From Reorganization to Evolution and Back

By William T. Powers

The development of Perceptual Control Theory began in the early 1950s when many workers were investigating similar behavioral models based on control theory. The thread that is now called PCT drew on control engineering, cybernetics, and engineering psychology, as well as applications of control theory in physiology. As PCT was taking shape, questions of learning and development arose and were addressed in the form of "reorganization theory" patterned after W. Ross Ashby's concept of superstability (Ref). As models were developed, this learning theory lagged behind the performance aspects of PCT which were aimed primarily at the analysis of ongoing well-organized kinds of behavior.

The most important underlying principle of reorganization theory, described in the initial article published in 1960 (ref), was that deviations of important variables in a organism from specific states called "reference levels" activated a system that produced random variations in the parameters of control. This was simply the old idea of "trial and error" reified, brought up to date, and described in terms suitable for modeling. The concept is irrefutable. Given that deviations of critical variables from their reference levels set the changes going and maintain them, it follows that if the changes correct the deviations, reorganization will stop and whatever organization is then in effect will persist. That organization of behavior will be superceded only if some change in internal or external factors causes deviations to occur again and random changes start again. This establishes a mode of learning quite distinct from the idea of reinforcement, which proposes that favorable events cause behavior to persist. Reorganization theory says that unfavorable events cause behavior to change.

The only hitch is hidden behind that word "if." This process is guaranteed to work only IF a series of random changes of organization will result in correcting the deviations of critical variables from their required states before the organism dies. Initially, it was very difficult to imagine how such a random process could be anywhere near efficient enough to work. Because of that difficulty, references to "reorganization" during the next 20 years simply had to assume that somehow it would work, and efforts to model

this process and thus demonstrate its features and flaws never got started. Clearly, if the trial-and-error concept could somehow be made to work, we would have a very powerful theory of change applicable to many aspects of living systems, so the decision was to remain optimistic. The result was very much like what has happened to the theory of natural selection in evolutionary theory. Natural selection was a sort of general explanation which would rescue any part of the theory that was having difficulties, rather like previous theories in which all difficulties were resolved by reference to God's Will. Reorganization theory offered a strong temptation to use it the same way.

At about the same time that reorganization theory was formulated, others trying to model evolution invented what is called the "genetic algorithm". In this theory the random changes of organization were brought about by the equivalent of random sexual recombination of genomes. Aside from the mechanism of random change, it was the same idea behind reorganization theory. Unfortunately, it does not solve the basic problem of inefficiency, either. To make models using this algorithm work, it was necessary for programmers to permit simulated organisms to survive and reproduce if they only changed *toward* the new organizations necessary to counteract selection pressures. They didn't actually have to succeed. This meant that the programmer included abilities in the model that the real organism was not thought to have: knowledge of a goal-state and the ability to detect how far from that state the organism was. Somehow the organism was allowed to survive if the distance to the goal-state decreased; how it could know that and what set the goal were unexplained.

It was not until 1980 that the breakthrough occurred which made the basic concept of reorganization theory described in 1960 into a practical idea. The breakthrough came in the form of a book on bacterial chemotaxis (Koshland, 1980). In this book an interesting principle is exemplified by the method of gradient-climbing used by E. coli.

Note: This essay was inspired by posts on CSGnet August 17-22, 2009, Subject: Memory and August 24, Subject: Reorganization and Evolution.

E. coli reorganization

The bacterium E. coli progresses up (down) gradients of attractants (repellents) by generating a series of random variations in its direction of swimming. These random variations, referred to as "tumbles", produce new directions of swimming that are demonstrably unrelated to the gradients, yet the result is reliable travel in the right direction. The mechanism behind tumbling seems to be nothing more than briefly reversing the direction of spin of some but not all of E. coli's flagellae.

E. coli's gradient-climbing ability is not a result of some subtle bias in the random tumbles. Instead, the mechanism depends on sensing the concentration of an attractant or repellent in the medium through which E. coli is swimming and changing the timing of tumbles according to whether the sensed concentration is increasing or decreasing. All the biochemistry involved in this odd control process is known. If the concentration of an attractant is decreasing, the next tumble occurs right away; if the concentration is increasing, the next tumble is postponed. For repellents, the relationships are reversed. The result is that the bacterium spends much more time swimming up the gradient of attractant than down it. In simulations of this process, the mean velocity of travel up the gradient is lower than it would be if the bacterium could simply turn and swim the right way, but not by a great amount.

