CHAPTER 5

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Organic Context of Short-term Behavioral Adaptation

I. Elementary Constituents of Organisms

All the different substances that exist are nothing more than different combinations of atoms. What makes the various substances different is nothing more than which elements are involved and how they are combined.

Living cells are made up of organic and inorganic constituents.

A. Inorganic Constituents of Cells

				Valence
Oxygen	65%	P=8	E=2-6	– 0 –
Carbon	18.5%	P=6	E=2-4	– C –
Hydrogen	9.5%	P=1	E=-1	H –
Nitrogen	3.3%	P=7	E=-2-5	– N<

1. Water

A very important constituent of organisms.

1. High solvent capacity
2. High heat capacity - can absorb much heat
3. High heat of vaporization - carries off much heat
4. High dielectric constant - functions as good dispersing agent for electrolytes
5. Can participate in many biochemical processes

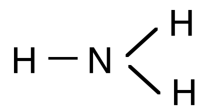
B. Organic Constituents of Cells

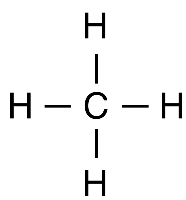
Compounds containing carbon

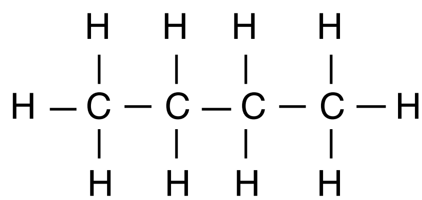
Carbon has four valence electrons which can be lent to, completed by, or shared with others. Carbon can combine with metallic and nonmetallic substances as well as other carbon containing compounds.

The bonds are strong and carbon can therefore serve as a structural framework for very large molecules.


water


ammonia


methane


propane

1. Carbohydrates

Six, or multiples of six, carbons
H and O in proportion of two to one as in water
Energy rich and most important source of organic energy

- Hexose sugars
  - Monosaccharides - glucose (used directly by cells)
  - Disaccharides - sucrose
  - Polysaccharides - starch glycogen

2. Lipoids

Not much in common but all insoluble in water, and soluble in ether

a. True Fats

Practically dry - so very efficient storage of energy

Immiscible in water, so may be important as protective coating against hydrolyzing enzymes.

3. Proteins

Most important of all organic compounds

Most complex
No organism lacks proteins
Each species has it own
Proteins built from about 20 amino acids.

All amino acids contain an amino group (NH2) (a base which acquires hydrogen ions) and a carboxyl group (-COOH) (which is acidic and can make available protons). Amino acids can, therefore, behave as an acid or a base depending on the solution they are in.

4. Nucleic Acids

a. RNA

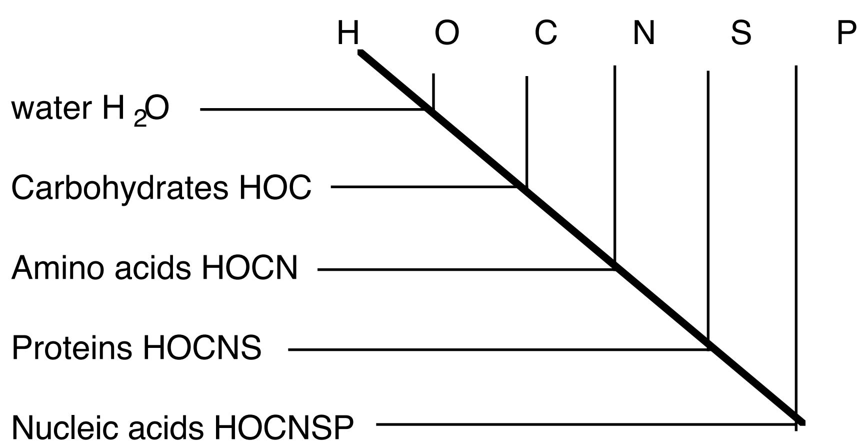
In nucleolus and cytoplasm and is concerned with everyday synthesis of proteins.

b. DNA

Carrier of the genetic code
Double helix with sequences of:
- adenine
- guanine
- cytosine
- uracil
- thymine

5. Hierarchy of Elements in Organic Matter

A simple diagram of the increasing complexity of constituents is seen in the following.



