Simulation of snake movements

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Approval sheet

The special project entitled "Simulation of fish / snake movements " by K.Srinivas is approved in partial fulfilment of the requirements for M.Des degree in Industrial Design.

Signature		Date
Guide		16.9.98.

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Contents

Objective

The ways in which biological mechanisms function are quite intriguing.The incomplete and tentative character of our knowledge in bio-mechanics was expressed by the great British biologist James Gray,who said , "A bird flying.....is one of nature's great master-pieces,and she guards very closely the secrets of her success.

The movement of fishes and snakes assumes another dimension of complexity because unlike other terrestrial animals they are limbless and flexible.Because the parts of the snake 's body that exert motive forces are never as clearly defined as those in species with limbs it is not obvious to a casual observer how such movement propels the animal forward.Such considerations make the movement of snakes a challenging task for simulation.

The objective of the project is to simulate snake movements and elucidate the way in the snakes actually manipulate their structure and apply forces to propel themselves forward. Secondly it aims at drawing inspiration from snakes to see new relations in materials and processes and create objects that would appeal to the human eye.

Understanding Movement

A body shifts forward if its centre of gravity moves forward.

The essential components

The mandatory components for any form of locomotion whether animate or inanimate are :

1. Stabilization of a multi-segmented structure - the skeleton, both intrinsically and extrinsically.
2. Propulsion by provision of an internal primary source of energy, namely muscle. This energy is then manipulated in the most efficient way to produce an external reaction.
3. A complex control system to maintain (1) and (2).

Principles of Biomechanics

The purpose is to define general principles of bio-mechanics for ease of understanding and analysing movement patterns.

The movement apparatus of living bodies is likened to a lever system.Bones are the levers rotated by means of muscles and external forces.

Basically there are two types of motion :

Translatory motion is the motion of a body moving from one place to another, with each part of the body moving an equal distance.The translation path may have any direction; the only criterion is that each particle of the body must move the same distance.

In rotatory motion the body/body segment rotates about an axis.

Human and animal movements tend to be complex and a third type of motion - a combination of translation and rotation, is the more common type of motion produced voluntarily.

Locomotion occurs, and the body translates as a result of rotations of two or more body segments.

Each anatomic axis and each axis external to the living body (external axis) may be described with respect to space - the axis may be represented as a line passing through the plane of motion and at a right angle to that plane.Therefore any rotatory motion in a horizontal plane will occur about a vertical axis.

The above description of motion provides the underlying basis for the analysis of motion.From this basis a determination of the sources or forces producing motion can be made.This description also provides an approach to the mathematic evaluation of motion in terms of linear displacement or angular displacement.

The role of muscles in the schema of movement

Muscles are the prime producers of movement. When a muscle contracts its attachments are normally drawn toward each other.This contraction exerts a tension on whatever is attached to the ends of the muscle.If the muscle fibres are pulling against the tendons or ligaments attached to bones ,the muscles will tend to draw the bones closer together. Skeletal muscles are activated voluntarily as well as reflexively,and their fibres contract with great rapidity.These muscles can shorten at speeds of upto 10 times their resting length in a second.The functional characteristics of skeletal muscles are rapidity and volitional control .

The flexor muscles have the task of initiating action,whereas the extensors maintain posture.

Procedure for assessment of basic anatomy of movement

One starts with the identification of the anatomic or external axes of rotation for the movements being performed.The plane of each movement is then identified as well as the type of joint about which the part is rotating.Possible muscles that might be contracting to produce or to facilitate the movement , as in the stabilization of a joint or other body part,should be listed These speculations are based on the plane of motion,as well as on attachments of muscles and their anatomic action,that is , flexion,extension and medial and lateral rotation.

Knowledge of the path of movement enables one to determine the probable muscles involved in producing the movement.

The Snake & it's Movement

Structure of the snake

The skeleton of snakes is a very simple framework,consisting of a long series of vertebrae,with the ribs free at their extremities and thereby pressing against the body wall as the snake rests upon the ground.There is no breast bone or other structure in the snake.The vertebrae articulate with respect to each other by means of a ball and socket joint.They are joined in such a way that one vertebra can bend up and down in relation to another through 28 degrees and swing from side- to- side through about 50 degrees.Even twisting movements can be approximated by a combination of up-and-down and side-to-side bending.

