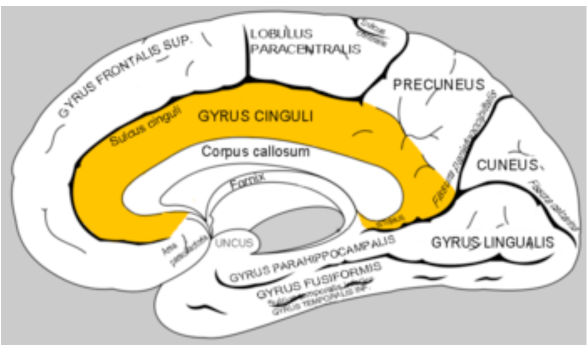
6. The Inborn Error Detector

Pee-wee: There's a lotta things you don't know anything about, Dottie. Things you wouldn't understand. Things you couldn't understand. Things you *shouldn't* understand.

Dottie: I don't understand.[1]

The brain has a built-in error detector: it sounds like wishful thinking but a part in one's brain does just that. Its function is to discover if *Something is wrong here*. It is the **cingulum** and OCs have a hyperactive cingulum.



The cingulum (or the cingulate gyrus) is a strip of brain tissue at the inside/bottom of the cerebral cortex. The figure at left is a slice right down the middle of one's brain, a sagittal section, as in Sagittarius, the archer. *Cingulum* means *belt*, and it stretches like a belt around the corpus callosum, a thick trunk line of nerve fibers that connect the right and left hemispheres. We have a cingulum in each hemisphere, and the front part of it (the anterior cingulate cortex) is our inborn error detector. Some of us have robust cingula. Others have puny cingula and you don't want to trust them with anything important if you can help it. A weak cingulum lets a lot of mistakes slip by.

An inborn error detector makes sense if we think of brain as it is rather than analogizing to computers or whatnot. Brain is an accretion of layers that have been lain down during evolution. Each layer has multiple parts – brain centers, nuclei or ganglia -- that perform different functions that reflect the functions of parts at lower levels, but the higher levels perform their functions in progressively more complex ways. At every level of brain evolution, there are parts responsible for perception, parts that execute behavior and parts in between that connect perception and execution. The intermediate parts lend a measure of thoughtfulness to the connection.

Consider the frog, whose brain is very simple, especially the parts that permit him to catch flies. If a frog's eyes perceive a bug flying by, the nerve that carries that information to the frog's brain connects directly to the nerve that directs the frog's tongue to stretch out and catch the bug. There isn't much in between and the frog doesn't have to think much about what he or she is doing. Evolution, having cultivated animals who need to do more than just catch flies, has gradually interposed neural elements, nerves, synapses, brain parts and neural networks between sensory input and behavioral output, and we have been paying the price ever since.

The brains of the higher animals are like a family of parts, some older in terms of when they evolved and some younger. Whatever level those parts occupy, they serve the brain's three functions, input, output and processing in between. The functions are served in the lowest part of brain, the brain stem, which we share with fish; in the basal ganglia, which we share with reptiles and birds; in the limbic cortex, which we share with lower mammals like rats and mice; and in the cerebral cortex, which we share with the higher primates, the hominoids. Since parts at every level participate in perception and execution, and parts at every level from the basal ganglia on up participate in processing, or cogitation, evolution has preserved the connections among the relevant parts at every level.

If Nature had been kinder to students of brain anatomy, She would have marked all these parts with well-defined margins and in different colors, like the pancreas, liver and bowel in one's abdominal cavity. The connections among pancreas, liver and bowel, though, are simple and straightforward: a few tubes and some blood vessels. The connections among parts and layers of brain are inordinately complex, and even today they haven't been all worked

[1] Pee-wee's Big Adventure

out. Every time one picks up a journal in this learned field, one reads that new connections have been discovered. It's hardly a surprise, because the 100 billion neurons in human brain contain more than 60,000 miles of connecting fibers.(Hofman, 2014)

Fitting 60,000 miles of anything into a cranial cavity with room for a liter and a half of wine was a formidable exercise and to accomplish the feat Nature abandoned the possibility of color coding and sharply defined margins. The parts of brain, therefore, are contained in 1500 cc of jelly-like substance, their borders are diffuse and they are not easy to differentiate one from another. They aren't discrete organs but meld together in the more-or-less homogenous brain substance.

