How Do We Convert Knowledge to Action? And Some Related Questions.

By Ted Cloak 3/30/2024

What follows does not purport to be a completed study. It is simply a set of hypotheses; in other words, a proposal for a very multidisciplinary scientific theory. I hope readers will evaluate it by the following criteria: Does it propose a solution to an important problem or problems? Is it plausible within the limits of evolutionary possibility, avoiding design and teleology? Does it abjure introducing entities beyond necessity; i.e., is it limited to the four Basic Forces of Nature[1] *as fundamental underlying causes? And finally, can it lead to, and be subject to, multidisciplinary empirical research?*

Causal explanations are the very stuff of science, including behavioral science of all kinds — from psychoanalysis to ethology (the study of animal behaviors in their natural habitats). Following an observation or experiment, we explain why the animal did what it just did. Typically, we do that by citing events of evolution or learning. But somewhere between those events and the observed activity there is a missing causal link, an explanatory gap.

For an example from experimental psychology, suppose we are explaining why a Skinner-trained pigeon is pecking at a disk. We know it intends to peck at the disk, because it is in fact pecking at the disk, and we know why it intends to peck at the disk—It has learned through trial-and-error. <u>But therein lies the gap.</u> What we don't know is why its intent to peck at the disk results in its actually pecking at the disk. We probably just assume that there is some sort of causal connection between intending and actuating, between <u>knowing</u> what to do and <u>doing</u> it.

Moreover, to accomplish the task, the pigeon intends to move certain muscles in exquisite detail – smoothly, accurately, rapidly. What are the underlying causal processes that connect that intention to those movements? I want to close the gap, to solve the “knowing-to-doing” problem.

[1] Gravitation, Electromagnetism, and the Strong and Weak Interactions in the atomic nucleus. Cf. Monod 1971, Cloak 1981

Apparently, behavioral scientists of all sorts have relied on unspoken conventional wisdom to provide the linkage, simply assuming that if the animal knows what to do, of course it will know how to do it, and if it knows it needs to move a certain muscle a certain way to that end, of course it will know how to move it.

As far as I know, the knowing-to-doing gap problem has never been explicitly stated, even by William T. Powers (1973, Ch. 15) when he suggested a solution to it!

If verified empirically, the theory delivered in this essay will also explain

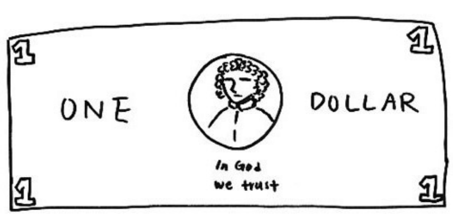
1. How pattern recognition in humans and animals works
2. How behavior works, especially how it can be so precise, quick, and powerful,
3. How observational learning works and how that explains
4. how most of culture works,
5. And even why it's counterintuitive for human beings to understand evolution.

To continue, I rely on several entities, some hypothetical, which are part of every animal's central nervous system:

A. **Perceptual Apparatus and Perceptions.** For our purposes in this essay, an organism's perceptual apparatus includes not only the machinery that processes sensory data from the outside world but also that which processes data from the animal's internal organs, such as the proprioceptions from joints, tendons, and muscles. Perceptions, accordingly, include such data. Perceptions also include data from sensory observations of the animal's own body and its movements. While the animal is awake, the perceptual apparatus constantly, steadily, sends perceptual signals to other parts of the brain (including, for some perceptions, the part that converts them into conscious images).

B. **Engrams.** “Engram” is a traditional name among psychologists for a bit of “memory” stored in the brain of an animal.[2] An engram’s evolutionary function is to contain information and keep it accessible. As such, it is analogous to a gene or to the storage of one picture or one GIF in your camera or smartphone. Engrams are stored perceptions, including immediate perceptions, ancestral perceptions acquired through genetic inheritance, and perceptions acquired during learning. An engram may be like a black and white still picture or it may include all sensory modes and all four dimensions – like a three-dimensional film clip with stereophonic sound plus[3]; or it may be a representation of a proprioception (whatever that might look like).[4] Engrams are thus the loci of everything an animal knows, so our brains include an incredible number of them, especially as we grow older and wiser.

The engram will not be an exact copy of the perception (Pearson and Kosslyn 2015). Epstein (2016) illustrates a possible difference between a perception and its engram copy when he reports a pedagogical demonstration he has used in his classes (to attack perfect representationism). He had an intern draw a U.S. dollar bill first from memory and then while perceiving a dollar bill. Here is the result, with my interpretation:



From memory: image, reflecting $\text{Engram}_{\text{One Dollar}}$

From life, reflecting perception of $1

[2] Semon (1904), cited in Ortega-de San Luis and Ryan (2022)
[3] A verbal or written perception may just be signaled and stored as is, in effect like text; but it often may be translated into a simulacrum of a sensory engram. How that process works is beyond the scope of this essay.
[4] Science is just beginning to understand some of the perceptions, and therefore the engrams, of other animals. Engrams may also represent emotions, especially emotions linked to behavior: hunger, anger, empathy, etc.