C. Subcellular Constituents of Cells

1. Cytoplasm

Cell membrane
Endoplasmic reticulum
Mitochondria
Lysomes

2. Nucleus

Nucleolus
Chromosomes

3. Evolutionary Pressure Towards Multicellular Organisms

Single cells can simultaneously do only a limited number of things given their small size and they can only reach a certain size. It, therefore, appears that the volume to surface law which governs the maximum size that a cell can attain, therefore also governs the complexity of single cell organisms. More complexity must come with multicellular organization.

II. Fundamental Vegetative Processes

The processes pertaining to an organism can be classified as vegetative or animative. Vegetative processes are the more fundamental and are shared by all organisms - plant or animal. Animative activities are superimposed on top of vegetative processes and are for the satisfaction of vegetative needs through interaction with the environment and are the neuromuscular activities of animals.

A. Conceptual Precursor: Molecular Machinery

Two principles could account for many basic cellular processes such as genetic replication and enzymatic activity.

1. lock and key machinery
2. stable templates

For example, suppose some shape "1" matches a second shape "2" as a round peg in a round hole. Other shapes "3" and "4" are like a square peg in a square hole.

Assembly

Suppose that a stable string of holes existed such as

1—3—5—7

then it would pick up its complementary pegs

1—3—5—7
2 4 6 8

which could in turn bind together

1—3—5—7
| | | |
2—4—6—8

If the existence of the 2—4—6—8 bonds overwhelmed the 1—2, 3—4, 5—6, and 7—8 bonds, then the 2—4—6—8 compound would be ejected from the template. There would then be a 2—4—6—8 chain floating around which could in turn accomplish work of some kind or which could collect its own "holes" if reproduction is important.

1—3—5—7
2—4—6—8

Disassembly

1—3—5—7 + 2—4—6—8

1—3—5—7
| | | |
2—4—6—8

1—3—5—7
| | | |
2 4 6 8

1—3—5—7 + 2 4 6 8

B. Vegetative Nutrition and Alimentation

Nutrition is the acquisition of essential raw materials and energy from the environment. Alimentation is the process of extracellular preparation and transportation of nutrients and the excretion of waste products. Vegetative nutrition and alimentation refers to modes of passive food acquisition preparation, transportation, and elimination shown by plants and the internal organs of animals.

Vegetative nutrition and alimentation depend on physical processes such as diffusion, selective membrane permeability, and chemical processes such as enzymatic digestion. Animative nutrition and alimentation consists of additional activities aided by neuromuscular organs and systems such as the search for, and acquisition of nutrients.

The metabolic processes of organisms are guided by enzymes. Enzymes are biocatalysts that control the direction and rate of chemical transformations. They are usually named for the substance they transform with the suffix "ase" appended. Enzymes probably have their effect by way of either the assembling or disassembling "lock and key" template process.

1. Krebs Cycle

The most well-understood biochemical metabolic process is the Krebs' citric acid cycle where there is conversion between adenosinedisphosphate and adenosintriphosphate. This stores energy much as winding up a spring or loading a cannon with gunpowder. The energy is ready to be released by a minor impetus.

$$\text{ADP} + \text{energy} \rightarrow \text{ATP} \qquad \text{ATP} \rightarrow \text{ADP} + \text{energy}$$

ATP is the universal donor of energy in organisms because it is so easily used.

The net efficiency of the conversion of glucose to energy is 50% which is quite good.

C Vegetative Reproduction and Propagation

1. Reproduction

The simple splitting of a cellular organism such as bacteria represents the simplest form of reproduction. Second is the passive fertilization and the distribution of seeds.

Cross fertilization greatly contributes to hereditary variation and therefore survival. Many organic adaptations exist which requires cross fertilization. The separation of the sexes being one of the most fundamental adaptations.

2. Morphogenetic Development

The sequential unfolding of development has many physical causes such as temperature, pH, and nutrient supply.