Some brain functions are localized to specific regions; these are the most basic functions, like physiological control, movement and perception, which are phylogenetically ancient. That means that similar regions perform the same functions in lower and higher animals. The higher functions of the human brain, however, evolved comparatively recently, among the primates first and then, in a fit of evolutionary exuberance, among the hominids. They are complex functions, not well-localized, but distributed in the vast expanse of the cerebral cortex. The mental operations that we experience as thinking, feeling and doing reflect the activity of the highest parts of brain but they are not localized to the cerebral cortex. Their operations must be integrated with the more basic functions of the lower brain.

This integrated activity is possible because of networks that exist to connect the various brain regions. Neural networks are composed of nerve cells, neurons, and their branches, axons and dendrites, that carry electrical signals away from one nerve cell and towards another. Communication between an axon carrying a signal away from one neuron to a dendrite that carries the signal to the next neuron is made by small molecules called neurotransmitters.[2] Books of this ilk, especially those written by psychiatrists, make much of neurotransmitter theory because the chemistry of neural communication is the basis for drug effects in many psychiatric and neurological disorders. The dramatic impact those drugs have had on modern life has strengthened the view of brain activity in terms of neuron-to-neuron communication. That is one way of viewing brain function but it is only a partial view.

Neurons are the building-blocks of brain activity but the functions of brain are not carried out by neuron A talking to neuron B. They are an expression of the activity of neural networks, assemblies of thousands or millions or billions of neurons communicating together or, better, resonating together. The chemical activity within such networks allows neurons to participate but the activity of a network is electrical not chemical.

A neural assembly or network vibrates or oscillates. As it oscillates, it generates a signal, as a radio transmitter does, and the nature of the signal is a reflection of the amplitude and frequency of its oscillations. It also reflects the behavior of the innumerable neurons who are participating in the network at that particular moment. The signal thus engendered we can think of as a **brain field**, like a magnetic or an electrical field, and it has elements of both. As the signal is generated, it incorporates or excludes groups of cells by changing the frequency of its vibrations. It does so at intervals measured in thousandths of a second. This ever-changing network of communicating nerve cells is something like a chorus.

Neurons can participate in many different cell assemblies, because assemblies are decidedly *ad hoc*. An assembly of brain cells comes together around a particular thought or perception and it changes as the thought comes into focus. Then a new thought comes into focus as different neurons join the network. Neural networks recruit cells from different regions in a constant state of integration and disintegration that seeks nothing more than to maintain an harmonious, rhythmic brain field. Such rhythmic assemblies generating brain fields are what we experience as thinking, feeling and doing.

The frequency of the vibrations of a neural networks may be slow, like the delta waves that characterize deep sleep, alpha waves which indicate a relaxed mental state and gamma waves, the highest frequency oscillations that high lamas can achieve during deep meditation. These oscillations show up as brain waves on an EEG that has electrodes planted on one's scalp. The EEG is a summary of all the electrical activity on the surface of the brain and is only a gross reflection of what is going on within.

[2] Neurotransmitters include dopamine, serotonin, acetylcholine and norepinephrine. There are more than 50 neurotransmitters in the human brain.

Beneath the surface of the brain, there are neural assemblies vibrating at different frequencies as they go about specific activities or as they take a bit of rest in what is called their default mode. In order to do something or to have a coherent thought or feeling, the oscillations of multiple neural networks have to be recruited. Simple reflexes like and eyeblink or a frog catching a fly require only one simple network, but anything more complicated than blinking one's eye or catching a fly with one's tongue requires the integration of multiple networks.

