The Cursian

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Part 1: The Cursian

The cursian is a round organism with 4 pairs of legs positioned equidistant around the body, as shown in Figure 1. An adult cursian grows to be an average of 1 inch in diameter, with legs of about .5 inches long when fully protracted. The cursian is covered in a hard Dura layer to protect it from the immediate environment. This layer extends over the lower half of the leg that is exposed. The rest of the leg is withdrawn into the body and only protracted to propel the animal for movement. The cursian has a central brain and segmental ganglia that correspond to the gut and legs. The gut follows the central axis of the animal and contains stretch receptors that signal when the animal is full. A cross-section is shown in Figure 2.

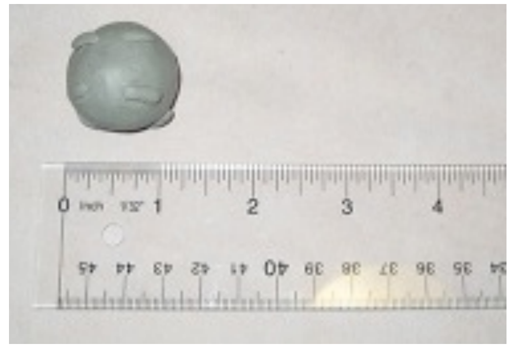

Figure 1 The average size of a Cursian

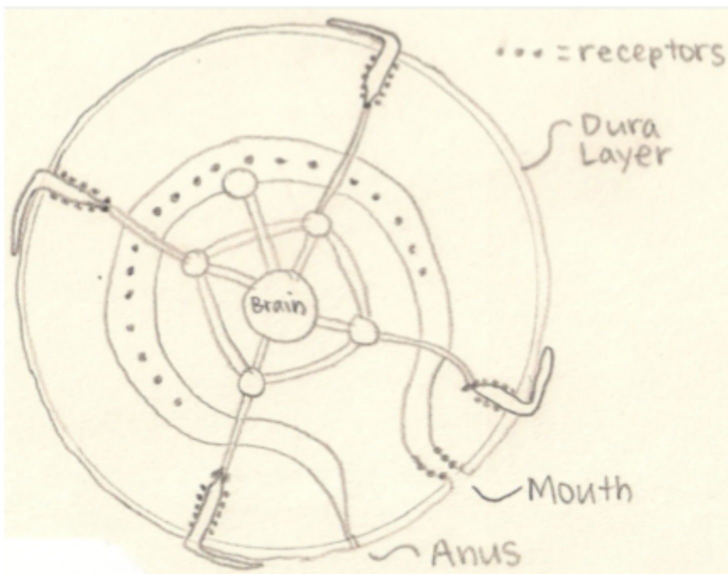

Figure 2 Saggital cross-section of a Cursian showing ganglia, effectors and sensory receptors.

The cursian possesses an extremely acute sense of smell, and this is its primary contact with the outside environment. The receptors for smell are located on and around the upper legs. It relies on olfaction: to tell when an enemy is near, which signals escape behavior, to know when another cursian or a potential mate is near, signaling a courtship response—a release of odorant molecules, and to detect nearby food and water sources, which it can taste with receptors in its mouth.

To roll, a cursian protracts one pair of its legs at a time. (Whichever is touching the ground at the moment.) This exposes the upper portion of the leg that is usually protected inside the body, and produces force, propelling the animal forward. To turn, a cursian will simply push with one leg and not the other. Because the animal is so small, it completes many revolutions per second, and is capable of making quick changes to its pattern of movement in response to environmental stimuli.

The nervous system has several ganglia. The exteroceptors for smell and taste relay directly to the brain, while the gut stretch receptors and leg proprioceptors relay to separate ganglia before connecting to the brain. Once these sensory signals reach the appropriate ganglia, and pass through interneurons, signals are then relayed back to the correct effector. In the case

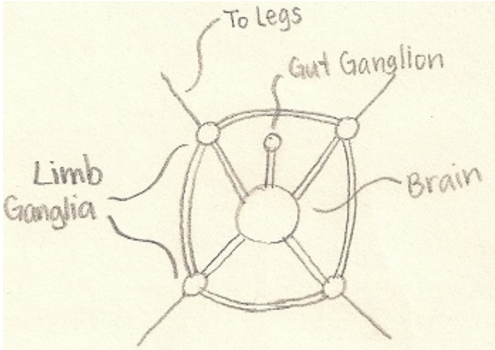

Figure 3 Summary of CNS ganglia

of courtship, a signal is passed to the leg joints signaling a release of molecules from the olfactory glands. For escape behavior, signals are sent to the legs telling which ones to protract, and therefore which direction the animal should be moving. This changes in response to olfactory signals. (If the smell of a foe is getting stronger then the animal will change direction until the stimulus decreases, etc.) When feeding, a cursian will smell food, move to the location of the food, stop when it reaches the food, and then locomote away from the food source once it receives satiety signals from the gut stretch receptors.