What engrams are as physical biological structures is yet to be determined. A physical engram could be a distributed sub-network of neurons and synapses, or it could be all biochemical, associated with a single cell.[5]

C. **Engram Function Managers (EFMs)**. Whatever they are physically, engrams are passive structures. They are simply data holders. The hypothetical Engram Function Manager (EFM), however, is a virtual machine defined by the several <u>functions</u> it performs on behalf of its associated engram. Exactly how an EFM performs each of those functions, and exactly how it is manifest as a biological structure or set of structures will have to wait for empirical research.

Together with engrams, animals have many thousands of Engram Function Managers, or EFMs. Humans have many millions, even billions. The functions each EFM performs are as follows:

1. **Engram Creation and Storage.** Upon receiving a perceptual signal, an EFM populates its engram with a match (of sorts) of the perception.
2. **Image Experience.** Sometimes, in some humans, EFMs cause their engrams to pop into awareness as images or "memories", somewhat like perceptual images. This function is beyond the scope of this essay, but see **Appendix**.
3. **Pattern Recognition.** Each current perception is fed into a search engine (analogous to Google) which attempts to find an existing engram which matches it ([Wikipedia: Pattern Recognition - Psychology](https://en.wikipedia.org/wiki/Pattern_recognition_(psychology))). If that succeeds, the engram's EFM identifies the current perception. That's how, moment by moment, an animal knows what its sensory apparatus is telling it. <u>EFMs performing Function 3, along with perceptions, are constantly operating many times per second of waking time.</u> When you recognize a dollar bill, what's going on biologically is you are systematically comparing your perceptions with your existing engrams until, having come upon your $\text{Engram}_{\text{dollar bill}}$[6], you get an adequate match. That happens constantly and

[5] Marx and Gilon (2012, 2019). Ortega-de San Luis and Ryan (2022) provides a comprehensive up-to-date review of the considerable work that has been done to identify the biological basis of the engram.

[6] The subscripted names, throughout, are merely and entirely illustrative. They are not part of the hypothesis.

very fast, of course, and you're quite unaware of the underlying process or indeed that it is happening.

Identifying a perception may activate behavior.

4. **Behavior.** Behavior is the flip side of pattern recognition. The animal starts with an engram, and by using some of its muscles tries to manage its interaction with its environment in such a way that its current perception matches the engram. William T. Powers (1973) called that process *Perceptual Control* because the animal is thereby controlling its perception.[7] He called the device that does the match-making the **Control System (CS)**. A CS is attached to each EFM which has the capacity for Function 4 (or perhaps creating a CS is an early step in Function 4). When activated, the EFM sends a signal representing its engram to its CS, which is also receiving signals from the perceptual apparatus.[8] The CS compares the perceptual signal with the engram signal and, until the two signals match, sends an activating signal toward the animal's motor apparatus.

   EFMs doing Function 4 are paired with their CSes. We'll call each such pair an "EFMCS", but continue to use "EFM" and "CS" (and "engram") separately as appropriate.

   <u>Please note that as long as a CS is activated, it will respond to any disturbance to its incoming perception that unmatches the signals, trying to recover the match. In short, the whole EFMCS Function 4 process is *goal driven.*</u>

<u>Even the simplest behavior, however, requires a whole set of EFMCSes</u>. Very few CSes send their output signals directly to the motor apparatus. Instead, most EFMCSes are intermediate modules in **hierarchies** of EFMCSes, of which only the

[7] I think Powers was going by the philosophical dictum that we don't know what's "really out there", we know only our perceptions and their changes. I think that was later played down by Powers and his followers, but the name stuck.

[8] I suspect that the CS also sends signals to the perceptual apparatus telling it what to look for.

bottommost CSes directly activate the motor apparatus. In general, EFMs are activated by output signals from CSes above them in a hierarchy, and their CS's output signals similarly activate (and sometimes modify or adjust[9]) the EFMCSes below them. The hierarchies extend from top EFMCSes with very general, mainly genetically sourced, engrams down through multiple EFMCSes serving those top ones, all the way down to EFMCSes activating individual muscle fibers. Many EFMCSes in the hierarchy head up hierarchies of their own, so the result looks like an upside-down tree of hierarchies.

For example, suppose you're looking for a dollar bill in your purse or wallet. Fortunately, you've done this sort of thing thousands of times before, as has your every ancestor going back to the beginning of animal life, so a lot of evolution and learning has made your search automatic. When activated, EFMCS $_{\text{One Dollar}}$, illustrated above, activates the top EFMs of numerous hierarchies, leading down to EFMCSes controlling your perceptions of movements of your head, arms, hands, eyeballs, etc.[10] If there's a dollar bill in the general area where you're looking, you are likely to perceive it very quickly, again with no awareness of the underlying process. You have Controlled a Perception of a Dollar Bill. You have closed the causal Gap between intending to see a dollar and actually seeing one. Knowing has resulted in Doing. You have converted knowledge to action.