The coming-together of neural networks is successful when their frequencies are entrained or synchronized. We do this all the time and quite easily, too, because our brains have learned to synchronize certain oscillatory patterns in combinations of networks during the long course of development and maturation. For example, synchronizing the neural networks that connect the occipital and parietal lobes (visual perception and spatial organization), the temporal lobes (language) and the prefrontal cortex (eye-movement, attention) is necessary for the act of reading, something that most of us do with facility. Reading is an over-learned behavior and the synchronization of broad swathes of brain tissue is virtually automatic.

THE STROOP TEST

The integration of neural networks distributed throughout the brain, including brain parts old and young, is a challenge that can give rise to conflicts, and these occur all the time. We can illustrate such a conflict with something called the Stroop test. (The Stroop is one of the tests on www.atonc.com.) Here is a reading assignment that you will not find difficult. Read these words aloud:

Blue Red Green Brown Purple

It's an easy assignment because reading is over-learned and the five words just entail the entrainment of the usual neural assemblies. Now, read these words aloud:

Blue Red Green Brown Purple

If anything, it is even easier even though two neural networks are involved, a reading network and a color-recognition network. The two networks operate concordantly because the lexical meaning of the words and the colors they are printed in are the same. Now try this one. Read the *colors* the words are written in:

Blue Red Green Brown Purple

This one takes longer because it is more effortful. The lexical meaning of the words is discordant from the colors in which they are written. Two neural assemblies are operating at cross-purposes and the challenge is to de-activate an overlearned response (the lexical meaning of a word) and to activate an unfamiliar and counter-intuitive response, naming the color of the word. A more powerful neural assembly has to be suppressed and there is an error-detector in one's brain that tells you it's the wrong thing to do. As it happens, OCs have more difficulty on the Stroop test than people who are not OC.

The connections between the older parts of brain, in the brain stem, and the younger parts in the cerebral cortex are quite strong because the latter is evolved from the former and they are interdependent. The continual cogitations of one's analytical mind in the cerebral hemispheres depends on lower brain regions for essential support functions, like perception (the thalamus), the execution of movement (basal ganglia, cerebellum) and the meaning of whatever it is one happens to be doing (the social/emotional brain in the limbic cortex). These connections are in the form of circular circuits, or **loops**, that integrate the activity of higher and lower brain regions. They are loops because the go from part A to part B to part C and then back to part A. All three parts participate in the loop, feeding-back and -forward until the activity of the loop is brought into proper synchrony.

The loops channel inputs from various sources. Different neural assemblies oscillating at different frequencies feed into the loop. It integrates inputs by binding them into a synchronized signal. The input networks adjust themselves until they are all in synch and the whole loop lights up. One can imagine different oscillations running round and round the loop until they are properly synchronized. When the signal has achieved synchrony coherent behavior arises, a thought, a feeling or an action program.

During the second and third parts of the Stroop test, there are two neural assemblies feeding into the OC loop. One is the neural network concerned with lexical meaning of the words and the other is the color-in-which-it-is-written network. When the two inputs are congruent, the OC loop lights up quickly. When the two networks are incongruent, their oscillations enter the OC loop in a dyssynchronous way, and rumble around the loop until they synchronize themselves at the frequency of the color network. The rumbling around takes a long time for all of us, but for OCs it takes a really long time. The dyssynchronous oscillations are perceived as an error and an error-detector built into the loop tries to correct it. A hyperactive error-detector, though, wants those oscillations to get just right, it's bothered because they fly in the face of normal reading. So it recruits additional chunks of neural tissue, especially in the cerebral cortex, to solve the problem. It calls forth an additional increment of top-down control. Ironically, not only do OCs take longer on the third part of the Stroop test, they make more errors than non-OCs do. They are so preoccupied with getting it right they get it wrong. There are times when brain science hits the nail on the head.