A substantial amount of research has been done to identify the cause of various changes in embryological development. A number of studies have shown:

a. Organizers

The transplantation of a section of a developing embryo to a different region can induce that new region to develop as if that new region were the original one surrounding the original tissue that had been moved.

b. Inherency

One of the most interesting demonstration of inherency is the transplantation of cells from one species to another (frog to salamander). The moved undifferentiated parts from a frog can come to develop as the body part appropriate for the place the undifferentiated cells were transplanted to. The frog cells develop as a mouth as governed by the location on the salamander where the frog cells were placed. The surprise is that the undifferentiated frog cells develop as a frog mouth in the salamander body.

c. Changes in Morphogenetic Development

Many extremely important evolutionary changes are effected by relatively small changes in morphogenetic development. Simple examples would be the retainment of a hairless state into adulthood rather than the emergence of hair shortly after birth. Secondly, the differential growth of specific areas can dramatically change the appearance of an organisms and finally the retainment of juvenile behavior in a subset of a species is a major portion of what is called domestication.

D. Vegetative Integration and Adjustment

The more fundamental and ancient integration system is a humoral one. It is hormonal communication, integration, and adjustment. There is no nervous system in plants yet they show integration and adjustment. The CNS is a very recent evolutionary development and integration was shown well before its emergence.

Hormones are chemically very heterogeneous and there is no relation between plant and animal hormones. Most animal hormones are not species specific though.

They are effective in extremely low concentrations (e.g., 1 in 5 billion).

Hormone concentrations are very important; at one concentration one effect can occur at another the opposite effect. Hormones production in many cases is under the control of their target so that a negative feedback system exists.

1. Vegetative or Hormonal Integration in Plants

Much of what animals achieve by swift animative neuromuscular action is attained in plants by slower structural adaptations under chemical control.

An early investigator in plant adaptation was Darwin. He noted that the tip of canary grass tipped toward the light because the tip was sensitive to the light, but that the extra growth occurred well below the tip. Darwin showed this by covering the tip but not where the growth took place. He showed that the effect was chemical in nature by cutting the plant and inserting a gel block. The chemical passed through the gel. Any neural structures would have been severed. These chemicals have been named auxins.

Darwin noted that plants were remarkably adaptive. They moved toward the light. He noted that the growing tip always moved as it grew. It tended to rotate. The upward growth of the plant is directed (negative geotropism). The turning of the growing tip is undirected in its rotation but tends toward the light. When the tip encounters a vertical obstacle, it tends to twine around it together with the upward growth. The plant is lifted to a higher location. The adaptiveness of a large class of plants can be explained by negative geotropism, circummutation and positive phototropism.

Plant movement is usually labeled in terms of the stimulus causing it such as phototropism or geotropism and positive or negative depending on whether its towards or away from the stimulus.

Most of the auxin caused adjustments in plants are accomplished by growth processes. If one side grows more than the plant bends the other way. These adjustments are slow.

2. Vegetative or Hormonal Integration in Animals

Hormones alters the rate of some target activity in the target cell. Every cell in the body is exposed to a hormone release. This control system is ideal when many systems of the body must be coordinated, such as: if predator, then increase heart rate, deepen respiration, dilate blood vessels in muscles, contract blood vessels in skin, release sugar from liver, etc. However, in some cases only a few parts of the body may react to the exposure. The effect of a hormone is prolonged whereas the effect of nervous activity is very short. The chemical structure of animal hormones vary, the source varies, the target varies, and the pervasiveness varies. There are probably many unidentified hormones remaining.

a. Hormone Coordination of Metabolic Processes

Insulin - maintains constant sugar concentration
Thyroxin - metabolic rate

b. Hormone Coordination of Reproductive Process

Androgens - male
Estrogens - female

Ring doves maintained in pairs go through cycles of courtship, nest building, egg laying, etc. every six weeks; doves maintained separately do not. Lehrman exposed female ring doves to normal or castrated males. Most of the females exposed to courting (normal) males showed signs of their courtship - nest building, etc. cycle. Most of those exposed to castrated males did not.

c. Hormone Coordination of Integrative Process

Pituitary
- Adrenohypophysis
  - growth hormone - skeletal growth
  - thyrotrophic - thyroid
  - corticotrophic - adrenal cortex
- Neurohypophysis
  - Neural origin - nerve cell secretions transmitting neural influences to glandular structure controlling vegetative functions

Hawk moths move up or down in relation to gravity depending on their age, the behavior is governed by the amount of juvenile hormone.

i. Pheromones

These are chemical substances which function like hormones except their transmission is outside the body.

