers and roots.

symbol

Alphabet letters and punctuation symbols can have number representations. Neuron series can represent numbers and so letters, symbols, and variables.

mathematical term

Mathematical terms are constants times variables raised to powers: a*x^b. Neuron series can represent symbols and can use powers and multiply, so five neuron series can represent mathematical terms.

polynomial

Polynomials are mathematical-term sums. Neuron-series arrays can represent mathematical terms, so neuron-series-array series can represent mathematical-term sums. For infinite polynomials, higher terms have negligibly small values, so finite polynomials can approximate infinite polynomials.

polynomial: functions

Over space, time, or numeric intervals, polynomials can represent functions, so neuron-series-array series can represent functions. Polynomials can represent periodic, trigonometric, and wave functions: sin(x) = x - x^3/3! + x^5/5! - x^7/7! + ..., and cos(x) = 1 - x^2/2! + x^4/4! - x^6/6! + ... Polynomials can represent exponential functions: e^a = 1 + a + a^2/2! + a^3/3! + ..., and e^(i*a) = cos(a) + i*sin(a).

polynomial: factoring

Polynomials can have smaller polynomials that divide evenly into the polynomial. For example, a^2 + 2*a*b + b^2 = (a + b)^2, so (a^2 + 2*a*b + b^2)/(a + b) = (a + b). Neuron-series-array arrays can factor.

equation

Equations set two functions equal to each other: 3*x + 2 = 2*x + 3. Neuron assemblies can represent functions and the equals operation, so neuron assemblies can represent equations. Because they can subtract, factor, and divide, neuron assemblies can solve linear equations. Linear equations can approximate other equations.

equation: inequality and relation

Neuron assemblies can represent equations, so neuron assemblies can represent inequalities. Inequalities can indicate relations: more, same, and less, or before and after.

equation: system

Two or more equations with same variables are equation systems. For example, 3*x + 2*y = 6 and 2*x + 3*y = -6. Large neuron assemblies can represent an equation system. Because they can subtract, multiply, and divide, and so substitute, neuron assemblies can solve linear-equation systems. Linear-equation systems can approximate other-equation systems.

algebra

Algebras have elements, such as integers. Algebras have operations on elements, such as addition and multiplication. Operations on elements result in existing elements. Neuron series can represent numbers and perform arithmetic operations, so neuron assemblies can represent algebra.

calculus

All differentiations and integrations use only exponentials, multiplications, and powers. Neuron series can represent logarithms, multiplication, and powers, so neuron assemblies can differentiate and integrate.

mathematical group

Mathematical groups have elements, such as triangles. Mathematical groups have one operation, such as addition or rotation. Operations map every element to the same or another group element. For example, if element is equilateral triangle, 120-degree rotations result in same element. Tables show group-operation results for all element pairs. Neuron assemblies can represent number tables and table lookup and so represent mathematical groups.

logic

Neuron series can represent letters and symbols, so neuron-series arrays can represent words and statements. Statements can use nested variable relations. Neuron assemblies can represent and understand grammar.

logic: truth value

Neurons can represent TRUE or FALSE by potential above threshold or below threshold.

logic: operations

Two or three neuron series can represent NOT, AND, and OR operations. NOT operations can change input into no output, or vice versa, using excitation or inhibition. AND operations add two inputs to pass high threshold, which neither one alone can pass. OR operations add two inputs to pass low threshold, which either input alone can pass.

logic: tables

Logic operations can use table lookup. First variable is in first column, second variable is in second column, and truth-values are in third column. Neuron assemblies can store tables and perform table lookup.

logic: conditionals

Conditional statements combine NOT and AND operators: p -> q = ~(p & ~q). Neuron assemblies can represent NOT and AND operations and so represent conditionals.

logic: reasoning

Reasoning uses statement series. Neuron-assembly series can represent statement series and so reasoning.

computation

Neuron assemblies can represent numbers and statements and perform logic operations, so complex neuron assemblies can use programming languages and compute. Neuron-assembly activity patterns can represent cellular automata, which can simulate universal Turing machines and so compute any algorithm.

geometry

Visual processing can represent geometric objects, relations, and operations [Burgess and O'Keefe, 2003] [Moscovitch et al., 1995]. Representations have same relative lengths, angles, and orientations as physical geometric objects in space.