There is one particular loop, the lateral-orbital-striatal loop, that it is particularly active in the OCs. The LOS loop occupies a **convergence zone** between the analytical mind, the vast expanse of the cerebral cortex and a host of other structures like the basal ganglia (striatum), thalamus and cingulum. It also touches upon brain regions that are associated with the experience of emotion. The functions of these structures and the loops that connect them can be subsumed in the general category of behavioral integration.

I shall refer to this loop as the OC loop, although there are many other loops and circuits that participate in the psychology of OC. The OC loop lights up when a patient with OCD is inserted into one of those functional imagers, like a PET scanner. The observation has been replicated many times, although there are other conditions, like anxiety, that also light up the OC loop. The association of this particular loop with OC is credible because it is complemented by information from other sources. The various neurotransmitters, for example, occur in different concentrations in regions of the brain. Because the drugs that ameliorate OC symptoms affect the neurotransmitters **serotonin** and **dopamine**, we should expect to find serotoninergic and dopaminergic neurons in brain regions that comprise the OC loop, and we do. There are psychological tests that OCD patients can't perform very well, like the Stroop test. The tests should reflect the known functions of parts of the OCD circuit, and they do, at least to a degree. There are symptoms that OCD patients have that patients with other neuropsychiatric disorders don't have; those symptoms reflect the known functions of the OC circuit. We know from lesion studies that damage to the OC loop is associated with irritability, emotional instability, failure to respond appropriately to social cues and lack of empathy. Many (but not all) of the symptoms of OCD are reflected in the known functions of the OC loop.

THE CINGULUM

All of the parts participating in a loop feed-back and -forward until the activity of the loop is brought into proper focus. The proper focus is determined by the cingulum which operates as if he were an *homunculus*, a little man, a word biologists use to describe the ghost in the machine. He really isn't a little fellow, although he has a mind of his own. He has the extraordinary ability to appraise the nature of all the inputs that feed into the OC loop. He must be doing something like measuring the frequency of the various signals, looking for dyssynchronies. When he finds them, he just sends them back into the loop until they are properly synchronized. His job is to make all of the inputs into the loop work smoothly together.

The cingulum integrates information from all of the various sources that comprise critical judgment – the nature of an event, its emotional and motivational importance and how it relates to one's prior experiences, the likely responses that one may make, the cost and the anticipated outcome of that response. All of those elements are carried by neural assemblies oscillating at different frequencies. As they are running about the loop, they gradually become synchronized. When they are, a coherent signal is generated and a behavioral output is generated. *By Gad, do it!* Or, *I would prefer not to.* If not, back they go into that reverberating loop. *I'm not sure. Let me think about this.*

As this is going in, one's cingulum is operating as a constraint, an *error detector*. It evaluates the nature of an event (Your boss says he has to leave early would you mind dropping the report at his apartment after work), its emotional and motivational importance (*This is weird*), how it relates to one's prior experiences (*The last time something like this happened I was filled with remorse*), and the anticipated outcome ([a] *Oh what the hell* or [b] *I'll ask Doreen to come with me*). The cingulum a slow operator so all this cogitation takes a while, say, a second or two, which is a long time for neural tissue. Then he (your cingulum) will either give the all clear signal (*OK, Sweetlips*) or an error message (*Me and Doreen will bring it by*). All the rest, as you know, is fairly automatic, though not necessarily unconscious.

He is a useful little fellow to have around, an inborn error detector that can access data from a number of neural assemblies, evaluate them critically and generate a message we have met before: *Something is wrong here*. We all have a pair of these cingula, and most of us give them both a good workout. Most of us also have a cingulum that is tolerant of a degree of uncertainty. A normal brain is tolerant of a certain amount of dyssynchrony or conflict. Absence of conflict, or error, is perfection, a machine-state. It has no place in biology.

