DRAFT

PERCEPTION AND MEMORY

Part 1
of

COMPREHENSION STRUCTURES

November 22, 2018

John E. Grisinger

Chapter 0
Introduction to Part 1

Much is known about the anatomy of neurons in the brain and their interconnections as well as the nature of the electro-chemical signals that travel from one neuron to another. We also know the following.

- Sensory organs, including the skin, receive stimuli whose energy causes signals to be sent to the brain.
- Automatic processes in the brain receive those signals to create perceptions that enable comprehension of the world.
- The cortex is essentially uniform in the kind and configuration of its neurons. That uniformity is evident by the plasticity of the cortex, i.e., its ability of segments to be repurposed when sensory inputs are altered.
- The cortex is where perceptions become memories and those memories enable comprehension.

Little is known about the glial cells in the brain. Little is known about how interconnected neurons process signals and nothing is known about how those signals provide the ability to perceive, remember or comprehend the world. All we know is that they do.

The mental processes that provide for motor control, including those for vision, and those for emotion have complexities resulting from the awkward way the brain evolved along with both its motor control and perception abilities. The cortex, in contrast, is a relatively new addition to the brain. The growth of the cortex that resulted in human beings is very recent and was very rapid. That rapidity was likely possible because it simply added more of the same kinds of neurons to increase memory for more complex comprehension. Such rapidity wouldn't have been conducive to creating a variety of function-specific neurons for that purpose.

What we know about neural processes and where they occur in a brain is from what has been identified and measured in experimental situations: neural responses to specific inputs and where they occur. Neural process for memory and comprehension are not amenable to such experimental procedures. However the simplicity and uniformity of the cortex where memory resides makes it amenable to analysis by reverse engineering starting from what is known about perception and comprehension. The results of my reverse engineering efforts are reported here.

In this work I present a hypothesis for how neural signals organize neurons in a way that enables perceiving, remembering and comprehending. This work started as an effort to find the simplest information platform consistent with the open-world assumption and consisting only of directionally interconnected elements that form *structures* that each stored an item of information, i.e., an entity, attribute or concept thereof. I was able to demonstrate how each form of information could be stored by *structures* having configurations that are specific to each form

of information. While documenting that platform, I sought to compare it to memory in the cortex where all forms of comprehension can be stored. I reasoned that the cortex must also store structures like those in the information platform. I recognized that the configuration of neurons in the cortex is too simple to store in the same manner as the platform. Since a cortex, like an information platform, only stores what is entered, I looked at the patterns inherent in the signals arriving at the cortex and how structures might store them.

I searched for a simple neural signaling mechanism by which cortex neurons could create structures. This effort applied reverse engineering plus:
•   what is known about the anatomy and physiology of neurons in the cortex and in the sense organs as they relate to perception and memory;
•   what a brain does and does not store, and what can be recognized and recalled;
•   the need to begin by storing nothing, then grow and mature; and
•   self-awareness of perception and comprehension.
Ignored were those portions of the cortex that do not involve memory, including emotion and motor control. The search was constrained by simplicity, internal consistency, low energy consumption and a viable and describable evolutionary pathway.

I found a very simple neural signaling mechanism that enabled cortex neurons to create structures that store the patterns received from sense organs. That mechanism also creates linkages between the *pattern structures* that were created or recalled simultaneously, thereby storing their "togetherness". Those interlinked pattern structures were found to be able to store each form of comprehension.   The resulting hypnotized mechanism and the interconnected pattern structures it creates can be summarized as follows.

> All that is needed for a cortex to create interconnected pattern structures to perceive and comprehend the world is for each of its neurons to: 1) store which neurons sent signals that caused it to generate a signal of its own, and 2) use what is stored to at least temporally control signals received from other neurons.

In addition, the only "information" conveyed by neural signals is found in signals arriving directly from detector neurons. That information is the power of the stimuli and identification of which kind of detector neuron it came from, and, for audition, its acoustic frequency. The powers and pulse patterns of other signals convey no information, only which neurons' signals were able to arrive simultaneously and generating a new signal. Also, there are no circuits, no feedback and no computation.

Part 1 describes the details of that mechanism and demonstrates how it creates pattern structures storing what was perceived, as well as sequences of pattern structures, i.e., for movement, change and sound. A few specific hypotheses for neural and non-neural behaviors are identified to account for what is understood and experienced. The presumption here is that the processes not accounted for: 1) are related to cortex abilities not addressed here, e.g., motor control; 2) are efficiencies in visual and auditory perception found elsewhere in the cortex that evolved after what is described here. The reverse engineering effort itself is not further described.

Part 2 [not included here] describes and demonstrates how interconnected pattern structures created by activating neurons are able to store what is needed for comprehension, specifically, understanding the world in terms of the following: representors and concepts; generalization and specialization; reality and imagination; ignorance and uncertainty; spatial and temporal existence, and their adjacencies; wholes and their parts; form and substance; physical processes; human relationships; collections; signification in particular and language in general.

Since Part 1 crosses several disciplines, I wrote it for readers who may not have encountered all of those disciplines, including cognitive science. The resulting work does not describe all the facets of perception and comprehension in depth: it couldn't. Rather it describes its topics as thoroughly as needed to identify how pattern structures are created and become interconnected using a consistent terminology and diagrammatic conventions.

By way of introducing some of the terms used in this work, the following flow chart displays the major processes, the "memory stores" and the signal flows between them. These processes and flows are oriented like a human body: the mind at the top and nearly all sensory input below. A process, whether a *physical process*, or *mental process*, is depicted by a rectangle; the two triangles depict the two distinct types of memory stores in the brain: one enabling perception, and the other enabling memory and comprehension. Memory consists of interconnected structures. All *external stimuli*, depicted by a thin arrowed line, are the different external forms of energy that sense organs detect; a thick arrowed line depicts the neural signal paths through the nervous system.
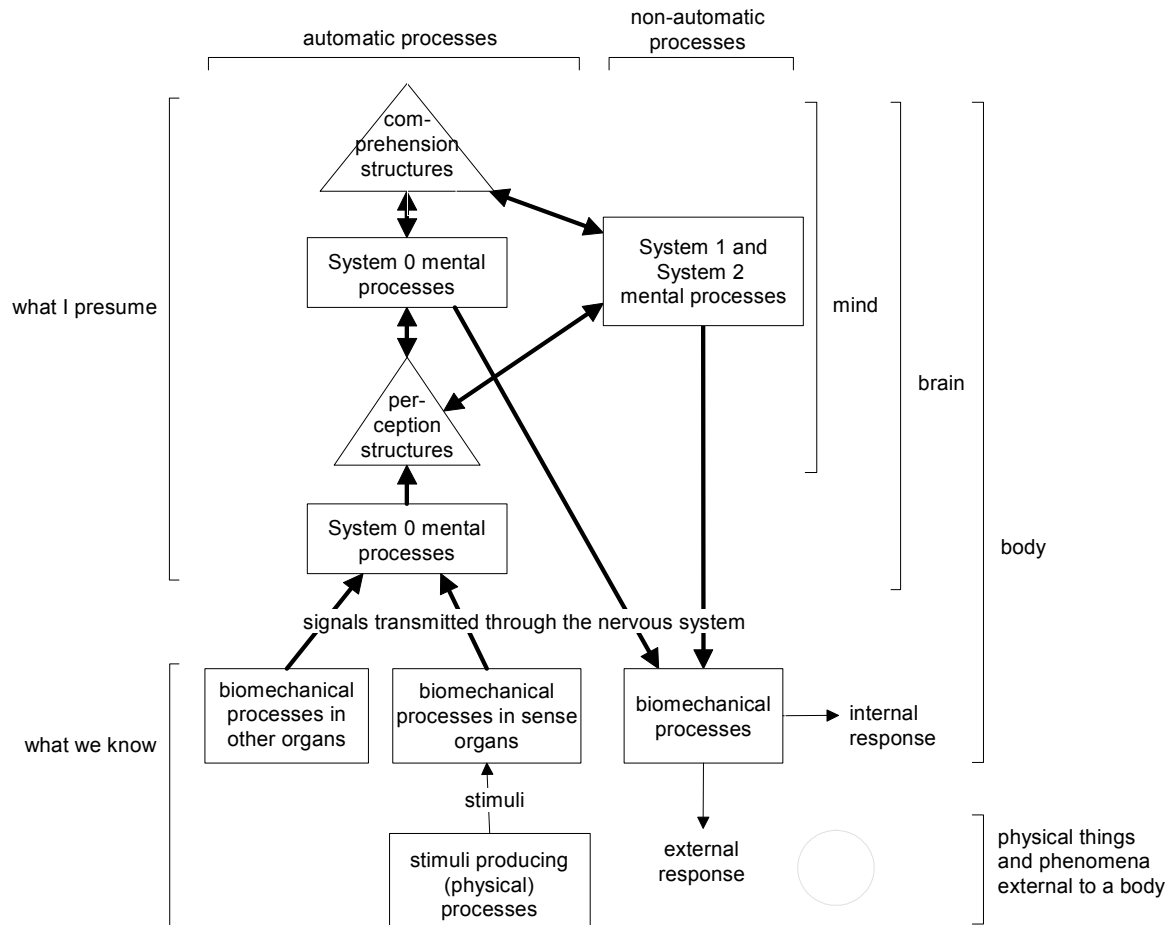
Figure
Cognition Flow Chart

The world, as used here, is what the mind comprehends as the collection of all things that exist, physical and otherwise, i.e., in *the world*. Thus, *the world* includes one's own body as well as its mind, at least so far as one's mind can be comprehended.

What is comprehended as being in the world out side the mind usually has a *kind signifier*, e.g., 'neuron', 'tree', and 'water'; that which is only within a mind, i.e., created by thought alone, has or is assigned a *type signifier*, e.g., structure, and is identified as such.

The mental processes and memory stores illustrated above are the subject of this Part. The processes identified above are drawn from the work by Kahneman [Kahneman, Daniel; Thinking, Fast and Slow] where he described two non-automatic mental processes: one *intuitive* (fast) and the other *thoughtful* (slow), and identified them as System 1 and System 2, respectively. System 2 is also referred to as *critical thinking*. Although he presented them as metaphors rather than as an established cognitive distinction, I use them to distinguish and type the mental (cognitive) processes as described below. That terminology is extended to include System 0 for *automatic* mental processes. The three mental processes are tabulated below along with examples. When first introduced, each mental process is identified by its system: 0, 1 or 2, and assigned a type signifier.

4

Types of Mental Processes

mental process type and label	definition	examples
automatic/ System 0	an automatic mental process that creates/alters what is stored by virtue of neural behavior alone	generating a visual presentation of what is perceived; immediately reacting to a moving vision or a loud sound; recognizing or not recognizing something seen or heard
intuitive/ System 1	a learned mental process that creates/alters what is stored	reacting to a perceived threat; doing arithmetic; being aware of a person's mood
thoughtful/ System 2	mental process that creates or alters what is stored by thought	searching to recall a memory; imagining something new; evaluating risk; interpreting art

Organization of this Part

I organized the remainder of this part as follows:

       Chapter 1: Neuron Anatomy and Physiology
       Chapter 2: Pattern Structures and Perception Structures
       Chapter 3: Perceiving Structures Configurations
       Chapter 4: Attending to Presentations and Creating Memories
       Chapter 5: Remembering and Forgetting
       Chapter 6: Observations, Commentary and Extended Summary [omitted for now]

Let's proceed.

Chapter 1
Neuron Anatomy and Physiology

A mind can be understood in terms of the anatomy of its neurons, i.e., their interconnections, and the physiology that enable them to generate signals, process received signals and store something about how they arrived, i.e., their behaviors. These topics are discussed in turn in this Chapter as they apply to the neurons that enable perception and memory.

Since those interconnected neurons can be understood as a network that carries signals, there is a tendency to regard electrical devices as their analog. The fallacy in this thinking is that whereas the configuration (wiring) of components of an electrical device determines its behavior, the interconnections serve only to direct signals. "Wiring" of neurons is due the current and ever-changing ability of neurons to accept or reject signals and respond to what signals arrive by generating or not generating new signals. "Wiring" in the latter sense is the subject of this Part.

I organized this Chapter as follows:
   Section 1: Neural Evolution and Anatomy
   Section 2: Neural Physiology
   Section 3: Spike Matching and Signal Generation in Memory Neurons
   Section 4: Neural Tuning

Section 1
Neural Evolution and Anatomy

The following summarizes what is known about the human brain.

   The cerebral cortex, the largest part of a human brain, is a sheet of neural tissue that is the outermost part of the cerebrum. It plays a key role in memory, attention, perceptual awareness, thought, language, and consciousness. It is estimated to contain 15–33 billion neurons. Each neuron is connected to about 7,000 other neurons. It has been estimated that the brain of a three-year-old child has about 1,000 trillion synapses. This count declines with age, stabilizing by adulthood from 100 to 500 trillion synapses. A signal generated by a neuron is sent in one direction to other neurons. A signal reaches another neuron when it crosses the synaptic gap between them.

   Human cortexes differ from the cortexes in other species only in the count of neurons and the observable layers of the neuron configuration. For an adult human it can be visualized as a crumpled sheet that when spread out is has the area of a large dinner napkin that is roughly 2–4 mm thick. In the newer portion of the cerebral cortex (i.e., the neocortex) there are six identifiable horizontal layers (fewer in lesser developed animals), each with different types of neurons and connectivity. Another feature of the cortex is its lack of features: it is uniform. That uniformity is taken to mean that neurons are the same, they are organized in the same way with respect to each other and they process signals in the same way.

In addition to neurons, the brain has glial cells, non-neuron cells in the brain that are more numerous than neurons, are connected to neurons but are otherwise separate and operate independently from neurons. The behavior and functions of glial cells are poorly understood. As hypothesized later, they provide paths for recalling of memories.

Subsection 1
Neuron and Brain Evolution

Animalian evolution provides clues to the behavior of neurons described in this work. That evolution began with multicell organisms in the Cambrian Period and evolved to have the ability to comprehend its surrounding world.

During the Precambrian, single cellular organisms first came together and exchanged ions across their cell surfaces in order to share energy. Colonies whose divided cells remained with the same colony become multicellular organisms. Those cells on the exterior become specialized in ways that provided a protective barrier and maintained the organism's spherical shape to provide structural stability. They continued to be photosynthetic and transmit ions that provided energy to the interior cells. The interior cells became specialized at distributing that energy through ion exchange.

When mechanically strained by contact with a solid or consume resources, exterior cells sent additional ions/energy to its adjacent cells causing a response. If many cells are strained, the energy transfers would produce a cascading "shock to the system", which could cause the organism to change shape in ways that improve survivability by minimizing or moving, or surrounding a source of nourishment.

As multicellular organisms grew in size, their surface area to volume ratios decreased and their mass increases, resulting in exterior cells providing less structural integrity from their spherical shape. Structural integrity was provided either externally by a shell or internally by a skeletal system. Exterior cells become localized and specialized in their detection of mechanical and photon energy. Interior cells were able to take any shape and to become specialized in various ways including by straining a portion of the organism in response to localized strain of the exterior cells to provide a mechanical response. Some internal cells become specialize to transfer signaling ions to the cells responding to localized strain. As the distance between detecting and responding neurons moved apart, signal-carrying neurons become an elongated sequence of nerve cells.

During the Cambrian Explosion, multicellular organisms became bigger, more specialized, and more complex. Nutrient flows between cell interstices became directed and eventually become the circulatory system. Cells on surfaces that respond to specific stimuli (light, aquatic pressure waves and chemical reactions to substances) send signals to other cells becoming centralized in what became the brain. The utility of detecting these signals caused detection to be improved. Brain cells evolved to be able to send signals to many other brain cells becoming non-cortex pyramidal cells, enabling efficient detection of stimuli and motor neurons that control of responses to them. At first, nothing is stored; the brain is purely reactive. The ability to store

began with tactition and then to vision followed by other forms of perception. With the ability to centrally control other parts of the body, the body took on many different shapes, and grew controllable appendages for use in obtaining food or moving away from predators. The brain grew as new or changes in detection occur and muscle coordination becomes useful.

The primitive brain had evolved by creating neurons tailored to specific functions. When it created the cortex, it created neurons that could organize and store at least some of what it perceived all in the same way. Thereafter, rather than creating function specific neurons to enable comprehension, it was sufficient to add more of the same kind of neurons, both laterally and vertically, to store, organize and integrate what was perceived. Adding more neurons of the same kind is faster and more efficient, as well as more effective, than creating many different kinds of function specific neurons.

In the adaption to land, some creatures became warm blooded. Being in an atmospheric environment, exterior cells become specialized at using energy to send signals used to detect the presence and intensity of stimuli of the following energy sources:
> audition: arriving acoustic energy, first on portions of the skin and later in ears;
> thermoception: thermal energy from heat flow through the skin; and
> olfaction (smell): chemical energy from reactions with substances in the windpipe.

Throughout the evolution from individual cells to neurons, the two features that remain essentially unchanged are:
- the signal from one cell or neuron to another is transmitted by a flow of ions across the gap between them, for neurons, that gap is the synaptic cleft; and
- the energy that powers those signals is from the detected stimuli.

Subsection 2
Neurons and their Connections

Interconnected neurons generate and transmit signals in one direction through the nervous systems, from where they are detected to the brain. Within a neuron, that signal is an electro-chemical signal; between two neurons it is a flow of ions. Neurons are specialized in a variety of ways. The neurons of interest here are those that enable perception and storage what is perceived. Those neurons are presumed to reside in one or more unspecified layers in the cortex.

Interconnected neurons generate and transmit signals in one direction through the nervous systems and by passing ions from one neuron to then next. They encompass the entire nervous system and the brain. Neurons are specialized in a variety of ways. Those of primary interest here are described below.

Detector Neurons. A detector neuron located in one of the body's sense organs: the eyes, ears, mouth, nose, the skin, muscles and other organs inside the body. It receives stimulus energy and responds by using that energy to generate a signal that is sent through the body's nervous system to one particular *receptor neuron* in the brain. The different kinds of detector neurons respond to a specific form or range of stimuli.

Receptor Neurons. Receptor neurons are inside the brain where they each receive the signals from one detector neuron arrayed in three dimensions. There the receptor neurons receiving signals from the same sense organ are arrayed together, apparently at random, but separated from the receptor neurons for the other sense organs. Being arrayed randomly in three dimensions, their positions in the brain cannot reflect how their detector neurons arrayed in their sense organ. As illustrated shortly, a typical receptor neuron has: a soma, an axon that extends from the soma with branches that connect to *memory neurons* inside the brain. A receptor neuron generates the same signal that received from its detector neuron and sends through its axon to its connected *memory neurons*. The receptor neurons from the two eyes and the two ears terminate in different hemispheres in the brain.

Memory Neurons. A memory neuron is inside the cortex where it receives signals from either multiple receptor neurons or other memory neurons, and may respond by generating a signal of its own that is sent to other memory neurons. A memory neuron is a kind of pyramidal neuron or multipolar neuron. As illustrated shortly, a typical memory neuron has: a soma, an axon with branches, and numerous dendrites. The axon extends from the soma like a receptor neuron. Each axon terminal is opposite a dendrite, separated by their synaptic cleft. The soma of a receptor or memory neurons generates signals that traverse the axon and its terminal branches. A signal crosses the synaptic cleft at the end of a terminal branch to reach the dendrite of another memory neuron. Dendrites extend at most a few hundred micrometers from the soma. The axon can extend for much greater distances before dividing into hundreds of branches that end at an axon terminal.   Unlike other kinds of neurons, memory neurons can store something about which neurons caused the signal to be generated.

A taxonomy for different kinds of neurons is presented below.

```
        neuron
              detector neuron
                    :  (sub-kinds based on the stimuli that causes it to generate a signal)
              non-detector neuron
>                    receptor neuron
>                    memory neuron
```
(Underlining is used through out this work to identify a term that is being defined, in this case defined in this taxonomy, in this case by its sub-kinds. A colon in a taxonomy identifies missing sub-kinds. The symbol: > at the left is used to identify an atomic kind or type in the subject taxonomy.)

Displaying Memory Neurons

The following are two diagrams for memory neurons and its connections; the left diagram is pictorial; the right diagram is an abstraction used here. A line with a single or double unfilled arrow (−▷ or −▷▷) is used throughout this work to point from descriptive text or a type signifier to one or multiple depicted elements, respectively. The ellipses between depicted elements indicate that there are similar undepicted elements, in this case those undepicted elements are neurons and connections of the type displayed.

      The left diagram displays one complete memory neuron (on the bottom) and its distinguishable part, i.e., its anatomy, along with parts of other neurons to illustrate how

they are connected. The cell body, i.e., the soma and its dendrites, are depicted by a large shaded circle; the axon and each of its axon branches are depicted by a line with a solid dot at the end depicting its axon terminal. The synaptic cleft is where the solid dot touches the large shaded circle (at a dendrite). The wide arrow identifies the direction of signals from one neuron to another. As illustrated in this diagram, each memory neuron is directionally connected *from* many neurons *to* many other neurons. A receptor neuron is depicted by a circle with one nerve at the bottom.

The right diagram is a simplified and more useful depiction of neurons. A neuron is depicted by a circle; the lines between them are each a <u>connection</u>. A receptor neuron is later depicted by a circle with one line at the bottom. The neurons are generally depicted so that the signal direction is always upward.
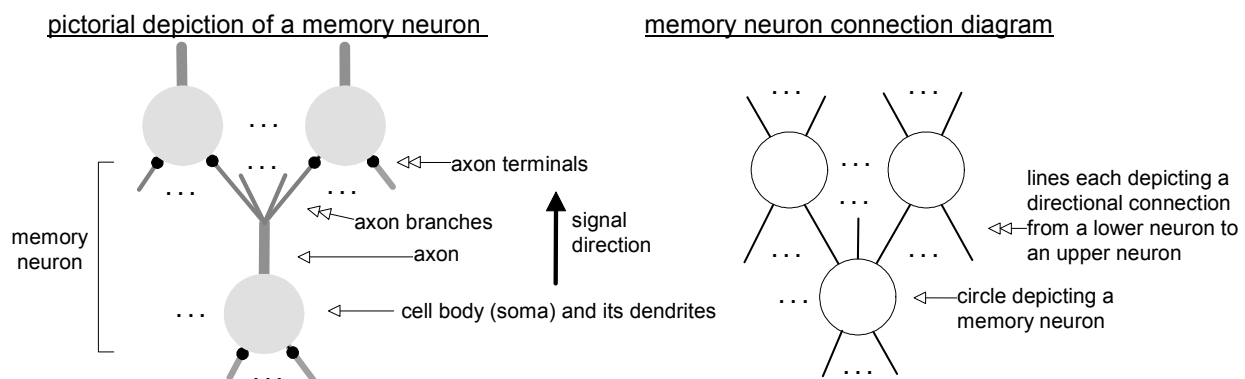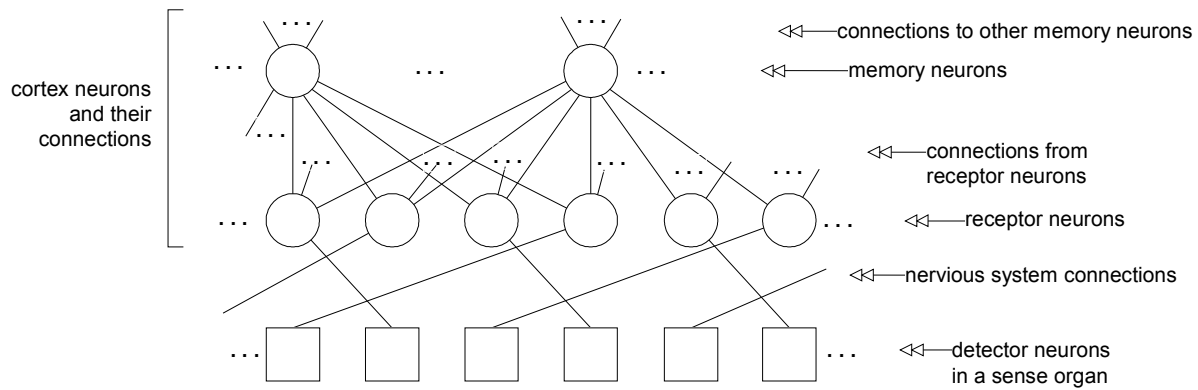

Figure 3-2
Memory Neuron Depictions

Connections Among Detector, Receptor and Memory Neurons

Each neuron is directionally connected with other neuron(s) as follows:
detector neuron	to 1 nerve in the nervous system
nerve	from 1 detector neuron to either 1 other nerve or 1 receptor neuron
receptor neurons	from 1 nerve to N memory neurons
memory neurons	from N receptor neurons or N memory neurons to N memory neurons

The configuration of detector neurons, receptor neurons and memory neurons are illustrated in this work as displayed in the diagram below. Connections and memory neurons are displayed as before including all neurons being oriented with respect to the upward directionality of their signals. Receptor neurons, which are randomly arrayed in three dimensions are each depicted by a circle positioned in a row below the memory neurons. Below the receptor neurons are their detector neurons depicted by a square. The displayed position of the detector neurons arrays are intended to reflect how they are (lineally, areally or spatially) arrayed in their sense organ, i.e., which are nearest to each other, although in one dimension. Each connection from a detector neuron to its receptor neuron identifies the path of the signals between the two without regard to the different nerves, kinds of neuron their, synapses and the parts of the brain that those signals may traverse on the way to the cortex. Those other brain organs are ignored because they do not alter the character of those signals as they affect perception.

10

Figure
Connections between Neurons by Kind in the Cortex

The interconnected receptor neurons and memory neurons form a physical network in the cortex. That network directs and constrains the transmission of signals among involved neurons. The connections in a cortex are presumed to not allow recursive signals, i.e., a signal generated by a neuron being able to directly or indirectly received by the same neuron. As illustrated above and more fully illustrated in Figure c_0, since a neuron has multiple directed connections to other neurons, a cortex can be understood as consisting of multiple hierarchies that have neurons in common, referred to here as an *intersecting hierarchy*. The lengths of the connections among memory neurons (axons and axon branches) are much shorter than the connections from receptor neurons. The shortness of those connections results in columnar structures in the cortex. Thus, hierarchies are highly localized with respect to the width across a cortex, thereby limiting the extent of their overlapping. The hierarchies presented above and those that follow reflect that limited overlapping.

Section 2
Neural Physiology

The neural physiology of importance here is how neurons behave with respect to signals, i.e., how signals are generated by a neuron and what happens to them when they arrive at a neuron.

Neural Signals

A signal generated by a neuron (of any kind) is a sequence of electrochemical spikes (or pulses) as described below.

Electrochemical Spikes. The soma of a neuron can generate one or a sequence of brief electrochemical *spikes* (also called action potentials) that travel *to* other neuron(s). Each spike transmits the same energy during a fixed duration of less than a thousandth of a second. It speeds along the axon ranges from 1–100 meters per second. Across a synaptic cleft, each spike is transmitted by ions.

Signal Form. A signal is a sequence of individually generated (electrochemical or ionic) spikes where two sequential spikes are separated by an *interspike interval*. Unlike each spike which has a fixed duration, interspike intervals have different durations. Thus, a spike can be regarded as a delimiter between two interspike intervals. This means of neural signal coding is the converse of Morse code for alphanumeric characters (which are coded by a unique combination of short and long spike durations with fixed interspike interval durations, i.e., the interspike intervals serve as delimiters). This form of encoding (precise spike timing of high-frequency firing-rate fluctuations) is referred to elsewhere as neural temporal coding (of neural information).

Signals Generated by Detector Neurons

While receiving stimulus energy, a detector neuron may generate spikes as some of the stimulus energy is converted to a signal's electrochemical energy (spikes) in a process called transduction. The duration of an interspike interval is not random or arbitrary: those interval durations have a pattern and that pattern is repeated after a fixed count of spikes. A repeated fixed count sequence of spikes is called a spike train having (fixed) a spike train pattern and a (variable) spike train duration. There is no detectable delimiter between two spike trains so an individual spike train itself is not identifiable.

Each kind of detector neuron evolved either independently or by the mutation of a detector neuron in the same sense organ. A mutated detector neuron detected different stimuli and generated a different spike train pattern. The differences in spike train patterns for mutated detector neurons were likely small compared to those that arose independently. The result is that *different kinds* of detector neurons generate spike trains with different spike train patterns while detector neurons of the *same kind* generates spike trains with the same spike train. Thus, a spike train pattern is a unique identifier of a detector neuron type, enabling cortex neurons to respond differently to different kinds of stimuli, e.g., the signals from red cones in an eye are distinguishable from those generated by blue cones.

In addition, the *interspike interval duration* between two spikes in a given pattern is not fixed: it and all other interval durations are relative to each other. For example if the following rows of numbers are *interspike interval durations* for two spike trains each having four spikes, these spike trains, having the same relative *interspike interval durations*, have the same pattern.