Part 2: Effector Organs

The cursian has two main types of effector organs: a mouth and eight legs. The mouth is a simple opening through the Dura layer that is composed of one large circular muscle with taste receptors embedded within it. The muscle continues into the gut, and is divided into segments to help push the food through the gut and out the anus. The mouth is innervated by motor neurons that synapse at the neuromuscular junction and release acetylcholine, which triggers an increase in the permeability to Na^+ and a depolarization and resulting contraction in the muscle cell. This contraction results in a sucking motion and intake of food by the mouth.

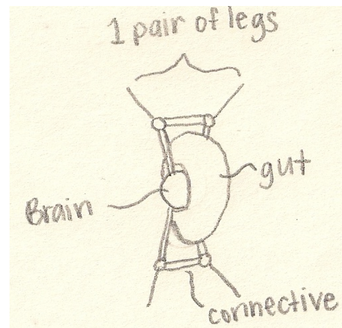

Figure 4 Detail of gut wrapping between connectives

Similar to annelids' circumesophageal connectives, a cursian's gut wraps around the central brain with the segmental ganglia positioned around it. The connectives that connect these ganglia to each other and to the brain must cross over and around the gut, as seen in Fig. 4.

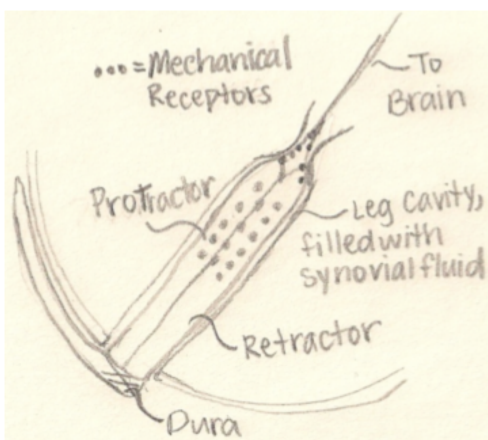

Figure 5 Detail of upper & lower leg with Mechanical Receptors

Although a cursian is capable of movement in any direction, a typical animal spends 90% of its time moving forward. This forward movement is propelled by bursts of its legs as they exit the body in pairs. A leg is divided into an upper and lower portion. The upper leg is protected inside the body during rest, while the lower leg is always exposed. The upper leg is composed of two large muscles, and the lower leg is composed of Dura, to protect it from the environment. A joint connects the upper and lower leg; this joint has limited mobility, mostly to absorb shock.

The inside of the leg cavity is lined with synovial fluid. This fluid acts as a lubricant, allowing for a quick protraction and retraction of the leg during motion. To protract the leg, motor neurons synapse directly on the upper leg protractor muscle, causing it to be released from the body. Once full protraction has been reached, motor neurons excite the retraction muscle, and the leg returns to its resting state. As stated before, the neuromuscular junction involves a release of acetylcholine by the motor neuron into the synaptic cleft, an increase in the permeability to Na^+, and a depolarization of the muscle cell.

