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Mind and Machine:
At the Core of Any Black Box There Are Two (Or More) White Boxes Required to Stay In

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This paper concerns the *Black Box*. It is not the engineer's *black box* that can be opened to reveal its mechanism, but rather one whose operations are inferred through input from (and output to) a companion observer. We are observers ourselves, and we attempt to understand minds through interactions with their host organisms. To this end, Ranulph Glanville followed W. Ross Ashby in elaborating the Black Box. The Black Box and its observer together form a system having different properties than either component alone, making it a *greater Black Box* to any further-external observer. How far into this greater box can a further-external observer probe? The answer is crucial to understanding Black Boxes, and so an answer is offered here. It employs von Foerster's *machines*, abstract entities having mechano-electrical bases, just like putative Black Boxes. Von Foerster follows Turing, Ashby, E. F. Moore, and G. H. Mealy in recognizing archetype machines that he calls *trivial* (predictable) and *non-trivial* (non-predictable). It is argued here that non-trivial machines are the only true Black Boxes. But non-trivial machines can be concatenated from trivial machines. Hence, the utter core of any greater Black Box (a non-trivial machine) may involve two (or more) *White Boxes* (trivial machines). This is how an unpredictable thing emerges from predictable parts. Interactions of White Boxes—of trivial machines—may be the ultimate source of the mind.
Keywords: Glanville, Black Box, mind, machine, von Foerster, Moore, Mealy

1. Introduction

This paper emanated from the 2019 Annual Conference of the American Society for Cybernetics, its theme: Acting Cybernetically. Here, we will critically explore the concepts of trivial and non-trivial machines. Understanding non-triviality is essential to understanding how organisms can act cybernetically, that is, how they come to understand and regulate their environments in a goal-oriented manner. Such actions are taken to imply intelligence. Indeed, we attempt to quantify intelligence by quantifying the behaviors—the conscious, willful acts, unlike mere physiological reflexes—that themselves imply a mind in any entity besides the observer himself. The observer's own mind will be taken to be evident to him through his own consciousness. Minds presumably exist within animals having recognizable brains. Whether other species have minds will not be debated.

Of course, behavior itself can be difficult to quantify, especially when experimental-research subjects cannot self-report. An example of reporting is the confirming of particular sensations evoked by stimuli (Nizami, 2017). In animals, primitive reporting (Yes/No, Left/Right, etc.) can be painstakingly conditioned. By-

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and-large, however, the animal remains a *Black Box* to the observer of behavior (Nizami, 2017). The reason for the capital B's will soon be explained.

Here, the attempts to understand a mind through sensory interaction with its host organism are placed in relation to the notions of the Black Box and its observer as proselytized by Ranulph Glanville (Glanville, 1982, 1997, 2007, 2009a, 2009b). The *black box* of an engineer or a physicist is a physical object that can be opened, letting its operation be comprehended. Nonetheless, there can be restrictions:

> Both the power and the problem with modern scientific instrumentation are reflected in the term *black box,* commonly used to describe the equipment. Today's black-box instruments are highly effective in making measurements and collecting data, enabling even novices to perform advanced scientific experiments. But, at the same time, these black boxes are "opaque" (in that their inner workings are often hidden and thus poorly understood by their users), and they are bland in appearance (making it difficult for users to feel a sense of personal connection with scientific activity). … Most scientific instruments today are filled with little more than circuit boards and integrated circuits. Even if they opened up the box and looked inside, most students (and even most scientists) would understand very little about how the instrument works. (Resnick et al., 2000, p. 9)

Opaqueness also occurs in software. Creel (2020, p. 4) observes: "As large-scale computation becomes vital to many scientific disciplines, scientists express dissatisfaction with the limited transparency it affords, especially when the new computational methods seem less transparent than previous methods for performing the same operation on smaller data sets … ." As Creel emphasizes,

> An algorithm is an abstract mathematical object. A computer program is a particular instantiation of an algorithm. Because an algorithm can be multiply realized in code, knowing the algorithm does not entail knowing the parts of a program or the relations between its parts. Programs that successfully carry out the same algorithm can be composed of different arrangements of parts, especially if they are written in different types of programing languages, whether procedural, functional, object-oriented, or assembly. (Creel, 2020, p. 10)

The present paper will not describe the brain as hardware, or the mind (or whatever phenomena generate it) as software. Indeed, we must abandon the popular but unjustified *computational* and *informational* models of brain and mind, which have fascinated so many for so long, but with so few convincing conclusions (Nizami, 2010, 2011, 2012, 2013, 2014, 2015, 2017, 2018, 2019). Further, as we will be concerned with an organ that helps generate behavior, let us emphasize once again what will be meant by *behavior.* Behavior will be taken as something that is done consciously and intentionally, and by a living thing. This contrasts, for example, to reflexes in living things, which would include the jerk of the lower leg when the knee is tapped by a physician, or the startle response in which a person involuntarily jumps upwards when suddenly exposed to an unexpected and very loud auditory stimulus, or the tendency of some single-celled organisms to move towards light. Likewise, the much-touted "behaviors" of Grey Walter's "tortoises" (Walter, 1950; Holland, 2003) are merely reflexes that are built into non-living things.

2. The Black Box and Its Observer

Glanville (2007) notes that much of his discourse on the Black Box originates in the writings of W. Ross Ashby (1956). Hence, we begin with Ashby. Ashby devotes a chapter to the Black Box in his book *An Introduction to Cybernetics* (1956), a book cited over 13,000 times (GoogleScholar)[2], a profound citation-count at a time when 100 citations is considered significant. (For a brief summary of Ashby's importance to science, see Ramage and Shipp, 2009.) Ashby's 1961 edition is more readily available, and is cited here. Now, if the *machine* of the engineer is incomprehensible (or the programming by the computer scientist is undecipherable), then the black box becomes a Black Box (Ashby, 1961). It is now understood only through inputs given by, and outputs noted by, an observer (Ashby, 1961). Indeed, this input/output cycle may never reveal the Black Box's physical parts, even though the Box's mechanism, if defined as a procedure for achieving a goal, might be inferable. For example, a mechanical realization (i.e., physical manifestation) of a mechanism may be indistinguishable from an electrical one (Ashby, 1961). Ashby (1961) gives examples of this, using *mechanism* in its streetwise definition as a physical realization of a procedure. Ashby notes that we can

> cover the central parts of the mechanism and the two machines are indistinguishable throughout an infinite number of tests applied. Machines can thus show the profoundest similarities in behavior while being, from other points of view, utterly dissimilar. (Ashby, 1961, p. 96)

Following Ashby, we might imagine machines that consist of both mechanical and electrical components, mechano-electrical systems whose actual mechanisms-as-physical-realizations are indistinguishable, one from another, through input and output. As such, mechanisms become irrelevant, to a logical limit taken by Glanville: "You cannot see inside the Black Box (there is nothing to see: there is nothing there—it is an *explanatory principle*)" (Glanville, 1997, p. 2; italics added). That is: "Our Black Box is not a physical object, but a concept … . It has no substance, and so can neither be opened, nor does it have an inside" (Glanville, 2009b, p. 154). The Black Box is now a procedure for achieving a goal. However, Glanville (1982, 2007, 2009a, 2009b) contradicts himself by maintaining that the Black Box has a mechanism, implied to be a mechano-electrical realization.

How can all this be? Glanville's Black Box sounds suspiciously like a mind. No-one can directly observe their own mind, or anybody/anything else's. *Mind* is an explanatory principle for what we call behavior. Nonetheless, mind emerges from a mechano-electrical realization which is the animal body, particularly the brain. This paper explores the notion of the mind as a Black Box.

