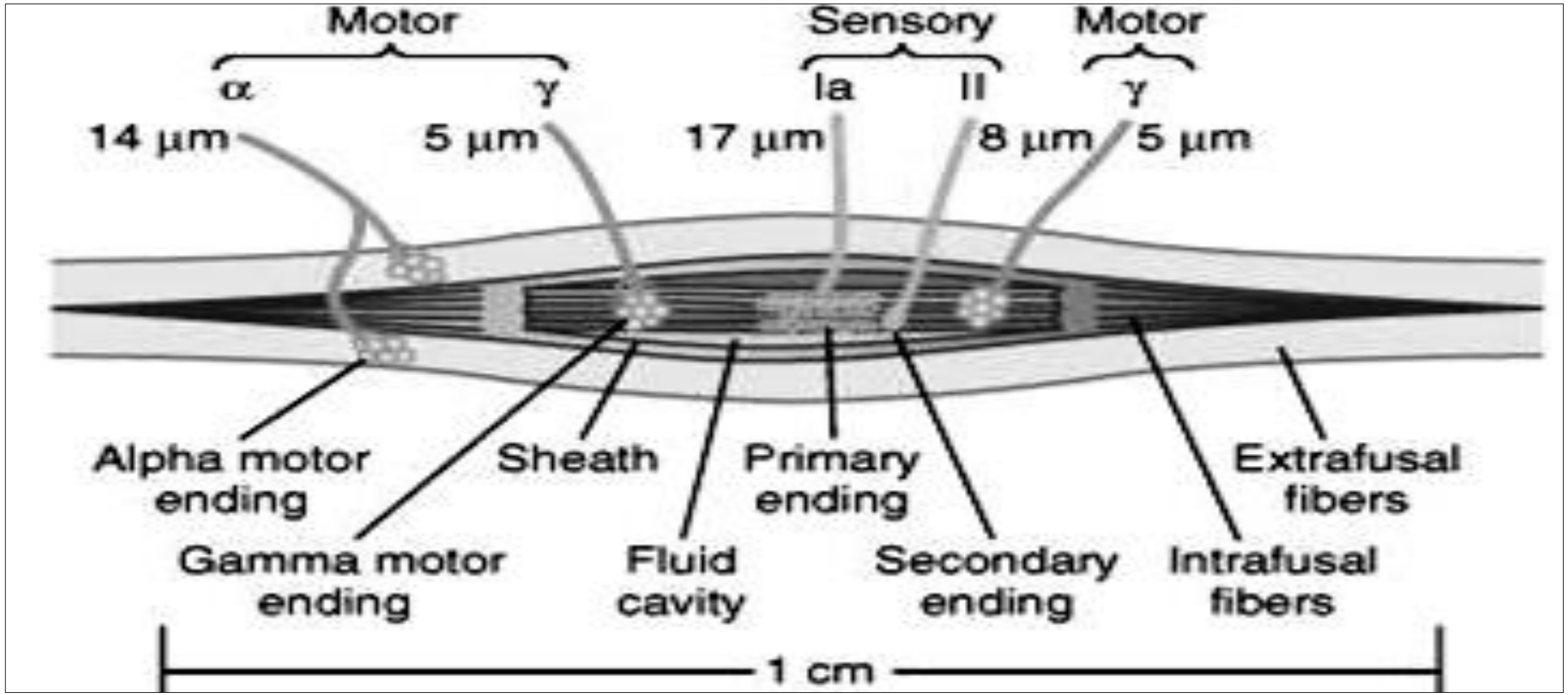
Locomotion and Reflexes

- The motor neurons that innervate the skeletal muscles are called **lower motor neurons**. They arise from spinal cord and brainstem e.g. α- and γ motor neurons of spinal cord.
- ***Upper motor neurons*** are those that arise from brain and modify the activity of lower motor neurons. The upper motor neurons control the muscle tone and locomotion in animals through descending efferent fibre tracts to spinal cord.
- The α- lower motor neuron is called **final common pathway** because it is this neuron that receives commands from different regions of brain, different segments of spinal cord and from interneurons and they are integrated for final passage to skeletal muscles.
- A motor unit consists of an α-lower motor neuron and all the skeletal muscle fibres innervated by this fibre.
- The spinal motor neurons are located at the ventral gray horn and are called ventral motor neurons. They project their axons into the peripheral nervous system.