In most hierarchies, the engram of the top EFM represents relative stability rather than movement. The EFMCSes below it in the hierarchy help it maintain that stability. For example, you extend your hand holding a cup for a refill of your favorite beverage. You are trying to control the perception of your hand keeping its position; that is, you are trying to keep your perception of your hand and cup matching your $\text{Engram}_{\text{Hand Holding Cup Steady}}$. But gravity is trying to thwart you. As it pulls your hand down a little, your perception deviates from the match.

---

[9] Yes, EFMs are adjustable. You can even voluntarily modify or adjust an EFM or its engram. How evolution accomplished this and yet kept the whole behavioral system from flying apart frankly boggles the mind. But, in the event, it did.

[10] At the lowest levels, EFMs and engrams may not be necessary. The output signals from a near-bottom CS may directly activate the lowest CSes or the muscle fibers. This is the burden of the first fourteen chapters of Powers 1973 and of Powers et al. 2011.

Accordingly, the $CS_{\text{Hand Holding Cup Steady}}$ triggers activating signals down its hierarchies, resulting in muscular contractions opposing that gravitational pull. Even though the downward movement is barely perceptible, it is resisted, restoring the match. This constant negative-feedback loop process continues until you decide to do something else with the hand and cup (or, of course, until something prevents you from continuing). Meanwhile, your hand and cup (appear to) remain steady.

Most such hierarchies are always “on” (the EFMs in them are constantly activated), certainly while the animal is awake. Their function is to monitor the animal’s internal and external environments, and try to maintain homeostasis despite the disturbances presented by those environments.

Examples of the stabilizing function of EFMCSes are legion. Another example is keeping your car on the road. Perceptual Control Theory considers such non-activities to be behavior.

Let’s review the $EFMCS_{\text{Hand Holding Cup Steady}}$ scenario. The output signal from that CS doesn’t go directly to the motor apparatus. Instead, it activates/adjusts EFMs of angular positions of joints: shoulder, elbow, wrist, perhaps fingers. Those EFMs’ CSes in turn activate/adjust the EFMs of [proprioceptions] of the various elements of the motor apparatus, including muscles, involved. $CS_{\text{Hand Holding Cup Steady}}$ is <u>using</u> those subordinate EFMCSes in its hierarchies to maintain its perception of your hand remaining still.

In turn, $EFMCS_{\text{Hand Holding Cup Steady}}$ is itself subordinate to, say, $EFMCS_{\text{Drinking Beverage}}$, which in turn is in one of many hierarchies topped by $EFMCS_{\text{Stayin' Alive}}$ and extending down via $EFMCS_{\text{Getting Together with Friends}}$ and $EFMCS_{\text{Having Coffee}}$,etc.

Now suppose you decide to drink from the cup. $EFMCS_{\text{Drinking Beverage}}$ switches to activating $EFM_{\text{Cup Moving Toward Mouth}}$ instead of $EFM_{\text{Hand Holding Cup Steady}}$. $EFMCS_{\text{Cup Moving Toward Mouth}}$ activates and adjusts $EFM_{\text{Elbow Joint Bending}}$ and so forth. *The smooth rapid accurate curvilinear movement of the cup is the result of constant* *mid-course correction of a huge host of hierarchically organized EFMCSes*, all trained by your and your ancestors' experiences.

Thus any EFM may be activated by multiple EFMCSes above it, and any CS may activate multiple subordinate EFMs. The resulting network of hierarchies shows that the very simple structures and processes of the EFMCS and perceptual control can ramify into seriously complicated structures and processes.

To sum up Function 4, behavior exists to control perception; that is, to obtain and maintain perceptions which approximate engrams. (Powers puts this even more strongly: Behavior *is* the control of perception.) *Indeed, in a universe in constant flux, how else could such complex actions be accomplished with such speed and such precision?*[11]

How Observational Learning Works

Observational learning, or the "modeling" version of it in Bandura's (1977) terms, occurs when a naive observer animal watches another animal behave and later reproduces that behavior. It provides an excellent example of the engram plus perceptual control mechanism.

To explain how observational learning works, I introduce a primitive example. This is my interpretation of an experimental study by Thonhauser et al. (2013).[12] The purpose of the study was to ascertain whether a stingray (*Potamotrygon falkneri*)

---

[11] Steven Pinker (1997, p. 11) came up with an excellent illustration of that question: "Controlling an arm presents a new challenge. Grab the shade of an architect's lamp and move it along a straight diagonal path from near you, low on the left, to far from you, high on the right. Look at the rods and hinges as the lamp moves. Though the shade proceeds along a straight line, each rod swings through a complicated arc, swooping rapidly at times, remaining almost stationary at other times, sometimes reversing from a bending to a straightening motion. Now imagine having to do it in reverse: without looking at the shade, you must choreograph the sequence of twists around each joint that would send the shade along a straight path." But his solution/explanation, immediately following, is nothing but hand-waving: "The trigonometry is frightfully complicated. But your arm is an architect's lamp, and your brain effortlessly solves the equations every time you point." Compare that with the hierarchical PCT explanation of almost the same challenge, above. It's an analogue solution, not a digital one. You *never* stop "looking at the shade (hand and cup)"; you keep your perception under constant control.