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2. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=w+ross+ashby&btnG=

3. Whitening the Black Box

Let us clarify Glanville's notion of the Black Box as a phenomenon or principle or concept. First, let us assume that the Black Box is spatially located, thereby avoiding a universal Black Box that might be named God or Nature. Hence there must be a localized mechano-electrical system that is the basis for (i.e., that produces) the Black Box. For example, the brain with its extended network of neurons and blood vessels indisputably produces the mind, whose existence is evident through conscious, intentional behavior. This specific relation of brain, mind, and behavior appeared in the literature almost a century ago (Patrick, 1922) and probably dates to much earlier times. The mind is not independent of its host body; likewise, the Black Box is not independent of its mechano-electrical basis.

Figure 1 schematizes the Black Box and its observer. The observer makes inferences about the Black Box by presenting stimuli, the inputs, and recording the Box's consequent responses, the outputs (Ashby, 1961; Glanville, 1982, 1997, 2007, 2009a, 2009b). Glanville (1982, p. 1) states that the observer gains a *functional description* of the Black Box. That is, "The 'functional description' … describes how the observer understands the action of the Black Box" (Glanville, 1997, p. 2). With the box being closed, the functional description is: the mechanism as a procedure for achieving a goal. The *procedure* arises from the mechano-electrical basis. In inferring the procedure, that is, the conceptual transformations happening within the Black Box, the Black Box is *whitened* (Glanville, 1982). Practical examples of whitening through input/output might include an experimental psychologist studying the behavior of a human or an animal, or a physiologist making a noninvasive electrical recording (Nizami, 2015, 2017). As the reader might suspect, an experimenter's whitening of a research subject may involve a likewise whitening of the experimenter, from the research subject's perspective, as will now be described.

4. Observer as Black Box, Black Box as Observer

Whitening of the Black Box becomes more intriguing yet. Glanville (1982, 1997, 2009a, 2009b) declares that the observer can be considered a Black Box, from the Black Box's viewpoint. Consider that an output of the Black Box is an input to its observer; an input to the Black Box is an output from the observer. Hence, "we come to assume that the Black Box also makes a functional description of its interaction with the observer" (Glanville, 1997, p. 2). The Black Box whitens its observer, by acting as an observer (Glanville, 1982).

Imagine now the mind as a Black Box, probed through input and output. We call this action psychiatry or psychology. But each psychiatrist or psychologist has their own mind, which itself is a Black Box! Those particular Black Boxes regulate everything that those particular observers say and do; the observers themselves are Black Boxes. And indeed, W. Ross Ashby (1961) and a contemporary of his, E. F.

Moore (1956), both imply that a psychiatrist and a patient are interacting Black Boxes. When the psychiatrist (or the experimental psychologist) probes the patient (or the research subject), each participant (if awake and aware) is an observer, who regards the other as a Black Box. Such interacting parts can be regarded, in total, as a system. Ashby (1961, p. 87) thinks of experiments themselves as systems: "By thus acting on the Box, and by allowing the Box to affect him and his recording apparatus, the experimenter is *coupling* himself to the Box, so that the two together form a system with feedback."

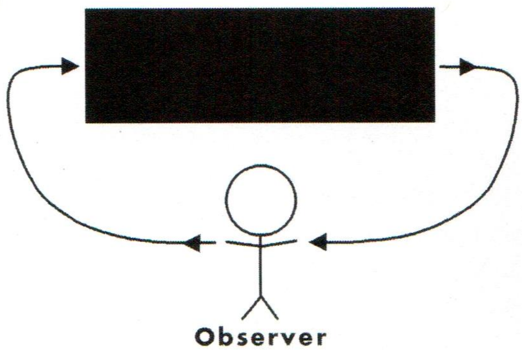

Figure 1. The Glanville notion of the Black Box and its observer.
The observer sends inputs to the Box, and receives outputs from it.

5. Black Box + Observer = System: Inside Every White Box There Are Two Black Boxes Trying to Get Out

In Ashby's system, experimenter and Box each feed back to the other, each becoming both observer and Black Box. The total system, let us call it the BlackBox/observer system, has different properties than either the Black Box or the observer alone: "The Black Box and the observer act together to constitute a (new) whole" (Glanville, 2009a, p. 1; see Glanville, 2009b, p. 161). This new whole is called the *White Box* from 1982 onwards (Glanville, 1982-2009b).

Figure 2 schematizes the White Box. If now the observer himself is taken to be a Black Box, then the title of Glanville's paper of 1982 becomes comprehensible: "Inside every White Box there are two Black Boxes trying to get out." According to Glanville (1982, 2009a, 2009b) the White Box, as a system, is nonetheless Black to any further-external observer.

6. Interim (1): Trivial Machines

To further explicate the relation of mind to Black Box, it is necessary to digress into a definition of the machine. Machines were introduced in section 2, as mechano-electrical devices. However, a product of a mechano-electrical basis—a product that is an abstract entity such as the Glanville Black Box—can itself be a machine as characterized by von Foerster (2003, p. 207, italics added): "The term 'machine' in this context refers to *well-defined functional properties of an abstract entity* rather than to an assembly of cogwheels, buttons and levers, although such assemblies may represent embodiments of these abstract functional entities [machines]." As an abstract entity, consider the mind; among its functional properties, consider perception, itself inseparable from consciousness, and consider also the capabilities embedded in consciousness, such as remembering, calculating, and reason-based decision-making. Machine = Black Box = Mechanism as a procedure for achieving a goal.

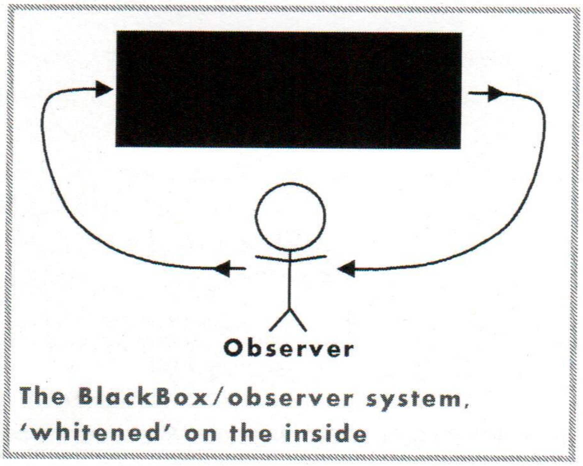

Figure 2. The Black Box and its observer mutually whiten through interaction, making a system (dashed boundary) that is whitened inside.

Von Foerster (1984, 2003) recognizes two types of machines: trivial, and non-trivial. As he explains,

> A *trivial* machine is characterized by a one-to-one relationship between its "input" (stimulus, cause) and its "output" (response, effect). This invariant *relationship* is "the machine". Since this relationship is determined once and for all, this is a deterministic system; and since an output once observed for a given input will be the same for the same input given later, this is also a *predictable* system. (von Foerster, 2003, p. 208; italics added)

Algebra-wise, von Foerster explains that for input $\boldsymbol{x}$ and output $\boldsymbol{y}$, "a $\boldsymbol{y}$ once observed for a given $\boldsymbol{x}$ will be the same for the same $\boldsymbol{x}$ given later" (von Foerster, 1984, p. 9). According to von Foerster, "one simply has to record for each given $\boldsymbol{x}$ the corresponding $\boldsymbol{y}$. This record is then 'the machine'" (von Foerster, 1984, p. 10).