Geometric objects are points, lines, angles, and surfaces. Geometric objects have location, extension, and shape. Geometric objects have brightness, hue, and saturation. Geometric-object relations are up, down, above, below, right, left, in, out, near, and far. Geometric operations are constructions, transformations, vector operations, topological operations, region marking, and boundary making and removing.

geometry: point

Dendritic-tree center-region input excites ON-center neurons. Surrounding-annulus input inhibits ON-center neurons. ON-center neurons can represent points [Hubel and Wiesel, 1959] [Kuffler, 1953].

geometry: line

Lines are point series, so ON-center-neuron series can represent straight and curved lines [Livingstone, 1998] [Wilson et al., 1990]. Neuron-series length can represent line length.

Lines are boundaries of regions. Distance and intensity change rates are greatest at boundaries.

geometry: surface

Surfaces are line series, so ON-center-neuron arrays can represent flat and curved surfaces. Distance and intensity change rates are small in surfaces. Neuron-array area can represent surface area. Line boundaries are surface edges and separate surfaces.

geometry: orientation

Lines and surfaces have orientation/direction. Topographic-map orientation columns, perpendicular to cortical neuron layers, detect orientation. Orientation columns are for specific space locations. Orientation columns are for specific line lengths and sizes. Therefore, orientation columns represent one space location, one orientation, and one line length [Blasdel, 1992] [Das and Gilbert, 1997] [Dow, 2002] [Hübener et al., 1997] [LeVay and Nelson, 1991].

geometry: angle

For same space location and line length, adjacent orientation columns detect orientations. Neuron assemblies calculate plane angles between two line orientations or solid angles between three line orientations. Object and body rotation movements have angle changes.

geometry: geometric figures

Neuron assemblies can represent points, lines, orientations, angles, and surfaces, so neuron assemblies can represent geometric figures, such as spheres, cylinders, and ellipsoids.

geometry: distance

Neuron-series length can represent distance between two points. Neuron series can have all orientations, so neuron series can detect distance in any direction.

Topographic-map orientation columns calculate line and surface orientations. At farther distances, concave angles appear smaller, and convex angles appear larger.

Closer regions are brighter, and farther regions are darker, so neuron excitation can estimate distance.

Closer surfaces have larger average surface-texture size and larger spatial-frequency-change gradient. Neuron assemblies can detect surface texture and spatial-frequency-change gradients and estimate distance.

Object movements and body movements occur over distances, and neuron assemblies can track trajectories.

geometry: triangulation

To find triangle lengths and angles, neuron assemblies can use trigonometry cosine rule or sine rule.

geometry: trilateralization

Trilateralization finds point coordinates, using three reference points. The four points form a tetrahedron, with four triangles. Distance from first reference point defines a sphere. Distance from second reference point defines a circle on the sphere. Distance from third reference point defines two points on the circle. Neuron assemblies can measure distances between points and angles, and can use the cosine rule or sine rule to find all triangle angles and sides.

Animals continually track distances and directions to distinctive landmarks. Animals navigate environments using maps with centroid reference points and gradient slopes [O'Keefe, 1991].

geometry: space

Brain can represent perceptual space in topographic maps [Andersen et al., 1997] [Bridgeman et al., 1997] [Gross and Graziano, 1995] [Owens, 1987] [Rizzolatti et al., 1997].

Midbrain tectum and cuneiform nucleus have multimodal neurons, whose axons envelop reticular thalamic nucleus and other thalamic nuclei to map three-dimensional space.