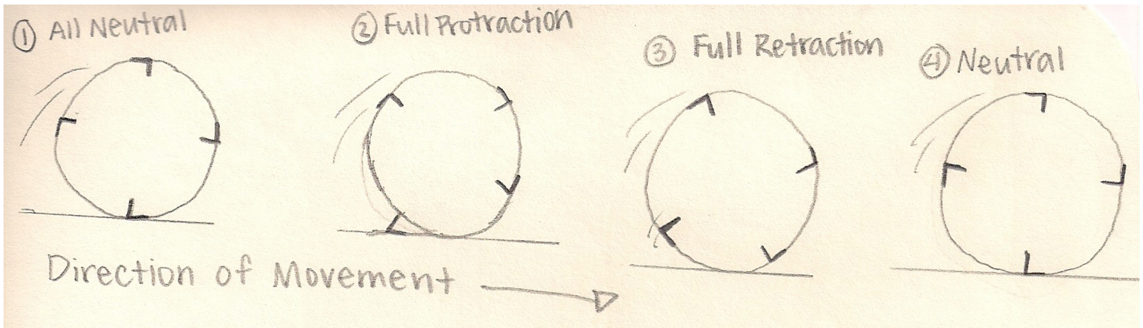

Figure 6 Method of Locomotion

Part 3: Sense Organs

The cursian possesses two types of exteroceptors—taste and olfaction. In the taste system (Figure 7), the activating energy is a food or water molecule and the receptor cells are the taste buds found on the walls of the mouth. A cursian eats fungi, fruit, and vegetables, and drinks fresh water. Gustatory transduction in the cursian works similar to that in humans. An activating molecule binds to a receptor and has either a direct effect on ion channels and results in a depolarization of the membrane or acts through a second messenger to trigger a G-protein and protein kinase cascade to depolarize the membrane. There are three types of labeled lines: Glucose receptors, which respond to most of the cursian's diet from basic plants to very sweet fruits (with fruits being the preference); Water receptors, which can distinguish between fresh and salt water; and a Protein receptor for when a cursian may ingest nuts, seeds, or other protein sources.

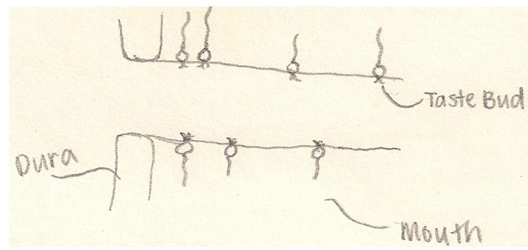

Figure 7 Detail of mouth with Taste Receptors

Olfaction is the cursian's most complex sense. The activating energy is any of a variety of odorant molecules, and the receptor cells are olfactory receptors that line the upper leg and inside of the leg cavity. For transduction, first the odorant molecule dissolves in the synovial fluid that covers the leg, easing its protraction & retraction. This fluid also covers the olfactory receptors. When the leg is retracted back into the leg cavity, it pulls odor molecules in with it, and exposes them to an additional hundreds of receptors that line the leg cavity inside the animal.

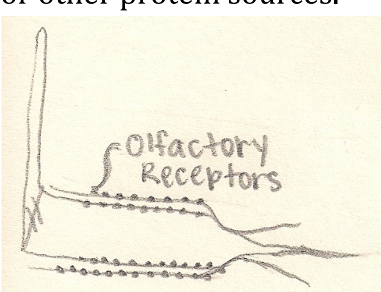

Figure 8 Detail of leg with olfactory receptors

Once the leg is inside, and the odor molecules are dissolved in the fluid, transduction can now take place. Binding to a receptor activates a G-protein-coupled receptor that does one of two things: activates a phospholipase C and IP_3, or links to adenyl cyclase, both of which lead to an increase in the permeability to cations and a depolarization of the membrane. While humans have about 30 known receptors for smell, cursians have double that amount, and this accounts for the incredible specificity found in that system.

There are four categories of olfactory labeled lines. First there are G (Giant) Receptors, which respond to food or water particles and trigger the feeding response. Second are F (Fright)

Receptors, which respond to foreign pheromones released by predators, and this triggers escape behavior and locomotion. Third are C (Courtship) Receptors, which respond to odorant molecules released by other cursians, and triggers a release of its own courtship molecules. Finally, D (Disgust) Receptors, which respond to noxious stimuli, including poisonous mushrooms, toxins, other airborne pathogens, etc, and this inhibits feeding.

The cursian also has several proprioceptors, including: a gut stretch receptor, amplitude and phase-modulating proprioceptors, and mechanical receptors on its limbs that detect if the leg is protracted or not. The mechanical receptors are found on the very proximal end of the leg, and fire in response to a loss of contact with the body when it leaves the body cavity and pushes off for locomotion. (See Figure 5 for diagram of the location of the mechanical receptors.) The mechanical receptors have two types of labeled lines. The first codes for the velocity of the animal. Timing for when each individual leg leaves its cavity is sent to the segmental ganglia and then collected by the brain. The brain then analyzes the time differences, and the cursian can tell exactly how fast it is going and correct its speed through negative feedback and regulatory connections to the muscles.