Abstracting the principles involved in E. coli locomotion leads to an algorithm for optimizing processes which have effects that can be measured in terms of gradients. The "swimming" of E. coli turns into a continuing steady change in the parameters of the process, and the "tumbles" turn into reorganizations that randomly alter the rates of change of the parameters. If there are N parameters, the direction of swimming is the vector sum of N velocities along the axes of N-dimensional hyperspace. This can be visualized as repeatedly adding a small speed vector to the parameter vector, so a point representing the current parameter values moves through this space in the same way E. coli swims through the medium in which it lives. The parameters change continually at different rates. After a tumble, which is like a mutation, the parameters go on changing continually, but now at different rates relative to each other. That changes the direction of motion through the parameter hyperspace. The operant phrase is "different rates relative to each other"—the hyperspace part is just a useful metaphor.

So far we have a process that continually changes the parameters of a system, and which can be switched from one direction of change (in hyperspace) to another by randomly altering the rate of change of each parameter. The remaining part of the model determines the conditions under which a random reorganization will happen. In Perceptual Control Theory, a fictitious "reorganizing system" is proposed which alters the learned systems in the brain so as to control, indirectly, certain critical variables on which life depends.

The phenomena produced by the theoretical reorganizing system bear strong resemblances to at least one geneticist's description of genetic drift, allowing for some differences of interpretation:

http://lifesci.rutgers.edu/~heylab/sconcept/sexdrift-select.html#drift

<div align="right">

Jody Hey, Evolutionary Genetics
Professor, Department of Genetics
— Rutgers University

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From a genetic perspective, natural selection can be defined as variation in reproductive success caused by genotypic variation (Lewontin, 1970), and it is often cast as a directed force of evolutionary change in contrast to the random force of genetic drift. However at the level of DNA where there is linkage, natural selection on functional DNA sequence variation contributes to the genetic drift that occurs among linked sequences. **In a genetic species of asexual organisms, a mutation that changes a DNA sequence and causes natural selection, also causes a new pattern of genetic drift among organisms that carry that mutation.** In effect, a new genetic species is created by the mutation; although one of the species will probably be replaced by the other. For the DNAs of organisms with recombination, the acceleration of genetic drift by natural selection depends on the degree of linkage, the number of sites of functional variation, and the strength of natural selection on the functional variation (Hill and Robertson, 1966; Felsenstein, 1974).

There are some difficulties with this view, in that "degree of reproductive success" implies a gradient of successes, whereas reproduction either happens or does not happen. There can be degrees of success in a population, but characteristics are passed through individuals. Individuals either reproduce or do not;

whether they succeed or fail, they have no (or little) effect on another individual's characteristics or degree of success. Nevertheless, this view can be modified to use a much more efficient method of selection. Clearly, the analog of E. coli's "swimming" has been observed in the genetic drift of organisms, and the phenomenon of reorganization as current visualized has been seen: *"... a mutation that changes a DNA sequence and causes natural selection, also causes a new pattern of genetic drift among organisms that carry that mutation."* The "mutation" is, of course, a tumble, and the "new pattern of genetic drift" is a new direction of change in hyperspace.

We now have a vastly more efficient form of random change which makes the creation of successful new organizations much more likely than it was under the old idea of random jumps from one organization to any other within the possible range. The increase of efficiency over random jumps in only two dimensions is 50 to 70 times in one model, and increases rapidly as the number of variables increases. This will greatly help the genetic algorithm model (in cases where this algorithm is not already used without being named), and has made the PCT concept of reorganization practical.

Purely local reorganization

In more recent years, in connection with psychotherapy, a principle was proposed in an attempt to solve the problem of reorganizing what didn't need to be reorganized. "Reorganization follows awareness" said that while deviations of critical variables from genetically-specified reference conditions caused reorganization to start, awareness could then direct the process to various places in the hierarchy. If awareness tended to seek out problem areas, we then had at least one way to keep reorganization focused where it was needed. But this introduced another bit of magic: awareness and its mobility. While those phenomena clearly exist, they are wild cards in any explanatory theory since we can't explain *them*. We do not want any more wild cards in our explanatory theories that we absolutely have to have. Even when we have no alternative, they never stop nagging at the theoretician's conscience.

In the 2000s, a serious attempt was made to model rather complex reorganizations as part of a book on the computer models associated with PCT (Powers 2008) [*Living Control Systems III: The Fact of Control*].