    1 4 2 3
    2 8 3 6

Signal Energy and Power

Signal Power. Since each spike has the same fixed energy and each spike train has a fixed count of spikes, each spike train with the same pattern has the same energy. However, since the interspike duration varies, the rate at which spikes are generated varies. Thus, while generating a spike trains at a fixed rate, the signal has a fixed power (energy/time); while that rate varies, the power of the signal varies. The power of a signal is a useful statistic for comparing signals, e.g., in the above example, the lower of the two interspike interval durations has one half the power of the one above it because those durations are twice as long and have twice the duration (ignoring the fixed duration of the four spikes). A signal's power is expressed in terms of a spike train or its absence as follows:

> spike train power: spike energy × spike count in a spike train / spike train duration
> signal power: spike energy × spike count / duration of spike count

No signal is generated if the stimulus power is below a threshold, e.g., when something is "too dark to see". If there is an upper limit on spike train power (when interspike interval duration is at a minimum), it is higher than what will damage the detector neurons. High power signals initiate actions to prevent such damage.

A detector neurons' signal power varies monotonically (but not linearly) with the stimulus power that produced it, i.e., when stimulus power increases or decreases, spike train power increases or decreases, respectively. Thus, a signal generated by a detector neuron is able to convey "information" by two independent components: its power and its signal pattern. The former identifies the power of the stimuli and the latter identifying the kind of detector neuron that generated it.

The sufficiency of stimulus energy to generate signals from detector neurons and beyond is stated in the following hypothesis.

> **Stimulus Energy Hypothesis**. Above a power threshold, the energy a detector neuron receives from a stimulus is sufficient to generate the signal it sends to its receptor neuron. The energy generated by a detector neuron less any loss of that energy as it travels through nerves to its receptor neuron is sufficient for a receptor neuron to regenerate that signal.

In addition to minimizing the energy needed to detect stimuli, this hypothesis avoids the need for evolution to find a way to provide additional energy for detection of stimuli.

Section 3
Spike Matching and Signal Generation in Memory Neurons

Spike trains generated by detector neurons arrive at receptor neurons in the brain. This section describes a mechanism for how those signals come together in the brain and the effect it has on memory neurons.

I begin with the following hypotheses about how receptor neurons process arriving signals and how a signal maintains its power and integrity on its way to a memory neuron.

> **Receptor Neuron Spike Energy Hypothesis**. The energy of a spike received by a receptor neuron is sufficient for it to generate one spike immediately upon arrival, thereby replicating the spike train originally created by its detector neuron and sending it to a memory neuron without delay. The generated spike may have less energy than the received spike, but that energy is presumed to be sufficient to reach and possibly affect memory neurons. If different kinds of receptor neurons generate spikes with different energies, that difference does not affect the behavior of memory neurons.

> **Signal Integrity Hypothesis**. When a spike in a spike train reaches the end of an axon from a receptor neuron or a memory neuron, it and the following spikes traverse only one axon branch. The energy of a spike is not divided and the signal arrives intact at an axon terminal with little if any loss before crossing the synaptic cleft to reach a memory neuron's dendrite.

This hypothesis is based on realizing that if a spike's energy were divided in order to traverse multiple axon branches, it energy would be diminished, possibly by orders of magnitude. If those spikes are amplified before reaching the syntactic cleft, nearly all of that additional energy would be wasted. (How one axon branch is selected is discussed later.)

Consistent with what is known about the behavior of memory neurons, the following hypothesis is the simplest and most parsimonious way that a memory neuron could respond to an arriving signal's spikes and generate new spikes to create a new signal.

> **Memory Neuron Spike Generation Hypothesis**. If two or more spikes from different signals sufficiently overlap on their arrival in a memory neuron's soma, the energy of those spikes is used to immediately generate a spike of its own. The energy of each generated spike is the same regardless of the energy of the arriving spikes. A spike that arrives without overlapping another spike does not generate a spike and its energy is stored by the memory neuron or lost. (How much temporal overlap of two arriving spikes is necessary to cause the generation of a new signal is not known and not relevant.)

Stated more simply, simultaneously arriving spikes cause a memory neuron's soma to generate a new single spike at a fixed energy. It is as if (two or more) simultaneously (or nearly so) arriving spikes continue on as a single spike using the energy they arrived with. (A discussion of the energy flows in a memory neuron for this and other processes is presented later.) (The combining of spike energy in this manner has been referred to elsewhere as a summation.)

When a memory neuron has received signals that enable to generate a signal of its own, that neuron is referred to as being *active* or having been *activated*.

Continuous Signal Generation

The following subsections discuss each case for the different ways that a memory neurons can generate a signal from two arriving signals. The case for three or more arriving signals is not presented here because that case is a self-evident extension of those described below and is not a significant factor in memory neuron behavior as described later. That discussion is followed by a discussion of the probabilities of certain signal power combinations.

Subsection 1
Spike Generation by In-Phase Signals with the Same Pattern and Same Power

The two cases for two arriving signals with the *same spike train pattern* and having the *same power* are *in-phase* or *out-of-phase* arrivals as illustrated in the table below.

> The two arriving signals' spikes are displayed in the first two rows with the generated spikes displayed in the third row. A spike is depicted by a thick vertical bar with the same width and height (suggesting its fixed duration and fixed energy) with varying intervening spaces for the varying interspike intervals. The spikes are arrayed temporally from right to left and temporally aligned vertically so that a generated spike is below the two simultaneously arriving spikes that generated it. A vertical bar (|) is inserted to (arbitrarily) mark a point that is common to both spike trains in order to better illustrate the phase shift. Although illustrated as both having the same power, the same results apply when the two powers vary synchronously.

Signals with the Same Spike Train Pattern and Power

signal	temporal sequence of spikes in a signal with the same pattern	
	in-phase patterns	out-of-phase patterns
two arriving signals with the same power	▮ ▯▮▮ ▮ ▮▮▮ ▮ ▮ ▮▮▮ ▮	▮ ▯▮▮ ▮ ▮▮▮ ▮ ▮ ▮▮▮ ▮ ▮▮
	▮ ▯▮▮ ▮ ▮▮▮ ▮ ▮ ▮▮▮ ▮	▮ ▮ ▮ ▯▮▮ ▮ ▮▮▮ ▮ ▮ ▯▮▮ ▮
generated signal	▮ ▯▮▮ ▮ ▮▮▮ ▮ ▮ ▯▮▮ ▮	▮ ▮ ▮ ▮ ▮ ▮ ▮

Note that two arriving *in-phase* signals with the same power and pattern generate a signal that replicates the arriving signals and their power. Note that two arriving *out-of-phase* signals generate a signal with fewer spikes and, therefore, less power than the arriving signals and, although not immediately evident, it has a spike train pattern of its own determined by the pattern of the two arriving spike trains and their phase shift.

In addition, two arriving signals with the same spike train patterns need not (and are unlikely to) have exactly the same power. Arriving signals with the same spike train pattern and slightly

15

different powers will occasionally be in-phase long enough for a neuron to generate a signal with the same pattern as its arriving signals. For higher power differences, they will be *in-phase* more often but more briefly without generating a signal with the same pattern. This latter case ("higher power differences") is included below.

Subsection 2
Spike Generation by Signals *Not* having the Same Pattern or *Not* having the Same Power, or Both

The above can be considered a special case. The case discussed here occurs whenever:
• the signals have the *same spike train pattern* but *different powers* whose difference prevents generating the arriving spike train pattern (as described above); or
• the signals have *different spike train patterns* or no spike train pattern, irrespective of powers.
The spike sequences of two arriving signals for these cases are illustrated below in the same manner as above.

Signals with the Different Patterns or Different Powers

signals	temporal sequence of spikes	
	same spike train patterns with different powers	different spike train patterns or no pattern (powers irrelevant)
two arriving signals	‖ ▌ ▌ ▐ ▌ ▐ ▌ ▐▐ ‖ ▌ ▌ ▌	▌ ▌ ▐▐ ▌ ▌ ▌ ▐ ▐
	‖ ▌ ▌ ▐ ▌ ▌ ▐ ▐ ▌ ‖	▌ ▌ ▌ ▌ ▐ ▌ ▐ ▌
generated signal	▌ ▌ ▌	▌ ▌ ▌

Note the following.
• There are fewer generated spikes than either of the arriving signals and, therefore, it has less power than either of the arriving signals.
• If the spike train patterns are different or there is no pattern, the generated signal does not have a pattern.

Note that in all cases, increasing the powers of arriving signals does not affect how tuning occurs, only the power of the generated signal.

Subsection 3
Relative Probabilities of Signal Power Combinations that Can Generate a Signal

Based on the above, we can describe the following *relative probabilities* of a memory neuron generating a signal from two arriving signals having powers, 'p and p':
the relative probability of arriving signals having powers: 'p and p'; and
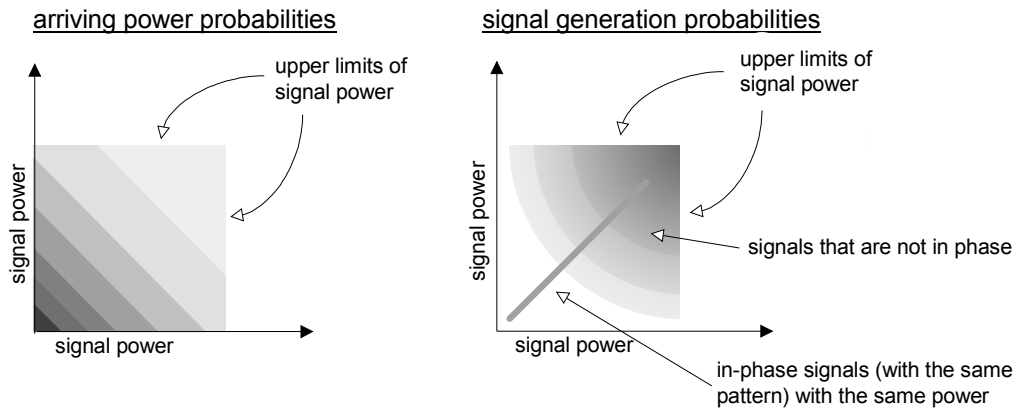the relative probability of generating a signal that is either *in-phase* or *out-of-phase*.

These probabilities are plotted in the two graphs displayed below following their discussion. The powers 'p and p' are on the x- and y-axes linearly increasing away from the origin; the shading identifies the relative probabilities for a given 'p and p'. The darker the shading the higher the relative probability. The boundaries of shading at the top and right of the diagram are the limits of available power; the absence of shading within the bounds of the diagram identifies where there is insufficient power to generate a signal. Although shaded darkly, the highest relative probabilities are low and not determinable here. (The variation in relative probability is continuous; the discrete changes shown in the diagram are due to graphical tool limitations.)

Relative Probabilities of Signal Power Combinations Arriving at a Neuron. The probability of stimuli power from natural sources has a negative exponential distribution, i.e., lower power stimuli have a higher probability that those at higher power. This distribution is reflected in the signals from detector neurons that arrive in the brain send signals to other neurons farther up the cortex. For a negative exponential distribution, the combined probability (P) for two powers is proportional to $(e^{-'p} \cdot e^{-p'})$, which simplifies to $e^{-('p + p')}$. Thus, any combined probability is proportional to the sum of the powers: ('p + p'). The left graph below displays lines of equal probability for given values of ('p + p') as a straight line normal to the line for 'p = p'. The probability is highest at the origin and decreases exponentially as signal power increases.

Relative Probabilities of Generating a Signal either *in-phase* or *out-of-phase*. These probabilities are as follows.

> **In-phase**. For signals with the same spike train pattern, signals are generated when they have equal powers ('p = p') and the patterns are in-phase. This probability is shown by the thick diagonal line radiating from the origin. The thickness of the line reflects the fact that powers do not need to be exactly the same to generate a signal Above the lower threshold, a change in powers does not affect the probability of generating a signal.

> **Out-of-phase**. For signals with different spike train patterns or absent a pattern, doubling the power in one signal, i.e., doubling the rate of arriving spikes, doubles the probability of each spike generating another spike. For two signals, that probability is proportional to the product of the powers: ('p • p'). The relative probability of generating a signal is also proportional to generating a spike, i.e., ('p • p'). The right graph below displays lines of equal probability for given values of ('p • p') as hyperbolas that are asymptotic to the two power axes. (The shaded probability variations vary uniformly; the displayed discontinuities are a graphical artifact.) As suggested by the absence of shading, signals can be generated only when ('p • p') that is above a threshold.

Figure
Graphs of Signal Powers and Relative Probabilities

The right graph shows where signal generation is possible and not possible by each method as well as where they both are possible. With *in-phase* signals it is nearly always possible. By mentally overlaying the two graphs, one can see that there are many signal pairs with combinations of 'p and p' at low and moderate power that do generate signals by either method. One can also see that signal generation by *out-of-phase* signals is more probable when the two signal powers are less different.

Section 4
Neural Tunning

This section describes how a memory neuron controls what signals can or cannot pass through its dendrites and reach its soma where they can generate signals.

Before beginning, the following terms are defined. When a memory neuron is generating a new signal from arriving signals, the neuron is said to be an <u>active (memory) neuron</u>, as a result of having been <u>activated</u> by its <u>activating (arriving) signals</u>. Thus, a memory neuron is either an active neuron or an <u>inactive neuron</u>.

It is useful to identify how a neuron was activated in terms of the kinds of neurons that activated it, and implicitly whether the arriving signals were *in-phase* or *out-of-phase*.
    <u>sameness activation</u> – activation by in-phase signals that were originally generated by
    detector neurons of the <u>*same*</u> kind and same power, often from the same source of stimuli.
    <u>togetherness activation</u> – activation that is not sameness activation, possibly from
    different sources of stimuli that happened to arrive <u>*together*</u>.

The active memory neurons and activating signals of interest here are those that are able to generate competent signals, i.e., signals that each consists of more than one or a few spikes and,

therefore, has the energy needed affect the behavior of its dendrites (discussed below). Incompetent signals are presumed be unused by other memory neurons.

Subsection 1
**Signal Receptivity at a Dendrite**

A neuron's dendrites are the points of control for signals from other neurons. A dendrite's ability to control signals is described in terms of signal *receptivity states*.

The observed receptivity states of interest here are summarized below:
- *inhibiting* – the dendrite resists signals crossing the synaptic cleft;
- *attracting* – the dendrite attracts signals to cross synaptic cleft (this state is commonly referred to as *excitatory*); and
- *neutral* – neither preventing nor attracting, signals arrive by chance.

When the brain first forms in utero, each dendrite receptivity states is either neutral or attracting. These terms are used to identify a dendrite in terms of its state, e.g., an *inhibiting* dendrite. As discussed later, the *inhibiting* ability of a dendrite to resist signals diminishes, possibly resulting in its inhibiting state becoming *neutral*.

These three states are shown below and the five possible state changes among them are identified by the arrowed lines in the flowchart below. The curved line is not a state change: it is resetting of inhibiting to full strength. These processes are the result of neural behavior discussed below.
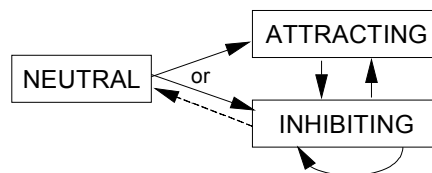
Figure
Flowchart of Dendrite States and State Changes

Memory Neuron Receptivity State Changes Before, During and After Activation

The following describes the hypothesized response by a memory neuron's dendrites to the neuron being activated or not activated. This behavior is the simplest found that enables memory neurons to store what is meaningful without requiring many more neurons and consuming the least amount of energy. What is meaningful and not meaningful is described in the next Chapter.

> **Tuning Hypothesis**.
> When a memory neuron is activated, each of its dendrites responds as follows:
> - *if* not carrying a signal, its receptivity state is set or reset to <u>*inhibiting*</u>; and
> - *if not attracting* and transmitting a signal, its receptivity state is set to <u>*attracting*</u>,
> where *setting* is a change of it receptivity state and *resetting* is renewing the current state, including resetting a diminished inhibiting state back to its full inhibiting strength. The receptivity state is presumed to be a simple response to a signal traversing or not

traversing the subject dendrite. (Inhibiting states possibly need to be set or reset before the attracting states to prevent erroneous states when activation terminates before setting is complete.) The energy required to set or reset receptivity states is from what remains of the energy in the arriving spike after generating new spikes including the spike energy from spikes that do not generate new spikes.

There is also the possibility that when a memory neuron receives a signal through a (non-inhibiting) dendrite and that signal does not cause activation of the neuron after some brief duration (because of the absence or brevity of the other signal) that dendrite responds by either momentarily inhibiting that specific signal or setting its receptivity state to *inhibiting* (using the energy from that signal), thereby redirecting that signal to another memory neuron.

When an individual spike or a spike train is the first to arrive at an inactive neuron's soma, the other dendrite(s) that are *attracting* briefly become *more attracting* thereby causing the axon branch(es) from connected neuron(s) that previously activated it to be the least resistant to receiving their signals.

The latter two parts of this hypothesis minimize non-productive attempts to activate a neuron as well as minimizing delay in finding neurons to activate and the energy required to do so.

The process of setting or resetting receptivity states of an active memory neuron's dendrites is called tuning. After tuning, a memory neuron is a tuned (memory) neuron, i.e., in a *tuned state*; a memory neuron that has never been tuned is an untuned (memory) neuron. The (receptor or memory) neurons that tuned a given *tuned neuron* are referred to as its tuning neurons.

Upon being tuned, a tuned neuron can be said to store (have "information" on) its *tuning neurons*. Thereafter, two or more *attracting* dendrites "encourage" signals from the neurons that tuned it to activate it again, and 2) "resists" signals from those neurons that did not tune.

Effect of Dendrites Receptivity State on Signals Traversing Axon Terminals

As suggested earlier, a dendrite's receptivity state determines if a signal can cross the synaptic cleft to reach the dendrite. The following hypothesis describes how those receptivity states affect a signal traversing that axon.

> **Signal Branching Hypothesis**. The receptivity state of a dendrite determines the receptivity of the axon branch carrying signals to that dendrite, i.e., if *attracting* or *more attracting*, a signal is induced to traverse the axon branch to the dendrite; if *inhibiting*, there is resistance to a signal traversing depending on the inhibition strength. (This can thought of in terms of electrical attraction and resistance, respectively). Which axon branch at the end of an axon a given signal traverses depends those receptivity states. When a signal reaches a branching point, it behaves as follows assuming there can be more than two axon branches:
> * If only one branch is *attracting* or *more attracting*, it traverse it;

20

- If one branch is *more attracting* and one or more are *attracting*, traverse the *more attracting* branch;
- if multiple branches are *more attracting*, it arbitrarily traverses one of them;
- if multiple branches are *attracting*, it arbitrarily traverses one of them;
- If none is *attracting* or *more attracting*:
  - If one is neutral, it traverses it;
  - if multiple are neutral, it arbitrarily traverses one of them; and
  - if none is neutral (all are inhibiting), it will force its way through the axon branch for the least inhibitory dendrite.

Whether the dendrites of untuned neurons begin as attracting or neutral, the behavior described above results in increasingly more inhibiting receptivity states where tuning signals become more likely arrive at a neuron that they previously tuned and activate it. Given that there are thousands of axon branches from an axon and that inhibition diminishes, the last case itemized above is rare.

Dendrite Receptivity States after Activation

Attraction is Stable. An attracting dendrite continues to be attracting until its neuron becomes tuned differently (as described shortly). This stability is presumed to reflect a neuron's origin as nerves that are always attractive. Since attraction does not diminish with time, a neuron that is not differently tuned can store its tuning neurons for a lifetime.

Inhibition Diminishes. An inhibiting dendrite is known to have a range of *inhibiting strength* (and elsewhere as "synaptic strength"), i.e., the ability to resist signals from traversing it. When set to inhibiting, its inhibiting strength is its maximum. Thereafter inhibiting strength diminishes until either:
- it is no longer inhibiting and its inhibiting state *diminishes to neutral*; or
- activation of the dendrite's neuron causes state to either: 1) reset it to maximum inhibiting strength or 2) change its state to attracting.

Loss of inhibiting strength is due to one or both of the following:
- the passage of time, or
- in response to inhibiting spikes, i.e., inhibiting ability slightly diminished each time it inhibits a spike.

The presumption that the *inhibiting* receptivity state diminishes but not the *attracting* state is based on the behavior of memory. If inhibition did not diminish, a neuron could never be reused and nothing would be forgotten. If they both diminished, everything would be forgotten.

Subsection 2
Neuron Tuning Behavior

The following are the consequences of the memory neuron behavior described above and how that behavior results in different <u>tuning states</u>.

- Without the ability to lose attraction (other than by physical damage), once tuned, a neuron is never again untuned, i.e., a neuron's tuning state is either <u>un-tuned</u> or <u>tuned</u>.
- A *tuned neuron* either has or does not have inhibiting dendrites that have diminished inhibiting ability and is then susceptible to being tuned differently, i.e., a neuron's tuning state is either <u>fully-tuned</u> or <u>semi-tuned</u>.
- A *tuned neuron* that has more than two tuning neurons is likely to be activated by fewer signals and be tuned differently, thereby causing the dendrites that did not receive a signal to be set to inhibiting. Thus, a neuron tuned by more than two neurons is unstable, and a tuned neuron's tuning state is either <u>stably-tuned</u> or <u>unstably-tuned</u>.

A complete taxonomy of memory neuron types based on *tuning states* is as follows.

    memory neuron
>   <u>untuned (memory) neuron</u> (having no attracting dendrites)
      <u>tuned (memory) neuron</u>
        <u>fully-tuned neuron</u>
>   <u>stably fully-tuned neuron</u>
>   <u>unstably fully-tuned neuron</u>
        <u>semi-tuned neuron</u>
>   <u>stably semi-tuned neuron</u>
>   <u>unstably semi-tuned neuron</u>

Time is required for a neuron to activated by other neurons' signals. That time, referred to here as <u>activating step time</u>, is from when a neuron's soma begins to generate a new signal, that signal traverses the axon, axon branches, the synapse, and the dendrites, and the connected neuron's soma can begin to generating a signal of its own. The variability in the activating step time is due to the length between the two somas and when another signal arrives at the connected neuron's soma. The time required for activation to cease is the <u>deactivating step time</u> which is presume to be the time for last pulse in the activation's signals to reach the connecting neuron's soma.

Tuning Processes

The following flowchart illustrates the five atomic tuning states presented above with each process that can change a tuning state (straight arrowed lines) or reset a tuning state (depicted by curved arrowed lines). The line also identifies the likelihood of those *tuning processes* as follows: unusual (dashed), seldom (fine) and routine (thick).
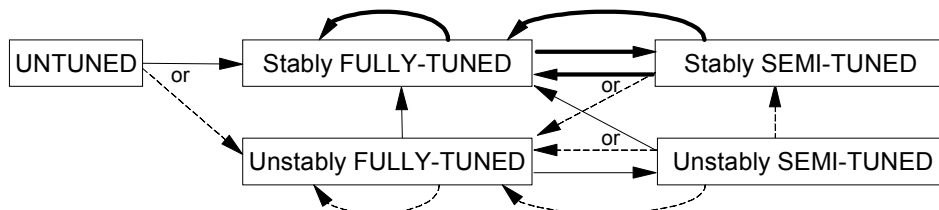
Figure
Flowchart of Memory Neuron States and State Change Processes

The tuning processes illustrated above affecting a neuron's tuning state are described below (and how they are depicted above).

        inaugural tuning – tuning that first tunes an *untuned neuron* (depicted by the two lines on the left);

        retuning, either:

                recovery tuning – tuning (by tuning neurons) that sets a *semi*-tuned neuron's neutral states from neutral to inhibiting and returns (resets) inhibiting states back to full strength (curved lines from SEMI-TUNED to FULLY-TUNED); or

                resetting only tuning – tuning (by the same neurons) that resets a *fully*-tuned neuron's inhibiting states back to full strength (curved lines from and to FULLY-TUNED);

        differently tuning – tuning that tunes a *semi-tune neuron* so that it is *differently tuned*, i.e., has different tuning neurons (straight lines pointing left from SEMI-TUNED to FULLY-TUNED);

        stabilizing tuning – tuning that (stably) tunes an *unstably tuned neuron* so that one or more attracting states become inhibiting, thereby having fewer tuning neurons than before (lines pointing up from unstably TUNED to stably TUNED); and

        destabilizing – a stably-tuned neuron that becomes unstably tuned when an inhibiting neuron diminishes to neutral (lines pointing right from stably TUNED to unstably TUNED).

Nothing is suggested here about the following tuning parameters: how many simultaneous pulses are needed before a neuron generates a signal and how long it takes for destabilizing to occur.

Note that the combination of the low probability of a neuron being tuned by more than two neurons is lowered by stabilizing tuning. Note also that the form of activation (by sameness or togetherness) does not limit the subsequent method of activation if the tuning neurons' signals have the same spike train pattern.

        A neuron tuned by *togetherness* activation can be subsequently activated by *sameness* activation, including by powers too low to activate by *togetherness*.

        A neuron tuned by *sameness* activation can be subsequently activated by *togetherness* activation, but might require higher powers.

The overall effect if these tuning processes are as follows.

- A tuned neuron will tend to remain tuned by the same tuning neurons as long as they continue to send signals that retune it.
- If retuning is below a certain frequency, a neuron becomes susceptible being differently tuned: the longer before retuning occurs the more susceptible it becomes.
- As more of a neuron's axon branches become inhibiting, the more likely a signal from that neuron will arrive at a neuron it previously tuned and retune it.
- A tuned neuron that is sufficiently "isolated" from signals that can tune it differently, the longer it remains tuned no matter how many inhibiting dendrites change their state to neutral.
- A pair of neurons can tune more than one neuron but only one at a time for a given signal.

Signals from any pair of neurons that generate signals with the same signal pattern and power are unlikely to be in-phase when they are created. That phase difference can be "cancelled out" on arrival if traversed connections that have appropriately different lengths. Since *in-phase* signals can activate by *sameness* at much lower powers than *out-of-phase* signals (by togetherness), sameness activation can occur where togetherness activation cannot. Thus, a low power signal that cannot activate a neuron by togetherness may be redirected as noted earlier, possibly finding a neuron where it can activate by sameness.

The duration that a neuron has the same tuning neurons, i.e., from being tuned to being differently tuned, is its <u>tuning lifespan</u>. That lifespan is determined by both:

- how long it takes for an inhibiting state to diminish to neural; and
- the signal environment where that neuron is found.

In addition, neurons occasionally generate one or a few spikes that do not form a complete spike train. That behavior, called pinging, may be due to a variety of reasons not addressed here, and may serve to maintain the inhibitory state of the neuron it tuned. Although the rate that inhibiting strength is diminished and lost could vary from the bottom to the top of the cortex, nothing addressed here suggests that such variation is necessary for human perception and comprehension.

Unstably tuned neurons do not appear to be relevant to the ability to perceive or comprehend either or both because they are unlikely and are likely to be stably-tuned soon after being tuned. As such they are not discussed further in this work. The relevant tuning processes and their signifiers are as follows.

    tuning
        retuning
            recovery tuning
            resetting only tuning
        <u>not retuning</u>
            inaugural tuning
            differently tuning

Since *activation* of a memory neuron involves *tuning* as defined here, identifying a neuron as active or having been activated implies that it is being tuned or has been tuned and is not explicitly identified.

Tuned Neuron Structures

The most important consequence of these behaviors is that activated memory neurons generate signals that activate other neurons farther up the cortex, tuning or retuning each neuron along the way. That behavior continues until the signals generated by the uppermost active neurons cannot generate signals that are powerful enough to cause activations farther up the cortex. Interconnected tuned memory neurons form a directed network in the cortex. Any network of interconnected tuned neurons, and well as segments thereof, is referred to here as a structure. Applying the terms introduced in Part 0 describing the notion of a network to a structure we get:
• a tuned memory neuron is said to be *involved* in a structure; and
• a structure whose interconnected tuned neurons are involved in a larger structure is a *segment* of that larger structure and is said to be involved in it

A structure is said to be *created* by the tuning of the memory neurons involved in it. The least complex structure is a single neuron tuned by its tuning neurons; the most complex structure involves all tuned neurons in the brain, i.e., the mind itself.

Section 5
Summary and Observation

Tuning Behavior

I described how signaling tunes memory neurons enabling them to store which two (or more) neurons tuned them and how what is stored is used to control which neurons can send signals later. Nothing else is stored by a tuned neuron – not even the method of tuning. As demonstrated in the remainder of this work, this is all that needs to be stored for the brain to be able to perceive and comprehend the world based on what it perceives. The hypotheses are the result of reverse engineering based on what is currently known about the anatomy and physiology of neurons in the cortex; neuron evolution; the constraints imposed by signal processing and energy conservation; and omitting useless complexity.

The described and hypothesized neuron behaviors appear to be both the simplest possible, most stable, most evolutionary reasonable and least energy consuming memory that are able to reliably store something about the signals it received. As demonstrated in the remainder of this work, this tuning behavior is sufficient to explain all perception and the framework for comprehension.

Evolutionary Pathway

There is a simple evolutionary pathway to this neural behavior. As cells evolved, some evolved in ways that maintained their ability to transfer ions through them and across the gaps between them, first by elongations that became specialized in exporting ions to more distant neurons while maintaining their ability to receiving ions. Some of those elongated neurons reached one or multiple receiving neurons. Those sending signals to one receiving neuron were able to transfer signals with the least power loss over that distance and grew longer becoming nerves. Those neurons that received signals from multiple other neurons evolved to be receptive to those

25

signals that could generate a signal and ignore the others, otherwise it would receive signals too weak to generate a new signal.