- Sexual attractants
- Chemical alarms
- Chemical trails
- Social control as in honeybees
  - The queen produces a substance which inhibits the development of ovaries in the female workers. When the hive gets too large, some females don't get the substance. Ovaries develop in other bees and large queen cells are built and new queens are produced.

III. Evolution

It is important to reiterate that the idea of evolution was generally well accepted before Darwin and that now evolution is such a well-established fact that there is no real controversy among educated people.

Important aspects of nature are: 1) there is a tremendous diversity in life forms, 2) in spite of that diversity there is an obvious gradient of increasing complexity made up of species which share many characteristics, 3) each species is very well adapted to the requirements of its niche, 4) life forms increased in complexity across geological time, and 5) most species over reproduce (i.e., each. pair of animals has more than two offspring but the total count of each species remains relatively constant).

A. The Origin of Species and Instincts

There are three elements to evolution. 1) variation., 2) selection, and 3) non-regressive replication. For example, if there are fast and slow rabbits and the slow rabbits are eaten more often than fast rabbits and fast rabbits tend to produce fast rabbits, then the rabbit species will come to run faster.

Variations are often produced by changes in development; typically via missed steps, a fixated stage, change in relative size of elements, or a change in the timing of the stages. Structural and behavioral elements are critically important in selecting which individuals will put more or less than their share of offspring into the next generation. Examples of the importance of behavior in evolution relate to predation, social organization, parenting, and sexual selection. Obvious examples would be birds with very bad eyesight will not out reproduce birds with good eyesight. Rabbits that startle easily will probably out reproduce those that are friendly to all approaching animals.

Reproductive isolation can be effected geographically as when a group is isolated on an island, or can be effected behaviorally as when very similar bird species do not interbreed because their mating rituals are very different. Reproductive isolation functions to accentuate the expression of particular traits by reducing the moderating influence of a wide variety of outside genetic material. The effects of reproductive isolation on "Hillbillies" where everyone in the valley has red hair are frequently portrayed in movies.

1. Understanding Behavior Through Evolution

Similar species have similar behaviors. In fact, they can be categorized as similar to the extent that they do behavior similarly. Some seemingly anomalous behaviors could be understood as remnants or ritualized behavior.

For example, Mallard duck females incite their mate to attack other ducks by looking over their shoulders at the other ducks. The origins of this inexplicable "signal" can be better understood by observing a similar species, the shelduck. In this species, a complete and therefore more "understandable" version of the behavior occurs and gives insight into the evolutionary origins of the behavior of the mallard. The female shelduck attacks other ducks, but when close "becomes afraid" and runs away but tends to look over her shoulder when far enough away. She then "gathers courage" and attacks again. Much of the time is spent in the intermediate stage of body facing away from the offending ducks, but head over the shoulder facing toward the offending ducks. This behavior sequence generally incites attack in the male shelduck

A second example of a remnant behavior is goose bumps or goose flesh in humans. It is an evolutionary carryover of piloerection or feather erection in earlier evolutionary stages.

B. Genetics and Behavior

In the simplest form, the genetic model argues that an offspring receives one inheritance factor from each parent and together they determine the expression of a trait. Suppose the factor was height. This factor would be called a gene - the height gene. Suppose there was the possibility of being tall or short. The two forms of the height factor are labeled alleles. If the offspring received two tall alleles, then it would be tall. If it received two short alleles, it would be short. When the two alleles are different, then a typical occurrence is that one is dominant and it overrides the effect of the other. If tall were dominant, then a tall short combination would result in a tall offspring. If many genes are involved, the trait is said to be polygenetically inherited. Genes appear to produce sequences of amino acids which are proteins and enzymes.