[12] I was directed to the study by Prof. Gordon Burghardt, one of its authors.

can learn a behavior by watching another stingray perform that behavior; that is, whether a very primitive animal can do observational learning. Again, this is my paraphrase and interpretation of the Thonhauser study:

Five pairs of stingrays, each pair consisting of a "demonstrator" D stingray and an observer O stingray, were separately put through runs of the same observational learning experiment, with five virtually identical outcomes.

Each run of the experiment started with "RayD", a naïve demonstrator stingray, trying to extract a food reward inserted in an open-ended PVC pipe segment. After many attempts, through many trials, by trial and error she hits upon a technique that works, "Suck-and-Wave". Subsequently, she successfully uses Suck-and-Wave to get the reward in at least ten consecutive trials, the criterion set by the experimenters. It's time for her to become a demonstrator.

Now comes "RayO", a naïve observer stingray. Although he has never before confronted the apparatus, he watches avidly as RayD goes through her paces in several successful trials. (You can even see his eyeballs following her movements.)

After a 30-minute wait, it's RayO's turn to try to get the treat. Just like RayD, he uses trial-and-error and ends up using Suck-and-Wave for success in at least ten consecutive trials. But it takes him fewer than half as many trials as it took her to reach that criterion! How in the world does he manage that? Here's how:

Watching RayD, RayO has recorded his perceptions of her actions, including Suck-and-Wave, as engrams and EFMs (Function 1) in his brain. Then, on test, he too engages in trial-and-error learning, systematically activating certain EFMCSes in his repertoire[13], now including $\text{EFMCS}_{\text{Suck-and-Wave}}$ (Function 4), and trying to match his perceptions of his own actions to each engram. With each trial, the likelihood of his trying to match $\text{Engram}_{\text{Suck-and-Wave}}$, instead of one of the other engrams, increases because matching it is followed by obtaining the reward. Because he had already acquired $\text{Engram}_{\text{Suck-and-Wave}}$ by observing RayD's action, he didn't have to go through the tedious trial-and-error process she went through

[13] Which EFMs he tries are specified by the EMCS (Function 4), directly above in a hierarchy, activating them one after another.

to acquire it. Therefore, it takes RayO fewer than half as many trials as it took RayD to reach criterion. <u>That held true for five different complete runs of the experiment, each run using a different pair of naïve animals.</u>[14]

Observational learning is thereby confirmed in stingrays.

It's clear that RayO used the perceptual control process again and again, for each of his ten consecutive successes. But, one may ask, how did RayD reach <u>her</u> ten consecutive successes? Did she have an $\text{Engram}_{\text{Suck-and-Wave}}$? Yes, she did; she constructed it herself, except that first she had to stumble upon the suck and wave action through trial-and-error (perhaps she did so by combining an $\text{Engram}_{\text{Suck}}$ and an $\text{Engram}_{\text{Wave}}$ that she already had). She thus created her own $\text{Engram}_{\text{Suck-and-Wave}}$ <u>by recording her perception of her own suck-and-wave action</u> (EFM Function 1).

Has anyone proposed a better apparatus than the EFMCS combination to provide a biological basis for observational learning? Apparently not,[15] so <u>I think the very existence of observational learning provides strong empirical evidence for the EFM hypothesis and for Powers' Perceptual Control Theory.</u> I happily extrapolate both to all animal behavior, back at least to our most recent common ancestor with stingrays and even to octopi, the successful subjects of another observational learning experiment (Fiorito & Scotto 1992).[16]

Engrams , Memes, and Culture

It's truly remarkable how culture has developed from that very complex system: RayO's $\text{Engram}_{\text{Suck-and-Wave}}$ replicate of RayD's $\text{Engram}_{\text{Suck-and-Wave}}$ turns out to be what I called a "cultural instruction" (1968a, 1975a) and Richard Dawkins famously dubbed a *meme* (1976, 1982). Biologically, <u>a meme is simply an engram</u>

[14] Needless to say, the experimental results met all the standard requirements re statistical significance, etc.
[15] Some workers, e.g. Lago-Rodríguez et al. 2014, assert that mirror neurons are implicated in observational learning. I suggest that mirroring, imitation, etc. are simply other outcomes of the process outlined here, except that the observer already possesses the engram and EFM involved.
[16] Our most recent common ancestor with stingrays (*Potamotrygon falkneri*) was a jawless "fish", about 290 million years ago. Our most recent common ancestor with *Octopus vulgaris* was a sea-bottom flatworm, about 541 MYA. (Early Life n.d.)

that has been acquired by means of observational learning (or verbal tuition, as we shall see) from another animal. Occasional examples of observational learning pop up as early in evolutionary history as other forms of EFM acquisition, at least as inferred from laboratory experiments.[17]

Memes are the building blocks of culture. However, it takes a lot more than one meme or a few to build ***a*** culture. [18] As far as we know, only humans have adopted observational learning as a principal mode of engram acquisition, enabling us to acquire memes by the millions [19] and build cultures.