This resulted in neurons that either: send one signal over long distance without significant loss (nerves) or generate signals from multiple signals. These signals coexisted as they do today. This enabled exterior cells to become specialized (for feeding, detecting, propulsion), and cell mass to increase in size. As the body grew bigger and shaped differently, there was an increase in the separation of the detector neurons on the surface and where the signals were used. What later became the brain may be due to "signal gathering neurons" and the nerves that they receive them from becoming more centralized in the body where they are better able to receive signals that can be used to generate a new signal. Useful neuron mutations were those that 1) alter dendritic behavior as signal activity rate changes for different inhibiting strength or able to respond to different spike patterns and strength variations, 2) increased the count of connections between neurons. With the ability to inhibit useless signals, signal gathering neurons store which neurons sent those signals. This inevitably leads to storing the areality of surface tactition, which enables distinguishing where something is felt and greatly improving its appropriate response. Within this primitive brain this behavior occurs without the need for any additional source of energy. As detector neurons mutate and evolve, different forms arise using the same mechanism.

Commentary

The hypotheses about neural behavior presented here may be regarded as too simplistic considering that:
• Neurons and their interactions have been reported elsewhere as are more complex than those described here;
• A variety of different kinds of memory neurons have been identified; and
• The extreme differences among perception types suggest that neurons are specialized.

The reasons why greater neural complexity is unneeded to handle comprehension complexity are as follows.
• Memory neurons have essentially the same behavior across all animalia, suggesting that there is only one means by which such neural behaviors can occur, at least in a biological form.
• Any variation in neural behavior only affects how it controls signals passed from one neuron to another, leaving little flexibility in what a memory neuron can do.
• Complex systems, biological or otherwise, evolve slowly by beginning with simple parts and making simple changes or by adding new capability. Any mutations of neurons, or how they might form interacting assemblies, in even a simple brain, would be highly localized.
• The ability to handle comprehension complexity could have easily and quickly evolved in the human brain by adding more of the same kind of neuron horizontally and vertically in the cortex. Similarly speedy evolution is unlikely, and may be impossible, by mutations that created new neurons randomly distributed in the brain.
• Increasing the ability of a brain to handle more complex comprehension can be achieved by increasing the number of interconnected memory neurons or by evolving neurons to address particular situations. Given the enormous number of such neurons and their

plasticity, a hypothesis that requires evolving more complex neurons is difficult to justify (see Occham's razor).

Any differences among memory neurons are presumed to be due to the following:
* *tuning parameters* varying vertically (resulting in identifiable cortical layers);
* different counts of dendrites and axon branches

Instinctive behaviors are presumed to be due to neurons whose receptivity states are preset and unchanging and connected with other neurons in a way that enables those behaviors and responses. This topic is not addressed in this work.

Finally, this reverse engineering effort arose from the study of the less complex aspects of comprehension, i.e., what arose from *primitive animalia* perception. These results reflect something very general about perception and comprehension that is generally applicable to *primitive animalia* that evolved in the terrestrial environment. creatures. What is presented here is at least what cognitive ability where was before human cognition arose.

The following Chapter applies this behavior to how perceptions arise and how tuned neurons self-organize to create structures.

Chapter 2
Pattern Structures and Perception Structures

Having described the behaviors of detector, receptor and memory neurons, hypothesized and otherwise, here I consider their purpose: the ability to *perceive* the surrounding world and to *present* to the mind what is perceived. Here the term: <u>perception</u> refers to the brain's ability to receive signals generated by detector neurons and activate cortex neurons.   The activation of cortex neurons is what generates a <u>presentation</u>, e.g., seeing, hearing and feeling. Presentations are generated whether or not the mind pays attention to it. As described in this chapter, perceiving creates directed networks of neurons specific to each means of perceiving by each sense organ.

Introduction

In utero as neurons in a human brain are created and connect with each other, signals begin to arrive from detector neurons in the ears and skin and activate memory neurons. After birth a brain receives an onrush of new signals and more powerful signals from the ears and skin. That a rich signal environment, tuned neurons create structures in the cortex; they continue to exist as long as activating signals are at least occasionally received.

I organized this Chapter as follows:
>Section 1: Activations and Pattern Structures
>Section 2: Perception Presentations
>Section 3: Perceiving Structures

Section 1
Activations and Pattern Structures

This section first describes the differences in sense organs that are of interest here and the differences in those sense organs' receive stimuli. The remainder discusses the structures those activations create.

Subsection 1
Characteristics of Sense Organs and Activation Patterns

Sensory Organs Characteristics

Each kind of sense organ responds to one kind of stimulus energy received by one or more kinds of detector neurons. The following tabulates the sense organs of interest here, i.e., those whose signals enable comprehension of the perceived world. Muscle strain is included, but not other interoception detector neurons t respond to internal organ distress, e.g., hunger. The table identifies each sense organ's detector neurons and it characteristics, and is ordered by decreasing

sense organ complexity. The right column groups displays each the perception type of interest here and its abbreviation (along with the count of sense organs of that kind are found in a body). These perception type signifiers are generally the technical terms for the ability to perceive; terms such as sound, taste and smell identify presentations.

Sense Organs of Interest and their Characteristics

sense organ and its location	detector neuron array	kind(s) of detector neuron(s) arrayed in each sense organ	source of stimulus energy	perception type based on kind of sense organ [abbreviation] and (count of those organs)
retina of each eye	areal	1: rod	photons	scotopic vision [sV] (2)
		3: red, blue and green cones	photons	photopic vision [pV] (2)
cochlea in each ear	lineal	1 (each responding to a different frequency)	mechanical strain*	audition [A] (2)
taste buds on the tongue	areal	5 (each responding to sweet, sour, salty, bitter or umami, i.e., savory)	chemical reaction with non-gaseous substances	gustation [G] (1)
olfactory epithelium in the nose	areal	6 (not individually identified)	chemical reaction with gaseous substances	olfaction [O] (1)
cutaneous sensors in the skin, mouth, and tongue	areal	2: tactition detector neurons	surface mechanical strain	surface tactition [sT] (1)
			sub-surface mechanical strain	deep tactition [dT] (1)
		2: thermoception detector neurons	thermal difference below or above body temperature	$\vee$thermoception [vT] (1)
				$\wedge$thermoception [^T] (1)
each muscle	spatial	1 in each muscle	mechanical strain	muscle strain [mS] (N)

 * due to vibration of hairs by sound-induced waves in the liquid inside the cochlea

Note that vision and audition stimuli, the most complex perception types as well as being bilateral, are from *arriving stimuli*; the remainder are from *bodily contact stimuli*. The eyes are unique, each actively moving to find and enhance a portion of its received stimulus; all other sense organs are passive, accepting whatever stimuli arrive. A muscle having its own detector neurons makes it its own sense organ.

The following is a complete taxonomy of the perception types and super-types relevant here. Also listed for each perception type are signifier (in single quotes) used to identify each of the five types of sensing as popularly understood and each type of presentation. The sensing and presentation signifiers are sometimes used in lieu of perception types where useful.

taxonomy	sensing	presentation
perception		
exteroception (acting on the body)		
bilateral perception		
vision	'seeing'	'sight'
> scotopic vision		
> photopic vision		
audition	'hearing'	'sound'*
non-bilateral perception		
> gustation	'tasting'	'taste'*
> olfaction	'smelling'	'smell'*
cutaneous perception	'feeling'	
tactition		
> surface tactition		'touch'
> deep tactition		'hardness'
thermoception		
> ∨thermoception		'coolness'
> ∧thermoception		'warmness'
> muscle strain (muscle interoception)		'heaviness'

* these also refer to the perception's quality

Note that the traditional "five senses", listed above under "sensing", identifies exteroception *sense organs* rather than what is perceived and are not useful as perception types.

Derived Perceptions

When moving one's skin across a surface, there is variation in the intensity of tactition as well as horizontal forces that stretch the skin. This causes the following *derived perceptions*. These include:
• *slipperiness*, perceived by the combination of tactition due to stretching of the skin and muscle strain when moving the skin across a surface; and
• *roughness*, perceived by variation in tactition when moving the skin across a surface.
Derived perceptions are not discussed further or regarded as perception sub-type, but are included in a few later examples for the sake of completeness.

Activations and their Characteristics

The detector neurons in a given sense organ and perception type (e.g., photopic vision in the left eye) send signals that can activate neurons in the cortex in a variety of ways. At a given moment in time, some or all are of those detector neurons are activated, and those activations all have the same power or a distribution of different powers. Those activations are what generates presentations.

Until now, the singular noun: *activation* has referred to the activation of a single neuron, i.e., a neuron activation. For the remainder of this Part, the discussion is about those neurons whose simultaneous activations lasting long enough to create a single structure involving those neurons. To facilitate subsequent discussion, the singular unmodified noun: activation now refers to the simultaneous neuron activations of multiple (receptor or memory) neurons by signals from one sense organ and perception type. If the activation is with respect to neurons, the subject

neuron(s) are identified, e.g., neuron activation. Similarly, the singular noun: *power* now refers to the total power of the signals causing the activation of the subject neurons.

Each activation can be understood as having a *pattern* consisting of the array of its active neurons and *relative* distribution of powers among those neurons. This pattern is referred to as an activation's <u>activation pattern</u>. A given activation may or may not have a unique activation pattern. The distribution of powers, relative or not, is referred to as an activation's <u>power distribution</u> and is identified as relative or absolute. A relative power distribution for a loud or quiet audition activation of the same sound has the *same* activation pattern; for an absolute activation it is different.

The table below tabulates the variation in activations and activation patterns for each perception type in a sense organ. The last four variations are described below along with the terms used to describe the variations. A range is identified by an ellipsis (…).
absolute power distribution
- absolute power variation among active neurons in an activation:
  - none, i.e., on or off;
  - some: power variation is less than one order of magnitude;
  - great: power variation of several orders of magnitude.
- absolute power variation among different activations:
  - little: < one order of magnitude
  - some: ~one order of magnitude;
  - great: several orders of magnitude;
- activation turnover rate:
  - very high: > ten/sec
  - high: < ten/sec
  - low: < ten/minute
- activation pattern diversity – the count of unique activation patterns over a lifetime.

Activation Characteristics by Perception Type

perception type		variation in activations and activation patterns				
		duration	absolute power distribution among		turnover rate	activation pattern diversity
			active neurons	activations		
vision	scotopic vision	<0.1 sec	none	none	high	un-countable
	photopic vision	<0.1 sec	none … great	great	very high	un-countable
audition		<0.1 sec	none … great	great	very high	un-countable
olfaction		>0.1 sec	none	some	low	thousands
gustation		>0.1 sec	none	some	low	thousands
cutaneous perception	surface tactition	>0.1 sec	none	none	high	millions
	deep tactition	>0.1 sec	some	some	high	millions
	thermoception	>0.1 sec	none … some	some	high	millions
muscle strain		>0.1 sec	none	some	high	one

Although scotopic and photopic vision signals can arrive simultaneously, only one is experienced because the latter overwhelms the former. Signals from the two thermoception perceptions are always separate. Signals for deep tactition are always accompanied with signals for surface tactition. Tactition and thermoception signals do not occur simultaneously for remote sources such as heat from a fire or the Sun, and coldness of the air, but often occur simultaneously for physical things touching the skin. Tactition signals without thermoception signals are experienced when being touching oneself or another person. Since the arriving signals from the different types of cutaneous perception are often not simultaneous, signals from their detector neurons of the same kind tune many more memory neurons than from different kinds.

Discrete and Non-discrete Activations. For activations whose *shortest duration* is >0.1 sec., that activation is at least momentarily stable. Some can last for hours, e.g., an aroma or tactition when laying in bed. For vision and audition whose duration is <0.1sec., it is unstable, possibly continuously changing, e.g., a blurry photograph or a hearing a crashing sound. An activation whose pattern is stable is "meaningful" is referred to as a <u>discrete activation</u>; its counterpart, found in vision or audition, is a <u>non-discrete activation</u> whose pattern is "meaningless".

Naturally Discrete Activations. An activation other than for vision and audition are all *naturally* discrete because of the characteristics of their received stimuli are unchanged for >0.1 sec. The vision and audition activations that are naturally discrete are those that are momentarily unchanged, are:
• photopic vision activations that are the focus of attention, e.g., the Moon and a distance mountain; and
• audition activations that are relatively loud sounds over a narrow range of frequencies, e.g., the peep of a bird and a musical chord, as well as a few natural sounds such as a thunder clap or breaking of a twig.

(Sequences of discrete sound activations such as a bird's song are stored as discussed in Chapter 4.) As discussed in Chapter 4, *attending* to a portion of an otherwise be non-discrete vision or audition activation can create a discrete activation from an indiscrete activation. For example, *looking* at a portion of what we can see, along with visual focusing, and forming a momentarily fixed image; and *listening* within a narrow range of frequencies as their sound arrives.

Normal and Further Activation. In addition to the above, there is an additional process that increases the power of already active memory neurons while its presentation is being attended to. This behavior was reported by Carrie J. McAdams and John H. R. Maunsell [(Journal of Neuroscience 1 January 1999, 19 (1) 431-441)] who found that "… [visual] attention enhanced the responses of V4 neurons (median 26% increase) and V1 neurons (median 8% increase).". Although only reported for vision, this process is presumed to be common to all memory neurons. The active memory neuron that receive this increase in power is said to have been <u>further activated</u> by <u>further activation</u> (referred to by McAdams and Maunsell as *attentional enhancement*). Further activation appears to have evolved in terrestrial creatures to improve vision and audition. When activated neurons are not further activated (not being attended to), the memory neuron are said to have been <u>normally activated</u> by a <u>normal activation</u>. (Attention and further activation are discussed in Chapter 4.)

Unless otherwise indicated, activation is either discrete or non-discrete, and is either normal activation, or further activated (in addition to normal activation.

Subsection 2
Pattern Structures

When receptor neurons are activated, they activate and tune memory neurons above it. Those activated neurons may activate and tune neurons farther up the cortex. This upward *cascading activation and tuning* of neurons continues until no more neurons can be activated. The neurons so tuned may store the activation pattern at that moment. Those tuned neurons form a structure called a <u>pattern structure</u> having subtype signifiers: <u>discrete structure</u> and <u>non-discrete structure</u>, the latter conveying no meaning.

To explore discrete structures in more detail, I introduce and describe the first of many diagrams of discrete and other structure types with the following caveat.

> The structure diagrams presented in this work cannot display a realistic size, complexity or the irregularities involved in a real structure. They depict the fewest neurons in simplified regularized configurations collapsed into two dimensions in order to display features that are of immediate interest. In all of the following structures displayed in this work, I rely on the reader to be aware of these graphical limitations and to consider how real structures are configured.

The earlier diagram displaying a cortex's neurons hierarchically is extended here to introduce some of the display conventions for tuned neurons involved in a discrete structure. The two diagrams below use different display conventions to display what could be the first occurrence of

cascading activations that created a discrete structure. In both diagrams, the detector neuron arrays are representative of how they are (lineally, areally or spatially) arrayed in their sense organ, i.e., which are nearest to each other, although in one dimension. The displayed structure is a discrete structure because the duration of its activation was long enough to exhaustively tune memory neurons. The left diagram displays in two dimensions the relative position of each neuron and the possible irregularity in how neurons are tuned. The right diagram displays on the same tuned memory neurons but displayed to reduce that irregularity. Shading identifies currently active memory neurons as well as the detector and receptor neurons that caused those simultaneous activations. Most later structure diagrams do not distinguish between active and inactive neurons since what is of interest here is the configuration after many different simultaneous activations. There are four active tuning receptor neurons (w, x, y and z), two memory neurons tuned by receptor neurons (A and B) and a tuned memory neuron at the top (T) tuned by A and B. To depict tuned and tuning neurons:

- A tuned memory neuron is depicted with a thick border; and
- A connection from a tuning neuron to the neuron it tuned is displayed with a thicker line with a small circle identifying the axon terminal adjacent to an undepicted dendrite that allowed tuning to occur.

A tuned neuron's inhibiting connections are not identified. Like the earlier cortex diagrams, discrete structures can be "viewed as" looking horizontally into the structure's hierarchy so that a connection's directionality is upward. The hierarchy is usefully described as having vertical levels, each referred to here as a <u>level</u>. Since a cortex is not as regularly arrayed as illustrated above, a *level* is more a metaphor used to identify a minimal vertical increment of interest.
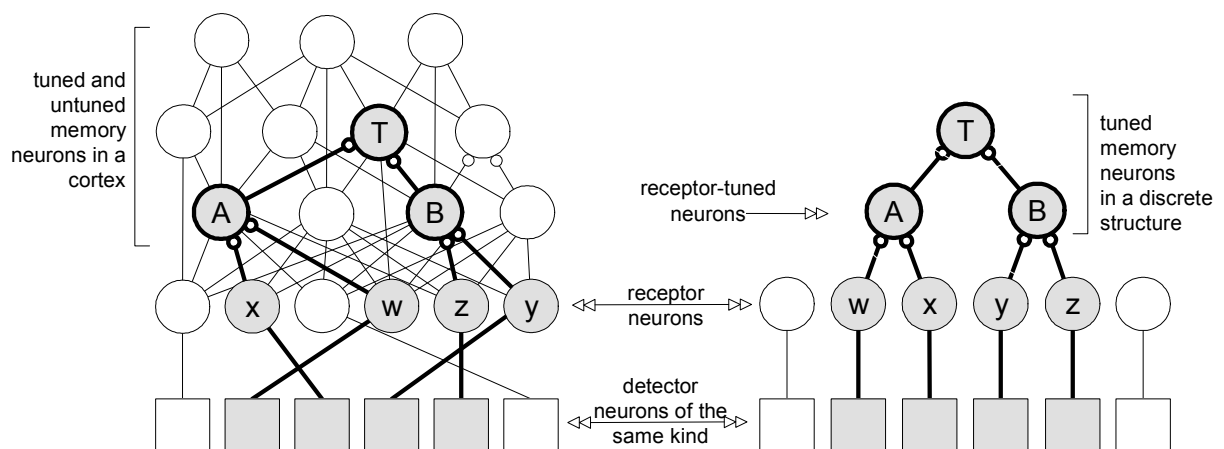
Figure_c_1
Examples of Active and Tuned Neurons Above the Bottom of a Cortex

The simplified diagram convention on the right diagram displays each receptor neuron (w, ... z) directly above its respective detector neuron, and the memory neuron it tunes is displayed above and close to its tuning neurons. Since the untuned neurons and their connections are uninvolved in a structure, they are usually omitted. Note that the configuration of active neurons resulting from a given activation can only be a simple (non-intersecting) hierarchy. A more complex example for one kind of detector neuron is displayed in Figure a3.

34

Note that in the left diagram the receptor neurons are displayed with their connections extending to nearly all memory neurons in the bottom level of the cortex, and memory neurons with their shorter connections are displayed as connected to fewer memory neurons that extend above them at different levels. A memory neuron that is tuned by receptor neurons at that the bottom level is referred to as a <u>receptor-tuned neuron</u>, e.g., neurons A and B in the above diagrams.

A discrete structure can be created by signals from different kinds of detector neurons in the same sense organ when their different signals come together to activate and tune memory neurons. Those discrete structures are discussed later.

Subsection 3
Creation and Loss of Discrete Structures

Beginning and Ending an Activation

The duration of an activation of receptor neurons is from when its activation pattern begins to when there is a different activation pattern or no activation. If >0.1 sec, it is a discrete activation. When signals from a discrete or non-discrete activation are first received by memory neurons, signals from those memory neurons cascade up the cortex with a delay before those neurons can begin generating a signal. When an activation ends, there is cascading deactivation as signals are no longer received. Cascading deactivation is faster than cascading activation, so that activations and deactivations cannot overlap.

With sufficiently long activation, cascading activation continue until the power available to activate more neurons are exhausted; if not sufficiently long, cascading activation is aborted before power is exhausted. Note that if the uppermost activations only retune neurons, the activation's absolute power distribution is not stored.

In addition there is the special case of a vision or audition discrete activation with a very few active detector-tuned neurons, e.g., a star in the night sky or a pure tone (illustrated in the example in Figure c_1). Regardless of the power of the detector neuron signals, cascading activation ends when there is only a single can be activated.

Degradation and Loss of a Discrete Structure

Without frequent enough subsequent activation that retunes a discrete structure's neurons, those neurons are likely to become differently tuned by other activations as they create new pattern structures. (Subsequent activation of a discrete structure is discussed later in this Chapter.) The loss of tuned neurons in a discrete structure degrades it, causing it to 1) become *less robust* because duplication is decreased and 2) store its activation pattern with *less fidelity*. As long as one of its remaining levels is sufficiently intact (only partially degraded), it may continue to store how its activated receptor-tuned neurons were arrayed but at less fidelity and but none of its relative power distribution. A degraded discrete structure is *lost* when what remains of its stored pattern, if presented, is not recognizable. Although lost, some of the tuned neurons in a discrete

35

structure remain among the other structures until they too are differently tuned. A non-discrete structure is effectively lost as soon as it is created.

Section 2
Perception Presentations

When memory neurons are active, they each "present themselves" to the mind. Active (presenting) neurons in a discrete structure present that structure's configuration and signal power. The intensity of a presentation or a portion of a vision or audition presentation is presumed to reflect the total of the signal power of the active memory neurons in all level therein. Since signals lose at least half of their power as activations cascade up the cortex, active neurons at higher levels contribute less than half of a presentation's intensity. Thus, the lowest active neurons always contribute more than half of a presentation's fidelity and intensity. The neurons that are farther up add to a presentation's intensity but with less fidelity.   (How memory neurons are able to display their detector neurons' array is discussed in the next Chapter.)

A <u>perception presentation</u> is generated by activating signals from detector neurons. A <u>memory presentation</u> is generated by recalling. (Activating by recalling is discussed Chapter 5.) When a discrete structure is *normally* activated (by detector neuron signals or recalling), we are not conscious of its presentation; when it is further activated, we become conscious of it, i.e., we see, hear, taste, smell or feel it.   Different *perception presentations* can have different and varying powers in their arriving signals. All *memory presentation* has no such variation, only the same low intensity.

The remaining discussion in this Section is about perception presentations. Unless otherwise identified, a *presentation* refers to a *perception presentation*.

Perception Presentation Characteristics

A presentation for each type of perception can be understood as having two or three of the following independent characteristics, i.e., *trait types*.
> <u>sensitivity</u>
>   <u>detection</u> – presentation characteristic that identifies its presence
>   <u>intensity</u> – presentation characteristic that varies above a lower limit
> <u>quality</u> – presentation characteristic that is either a spectrum or discrete, e.g., color or smell, respectively
> <u>shape</u> – areal configuration of a bounded presentation

Detection is intensity either: without a noticeable variation or whose lower limit and upper limits are the same. Note that since perceiving structures are nonexistent or very immature at birth, the earliest presentations are essentially "noise".

Presentations for scotopic visual and surface tactition are characterized as *detection* because they have no intensity range above their lower limit. This is presumed to be either due to:
•   their detector-tuned neurons do not have sufficient power to tune neurons higher up the cortex; or

- their intensity range is not noticeable because their power thresholds are only slightly less than those for photopic vision or surface tactition, and those latter presentations overwhelm the former.

The following table identifies the characteristics of a presentation for each perception type. The combinations of trait types are written as a product expression (an expression with terms for orthogonal variables). The difference between the array of the presentation and the array of the detector neurons that generate it is evident in the right columns. A presentation without an array is identified as "none", e.g., olfaction. Although not tabulated here, the sensitivity variation across a presentation is the same as the signal power variation across the detector neurons tabulated earlier.

Characteristics of Presentations by Perception Type

perception type	combination of trait types (written as a product expression)	presentation array	detector neuron array
scotopic vision	'night vision' detection × (vision) 'shape'	areal	areal
photopic vision	'brightness' (intensity*) × 'color' (quality) × (vision) 'shape'	areal	areal
audition	'loudness' (intensity*) × 'sound' (quality)	none	lineal
gustation	'taste' intensity × 'taste' (quality)	none	areal
olfaction	'smell' intensity × 'smell' (quality)	none	areal(?)
surface tactition	'touch' detection × touch shape	areal**	areal**
deep tactition	touch intensity × touch shape	areal**	areal**
∨thermoception	'coolness'	'coldness' (intensity) × thermal shape	areal**	areal**
∧thermoception	'warmness'	'hotness' (intensity) × thermal shape	areal**	areal**
muscle strain	strain intensity × pain shape	spatial***	spatial***

* of the dominant color or frequency; ** on the skin or in the mouth; *** throughout a muscle

Since the three trait types are independent, each perception type's presentation can be understood, and *expressed*, as the product of the applicable characteristics as shown above with the "×" indicating a product. (Expressions are discussed in detail in Part 2.) Each term identifies the trait type and is distinguished from the others by their trait signifier (in single quotes). A trait type not in parentheses and used with another term is also used to distinguish among trait types. Note that a photopic vision presentation has three trait types; the others have two. Note also that quality presentations are the result of either: 1) multiple kinds of detector neurons that can be simultaneously active or 2) one kind of detector neuron that each responds differently to different portions of the same received stimuli, i.e., different acoustic frequencies.

Note that quality presentations are continuous and not resolvable by the mind into their individual stimuli. This behavior is in contrast to cutaneous presentations, whose detector neurons are also in the same sense organ and are mixtures of at most two noticeable perceptions,

but are resolvable because they are often perceived alone and usually identified as having a source or cause.

Perception Presentation Qualities are Illusions

Although the sources of perception presentations are real, their quality presentations are illusions created in the brain from combinations of signals from detector neurons that respond to different stimuli. The world has no colors, tastes or smells: what we each feel is ours alone. Some types of perception presentations have a quality because they are useful for survival while they are being presented because they better distinguish among different sources of stimuli. As discussed later, individual sound frequencies cannot to be recalled, but audition sequences of relative frequencies can.

Section 3
Perceiving Structures

As pattern structures are created and become lost due to the creation of new structures, all tuned neurons receiving signals from the same sense organ become one interconnected structure. That structure, called a <u>perceiving structure</u>, involves all pattern structures plus the remnants of lost pattern structures. Each perceiving structure is specific to a sense organ and spatially separated from one another in the cortex because the nerves conveying their signals are bundled at their receptor neurons. Each type of perceiving structure can be understood as, like cortex neurons themselves, an intersecting hierarchy with many tuned neurons involved in multiple pattern structures. A perceiving structure's horizontal extent is limited by its receptor neurons and its vertical extent is limited by the maximum power of the arriving signals that created its pattern structures. An example of a simple perceiving structure is presented later in Figure a3 in the next chapter. Before presenting that example, the remainder of this Chapter describes the behaviors that affect how different perceiving structures are configured as it matures.

Perceiving Structure Variations with Height

As an activation cascades up the cortex, its signals activate memory neurons, tuning each neuron activated. The power generated by activated neurons is a maximum at the bottom and decreases as activation cascades up the cortex. Most receptor-tuned neurons are tuned; those in higher levels are more sparsely tuned. The higher the level, the sparser the tuned neurons in the perceiving structure.

At the bottom of the cortex, signals from detector neurons are always or nearly always arriving. The power of each signal varies monotonically with the power of its stimuli between a lower detection threshold and an upper limit where damage to the detector neuron occurs. As described earlier, the distribution of signal powers range from very many low power signals to very few high power signals. Low power neuron activations are mostly by sameness; at higher powers where ('p • p') is above the threshold for togetherness activation, that form of activation occurs; and at still higher powers, the probability of togetherness activation nears certainty. Also,

if inhibiting states are affected by signal activity (as suggested earlier), the neurons nearer the bottom where signal activity is greatest will more quickly become unstably tuned and will be differently tuned sooner that those higher up, i.e., tuning lifespans may increase upwards in a perceiving structure.

The top of a perceiving structure is where none of the tuned neurons were able to tune neurons farther up the cortex. A tuned neuron nearer that top, being less likely to be retuned, is likely to become unstably tuned. However since there are fewer activating signals, the likelihood of becoming different tuned may be less than the neurons below it.

Maturation of Perceiving Structures

Activations create and change perceiving structures that, like the body itself, grows in size and matures. These are automatic processes over which we have little control. With the exception of muscle strain, perceiving structures are created by highly diverse (discrete and non-discrete) activations whose occurrence is arbitrary.

The initial onrush of signals received very early in life finds few inhibiting neurons so that tuning is effectively random. Those initial activations are neither typical nor do they reflect the variety encountered later. As life unfolds in an increasing variety of environments, the sources of stimuli causing those activations becomes both more varied as well as somewhat routine. Many of the earlier activations are less probable that those of that occur later in life. Thus:

tuned neurons whose retuning probability is high tend to be retuned; and
tuned neurons whose retuning probability is low tend to be differently tuned.