The second labeled line for the mechanical receptors codes for the position of the leg. These receptors are embedded farther into the membrane, similar to the myotactic reflex in humans, and respond to contractions of the leg muscle. These receptors are important for coordinating leg motion and also if a cursian loses a limb. Transduction for both types of labeled line works in a similar fashion. The mechanical receptor causes an increase in the permeability to Na^+ and K^+ which leads to a depolarization in the membrane and an action potential.

Both types of mechanical receptors are examples of phase and amplitude modulating proprioceptors, which work either directly on the motor neurons or on the CPGs. Phase modulating proprioceptors result from the timing of the CPGs, while amplitude modulating proprioceptors only modify motor neurons by controlling the number that are active, the size of active neurons, and their discharge frequency. These reflexes are present in the legs of the cursian and alter the discharge patterns for locomotion.

The gut stretch receptor also works like the myotactic reflex with one type of labeled line. The activating energy is a widening of the gut, the receptor cells are attached around the gut to sense changes in its size, and the transduction process begins when the stretch receptors become activated. These then relay to the ganglion for the gut and this terminates feeding by inhibiting the motor neurons that control the mouth (a negative feedback loop).

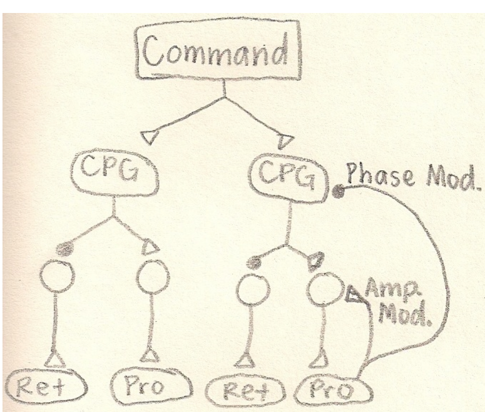

Figure 9 Command & CPG system for forward locomotion

Part 4: Pattern Generating Networks

Forward movement is propelled by alternating synergist bursts of one of the cursian's four pairs of legs. The CPG transmits opposite inputs to the motor neurons for the protractor and depressor muscles in the same leg, leading to an antagonist motion. The muscles also have phase and amplitude modulating proprioceptors which respond to changes in their immediate environment and can alter the CPG or motor neuron directly. Similar to loaded cockroach walking, these proprioceptors can change the burst period or the protractor discharge frequency in response to a stimulus.

When a cursian turns to change direction, it switches from synergist bursting in pairs of legs, to antagonist bursting using one leg at a time. A coordinating system mediates the communication between these two CPGs. This mechanism is run by a new command neuron and is mediated by an intercolated interneuron, which reverses the sign from excitation to inhibition of the leg that is no longer protracting. These command systems are present for each pair of legs and are on both sides of the body. Facilitation due to sensory feedback from the olfactory receptors determines the degree of inhibition by the interneuron. A facilitating neuron releases serotonin to decrease the amount of inhibition by the interneuron. No release of serotonin, means full inhibition, and a full push with the other leg, resulting in a turn of the cursian towards the leg that did no push. With only a few cycles of motion, the cursian can make a complete 180° change in direction. If the cursian wishes only to modify its path, the facilitating neuron will release a large amount of serotonin and stimulate the inhibited interneuron, causing an almost equal push from both legs, and the cursian will turn a little bit.

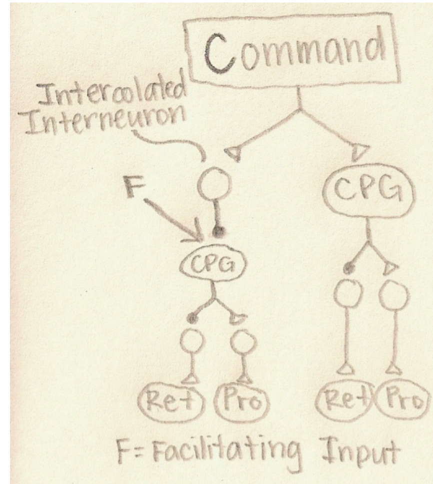

Figure 10 Command & CPG system for turning

Feeding is facilitated by an endogenous burster linked directly to the muscle. In the diagram I also included the gut stretch proprioceptor, which inhibits the burster once satiation has been achieved, and therefore terminates feeding. The taste receptors in the mouth are not included in the diagram because they continue a positive feedback loop that continues feeding until the gut receptor overrides their response. The only other way to terminate feeding is with an olfactory stimulus—the smell of a poisonous substance will immediately cause the animal to stop all motion of the mouth muscles.