Observational learning enables humans to acquire behavior of almost every sort. The clearest examples occur when D is unaware that O is watching or listening, as when children acquire memes for the facial expressions, gestures, gait variations, social norms, and linguistic elements characteristic of their group; in other words, when they acquire bits of their group's culture. The ease and speed with which children do that would indicate the existence of a genetically evolved high-level self-starting $\text{EFMCS}_{\text{Learning by Observation}}$; in humans, obligate observational learning has itself become a top-level EFM, at least for kids. It's practically instantaneous, with little or no trying of alternative engrams before adopting the observed one.

On the Coevolution of Observational Learning and Culture

Memes for making and using tools are also obvious examples. It appears that the genetic adaptive trend leading to high-speed obligate observational learning took place during some 700,000 years beginning about 2 to 2.5 million years ago, as our ancestor *Homo erectus* spread throughout Africa and into most of the eastern hemisphere (Wikipedia: Homo Erectus). Morgan et al. (2015) postulates an evolutionary sequence of (1)imitation/emulation, (2)basic teaching, (3)gestural teaching, and eventually at least the beginnings of (4)verbal teaching. The

---

[17] Cf. the examples referred to in Thonhauser et al. 2013:927. See also Wikipedia: Observational Learning.

[18] The spread of yam-washing and grain-filtering found in some troops of Japanese macaques comes to mind here, as do certain tool-making behaviors of chimpanzees. One argument for calling those infra-human examples "cultural" is that, at least at first, memes tend to spread rapidly within a local group but stop at group boundaries.

[19] "Most human behavior is learned observationally through modeling: from observing others, one forms an idea of how new behaviors are performed, and on later occasions this coded information serves as a guide for action." (Bandura 1977:22)

sequence is based on the reverse engineering of *H.erectus's* Lower Paleolithic Oldowan stone tool technology as it evolved into the much more sophisticated Acheulean stone tool industry. $EFM_{Learning\ By\ Observation}$ evolved through genetic mutation and Darwinian natural selection of *H.erectus's* genes. That genetic evolution contemporaneously enabled the tool tradition (and many other *H.erectus* cultural features) to evolve through memetic "mutation" (e.g., the trial-and-error process by which stingray RayD acquired $Engram_{Suck\text{-}and\text{-}Wave}$) and Darwinian natural selection of *H.erectus's* memes (Cloak 1968c, 2002; Dawkins 1976, 1982; Cziko 1995; Boyd and Richerson 1985; Blackmore 1999; Wikipedia:Cultural Evolution).

Those two evolutionary processes resulted in a vast increase in the number of memes in the average *H.erectus's* brain, filling it up, which likely provided the selection pressure to expand the human cranium through an adaptive trend culminating in the crania of *H.Neanderthalensis* and *H.Sapiens*.

Just as natural selection of genes can result in complex functionally integrated wholes such as horses and ant colonies (Carroll 2005), so can natural selection of memes result in complex functionally integrated wholes such as pre-industrial village cultures and band cultures. On the other hand, memes are much more likely to "go rogue" than genes, as we all can attest -- think fads, slogans, tweets, etc. The cultures of modern industrial societies seem generally to be "that planless hodgepodge, that thing of shreds and patches" that Lowie derided (1920: 441).

Memes and Language: Verbal Tuition

At some point during the evolution of language capability,[20] it became possible to describe perceptions; i.e., express them with utterances, like "(I see) a bird" or "(I smell) a rat", thus evoking an EFM_{bird} (Function 2) or EFM_{rat} (Function 2) in the hearer and perhaps activating some behavior (EFM Function 4). After that, it was

[20] I won't try to explain how speech and language evolved. See Wikipedia: Origin of Language.

an easy evolutionary step to describing one's engrams, which of course enables the hearer to adopt the engram (EFM Function 1), a copy which thereby becomes a meme. If the meme survives natural selection and is propagated, it becomes an element of its carriers' group's culture.

As language-culture evolves, a novel engram can be generated by a shift of words in a sentence or simply by "anything a person can imagine".[21] If he/she then describes the novel engram to another person it becomes a meme, subject to natural selection and, with luck, propagation.

With language-propagated memes, planning becomes possible: gratification can be deferred more widely and much longer in time. Opportunities for cooperation and competition increase greatly. Social groups can become much larger, although culturally less cohesive -- from band gatherings to empires.

Before language, the EFMs at the highest hierarchical level were those genetically provided to meet basic physiological and social needs for survival and reproduction, such as $\text{EFM}_{\text{Stayin' Alive}}$, $\text{EFM}_{\text{Taking Care of Mate \& Offspring}}$, and (since *H.erectus*) $\text{EFM}_{\text{Learning by Observation}}$. Memes were selected if they served those EFMs by becoming incorporated into hierarchies under them. But engrams in EFMs (Function 4), including memes of course, act as goals for perceptions of actions and their outcomes. Language lets us humans share and store goals that are more like the everyday usage of "goal", even including memes such as $\text{Meme}_{\text{Getting Rich}}$, $\text{Meme}_{\text{Serving God}}$, or $\text{Meme}_{\text{Fighting for My Country}}$ which can override the genetically acquired basic needs engrams.