- There are of two types of ventral horn motor neurons
- Alpha or somatic motor neurons -->supply to skeletal muscles.
- Gamma motor or intrafusal neurons -->supply to muscle spindles.
- These neurons are present in all areas of the gray matter of spinal cord – the dorsal, ventral and intermediate horns. They are more numerous than sensory and motor neurons of the spinal cord.
- *Functionally the interneurons* are either,
- Excitatory inter neurons- cause depolarization effects in the postsynaptic neurons.
- Inhibitory inter neurons-cause hyperpolarization effects at the postsynaptic points.
- These two types of inter neurons are involved in most of the spinal cord reflexes, except the myotatic reflex. They coordinate the sensory activities with the motor activities at the cord level.
- The *Renshaw cells* are inhibitory interneurons of the ventral horn motor neuronal pool.
- *Propriospinal fibres* are those that run from one segment of the spinal cord to another. They include both ascending and descending fibres and they participate in the multisegmental spinal cord reflexes.

Sensory Receptors of Muscle and their Role in Muscle Contraction

- To provide feedback information, muscles and tendons have two types of sensory receptors
  - **Muscle spindle**
  - **Golgi tendon organs**
- These receptors transmit their impulses not only to spinal cord but also to cerebellum and cerebral cortex.
- Central pattern generator (neuronal network that control specific repeatable motion) for controlling locomotion and for some protective mechanisms (scratching) are located in the spinal cord.


Motor
Sensory