The ribs also articulate with respect to the vertebrae.The ribs are attached by strong muscles at their free ends to the ventral shields (scutes),the number of scutes and ribs corresponding,so that it is possible to determine the number of ribs by merely counting these shields.

The column acts to limit the extent of the bending , to give a firm basis against which the muscles can contract ,and probably owing to their resilience to bring the back to the middle line after a contraction.

SCHEMATIC TRANSVERSE SECTION OF THE BODY WALL OF A REPTILE

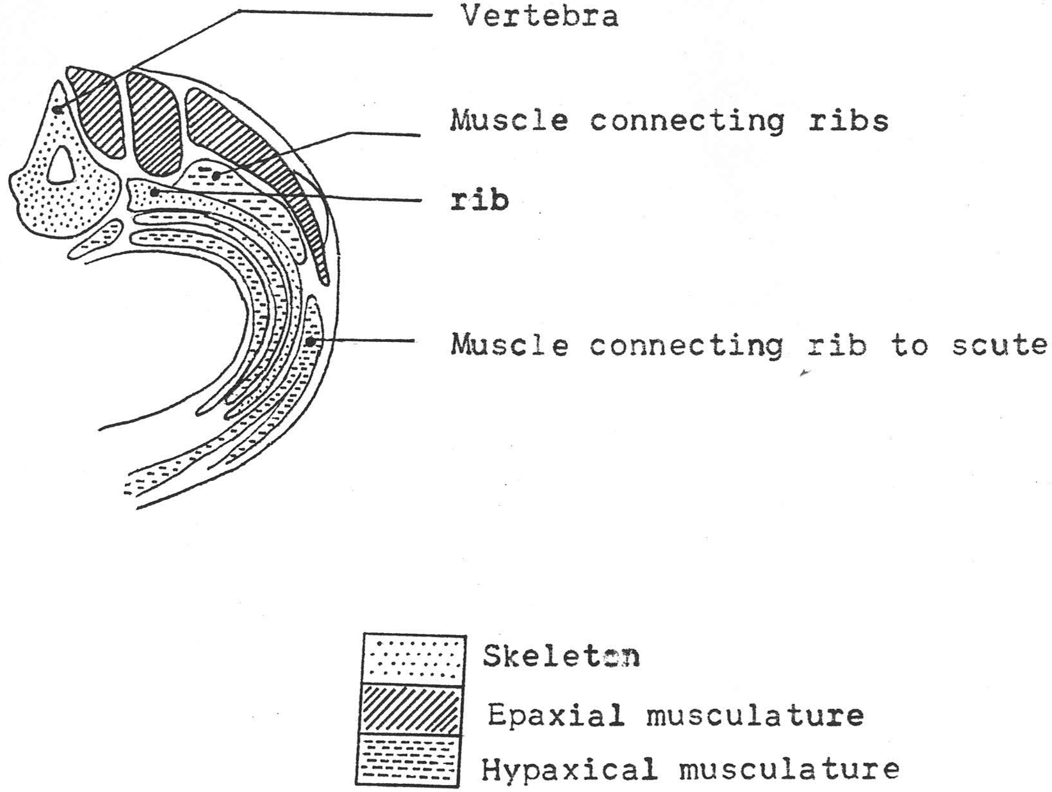


Fig 1

The fact that the divisions between the vertebrae are opposite the middle of the muscle segments and not between them may enable the muscle to bend the column more efficiently.

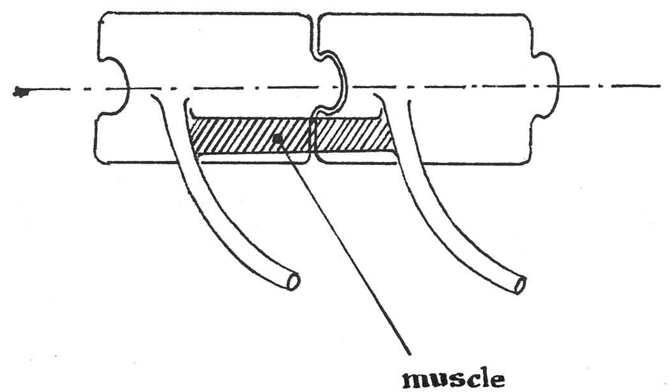


Fig. 2

Different forms of snake movements

Snake movements are divided into four distinct patterns :