The determination of what is inherited and what is learned is not as simple as "if every member does it, it's inherited; if there is variation, it is learned." For example, all humans wear clothes and there are 4-5 eye colors in humans.

IV. Differentiation of Animative Activities

There are two ways an organism can satisfy their metabolic needs:

1. synthesizing the organic compounds from inorganic substances
2. acquiring already synthesized organic compounds and transforming them into the species specific compounds

This difference may have lead to the difference between plants and animals. Animals must search for and capture food and avoid predation whereas plants are relatively passive. Most vegetative processes are dependent on humoral events, animative processes are dependent on biomechanical events.

Differentiated animative action has three aspects: 1) information gathering, 2) coordination and 3) execution of action.

In protozoa and lower metazoa all these aspects of animative activity are performed by a single structure, the undifferentiated cell. In higher forms structural differentiation permits the performance of these functions by separate cells or organs. in some coelenterates muscle cells contract in direct response to external stimuli without the intervention of other cell types. The second step in differentiation may be represented by the two cell type mechanisms present in the tentacles of various polyps consisting of an epithelial receptor cell and epithelial muscle cell. The most primitive form of the triple cell level of integration is also a coelenterate (medusa) which has a diffuse network of nerve cells through which excitation may pass from one part of the body to another.

A. Evolution of Contractile Mechanisms and Effector Organization

1. Ameboid Action

Ameboid movement is accomplished by reversible colloidal changes in the cell structure from a gel (viscous) to sol (liquid) state. The front is in a more liquid state. The back is in a more viscous state. Pressure from the back oozes the liquid front out further . If the front encounters a small object, that region of the plasma membrane gels which creates two arms which engulfs the object. If the encountered object is large, the entire front end gels thus reversing the direction of movement.

2. Ciliary Action

Molecular contraction can lead to significant work production if: 1) the contracting elements are oriented parallel to the axis of contraction, and 2) the fibrous molecules are tied to one another to form larger units.

Some primitive single cell organisms suggest the beginnings of this type of structure. There are two classes of well-developed structures specialized for work. Both have the same microstructure. Both are composed of two central filaments surrounded by nine equidistant pairs. Both convert chemical energy to mechanical work.

Flagella - a single long filament (euglena)

Cilia - fine hair like structures much like a wheat field. They remain stiff on the forward stroke and are flexible on the return. (paramecium)

3. Myoid Action

Gross overt contraction in protists and primitive metazoans. In animals, mechanical work is commonly produced by contractile substances that are capable of reversible shortening and lengthening. Actomyosin can be extracted from muscle and made to contract with ATP even though it is nonliving. It will not contract to electrical stimulation. In general, contraction of smooth muscles is slow but sustained. The contraction can be spread from muscle fiber to muscle fiber in the absence of innervation. Striated muscle is characterized by quick contraction and relaxation. Deinervation of skeletal muscle produces immediate paralysis.

B. Evolution of Transducer Mechanisms and Receptor Organization

Exposed protoplasm is affected by a variety of physical forces sometimes referred to irritability. Irritability of living tissue is the basis of the sensitivity of organisms to stimuli. Protection from the environment and sensitivity to stimuli are opposite demands on the organism. Specialized receptors were a way to get maximum protection while at the same time having "peep holes" through which the organisms can detect the outside world.

Simplest is fine branches of an afferent nerve which are directly affected by the stimulus. More complex receptors have specializations which allow them to be maximally sensitive to particular aspects of the environment and translate that into an intraorganic bioelectric signal. Basically, receptors generate a graded receptor generator potential which along with temporal or spatial, summation or inhibition creates a series of action potentials which are frequency coded or path encoded. Often transitions from one state to another is sharpened by lateral inhibition, which is well illustrated by the reciprocal organization in visual receptor fields. These are receptor fields with antagonistic surrounds which lead to the sharpening of the boundary delimiting the spatial locus of the stimulus.