An example of a trivial machine is provided by von Foerster (1984, p. 10) in the form of a table in which he assigns an output $\boldsymbol{y}$ to each of four possible inputs $\boldsymbol{x}$. The $\boldsymbol{x}$'s are the letters A, U, S, and T, and the respective outputs $\boldsymbol{y}$ are 0, 1, 1, and 0. Von

Foerster (2003, p. 208) notes that "All machines we construct and buy are, hopefully, trivial machines," that is, they are predictable.

7. Interim (2): Internal States

In reality, not all machines are trivial. A physical machine, as Ashby (1961) points out, can have internal conditions or configurations, which he calls *states*. Let us likewise assume that the products of physical machines can also have states, products such as *conceptual machines*, such as Black Boxes. Ashby notes "that certain states of the Box cannot be returned to at will" (Ashby, 1961, p. 92), which (he declares) "is very common in practice. Such states will be called **inaccessible**" (Ashby, 1961, p. 92; original boldface). Ashby continues: "Essentially the same phenomenon occurs when experiments are conducted on an organism that *learns*; for as time goes on it leaves its 'unsophisticated' initial state, and no simple manipulation can get it back to this state" (p. 92; italics added). *Learning* presumably means changes in abilities and knowledge, reflected in changes of behavior.

Here, mind is machine is Black Box. Learning is presumably concurrent with changes in the mind's mechano-electrical basis, the brain and its collaterals; changes in brain-states manifest as changes in mind-states. Thanks to learning, a response to a stimulus can differ from a previous response, and in unexpected ways. When a stimulus is a question, for example, von Foerster (2003, p. 311) notes that a child can offer a correct (because carefully trained) answer, or a correct (but unexpected) answer, or an answer that is intentionally capricious! Minds are not trivial machines. Note well that we are not claiming that brains or minds are algorithms or that brains or minds are computers, unlike other authors (as reviewed, e.g., in Piccinini & Scarantino, 2011).

We must therefore ask whether the observer of any Black Box can give input, and record output, without changing the Box's possible output to the next input. That is, can the Black Box be observed without being perturbed? Likewise, can a Black Box's output be observed by, but not perturb, the observer?

8. Interim (3): Sequential Machines

Conceivably, there are perturbable machines. Such devices were envisioned long before Ashby (1961). Indeed, Turing (1937) conceives of a machine whose input and/or output can change the response to the next input. Turing describes the machine only in terms of its process, as follows: The machine has a finite number of internal states, called *conditions* or *configurations*. The machine accepts an input in the form of a continuous tape, divided into equal segments, each segment either containing a symbol or being blank. The machine scans one tape segment at a time; the scanned symbol (or blank), along with the machine's current configuration, altogether determine the impending response. That response can include erasing a symbol from the tape; or printing (or not), on a blank segment of the tape, a symbol consisting of a digit (0 or 1) or some other symbol; or shifting the tape one segment to the left or one segment to the right (Turing, 1937).

Turing's machine exemplifies what came to be known as *sequential machines*. One class of sequential machines was described by Moore (1956). Moore, like Turing, used operational descriptions:

> The state that the machine will be in at a given time [the current state] depends only on its state at the previous time and the previous input symbol. The output symbol at a given time depends only on the current state of the machine. (Moore, 1956, p. 133)

In other words, an input evokes an output, which is nonetheless determined only by the present internal state. That state then changes to another state, determined by whatever was the input and the internal state. Each internal state represents a capability to do something (to the inputs), that is, a readiness of the system.

Moore (1956) provides an example of a sequential machine, in the form of two tables that relate inputs, outputs, and internal states (Moore, 1956, p. 134). Let us presently symbolize an input by $\boldsymbol{x}$. In Moore's paper, the identities of the inputs were also the identities of the possible outputs; but for the sake of distinction, let us presently symbolize an output by $\boldsymbol{y}$. One of Moore's tables shows the present output $\boldsymbol{y}$ of the machine, as a function of the present state. Let us symbolize the latter by z. Let $\boldsymbol{y=Y(z)}$ denote the relation between $\boldsymbol{y}$ and z, and let it be realized by the trivial machine called the *Output Generator*. The second of Moore's two tables shows "the present state of the machine … as a function of the previous state and the previous input" (Moore, 1956, p. 134). Let us call Moore's previous state z_{-1} and the previous input $\boldsymbol{x_{-1}}$. Let z_{-1} and z be realized by the trivial machine called the *State Generator* that obeys the relation $z=\boldsymbol{Q}(\boldsymbol{x_{-1}}, z_{-1})$.

This algebra is truly necessary, in order to link Moore's concepts to other important concepts, namely those of von Foerster (1984, 2003), and those of Mealy (1955), the possible origin of von Foerster's ideas, all of which is discussed below. But back to Moore (1956): Moore uses four possible internal states, which he labels $\boldsymbol{q_1}$, $\boldsymbol{q_2}$, $\boldsymbol{q_3}$, and $\boldsymbol{q_4}$, and two possible inputs, $\boldsymbol{x}$=0 or $\boldsymbol{x}$=1, the two digits used in binary computation. Recall from above that Moore explains a sequential machine by using two tables that relate inputs, outputs, and internal states. Presently, for the sake of comprehensibility, Moore's two tables have been re-arranged into five smaller tables. Four show z as a function of $\boldsymbol{x_{-1}}$ for the four possible values of z_{-1} (namely, $\boldsymbol{q_1}$, $\boldsymbol{q_2}$, $\boldsymbol{q_3}$, and $\boldsymbol{q_4}$); the remaining table shows $\boldsymbol{y}$ as a function of z. The five tables have then been collected. Table 1 shows that collection.

Consider an example of how the Moore sequential machine works. First, note from Table 1 that the present internal state $z=\boldsymbol{q_4}$ could have arisen from the previous state $z_{-1}=\boldsymbol{q_3}$ and the previous input $\boldsymbol{x_{-1}}$= 0 or 1, or alternatively from the previous state $z_{-1}=\boldsymbol{q_1}$ and the previous input $\boldsymbol{x_{-1}}$=0. Regardless, a new input $\boldsymbol{x}$=0 *or* $\boldsymbol{x}$=1 evokes the output $\boldsymbol{y}$=1, after which $z=\boldsymbol{q_4}$ becomes $z_{-1}=\boldsymbol{q_4}$ and either $\boldsymbol{x}$=0 (if having been given) becomes $\boldsymbol{x_{-1}}$=0, *or* $\boldsymbol{x}$=1 (if having been given) becomes $\boldsymbol{x_{-1}}$=1. By coincidence, the internal state is now z=q_2 (according to Table 1) regardless of what value was x. A subsequent input x=0 *or* x=1 will result in y=0; hence, the sequence continues.

Table 1: Relations in E. F. Moore's (1956) Example of a Sequential Machine.

$z_{-1} = q_1$	
x_{-1}	z
0	q_4
1	q_3

$z_{-1} = q_2$	
x_{-1}	z
0	q_1
1	q_3

$z_{-1} = q_3$	
x_{-1}	z
0	q_4
1	q_4

$z_{-1} = q_4$	
x_{-1}	z
0	q_2
1	q_2

z	y
q_1	0
q_2	0
q_3	0
q_4	1

Note: The four leftmost tables describe the State Generator, which fulfils z=$Q(x_{-1}, z_{-1})$ for internal states q_1, q_2, q_3, **and** q_4. Whichever of those is the current internal state determines the output y of the Output Generator, which obeys y=$Y(z)$ according to the rightmost table.

In Moore's scheme, a particular output can result from different internal states; further, a particular internal state can result from different inputs. What we presently call the State Generator and the Output Generator are deterministic (i.e., non-random), and they are predictable insofar as an outside observer supplying input and recording output can gain increasing confidence about each generator's operating rules. Both generators are therefore trivial machines. This is a crucial distinction, as follows.