Lateral undulation

Rectilinear locomotion

Concertina progression

Sidewinding

Lateral Undulation

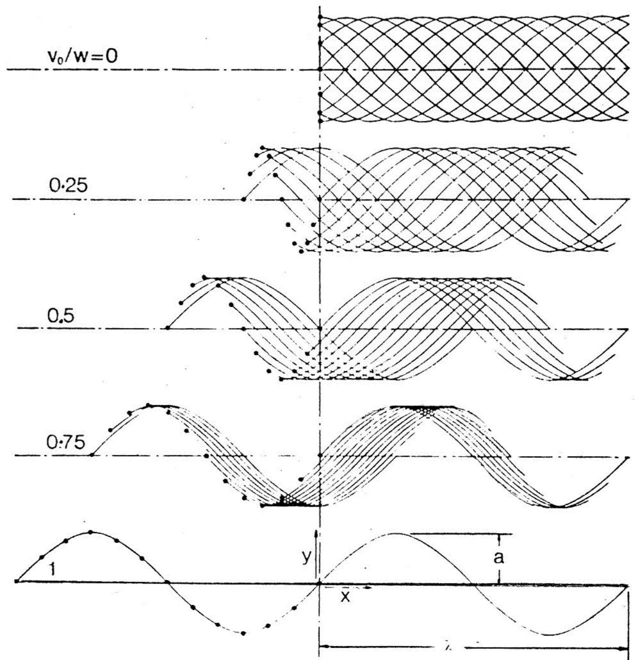
The normal forward movement of snakes on land is a creeping movement . The snake describes a 'snaking line'with its head,and the body follows this line over its entire length.The path laid out acts like a river bed between the banks of which the snake moves without leaving .The head acts as a steering element.In an idealized situation the snake's track can be seen to be a single wavy line each portion of the snake's trunk having traced this path.

The snake begins to undulate laterally by bending the forward part of its body.This movement establishes a wave like contraction that travels down the trunk.

When muscles contract and form a loop it causes a rotation about an external vertical axis.Internally it means that the snake is actually stiffening a part of the body so that it can exert a force on an external object to move forward. The contraction takes place to rotate the vertebrae laterally about their axis and partially assist their motion with respect to each other.This would result in a relatively stiff loop which can be used to exert forces.

Here it is significant to note that the snake does not move by exerting forces on the ground under its belly.Instead it moves by exerting forces laterally on irregularities in the snake's path - small elevations and depressions,pebbles,tufts of grass and so on. This is why a snake is not able to move on a plate of glass or any smooth surface.The snake in effect pushes itself off from such points the way a man sitting on a chair with castors can push himself away from a desk.

The speed at which a loop progresses down a snake's body towards its tail equals the forward speed of the snake ; the moving loops thus seem to be stationary with



Movement of slender body.

Oscillation wave of constant amplitude

w = Speed with which the waves (loops) move backward relative to the head

v_o = Forward speed of body.

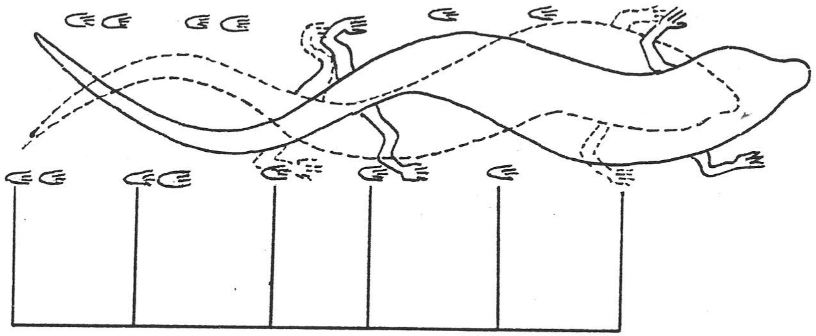
Fig 3

respect to the ground.This can better be understood by the diagram on page no. 14 (fig. 3).This diagram also illustrates that if v=w the snake can utilise fixed points on the ground to advance forward.

All the above facts are unique to the snake because it moves on land without limbs. It is interesting here to mention the motion characteristics of a tetrapod that resembles a lizard (fig. 4).This class of creatures evolved from fishes.Here the bends of the body can still be noticed.The stride of the limbs was at first an automatic result of the bending of the body.The limbs on one side of the body would be swung forwards as part of the body to which they are attached bends forward that side,and back again as the bend is reversed.