This behavior causes a perceiving structure to mature, i.e., to reflect what activation patterns are likely and to lose those that are not. A structure that has matured is a *mature perceiving structure*; until then it is an *immature perceiving structure*. Maturity is reached sooner if its *activation turnover rate* is higher (e.g., vision and audition). Given that high probability tunings tend to supplant those with a low probability, identifying which tunings are low- or high-probability enables identifying how structures mature and how they are configured. The following discusses what occurs during maturation.

Tuning Method Bias. Given the high probability of receptor-tuned neurons receiving low power signals and the inability of those signals to tune by togetherness, those neurons become tuned by sameness. Farther up the cortex where sameness tuning is unlikely, tuning by togetherness continues to occur. For perceiving structures receiving signals from more than one kind of detector neuron:
- each receptor-tuned neuron becomes tuned (by sameness) by signals from the same kind of detector neuron.
- neurons farther up the cortex becomes tuned (by togetherness) by signals that originated in either the same kind or different kinds detector neurons.

Synchronisation of Receptor-tuned Neurons. Being tuned by sameness from signals from the same kind of detector neurons, there are multiple receptor-tuned neurons that were tuned by the

same pair of receptor neurons because their connections have different lengths that synchronize their pike trains to tune by sameness.

Reconstituting. Receptor neurons, being randomly arrayed in the brain, do reflect how detector neurons are arrayed in their sense organ. For perception types with at least some signal power variation across the sense organ (tabulated earlier), the following occurs.
*   Two detector neurons of the same kind that are *nearest each other* have the highest probability of causing the activation of detector-tuned neurons and do so with both signals having the same power.
*   Two such detector neurons that are farther apart have lower probability of being so activated and that probability rapidly decreases to mere chance.
The signals from those *nearest* detector neurons will repeatedly cause sameness activations that supplant those that are not so activated. This behavior is not limited to receptor-tuned neurons: it extended up through the perceiving structure. This tuning behavior is referred to as *reconstituting*, i.e., tuning behavior occurring in a perceiving structure that reconstitutes how detector neurons for certain perception types are linearly or areally arrayed. (Figure d0 illustrates the results of this behavior for areal arrays.) Muscle strain in each muscle, having intensity variations with respect to one another, are also reconstituted for each muscle.

Regularizing. As illustrated by the powers/activation graphs presented earlier, activating by togetherness is more probable when the two signal powers are less different. Neurons tuned by signals with significantly different powers, being less probable, become supplanted by those that are closer to being equal. This behavior, referred to as *regularizing*, is discussed further in the next Chapter discussing distinct multi-tuned intersecting hierarchical structures.

Stabilized Tuning of the Memory Neurons. After repeatedly being often differently tuned, memory neurons find the receptor neurons that are most likely to be active at the same time. Subsequent activations retune those neurons; tuning neurons differently mostly occurs when there is an activation with a different pattern or different relative power distribution, or both. This includes the receptor-tuned neurons that become tuned by sameness by the same pair of receptor neurons but for different pulse train synchronizations. In a mature perceiving structure, memory neurons, in effect, store the discrete activations with the most common combinations of activation patterns, therefore, the discrete activations most likely to be presented in the future.

Resulting Perceiving Structures

The differences among perceiving structures are due to differences in the perception type's detector neurons and its activation characteristics (as tabulated earlier). A muscle strain perceiving structure, being unaffected by these behaviors, does not mature.   Gustation and olfaction perceiving structure mature incrementally after new substances are encountered and regularizing occurs. Each of the four cutaneous perception perceiving structures have activation patterns with sensitivity over an area at different locations on the body, but differ in areal extent. Initially these perceiving structures consist of separated discrete structures. As each location on the body is repeatedly stimulated, those activations and the structures they create overlap those having adjacent detector neurons to create mature perceiving structures that are continuous over

the body surface. The configuration of the neurons in each type of perceiving structure is the subject of the next Chapter.

Also, each activation of a neuron within a perceiving structure is either *retuned* or *differently tuned* because it has been 1) inaugurally tuned and 2) none become unstably tuned because they are frequently retuned often enough so that none are become unstably tuned. Thus *tuning* now refers to either retuning or differently tuning.

Each mature perceiving structure has one discrete structure (i.e., for muscle strain in each muscle) or multiple discrete structures that overlap by sharing tuned neurons. A perceiving structure other than for muscle strain is a composite of its pattern structures plus the remnants of lost pattern structures. That sharing is greatest in the lower levels; near and at the top there is little or no sharing and those neurons distinguish among the different discrete activation patterns. The enormous variety of different activations patterns are distinguishable because only relatively few tuned neurons are needed to distinguish one stored activation pattern from another.

How discrete structures are *involved* in their mature perceiving structures is described below and illustrated in the next Chapter.
- For vision or audition, its discrete structures are *intermingled* with one another across its reconstituted perceiving structure.
- For gustation or olfaction, each perceived substance has a discrete structure that *stands separately* in its perceiving structure.
- For each cutaneous perception type, its discrete structures *intermingle* with those that are areally adjacent in its reconstituted perceiving structure.
- For muscle strain in each muscle, there is one Discrete structure that *stands alone* in its perceiving structure.

What a Perceiving Structure's Discrete Structures Store

A discrete structure in a mature perceiving structure does not store an activation pattern in a way that allows it to be independently retrieved because the discrete structures are not "freestanding," rather they overlap one another. An activation can be thought of as "imprinted" onto the perceiving structure on and around those previously "imprinted". In the absence of ongoing activation, there is no identifiable discrete structure. To be "retrieved," a discrete structure must be at least partially *reactivated* by an activation pattern that is very similar, likely from the same physical thing or one of the same kind. How we *recognize* and *recall* what is "stored" by reactivation is discussed in Chapter 5.

Chapter 3
Perceiving Structure Configurations

Introduction

This Chapter delves into the details of perceiving structures, both generally and by perception type, and introduces different ways of describing and displaying them. This includes a description of the segments commonly found in these structures and the particulars of each type of perceiving structures in terms of its segments and ends by summarizing the configurations found in these structures.

I organized this Chapter as follows:
Section 1: Segmenting Perceiving Structures
Section 2: Configuration of Each Type of Perceiving Structure
Section 3: Summary of Perceiving Structures

Section 1
Segmenting Perceiving Structures

Each perceiving structure can be understood in terms of its segments and the configuration of neurons in those segments. Some perceiving structures have only one segment.

Discussed in the following Subsections are *linking structures* followed by the first two atomic *intersecting hierarchical structure* sub-types defined above and lastly discrete structures. The latter two types of *intersecting hierarchical structures* are discussed with the particular perceiving structures of which they are a segment.

Subsection 1: Linking Structures
Subsection 2: Mono-tuned Intersecting Hierarchical Structures
Subsection 3: Distinct Multi-tuned Intersecting Hierarchical Structures

Subsection 1
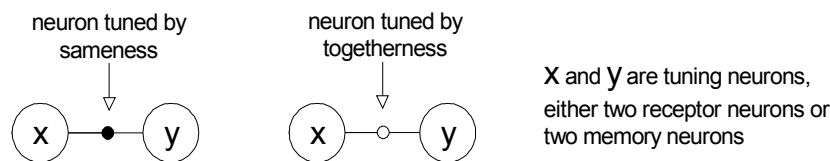**Linking Structures**

A linking structure involves one or more tuned neurons that are tuned by neurons at (what can be regarded as) the next lower level in the cortex. (Linking structures between discrete structures are introduced later.) In a linking structure, each tuned neuron is referred to as a link. Each link is said *to link* (or to be *linking*) its two tuning neurons, and those two neurons are said to be *linked*. Unlike a connection from one neuron to another, a link has no directionality. The simplest possible *linking structure* has a single link because it cannot be segmented. A linking structure is created by sameness or togetherness activations so the linking structure is either a sameness linking structure (with only sameness links) or a togetherness linking structure (with

only <u>togetherness links</u>). Note that a link, as defined, either links receptor neurons or links memory neurons at some level in the cortex hierarchy. Any tuned neuron can be understood as a link but that understanding is only useful here when discussing linking structure.

Displaying Links

A link is usefully depicted as illustrated below with the two tuning neurons it links as the result of either sameness or togetherness activation.
- A link is depicted by a line between its two tuning neurons with a small circle (dot) in the middle. The dot depicts the soma of the tuned neuron and the lines on each side depicts the connections from those two tuning neurons.
- The small circle is either solid (i.e., filled) or open to identify the method of tuning. The identification of the method of tuning and a mnemonic for remembering it is:
   a **S**olid small circle is tuning by **S**ameness; and
   *an **O**pen small circle is by t**O**getherness.*

neuron tuned by
sameness

neuron tuned by
togetherness

x and y are tuning neurons,
either two receptor neurons or
two memory neurons

x ●─● y   x ─○─ y

Figure
Tuned Neuron Depicted as a Link

Link Cluster Structures and their Configurations

Tuning neurons are interlinked if there is at least one series of links from each tuning neuron to every other tuning neuron. Multiple interlinked tuning neurons with the same type of links is called a <u>link cluster structure</u> or simply <u>link cluster</u>.

The lowest link cluster in a perceiving structure involves receptor neurons that tune the receptor-tuned (memory) neurons. As a result of *tuning method bias*, those links are tuned by sameness. Link clusters higher up the perceiving structure have links that mostly tuned by togetherness. These cluster type signifiers are: <u>sameness (receptor neuron) link cluster</u> and <u>togetherness (memory neuron) link cluster</u>, respectively. A taxonomy of linking structures is presented below.
   linking structure
      <u>link</u> – a linking structure that involves two tuning neurons that tune one memory neuron
>   <u>sameness link</u> – link (structure) created by sameness tuning
>   <u>togetherness link</u> – link (structure) created by togetherness tuning
      <u>link cluster (structure)</u> – linking structure that involves more than two tuning neurons
         sameness (receptor neuron) link cluster
         togetherness (memory neuron) link cluster

As a result of *regularization*, in a mature perceiving structure for vision, gustation or olfaction all receptor-tuned neurons receiving signals from the same kind of detector neuron are tuned by sameness. Thus, there are different receptor neuron link clusters for each kind of detector neuron (as illustrated later).

As a result of *reconstitution*, in a mature perceiving structure for perception types with at least some activation signal power variation across the sense organ, link clusters reflect the relative position of the detector whose signals tuned them. That reconstitution is either:

- *areal reconstitution* for the areal positions of vision and cutaneous detector neurons; and
- *lineal reconstitution* for the lineal positions (and acoustic frequency) of audition detector neurons or the acoustic phase difference between both ears as discussed later.

Not being reconstituted, link clusters for gustation, olfaction and muscle stain have links that are effectively random.

Displaying Link Clusters

The different configurations of link clusters and their simplifications are illustrated in the following diagrams for a *receptor neuron (sameness) link cluster*. Those higher up the cortex have the same configuration are but tuned by togetherness. These <u>link cluster diagrams</u> are oriented as if looking down at tuning neurons in a level in the perceiving structure's hierarchy.

> The left two diagrams display the link clusters reconstituted for the areal and lineal positions of the detector neurons. The tuning receptor neurons are displayed in the same relative positions as their detector neurons, allowing each link to be displayed between the two nearest receptor neurons. In the lower diagram, the lineally arrayed receptor-tuned neurons are displayed equally spaced from end to end (lineally) but are displayed offset from each other to enable depicting their links by straight lines. A similar diagram for a non-reconstituted (random) link cluster is not useful because they are effectively random. It is important to note that there are multiple different links between the same pair of receptor-tuned neurons for different synchronization of signal patterns that to tune by sameness.

> The simplifications of each of the three configurations of link clusters (areal, linear and random) are displayed on the right both for sameness tuning and togetherness tuning, respectively. Each displayed simplification is depicted by a shaded circle, suggesting a multiplicity of neurons. Their double line(s) identify the multiple links in the cluster. One or two straight double lines identifies the tuned neurons as areally or linearly reconstituted, respectively; the jagged double line identifies it as not reconstituted. (This is the first use of a single symbol to depict multiple neurons in a structure in lieu of displaying them individually.)

> The two single-arrowed double lines (==>) each point from what is simplified to its simplification. The use of an arrow is intended to identify the irreversibility of a simplification due to the loss of the displayed information. respectively.
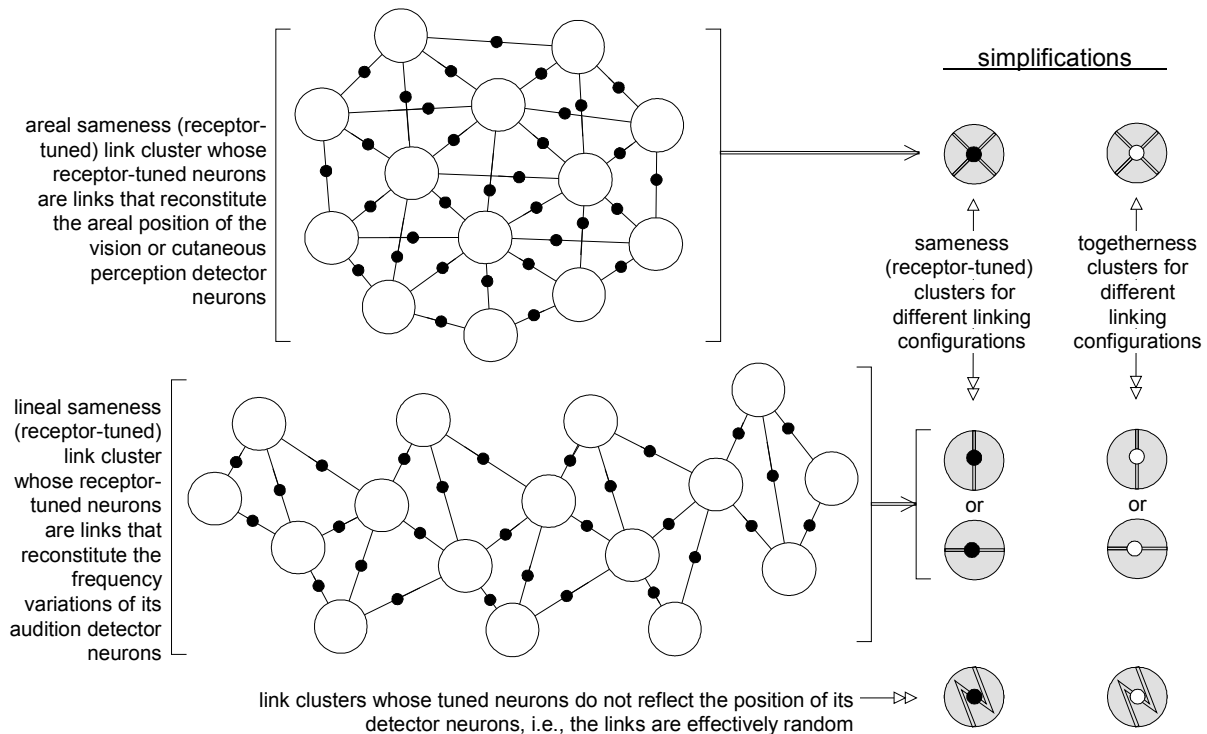
Figure_d0
Examples of Each Type of Link Cluster and their Simplifications

Note that in order to reconstitute the positions of detector neurons, the receptor neurons' axon branches for vision, audition and cutaneous perception need to be able to extend across the entire segment of the region of cortex where the subject perceiving structure is found. There is no similar need for memory neurons.

When describing the relative position of two linked neurons in a link cluster, they are said to be either:

> directly linked if they are a link's tuning neurons; or
> indirectly linked if they are not a link's tuning neurons.

Therefore, each tuned neuron in a link cluster is *directly* or *indirectly* linked to the other neurons in that link cluster.

Lineal Boundaries in Areal Link Clusters

Discontinuities and variations in how neurons are activated and presented in an areal link cluster are comprehended as *lineal* boundaries. (*Areal* boundaries are with respect to surfaces are discussed in Part 2.) Lineal boundaries are seen between either, or both, color and brightness in vision presentations or felt between boundaries for intensity in cutaneous perception presentations. These boundaries are typed by the abruptness of that boundary among areally arrayed neurons in a discrete structure as follows.

      crisp lineal boundary – lineal boundary with an abrupt discontinuity in an otherwise uniform activation
      pattern, e.g., the boundary around a letter displayed here
      fuzzy lineal boundary – lineal boundary with a gradual discontinuity of discernable width in an otherwise
      uniform activation pattern, e.g., the edge of a cloud
   ambiguous lineal boundary – lineal boundary that is mentally comprehended amid a lineally uniform variation in
   activation patterns, e.g., colors in a rainbow or warmness variations on the skin

A visual lineal boundary between a physical thing and its surroundings is nearly always crisp, animal hair and fir being examples of exceptions. Parts of a manufactured physical thing are also usually crisp; parts of a natural physical thing are usually fuzzy, e.g., features of a person's face.

The following example diagrams illustrate a crisp, fuzzy and ambiguous boundaries by looking through a plane normal to both a receptor-tuned areal array and the lineal boundary. The differences in the neurons on each side of the boundary identified by shadings are due to either differences in activation power, or, for the first two, being activated or not activated.   A visual lineal boundary is presented by the composite of its three receptor-tuned areal arrays for each kind of detector neuron, i.e., red, blue and green (introduced in the next chapter).
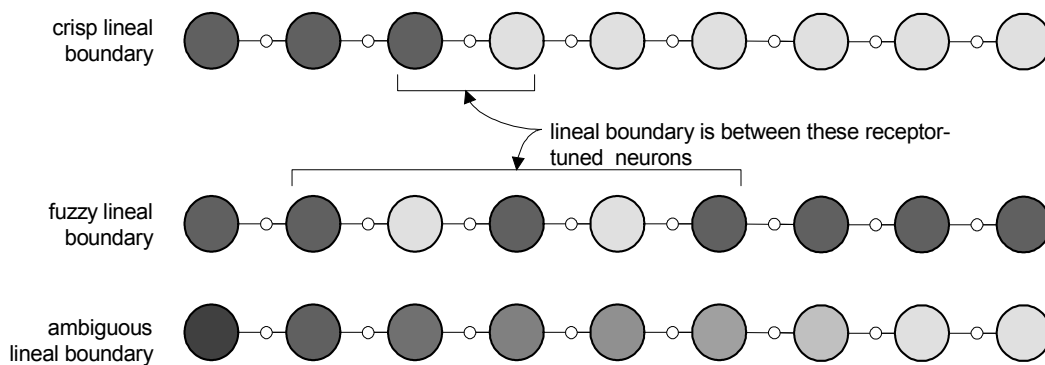
Figure
Crisp, Fuzzy and Ambiguous Lineal Boundaries in Areal Link Clusters
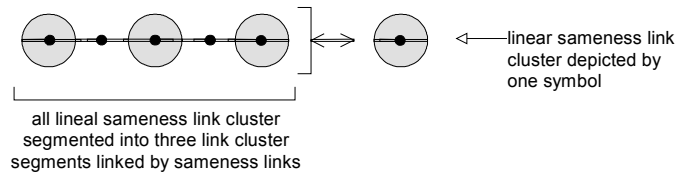
Segmenting Link Clusters

A (areal or lineal) link cluster can be segmented into smaller link clusters that is signified as: link cluster segment (structure). This can be viewed as "slicing" a link cluster through its links based on some criteria. The "sliced" links become links between the two link cluster segments.

Link cluster segments are not simply something introduced here to describe structures. Segmenting areal and lineal link clusters is the means that all minds use to enable thinking about and describing continuity. They allow a mind to identify and organize what is presented. This is exemplified by all languages having signifiers for link cluster segments of things having cultural relevance, e.g., separating of the colors of a rainbow and features of faces.

A linear link cluster segmented into three segments is illustrated below. The double arrowed line identifies the depictions as equivalent. A criterion for this segmenting might be to create three

segments with the same count of detector neurons and do so to minimize the count of "sliced" links. As depicted, the three segments form a <u>lineal sameness link cluster segment</u>.

- A link cluster segment is depicted in the same way as the link cluster it is a segment of. It being a segment is identified by also displaying some or all of the other segments with a line between them depicting their "sliced" links.
- The links *linking* a pair of link cluster segments is depicted the same way as those inside the simplified depiction of a link cluster. Since those "sliced" links are between different neurons in the segmented link cluster, they are separate and referred to collectively as a <u>linkage</u>. (A linkage is not a structure because the links are not themselves interlinked).

all lineal sameness link cluster
segmented into three link cluster
segments linked by sameness links

Figure
Example Sameness Link Cluster Segments of a Lineal Receptor-tuned Link Cluster

Linear link cluster segments and their linkages are collectively referred to as a <u>(non-directional) chain</u>, having sub-types: <u>sameness chain</u> and <u>togetherness chain</u>. A non-directional chain stores what is referred to as a *spectrum*. This and other chain types are discussed later.

Subsection 2
Mono-tuned Intersecting Hierarchical Structures

A mono-tuned intersecting hierarchical structure, defined earlier is created by signals from detector neurons of the same kind and is one of the following: an entire perceiving structure; a segment of a perceiving structure; or discrete structure. The example presented here is for either the entirety of a perceiving structure or a segment of a multi-tuned perceiving structure.
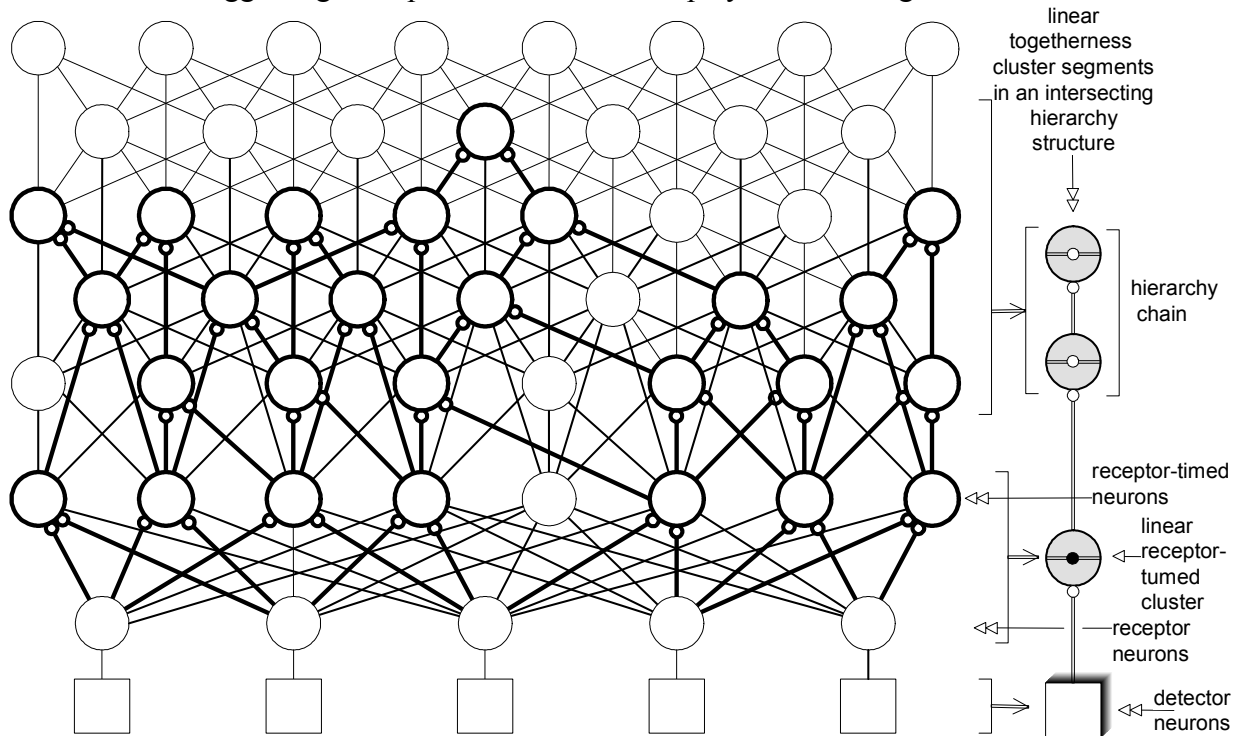
The diagram on the left displays a mature structure displayed as overlaying the network of cortex neurons using the convention introduced earlier. As before, the reader is expected to appreciate that this diagram cannot illustrate the variety and complexity inherent in this and other perceiving structures, including its discrete structures.

The diagram on the right is a simplified diagram that displays the same structure.
- Neurons at multiple different levels in the cortex are displayed as link clusters. The horizontal line through the circle and its dot identifies its links as having been created by sameness or togetherness activation. These link clusters are regarded here as forming a <u>(directional) hierarchy chain</u>.
- Detector neurons and receptor neurons are displayed as shadowed shapes, the shadow suggesting those neurons are arrayed one behind the others normal to the page. Not being linked, they are not link clusters.

- The link clusters and the neurons below them are *connected* (not linked). Those directional connections are depicted by a double line with a circle on the end suggesting multiple connections as displayed to their right.

linear
togetherness
cluster segments
in an intersecting
hierarchy
structure

hierarchy
chain

receptor-timed
neurons

linear
receptor-
tumed
cluster

receptor
neurons

detector
neurons

Figure a3
Generic Example of a Mature Perceiving Structure and its Simplification with Link Clusters

As illustrated above, each receptor neuron and receptor-tuned neuron is shown as tuning multiple other neurons, but each receptor-tuned neuron is tuned by two receptor neurons that are links that reconstitute the linear position of the detector neurons. In the receptor-tuned link cluster, each of the five receptor neurons is linked by two or three links, seven in total.

In this more complete example we can notice the following about whether the configuration of tuned neurons in a mature intersecting hierarchical structure is *reconstituted* or *non-reconstituted*.
- It being an intersecting hierarchy is clearly evident.
- Each tuned memory neuron is tuned by two (memory or detector) neurons.
- Nearly every receptor neuron tunes one or multiple memory neurons and each memory neuron tunes none, one or more other neurons above it. Note that multiple neurons can have the same pair of tuning neurons
- Note that some pairs of tuning neurons, including receptor neurons, tune more than one neuron. Thus, a neuron in a link can be redundant.
- A neuron's tuning neurons may both be tuned by the same neuron.
- The density of tuned neurons decreases vertically and there is an upper limit beyond which no neurons are tuned by signals from detector neurons.

- Those topmost neurons are tuned by neurons that have nearly exhausted their ability to tune, and are only tuned because the signals happened to find another neuron to tune.
- It is ragged at top due to variations in signal powers; and
- The structure has many tuned neurons arrayed horizontally but there are few vertically, i.e., tuning only extends a few neurons up the cortex.

Looking back at Figure_c_1, we can note that regardless of arriving signal power, if there are very few detector neurons that generate a signal, only a few neurons can be activated and tuned. As a result, the ability to activate neurons is limited both by the powers of the arriving signals and how many arriving signals there are. Also note that reconstitution being enabled by the receptor neurons' connections extending at significant distances, the memory neurons' connections only need to reach nearby neurons.

Describing the relative connectedness of two neurons in a hierarchical perceiving structure is similar to that for linked neurons in a link cluster. Two neurons are said to be:
> directly connected if the tuning signal traversed one axon;
> indirectly connected if the tuning signal traversed more than one axon; or
> unconnected if tuning signals from either one is unable to reach the other.

Thus a neuron in a hierarchical perceiving structure is either directly or indirectly connected from its receptor neurons.

Subsection 3
Distinct Multi-tuned Intersecting Hierarchical Structures

The subject structure, defined earlier, is an intersecting hierarchical structure where different kinds of detector neurons that generate *distinctly* different signal patterns having uniform activating signals power variation, i.e., gustation and olfaction. An activation by these detector neurons is due to reactions with a specific substance (or possibly substances that coincidently causes the same reactions). It is presented as having:
- an intensity due to the signal powers; and
- a quality (taste or smell) due to signals from either: one kind of detector neuron, or a combination of different kinds of detector neurons where the signals from each kind of detector neuron has a fixed power ratio with one another.

The activation turnover rate being so low (<10/minute) and having no power variation, each of the few thousand activation patterns is stored.

The following diagrams present a greatly simplified example for such a perceiving structure receiving signals from just two different kinds of neurons, labeled "a" and "b" and being activated by only one activation pattern. To make the example even simpler, the powers of the "a" detector neurons signals are twice those of the "b" neurons, i.e., a power ratio of 2:1. (Structures with multiple power ratios with more than two kinds of detector neurons are presented in the next Chapter.)
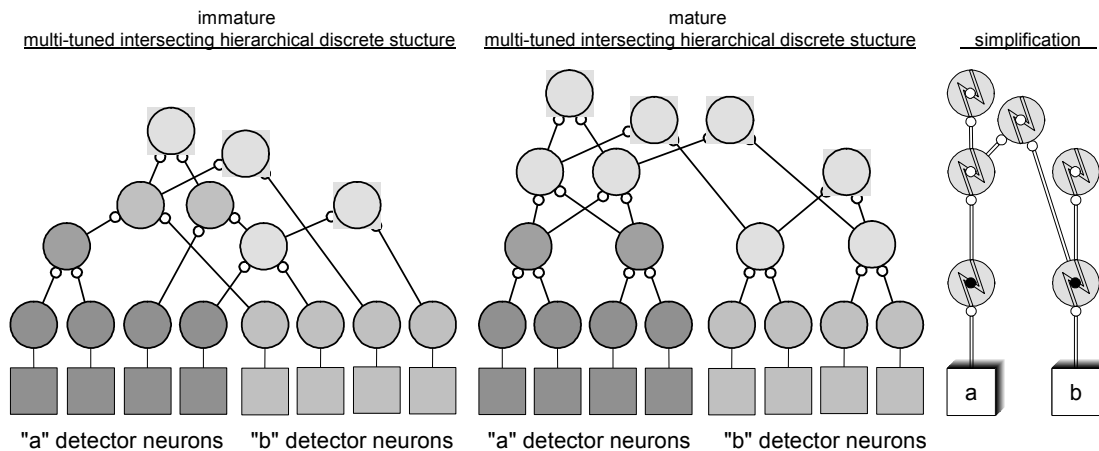
> The first two diagrams on the left are greatly simplified neuron diagrams with all of its neurons currently activated by signals with the subject power ratio. The shading

identifies the relative power that caused a neuron's activation: the darker the shading the greater the power, with shading (power) decreasing as activation cascades up the cortex.