Motor
α
γ
Ia
II
γ
14 μm
5 μm
17 μm
8 μm
5 μm
Alpha motor ending
Gamma motor ending
Sheath
Fluid cavity
Primary ending
Secondary ending
Intrafusal fibers
Extrafusal fibers
1 cm

Receptor Function of Muscle Spindle

- The receptor organs of the skeletal muscle are encapsulated within the belly of the skeletal muscles and are called as the ***muscle spindle organs,*** they are excitable by simple stretch in the skeletal muscles.
- Muscle spindle organs are complex receptor organs made of specialised striated muscle called the ***intrafusal muscle fibres;*** they are present within a connective tissue capsule, which are attached to the surrounding skeletal muscles.
- The muscle fibres of the skeletal muscle, which produce the physical shortening of the muscle, are referred to as ***extrafusal muscle fibres*** that are innervated by **a-motor neurons.**
- The intrafusal muscle fibres have contractile proteins at their polar ends but none in their middle, equatorial region. Therefore, their polar ends can contract but the central (equatorial) region cannot.
- Sensory (afferent) nerve arises from this equatorial region and it carries impulses from the muscle spindle to the CNS by way of peripheral nerves.

- The only way in which action potentials can be produced along a spindle sensory nerve is by stretching (lengthening) the middle equatorial part of the intrafusal muscle fibres.

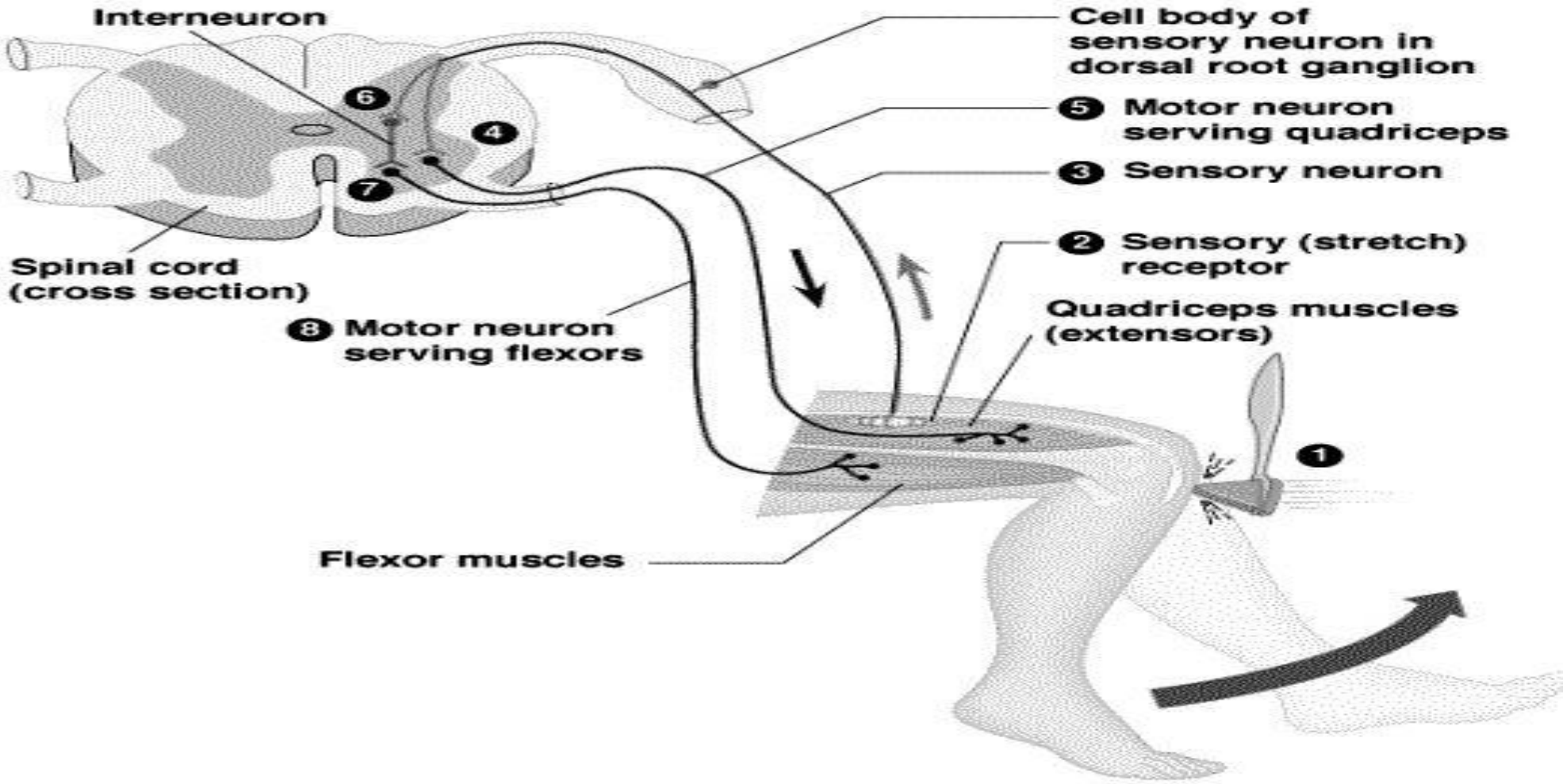
- Once the intrafusal muscle fibres are stimulated, action potentials are generated in the sensory nerve, in direct proportion to the lengthening of the middle of the intrafusal fibres.