What is even more interesting is that even the path of the centre of gravity of the human being during walking is serpentine(fig. 5).For stability during walking it is necessary that the center of mass of the whole body remain within the support area. This means that during walking the C.G.would need to be moved over each foot in turn to achieve this.It is in fact moved towards the support foot storing potential energy which is returned as it then falls back.The interval is very brief(about 400 ms).

Motion of a Lizard-like tetrapad



Fore Limb

Fig. 4.

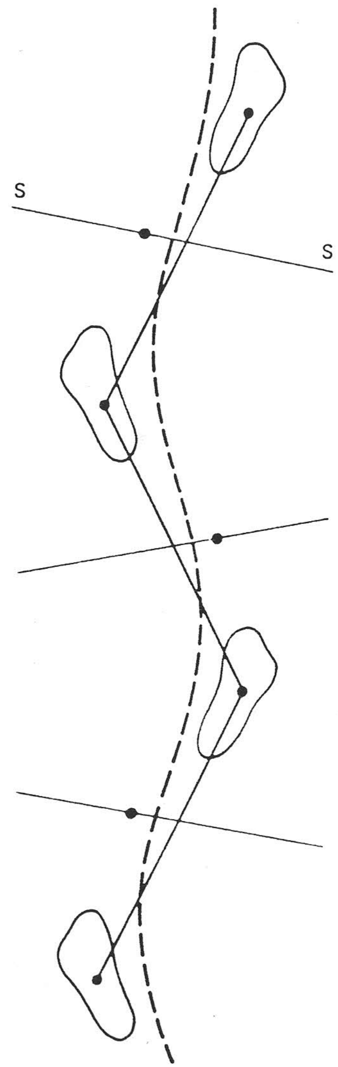
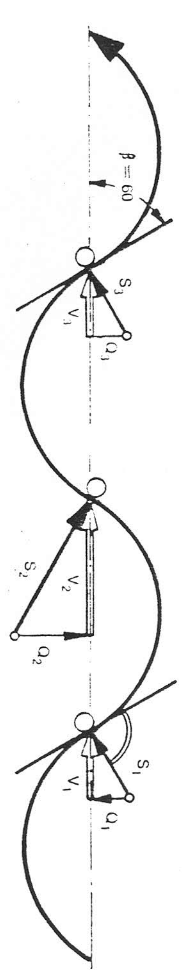


Fig 5 Normal walking. The dotted line is the path of the centre of mass (gravity). Note that it does not go over each foot as this assumes support. S-S is the shoulder line and moves in the opposite direction to the pelvis.

Both the motions described before (of the lizard and the human being) also involve a slight movement of the C.G. in the vertical plane.This is because both of them utilise the ground reaction to move.

Coming back to lateral undulation another important fact is that for continuous forward progresion the snake requires a minimum of three contact points at all times. The snake pushes against two of the sites to generate forces and uses the third to balance the forces,produced at the other two so that its body can move in a particular direction (fig. 6).

Yet lateral undulation does not work under all circumstances.It is useless for travelling down a tunnel with parallel sides -no backward directed forces can be exerted against the sides of the tunnel.It is also ineffective on a flat surface that lacks elevations and depressions ,and on a rounded surface such as a branch or a fallen tree trunk.An alternative is Rectilinear Locomotion.



SNAKE ON LAND

Crawling by means of lateral thurst at three obstacles

3 points of support along a steeper side surface ($\beta=60^{\circ}$) without friction against the obstacle.

Fig. 6.

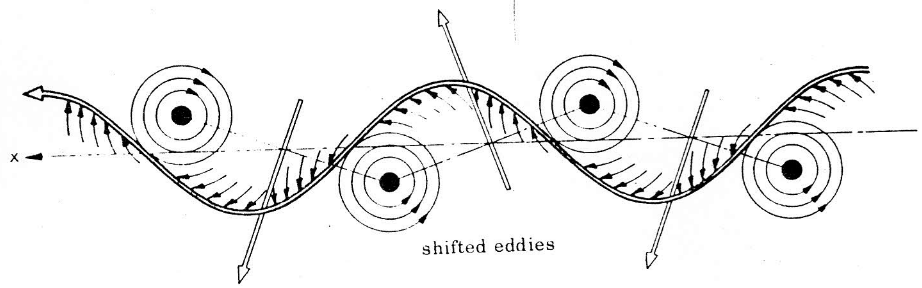


Fig. 7

Undulant path of a snake

It needs a minimum of three points to define the direction of travel.