The left diagram is for the subject perceiving structure when it was immature, possibly during inaugural tuning. The configuration displayed is for activation that is effectively a random.

The middle diagram is for the same structure after it has matured because of both *tuning method bias* (as shown by the neurons that tune the receptor-tuned neurons) and *regularization* for those above having tuning neurons having fewer power differences (i.e., shading). With regularization, the more probable tunings above the receptor-tuned neurons have supplanted those early random tunings by virtue of the most probable togetherness tunings are those with lesser differences in their powers. Note that the mature structure in effect "stores" the power difference in the two kinds of detector neurons for that combination of stimuli. The power ratio is reflected in which neurons tune the multi-tuned neurons

The simplification depicts a more complex version of the mature structure using link clusters in *intersecting* hierarchy chains. The multiple receptor neurons and the multiple detector neurons are depicted as before, but with a letter identifying each kind of detector neuron. The two lowest link clusters are the detector-tuned neurons are for each kind of detector neuron and the upper link clusters are for the neurons tuned by the given activations: those on either side are tuned by only one kind of detector neuron, and one in the center by two kinds of detector neurons. The latter link cluster has connections from the other link clusters that reflect the subject power difference.

immature
multi-tuned intersecting hierarchical discrete stucture

mature
multi-tuned intersecting hierarchical discrete stucture

simplification

"a" detector neurons   "b" detector neurons   "a" detector neurons   "b" detector neurons

Figure A5
Immature and Mature Multi-tuned Intersecting Hierarchical Structures Tuned by Signals from Two Different Kinds of Detector Neurons and a Simplification

Note that signals with different signal power ratios would result in different configurations of link clusters. The effect of having additional different kinds of detector neurons is obvious.

Section 2
Configuration of Each Type of Perceiving Structure

Each perceiving structure is configured in a manner that is the result of its activation patterns and the characteristics of those activations. This Section discusses the configuration of each type of perceiving structure in terms of its link cluster segments.

Perceiving Structure Types based on Configuration

Perceiving structures are usefully typed based on how they are configured in terms of the segments described above. Those types are presented below in a tabulated taxonomy. To the right is the subject perceiving types and a description of the configuration. The underlined terms in the configuration description are those that served to distinguish these configurations.

Perceiving Structure Types Based on Configuration

taxonomy of perceiving structure types based on configuration		perceiving types	configuration description
detection (non-hierarchical) perceiving structure		scotopic vision, surface tactition	for each type of perception, one mono-tuned receptor-tuned _link cluster_
intensity or quality (hierarchical) perceiving structure	intensity perceiving structure	deep tactition, thermoception, muscle strain	for each type of perception, one mono-tuned intersecting hierarchical structure for each sense organ with indistinct discrete structures
	quality perceiving structure	gustation, olfaction	one multi-tuned discrete structure for each organ that have separately standing discrete structures for each perceived substance
		photopic vision	for each ear, one multi-tuned intersecting hierarchical structure with distinct embedded discrete structures
		audition	for each eye, one variably-tuned intersecting hierarchical structure with distinct embedded discrete structures

A complete taxonomy of segment types is presented below.

> linking structure – all or a segment of a perceiving structure whose tuned neurons convey non-directionality, i.e., tuning neurons that are at the same level in the intersecting hierarchy.
> discrete structure (defined earlier) – all or a segment of a perceiving structure.
  intersecting hierarchical structure – a structure created by activations where whose tuned neurons form an intersecting hierarchy or a discrete structure. The tuned neurons at the bottom of an intersecting hierarchical structure are receptor-tuned neurons. This structure type is one of the following sub-types:
> mono-tuned intersecting hierarchical structure – an intersecting hierarchical structure created by activations where all neurons are tuned by signals from the *same kind* of detector neuron, referred to as *mono-tuned* neurons (scotopic vision, cutaneous perception and muscle strain).
  multi-tuned intersecting hierarchical structure – an intersecting hierarchical structure created by activations where some or all neurons are tuned by signals from *different kinds* of detector neuron, referred to as *multi-tuned* neurons, that is one of the following.
    distinct multi-tuned intersecting hierarchical structure – a multi-tuned intersecting hierarchical structure created by activations where the detector neurons generate distinctly different signal patterns.

51

>   <u>non-reconstituting distinct multi-tuned intersecting hierarchical structure</u> – a distinct multi-tuned intersecting hierarchical structure created by activations without signal power variations, i.e., no reconstitution (gustation and olfaction).

>   <u>reconstituting distinct multi-tuned intersecting hierarchical structure</u> – a distinct multi-tuned intersecting hierarchical structure created by activations with signal power variations that causes reconstitution (photopic vison).

>   <u>indistinct multi-tuned intersecting hierarchical structure</u> – a multi-tuned n intersecting hierarchical structure created by activations from one kind of detector neuron but each neuron generates a signal pattern that is effectively different from the others in that sense organ, i.e., detector neurons in an ear (audition).

The configuration of each type of perceiving structure is presented in the following subsections.
      Subsection 1: Muscle Strain and Cutaneous Perceiving Structures
      Subsection 2: Gustation and Olfaction Perceiving Structures
      Subsection 3: Vision Perceiving Structures
      Subsection 4: Audition and Olivary Perceiving Structures

Subsection 1: Muscle Strain and Cutaneous Perceiving Structures

The subject perceiving structures are the simplest. There is one muscle strain perceiving structure for each muscle consisting of a single discrete structure that *stands alone*. There is one cutaneous perceiving structure for each of the four types of cutaneous perceptions that are areally reconstituted to reflect the surface of the body resulting in *intermingling* discrete structures for adjacent areal portions of the body. Although these five receptor-tuned neurons are independent for each other, they are interlinked by binding links as discussed below.

These five are displayed below by their link clusters with each type identified by its abbreviation displayed inside the square depicting its receptor neurons. The multiplicity of muscle strain discrete structures is indicated by shadows. Surface tactition (sT) is only a *receptor-tuned link cluster*; the other three are also have *mono-tuned intersecting hierarchical structures*. The binding linkages are shown linking their receptor-tuned neurons.
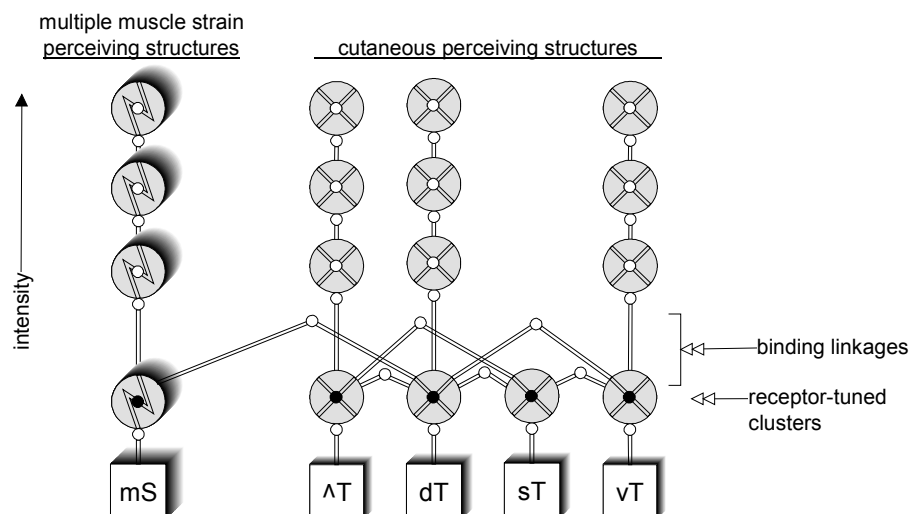
Figure_aa
Muscle Strain and Cutaneous Perception Structures

Each touch to the skin or tongue is a discrete activation on a generally small area of the body, and those touches often activate receptor-tuned neurons for two or three different kinds of cutaneous detector neurons. Muscle strain that stretches the skin activates deep tactition receptor-tuned neurons. These activations being simultaneous and localized, they create links between the neurons in different receptor-tune neurons (and possibly higher), thereby interlinking those structures for a particular location on the body. The links between the neurons in two different receptor-tuned clusters create what is referred to here as a <u>binding linkage</u>. Unlike the other linkages (and their links) discussed so far, this one is between different perceiving structures. (Other linkages between different structures are discussed later.) The term *binding* is used because this linkage type addresses the so-called binding problem and stores what is referred to as *binding* memory. Binding linkages do not readily link perception structures that are in opposite hemispheres.   The binding linkages between simultaneously active receptor-tuned clusters as illustrated above. Binding linkages are displayed in the same way as other linkages but with an upward (or downward) kink to more easily display them among the structures they link. Except for the two types of thermoception, all cutaneous perception structures have binding linkages. Additional types of binding linkages are discussed further in the next Chapter.

Since each receptor-tuned neuron for the four cutaneous receptor-tuned link clusters is for a (reconstituted) location on the body, their interlinking creates a map of each location on the body surface. With the binding linkages with muscle strain, each muscle becomes "embodied" within that body map.

Subsection 2
Gustation and Olfaction Perceiving Structures

The subject perceiving structures are each created entirely by a succession of discrete activations with different activation patterns but having no activation pattern variability. Each discrete activation is due to a different ingested or inhaled substance that stimulates one or multiple detector neurons whose signals are from:
•   one kind of detector neuron; or
•   some or all kinds of detector neurons having signal powers that are in fixed ratio(s) relative to each other.
Each resulting perceiving structure is a distinct multi-tuned intersecting hierarchical structure with discrete structures that *stand separately* for each perceived substance. These perceiving structures do not mature as a whole, rather each discrete structure matures separately as it becomes regularized.

Gustation having five different kinds of detector neurons and olfaction having six, many different combinations of signals can be distinguished. Considering only combinations where the signal from each kind of neuron is on or off, there are, there are 31 and 63 combinations, respectively (i.e., $2^n - 1$ combinations, where n is the count of different kinds of detector neurons). Given that most substances generate signals with different signal power ratios relative to each other, the combinations increase somewhat exponentially with the count of possible signal power ratios.

To illustrate this behavior in a mature structure, I extend the earlier example with "a" and "b" detector neurons and one power ratio to the same two neurons each having a relative powers of: zero (no power, i.e., no signal), 1 and 2. This results in five different combinations of activation (and different presentations) having the following eight combinations of power ratios, P_a/P_b:

      2:0 2:1 2:2 1:2 0:2
      1:0   1:1   0:1

The lower row and upper rows list the power ratios for low and high signal powers, respectively, i.e., the same taste or smell but at lower or higher intensity. Note that as identified by this limited example, the second and forth power ratios (2:1 and 1:2) only serve to detect a taste or smell because they have no intensity variation. The following diagrams illustrate this example.

> The left diagram displays the example using the simplification convention used earlier for a *multi-tuned* perceiving structure but applied here for eight power ratio combinations displayed as link clusters. Two are individual link clusters and the three pairs of link clusters are link cluster segments, each pair in a hierarchy chain. *Standing separately,* the two individual link clusters and the three hierarchy chains are each a discrete structure for a perceived substance. The link clusters segments on each side are mono-tuned; the three in between are multi-tuned labeled x, y and z.

> The two diagrams on the right are both generalizations that apply to any count of detector neurons that generate signals with power ratios specific to different detected substances. Detector neurons are displayed with N inside for any count of different kinds of detector neurons.

>> The left generalization displays three of the many different power ratios as hierarchy chains: two of the N *mono-tuned* neurons and one for all of the *multi-tuned* neurons with the remainder are implied by ellipses. The multitude of connections between link clusters are similarly implied.

>> The right generalization is a simplification that displays the entirety of this type of perceiving structure, using a trapezoid to depict intersecting hierarchy structure suggesting that there are more tuned neurons at the bottom than the top, and many fewer in its vertical (intensity) direction. The count of receptor-tuned neuron link clusters is identified to the above right of its depiction. Being a generalization, that count is N.

gustation or olfaction perception structure for
2 kinds of detector neurons with two signal powers

gustation or olfaction perception structures
simplified and generalized for N kinds of detector neurons
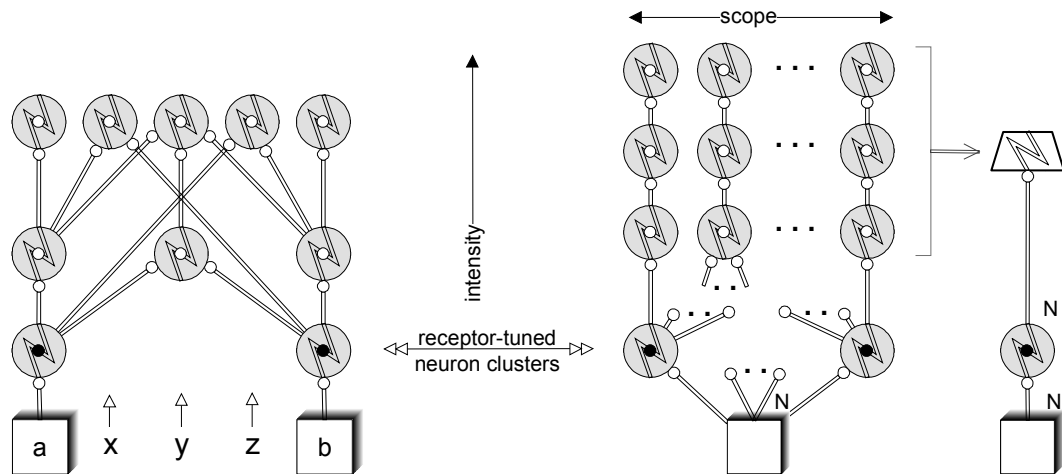
Figure_a0_new
Gustation and Olfaction Perceiving Structures

Note that the neurons in the different receptor-tuned neuron link clusters are linked by virtue of tuning multi-tuned neurons.

As suggested in the earlier example for multi-tuned neurons with one power ratio, each activation can activate neurons in the other hierarchy chains. However that activation only affects the neurons in the lower segments of those other stacks and only the power ratio combinations that are specific to a hierarchy chain can activate neurons in the upper segment of portion of the chain(s) unique to that combination and power ratios.

Each hierarchy chain in these perceiving structures is a different discrete structure. Collectively, these hierarchy chains are referred to as a scope, i.e., different discrete tastes or flavors, in contrast to those that form a *spectrum*, i.e., varying continuously.

Note that if this analysis is correct, a particular taste or smell that is the result of activation by most or all the N different kinds of detector neurons should have a smaller intensity range than those that are the result of activation by only one or two.

Gustation and olfaction discrete structures are often active simultaneously, as well as are discrete structures for gustation and surface tactition. This creates binding linkages between the subject perceiving structures as illustrated in the diagram in the summary in the next section.

Subsection 3
Vision Perceiving Structures

The subject perceiving structures are created in each of the two hemispheres of the cortex by both discrete and non-discrete activations having activation pattern variability. For scotopic vision, the perceiving structure is simply one areally reconstituted receptor-tuned link cluster for each

eye; for photopic vision it is a *reconstituting distinct multi-tuned intersecting hierarchical structure* for each eye, both having *embedded* discrete structures.

While scotopic vision and gustation | olfaction perceiving structures are relatively easily described and illustrated, photopic vision is not. This is due to having non-discrete activations and reconstitution that result each in photopic vision perceiving structure that each store continuous color variations. Photopic vision structures can be described and understood in terms of color spectra as described below.

Color Spectra

The three kinds of color detector neurons (red, blue and green cones) in an eye are stimulated by absorbing light over different (but overlapping) light frequency ranges that center around the frequencies for red, blue or green. The resulting presentations are described by the Munsell Color System (abbreviated HCL). That system resolves all normally perceived colors according to their color similarity in three continuous orthogonal *color spectra*: hue; chroma (or saturation); and lightness (black <> white). Light intensity, i.e., brightness (dark <> light) is orthogonal to each of the three color spectra, e.g., black (a lightness) can have any brightness. Consistent with that system, the term *color* used here includes black, white, and the greys in between.

The Munsell Color System is illustrated below left with colors displayed as if orthogonally arrayed in three spatial dimensions, one for each color spectrum (nd having the brightness used to illuminate that diagram) It is in the shape of two cones with abutting bases. Displaying these spectra geometrically enables it to be described in terms of polar coordinates through the centers of the two cone shapes:
•   the *lightness* spectrum is the axis normal to the polar coordinate plane;
•   the *hue* spectrum is the angle of a polar coordinate around the axis (at any lightness); and
•   the *chroma* spectrum is a polar coordinate; i.e., radial to the axis (at any lightness).
The lightness spectrum extends between white and black with shades of grey in between. The outermost hue in the hue spectrum is where the commonly signified colors are found, i.e., red, orange, yellow, green, blue and violet. (Despite the arrows in this diagram, each spectrum is non-directional.) Although depicted on the exterior as smooth, the "surfaces" actually somewhat ragged as illustrated in the diagram found at
http://www.harding.edu/gclayton/color/topics/001_huevaluechroma.html.
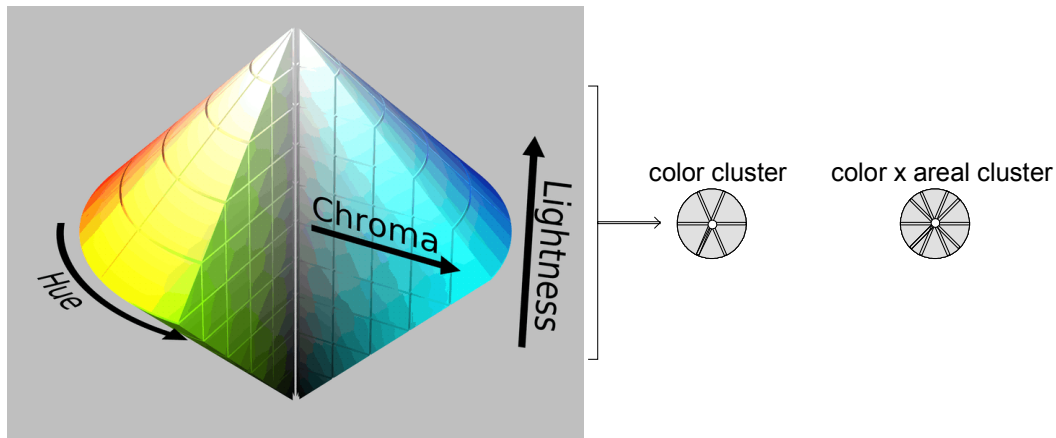
(From Wikipedia. August 18, 2012: Hcl-hcv_models.svg: Jacob Rus

Figure
Munsell Color System Illustration and its Simplification Using Link Clusters

Illustrating a Vision Perceiving Structure Color Using Link Clusters

The two link clusters displayed above are a <u>color link cluster</u> that involves all tuned neurons in the subject perceiving structure *at a given brightness* with each of its three spectra identified by a double line. Since spectra are orthogonal to the two areal dimensions, all five dimensions can be depicted by a <u>color × areal link cluster</u> also displayed above.

An entire photopic vision perceiving structure can be illustrated using color × areal link clusters as illustrated below along with the scotopic vision perceiving structure for detector neurons in the same retina. The receptor-tuned link clusters for each kind of photopic vision detector neuron are shown with connections to the multi-tuned intersecting hierarchical structure depicted by a single hierarchy chain. An ellipsis between the ends of stub connections identifies either variability the count of those connections or inability to display all of them. The scotopic vision perceiving structure is displayed with a shorter hierarchical chain to reflect it's more limited intensity (brightness) range.

Like the different cutaneous perceiving structures, there are binding linkages among the four vision receptor-tuned neuron link clusters by virtue of being areally reconstituted for the same location on the retina. The simplification of the photopic vision perceiving structure uses a trapezoid also identifying the color and areal dimensions.
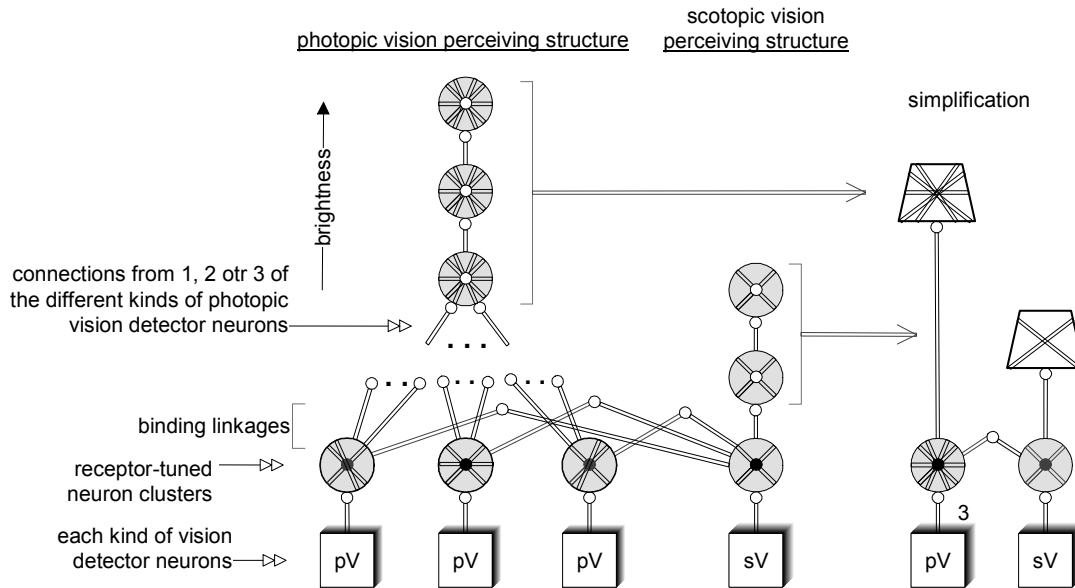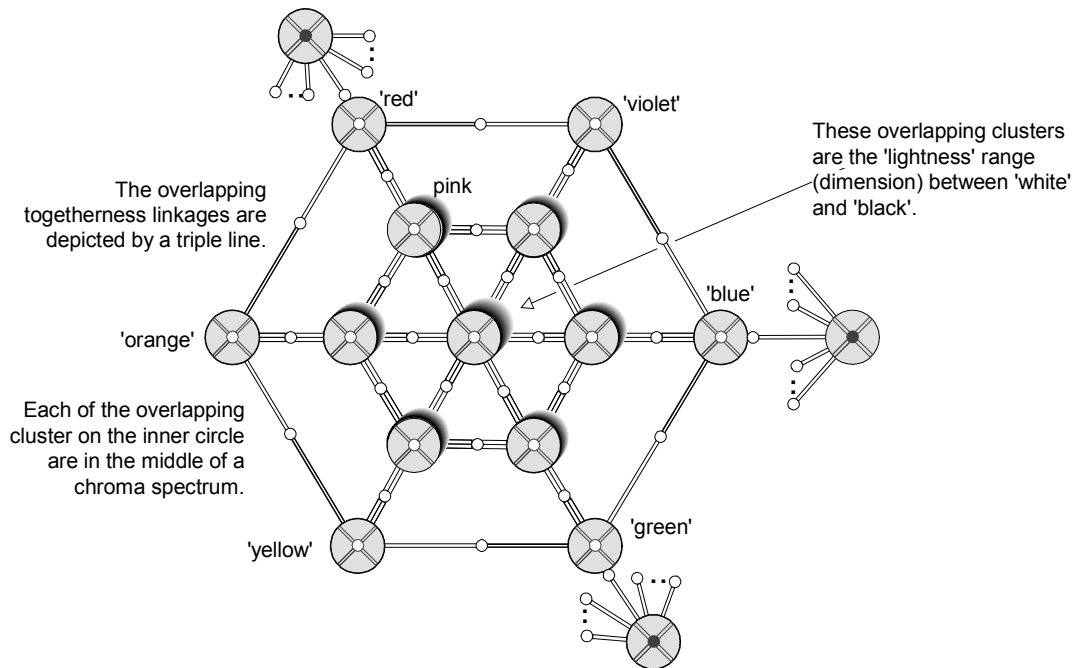
Figure_color_0
Vision Perceiving Structures for One Eye

The two diagrams below are different displays of a photopic vision perceiving structure for a given brightness using areal link clusters with each cluster for a range of color. These diagrams can be understood as for either the entirety of the subject perceiving structure type or among a few neurons activated by signals from a few nearby detector neurons sufficient to present a "pixel" for that location. The x-shaped double lines inside each link cluster identifies its areality.

The first of these diagrams displays an areal link cluster for each color configured consistent with the Munsell Color System illustrated above as if looking down the vertical axis of the cones. An areal link cluster is depicted by circle with the x-shaped double lines inside. The areal link clusters fully displayed are those on the top of the upper cone; the areal link clusters below it are indicated by shadowing. Each areal link cluster is shown linked by togetherness linkages between those with the colors that are most nearly the same and along the direction of one of the three spectra. Overlapping linkages are displayed by a triple line. The words in single quotes are English language signifiers that *signify* a link cluster. The three (mono-tuned) color-specific receptor-tuned link clusters are displayed on the outside of the cone along with additional connections (depicted as stubs) to the multi-tuned receptor-tuned areal link clusters.

The outermost areal link clusters are different hues in the hue spectrum at the (outside) end of a chroma spectrum. The overlapping link clusters at the center are the entire lightness spectrum between black and white. The link clusters between the outermost and the center are different hues for an intermediate chroma for any lightness with that hue, e.g., 'pink'.

Figure_color_4
Color-specific Areal Link Clusters at some Level in a Photopic Perceiving Structure

The displayed linkages between these link clusters form three different (non-directional) togetherness chains. These chain types are:
- circular (unbounded) chain for *hue* alone or at some combination of chroma and lightness;
- radial (partially bounded) chain for *chroma* at some hue and lightness; and
- bounded chain for *lightness* alone or at some combination of hue and chroma.

There are many signifiers for hues beyond those displayed here, e.g., turquoise, magenta and jade, and some expressed by combining other color signifiers, e.g., blue-green.
Which colors have signifiers are those for common substances, e.g., blood 'red' and sky 'blue'. Some are specific to what substances of importance to a culture, e.g., 'coral' and 'jade'. Middle chroma color signifiers are often expressions, e.g., pale blue and greyish pink.

The second diagram displays a segment of the same structure in the form of a "vertical" section through the two abutting cones along the 'red' chroma, i.e., between the 'red' hue and the entire lightness spectrum. Also displayed is the 'red' receptor-tuned link cluster with its linkage with the 'red' areal link cluster. A signifier is displayed for each link cluster.
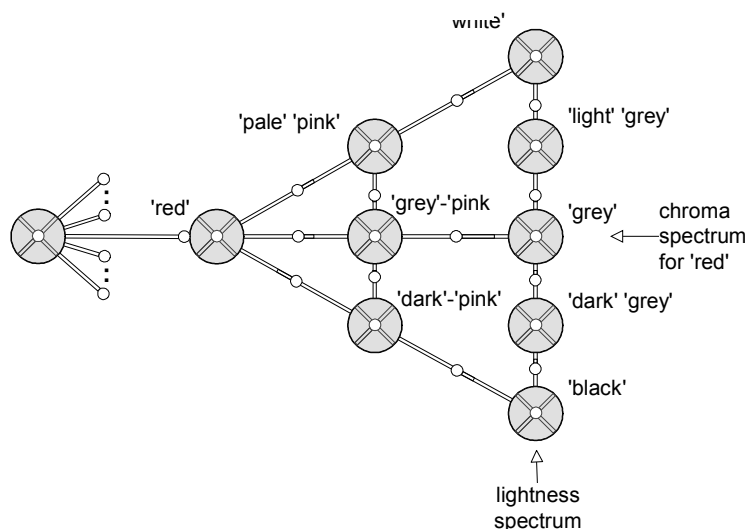
Figure_color_2
Color Areal Link Clusters along the 'Red' Chroma Spectrum and in the Lightness Spectrum

Subsection 4
Audition and Olivary Perceiving Structures

There are three perceiving structures that are created in response to acoustic stimuli.
- The two *audition perceiving structures* in the left or right cortex receive signals from one ear and store their discrete activations as *intermingled* discrete structures.
- The <u>olivary perceiving structure</u>, introduced here, is in the superior olivary complex in the brainstem where it receives acoustic signals from both ears, thereby enabling it to detect the angular direction to the source of a sound by the phase difference in signals from the two ears.