Moore's sequential machine is the concatenation of three things: two trivial machines, and a register of the current internal state, a register which is also a trivial machine. The overall result, however, is a non-trivial machine, meaning it is non-predictable. That is, the whole is more than the sum of its trivial parts. This seems to be a case of emergence (Nizami, 2017, 2018). How, then, would an observer of the sequential machine (rather than its maker) gain the data to fill Moore's two tables? Moore (1956, p. 132) introduces "a somewhat artificial restriction that will be imposed on the action of the experimenter. He is not allowed to open up the machine and look at the parts to see what they are and how they are interconnected." That is, "the machines under consideration are always just what are sometimes called 'black boxes', described in terms of their inputs and outputs, but no internal construction information can be gained" (Moore, 1956, p. 132).

Moore himself offers no graphical illustration of a sequential machine as a Black Box. Nonetheless, such an illustration can be imagined. Figure 3 shows a sequential machine configured as a Black Box, one whose inventor must know that it contains three trivial machines. Their operations follow the relations expressed in tables such as Moore's. The box can be imagined as having a four-step input/output cycle. Figures 4, 5, 6, and 7 show that cycle.

9. Interim (4): Non-Trivial Machines

Sequential machines have broad importance. They are cases of what Heinz von Foerster (1984, 2003) would later call non-trivial machines. Like Moore (1956), von Foerster (1984, p. 11) provides an example in the form of two tables. Let us use ***z'*** to denote the state of *z* which occurs after ***y*** is output. The tables describe the output ***y*** and the next state ***z'*** in terms of the input ***x***, but for only two possible internal states *z*, here dubbed **I** or **II**. Such a machine is the simplest non-trivial machine; if there was only a single internal state, then a particular input would always evoke a particular pre-determined, unchanging output, hence the machine would be trivial. Von Foerster nonetheless uses the same examples of input and output for his non-trivial machine as he uses for his trivial machine (see above): ***x*** = A, U, S, or T, and ***y*** = 0 or 1.

The entries in von Foerster's two tables (von Foerster, 1984) can be re-ordered, making four new tables, two for each of *z*=**I** and *z*=**II**. Two of the tables show ***y*** as a function of ***x***, and two of the tables show ***z'*** as a function of ***x***. All four tables can be collected. Table 2 shows that collection. The trivial machine that realizes the relation expressing ***y*** as a function of ***x*** is the equivalent of Moore's Output Generator, and the trivial machine that realizes the relation expressing ***z'*** as a function of ***x*** is the equivalent of Moore's State Generator (Fig. 3). But von Foerster respectively calls them the Driving Function and the State Function, respectively.

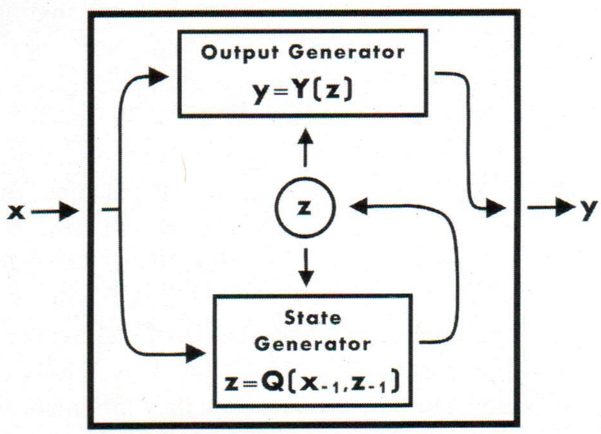

Figure 3. A Moore (1956) sequential machine. The boxes and lines and the circle represent hypothetical mechano-electrical parts. The lines with arrows also represent the parts' operating relations, which need not occur simultaneously, although they are shown for illustration purposes as happening simultaneously. The operation of the parts actually follows the cycle shown in Figs. 4, 5, 6, and 7. The internal state *z* actively affects the Output Generator, which fulfils ***y=Y(z)***, and the State Generator, which fulfils $z=Q(x_{-1}, z_{-1})$. ***Q*** produces a new state *z* after ***y*** is output by ***Y***, which occurs after ***Y*** is prompted by the input ***x*** (see Figs. 4, 5, 6, and 7).

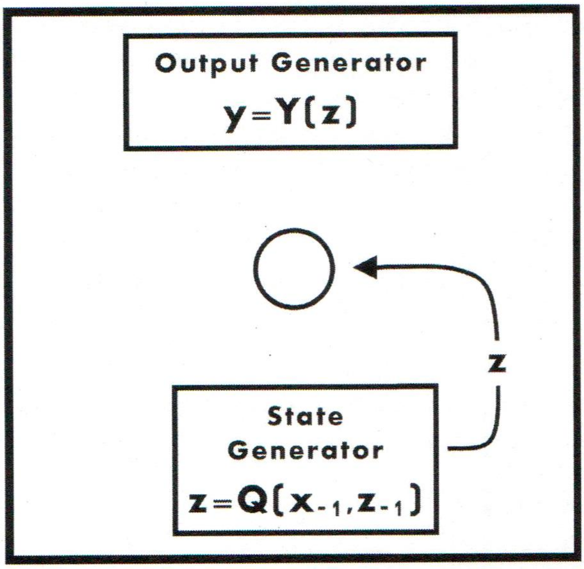

Figure 4. The operation of a Moore sequential machine. Here in Step 1 of the cycle, the internal state z is determined by the previous input x_{-1} and the previous state z_{-1}, and moves to an internal register (circle).

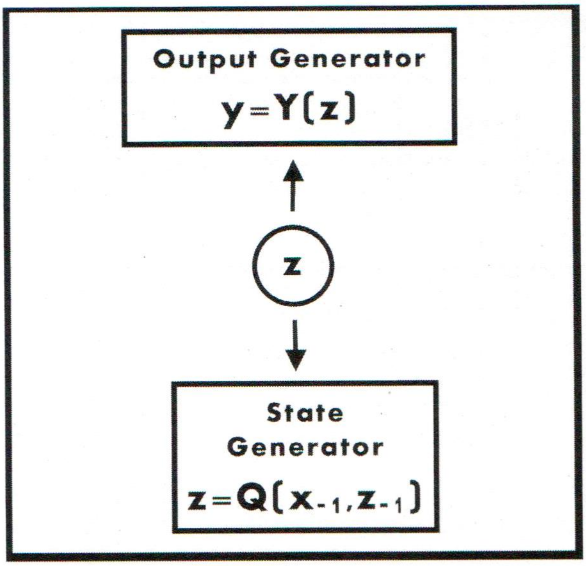

Figure 5. Step 2 of the cycle of a Moore sequential machine. Here, the internal state z actively affects the Output Generator Y and the State Generator Q prior to input.

Von Foerster's (1984) machine conceivably follows a four-step operational cycle like the ones shown in Figs. 4, 5, 6, and 7 for Moore's machine. Figures 8, 9, 10, and 11 show a hypothetical four-step operational cycle of a von Foerster machine. But the machines of Moore (1956) and of von Foerster (1984, 2003) profoundly differ in one particular detail. To Moore (1956), the input x has no bearing on the immediate resulting output y (Figs. 6 and 7), only on its successor by way of the internal state. Moore's y is evoked by x, but is only indirectly a function of x by way of the internal state. In contrast, in von Foerster's (1984, 2003) machine, x directly affects y, and x also indirectly affects the next output, by way of the internal state.