Rectilinear locomotion differs from lateral undulation in two respects : it involves the application of force somewhat downward instead of laterally, and it is effective only if friction is established between the snake's skin and the ground.In order to move in this mode the snake fixes several series of scutes and starts to move the skin between them.For example ,it pulls together a series of scutes near its head , fixes them against the ground and then moves the rest of its body with respect to this fixed zone and several similar zones behind it..As the body of the snake moves forward the skin is stretched , pulling the forward most scutes of each series out of contact with the ground ,while additional scutes are continuously pulled up to the rear edge of the series.In this way a constant length of belly surface remains fixed to the ground. Normally a snake fixes two or three of these zones to the ground at once , and they can be seen to move continuously to the rear as the snake progresses.

The scutes are shifted forward by slender muscles that stretch forward from the sides of each scute to points high on the sides of each rib.A second set of muscles run to the rear at a shallower angle to attach the skin to the bottom ends of the ribs. Contraction of muscles in the first group pulls the skin forward and up, out of sliding

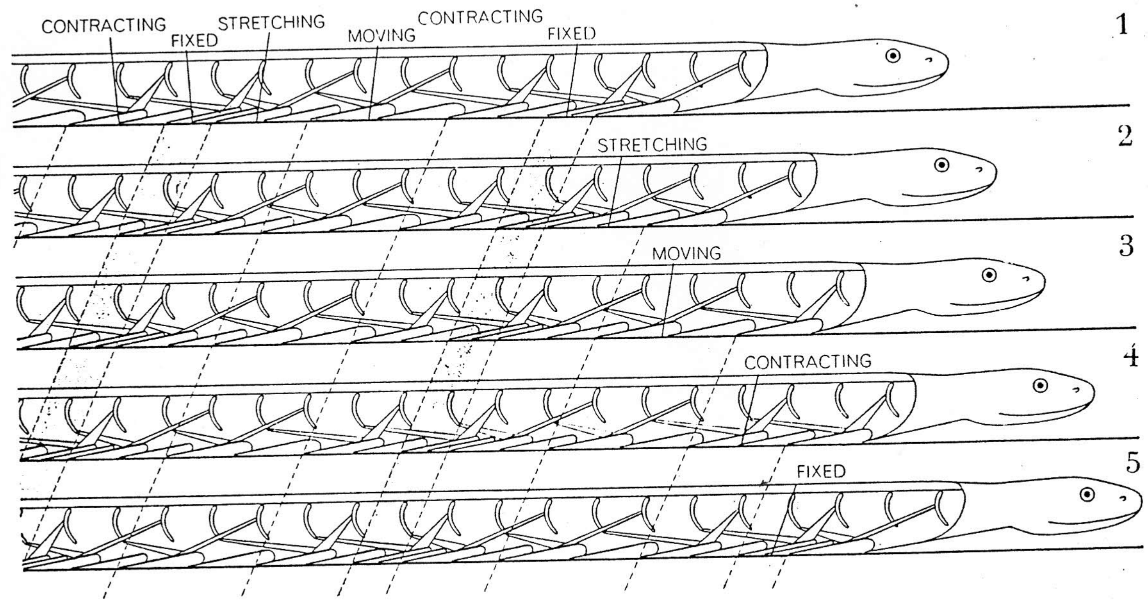


Fig. 8

RECTILINEAR LOCOMOTION enables a snake to advance in a straight line as it stalks prey or crosses a flat surface. In the snake pulls together two sets of scutes, its large abdominal scales, and fixes them against the ground. By pulling against these fixed zones that have established frictional contract with the ground the sname propels itself forward.

contact with the ground. Contraction of the stouter and better placed muscles of the second group accelerates the snake's mass and maintains its constant forward movement.

Such progression, however is slow because each must establish a stationary contact with the ground before it can transmit horizontal foces.

Most snakes that do not have muscle and bone structure necessary for rectilinear locomotion can still use static friction in locomotion by employing concertina progression.In order to move in this way the snake draws itself into an S-shaped curve,similar to the posture assumed in lateral undulation,and sets the curved portion of its body in static contact with the ground .Motion begins when the head , the neck and the forward part of the body are extended by forces transmitted to the ground in the zone that remains in stationary contact.These forces produce movement by acting against the force of friction generated by the weight of the body.