The characteristic of these signal patterns is discussed first, followed by their perceiving structures.

Audition Detector Neuron Signals

In each ear, there are approximately 32,000 hair cells lineally arrayed inside each ear's cochlea. An acoustic wave travels into the ear and vibrates the liquid within the cochlea. At each hair cell, the shape of cochlea causes the liquid to resonate within a particular narrow frequency range and power. That causes each of it's hair cell's hair to oscillate at a frequency and power that is monotonic to the liquid's frequency and power. In a young healthy ear, detector neurons respond to individual acoustic frequencies between ~20 and ~20,000 Hertz (cycles / sec) or a wave cycle between ~50. and ~0.05 ms (milliseconds), a variation of three orders of magnitude. Detector neurons respond to an acoustic power range over several orders of magnitude.

Neither a hair cell nor its spike train can respond to frequency and power differences over several orders of magnitude, even through the hairs on the cells are more rigid at higher frequencies making them respond more slowly that those at lower frequencies. Instead, the frequency and the

power conveyed by a signal generated by these detector neurons are proportional to the logarithm of the frequency and the logarithm of the acoustic power.

The only way for a sequence of spikes to convey acoustic frequency is by spike trains whose durations are each monotonic with the logarithm of the subject frequency. Since each spike has a duration of ~1ms, a spike train with even only one spike cannot convey that frequency. Instead an acoustic spike train must be generated by multiple oscillations so that each spike train conveys some multiple of the acoustic frequency. Since we can seemingly hear each of the acoustic waves at low frequencies, that multiple must at least approach 1 at low frequencies. Even with these multiples, the ability to convey the wave's power along with its frequency exceeds what is possible by a spike train as described earlier in Chapter 1. I hypothesize what appears to be the simplest means of conveying frequency and power.

> **Audition Spike Train Hypothesis**. An audition spike train pattern consists of a single spike generated after a fixed multiple of oscillations of a hair cell's hair with each spike's energy reflecting (monotonic with) the energy received from the acoustic wave during those oscillations. Thus, the frequency of each spike is monotonic with a frequency in the arriving acoustic wave and the power of the spike train is monotonic with the power of the acoustic wave at that frequency. The variation in spike energy is presumed to be variation in the spike's duration rather than amplitude since duration increases the likelihood of matching spikes and the spike's amplitude is likely fixed by the processes that generate and convey spikes.

A neuron activation by a signal whose spike train consists of a single spike is either by:
- sameness: same frequencies arriving in-phase, e.g., 1:1 correspondence; or
- togetherness: different frequencies where the frequency ratios are of integers, e.g., 2:1, 2:3, etc.

Because of activity pattern diversity, signals from close by hair cells having the same or nearly the same spike frequency, activation by sameness is predominate, both among the detector tuned neurons and activation farther up the cortex. In a mature structure generated by such signals, the oscillation frequency of the hair cells (and their position in the cochlea) is lineally reconstituted. What is presented is the arrival of spikes at a detector-tuned neuron, both frequency and signal power, i.e., loudness.

We are aware that we can immediately identify the angular direction to the source of a sound and its approximate distance away. The primary means of identifying direction is by the phase difference between the acoustic waves arriving at each ear, discussed further below. Secondarily, sounds from the far left or right are so identified by their difference in loudness. The means of approximating distance away, enhanced by the shape of the ears, is by the differences in: expected loudness; range of frequencies at distances away from the ears; and echoing that increases with distance.
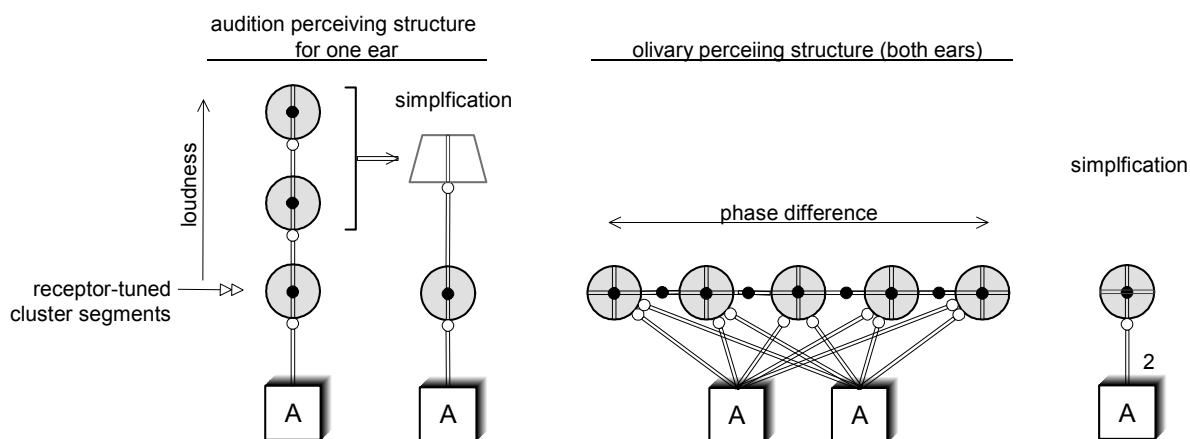
Audition and Olivary Perceiving Structures

Mature audition and olivary perceiving structures differ because reconstitution tunes detector-tuned neurons as follows:

- for each audition structure, by signals from a pair from the same ear; and
- for an olivary structure, by signals from both ears.

Signals from both ears are able to tune when the difference in the lengths of the connections compensates for the phase difference due to the angular direction of the arriving sound. Like other perceiving structures, the subject perceiving structures are described and illustrated in terms of the configurations of their link clusters.

Audition. A mature audition perceiving structure is an *indistinct multi-tuned intersecting hierarchical structure* that lineally reconstitutes for (hair cell oscillation) frequency alone. A link cluster identifies that lineal spectrum by a vertical line. The two left diagrams below illustrate an audition perceiving structure for one ear, one a simplification of the other. The unsimplified diagram depicts the lineal sameness link clusters in a hierarchy chain. The simplification depicts the intersecting hierarchy structure by a trapezoid.

Olivary. A mature olivary perceiving structure is reconstituted for both hair cell oscillation frequency and phase difference. The greater the right or left angle to the source of a sound, the greater its phase difference in that direction. That phase difference is eliminated by connection lengths compensate for that difference. Having the same frequency and being in-phase, they can tune neurons by sameness; otherwise, there is no tuning. The result is that in addition to lineally reconstituting for frequency, it also lineally reconstitutes the angular direction to sources between far left and far right. Note that reconstitution is lineal for two different (and orthogonal) spectra. Since all that is needed is to detect phase difference (angular direction) this structure is presumed to consist of only a receptor-tuned link cluster. The two right diagrams below illustrate an olivary perceiving structure, one a simplification of the other. The unsimplified diagram depicts that link cluster in lineal segments in a sameness chain for the angular direction spectrum. Each segment identifies the frequency by a vertical double line and phase difference (angular direction) by a horizontal double line. The right diagram depicts its simplification.

Figure_audition_x
Audition and Olivary Perceiving Structures

The mechanism for awareness of the angular direction to the source of a sound based on phase difference is presumed to be due to binding linkages between receptor-tuned link cluster segments for phase difference in the olivary perceiving structure and their corresponding vision

link cluster segments for different angular directions in each audition perceiving structure. This binding linkage is illustrated in the diagram in the summary in the next section.

Section 3
Summary of Perceiving Structures

This chapter ends by summarizing and making observations about perceiving structures.

Each type of perceiving structure is automatically created as the result of signals generated by detector neurons in sense organs cascading up the cortex or olivary structure causing memory neurons to be activated and tuned. That creation and resulting characteristics of perceiving structures are shown to be the result of repeated neuron activation and tuning as described in Chapter 1, what is known about the sensory organs and the characteristics of the signals from those organs. Although each tuned neuron only stores which neurons tuned it, each perceiving structure stores the tuning signals' patterns and for some perceiving structures the configuration of the detector neurons. A perceiving structure can be thought of as the composite of all surviving presentations.

The following figure displays each of the perceiving structures of interest here using the convention introduced earlier plus the following.
•   Inside each square depicting detector neurons are arrowed line(s) that identify the array of detector neurons as lineal, areal or spatial, and a count identifies the different kinds of detector neurons in a sense organ.
•   If there is more than one depicted sense organ or structure, its count is identified at the upper right of its depiction.
•   Binding linkages, depicted by a kinked double line and a circle, are displayed between pairs of receptor-tuned neuron structures. Those binding linkages not displayed previously are those involving gustation, audition and vision.
The two perceiving structure segment types depicted are: a circle for one or more receptor-tuned structure(s) and a trapezoid is one or two intersecting hierarchical structure(s). As illustrated, surface tactition and olivary perceiving structures have no intersecting hierarchical structure.

The four cutaneous receptor-tuned link clusters are reconstituted for the areality of the skin, mouth and tongue, and the two pairs of vision receptor-tuned link clusters are reconstituted for the areality of inside the two retinas.
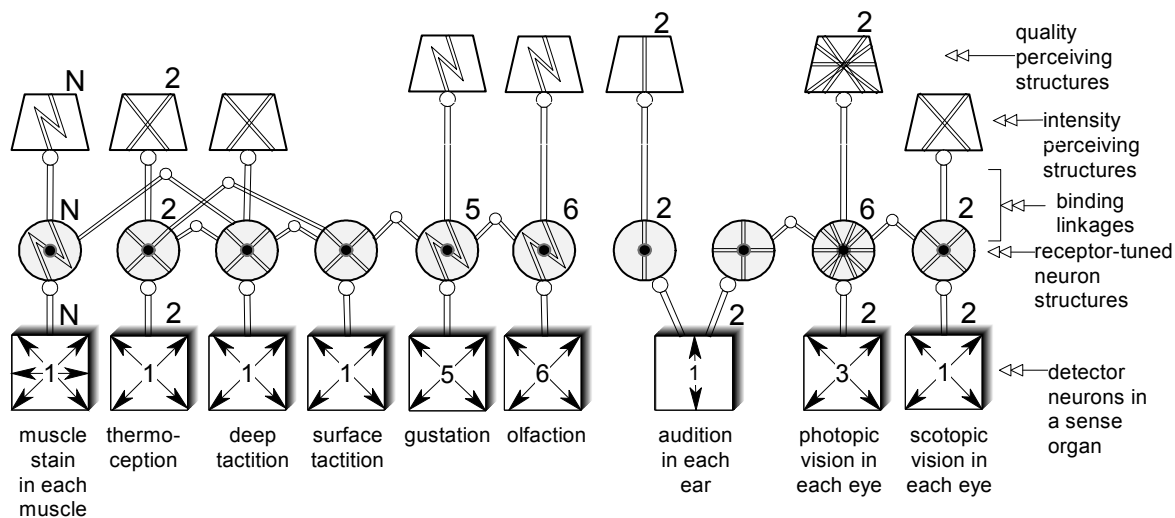
Figure_b2 (part)
Perceiving Structures and their Binding Links

Note that audition and photopic vision have no binding linkages with the other perception types. Those linkages are found between discrete structures specific to physical things and processes as discussed in Chapter 4.

Quality Presentations

Having identified the structures within a perceiving structure and their activations, a fuller explanation of quality presentations is possible. For audition, the acoustic frequency distribution presentation is a mixture of memory neuron activations by a combination of variations in the same spike train patterns at different intensities. For the other quality perceptions, a presentation is a mixture of memory neuron activations by different spike train patterns having different intensities. The multi-tuned neurons farther up the perceiving structure are effectively randomly tuned and less powerfully activated, thus contributing little if anything to the resulting presentations.

Linear Link Cluster Configurations

Perceiving structures have the one-dimensional link cluster configuration are tabulated in the following taxonomy.

	one-dimensional link cluster configuration	
>	hierarchical (directional) chain	
	non-directional link cluster configuration	
>	scope – separate link clusters	gustation, olfaction
	spectrum – non-directional chain	
>	circular spectrum – non-directional chain without ends	hue
	non-circular spectrum	
>	radial spectrum – non-directional chain with one end	chroma
>	fully bound spectrum – non-directional chain with 2 ends	lightness, acoustic frequency, angular direction to a sound

The notion of directionality in a chain, whether in a perceiving structure or elsewhere, is based on the *extendability* applies to a two-ended chain where one of the two ends is extendable. Its *directionality* is from the unextendable end to the extendable end. Extendability in one direction is found in hierarchy chains because there can be ever higher intensities but is unextendable below its threshold of detection where there is an absence of the perception itself.

A spectrum (chain) has no directionality, and is either un-extendable or extendable in both directions. It is not extendable in one direction. Extendability in one direction is not found in a spectrum because: 1) neither end is extendable (e.g., lightness and chroma, i.e., linear and radial spectra, respectively); 2) there are no ends because it is circular; or 3) each end is extendable (e.g., acoustic frequencies, discussed in Part 2). Acoustic frequency is a quality but is mistakenly regarded as directional because Hertz (cycles/sec) can be zero. However, zero Hertz (cycles/sec) identifies the absence of a signal, i.e., no cycles; a "count/sec" as no lower or upper limit.

Observations

Although perceiving structures are described and illustrated as separate, they abut and may slightly overlap at their edges. They are clearly separated at the bottom by their detector-tuned structures whose neurons are tuned by sameness. But farther up the cortex, tuning by togetherness can cause signals from different sense organs to be tuned. Perceiving structures are well separated if the discrete activations are separated. Routine simultaneous discrete activations by different sense organs can create perceptions that involve both. This may be the cause of some forms of synesthesia

A mutation in a detector neuron in a sense organ can result in the ability of that sense organ to response to an additional type or different range of stimuli. If that mutation also alters its spike train pattern and the signal activates the same memory neurons as the other signals from that sense organ, the subject perception is different: the presentation is richer and the perceiving structure is more complex. The independence of the brain means that such a mutation does not need to be accompanied by a change in the brain in order to respond to signals with a different signal pattern. The ability to enhance a perception by detector neuron mutations alone is evidenced by the variety of vision, gustation and olfaction detector neurons found in different animals without having corresponding differences in the brain. It is further evidenced by tetrachromacy, an uncommon mutation found in women where mutated blue photopic detector neurons produce a fourth kind of cone that, presumably, significantly enhances the ability to distinguish among blue hues and forms a forth color spectrum.

As noted in Chapter 1, the spike train pattern differences are likely small for detector neurons in the same sense organ that evolved by mutations compared to detector neurons that arose independently such as for gustation and olfaction. This suggests that the signal train patterns for photopic vision and cutaneous perception are only slightly different, meaning that their ability to tune neurons by togetherness is greater than for gustation and olfaction. This greater spike train pattern simplicity corresponds to the much greater intensity ranges for the former two perception types than the latter two.

Simply having created perceiving structures does not result in comprehension: we must pay attention to them. The next Chapter describes how a mind responds to what is presented by discrete structures that become involved within perceiving structures, particularly those that are frequently looked at or listened to.

Chapter 4
Attending to Perception Presentations and Creating Memories

Having described the creation of perceiving structures and how their activations are presented to the mind, I now discuss the mind as it attends to those presentations, the structures that arise from that attending, and the linkages that are created.

Introduction

With the development of a brain and the ability to present perceptions and store what was perceived, some creatures later developed the ability to attend to presentations of interest: to *look at* and *listen to* presentations rather than simply to *see* and *hear* them because it created discrete structures. In so doing, they are better presented and otherwise non-discrete structures become discrete, both useful for survival. The ability to attend did not replace that more primitive ability. As discussed here, the ability to attend is in addition to the ability to perceive discussed previously.

We are aware of what is being presented when we *look at*, *listen to* what we see or hear; or when we notice what we are *tasting*, *smelling* or *feeling*. We are only aware of a presentation when we <u>attend</u> (or pay attention) to all or some portion of it; otherwise, we are unaware of it. Each such occurrence is an <u>attendance</u> (to a presentation). A*ttending* may be described as "paying attention to" *perception presentations* as needed to comprehend what there is and what is happening in the perceived world and to oneself. (As discussed later, *remembering* may be described as recalling a memory presentation.)

We begin to attend to our perception presentations immediately after detector neurons begin generating signals that cause activations that cascade up the perceiving structure. When those activations cease, the presentation disappears, often be replaced by another. Attending to perception presentations are not just one way to experience the world; it is the only way.

I organized this Chapter as follows:
        Section 1: Directing, Enhancing and Attending to Perception Presentations
        Section 2: Further Activation of Attended Discrete Structures
        Section 3: Externally Linked Attended Discrete Structures
        Section 4: Summary of Chapter 4

Unless otherwise indicated, the remainder of this Chapter is about attending to *perception presentation*; attending to its counterpart, *memory presentations*, is discussed in Chapter 5.

Section 1
Directing, Enhancing and Attending to Perception Presentations

We are continually receiving stimuli from the world around us and generating perception presentations that create presentations for each perception type. The mind would be overwhelmed if it had to attend to more than one at a time and it could not ignore all of them. We can presume that the mind evolved to attend to only what might be relevant: initially in reaction to what was presented and later more thoughtfully to what was of interest so that we can comprehend the perceived world.

The following provides clues to our ability to attend to *perception* presentations that are addressed in this Chapter.
- We can attend (pay attention) to only one presentation at a time.
- Until it is attended to, we are not conscious of presentations that are available to be attended to.
- We can ignore all presentations when awake and we are unaware of them when asleep.
- We can only attend to one portion of a visual or auditory presentation.
- Changing what is attended to is seemingly immediate.
- An attendance to a presentation can last from a fraction of a second too about a minute (with effort).
- What we attend to is sometimes under our control and sometimes not, i.e., some presentations demand our attention and we automatically attend to them.
- We may try to enhance the clarity of a presentation by moving our body to its source.
- Only the presentations that are attend to can be comprehended and remembered.

Most of what is described above is the result of the three the processes listed and defined below in their sequence of occurrence. Their applicability to different perception types is discussed in this Chapter.

Directing – the process that finds a normally active discrete structure unconsciously presenting a *perception* presentation that is *of interest* and then initiates the following process. (The term: *directing* is from the phrase: "I direct your attention to...".)

Attending – the automatic process that seemingly enhances the found discrete structure's *perception presentation of interest* causing the mind to become aware of it while ignoring all other (perception or memory) presentations; and

Enhancing – a perception type-specific process that may increase the intensity or fidelity of a *perception presentation of interest* then being attended to, specifically:
- Improving lighting or hearing ability;
- Moving the source of presentation, moving closer to it or aligning the body with it;
- Increase intake to improve gustation or olfaction;
- Cupping the ears to improve audition; and
- Enhancing vision (as discussed in Subsection 2).

(Directing and attending apply as well to *recalling* as discussed in the next Chapter).

Subsection 1
Directing and Attending in General

Very early in life, there are only automatic directing and attending with little remembrance of things past and the mind lives entirely in the present. Later when enough of what was perceived is able to be stored, a mind begins to intuitively direct attention of what was presented before, thereby enabling "object permanence". Still later when more is stored a mind begins to intuitively direct attention to surprising presentation, e.g., a tap in the back. Thoughtful directing begins last.

The following discusses directing and attending to *perception presentations*.

Directing to a Perception Presentation of Interest

A mind is not aware of a presentation of a discrete or non-discrete activation until the mind is directed to attend to it as a result of it becoming a *presentation of interest*. For a vision, audition or cutaneous perception, what is of interest and attended to is a portion of the entire presentation; for olfaction, gustation and muscle strain, it is the entire presentation. A vision or cutaneous presentation areas attended to is within some distinct or fuzzy lineal boundary having some shape, e.g., a written letter, a person, a cloud or a touch each having a shape. For audition, it is a bounded range of acoustic frequencies. In neither case is a boundary itself attended to.

The following taxonomy identifies and describes the *directing process* types along with the different features of a presentation that cause directing. (As noted parenthetically below, these types have also been identified by others as included in attending [http://en.wikipedia.org/wiki/Attention; October 24, 2014].) All attending is regarded as the same regardless of what type of directing caused it.)

reactive directing – the process that identifies and causes a presentation to be attended to. Reactive directing is involuntary, driven by a presentation that "calls attention to itself". (Referred to by others as *bottom-up processing, stimulus-driven attention or exogenous attention*). Reactive directing is either:

Automatic (reactive) directing – (System 0) directing behavior that is an inborn response to a threat because it "stands out from the background", i.e., it is a new *discrete structure*, defined earlier as a structure that stands out from the background. (This ability may be due to signals that are processed in the extrastriate areas of the cortex that find unconscious previously attended discrete presentation before those signals arrive at the detector neurons.) Examples of automatic directing include:
- a high intensity presentation including pain or a significant change in intensity.
- a repulsive taste or odor;
- a noticeable touch; and
- rapid visual movement or a flash of light;

Intuitive (reactive) directing – (System 1) directing that is in response to a learned threat or opportunity, or to what is of some other interest. The mechanism for intuitive directing is presumed to be due to being similar to or retuning a *discrete structure* having that activation pattern . Examples include:
- a sound, especially a person speaking;

- • a visual presentation of a physical thing that is increasing in size possibly causing a collision; and
- • a visual presentation of a shape or a physical thing that is or could move; or

<u>thoughtful directing</u> – (System 2) directing to what a mind chooses what to attend to. (Referred to by others as *top-down processing, goal-driven, endogenous attention, attentional control or executive attention*). Examples are people watching and attending to a single voice in within a frequency spectrum among other voices. Other interests include what is being presented by a particular muscle, cutaneous perception, gustation or olfaction.

Directing can initiate behavior that seeks to identify the source of a perception by moving the body to see the source of a sound, a smell or a cutaneous presentation. This process is: automatic, e.g., when hearing a voice behind one's back; intuitive, e.g., when the presentation is of importance; or thoughtful, e.g., curiosity.

Attending to a Presentation

Attending to a presentation is an automatic (System 0) process initiated by directing. A presentation *being attended to* is an <u>attendant presentation</u>; afterwards it is an <u>attended presentation</u>.

A mind can attend to only one presentation at a time, but can quickly direct attention to another presentation of the same or different perception type. A presentation can be ignored by thoughtfully directing attention elsewhere. When we are ignoring all presentations, our mind is "elsewhere".

Attending begins when directing has identified a presentation of interest, and ends when 1) directing "turns attention" to another presentation or one's thoughts, or 2) all attention to perception presentations ceases when falling asleep. Except for vision, the time from the beginning of directing to the beginning of attending is below what a mind can detect. Vision requires additional processes (vergence and focusing) whose duration is detectable.

A mind attends to one portion of a visual or audition presentation at a time and remains unaware of the unattended surrounding portions. Visual attendings often proceed sequentially from one portion to another; auditory attendings are nearly always sequential in response to changes within an acoustic frequency range.

Thoughtful directing can only occur when initiated by an awake mind that decides to "look at what is happening". While awake, a mind can intentionally arrest intuitive directing in order to relax or to be "lost in one's thoughts". A mind passes through this state when going to sleep and awakening. Whether wake or asleep, a mind cannot arrest automatic directing.

For gustation, olfaction, and muscle strain, an activation pattern is uniform across the entirety of the presentation, attended or not; for a cutaneous perception it is uniform across the attended portion of the presentation; and for vision and audition it is rarely uniform across the attended portion of the presentation.

The terms: *perceiving* and *attending* distinguishes between what occurs to generate a presentation and being aware of what is presented. This distinction is reflected in the verbal forms used to identify perception types as tabulated below along with the nouns for presentations listed earlier. The verbs for vision and audition perceiving and attending have verbal forms that are not gerunds of the noun for its presentation because, unlike the others, we are continually aware of the presence of vision and sound presentation and attending a portion of it. The two prepositions for visual or auditory attending serve to recognize that the source of the presentations is outside the body.

perception type	perceiving	presentation	attending
vision	'seeing'	'sight'	looking (at)
audition	'hearing'	'sound'	listening (to)
gustation	'tasting'	'taste'	tasting
olfaction	'smelling'	'smell'	smelling
cutaneous perception	'feeling'	[various]	feeling
muscle strain	–	'heaviness'	feeling

Subsection 2
Vision Enhancing Processes

Visual attending involves several mechanical enhancing processes, discussed below, that occur prior to, during and following attendance. These process serve to improve visual fidelity of presentations of interest and the portions of the surrounding presentation.

Unlike other sense organs, the density of detector neurons in the eyes varies significantly across the retina. This is illustrated below for the variation in the density of rods and cones with the angle away from the center of the retina's fovea where the density of cones is the highest. The cone density is at a maximum in the center of the fovea; there are no rods in the fovea's center but density is high surrounding it. The blind spot is where the optic nerves leave the in the retina.
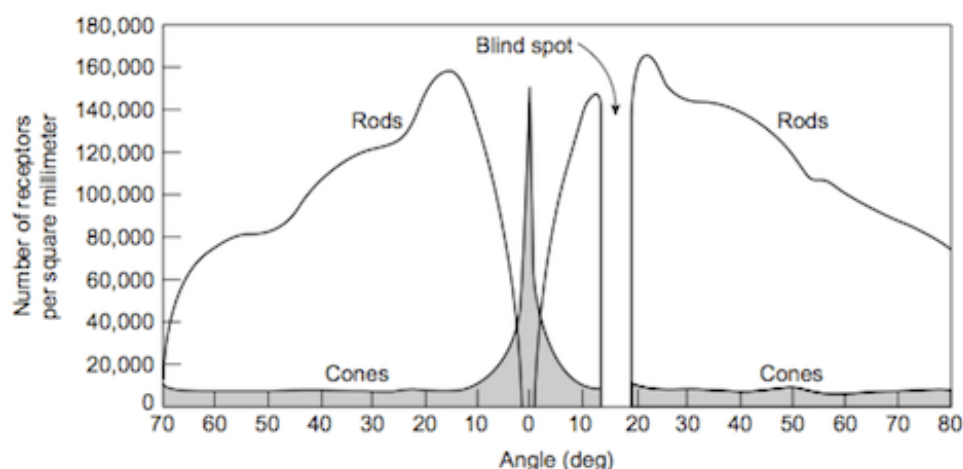
Distribution of Cones and Rods in a Typical Human Retina (Lindsay and Norman)

Lindsay, Peter H., and Donald A. Norman. Human Information Processing. New York: Academic Press, 1972. found at:

Photopic visual clarity is greatest in the center of the fovea where cone density is the highest, decreasing rapidly away from that center. The area of the fovea extends is about 10°each way from the center, about the width of this paragraph when being read; the area of the fovea with the greatest density of detector neurons is about the size of the period at the end of this sentence. At about 5° away the density is about an order of magnitude below the maximum.

For non-vision perceptions, directing causes nearly immediate attending to a presentation or a portion of an audition or cutaneous presentation. For vision, directing initiates mechanical processes that adjust to provide maximum visual acuity prior to and during the onset of attending. These two processes are described below.

Aiming and Fixating. Directing having identified a vision presentation portion that is of interest, the eyes are aimed so that light from the presentation of interest arrives at the fovea, i.e., in the direct line of sight. If the eyes rotate more than about 1° degree, the presentation can change significantly possibly causing directing within that areal portion. Thus, aiming consists of:
• 	coarse aiming – aiming to somewhere within the areal portion identified by directing; and
• 	fine aiming – after course aiming or while attending to a presentation, directing to and then fixating to a point within the areal portion.
Once fixated, attendance begins.

Verging and Accommodating. At the start of attending, the eyes adjust to improve acuity at the center of the presentation by:
• 	*verging* – rotating to a convergence angle where the centers of each fovea both aligned with the center of the presentation eliminating blurriness due to parallax and providing stereoscopic vision to judge the distance to what is presented; and
• 	*accommodating* – adjusting each lens' shape so that the center of the presentation is "in focus" at its fovea.
These processes are noticeable as a presentation "comes into focus" when the source of the light is much nearer or farther away from the eyes than that of the previous attendant presentation. At the beginning of an infant's ability to see, its mind learns how to move the muscles in each eye to quickly improve acuity. It also learns the correlation between the convergence angle and distance to the source.

With effort, visual attention can remain fixed at the same spot. Without effort and if attention is not directed to a different presentation, the eyes automatically move within ±2° away from the initial line of sight to a different portion of the attendant presentation. This movement is referred to as a *saccade*, each one lasts 0.02 seconds. A saccade is too fast for verging and accommodating to be useful but is usually not relevant because the portions attended to by saccading are within the fovea and at the same distance away.

The presumption here is that the attended presentation creates one discrete structure even with saccading. What is stored is the shape of the vision presentation, i.e., a discrete structure having areal link clusters that reflect what is within a crisp or fuzzy lineal boundary. What is "of interest" and what directing directs to is a shape, not a shape's boundary. This applies to cutaneous

presentations as well. Attention can be directed to a drawn line only because it has a distinct lineal boundary on each side.

Section 2
Further Activation of Attended Discrete Structures

A discrete activation that reactivates a discrete structure *explains* our ability to immediately recognize a presentation (as discussed further in Chapter 5). Frequent reactivation *explains* how a discrete structure is not lost amid the ongoing signal activity in its perceiving structure. What is *not explained* is how a discrete structure that has not been reactivated for many years can continue to be stored and recalled, particularly for a vision or audition discrete structures where signal activity is ongoing for most of the day.