- The impulses generated when the sensory neurons are stimulated are transmitted to the CNS where they make excitatory monosynaptic connection with a-motor neurons that supply the extrafusal fibres of the same muscle.

- This leads to the contraction of the whole muscle and it results in shortening of the muscle spindles' equatorial region.

- This shuts-off the action potential from the spindle receptor and muscle contraction is stopped.

Role of Muscle Spindle in Voluntary Motor Activity



Golgi Tendon Reflex - Inverse myotatic reflex: (clasp-knife reflex)

- The sensory receptor organs for this reflex are the ***Golgi tendon organs****;* they are located within the tendons of somatic skeletal muscles and are responsible for the initiation of the inverse myotatic reflex.
- The Golgi tendon receptor organs are excited during muscle contraction that produces stretch upon the tendon, whereas the muscle spindles are not excited by muscle contraction.
- Golgi tendon organs are sensitive to *change in the muscle tension* during increased stretch imposed upon the tendon by skeletal muscle contraction.
- This reflex activity tends to reduce the tension in the muscle undergoing intense stretch.
- It is a protective reflex action that prevents over stretching of muscle/tendons and prevents the rupture of the muscle.
- It also functions antagonistically against the myotatic reflex to produce smooth coordination of skeletal muscle activity.

Reflex

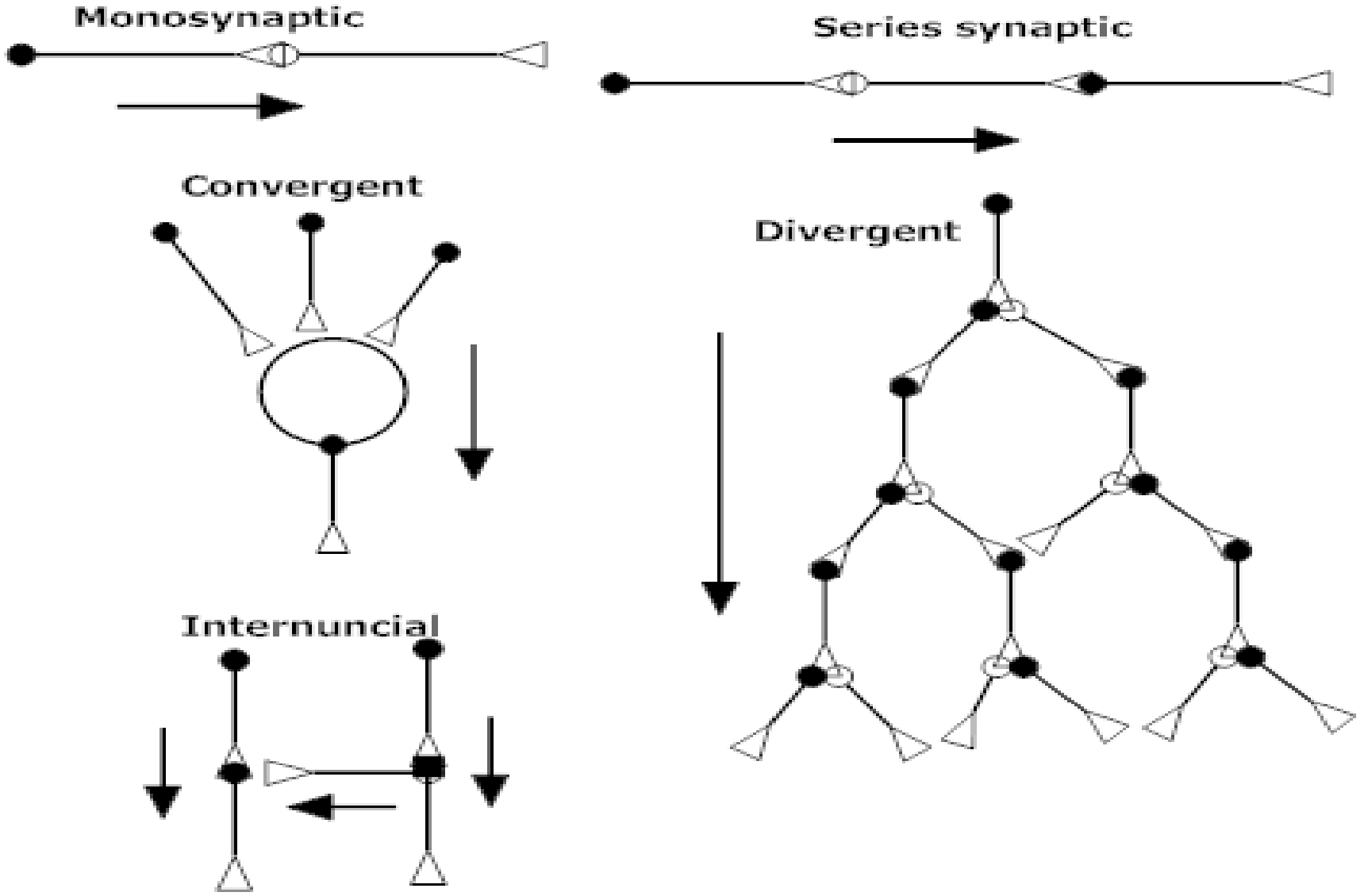
- A reflex is a ***specific, stereotyped, involuntary motor response*** *to sensory stimulation*.
- Each reflex automatically regulates a body function

Components of reflex arc:

- The neural circuit for reflex is referred to as ***reflex arc.***

Five components commonly make up a reflex arc.

1. Receptor organ(in sensory cells)
2. Sensory (afferent) neurons
3. Interneurons in spinal cord or brain
4. Motor neurons (efferent)
5. An effector organ (muscle or glands).