As an example of how the von Foerster non-trivial machine works, note from Table 2 that when z=**II** and an input x=U occurs then the output y=0 is evoked and the internal state changes to z'=**II**, which coincidentally is the same state as before.

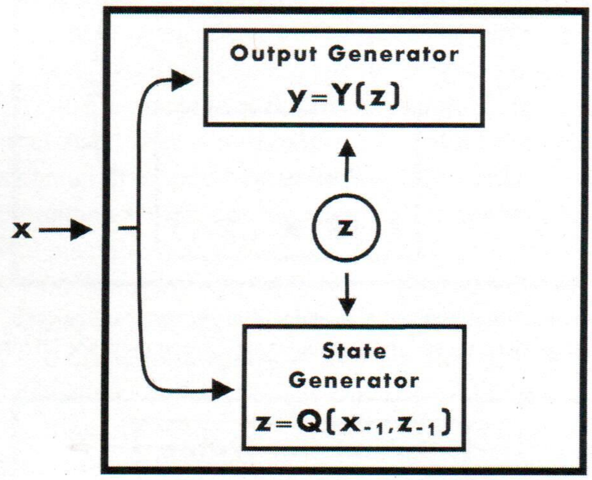

Figure 6. Step 3 of the cycle of a Moore sequential machine. Here, x is input, affecting the Output Generator $Y(z)$ and the State Generator $Q(x_{-1}, z_{-1})$.

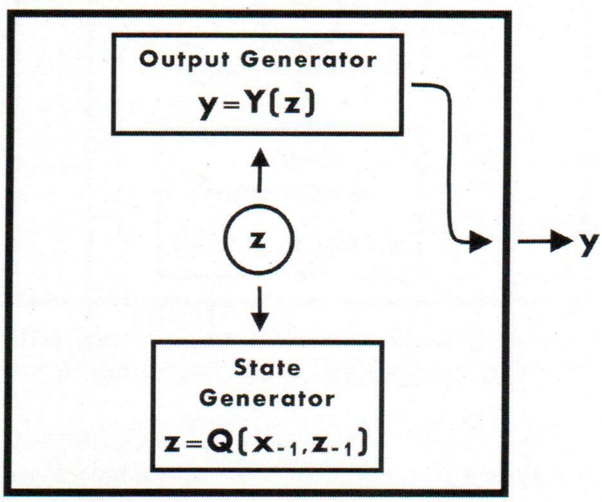

Figure 7. Step 4 of the cycle of a Moore sequential machine, in which the Output Generator $Y(z)$ produces the output y.

10. Interim (5): the Mealy Machine, a Realization of Machine as Mechano-Electrical Device

In describing his non-trivial machine, von Foerster (1984, 2003) presents examples of what has become known as a Mealy Machine, after George H. Mealy (1955), a contemporary of Ashby and Moore. Mealy's archetype machine (Mealy, 1955)

> has n binary-valued input variables, $x_1, x_2, \ldots, x_n$; m binary-valued output variables, $y_1, y_2, \ldots, y_m$; s binary-valued excitation variables, $\overline{q}_1, \overline{q}_2, \ldots, \overline{q}_s$; and s binary-valued state variables, $q_1, q_2, \ldots, q_s$, corresponding one-to-one with the excitation variables. (Mealy, 1955, p. 1050)

In the present notation, $z=\{ q_1, q_2, \ldots, q_s\}$ and $z'=\{ \overline{q}_1, \overline{q}_2, \ldots, \overline{q}_s\}$; Mealy's choice of the word *excitation* will be explained shortly. Mealy's machines are realized as electrical circuits, although they can contain mechano-electrical parts such as the relays of Mealy's era.

Table 2: Relations in von Foerster's example of a Non-Trivial Machine.

z = I	
x	y
A	0
U	1
S	1
T	0

z = II	
x	y
A	1
U	0
S	0
T	1

z = I	
x	z'
A	**I**
U	**I**
S	**II**
T	**II**

z = II	
x	z'
A	**I**
U	**II**
S	**I**
T	**II**

Note: The two left-hand tables describe the Driving Function $y=Y(x, z)$, and the two right-hand tables describe the State Function $z'=Z(x ,z)$, for internal states **I** and **II**.

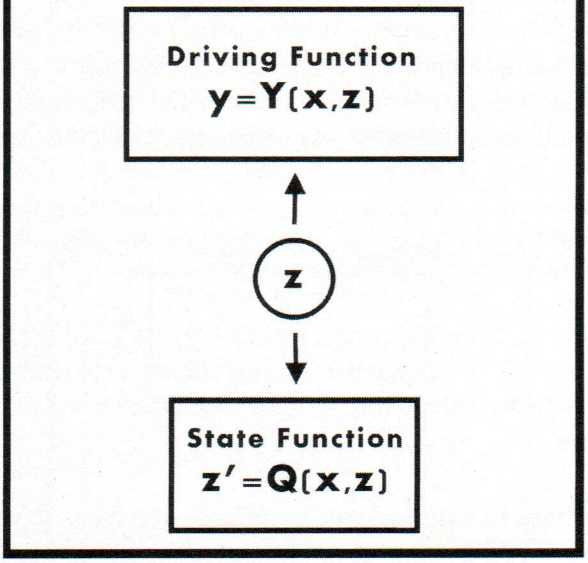

Figure 8. The operation of von Foerster's Non-Trivial Machine (1984), interpreted as a cycle. The non-trivial machine involves two trivial machines, one fulfilling the Driving Function and the other fulfilling the State Function, the respective operational equivalents of the Output Generator and the State Generator in Fig. 3. The register for the internal state *z* may also be considered a trivial machine. In the Moore machine illustrated in Figs. 4-7, however, *y* is a direct function only of *z*; here, in contrast, *y* is a direct function of both *z* and *x*. The above illustration shows Step 1 of the cycle of the von Foerster non-trivial machine, in which the internal state *z* actively affects the Driving Function ***Y*(*x*, *z*)** and the State Function ***Q*(*x*, *z*)** prior to input. This is the same as Step 2 of the Moore machine (Fig. 5), the difference in the order being caused by Moore's emphasis on the internal state's dependence on the previous values of the input ***x*** and the internal state *z*.

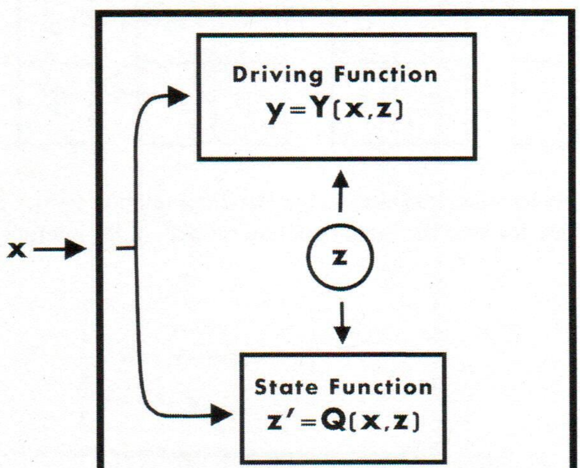

Figure 9. Step 2 of the cycle of von Foerster's non-trivial machine. Here, ***x*** is input, affecting the Driving Function ***Y*(*x*, *z*)** and the State Function ***Q*(*x*, *z*)**.