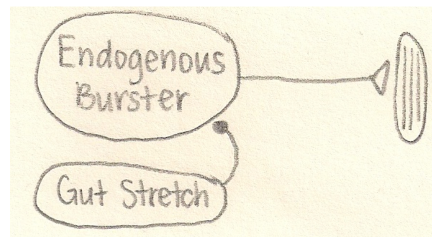

Figure 10 CPG for feeding

Courtship is quite interesting in cursians, and runs on a positive feedback loop. Cursians always emit molecule N, neutral molecule. When they run into another cursian, they immediately sense the presence of this molecule, and can tell if the other cursian is of the opposite sex. If so, the cursian will begin to emit molecule A, attraction molecule. The potential mate will now detect the presence of both molecules N & A in the air, and, if it chooses to partake in courtship behavior, secrete its own molecules N & A of similar ratio. The higher the amount of A, the stronger the attraction between the two cursians. If a cursian runs into another cursian of the same sex, it continues to release only molecule N. If it releases molecule A, but does not receive a reciprocal response from the other cursian, then it will decrease the level of A that it is releasing, and eventually be only releasing molecule N again.

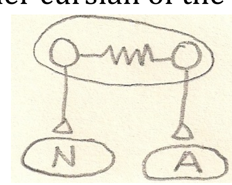

Figure 12 CPG for Courtship

This courtship response relies on neuromodulation. It works through a direct binding of a G-protein to the motor neuron that is synapsing onto the glands that release molecules N & A. Once the courtship response has been triggered in the cursian, the G-protein βγ-subunit modulates the N motor neuron directly and the G-protein α-GTP subunit modulates the A motor neuron directly to mimic the concentration of N & A molecules taken in. The glands then release the appropriate amounts of each odorant and the positive feedback loop continues. The motor neurons that innervate the glands are connected tonically so they fire in synergism so the release of molecules occurs simultaneously.

Escape is triggered by olfactory receptors, which sense the pheromones released by foes. The olfactory receptors also tell the cursian the direction of the foe because it can locate where which leg it is closest to by which leg terminal receptor the molecule was received on. Once the animal has decided to escape, it tells its legs to move. Signals are sent to the brain and then back to the appropriate command system. If the cursian has to first turn, the brain will activate the command for antagonist locomotion on the appropriate side. If the cursian can escape by running forward, it will activate the command for synergist locomotion.

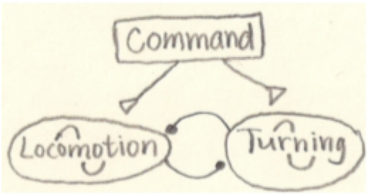

Figure 13 Command & CPG system for escape behavior

Once the cursian has decided which type of movment to make first, it alternates this movement with the other. For example, if the cursian determines that turning is the appropriate action to take, it will then run forward, turn again, run forward, turn again, etc. with equal amplitude and timing of bursts. The CPGs for turning and locomotion reciprocally inhibit each other and are both turned on by the same command neuron. Coordinating neurons also play a role here because they must coordinate the CPGs between synergist and antagonist locomotion so the cursian can smoothly transition between the two. Escape behavior terminates when the cursian no longer receives olfactory stimuli that the predator is nearby.