C. Evolution of Control Mechanisms and the Nervous System in Invertebrates

Across invertebrates control systems vary greatly.

1. No Neuronal Coordination

a. Protozoa

i. Bacteria

It has been shown that salmonella can move up or down a chemical gradient by placing a capillary tube with an attractive substance into a culture of salmonella. More entries into the tube were found then could be expected by chance. There are only two ways the bacteria could have done this:

1) Comparing the concentration at either end of their bodies. Given that the

bacteria were only 2 microns long the bacteria would have to be able to detect a difference of only 1 in 10,000 in the concentration

2) Comparing the difference in concentration at two different times.

For example, getting to the good environment could be easily accomplished if the bacteria move randomly when the concentration was the same (i.e., stay in the same spot) and if they moved straight when the concentration got better (i.e., swim in the good environment).

Salmonella were shown to do this by changing the concentration in a step change and mixing the solution well. If the bacteria tested front end with back end, they would show no change. If they time sampled, they would tumble when the solution got worse, and swim straight when the solution got better. That's what they did.

ii. Ameba

Amoebas are capable of not only moving around but also exhibiting organized behavior. They have discriminative as well as adjustive capacities. Amoebas manifest rudimentary sensory capacities, when they move toward or away from a source of stimulation even though differentiated sensory mechanisms are not present.

iii. Paramecium

Paramecium show an avoidance reaction to a variety of stimuli. They stop moving and reverses direction. They do this by reversing the beat of their cilia, then turning slightly, then moving forward again. The turn is random because the paramecium has no distance receptors to determine the vector to the stimulus. If the anterior part of paramecium is stimulated mechanically, the permeability of the cell membrane to calcium ion increases, the cilia reverse their beat due to the resulting changes in the ion balance and electrical charge across the cell membrane. Stimulation of the posterior part of the cell increases potassium permeability and the cilia beat more rapidly.

iv. Stentor

The basic behavior of stentor is contraction. If stentor is offered a noxious substance, it not only reverses the beat of oral cilia but the stalk bends sideways. If stimulation is intense, the stalk contracts and with further stimulation, the stalk detaches. This mode of action is made possible by the longitudinally arranged contractile fibers (myonemes) in the stalk which because of their obvious muscle like action may be called a myoid mechanism. The contraction of stentor to a light touch is reduced with repeated exposure.

b. Prolifera (sponges)

i. Sponges

In metazoans such as sponges, nerve cells are absent. The contractile cells in the osculum of sponges respond directly to external stimuli without mediation of nerves.

The behavior of sponges is dependent on all three primitive action mechanisms. Ameboid motility, ciliary beating, and myoid contraction. Coordination among these action mechanisms does not exist in sponges.

2. Peripheral Nerve Nets and Peripheral Ganglia

a. Coelenterata (Jellyfish)

They are the least complex (two layers of cells) and most simply organized of the animals with a nervous system. The nervous system is diffuse and lacks definite centralization. It is a nerve network of bipolar, tripolar, and multipolar neurons. The synapses are mainly unpolarized (i.e., transmission of impulses occur in either direction).

Nerve cells first appeared during evolution in coelenterates. In the tentacles of polyps, rudimentary nerve cells (protoneurons) are present which perform the dual function of receptors and nerves. These protoneurons are the forerunners of the differentiated nerve cells intervening between receptor and effector. In Coelenterates such as hydra primitive nerve cells are present, forming a subepidermal nerve net or plexus in some parts of the body of coelenterates such as in the marginal and oral rings of medusa. The nerve nets are organized into a through conducting system resembling in some respects the multisynaptic pathways of higher forms. If a prey brushes a tentacle, the autonomous specialized effectors, the sting cells, sting the prey (they will function that way when removed from the tentacle). The grasping of the prey by the tentacle is released by glutathione released by the damaged cells of the prey. Reaction in coelenterata are sequenced by way of the stimulus strength. The initial behavior requires the least to trigger the final behavior requires the strongest stimulus.