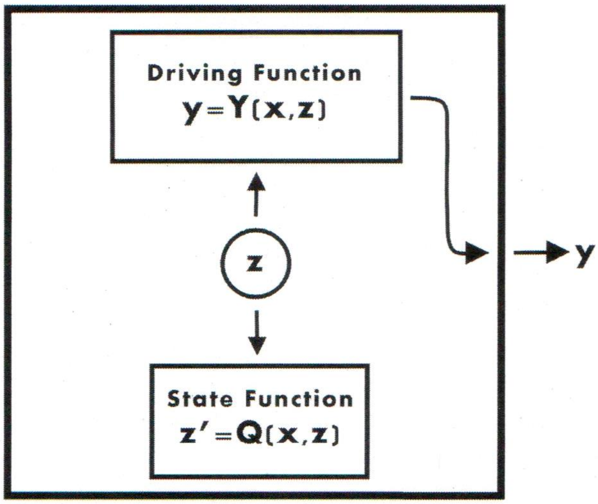

Figure 10. Step 3 of the cycle of von Foerster's non-trivial machine. The Output Generator ***Y*(*x*, *z*)** produces the output ***y***.

Mealy's machine, like those of Moore and of von Foerster, is best explained through examples. Mealy (1955) offers several; the operating relations of one of the simpler examples is reproduced here. Table 3 shows those relations. The input $\boldsymbol{x}$, the output $\boldsymbol{y}$, and the various internal states $\boldsymbol{q}_i$ and $\overline{\boldsymbol{q}}_i$ are all assigned values of 0 or 1. Mealy explains his own use of 0s and 1s as follows: he wishes to design an electrical circuit in which "*Any lead or device within the circuit may assume, at any instant of time, only one of two conditions, such as high or low voltage, pulse or no pulse*" (Mealy, 1955, p. 1047; italics in original). A pulse may be of voltage or of current.

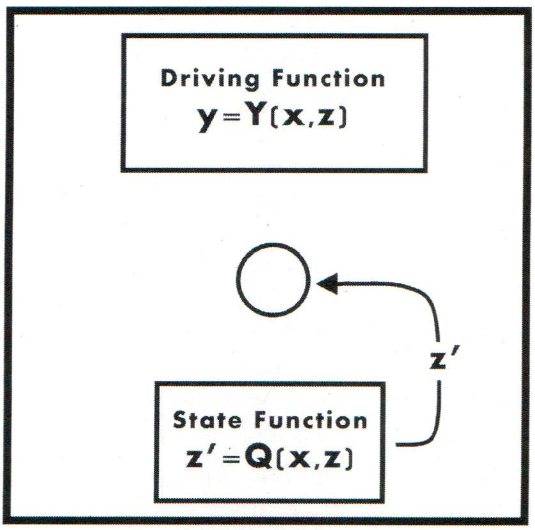

Figure 11. Step 4 of the cycle of von Foerster's non-trivial machine. The next internal state, ***z'***, is determined by the just-given input ***x*** and the current internal state *z*, and it moves to the internal register (circle).

There is a further condition: "*The behavior of the circuit may be completely described by the consideration of conditions in the circuit at equally-spaced instants in time*" (Mealy, 1955, p. 1047; italics in original). Altogether, this statement along with its predecessor define a *synchronous circuit*. Mealy clarifies this term:

> (1). There is a so-called clock which supplies timing pulses to the circuit. (2). Inputs and outputs are in the form of voltage or current pulses which occur synchronously with pulses from the clock. (3). The repetition rate of the clock pulses may be varied, within limits, without affecting the correct operation of the circuit, so long as input pulses remain synchronized with the clock. (Mealy, 1955, p. 1047)

Present-day electronic devices may contain circuits that are synchronous and those that are not, called *asynchronous circuits*. The distinction between synchronous and asynchronous machines is important because it is non-trivial to the actual function (and hence the design) of the machines.

Mealy, having given his pre-conditions, now provides

> an abstract definition of a switching circuit: *A switching circuit is a circuit with a finite number of inputs, outputs, and (internal) states. Its present output combination and next state are determined uniquely by the present input combination and the present state. If the circuit has one internal state, we call it a* combinational circuit; *otherwise, we call it a* sequential circuit. (Mealy, 1955, p. 1049; italics in original)

We might ask what allows a *present state* that is physically distinguished from a *next state*. Mealy's answer is that circuits can contain *delay elements*, where "The unit of delay is the interval between the start of two successive clock pulses" (Mealy, 1955, p. 1048). The lines of electrical conductance that contain delay elements are *delay lines*. The excitation variables are assigned as inputs of delay lines; the state variables are assigned as outputs of delay lines. Therefore the input of a delay line is its output one clock cycle later; each $\boldsymbol{q_i}$*'s* next value is $\overline{q}_i$, where both variables manifest as pulses (indicated by 1) or not (indicated by 0).

Mealy (1955) then extends his concepts to asynchronous circuits, where

> We agree (1) that no clock will be used and (2) that "1" in switching algebra will correspond to a high voltage or current, an energized relay coil, or operated relay contacts. We must now pay careful attention to circuit conditions at *every* instant of time. (Mealy, 1955, p. 1067; italics in original)

Here, the difference between a present state of 1 and a consequent next state of 1 is the difference between a relay being operated and a relay being energized to allow imminent operation. Further details are unnecessary here, and the reader is left to peruse the details in Mealy (1955), heeding his admonition (Mealy, p. 1071) that tables of relations such as Table 3 might not "always be used for both a synchronous and an asynchronous realization of a given circuit". Asynchronous circuits in particular are dealt with by Huffman (1954a, 1954b), who both Moore (1956) and Mealy (1955) cite as being highly relevant to their own work. Finally, note well that the relations in Table 3 represent a particular example of equations that arise from *switching algebra* for the design of sequential circuits.

11. Mind as Black Box

To Moore, scientists themselves belong to systems: "The experiment may not be completely isolated from the experimenter, i.e., the experimenter may be experimenting on a system of which he himself is a part" (Moore, 1956, p. 133). Hence, "The experimenter [who probes the machine] could be described as another sequential machine, also specified in terms of its internal states, inputs, and outputs" (Moore, 1956, p. 135). That is: "The output of the machine being experimented on would serve as input to the experimenter and vice versa" (Moore, 1956, p. 135).

Further logic-wise (but earlier text-wise), Moore (1956, p. 132) notes that a psychiatrist experiments on a patient, giving inputs and receiving outputs. Moore's Black Box is evidently the mind. As Moore declares (1956, p. 132), "The Black Box restriction corresponds approximately to the distinction between the psychiatrist and the brain surgeon." Moore explains that the surgeon can alter the brain, but only the psychiatrist can alter the mind. Modern surgeons might disagree; after all, the mind arises from the brain, and the brain is a mechano-electrical device that is organic and that matures with time, and that can be altered. But surgery that is intended to affect the mind will perforce have unknown side-effects, and is usually beyond the surgeon's remit; such behavior-altering practices as frontal lobotomies and electroshock therapy, for example, have long been discredited.

Table 3: An Example of Relations in a Mealy Sequential Machine.

q_1	q_2	x	$\overline{q}_1$	$\overline{q}_2$	y
0	0	0	1	0	1
0	0	1	1	0	1
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	1	1	0
1	0	1	0	1	0
1	1	0	0	0	0
1	1	1	0	1	0

Note: This single table expresses both the Driving Function $y=Y(x, z)$ and the State Function $z'=Z(x, z)$. Recall that z consists of q_1 and q_2, and that z' likewise consists of $\overline{q}_1$ and $\overline{q}_2$. The three left-hand columns describe all possible combinations of $z=\{q_1, q_2\}$ and x, and the right-hand three columns describe the consequent values of y and $z'=\{\overline{q}_1, \overline{q}_2\}$ for one particular imagined electrical circuit.