More About the Nature of Engrams and EFMs

The EFMCS evolved genetically and is therefore, of course, genetically programmed. Each of an individual animal's engrams may also be genetically programmed, or may be captured from an immediate perception (EFM Function 1). With language, a meme may be constructed from a perception of an utterance

[21] I think combining two or more engrams, letting them run together, and adopting (or rejecting) the outcome, fits well into D. T. Campbell's (1960) theory of creative thought. Example: "What if I was sitting on the horse, instead of hitching it to a cart?"

or a paragraph on a page. Besides being visual, the content may, like a perception, be based on any sensory mode or even be multimodal. It may be three dimensional. It may even be four dimensional, like a 3-D film clip.

I would add that we animals build our engrams, adding to them and paring them down. For instance:

- With repeated perceptions of the same person, place, or thing, our engrams grow and become more comprehensive, more representative of the "entire" person, place, or thing. A hologram might be a good metaphor for an engram here.
- We animals build "maps" of our territories, sequential engrams of landmarks we want to recognize on our way to various locations and on our way home.
- Humans, at least, can combine disparate engrams, and can even subject the resulting engrams to internal selection (Campbell 1960).
- It's well known that our engrams change every time we access them. Even genetically programmed engrams are subject to modification by individual carriers' experiences.

A Possible Biology of the EFM

Marx and Gilon (2012, 2019) have shown that a "memory" (an *engram*) could be stored biochemically in the *extracellular matrix* surrounding a neuron. Accordingly, I propose that a EFMCS may be stored in and around a single neuron – the engram in the extracellular matrix, and the EFMCS in the cytoplasm or perhaps in a heretofore unrecognized organelle.[22] A decisive advantage of such hypotheses, over any which propose that several neurons are required for an

[22] Umea University 2023, citing Maurya et al. 2022, might well be an example of this.

EFMCS, is that intracellular chemical signals are several orders of magnitude faster than signals linking neurons via axons, synapses, and dendrites.[23]

If that hypothesis seems unlikely, remember that almost every cell in an organism contains a prodigious collection of active macromolecules: all those necessary for directing the construction of that organism; the cell's machinery for reproducing itself, feeding itself, repairing itself, etc.; and the incredible machinery by which the cell's DNA directs the assembly of just those proteins, including enzymes, necessary for the cell to fulfill its specific function in the organism (Carroll 2005; Fester Kratz 2020:291-310). There must be plenty of room in a cell and its surroundings for an EFMCS.

As for the necessary connections between a cellular-level EFMCS and the sensory and motor apparatuses, I trust evolution, over the entire planet and millions of generations, to have made and perfected them.

Summary and Conclusion

The biology of animal behavior, including human behavior, is not just an extensive tweaking of the reflex arc,[24] it is entirely produced by seeking to match perceptions to engrams (EFM Function 4). Engram Function Managers (EFMs) are physical structures in the brain, and every animal has hundreds or thousands of them (we humans have millions). EFMs (Function 4) are accompanied by a mechanism of perceptual control, a control system (CS), which generates muscular activity attempting to match the animal's perception to the engram, thus closing the gap between knowledge and action. Engrams, accordingly, are the elemental units of behavior. They exist in complex networks of stacked hierarchies and are acquired by genetics, individual learning, observational

[23] On the other hand, abutting cells do communicate chemically (Fester Kratz 2020:123-138), so perhaps a tight cluster of neurons could make up an EFMCS. See Ortega-de San Luis and Ryan (2022, 2023).

[24] "the nerve pathway involved in a reflex action, including at its simplest a sensory nerve and a motor nerve with a synapse between." From Oxford Languages.

learning, and, in humans, verbal teaching. <u>Engrams acquired by the latter two tactics are memes, the elemental units of culture.</u>

The EFMCS/Engram theory explains the phenomenon of observational learning very well, and explaining observational learning, in turn, provides strong support for the theory.

Conversely, a search for an engram to match a perception (EFM Function 3) explains the essential ability for pattern recognition.

Because of the speed of the functions, it's likely that each engram and EFMCS is stored in and around a single neuron or tight group of neurons.

Following Powers, and like Mendel, I have identified the "factors" at work, and what they do. Have Marx and Gilon or Ortega-de San Luis and Ryan, like Watson and Crick, already specified what one of them, the engram, is biologically? Can someone else specify what the EFM and CS are, biologically (e.g. Berg 2023, Jarvis 2022)?

Why It's Counterintuitive for Human Beings to Understand Evolution

The EFM hypothesis, based as it is on Perceptual Control Theory, shows that all animal behavior is goal driven. The hypothesis is utterly teleological: Everything an animal does is by design. That's how we see the world. We naturally see everything happening by design, on purpose, including the existence and development of living things.