Snakes sometimes supplement weight induced friction by muscular force , thereby enlarging the static friction reservoir.Such modified concertina progression is often

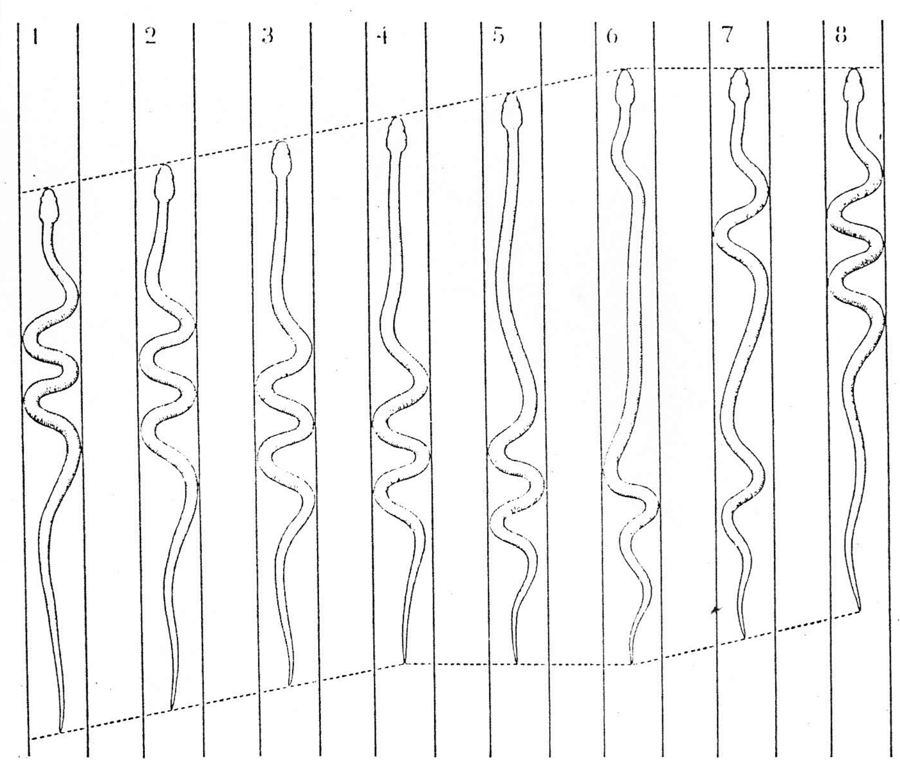


Fig 9.

CONCERTINA MOVEMENT enables a snake to move in a narrow channel. In 1 the snake begins to move by bracing S-shaped loops against sides of channel. The Snake then begins to extend its head and forebody (2) while pushing against passage walls until forward extension is complete (6) used to traverse a straight - sided channel or to climb tree branches.In the first instance the snake widens the amplitude of its S-shaped loops,actively pushing them into contact with the channel's walls. In the second instance the snake forces its stationary surfaces into contact by constricting around a branch.

Concertina progression is essentially a low speed pattern of movement because the animal must pause while it brings its rear end forward so that it can proceed again. Although concertina and rectilinear progression are suited to surfaces where lateral undulation would be ineffective,the price is lack of speed.

For pursuit or escape snakes need a mechanism that enables them to employ static friction without sacrificing speed.What is needed is a means of locomotion that keeps the zones that are in static contact from slipping,allows contraction waves to pass continuously and regularly down the snake's body and prevents minor irregularities in the surface affecting the pattern. Such a form of locomotion is sidewinding.A sidewinding snake achieves firm static contact by moving so that its body lies at right angles to the direction of its travel.The track of a sidewinding snake that has traversed a smooth flat surface appears as a series of straight parallel lines , each inclined some 60 degrees to the snake's direction of motion and and each about as long as the snake itself. The rear end of each line is bent into a short ,forward pointing hook.The track of scutes is well defined; slippage, if any ,can therefore only be sideways.

The series of actions producing these tracks can be visualized by assuming that the snake is lying so that its tail points about 60 degrees away from the direction in which the animal is going to move.The snake's head is raised and turned through an obtuse angle , so that it faces in the direction of travel. Only the bend of the snake's neck is in contact with the ground; this produces the hook at the reae end of each track.