Directing to a presentation causes the active memory neurons that are presenting it to receive additional activation signal energy that increases the power of the received signals during that attendance. Each neuron receives the same amount of additional energy irrespective of the power of the signals that initially activated the neurons.

By attending to the presentation of a non-discrete activation or a continuously varying activation, the presentation's normally activated memory neurons are further activated long enough to prevent them from immediately becoming inactive. That momentarily "preserved" activation enabling it to create a discrete structure. In effect, this behavior "discretizes" non-discrete and continuously varying activations, most commonly vision and audition activations.

By attending to a presentation of a normally discrete activation (for any perception type), its further activated memory neurons generate more powerful signals. Those signals cause activation that cascade farther up the cortex than would otherwise occur, creating a "taller" discrete structure. Like the neurons below it, the neurons tuned by further activation reflect the activation pattern stored by the receptor-tuned neurons that presentation but with less fidelity.

A discrete structure whose presentation was attended to and thus further activated is referred to as an <u>attended (discrete) structure</u>; its counterpart is an <u>un-attended (discrete or non-discrete) structure</u>, i.e., created by normal activation alone. Attended or not, these structures are involved in their perceiving structure.

Further activation has the following effects on perception.
- It "discretizes" non-discrete activations, i.e., fast moving physical things and fast speech, allowing them to be recognized.
- It extends tuning farther up the perceiving structure where the discrete structures' upper segments are in a less active signal environment and their stored signal patterns are less likely to be lost.
- Its more powerful signals make presentations more vivid and easier to separate from unattended presentations , which are particularly noticeable when we attend to a single person's voice amid other voices.

73

The longer the duration of attention/further activation, the more neurons will be tuned until the power of the further activation is exhausted. Staring at an attended vision presentation is sure to exhaust further activation. The length of the primary notes in a musical composition must be sufficiently long to create a discrete structure that is sufficiently far up the cortex to be resistant to being lost.

Example of the Creation of an Attended Discrete Structure

The following diagram illustrates what happens during further activation and the attended discrete structure it creates. The diagram displays the upper segment of a very simple perceiving structure depicting neurons that are inactive (unshaded), normally activated (lightly shaded) and further activated (dark shading); those with diagonal lines are newly tuned by signals from further activation, i.e., were added to the top of discrete structure after it was attended to. Note that neurons tuned by further activation, being newly tuned, are possibly tuned by more than two neurons, particularly the uppermost neurons where tuning is by togetherness is at low power.
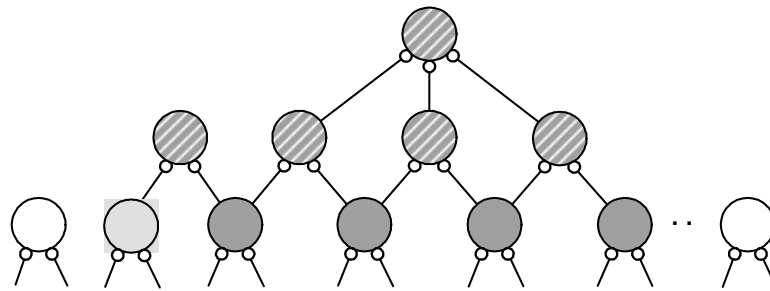
Figure PRES_1
Attended Discrete Structure Example

Section 3
Externally Linked Attended Discrete Structures

Two discrete structures that are partially active at the same time create linkages that each *link* neurons in those two structures. (How both are simultaneously active is discussed in Chapter 5.) Those links form a linkage called an external linkage made up of external links. The links and linkages discussed earlier were those that linked neurons *within* a structure (as defined in this work). They are now referred to as an internal link and an internal linkage. An external linkage is a external similarity linkage if its creating activation patterns were the same or very similar (discussed in the next Part), and is an external togetherness linkage if its creating activation patterns were different. An external link or linkage is depicted the same as those that are internal, i.e., using a small open or solid circle to indicate togetherness or similarity; it being internal or external is evident by what are linked. The external linkages discussed in the remainder of this Part are external *togetherness* linkages, one type of which is a *binding linkage*, discussed earlier. External *similarity* linkages are discussed in Part 2.

Like a discrete structure neuron, as external link neuron becomes less inhibiting or differently tuned, it is lost or more likely to be lost. As neurons in an external linkage are lost, it becomes it is less robust as duplication decreases and when all are differently tuned, the linkage is *lost*. Those external links that are not lost are those that are frequently retuned or replicated. In addition, as one or both of the externally linked discrete structure(s) degrade, the linkage between them also degrades; when one or both structures are *lost*, their linkage is *lost*. An external link between partially degraded or lost discrete structure(s) in the same perceiving structure may become another meaningless link within its perceiving structure.

Although external links can be created between discrete structures without both being attended to and further activated, those that are further activated are much more likely to be "meaningful" as well less likely to be soon lost. Those links that were not attended to when they were created are ignored because they appear to be irrelevant.

The discussion below first describes external link creation followed by two subsections that describe the important cases for those linkages.

Creating External Togetherness Linkages

An external linkage is created when are two discrete structures at both partially active at the same time as they are sequentially attended to.   While one structure's neurons are in the process of becoming activated by activations cascading up the cortex, the other structure's neurons are becoming deactivated by deactivations cascading up the cortex.

An external linkage is "meaningful" or coincidental. Examples of the former are for discrete structures for the taste and smell of a food, or for the sight and sound of a bird. Most coincidental external linkages are random, e.g., a sound and a smell. An example of an intentional (non-random) coincidental linkage is attributing the sound made by a ventriloquist to its dummy. Most coincidental linkages are lost because they are not repeated. The creation of "meaningless" external linkages is ignored in subsequent discussion and examples.

The example below applies the display convention used in the previous diagram to display two sequentially attended discrete structures with their lower and upper segments active or inactive as described above. The attendance sequence is from left to right.
- The discrete structure on the left depicts the neurons that are at that moment active and those below them that just became inactive by cascading deactivation.
- The discrete structure on the right depicts the neurons are just became active by cascading activation and those above it depicted by dashed lines have yet to become activated.
- External links between neurons the two different structures are depicted the same as an internal togetherness link but with a kinked line. (Graphical limitations prevent displaying external links among neurons within the structures.)
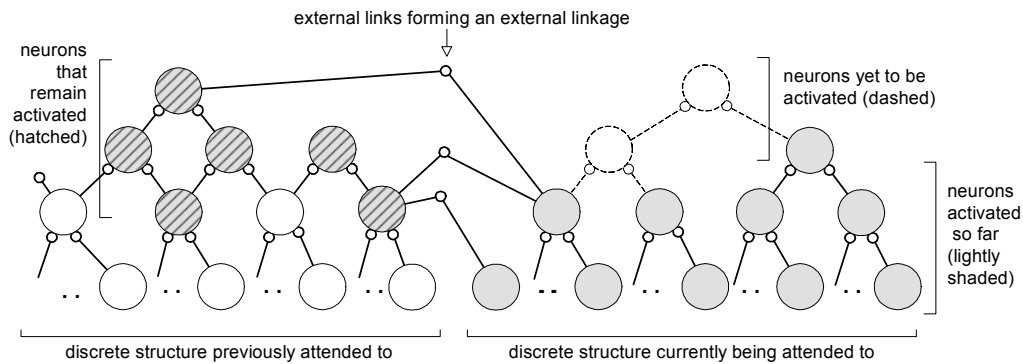
Figure PRES_3
Linked Pair of Sequentially Attended Discrete Structures and their External Linkages

Note the following about activations.
*   In the preceding structure, *cascading deactivation* is proceeding from the bottom to the top so that those neurons in the lower segment of the structure are no longer active but those in the upper segment remain activated and able to find neurons to tune.
*   In the succeeding structure, *cascading activation* is proceeding from the bottom to the top so that those neurons in the lower segment of the structure are activated but those farther up have yet to be activated or tuned.

Note that by having one or more linkage, an attended discrete structure has fewer neurons involved in that structure because some tunings create linkages.

As suggested in the above diagram, external links created by sequentially attended discrete structures tend to be neurons in the upper segment of the preceding discrete structure and the lower segment of the succeeding structure, i.e., they tend to be angled downward in the direction of attendance. That angular tendency stores the directionality of the activation sequence. The longer the duration between of successive attendances, the steeper the average "downward angle" of these links.

Note that movement along the skin does not create a sequence of discrete attendances. Rather it is a single *indiscrete* structure that has subsequent tuned neurons added to it as it moves.

There are three types of external linkages described below based on what types of discrete structures that are attended to.

|	
two different perception types	short duration but direction is *irrelevant*
vision separated by a saccade	short duration and directional
audition between two sequential sounds	long duration and directional

Directionality is irrelevant where shown above because a link between two different perception types conveys no useful comprehension.

A duration between sequential attendances is either:
*   <u>short</u> when it is constrained only by how fast the mind moves an attendance to the next presentation, including a saccading, resulting in an external linkage having a flat downward angle; or

-     <u>long</u> when attendance has to wait for the next audition presentation to arrive, resulting in its external linkage having a steep downward angle,

Simplifications that display external togetherness linkages in a way that also conveys the differences in downward angles described above are displayed below. A triangle is used to depict a discrete structure. Although that symbol's top is a point, the top of a discrete structure is more likely to be somewhat flat or irregular. Being an external linkage is indicated by it linking two discrete structures; being an external togetherness linkage is indicated by the open circle. The "angular tendency" and its directionality is identified by arrow(s) on a linkage. The absence of an arrow indicates irrelevance of directionality; one arrow indicates weak directionality; and two arrows indicate strong directionality.
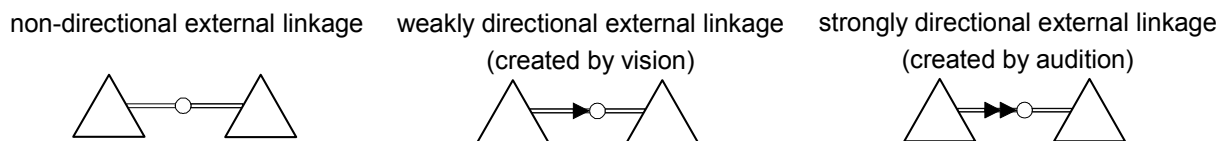
Figure
Simplified Depictions of Externally Linked Discrete Structures

Attended discrete structures having an external linkage are those that were attended to because their presentations were of immediate interest and were created by different activation patterns. Being further attended to, there are more links making the linkage more robust. In addition, they are likely to be of interest later when one of the attended discrete structures recalled by the other and are retuned and less likely to be lost. (Recalling sequence chains is discussed in the next Chapter). These linked attended discrete structures are either:

The following two subsections describe the important circumstances where these external linkages are created.

Subsection 1
Sequence Chains

Two or more externally linked discrete structures of the same perception type (vision or audition) can be sequently linked to form a chain of any length. Such a chain is called a <u>sequence chain</u> and is created automatically while attending to the same perception type. An individual external linkage (or a link) in a sequence chain is a <u>sequence linkage</u> (or <u>sequence link</u>). There are nearly always more than two attended discrete structures linked in succession. As described below, an audition sequence chain is how we are able to store sounds, primarily words, music and the "sound" of a person's voice.

The more relevant cases where chains are created are discussed below. Although not addressed here, motor control for body movements may also use sequence chains. The sequences of linked attended discrete structures are described here without example diagrams. Where diagrams are useful, they are presented in Part 2 where that case is discussed further. The first cases are for non-circular chains for audition followed by cases for vision: a process and several cases for

movement. Audition non-circular sequence chains store what is referred to elsewhere as *auto-associative memory*. These chains are briefly discussed last.

Non-circular Audition Sequence Chain

An audition sequence chain can be created when listening to a non-repeating sequence of attended (discrete) sounds, i.e., an <u>audition non-circular sequence chain</u>. This is how a continuous varying sound is stored. The most obvious examples are words, word phrases, music and natural sounds, e.g., the song of a bird. How the characteristics of a sound are stored by an audition non-circular sequence chain is as follows.

> Frequency Distribution. A separated audition discrete structure stores at least some of an acoustic frequency distribution, but without storing what those frequencies were. However, two sequentially active discrete structures for a sound sequence that can be recalled share neurons where at least some frequencies that are the same. Since each frequency distribution includes a dominant frequency, the *relative difference* between the dominant frequencies is stored, including no difference. This is evident by the fact that when we bring a song to mind, we must begin with an arbitrary pitch for the dominant frequency and then recall the following notes with the stored difference in that frequency.

> Duration of a Discrete Sound Activation. The duration of a discrete sound activation is stored by the height of the discrete structure: the bigger the structure the longer it took to create it and the more time required for it to be recalled as discuss in the next Chapter.

> Duration between Discrete Sound Activations. The duration between two discrete sound activations is stored by the amount of the downward angle of the linkage as discussed earlier: the greater the angle, the longer the duration before the next structure can begin to be recalled as discuss in the next Chapter.

Vocalizations. A spoken word or phrase is a sequence of one or more *attended phonemes* without their loudness. (A phoneme is commonly defined as the smallest contrastive linguistic unit which may bring about a change of meaning.) A speaker may add a meaningless sound between other words to avoid long gaps as a chain is forming.

Mechanical Sounds. A mechanical sound, including music, is a sequence of discrete sound activations, also without their loudness and their frequency range. Not having a frequency range is evident by our inability to recall a particular frequency.

Natural Sounds. A natural sound is any sound other than those above. It includes bird songs, thunder, the wind and a physical thing falling.

Vision Sequence Chains

Unlike audition sequence chains, each discrete structure in a vision sequence chain is controlled by what presentation is if interest among many others. For a moving physical thing, there is no consistency in the sequence of attendances to different parts of the same or same kind of physical

thing. For a relatively static physical thing, e.g., a particular face, chair or tree, the sequence of attendances to its different parts may be consistent from one attendance to another because those parts have a decreasing order of interest. This behavior is suggested by our ability to recall a particular person's face from a caricature, i.e., a distorted depiction that emphasizes features that would be of most interest, as well as other visual abstractions of both a particular physical thing, e.g., the Statue of Liberty, and kind of physical thing, e.g., a cat. In addition, this suggests that we recall a seen physical thing by a few unique features rather than its entirety. Although not discussed further here, a vision sequence chain may include one or more discrete structures created by a presentation for the same source of stimuli, thus intersecting itself.

Fast Physical Process Vision Sequence Chain. A vision (non-circular) sequence chain can be created by a source of vision stimuli that is undergoing a process fast enough to be of interest. A process is presented as a sequence of changes in shape, size or color(s) within the same volumetric boundary, e.g., flowing water, blowing up a balloon and a chameleon changing its colors. (Moving is not a process: what *causes* a change in the rate of movement is a process.) Most vision processes are too slow to create a sequence chain. Non-vision processes that change a quality, i.e., change in taste or smell, do not change fast enough to create a chain. (Structures for both fast and slow processes are discussed in Part 2 discussing temporal existence.)

Lineally Ordered Vision Sequence Chain. A vision sequence chain can be created by a static lineally arrayed source of vision stimuli with distinguishable shapes that are adjacent, e.g., reading text, presumably in the order it was written.

Areal (Un-ordered) Vision Sequence Chain. A vision sequence chain can be created by a static source of areally arrayed vision stimuli with distinguishable shapes that are adjacent to or include each other. While creating that chain, there can be a change in the vergence angle and focus between two attendances, i.e., when attending crosses the border between two shapes. The greater the change in the vergence angle and focus, the greater the duration of the delay between the creation of the two discrete structures and the greater the (stored) downward angle of the linkages between those two structures. The change or lack of change in the convergence angle and focus is due to the characteristics of the source of the stimuli as described below. The change in a convergence angle and the change in focus enable those characteristics to be distinguished and to be used by the directing process. (The downward angle may provide a way to identify those characteristics when the sequence chain is recalled.) Described below are the source characteristics when a change in convergence angle and focus when looking at two or more different presented shapes that are adjacent to or where one includes the another.
• 	No change, i.e., the presentations face the eyes – a physical thing having portions;
• 	Gradual uniform change – a plane surface having an orientation to the body's axis (e.g., the ground or wall);
• 	Different gradual uniform changes – a physical thing with differently oriented (adjacent) surfaces (e.g., sides and top) or different physical things that are adjacent (e.g., a chair on the floor);
• 	Multiple small changes – a physical thing as a whole having parts (e.g., a chair or a tree);
• 	Large change – One physical thing behind another; and
• 	Convergence angle changes to $0°$ – a physical thing against a background.

Body-in-motion Vision Sequence Chain. A vision sequence chain can be created by attending to one's surroundings while in motion, e.g., walking, to avoid obstacles or when searching for a particular physical thing.

Dynamic sources, sources that move fast enough to be visually noticed and are of continuing interest and can create a chain. Each case is for a different way a source can move.

Tracked Movement Sequence Chain. A vision sequence chain can be created by a physical thing as it moves against a static background slow enough so that the eyes, and possibly the head and body, move so that there is a sequence of attendances with vision remaining focused on what the presentation. For example, watching a person as they walk or run. The following movements *do not* create a sequence chain, only a single attended discrete structure.

>   **Blur**. A moving presentation with successive attendances with directing and without tracking by (e.g., a buzzing fly). The time needed for directing is too long to create a chain.
>   **Streak or Flash**. A presentation that is moving too fast for more than a single attendance because vergence and enhancement are not possible (e.g., lightning, a trail of light from the glowing ember being waved in the air, and a ball thrown close to the face).

When a moving presentation begins to move or comes to rest, it is then adjacent to other presentations which were previously are subsequently attended to where the sequence of linked attended presenting structures for that source both without and with a linkage to other structures. Respective examples are harvesting fruit and a physical thing hitting the floor.

Forward or Backward Movement Sequence Chain. A vision sequence chain can be created by a source of stimuli moves directly toward or away from the viewer (parallel with the line of vision) with increasing or decreasing size.

Articulated Movement Sequence Chain. A vision sequence chain can be created by articulated movement, i.e., movement around a point of rotation, e.g., the limb of a creature, a moving leaf on a tree or a page in a book. A mind is first directed to any movement and then to what the moving presentation is adjacent to. Directing alternates between the two adjacent presentations creating a sequence chain involving discrete structures for what is moving and what is not. Where they are adjacent may be comprehended as a joint. (This is discussed further in the Part 2 discussion of adjacency.)

Fluctuating, Oscillating or Rotating Movement Sequence Chain. A vision sequence chain can be created by the source of the stimuli fluctuates, oscillates or rotates, i.e., repeating non-linear movement, e.g., a flame in a wood fire and lips when speaking, create a sequence of linked attended presentations will include some that are the same, either erratically or routinely.

Audition Circular Sequence Chains

An audition circular sequence chain can be created when a sequence of about four sounds is repeated without a pause. Such chains are likely how we are able to store echoic memories, memories of short audition sequences that are quickly forgotten because they have no linkage with the beginning of the sequence. Those short audition sequence chains are created by thoughtfully

and repeatedly saying to oneself the same sequence of sounds. An audition circular sequence chain can also be created to remember visually recognizable symbols or shapes that have signifiers that can be immediately recalled, e.g., parts of a phone number or geometric shapes. An audition or vision sequence longer that about four can be parted by chunking to create multiple chains. This behavior appears to be what has been identified as working memory,

Summary of Sequence Chains

Sequence chains are summarized below as a taxonomy.
    audition circular sequence chain
    non-circular sequence chain
>   audition non-circular sequence chain
      vision (non-circular) sequence chain
>   physical process vision sequence chain
        <u>non-process</u>
            <u>static</u>
>   lineally ordered vision sequence chain
>   areal (un-ordered) vision sequence chain
            <u>dynamic</u>
>   body-in-motion vision sequence chain
            <u>watched movement</u>
                linear movement
>   tracked movement sequence chain
>   forward or backward movement sequence chain
                <u>non-linear movement</u>
>   articulated movement sequence chain
>   fluctuating, oscillating or rotating movement sequence chain

Specious Present. Each attendance to a vision presentation while creating a sequence chain lasts for some minimum increment of time. That sequence of presentations gives rise to the sense of the moment by moment passage of time. Each such *moment in time* is referred elsewhere as the *specious present* as lasting about 0.2 seconds, what the mind regards as the instantaneous *Now*. (cf. Stanford Encyclopedia of Philosophy: The Experience and Perception of Time; June 19, 2012 http://plato.stanford.edu/archives/win2004/entries/time-experience/). This momentarily fixed presentation is what is referred to elsewhere as sensory memory, reported to persist for several milliseconds.

Subsection 2
Binding Linkages Between Attended Discrete Structures

When two presentations are attended to one after the other for either: 1) different types of perceptions, or 2) non-sequential for vision or audition, those attendances create a *binding linkage* between them. The linkages' directionality is effectively meaningless because the presentations are usually simultaneous with quick back-and-forth attendances that create binding linkages with flat downward angles in both directions. Binding linkages are also created between among different discrete structures in the same one or two sequence chains, especially when a signifier is being vocalized. (Since *binding linkages* extend farther across the cortex than *internal linkages* or *sequence linkages*, binding linkages may be in the hippocampus. The hippocampus has been

found to connect the two hemispheres of the brain and to support forms of memory that require such distances. For simplicity here, binding linkages are regarded and depicted the same as other external linkages.)

The binding linkages that are most readily apparent are those between attended discrete structures. Such a linkage is usefully identified as an <u>attribution linkage</u> linking discrete structures for a non-vision perception and a vision perception of its source, e.g., the smell to what is looked at; and a <u>signification linkage</u> linking discrete structures for any perception type and one of its signifiers. A <u>correlation linkage</u> is one of the binding linkages introduced earlier between different types of perceiving structures. As demonstrated in Part 2, *attribution linkages* are how we comprehend how the different perceptions come from the same source and *signification linkages* are how we are able to organize and recall all that we comprehend. These binding links are tabulated below with an example for each. Those binding linkages for different portions of the same presentation are noted with an asterisk. Binding linkages and what they link are also illustrated in the next Section.

Binding Linkage Types with Examples

binding linkage type	examples by source type		perception pairs	
attribution linkage	physical thing	flower	photopic vision	olfaction
		food being seen or being eaten, or both	photopic vision	gustation and olfaction
		physical thing seen in touch with the skin	photopic vision	surface tactition and one or both of the following: deep tactition and thermoception (conduction)
		lifting a physical thing, or an attempt to do so	photopic vision	muscle strain, i.e., heaviness
	process	person talking, bird singing, or rain falling	photopic vision	audition
		wood burning	photopic vision	audition and thermoception (radiation)
signification linkage	hearing the signifier for an image, taste, smell, touch, warmth or coldness, or heaviness		audition	photopic vision
				gustation
				olfaction
				cutaneous perception
				muscle strain
	hearing an animal sound and its onomatopoeic word		audition	audition
	seeing a symbol and the thing it represents		photopic vision	photopic vision
correlation linkage	food being seen while eating		gustation	olfaction
	different cutaneous perceptions, e.g., being touched by an ice cube; both forms of tactition		cutaneous perception	cutaneous perception
	touching or skin stretching by a strained muscle		tactition	muscle strain
	ongoing vision		photopic vision	scotopic vision
	angular direction to a sound		photopic vision	olivary

The diagram below displays each type of perceiving structures and their binding links as displayed earlier. Displayed above each perceiving structure are the discrete structures involved that perceiving structure. That multiplicity is indicated by a shadow and their perception types are identified by abbreviations introduced earlier displayed inside the triangle. Sequence linkages are displayed below the discrete structures. The binding linkages tabulated above are displayed as follows: correlation linkages are those between different perceiving structures; the remaining binding linkages are displayed above the discrete structures. The binding linkages displayed by a loop are the signification linkages between two different audition or vision discrete structures.
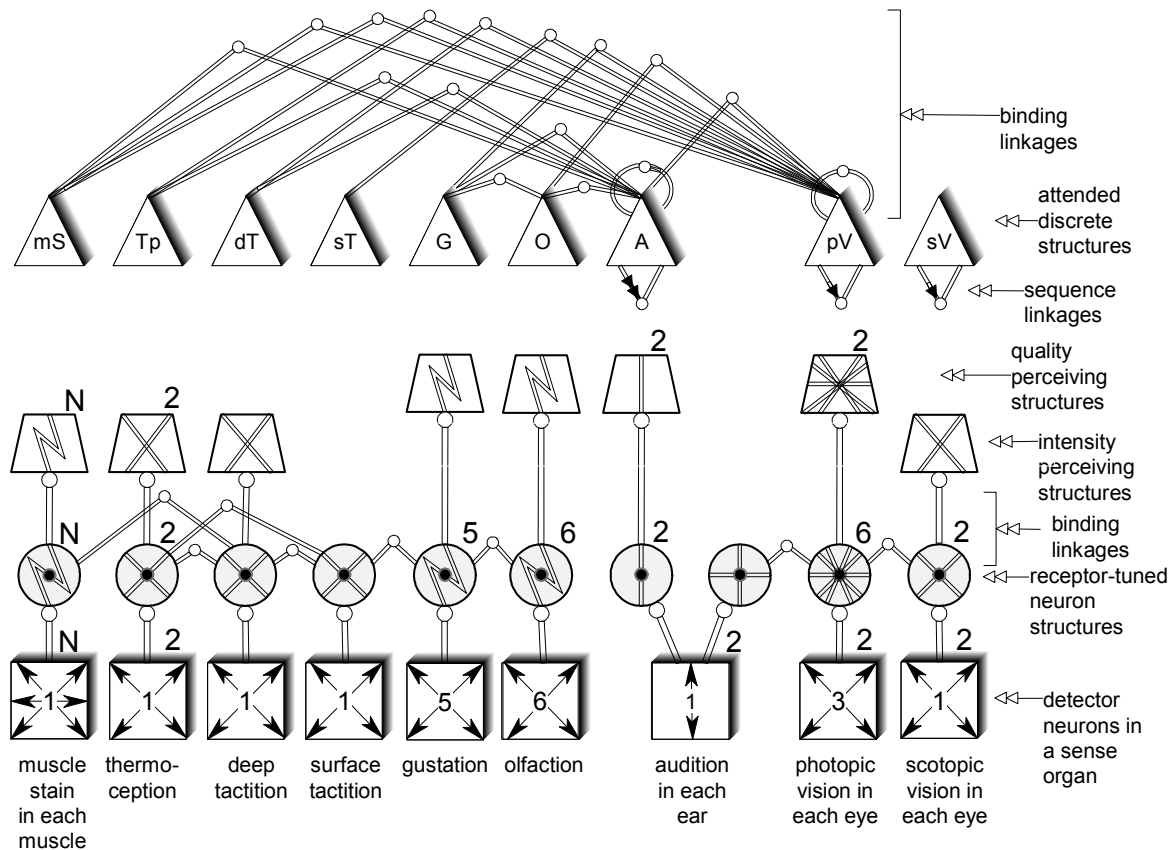
Figure_b2
Perceiving Structures with Linked Attended Discrete Structures

Note the differences in binding links between perceiving structures and discrete structures. Note that photopic vision and audition discrete structures have binding links with nearly all other perception types. Since scotopic vision makes a negligible contribution to comprehension, it is not discussed further in this work.

Chapter 5
Remembering and Forgetting

Introduction

Having discussed discrete structures that store what was presented and the external linkages between those structures, I now describe how they are able to be remembered, what is presented when remembering occurs and why they are forgotten. But first some definitions.

Given the preceding discussion, <u>memory</u> is defined as what is stored by discrete structures and their external linkages. *Remembering*, commonly described as "bringing to mind" what was presented before, is defined here by its two sub-types as follows.
> <u>remembering</u>
>> <u>recognizing</u> – activating at least some of the neurons in a discrete structure by signals received from detector neurons while attending to a perception presentation
>> <u>recalling</u> – activating some or all of the neurons in a discrete structure by signals received from a previously activated discrete structure that is external linked.

All or a segment of a sequence chain can be recognized or recalled. Note that *remembering* as used here does not also refer the process of storing what was presented.

<u>Forgetting</u> is defined as the inability to remember, i.e., to recognize or recall what was stored. We are able to notice when we are recognizing what is presented or recalling to find what is being presented by the immediacy of the former and the delay in the latter. As described here, remembering is two different methods of activating and presenting what is stored in the place where it is stored (unlike computer systems where it is copied and moved elsewhere).

Mechanics of Remembering

Before discussing the two remembering processes, consider the characteristics of storing and retrieving in general. We can observe that storing and retrieving what is stored are different processes: one that physically stores and the other that *attempts to* retrieve what is stored. In each electrical or mechanical mechanism used to manage information, the *storing* process is separate and independent of the *retrieval*. Two examples are: an area of a tape is magnetized to store each bit, but those magnetizations are separately detected; a read-only CD is mechanically pitted to store a bit, but those pits are detected by light. Biological "storing" of a duplicate copy of a DNA molecule is separate from how it is "read" to build proteins. Even reading and writing text are different processes. This suggests that this separation and independence is fundamental, possibly because they must be able to occur simultaneously and operate independently. We can understand *storing* as creating a discrete structure that stores a discrete activation pattern, and remembering as a separate and independent process that retrieves what was stored. Since remembering without first storing is impossible, storing must have evolved first.