Monosynaptic
Series synaptic
Convergent
Divergent
Internuncial

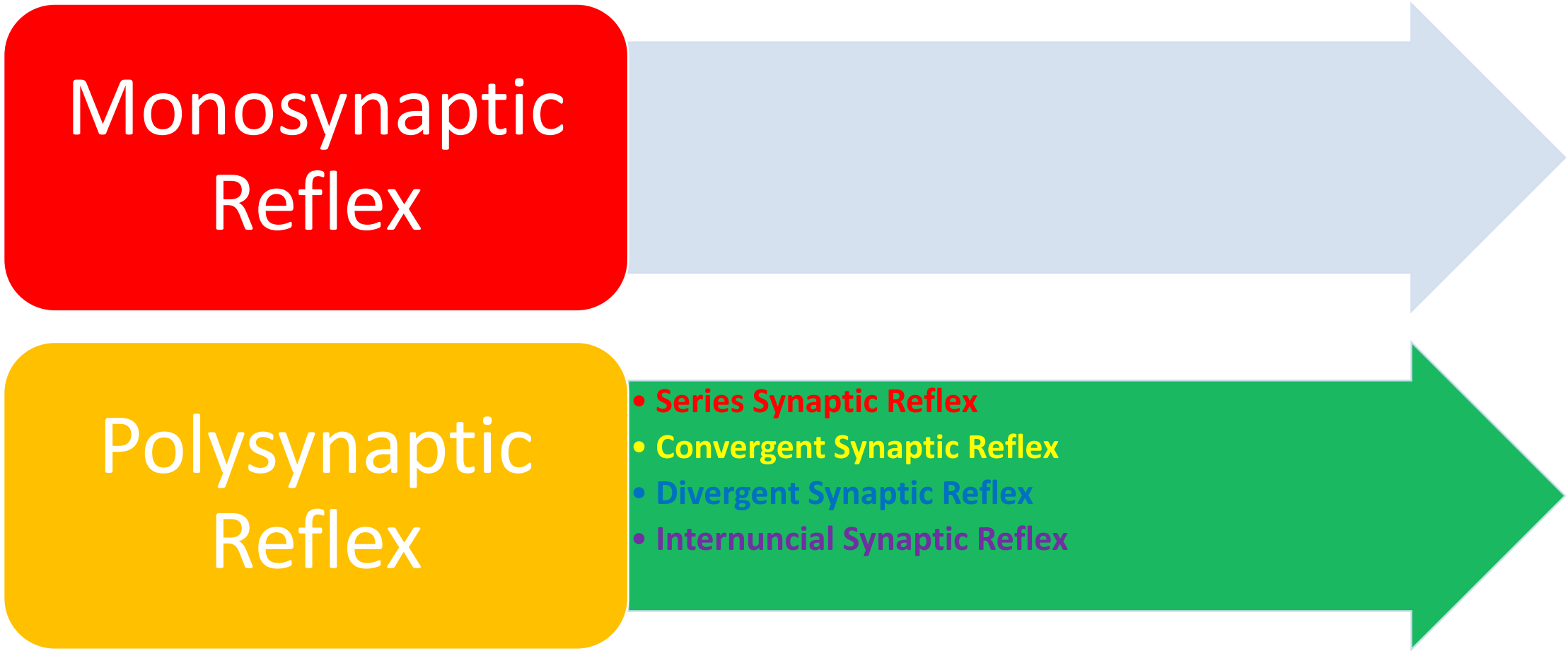
Classification of Reflex Arcs

- **Neurons may combine to give at least five types of reflex arcs.**
- **Monosynaptic reflex arc**: There is a single synapse between sensory and motor neurons of the spinal cord (without interneuron) e.g. Myotatic reflex
- **Polysynaptic arcs:**
- **Series synaptic reflex arcs-->** several simple reflex arcs are united in series to give a chain of reflex arcs, e.g. flexor and extensor responses related to muscle tone.
- **Convergent effector reflex arcs-->** two or more afferent neurons are in synaptic relation with only one efferent neuron. Hence, stimulation of many receptors converges to excite a single effector.
- **Divergent effector reflex arc-->** one afferent neuron is synaptic connection with two or more efferent neuron. Stimulation of a single receptor diverge through many neurons to excite more than one effector
- **Interneuronal reflex arcs-->** two or more afferent neurons are connected with two or more effectors. Stimulation of either of the two receptors causes reflex response in one or both effectors. The connections are established through interneurons. It provides reciprocal excitation and inhibition for smooth co-ordinated activity.