As the snake starts to move forward it lifts its head and neck of f the ground .In order to reach the next track the forward part of the body has to curve in a loop. The extension of the snake's front end continues until approximately a quarter of the trunk is cantilevered out of contact with the ground.The head then arches downward as the cantilevered trunk remainsoff the ground;in making the first contact the neck bends at the next track of the sequuence,so that another hook is produced.Successive sections

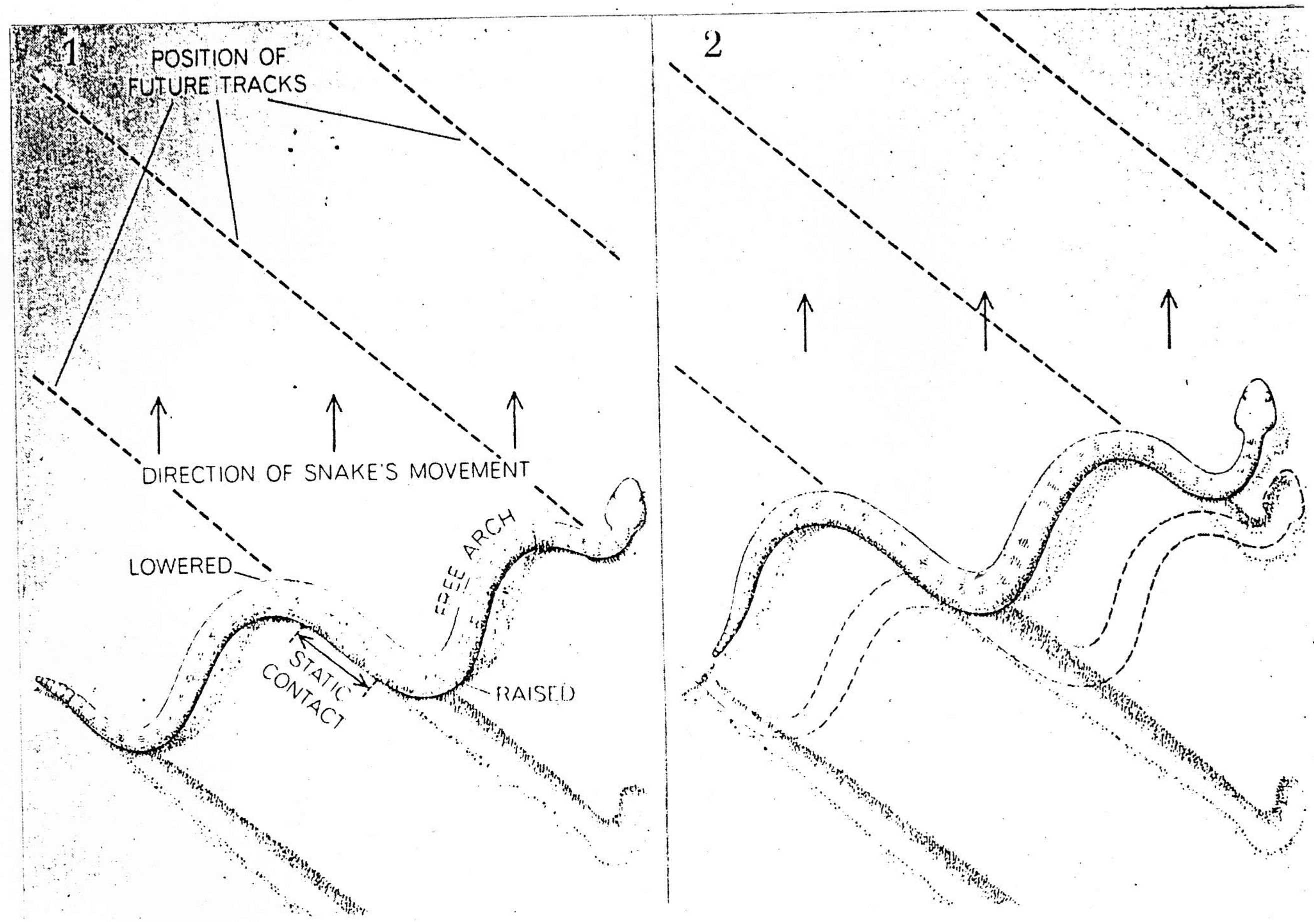