I organized this Chapter as follows:

Section 1
Recognizing Discrete Structures in Perception Structures

Chapter 2 described how each discrete structure is "imprinted" on a perceiving structure. Each of those discrete structures may degrade; if lost, i.e., no longer able to store what was presented, its remnants remain involved in the perceiving structure. Discrete structures for photopic vision, audition and cutaneous perceptions share tuned neurons with one another for different colored shapes, mixtures of acoustic frequencies, and each location on the body. For gustation, olfaction and muscle strain there is one discrete structure for the taste or smell of each perceived substance, and one discrete structure for each muscle. Many discrete structures have binding linkages, and many vision and audition discrete structures have sequence linkages.

Chapter 2 also described reactivation of a discrete structure by a new activation having the same or similar activation pattern, possibly the same or same type of source. Reactivations are regardless of the discrete activation's power and irrespective of partial degradation. The effect of detector neurons reactivating and not reactivating is suggested below.

> In a mature presentation structure, an activation pattern will reactivate some neurons and differently activate some others. Since *retuning* consumes less energy that *differently tuning*, the greater the fraction of neurons that are differently tuned, more energy is consumed for the same count of activated neurons. Thus an often reactivated discrete structure will mostly *retune* neurons therein consuming minimal energy per neuron, while a unique perception will mostly *differently tune* neurons to create a new structure consuming much more energy per neuron. The higher average neuron energy is presumed to automatically direct attention to presentations that are *unrecognized*. Once such a presentation has been sufficiently imprinted on its perceiving structure, the discrete structure will be *recognized* and not be directed to again.

This behavior explains why both recognition and non-recognition of an activation pattern is immediate. It also explains how unrecognized unconscious presentations are brought to attention.

While attending to a recognized presentation, we may acknowledge that fact by saying: "I know you" or "I recognize that voice". An infant does not recognize most presentations' patterns and behaves by actively directing to its surroundings. As its inventory of unique discrete structures increases, nearly everything within our environment becomes recognized. A normal muscle strain or cutaneous perception is always recognized because all of their possible discrete structures have been created. A recognized but unexpected cutaneous perception presentation may automatically initiate directing to the source of that stimuli.

When we do not recognize an attendant presentations, we become anxious and ask ourselves: "Why is that shape different?", "Why is it so big?", "Why does it have that color?", "Why is that up-side-down?", "What is that sound?", and "What is that smell or taste?". We may do the following to better comprehend the source of an unrecognized presentation before attention is directed elsewhere:

•   continue to attend or, if attention was directed elsewhere, direct attention back to what was presented (do a double take); and
•   if possible, enhance it.

For some of those unrecognized presentations, we may further examine it by attending to what surrounds it, watch it to see if it changes or moves, smell it, touch it, poke it with a stick or taste it.

Section 2
Recalling Discrete Structures

In addition to quickly and automatically *recognizing* a perception presentation's pattern, a mind can more slowly *recall* a discrete structure and have it presented as a memory presentation. A mind can also *recall* a sequence chain that are also presented. A discrete structure is recalled when it is further activated by the recalling process discussed below. Its memory presentation is discussed in the next Section.

We are aware of recalling when we seem to immediately and automatically recall: the name of our mother, the shape of a 'sombrero', and the next word in a song. The single quotes identify a word that is a signifier. Other times we "search our mind" as we try to "bring back a memory" about what is presumed to have been previously presented, e.g., "Who sang that song?". Each example can be seen to involve external linkages, either 1) binding linkages or 2) sequence linkages in a sequence chain where one linked discrete structure is active. An external linkage itself can be thought of as a "memory" of what two presentations were sequentially attended to. Note that although every discrete structure can be recognized separately from the others in their discrete structures, only those that have external links can be *recalled*.

In order for a discrete structure to be recalled it must first have at least some of its neurons normally activated. The only source of activating signals is from an activated structure it has external links with. Since a signal can travel in only one direction in a neuron's connection, a signal cannot travel across a link from one of its tuning neurons to the other. There must be some other method for signals to travel in either direction between neurons in two different discrete structures. I hypothesize a non-neural means of transmitting signals across an external link, i.e., a link whose link neuron is not a tuning neuron. As noted by Kandel, glial cells have been to participate in neuron signaling processes [Kandel, Eric R; <u>Principles of Neural Science</u>, 5th edition, 2013].

      Cross Link Signaling and Activating Hypothesis. There are glial cells that are threaded along the connections of between the two somas of an external link's tuning neurons that are able to transmit signals from one soma to the other. When one of a link neuron's two

tuning neurons becomes *further activated*, it begins transmitting a <u>cross link signal</u> to the other tuning neuron if that neuron is inactive. The arriving cross link signal normally activates that neuron.

Unlike detector neuron signals, which arrive at the bottom of a discrete structure, cross link signals arrive at multiple levels within the structure. (See Figure PRES_3 presented earlier.) Those arriving signals normally activate some neurons that in turn activate a few neurons above it: there are no cascading activations. Although not all neurons in the structure are activated, the activation is sufficient to unconsciously present the stored activation pattern. That activation retunes neurons in both the discrete structure and the links. That normal activation may be the reason we sometimes have a "feeling of knowing" what we are attempting to recall is stored but has yet to come into consciousness, i.e., has yet to be further activated.

Once some of the neurons in a discrete structure become normally activated, the behaviors described earlier: directing, and attending / further activating, are presumed to occur as well. These processes are restated below in a form that applies to activations in general.

> Directing – the process that finds a normally activated (and presented) discrete structure of interest and initiates attending / further activating.
> Attending / further activating – the automatic process that increases the power of signals to a discrete structure when directed to do so, and then:
> • causes the mind to be consciously aware of its (perception or memory) presentation;
> • activates and tunes additional neurons above the structure, thereby increasing the height of the structure (because the further activated signals arrive at neurons found throughout the structure, not just from the bottom); and
> • sends cross link signals to each of the linked discrete structures (if any) and normally activates their neurons causing each structure to be unconsciously presented (as a memory presentation).

Note the following.
• The recalling sequence is recursive.
• Recalling begins at a further activated discrete structure that was normally activated by detector neurons.
• Once started, recalling continues until terminated when directed to a *perception presentation*.
• The energy that enables recalling is from further activation.
• Neurons activated by recalling strengthen discrete structures against being lost and make linkages more robust.

Also note that directing can backtrack to a previously activated discrete structure, particularly if recalling further activates a discrete structure with only one external link. Backtracking that causes two unlinked structures to both be activated may create an external link between them. In addition, a vision sequence chain that intersects itself enables sending cross link signals to three other discrete structures in that chain.

Recalling Across a Discrete Structure

For signals to cross more than one linkage, signals arriving at an intermediate discrete structure must normally activate at least a few of the tuning neurons of the links of at least one other linkage. The ability to tune those tuning neurons is determined by how they are arrayed with respect to the tuning neurons of the arriving signals.

> If all link neurons' tuning neurons are found throughout the structure, i.e., the linkages have a shallow or no downward angle (found in binding linkages and vision sequence chains), then signals arriving on any linkage will activate others throughout the structures.

> If the linkages have steep downward angles (found in sequence links in audition sequence chains), the link neurons' tuning neurons are not distributed throughout the structure. To discuss this case, consider a discrete structure with linkages "A" carrying the arriving signals and "D" carrying the departing signals, i.e., the A tuning neurons are below the D tuning neurons.   This difference in the distribution of tuning neurons affects the ability of subsequent signals to pass through the discrete structure.

>> Signals arriving at the A tuning neurons cause upward activation that reaches those for D, allowing signals to pass through in the direction of their creation.

>> Signals arriving at the D tuning neurons also cause upward activation but they to not reach the A tuning neurons because they are below those for D.

This explains why there is no apparent directionality in sequence chains other than those for audition, i.e., only audition sequence chains have a steep downward angle.

Recall Directing Types

The three types of directing apply to recalling as follows.

Automatically directed Recalling
Automatically directed recalling is presumed to occur if there is only one other linkage or only one with a downward angle that allows it

Intuitively directed Recalling
Intuitively directed recalling occurs if there is one linkage that is significantly more robust (has more links) than the other linkages. This may occur if the more robust linkage has been used extensively used in previous directing and has remained robust while the others have not. One example is a linkage between a person and their name.

Thoughtfully directed Recalling
Thoughtfully directed recalling is used if intuitive recalling was not successful. Unlike the others it is slow, sometimes difficult, used much less frequently than intuitively directed recalling, and we notice it when we are "engaged in thought". It is particularly noticeable when walking and then literally "stop in our tracks" because no attention was being given to perception presentations thereby disabling the ability to navigate through our surroundings. Depending on the goal, thoughtful directing "decides" which, if any, among several normally activated discrete structure

is most likely to "reach the goal". Once the goal is reached, there may be a new or more specific goal or no goal. A goal is either specific or non-specific.

Specific Goal. Having a specific "goal in mind" directs to a discrete structure for a memory of interest that addresses the question posed by that goal. For example:
• Trying to recall where I put my keys; and.
• Trying to recall the title of a song being played.
Goal-directed recalling ends when the goal is reached or we give up trying, i.e., when we say to our self: "I can't remember".

Non-specific Goal. Without a specific goal or having a vague "goal in mind", directing is an attempt to understand something or to answer a general question without expecting a clear answer. Directing may meander with backtracking that creates links between previously unlinked discrete structures. Some of those newly linked discrete structures may be comprehended as having a previously unrecognized relationship or having characteristics in common, possibly resulting in a new idea, a metaphor, something humorous, and even a conspiracy theory. Sometimes the result is either a moment of reflection or an "aha moment" that is worth documenting.

Section 3
Growing and Moving Discrete Structures Up the Cortex

The recalling behavior described above has the additional effect of causing the top of recalled discrete structures to grow further up the cortex. When a discrete structure is recalled, some of the recalling signals arrive across links at or near the top of the structure where they reactivate those neurons. Those reactivated neurons differently tune neurons immediately above the top of the recalled discrete structure, thereby extending the structure further up the cortex. The activation pattern stored by the recalled discrete structure is reflected in the differently tuned neurons. Those differently tuned neurons can also create new external links at the new top of the discrete structure enabling their reactivation when next recalled. This process repeats itself with each recalling. Presuming that further activations increase signal power by the same amount, recalling results in the same height increase, possibly as little as one level. The effect of this growth is discussed below.

Discrete Structure Separation

A perceiving structure has ongoing detector neuron signal activity that is greatest at its bottom and dissipates upwards (as illustrated later in this Section). That signal activity both retunes and differently tunes neurons in the discrete structures embedded therein. Discrete structures that are nearly continually retuned can last a lifetime. (One example of nearly continual retuning is surface tactition which is frequent and always the same). Those that are not continually retuned are degraded beginning at the bottom and proceeding upward until they are lost. With the loss of the lower levels, there are no connections or reactivations by signals from receptor neurons, and thus no recognition. A surviving discrete structure that has lost its connections with the detector

neurons is referred to as a <u>separated discrete structure</u>; its counterpart, one that is used in recognition, is an <u>unseparated discrete structure</u>. Although separated, it continues to be involved in its perceiving structure and may have linkages that enable it to be recalled. With degradation and loss of the bottoms of separated discrete structures, there are more neurons available below them to be differently tuned by new discrete structures. In order to avoid being lost, a separated discrete structure must be recalled sufficiently often to move incrementally upward as fast as or faster than its lower levels are lost. Even as it moves up the perceiving structure, each level continues to store something of the activation pattern that initially created it.

Continued Upward Movement

Incremental growth of a separated discrete structure by recalling is not limited to being within its perceiving structure: it can grow above that structure and may continue to grow until the entire structure reaches the top of the cortex where further growth is not possible. There is no need for these linked discrete structures to be at or near the same levels in the cortex, only that they have external linkages. In addition, new external links are created between the newly tuned neurons at the top of those structures and possibly elsewhere, creating more robust linkages.

Growing discrete structures and their growing external linkages may encounter other discrete structures and their links above them. These encounters degrade the bottom of the encountered discrete structures and degrade their linkages by differently tuning their neurons. An encounter has one of the following affects on an encountered discrete structure or external linkage:
• 	it is <u>completely lost</u> because the encountering structure grew through it, possibly after being recalled several times;
• 	it is <u>partially lost</u> because the encountering structure grew through a side of it; or
• 	it is <u>diminished</u> because the encountering structure only grew through some of neurons without losing what was presented.
Such encounters are unavoidable because new discrete structures and their external linkages are always being created below the separated discrete structures. Those that *survive* (not completely lost) are the ones that are recalled sufficiently often so that they grow upward as fast enough to avoid encounters. Note that a separated discrete structure's height can vary greatly depending on how often it is recalled and how often it is encountered.

The behaviors described above have the following consequences for separated discrete structures:
• 	most are *lost*;
• 	a few *survive* for a time when they are recalled sufficiently often; and
• 	there are very few that *last a lifetime* because they are continually recalled or avoided being encountered by other structures.

When a discrete structure is lost, all of its linkages are lost. When an external linkage is lost, a possible path for future recallings is unavailable. A discrete structure can lose all of its linkages without being lost itself. However, it cannot be recalled: it is isolated even though it continues to store at least some of its activation pattern.

Activation Variability in and Above a Mature Perceiving Structure

The variability of the *rate* of normal activation signal activity (power/time) with cortex *height* is illustrated in the following schematic diagram. The two types of signal activity, detector neuron signal activity and cross link signal activity, are separated by a dashed line. The displayed rates are intended to be illustrative, not definitive. The y-axis is the height in the cortex with the perceiving structure extending about 1/3 of the way up; the x-axis is the signal power rate at different heights. The signal activity rates reflect that of an adult mind that has discrete structures that have reached the top of the cortex. All detector neuron signal activity is with the perceiving structure realm; cross link signal activity is highest at the bottom of the cortex and decreases to zero at the top. Although depicted as a distinct horizontal boundary, the separation of the two realms is fuzzy as well as variable. Perceiving signal activity is shown to be highest at the bottom and decreases rapidly with height.
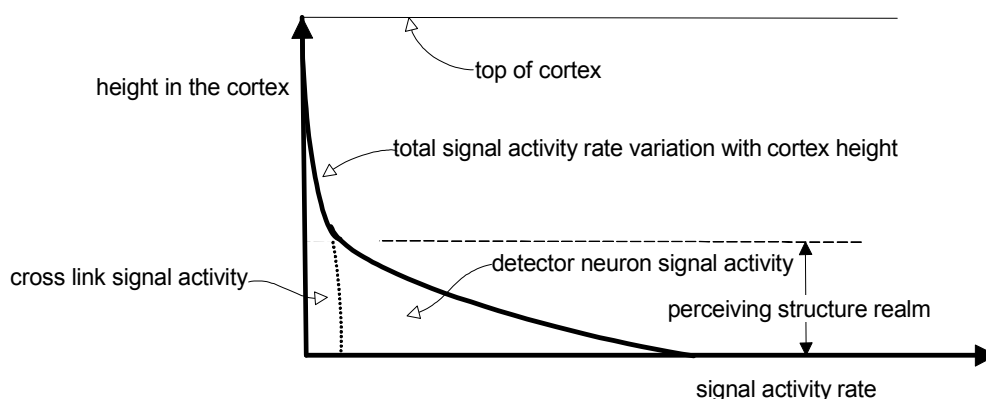
Figure
Schematic Diagram for the Signal Activity Rate Variation in the Cortex

What is Stored by an Unseparated and a Separated Discrete Structure

When created, the discrete structure's receptor-tuned neurons store the activation pattern in all of its fidelity; its intensity distribution is stored by the height of activation. At each higher level in the structure, there are fewer tuned neurons available to store the presented activation pattern, and thus less of the fidelity in that pattern can be stored. When a discrete structure becomes separated and loses its receptor-tuned neurons, it loses the fidelity stored therein. That lessening of stored fidelity occurs as the levels at the bottom of the structure are degraded. With movement up the cortex, the lessening of fidelity is inevitable.

An unseparated discrete structure, having connections from detector neurons, stores the discrete presentation which can be resolved into the following all that is presented, i.e., two or three of the following:
- visual shape stored by how its tune neurons are areally configured;
- intensity distribution across the tuned neurons stored by the heights of the tuned neurons structure above the receptor-tuned neurons; and
- quality distribution across the tuned neurons stored by the combinations of different kinds detector neuron(s) tuned at a fixed power ratio or the different in responses to acoustic frequencies.

92

When a discrete structure becomes separated, the intensity distribution is relative rather than absolute because what remains is not the same as what was created. Quality is no longer stored because which kinds of detector neurons caused it to be tuned are lost. (As described in the next Part, we can store intensities and qualities by signifiers without storing the quality or intensity itself.) Thus, all that an individual separated discrete structure can store and present when recalled are:

- visual areal shapes and intensity distributions found in the red, blue and green receptor-tuned areal sameness link clusters, and presented as colorless overlapping shapes and an intensity distribution (e.g., shades of grey); or
- an *occurrence* of a discrete quality activation for: a vision without shape, a sound, a smell, a cutaneous perception or a muscle strain.

A sequence chain of separated discrete structures can store and present:

- a sequence of relative acoustic frequency differences; or
- colorless visual areal shapes and intensities that are adjacent, or change during a fast physical process or fast movement.

Recalling an *occurrence* is with respect to some context of something else, usually a place or an event. For example, the occurrence of a smell at a place, possibly expressed as "I remember a musty smell when I was here last.".

Note that the edges of a recalled shape do not need to be "detected", they are a feature of what is stored.

The above assertion about the inability to recall a quality appears to be in conflict with our apparent ability to recall and present a color, and, to a much lesser extent, to recall and present other qualities. Dreaming in color has been reported. One possible explanation is that these quality memory presentations are imagined; another is that recalling continues until an unseparated discrete structure is recalled having the subject signifier, and its presentation is the formed from occasional "pings" from its detector neurons whose signals convey their pattern.

Recalling Sequence Chains

Just as an individual discrete structure can grow up the cortex and become separated, so to can all or a portion of a sequence chain. This is particularly noticeable for words and music which are strongly directional and are recalled years after previously hearing them. Until a sequence chain's discrete structures become separated, each of its discrete structures and linkages are subject to being degraded and lost by detector neuron signal activity. Loss of any one may result in being un-recallable. Thus short frequently recalled chains such as for the sound of individual words are certain to be separated sequence chains.

Recalling a vision sequence chain begins when any one of its discrete structures is recalled from another "recalling" (separated or unseparated) discrete structure for a signifier, a similar shape or any reminder it. From there it may proceed in either direction along the chain as well as back and forth among discrete structures for the wholes and parts of a physical thing.

Recalling an audition sequence chain begins when its first or the first few structures are recalled across linkages from another (separated or unseparated) discrete structure. The "recalling"

sequence chain for a song can be its few notes, its title or for any reminder of it. When each discrete structures in a chain is recalled, we "hear" the sound in our mind as it is presented, and we may vocalize it, i.e., speak or sing. We may also recall discrete structures in a chain while it is being listened to.

In either case, recalling subsequent discrete structures in the chain then continues automatically until the chain ends or recalling is aborted by attending to something else. Also a "recalling" discrete structure can be involved in another a chain.

Section 4
Remembering, Forgetting and Observations

This chapter closes with examples of particular forms of remembering, the experience of forgetting, a comparison of the forms of memory as described here with the memory types commonly encountered and lastly how evolution might have resulted in the ability to remember as discussed here.

Subsection 1
Particular Forms of Remembering

The following describes forms of remembering that have particular interest along with some examples.

Recalling While Asleep. Dreaming is the result of recalling using automatic and intuitive directing during which no new discrete structures or linkages are created. Dreaming begins with a perception presentation and continues until it is interrupted by automatic directing to a touch, a sound or some other perception presentation. Our difficulty in recalling our dreams is presumed to be due being unable to retrace the recalling sequence. When we do recall a dream, it is because a discrete structure recalled during a dream was remembered soon after awakening.

Recalling While Daydreaming. Daydreaming, being "lost in one's thoughts", is the same as dreaming, but is much shorter because of it is easily interrupted by automatic directing to vision presentations and being around sources of sound. Recalling a daydream is easier because what initiated it may be available for subsequent attendance.

Recognizing and Recalling Text While Reading. After learning to read, each commonly written word is stored by a discrete vision structure that has a link with the first audition discrete structure in a sequence chain for its sound. If the sound sequence chain is a signifier, it may be linked with a vision discrete structure for with is signified. When such a word is attended to, it is recognized and the sequence chain for it sound is recalled and possibly followed by recalling a vision discrete structure.

Recalling Along a Signification Linkage. Signifiers are stored by audition sequence chains that have signification linkages with discrete structures. By virtue of having a robust language, nearly every kind of stimulus' source, its traits and processes have one or more signifiers. All noun forms are signifiers: proper, common, verbal and pronoun; plural nouns identify a multiplicity thereof. Many adjectives and adverbs are also signifiers, e.g., 'sweet' and 'fast'. And, as discussed in Part 2, audition sequence chains are highly interlinked with each other, enabling rapid recalling throughout the cortex. As recalling proceeds, multiple signifiers may be recall along the way. The following are examples of recalling using signifiers. A word in single quotes identifies it as a signifier stored by an audition sequence chain.

> Looking at something that is red and recalling 'red'.
> Looking at a skunk or smelling its odor, and recalling 'skunk'.
> Having recalled 'sweet', recalling it in Spanish, i.e., 'dulce'.
> Listening to an unrecognizable sound with no signifier and recalling 'noise'.
> Listening to signifier and directing visual attention to a presentation for that signifier.
> Listening to a song, and recalling its title and performer.
> Listening to a played musical pitch and recalling its musical note signifier, e.g., 'C sharp', or its converse, i.e., perfect pitch.

Remembering a Person. The reason why we have a great ability to recognize a person by their face, along with their hair, body shape and the "sound of their voice", is presumed here to be our keen interest in them. This likely evolved in tribal societies to provide social security by immediately recognizing other members and to "read" social queues. While listening to a speaker, we automatically attend to the moving features of their face as well as "read" their lips to further comprehend what is being said. The time devoted to attending to faces may be enough to acquire sufficiently many discrete structures for each portion of those faces in all of their orientations to enable the immediate recognition. When we do not recognize a person, we use recalling to find those facial and other shapes for "parts" stored by separated discrete structures in a vision sequence chain for the "whole" of that person.

Just as we can recognize a voice or song from as few as three notes in a sequence chain, I suggest that we do something similar for visually attended physical things, particularly the wholes and parts of faces. In addition, the sequence of attendance to different parts of a given face may be consistent from one attendance to another because each face has its own order in which those features that are of interest. This is evidenced by caricatures that need only a few parts to recognize a face.

Remembering a Physical Thing at a Place. When attending to a recognized place andattending to a physical thing at that place, that physical thing may be recognized, not recognized, recognized as being previously elsewhere (not at the recognized place), or recognized but oriented at the same place. If it is unrecognized but similar to what was previously attended to at that place, it is comprehended as having undergone a change, i.e., a slow process that does not create a sequence chain, e.g., ice melting or a flower blooming.

Subsection 2
Forgetting

As suggested in this work, forgetting is due to neurons being differently tuned. Without the ability to forget what is no longer relevant, the mind would be full of useless and redundant structures and have too many useless linkages that would impede recalling. Here I briefly describe forgetting as we experience it using examples.

> We are aware that we have forgotten a memory only when we are aware that we can't remember something that we know from context that we once attended to. For example:
> - unseparated discrete structure loss: "I *recognized* that yesterday but not now."; and
> - separated discrete structure loss: "I was in first grade but I can't *recall* the other students."

> We are aware that we have forgotten how remembered things are related, i.e., loss of a link, e.g., "I don't *recall* which friends were at the party.".

> We are aware that we did not pay attention to things in a way that creates a linkage, e.g., "I can't *recall* where my keys are.".

We may also be aware that we are ignorant of a thing based on context, i.e., a structure not created, e.g., "I was not there to see it.". Without some context, we are ignorant of our ignorance.

Seemingly forgotten memories may be recalled later because recalling began from a different discrete structure or different linkages were crossed. We can recall a seemingly "long forgotten" memory when a discrete structure is recognized, e.g., when presented with a name or an old photograph. Infantile amnesia, loss of memories in infancy, are likely forgotten because they were lost by encounters with growing discrete structures that were of greater recalling interest.

The methods used to improve memory for a given physical are ways to enhance attendance to its presentations, to employ thoughtful directing, and to create linkages with other physical things. Examples of the latter are linkages with places, people and unusual characteristics and signifiers, including corruptions of those signifiers. For example, when meeting a person, repeating their name (signifier), and thoughtfully studying the features of their face. We can remember where we placed something if we attend to them while at that place.

Subsection 3
Observations

Noted without further discussion is that consciousness may be the result of further activation.

Learning

Learning occurs when we are aware that a mistake was made and we immediately or shortly thereafter (intuitively or thoughtfully) try something different until there is a success. This causes

activation and retuning of multiple different discrete structures and links for both the mistakes and the success. If we do not make a mistake, only those structure and linkages for the success are tuned. Over time, there are more retunings of the successes than the failures. Learning is complete when we when there are only linkages for the successes. This is a form of feedback that insures that there are more successes than any one type of failure so that successes are increasingly likely to be repeated.

Explaining the Different "Types of Memory"

The idea that there are types of memory is conventionally described using various models that are based the psychological studies of the ability to remember in testing environments. When those types of memory are described in terms of storage and capacity, they suggest distinctly different locations in the cortex. As presented here, those types identify something different and they can be explained in terms of structures and their activation as described above. Memory types are listed below with their observed durations and their explanation using the terms introduced here. Non-declarative memory is ignored because it applies to motor control and emotional responses. Working memory is presumed to be an aspect of short- and long-term memory as suggested by the explanations.

"type of memory"	duration	explanation
long-term memory	≤ lifetime	
declarative memory		discrete structures that can be recognized or recalled
episodic memory		internally linked discrete structures for events*
semantic memory		audition non-circular sequence chains
associative (binding) memory		binding linkages
auto-associative memory		non-circular sequence chain
haptic memory**		cutaneous perceiving structures forming the body map
short-term sensory memory	1-10 sec	separated or unseparated) discrete structure while active
iconic memory		active vision perception presentation
echoic memory	3-4 sec	active audition perception presentation
working memory	3-4 sec	audition circular sequence chain (discussed earlier)

* discussed in Part 2
** elsewhere regarded as short-term sensory memory

Note that each discrete structure is stored only in the mind but may move upwards in the cortex when it is remembered. and is not place. There is only one storage location, i.e., a memory does not moved from short term memory to long term memory or copied into for use in working memory.

Evolution of Storing and Remembering

Based on the analysis in this and the previous Chapters, the following speculates an evolutionary sequence that is sufficient to create the cortex and the processes occurring therein, including storing evolving before remembering.

> The most primitive brain was composed of neurons that evolved from nerves to be able to send tactition detector neuron signals to several motor neurons elsewhere in the body. Nothing is stored; the brain is purely reactive.

Some of those neurons mutated to receive signals from multiple other neurons and to multiple other neurons. Dendrites formed to limit signals to that prevent damage from too much signal power, i.e., they stored which few neurons can send activating signals at the same time. These were the first memory neurons.

With the ability to store which detector neurons' signals could activate a memory neuron, memory neurons could reconstitute the relative areal positions of tactition detector neurons on the body surface. Tactition and its presentation arose as a distinct perception type enabling better response to a threat or opportunity. The cortex was formed.

Some localized tactition detector neurons became more photosensitive creating a primitive form of vision. Eyes formed with denser detector neurons configured to better receive and present reconstituted images that could perceive relative movement as well as shapes and sizes. The brain and eyes move close to each other.

With the ability to store vision presentations in discrete structures, the brain became able to distinguish between activation patterns that did and did not activate the same memory neurons in order to recognize or not recognize a presentation as possibly an opportunity or a threat, and respond accordingly. The cortex and grew horizontally to improve presentation fidelity and vertically to enable interlinking of unseparated discrete structures to better recognize a visual presentation.

Vision evolved to have more than one kind of detector neuron in order to store recognizable edges within a shape, e.g., a face.

Goal-directed behaviors evolved to direct attention to a presentation, including a portion of a tactition or vision presentation, and to further activate the neurons in an attended presentation to better respond to threats and opportunities. This also enabled discrete structures to grow up the cortex.

The glial cells evolved to provide signal energy for further activation and to transmit signals between discrete structures in a way that enabled recalling discrete structures. The cortex added layers that increased the cortex's height enabling it to store more separated discrete structures for longer periods.

In conjunction with the ongoing invention of language, the cortex further expanded horizontally to increased what could be stored and linked, including sequence chains for words. With a language, there was a more effective means of organizing thoughts and recalling memories, and verbally communicating among members in a tribal society. (How words organize thought is discussed and illustrated in Part 2.) Included with language is a propensity to attend to faces to facially express oneself to improve identification of individuals in a society. The cortex also added layers to store more discrete structures longer enabling a lifetime of experience to be passed on to the subsequent generation.

[End of Part 1]