Regardless, for a sequential machine to be a mind, it would need to be capable of an enormous number of possible operations. Many of those operations, if not all, would be learned. How many such operations are possible? The answer is "surprisingly many," but the necessary explanation is elaborate and must be left to later work.

12. How a Further-External Observer Would Interact With the System

Section 7 introduced the question of whether the observer of any Black Box can give input, and record output, without changing the box's possible output to the next input. That is, can the Black Box be observed without being perturbed and, likewise, can a Black Box's output be observed by, but not perturb, the observer? The above review of the concept of machines allows these questions to be answered.

Consider the following thought experiment, which may be considered a proof-by-negation. Recall now the system that is the White Box of Fig. 2. Let us assume that the Black Box can be probed by its observer without being perturbed. Let us further (but only momentarily) assume that understanding something does not require perturbing it. Suppose also that the observer remains unperturbed by the output from the Black Box. Altogether, the BlackBox/observer system is unaltered by its internal interactions. Hence, the degree to which the observer and the Black Box understand each other will be limited only by the number of possible inputs from each to the other. The Black Box and its observer can fully whiten each other in time. They are trivial machines.

Imagine now a *further-external observer* who interacts with the system that is the White Box of Fig. 2. If the core Black Box and its observer are indeed trivial machines, then if the system that they form is probed by a further-external observer, the latter can ignore the box's immediate observer and directly interrogate the box. This direct access applies by induction to all *further-outward observers*. And Glanville did illustrate this exact situation (Glanville, 1982; illustration omitted). The combination of any observer with the core Black Box forms a system that is no different than the combination of any other observer with the core Black Box, unless the observers themselves differ.

Consider now the alternative. Imagine that the core Black Box cannot be probed by its immediate observer without being perturbed, and that, similarly, the immediate observer cannot receive output from the core Black Box without changing. Box and observer are now non-trivial machines. But a non-trivial machine concatenated with a non-trivial machine is, perforce, a non-trivial machine. That is, the core Black Box and its immediate observer are now truly entangled; no further-outward observer can tell them apart and hence ignore the immediate observer. The core BlackBox/observer system, Glanville's White Box (Fig. 2), is now a Black Box to any further-external observer. Figure 12, inspired by Glanville (2009b, p. 164), illustrates this situation. The concatenation of the further-external observer with the core BlackBox/observer system constitutes a new system which is perforce a non-trivial machine, regardless of whether or not the further-external observer himself is a non-trivial machine. Probing the core BlackBox/observer system through input would perturb it.

It follows that the system comprising the core BlackBox/observer system and the further-external observer is itself a Black Box to any *yet-further-external* observer. It can be perturbed by that observer, who can only infer, but not know with certainty, what or who is inside it. Glanville (2009a, p. 1) notes that "each Black Box is potentially made up of a recursion of Black Boxes (and observers)". Figure 13 shows this recursion. Glanville (2009a, p. 1) implies that in "a recursion of Black Boxes (and observers)," none of the observers know of each other's existence.

13. At the Core of Any Black Box There Are Two (or More) White Boxes, Required to Stay In

The title of Glanville's landmark paper of 1982 was "Inside every White Box There are Two Black Boxes Trying to Get Out." Figure 14 (upper) shows this arrangement when the observer himself is a Black Box. But the arguments above suggest a new interpretation. Let us presume that the core Black Box is a non-trivial machine, composed of concatenated trivial machines. Then, no matter how many nested layers of Black Boxes and observers might occur Russian-Doll fashion within any Black Box (Fig. 13), the latter Box has an utter core containing a Black Box which consists of two (or more) White Boxes, boxes that are required to stay in, providing a mechanism—observed by an observer who, if he's a Black Box himself, also consists of two (or more) White Boxes, and so on. Figure 14 schematizes the old versus new approaches to the relation of White Boxes to Black Boxes.

14. Summary and Conclusions

No-one can directly observe their own mind, or anyone else's. Here, we attempt to understand the mind indirectly, through the concepts of the Black Box and its observer. Ranulph Glanville proselytized these concepts after W. Ross Ashby. Ashby's Black Box differs crucially from an engineer's or a physicist's black box, insofar as it is un-openable. But Glanville pushes further, taking the Black Box to be an explanatory principle, nonetheless having a mechanism. These notions well-characterize the mind. There are other parallels. The Black Box is interrogated by an observer, who presents stimuli to the Black Box, the inputs, and who records the stimulus-evoked responses, the outputs. This resembles a naïve initial impression of psychiatry and psychology; the reality of all these things is, of course, more complicated. Through input/output interactions with the Black Box, the observer obtains what Glanville calls a functional description, one which whitens the Black Box. Likewise, however, the Black Box may whiten the observer—after all, the output from one is the input to the other. Altogether, the Black Box and its observer form a self-illuminating system, called a White Box, having different properties from either the Black Box or the observer alone. The White Box is nonetheless black to any further-external observer. Let us therefore call this White Box the greater Black Box, and realize that it may be probed by a further-external observer.

To develop the notion of Black Box as mind, the present paper explores the concept of the machine, a mechano-electrical device. As imagined by von Foerster, however, a product of a mechano-electrical basis—an abstract product having functional properties, such as the Glanville Black Box—can itself be a machine. Consider the mind, therefore, as such a machine; consider consciousness, perception, remembering, calculating, and reason-based decision-making (amongst other characteristics) as the machine's functional properties. Von Foerster recognizes two types of machines: trivial, and non-trivial.

Ashby notes that a physical machine can have internal configurations, called states; we may, likewise, assume that the products of physical machines—such as conceptual machines, such as Black Boxes—can also have states, states that cannot be returned-to at will. Given this realization, we may ask whether the observer of any Black Box can give input, and record output, without changing the Box's possible output to the next input. That is, can the Black Box be observed without being perturbed? Likewise, can a Black Box's output be observed by, but not perturb, the observer?

Perturbable machines were envisioned by Turing, who conceived of a machine whose input and/or output can change the response to the next input. Turing's machine exemplifies a sequential machine. One class of sequential machines was described by Moore: An input evokes an output, one determined only by the present internal state. That state then changes to another state, determined by whatever was the input and the internal state; hence, each internal state represents a capability to do something to the inputs. Moore's sequential machine is composed of two trivial machines, plus a register of the current internal state; the register is also a trivial machine. The totality, however, is a non-trivial machine. Being non-predictable, the whole is now more than the sum of its trivial parts.

A mind, like a machine, can be imagined as having numerous states, which allow a broad range of behaviors. Those states can change (and their number can increase) through learning. For example, our response to a stimulus (such as an event, or a question) can differ from our previous response, and in unexpected ways. In sum, the mind is a non-trivial machine, an abstract entity having a mechano-electrical basis; it is a Black Box, an explanatory principle.

Like Moore, von Foerster provides an example of a non-trivial machine. But the machines of Moore and of von Foerster profoundly differ; in Moore's machine, the input has no bearing on the immediately-resulting output, only on its successor, by way of the internal state. In von Foerster's machine, however, the input directly affects the output, as well as indirectly affecting the next output by way of the internal state. This characterizes a Mealy machine, a concept realized in electrical circuits; in the Mealy machine, the present output combination and the next state are determined uniquely by the present input combination and the present state.

According to Moore, the experimenter probing a sequential machine could himself be described as a sequential machine, also specified in terms of internal states, inputs, and outputs; the output of the machine which is being experimented-upon would serve as input to the experimenter, and vice versa.