Part 5: CNS Network

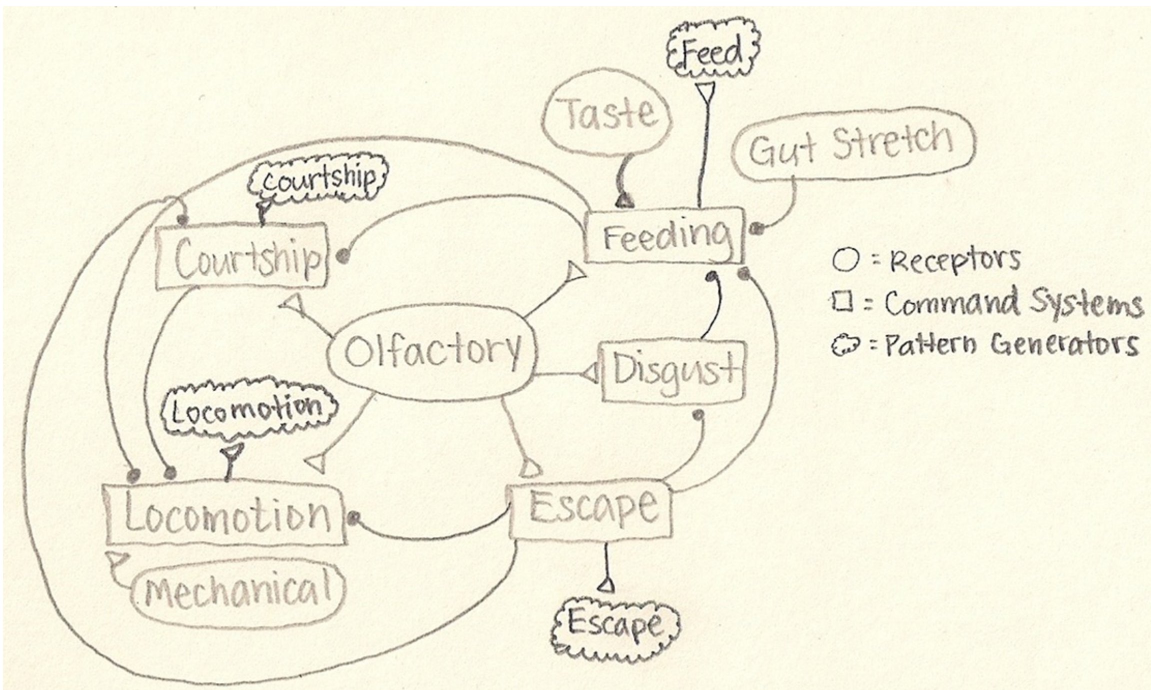

Figure 14 Diagram of entire CNS network

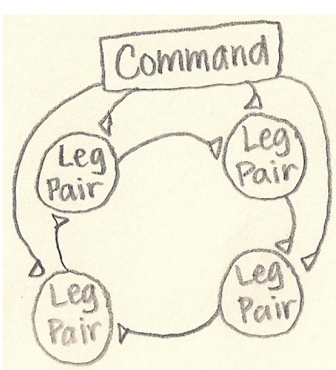

Figure 15 Coordinating system for leg motion

The CNS network results in four main CPG patterns, detailed earlier in section 4. These are feeding, courtship, locomotion, and escape. Escape is composed of forward locomotion and turning. Sensory feedback modulates these responses.

In addition, there is one main coordinating system, which regulates the pattern of leg discharge for locomotion. In this circuit, seen in Figure 15, each pair of legs excites the next and all the pairs are turned on by a command. When the cursian decides to stop locomotion, due to a sensory stimulus, this will turn off the command, and shut off each leg pair in succession until the creature has come to a stop.

Truth Table

	Sense Mate	Sense Enemy	Smell Food	Smell Toxin	Eat Food	Gut Stretched
Sense Mate	Courtship	Escape	Feed	Courtship	Feed	Courtship
Sense Enemy	Escape	Escape	Escape	Escape	Escape	Escape
Smell Food	Feed	Escape	Feed	Stop Feeding	Feed	Stop Feeding
Smell Toxin	Courtship	Escape	Stop Feeding	Stop Feeding	Stop Feeding	Stop Feeding
Eat Food	Feed	Escape	Feed	Stop Feeding	Feed	Stop Feeding
Gut Stretched	Courtship	Escape	Stop Feeding	Stop Feeding	Stop Feeding	Stop Feeding

For my truth table I compared four releasers from the olfactory receptors—sensing a potential mate, sensing an enemy, smelling food, and smelling a toxin—to releasers from the taste receptors in the mouth and the gut stretch receptors. Stopping feeding dominated, with 12 responses. Escape was very close, with 11 responses, feeding had 8 responses, and courtship had 5. Although I labeled in my table the behavior "stop feeding", this is synonymous with locomotion because as soon as the cursian ceases to feed, it begins to locomote. It was more relevant to put "stop feeding" in the table because many of the releasers dealt directly with the mouth and did not innervate the muscles in the legs (for example, the gut stretch receptors).