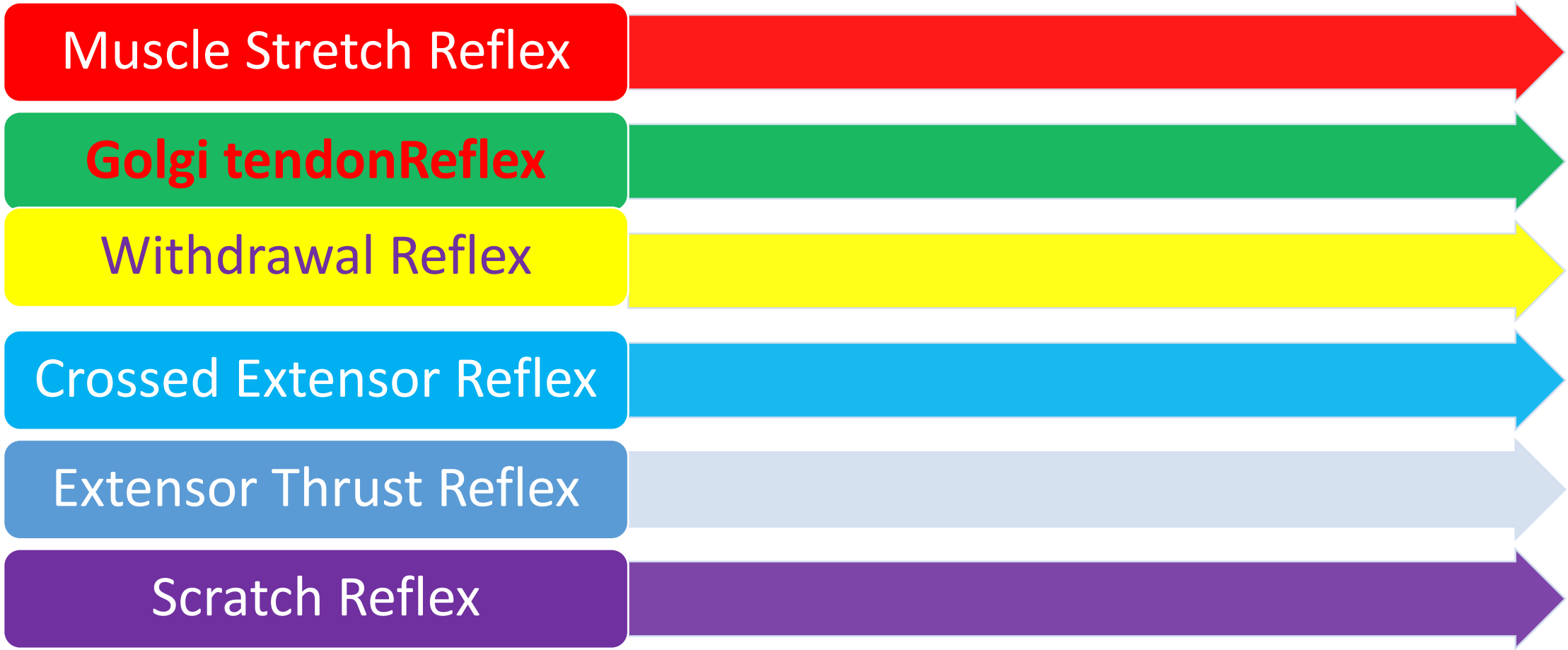
Muscle Stretch Reflex

- When a muscle is suddenly stretched, it produces reflex contraction of the same muscle; e.g., sudden tapping of tendon of a muscle contracts the muscle. This reflex is commonly referred to as myotatic or stretchreflex (a monosynaptic reflex)
- This reflex forms the basis for the maintenance of muscle tone.
- The CNS uses the information gathered from these receptors of the muscle to coordinate posture and locomotion.
- When the patellar tendon (insertion tendon of the quadriceps muscle) is struck with a blunt object, the whole quadriceps muscle is stretched, thus stretching the muscle spindle. Action potentials from the spindle receptors go to the lumbar spinal cord and cause excitation of a-motor neurons of the quadriceps muscle. This causes contraction of the muscle and the knee joint is extended – hence called the knee-jerk reflex. This is an example of muscle stretch reflex.
- Diseases of CNS, peripheral nerves and nerve-muscle connections cause abnormal stretch reflex. Clinically, this can be tested and the most commonly used clinical test is patellar reflex.
- A quick and firm tap on the tendon of quadriceps muscle immediately below the patella produces a strong stretch of the muscle which stimulates the muscle spindle and causes the quadriceps muscle to contract initiating the stretch reflex and the leg is drawn forward.