The peripheral nerve plexus of coelenterates may be considered the simplest type of a nervous system. It is capable of initiating and controlling gross sluggish movements that characterize the action repertoire of these animals. In the jelly-fish, the coelenterate nervous system reaches its highest level of differentiation. There are many types of nerve rings around the rim of the animal and sometimes ganglia occur. This is the very beginnings of a CNS. Jelly fish have the beginnings of true sense organs. They are sensitive to light, gravity or chemicals.

3. Ganglionic Centralization and the Beginnings of Cephalization

a. Echinoderms (Starfish)

Show the beginnings of peripheral ganglionic organization with suggestions of a more compact peripheral aggregation of neurons near the organ enervated.

The position of the nervous system in echinoderms may be considered intermediate between the completely diffuse peripheral system of coelenterates and the centralized systems of higher invertebrates and vertebrates.

The peripheral diffuse network has been retained only in animals that lead sessile or sluggish existences. In more active animals, it was replaced by a centralized system. Subepidermal networks are retained in higher forms in body structures that carry on their routine functions in a relatively sluggish manner such as in the gastrointestinal system.

The radial symmetry of the animal's structure affects the structure of the nervous system. Starfish arms are capable of coordinated movement, but normal movement requires an intact animal. In normal movement, one arm leads, when movement reverses a different arm leads.

4. Emergence of the Centralized Nervous Systems

The basic characteristic of a centralized nervous system is the segregation of communication lines from centrally located nerve centers or ganglia, where interaction among and coordination of various body parts may take place.

a. Platyhelminthes (Flat worms) (Planaria)

For example, flatworms are bilaterally symmetrical have a head end and have a differentiated ventral and dorsal surface. Low end flat worms have only rudimentary cephalization and the nerve trunks are scattered.

The lowest group of the bilateral phyla (three layers of cells) to possess a centralized nervous system. It includes a brain (in some) plus pairs of longitudinal cords. Receptors in this group range from single sense cells to multicellular complex eyes. High-end flatworms (e.g., planaria) have a more centralized nervous system. Cephalic ganglia or "brain" removal has severe effects in some playthelminthese. Their locomotion to or away from light or chemical is seriously impaired if removed. Planaria appear capable of learning Reflex conditioning with a light CS and shock US results in contraction to the light.

b. Annelida (Segmented Worms) (Earthworms)

In annelids such as earthworms, a subepidermal nerve plexus is still present but the main control of locomotion is performed by centrally situated ganglia which are connected with one another by a ventral nerve cord.

Each segment contains structures that are repeated. This had enormous significance. It allowed the construction of a very large basic system from which differentiation could occur. Each segment has a nerve ganglia. This group has a pair of cerebral ganglia (the brain). Giant nerve fibers occur. These fibers increase the speed of neural transmission and are involved in startle or escape reactions, removal of the cerebral ganglia does not prevent performance of certain activities such as locomotion, but more complex behaviors such as feeding and burrowing are affected.

Both central and segment to segment control of locomotion. If ventral nerve cord is severed, the coordinated wave of contraction spreads along the worm indicating that feedback from the earlier segment can control the contraction in the next consecutive segment. Additionally, if the worm is severed leaving only the ventral nerve intact, a wave of contraction can pass right across the severed portion of the worm demonstrating control via the ventral nerve.

c. Arthropoda (Insects) (Cockroaches)

Similar to the annelids, but the segments become specialized to do different things. Additionally, there are three regions of the brain: fore, mid and hind. The forebrain contains the optic ganglia and "higher levels of integration. This group seems stimulus bound in actions. Fly larva and wood lice react in a very predictable way to stimuli such as light or humidity, but some "learning" may occur Suspended headless, cockroaches will learn to hold a leg above a grid that shocks the leg. Many very complex reflexes that are independent of the brain can be demonstrated. Even when the brain is removed, crabs will transfer edible material from the claw to the anterior legs, then to the mouth parts and then eat the food if it has an acceptable taste.

d. Mollusca (Snails, Clams, Octopuses)

This group has extreme variability in the complexity of the nervous system. At one end, chitons are less complex than flatworms. At the other end, octopuses rival vertebrates. Octopuses have about 30 separate lobes in their brain. Octopuses learn a variety of things. It appears that visual learning and chemotactile learning are completely isolated in different lobes and only poorly communicate.