Although there are still unsolved problems, the attempt to model the reorganization of output processes, given arbitrary sets of controlled variables, was quite successful as far as it went. The E. coli algorithm clearly works well. Richard Kennaway was the first to see and point out (in an appendix to the referenced book) in mathematically respectable terms that this model enabled a control system to optimize itself with no knowledge about the properties of its environment. There are probably some properties of the environment that have to exist to make this sort of reorganization work, and we do not yet know what they might be, but in these models those requirements are clearly met.

This leads us to the most recent reorganization of the theory of reorganization.

Keeping in mind that bathwater may contain babies, we can now try to summarize all the considerations that have gone into developing the theory of reorganization, in the form of an updated model. We got rid of the embarrassing inefficiency of the random-jump mutation model by adopting the E. coli model. Now we can get rid of the problem of action at a distance, meaning the problem that discrepancies in one control system can drive reorganizing effects that work on other control systems even at different levels of organization. In one successful model in the cited 2008 book, a collection of 14 control systems reorganizes so as to modify all the output effects that could cause conflict between the control systems that are learning independent control of the joint-angles of an arm. The model begins with all 14 control systems affecting all 14 joint angles. The weightings in the output effects of the model are then altered by E. coli reorganization, until at the end most of the cross-connections have disappeared, and each system can control its own joint angle without causing any interference with the other control systems. This is reminiscent of the "pruning" process that reduces the large oversupply of neural connections in the neonate to a much smaller number by the time motor control has been established.

These control systems are all at the same level of organization. The simulation allows for either "global" or "local" control. In the "local" mode each control system reorganizes the fourteen weights in its own output function on the basis of whether its own control error is increasing or decreasing (averaged over a time long in comparison with the behavioral response times). That is sufficient for independent optimized control to appear in all the control systems.

But "global" reinforcement also works: the directions of change of all 196 weights are "tumbled" when a reorganization occurs: 14 output weights in each of 14 control systems. The signal for reorganization is based on the sum of all 14 error signals, in quadrature (square root of sum of squares). Local reorganization works just a little faster.

Now we can recognize a set of control systems proposed by Bernard and Cannon as the "homeo-static" systems. The outputs of these systems are biochemical; the reference signals are either genetically determined or in many cases are varied by neural signals reaching the pituitary from the hypothalamus. In the first crude model of reorganization, discrepancies between the controlled variable and the reference setting produced the usual actions that maintain homeostasis. If the errors became large or persisted too long, reorganization would commence—everywhere in the hierarchy of control. Let us now change that and say that reorganization will occur only in the system where the large protracted discrepancy appears, or possibly in the same level of organization where the errors appear.

If reorganization succeeds in a homeostatic system, the controlled physiological variable will once again be under control, remaining constant if the reference signal remains constant or changing as the reference signal changes. The higher systems that depend on the operation of the homeostatic system will experience no disturbances and their behavior will continue unchanged.

If, however, the homeostatic system cannot adapt far enough to regain control, the variable it is controlling will start to depart from the reference level it is receiving, or that is part of its innate design. That will constitute a disturbance of control systems higher in the hierarchy. For example, if blood glucose concentration is not maintained at the proper level by metabolizing fat or releasing glucose from storage, and if no reorganization of the system restores control of glucose concentration (perhaps because the organism has not been eating anything for a while), an error will be sensed by higher systems that is recognized as a sensation of hunger. Normally that would result in learned behaviors that find and ingest food. So that level of control could work well enough to limit the glucose concentration error at the lower level and also eliminate the hunger signal at the higher level.

If insufficient food is found, the food-seeking systems will begin to reorganize. They will continue to reorganize until the organism starves to death, or a new organization for getting food succeeds and restores the food intake to the level needed to maintain glucose concentration at the homeostatic level, and allow eating enough to eliminate hunger.

We can begin to see that local reorganization can eliminate control problems starting with the lowest levels, even biochemical levels, and extending as required to the higher levels of control. There is no need to direct reorganization to happen where it is needed: it always happens where it is needed. The connection between homeostatic control systems at a low level to reorganization of behavioral systems at higher levels is still there. It is just not direct now; it takes place in stages, level by level.

In fact, we may be near an answer to questions about where new levels of control come from. Reorganization can work from a number of starting points, including a starting configuration in which all the output weightings are zero, and all the input weightings are zero, too. All that is required is for a supply of uncommitted neurons of the right type to exist (a product of evolution), and for the raw capacity to reorganize to be present. The highest existing level of control will reorganize and behave so as to control its own variables as external disturbances change, and grow. When that control reaches its limit, the reorganizing capacity of the pools of uncommitted neurons will come into play and start adjusting the parameters of control, forming new control systems that control perceptions of the world in new ways. Of course the right types of neurons for supporting perception of the new type of variables must exist, and the right types of neurons for constructing the output functions that will be needed. What is possible to acquire by way of higher levels of control is set by the whole past history of evolutionary changes.