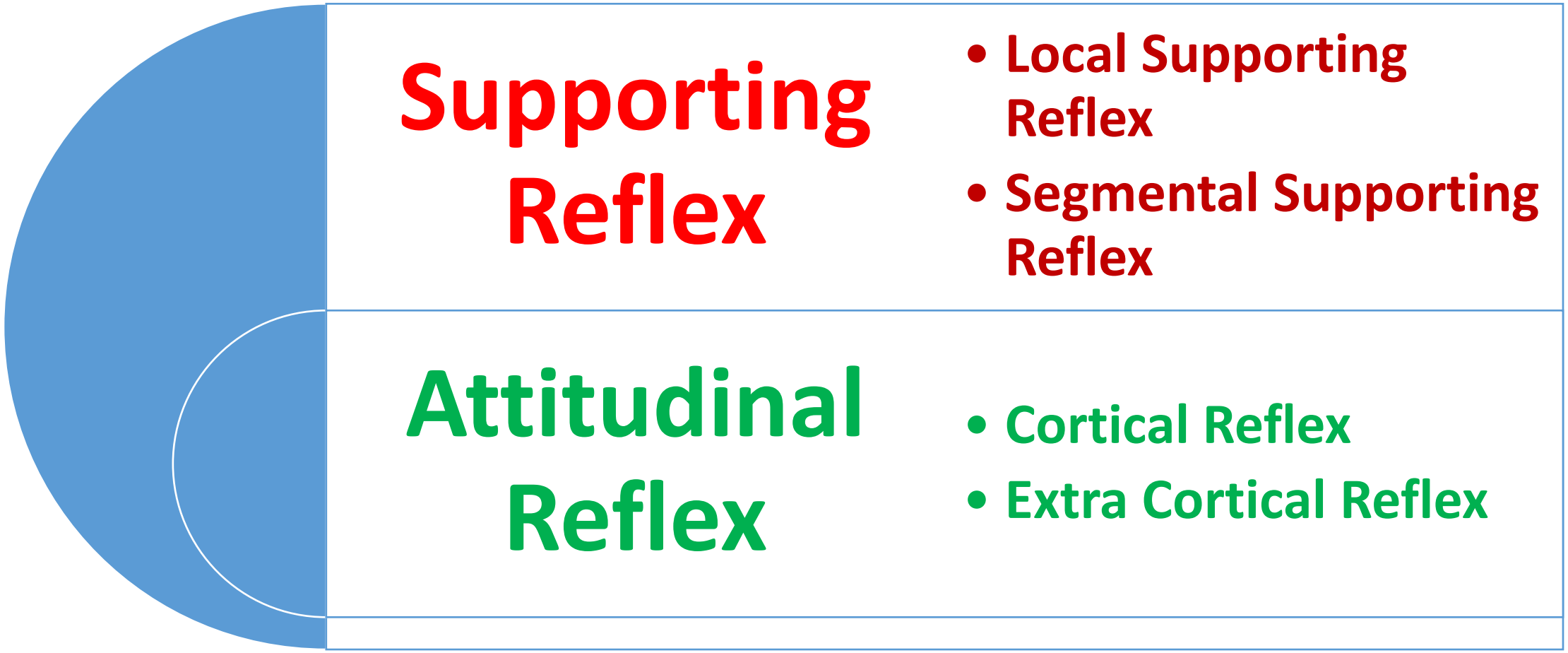
Neuronal Reflexes



Reflexes


Muscle Stretch Reflex
Golgi tendonReflex
Withdrawal Reflex
Crossed Extensor Reflex
Extensor Thrust Reflex
Scratch Reflex

Postural Reflex



Neuronal Reflexes

Cortical Reflex

- Tactile Placing
- Visual placing
- Vestibular placing
- Hopping

Extracorical Reflex

- Tonic NeckReflex
- Tonic Labyrinthine
- Righting Reflex

- **Withdrawal (flexor) reflex:**
- It is a protective reflex that serves to remove a body part from a painful stimulus by flexion.
- If a painful stimulus is applied to a limb, the animal will withdraw that limb automatically.
- The reflex arcs that produce the withdrawal involve many synapses; excitation of those muscles that will produce withdrawal by contraction of flexors and inhibition of extensors occur simultaneously.
- **Crossed extensor reflex:**
- About 0.2 to 0.5 sec after a stimulus elicits a flexor reflex in one limb, the opposite limb begins to extend. It is associated with the alteration of the posture involving extensors of the unaffected limbs to support the body.

- **Extensor thrust reflex:**
- When pressure is applied to the footpad (palmar or solar surface of the paw), simultaneous contractions of flexor muscles of the digits and the extensor muscles of the elbow extend the limb into a supporting column, which are initiated by myotatic reflex.
- **Scratch reflex:**
- It is multisynaptic reflex initiated by a combination of tactile and pain receptor organs which are associated with the terminals of class II, III and IV afferent nerves. They enter the spinal cord to terminate upon the interneurons.
- This reflex helps to remove the irritating stimuli from the skin of the dorsal and the lateral surface of the thorax and neck with one rear limb without affecting the posture of the animal.

POSTURAL REFLEXES

- Each species of animal maintain a normal orientation in space and this is referred to as *normal posture*.
- The posture of an animal is controlled by the activity of skeletal muscles of the neck and limbs. Structures that alter posture are located at all levels of the brainstem but most importantly within the medulla and pons.
- The control of posture involves many mechanisms capable of altering the activity of a-motor neurons of the spinal cord.
- The postural reflexes can be best studied in a decerebrate animal.
- Postural reflexes are group of reflexes that help to maintain body position and equilibrium either during rest (static) or during movement (kinetic) by changing the muscle tone in the limbs and trunk
- Postural reflexes can be divided into-
  - **supporting reflexes**
  - **attitudinal reflexes**

Supporting reflexes

- These reflexes involve initiating co-ordinated skeletal muscle activity to cause the limbs to be fixed into supporting columns against the pull of gravity.
- The supporting reflexes are further classified as
- *local supporting* (static) reflexes
- *segmental supporting* (static) reflexes
- *Local supporting reflexes:*
- These reflexes of the limbs produce a fixed standing posture, which prevents collapse under the force of gravity.
- **This reflex involves only a few segments of the spinal cord for reflex actions.**
- Local supporting reflexes include the myotatic reflex, and extensor thrust reflex.
- These reflexes are initiated by the stimulation of muscle spindle or cutaneous receptors of the limbs involved or by stimulation of the opposite limbs with noxious stimulus.