Evolution, on the contrary, is absolutely goalless. No design is involved in evolution. (The term natural *"selection"* is a misnomer. No person, Person, creature, or thing is selecting anything.) A slight random change (mutation) pops up in a gene some place. Sooner or later, because of a slight novelty in its action, and because that novel action increases its frequency <u>in its environment</u>, and with a lot of luck, that version of the gene is propagated. That, in essence, is evolution. (Besides, we can't see the gene, let alone the difference made by the mutation, without very modern and expensive laboratory tools; they are much too small.)

It's ironic that goalless evolution resulted in a totally goal-driven outcome, leaving humans teleologically inclined, extremely, and to have difficulty grasping the nature of evolution; viz. creationism and conspiracy "theories".

Appendix: But Ted, Where Did You Get These Ideas?

A while ago I realized that often, if not always, I think in pictures or images. Sometimes they come to me unbidden, like snapshots of old memories for instance, some going back to my early childhood. Other times I deliberately bring them up. Later, I became aware that I often imagine something I am going to do just before I do it. For instance, while marking up my shopping list, I often have an image of my picking an item off the shelf in the store.[25]

I'm now convinced that each such image reflects a distinct, underlying element in the brain, which I once called a Neural Image, or Nimage, but now prefer to call an engram. (I've said above that producing an image from its engram is Function 2 of an EFM.) Moreover, the brain of every animal is crowded with EFMs, *whether they produce images or not*. So much for images; this essay is about EFMs and engrams.

Donald T. Campbell introduced me to control systems theory in 1973, by recommending Powers 1973. I bought and read the book, but somehow it didn't take. I connected with Powers and the Control Systems group in April 2008 and began to understand the value of control systems theory, though not perhaps as most of the other members, including Powers, saw it. But I read Chapter 15 and apparently made engrams from it.

It's only in the last few years that I've begun thinking outside the box of conventional behavioral science. My degree, awarded in 1966 when I was 35 years old, is in cultural anthropology. Stumbling upon the work of Marx and Gilon very recently alerted me to the possibility that biochemistry, and then cell and molecular biology, might be essentially involved in the macro-behavior of animals

---

[25] Somebody apparently beat me to this: 'UPS drivers are required to follow "the methods," the company's set of extremely detailed directions for how to do their jobs…Drivers are told that, as they "move packages to the final selection area," in the back of the package car, <u>they should "visualize the actual delivery of each package."</u>' (Gunnerman 2023:48) (Emphasis added)

such as us. Reading Carroll 2005 and then Hoagland & Dodson 1995 and Fester Kratz 2020 helped. Hoffmann 2012 wrapped it up for me.

Acknowledgements

I thank Jonathan Briggs, Iris B. Kapil, Jerry Gilbert, and, especially, Connie Cloak for their essential help in putting this essay together.

-30-

References and Pertinent Readings

Bandura, A. 1977. *Social Learning Theory.* New York: General Learning Press.

Berg, Jeremy. 2023. Visualizing the inside of cells at previously impossible resolutions provides vivid insights into how they work.

Blackmore, S. J. (1999) *The Meme Machine,* Oxford, Oxford University Press.

Boyd, Robert, and Peter J. Richerson 1985. *Culture and the Evolutionary Process*. Chicago: University of Chicago Press.

Campbell, D. T. 1960. Blind variation and selective retention in creative thought as in other knowledge processes. *Psycholog. Rev.* **67,** 380-400

Carroll, Sean B. 2005. *Endless Forms Most Beautiful: The New Science of Evo Devo.* New York: W.W. Norton & Company

Cloak, F.T., Jr. 1968a. Is a cultural ethology possible? *Research Previews* 13: (2) p. 37-47.

Cloak, F.T., Jr. 1968. "The Wheel". automated slide presentation given by the author at the Annual Meeting of the American Anthropological Association, Seattle, November 1968. See Cloak 2002

Cloak, F.T., Jr. 1975a. Is a cultural ethology possible? *Human Ecology* 3: 161-182.

Cloak, F.T., Jr. 1975b. That a culture and a social organization mutually shape each other through a process of continuing evolution. *Man-Environment Systems* 5: 3-6.

Cloak, F.T., Jr. 1981. Why electromagnetism is the only causal 'spook' required to explain completely any human behaviour or institution. In *The Relationship of Verbal and Nonverbal Communication* (ed. Mary Ritchie Key), pp. 327-48. Mouton,The Hague.

Cloak, F.T., Jr. 1986. The causal logic of natural selection: a general theory. *Oxford Surveys in Evolutionary Biology* 3: 132-186.

Cloak, F.T., Jr. 2002. Cultural Darwinism: Natural Selection of The Spoked Wood Wheel. Verbatim rendering, with illustrations, of Cloak 1968c. Unpublished.

Cloak, F.T. 2015, A Natural Science of Culture; Or, a Neurological Model of the Meme and of Meme Replication. Version 3.2. http://www.tedcloak.com .