Vision processing derives three-dimensional images from two-dimensional ones by assigning convexity and concavity to lines and vertices and making convexities and concavities consistent.

geometry: spatial axes

Vestibular-system saccule, utricle, and semicircular canals establish vertical axis by determining gravity direction and horizontal directions by detecting body accelerations and head rotations. Three planes, one horizontal and two vertical, define vertical axis and two horizontal axes.

Animal eyes are right and left, not above and below, and establish horizontal plane that visual brain regions maintain.

Vision processing can detect vertical lines and determine height and angle above horizontal plane. Vertical gaze center near midbrain oculomotor nucleus detects up and down motions [Pelphrey et al., 2003] [Tomasello et al., 1999].

Body has right-left and front-back, and visual brain regions maintain right-left and front-back in horizontal plane. Horizontal gaze center near pons abducens nucleus detects right-to-left motion and left-to-right motion [Löwel and Singer, 1992].

Topographic-map orientation columns with same orientation align and link to establish coordinate axes, in all directions.

Sense and motor topographic maps have regularly spaced lattices of special pyramidal cells. Non-myelinated and non-branched superficial-pyramidal-cell axons travel horizontally 0.4 to 0.9 millimeters and synapse in clusters on next superficial pyramidal cells. The skipping pattern aids macrocolumn neuron-excitation synchronization [Calvin, 1995]. The regularly spaced pyramidal-cell lattice can represent topographic-map reference points and make vertical, horizontal, and other-orientation axes. Lattice helps determine spatial frequencies, distances, and lengths.

Medial entorhinal cortex has some grid cells that fire when body is at many spatial locations, which form a triangular grid [Sargolini et al., 2006].

geometry: coordinate system

Vision processing relates spatial axes to make a coordinate system. Spatial axes intersect at a coordinate origin. In spherical coordinates, space points have distance to origin, horizontal angle to horizontal axis, and azimuthal angle to vertical axis. In Cartesian coordinates, points have distances to vertical, right-left-horizontal, and front-back-horizontal axes. Brain and external three-dimensional space use the same spatial axes and coordinate system. Coordinate origin establishes an egocenter, for egocentric space.

tensor

Neuron series can represent number magnitudes and space directions, so two neuron series can represent mathematical vectors. Neuron arrays can represent vectors and motions, so they can represent spinors as rotating vectors.

Neuron arrays can represent vectors, so they can represent matrices, which can represent surfaces. Matrices can be two-dimensional tensors, which have all vector-component products as elements. For example, |x1*x2, y1*x2 / x1*y2, y1*y2| for vectors (x1, y1) and (x2, y2) has four elements. |x1*x2, y1*x2, z1*x2 / x1*y2, y1*y2 z1*y2 / x1*z2, y1*z2 z1*z2| for vectors (x1, y1, z1) and (x2, y2, z2) has nine elements.

Three-dimensional tensors have all vector-component products. Neuron arrays can represent matrices, so neuron assemblies can represent three-dimensional tensors. During eye, head, and body movements, tensors can transform egocentric-space coordinates to maintain stationary allocentric-space coordinates.

self-reference and mental space

Gödel numbers can contain compressed-information descriptions of themselves. Nesting allows self-reference. Topographic maps can contain descriptions of themselves. Topographic-map space information can contain space-information descriptions. Mental space can contain space descriptions. Complete brain-based mental-space descriptions can contain mental space {self-reference and mental space}. By nesting, mental space can be internal, in observer, and observer can be in mental space.

space by relaxation

Color processing finds surfaces and distances by mathematical relaxation techniques that locate complete and consistent positions {space by relaxation}.

state space and mental space

Color phase space can have three spatial dimensions, one time dimension, surface orientation dimension, black-white dimension, red dimension, blue dimension, and green dimension {state space and mental space}.