One wouldn't like to have a built-in error detector that was so intrusive it went off at the slightest provocation, like a smoke detector that went off when one blew out candles on the birthday cake. No, one wouldn't, but some people do, and you can guess who they are. In patients with OC, the error detector has a very low threshold. In fact, brain scans have indicated that OCD patients have cingula that are positively robust, if not muscle-bound. Technically, their cingula have more grey and white matter than most of us have in ours, even those of us who are fussy. PET scans have shown high levels of metabolic activity in the cingula, as if they were always working overtime, which they are. This, then, is part of an OC's psychology: he has a very low threshold for that error message, *Something is wrong here*.

It may be that the OC is born with a hyperactive error detector, or perhaps his error detector has been so exercised by dealing with inappropriate inputs that he got bigger to meet the challenge. Whatever the explanation, the cingulum represents an additional bottleneck in the execution of effective action. An hyperactive cingulum can generate exaggerated or false error signals. They trigger the feeling that things are "not just right" even when no actual error exists.[3] Not only is the cingulum of OCD patients robust and hyperactive, but its microstructure is all awry and it likely connects to parts of the brain that it shouldn't. It's not only a bottleneck, it can be a world-class traffic jam that will tie you up and then lead you away from the Holland tunnel and back onto the Pulaski skyway.

INTERNAL CONFLICTS

The anterior cingulum has been burdened with so many roles he must know how to manage things. Engagement of the anterior cingulum occurs in language, learning and memory, target-detection, imagery, motor control, multitasking and also empathy. He probably does have a general supervisory role, responding to special events when adjustments are needed to optimize performance or avoid negative events. One of his roles is to be an inborn "error detector," the errors in question being "conflicts" between competing neural assemblies.

One set of neural assemblies is happy to be sitting on the settee with his girlfriend to watch the latest episode of Game of Thrones. Another neural assembly, however, has been thrown out of synch by the volume control knob, which happens to be set to an odd number. We all know that it is preferable to turn one's volume control knob to an even number, ideally 52, but most of us have cingula that are as eager to relax and enjoy the show as the rest of our parts are. Even a fussy cingulum will let it go. But a hyperactive cingulum will just keep the OC loop running round and round until he asks his girlfriend to get up and adjust the volume control knob. The reverberating loop generates a lot of heat: *Why do you always leave the remote on the TV table?* he says. Such events should activate her cingulum in the service of finding another boyfriend.

The idea of internal conflicts animating special kinds of mental activity has probably been overdone in the history of psychiatry, but in modern studies the activity of the cingulum can be measured with functional imaging and conflict can be defined in terms of neurocognitive tests, like the Stroop, in which a subject has to choose between conflicting sets or perspectives. Such measures have led psychologists at Carnegie-Mellon to propose that the cingulum responds to the occurrence of error by calling down an *additional increments of top-down control* from the cerebral cortex.

1. Information processing is controlled top-down from the frontal cortex which helps to prevent the occurrence of error.
2. When errors do occur, the conflict monitoring system in the cingulum is engaged.

[3] Neuroimage. 2005 Jan 15;24(2):495-503. Dysfunctional action monitoring hyperactivates frontal-striatal circuits in obsessive-compulsive disorder: an event-related fMRI study. Maltby N, Tolin DF, Worhunsky P, O'Keefe TM, Kiehl KA.

3. Activation of the error monitoring system triggers an intensification in top-down control by the cerebral cortex.

The cingulum, then, is an error detector that functions to call down top-down control: *The man doesn't want you read the word but to say what its color is*. Then it calls down an additional increment of top-down control and one's analytical-theoretic mind announces, *Just say what the colors are. It's a test and if you don't do right we're never going to get out of here.* Top-down control is not always a bad thing.

Unless one has a hyperactive error detector that calls down too much top-down control. *That moron wants me to read these words in precisely the wrong way. Maybe this is a test but I would like to know what the hell is he driving at? I better get this right. Oh Gosh, I got it wrong again. We're never going to get out of here.* Cogitations of this kind involve a lot of neural energy between sensory input and motor output. An educated frog would do better.