Cziko, Gary 1995. *Without Miracles: Universal Selection Theory and the Second Darwinian Revolution.* Cambridge, MA: MIT Press.

Dawkins, Richard 1976. *The Selfish Gene.* Oxford University Press, Oxford.

Dawkins, Richard 1982. *The Extended Phenotype: The Gene as the Unit of Selection.* Freeman, Oxford.

Early Life on Earth – Animal Origins. n.d. National Museum of Natural History.

Epstein, Robert 2016. The empty brain (Your brain does not process information and it is not a computer). https://aeon.co/essays/your-brain-does-not-process-information-and-it-is-not-a-computer . Plus Comments.

Fester Kratz, Rene 2020. *Molecular and Cell Biology for dummies.* Hoboken, NJ, Wiley.

Fiorito G & Scotto P 1992. Observational learning in *Octopus vulgaris*. *Science* 256:545–547.

Hoagland, Mahlon & Dodson, Bert. 1995. *The Way Life Works.* New York, Random House.

Hoffmann, Peter M. 2012. *Life's Ratchet: How Molecular Machines Extract Order from Chaos.* New York, Basic Books (Kindle Edition).

Gonnerman, Jennifer. 2023. The total package. *The New Yorker*, 16 January 2023:40-9.

Jarvis, Michaela. 2022. Cell Rover: Exploring and augmenting the inner world of the cell. MIT News, 9/22/2022.

Kroeber, A.L. and Kluckhohn, Clyde. 1952. *Culture: A Review of Concepts and Definitions. Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University XLVII(1)*. Any references are to the Vintage Edition (1963)

Lago-Rodríguez, A.; Cheeran, B.; Koch, G.; Hortobagy, T.; Fernandez-del-Olmo, M. (2014). "The role of mirror neurons in observational motor learning: an integrative review". *European Journal of Human Movement* 32: 82–103

Lowie, Robert H. 1920. *Primitive Society*. New York: Liveright Publishing Corporation.

Marx, Gerard and Chaim Gilon. 2012. The Molecular Basis of Memory. http://dx.doi.org/10.1021/cn300097b | *ACS Chem. Neurosci*. 2012, 3, 633−642.

Marx, Gerard and Chaim Gilon. 2019. The *tripartite* mechanism as the basis for a biochemical memory engram. *J. Integr. Neurosci*. 18(2), 181–185. https://pubmed.ncbi.nlm.nih.gov/31321959/

Maurya, D.K., Berghard, A. & Bohm, S. 2022. A multivesicular body-like organelle mediates stimulus-regulated trafficking of olfactory ciliary transduction proteins. Nat Commun 13, 6889 (2022). https://doi.org/10.1038/s41467-022-34604-y

Monod, Jacques. 1971. *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology*. New York: Alfred A. Knopf

Morgan, T. J. H. et al. 2015. Experimental evidence for the coevolution of hominin tool-making teaching and language. *Nat. Commun*. 6:6029 doi: 10.1038/ncomms7029.

Ortega-de San Luis, Clara and Ryan, T.J. 2022. Understanding the physical basis of memory: Molecular mechanisms of the engram.

Ortega-de San Luis et al. 2023. Engram cell connectivity as a mechanism for information encoding and memory function, *Current Biology* (2023), https://doi.org/10.1016/j.cub.2023.10.074

Pearson, Joel and Stephen M. Kosslyn. 2015. The heterogeneity of mental representation: Ending the imagery debate. *Proceedings of the National Academy of Sciences of the United States of America* 112:33 (August 18, 2015), 10089-10092

Pinker, Steven. 1997. *How the mind works*. New York: W.W. Norton.

Powers, William T. 1973. *Behavior: The Control of Perception.* Chicago: Aldine de Gruyter.

Powers, W. T., Abbott, B., Carey, T. A., Goldstein, D. M., Mansell, W., Marken, R. S., & Taylor, M. 2011. Perceptual control theory: A model for understanding the mechanisms and phenomena of control. Retrieved from http://pctweb.org/PCTunderstanding-2.pdf .

Semon, R. 1904. *Die Mneme (The Mneme)*. Leipzig: Engelmann W.

Szegőfi, Ákos. 2024. Beware Climate Populism. *Aeon,* January 25, 2024.

Thonhauser, K.E., Gutnick, T., Byrne, R.A., Kral, K., Burghardt, G.M., & Kuba, M.J. 2013. Social learning in Cartilaginous fish (stingrays *Potamotrygon falkneri*). *Anim Cogn* 16, 927–932 (2013). https://doi.org/10.1007/s10071-013-0625-z

Umea University. 2023. Researchers Discover a Previously Unknown Cellular Component Inside Neurons That We Use To Perceive Smell. *SciTechDaily*, February 15, 2023. https://scitechdaily.com/researchers-discover-a-previously-unknown-cellular-component-inside-neurons-that-we-use-to-perceive-smell/

Wikipedia: **Perceptual Control Theory**