- **Extensor thrust reflex:**
- When pressure is applied to the footpads of a dog, that limb is extended into a supporting column by the extensor muscles of the elbow, which are initiated by myotatic reflex.
- **Segmental supporting reflex:**
- These reflexes use many segments of the spinal cord. Segmental supporting reflex arcs involve the spinal cord and brain stem. The reflex is represented by crossed extensor reflex. These reflexes involve sensory input to a local area and produce reflex activity over a wide region of the spinal cord. The same reflex occurs in the opposite limb. When a hind limb is extended, the opposite forelimb is also extended.

Attitudinal reflexes

- It involves modification of posture as a result of varying positions of the head (changing the muscle activity to maintain body position appropriate for various body movements)
- Displacement of one part of the body is followed by postural changes in other parts so that a new attitude/posture is assumed.
- This is classified into two types: ***cortical reflexes*** **and** ***extra cortical reflexes*****.**

Cortical reflexes

- These reflexes are mediated through cerebral cortex and includes
- ***Placing reflex:***
- **Tactile placing reflex:**
- If a blindfolded animal is tipped down in space towards a supporting surface, it will extend either the forelimbs or the rearlimbs ready to place them upon contact with the supporting surface. This reflex activity is associated with the motor cortex of the cerebrum and is mediated through corticospinal motor system.
- **Visual placing reflex:**
- If an animal is not blindfolded and tipped down, the limb will be extended toward the supporting surface before cutaneous contact is made. This depends upon the integrity of the visual system and descending corticospinal motor systems.
- **Hopping reflex:**
- This reflex is partly a tactile placing reflex, but also involves the myotatic reflex arc supplying the limb musculature. If an animal is made to stand on one limb and is moved horizontally in any direction, the supporting limb will hop to maintain support for the body.
- **Vestibular placing reflex:**
- Linear acceleration of an animal through space stimulates the receptor cells of the macula of the utricle. If the blinded animal is dropped in a head-down position towards the ground, the forelimbs are reflexly extended and the toes are spread apart in order to support the body against an expected contact with the ground.

Extracortical reflexes

- It is mediated through spinal cord, medulla and pons.
- It is of two types - the *tonic neck reflexes* and *vestibular* (tonic labyrinthine*) reflexes.*
- Tonic neck reflex:
- Neck receptors include muscle stretch receptors and receptor organs that sense the position of joints between cortical vertebrae related to head position.
- Extension of the neck upwards causes flexion of the hind limbs, and extension of the forelimbs to maintain horizontal position of the head e.g. when an animal walks down a steep slope, fore-limbs extend and hind-limbs flex to keep the head horizontally
- When the neck bends downwards the opposite occurs–hind limbs extend and forelimbs flex –like walking up a steep slope.
- Turning of head to right side causes the extension of both the right limbs and the flexion of both the left limbs to support the body against gravity; this helps to prevent falling.
- If the turning is on the left side, it results in the extension of the left limbs and the flexion of the right limbs.
- In this reflex, even though the equilibrium organs have not detected change in position of the head relative to the vertical axis, change in position of the head relative to rest of the body is detected by neck receptors which activates this reflex

Tonic labyrinthine reflex: (vestibular reflex)

- The receptors for this reflex are located within the vestibular receptor organ. These receptors of the vestibular labyrinth are receptive to linear acceleration or to the position of the head within the field of gravity.
- Movement of the head results in the stimulation of the otolith receptors and inform the change in head position to the CNS through the vestibular nerve. The activity of the tonic labyrinthine reflex maintains the head in a position as close to a normal standing position as possible.
- The response to labyrinth reflex is opposite to the neck reflex.
- If an animal is tilted forward without bending its neck, the position of the head is altered relative to the vertical axis. This causes reflex extension of forelimbs and flexion of hind-limbs to partially restore the initial posture. If the animal is tilted backwards without bending its neck, it will extend the hind-limbs and flex the fore-limbs. (Similar posture is assumed by dogs, cats while walking a steep slope which help to adjust the centre of gravity to a more central part of the body and this increases stability of the animal).

Righting reflex

- When a cat is dropped in a free fall towards the ground, the animal will use the righting reflexes to recover normal posture and land on its feet.
- First the position of the head is adjusted relative to gravity, followed by adjusting the position of body relative to head. Otolith organs detect the acceleration of the animal towards the ground which initiates reflex extension of legs so that the animal readies itself to land itself on its feet.
- The sensory organs involved in this reflex are equilibrium organs of the ear, neck sensory organs and pressure sensory organs of skin