1
POSITION OF
FUTURE TRACKS
DIRECTION OF SNAKE'S MOVEMENT
LOWERED
FREE ARCH
STATIC
CONTACT
RAISED
2

Fig. 10

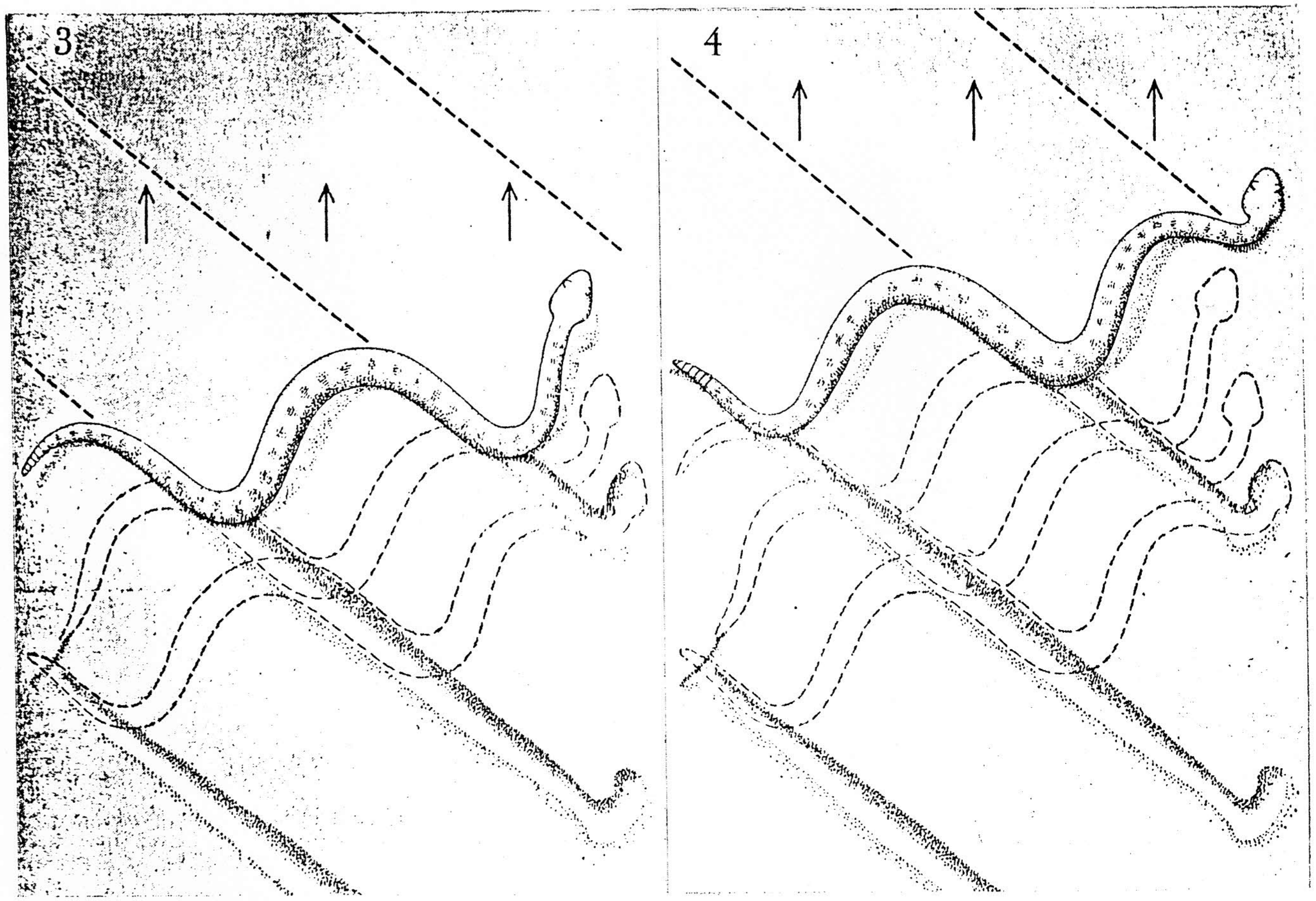


Fig. 10

of the body and then the tail follow along the new track, which parallels the preceding one.Considerably before the tail has been pulled into the second track the snake's front end starts into the third track.The body of a sidewinding snake thus lies on two or three separate tracks,with the body parts between tracks held off the ground.

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