Cursians have several types of behavioral sequencing. For feeding, there is an appetative phase and a consummatory phase. Both of these are regulated by olfactory cues. During the appetative phase the cursian locomotes around by either turning or walking forward, and when it smells food or water molecules, it locates the source, positions its body so that the mouth is directly above the source, and then stops locomotion. Next, the consummatory phase begins, and where the mouth muscles are activated and the cursian begins to feed, receiving feedback from the taste and olfactory receptors increasing the act. This continues until an overriding stimulus (such as the detection of a predator), or the gut stretch receptor, signals the mouth muscles to stop feeding. The cursian once again begins to locomote, and the appetative phase starts over again.

Another behavioral sequence is courtship, which also involves the stopping of locomotion, the initiating of courtship signaling, and resuming locomotion once again. This is modulated in the same way, by the olfactory system. When N & A molecules from anther cursian are detected, inhibitory signals are sent to the command system for locomotion and the cursian will stop moving. Next, the cursian will initiate courtship. Once courtship is over, it will resume locomotion, which is triggered by a neutral position of the body and a lack of stimulation of the olfactory courtship glands by molecule A.

A final behavioral sequence is escape. When escape is initiated, a cursian's F Receptors bind to an olfactory molecule and send relay a signal to the brain, turning on the escape command system. This initiates alternating patterns of turning and forward locomotion. These patterns continue until the system no longer receives olfactory signals detecting the presence of a predator. When this command system no longer needs to function, the regular command for locomotion takes over, and the cursian resumes regular behavior.

Part 6: Coping Behavior

A cursian has four man behaviors: escape, feeding, stop feeding/locomotion, and courtship. Escape is released when a cursian senses the olfactory molecule from a predator. This pathway is extremely sensitive, as a single molecule can trigger this response. When a molecule is received by the receptors in the olfactory organs in the legs, a signal is passed to the brain and then a motor command is relayed back to the legs triggering locomotion away from the source. At the same time, inhibition of all other behaviors takes place, until the enemy is no longer detected.

Feeding is triggered also by the olfactory system, when a food or water molecule binds to a cursian's G Receptors. This sends a signal directly to the brain, which is relayed to the mouth muscles and signals them to start a sucking motion. Because the olfactory system is so acute, the cursian finds exactly where a food source is and places the mouth over the location before sucking initiates. Feeding is terminated by the gut stretch receptors, by the olfactory D Receptors, and by the smell of a predator. It is maintained by the taste and smell of the food.

Terminating feeding is immediately followed by locomotion. When a cursian receives an olfactory stimulus terminating feeding, the message is relayed directly to the brain before reaching the muscles in the mouth; the gut stretch receptors relay to the gut ganglion before reaching the mouth. After the mouth has stopped moving, the cursian is now in neutral position, and locomotion resumes. Whichever leg is closest to the ground will protract, pushing the cursian forward and starting rotation. Proprioceptive feedback from the legs from mechanical velocity and position receptors help modulate the animal's increase in speed as it resumes regular locomotion. The entire time the olfactory system is taking in many molecules from the environment, and the locomotory system is the first to respond—it can change direction in response to an olfactory cue and initiate any other type of behavior—feeding, escape, or courtship.

Courtship only dominates over locomotion, and this is because it takes place when the animal is stationary. It is triggered when the animal's olfactory C Receptors sense the presence of another cursian of the opposite sex. If the cursian is in motion, it will immediately stop locomotion and begin the courtship sequence of behavior. Signals from the C Receptors are transmitted directly to the brain, which relay back to the muscles in the olfactory organs and trigger a release of molecules N & A. This continues until courtship is complete or until it is interrupted by another behavior.

When simultaneous behaviors are released, a cursian must choose between them. This depends on which dominates, as seen in the truth table above, and is due to several mechanisms. Overall, stopping feeding and escape almost equally dominate all other behaviors. When confronted with a choice between running away from an enemy or stopping feeding, escape behavior always dominates; there are just more releasers for stopping feedings, which is why the truth table may make it seem like this is the dominant behavior. Escape behavior dominates because it inhibits all other commands while the mechanism for stopping feeding is inhibition between CPGs. Courtship hormonally suppresses commands, such as locomotion, while feeding behavior and smelling food are the sensory suppression of commands for locomotion and courtship.