D. Protochordate and Primitive Vertebrate Nervous System

In amphioxus, the elongated body has many separate segments which can contract alternately on the right and left side. It has a notochord above which is a nerve cord which gives off bundles laterally to the right and left in each segment sensory and motor nerves are separate and enter through the dorsal and ventral roots. This "amphioxus" notochord is present in all vertebrates during early embryological development. The amphioxus has no autonomic nervous system.

The lamprey has a definite head, and specialized sense organs in the anterior region. The front part of the spinal chord is enlarged. It has a primitive skull.

The CNS of the lamprey represents the common core of the vertebrate brain. The neurons are unmyelinated but there is an autonomic nervous system.

E. Side Note: Neuron Components and Processes

The idea that the nervous system is composed of discrete cells with fibrous processes which have synapses is known as neuron theory.

1. Neuron Components

Dendrites - input, graded,
Cell body - metabolism
Axon, myelinated or unmyelinated - fast, all or none, nondecremental signal
Synapse - space between neurons where integration takes place
Chemical Transmission

2. Neuron Action

Resting
Action potential or spike
Absolute refractory - cannot retrigger
Relative refractory - retriggers with difficulty
Neurotransmitter release - noradrenaline, acetylcholine, dopamine, etc.
Changes in synaptic efficiency - altered by outcome "back propagation"

F. Review: Trends in the Elaboration of the Nervous System in the Invertebrates

1. Condensation

Many neural elements become concentrated into the ganglia and cords of the CNS.

2. Cephalization

A head is developed at the anterior end of the bilateral animal. Neural concentration occurs there. The trend across evolution is obviously toward cephalic dominance expressed structurally as increased growth and differentiation of the cephalic ganglion. This progressive process is referred to as cephalization.

3. Development of Ganglia

Cords arose by condensation of the network of plexuses of bipolar and multipolar neurons. Cell bodies become localized into ganglia so that cords consist mainly of fiber.

4. Differentiation

The brain further develops so that a separation of transmission function (tracks) and integration (ganglia and brain) function occurs.

5. Development of Giant Nerve Fibers

High speed transmission emerges with giant neurons associated with behaviors such as escape.

6. Evolution of Hormones

This is poorly understood. Initial hormones seem to have been the simple products of nerve cells. The secretion was used locally. This type of process can be seen in the flatworms. Storage of the secretion of nerve cells then emerged. This can be seen in annelids. The corpus cardiacum in insects corresponds to the neuron hypophysis in vertebrates. Later there was the emergence of nonnervous endocrine glands in various regions of the body under the control of neurosecretory cells in the CNS.

V. Mammalian Nervous System Components and Processes

A. Nervous System Gross Structure

1. Peripheral Nervous System

a. Autonomic Nervous System

A nervous control system very similar to hormonal control

i. Sympathetic Nervous System

Ganglia in trunk ready for exertion - noradrenaline-like stimulation of adrenal medulla.

ii. Parasympathetic Nervous System

Ganglia near organ - recuperate - acetylcholine

b. Somatic Nervous System

i. Sensory

ii. Motor

2. Central Nervous System

Proencephalon - forebrain - olfaction
  Diencephalon
  Telencephalon
Mesencephalon - midbrain - optic
Rhombencephalon - hindbrain - ear and balance
  Medulla
  Cerebellum
Spinal cord

B. The Neural Unit of Vertebrate Behavior

The simplest "input/output" neural unit that can control behavior contains two neurons. It is called a monosynaptic reflex arc (e.g., stretch reflex). The prototypical example being the knee tap leg jerk reflex.

The next most complex neural unit is a three neuron arc such as in a simple withdrawal reflex.

From a reductionistic perspective, all behavior is the result of neurons "talking" to each other. All decisions are neurons interacting and the actual referent for free will is nothing more than neuron interaction (and hormonal modulation).The field of Conditioning and Learning could be considered an examination of the ramifications of the communication between neurons when the adaptation of the organism to its environment is considered.