CONS>Consciousness>Speculations>Space>Mathematics>Vectors

spinors and mental space

Spinors are rotating three-dimensional vectors or quaternions. Perhaps, spins can define space axes, and three real-number orthogonal independent spinor components make three-dimensional space {spinors and mental space}.

tensors and space

Tensors are scalars, vectors, matrices, three-dimensional arrays, and so on, that represent linear operations. Tensors can model flows and fields. Integrating tensors over one dimension decreases dimension by one. Differentiating tensors over one dimension increases dimension by one. Three tensor differentiations can build three dimensions from one scalar {tensors and space}.

CONS>Consciousness>Speculations>Space>Physics

ether and mental space

The ether can fill space or define space {ether and mental space}. The ether can provide a substrate for sensations and observer.

holography and mental space

Holography can make three-dimensional images in space from two-dimensional interference patterns illuminated by a coherent-light beam {holography and mental space}. Perhaps, association cortex stores two-dimensional interference patterns and makes beams. However, association cortex has no coherent beam to make interference patterns, and interference patterns and intensities, features, and objects have no relation. Brain does not send out signals.

projection and mental space

Projectors illuminate film or otherwise decode stored representations to create two-dimensional or three-dimensional displays in media, such as screens or monitors. Perhaps, mind is projection, and brain is projector {projection and mental space}. However, mind must know sensations, not just display them. Projection starts with a geometric figure. Projection needs something on which to project. Projection has no opposites.

quantum mechanics entanglement and non-locality

Physical interactions are local. Forces are particle exchanges. For example, masses exchange gravitons to affect each other. Force fields change space and so affect particle motions. Physical interactions do not allow action at distance, except for quantum-mechanical entanglement. Two particles that have interacted have a joint wavefunction, made of superposition of the two particle wavefunctions. Because particle waves are infinite, the joint wavefunction is infinite. The two particles have quantum-mechanical entanglement over all space. Consciousness has experiences at distant places, with no interceding events. Perhaps, consciousness entangles everything over all space {quantum mechanics entanglement and non-locality}.

non-locality

In quantum mechanics, observation at one location can appear to immediately affect another observation at a distant location. Though physical waves send information at finite speed, quantum-mechanical waves collapse everywhere at once. Perhaps, mind involves non-locality. Consciousness links separate space points, and sense system and sensation, and so is non-local.

However, brain processing does not use waves, entanglement does not include knowing, and any entanglement in brain collapses in less than a microsecond.

tunneling and mental space

Perhaps, brain has potential barriers to outside world, but mind can tunnel through barriers to experience outside world {tunneling and mental space}.

CONS>Consciousness>Speculations>Space>Psychology

sense qualities and mental space

People seem to experience a sensory field outside themselves [Velmans, 1993]. Sense experiences are at locations in three-dimensional space. Sense qualities are the type of thing that allows consciousness of space {sense qualities and mental space}. Experiencing mental space requires sense qualities.

surface distances and mental space

The farthest surfaces, like the sky or distant mountains, seem to be a few kilometers away. The closest surfaces, like a book, appear smaller than their retinal visual angle indicates. Perhaps, rather than varying directly with distance, perceived sizes are logarithms of distances {surface distances and mental space}.

surface texture and depth

Gradient location-orientation histograms define surface textures. People assign depth using corresponding points in stereo or successive images and other monocular techniques {surface texture and depth}. Near objects have more texture details, and far objects have less texture details.

surface transparency and perspective

Windowpanes and perspective paintings represent depth and three-dimensional scenes in two dimensions, and their two-dimensional surfaces are apparent. If such surfaces have no reflection or any other property and so are invisible, they represent three-dimensional space perfectly {surface transparency and perspective}.

zooming and mental space

Scaling (zooming) maintains relative distances and angles {zooming and mental space} {scaling and mental space}. Zooming in can make a finite region equivalent to an infinite region, because the boundary becomes far away. Zooming out can make large regions smaller. Attention is like zooming.