Given all this, we can now address the question of whether the observer of any Black Box can provide input, and record output, without changing the Box's possible output to the next input; and in so doing, we can explore whether the Black Box leaves its own observer unperturbed. Consider what happens if the observer of any Black Box can provide input, and record output, without changing the Box's possible output to the next input, and likewise that the Black Box leaves its own observer unperturbed. If so, the observer's knowledge of the Black Box, and the Black Box's knowledge of its observer, will be limited only by the variety of the inputs from each to the other. The Black Box and its observer are now trivial machines. They will mutually discover this in time, as they whiten each other through input and output.

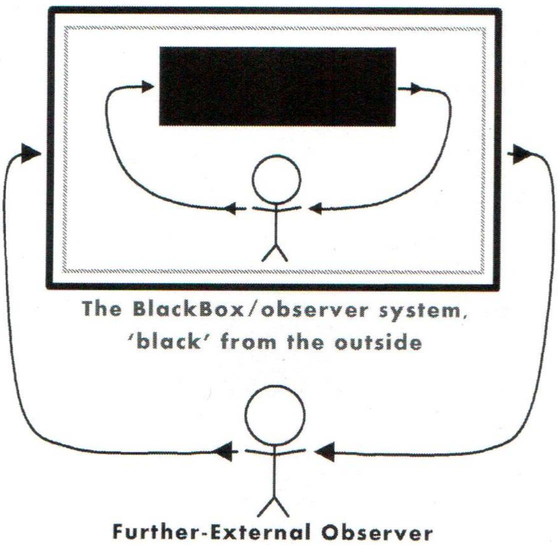

Figure 12. The core BlackBox/observer system as a Black Box from the viewpoint of a further-external observer.

Now consider the contrary. That is, imagine a non-trivial machine that is the Black Box. Imagine another non-trivial machine that is the observer. The BlackBox/observer duo continually alter each other as each receives inputs and produces outputs. Altogether, then, the BlackBox/observer duo form a new non-trivial machine. In this case, no further-external observer can differentiate the Black Box from its immediate observer; the internal observer cannot be recognized, and hence cannot be bypassed. The BlackBox/observer duo is now truly a system.

This system, the greater Black Box, is a non-trivial machine that will change when probed by the further-external observer. That is, the further-external observer and the greater Black Box altogether constitute a new system, which itself is a Black Box and a non-trivial machine. Likewise, this new system changes when probed by a yet-further-external observer. This may continue, in an expanding series of Black Boxes and their observers.

Finally, note well that conscious, wilful (intentional) behavior implies a Black Box that is a non-trivial machine, but that the converse need not be true. We will also reject the notion that brains or minds are algorithms or that brains or minds are computers.

Glanville's seminal paper (1982) was titled "Inside Every White Box There Are Two Black Boxes Trying to Get Out." But at the utter core of any Black Box we must expect to find mechanism—something equivalent to two (or more) White Boxes, which are required to stay in. Remember that the operation of non-trivial machines such as Black Boxes is not random, but that the operation may nonetheless be difficult, perhaps impossible, for an observer to comprehend. As such, the operation of Black Boxes—or of ensembles of them—may seem emergent. The mind, too, seems emergent (Nizami, 2015, 2017, 2018), such that ensembles of White Boxes and Black Boxes may be the ultimate source of the mind.

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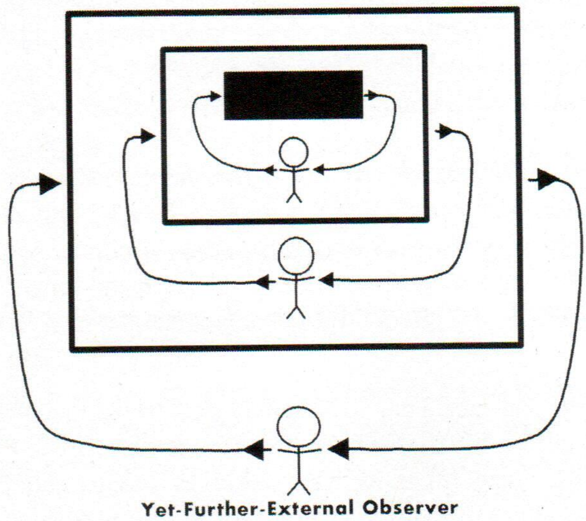

Figure 13. From the viewpoint of a yet-further-external observer, the greater system shown in Fig. 12 is a Black Box; and so on, with each further-outwards Black Box having its own immediate observer. Note well that the Black Box is the presumed product of a mechanism, so that the pictured boundary of any Black Box (and any consequent White Box) is operational but not necessarily physical.

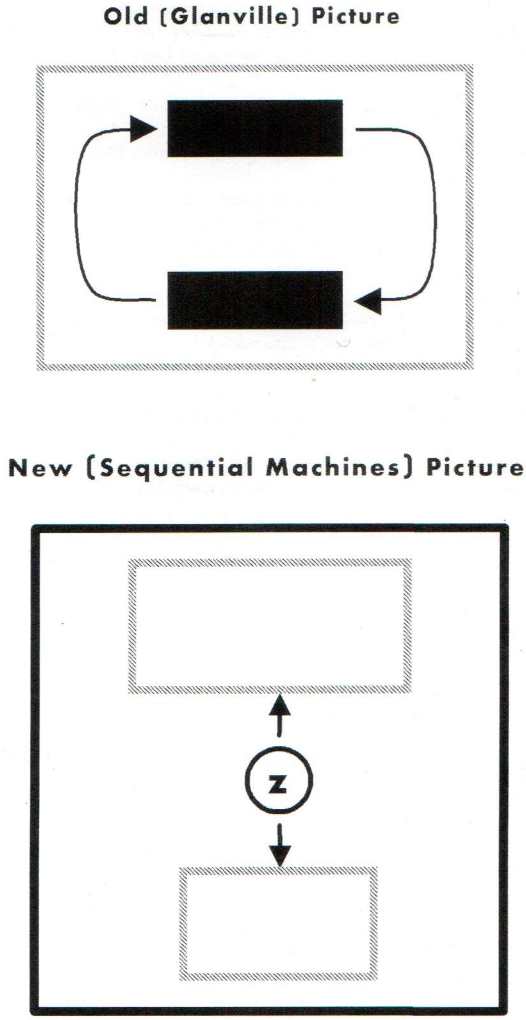

Figure 14. White Boxes versus Black Boxes. (Upper) The Glanville (1982) view that “Inside Every White Box There Are Two Black Boxes Trying to Get Out.” (Lower) The new view that at the utter core of any Black Box there are two (or more) White Boxes, required to stay in.

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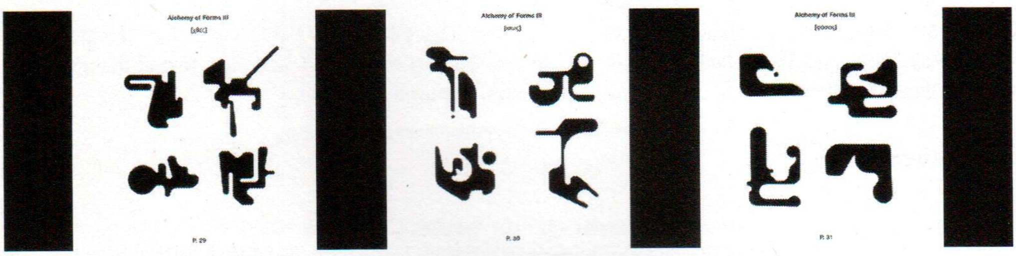

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Left: *Alchemy of Forms III [Yesterday]* // Aphex of electronic imitation.
Center: *Alchemy of Forms III [Maybe]* // Aphex of electronic imitation.
Right: *Alchemy of Forms III [Phases]* // Aphex of electronic imitation.