We have lost, temporarily, the role that awareness played in directing the locus of reorganization. We know that directing awareness does affect the places where reorganization is to happen. But what we have to determine now is just what that directing accomplishes. Then the model of reorganization will add its next small increment of credibility.

Bill Powers
24 August 2009

Reorganization—an evolving concept in PCT

Notes by Dag Forssell   May 2013

On page 3, Bill wrote:

> "This leads us to the most recent reorganization of the theory of reorganization."

PCT is not a finished product. It points in a new direction and lays a foundation for a future science of psychology based on solid scientific principles.

As Bill points out, the concept of reorganization has been part of PCT from the outset, as presented in his 1960 paper by Powers, Clark and McFarland: *A general feedback theory of human behavior*, but there are differences between noting the necessary existence of reorganization as such, attempts to illustrate a conceptual understanding of it, attempts to show that a process of reorganization can work to stabilize a large number of interconnected control systems and ultimately, finding out how it actually works at various levels of biological and mental functioning.

Clearly, Bill's concept of reorganization has been and continues to be a work in progress. It may be of interest to students of PCT to examine the original illustration in Bill's major work of 1973 (below), the update when it was republished in 2005 (page 6), and the updates to this same illustration Bill requested in emails to CSGnet in 2009 (page 7).

Bill's thoughts developed yet again following my belated (March 2013) implementation of his 2009 request. Such a progression of thinking, speculation, testing and understanding seems to me normal and natural when one works to develop illustrations in order to communicate a concept with others. The idea of reorganization driven by local error that Bill expresses in his essay may require a very different illustration. This may best be left for future PCTers to sort out.
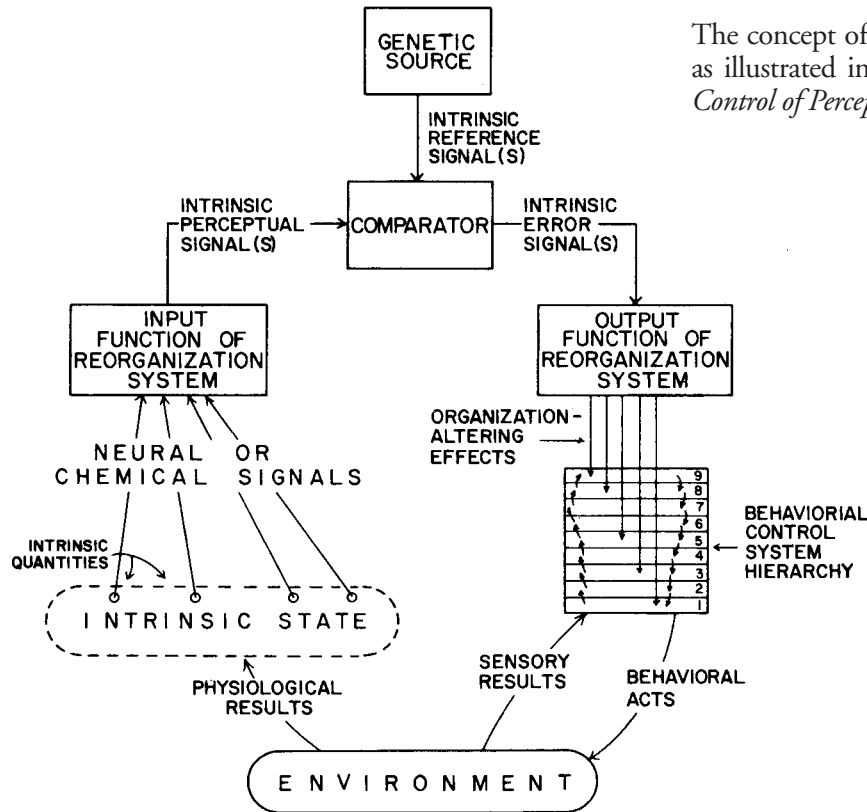
The concept of reorganization as illustrated in *Behavior: The Control of Perception* (1973)

FIGURE 14.1.   *Relationship of the reorganizing system to the behavioral hierarchy and physical environment. The control loop for the reorganizing system is closed via physiological results of behavior, not through sensory effects.*

The concept of reorganization as illustrated in
Behavior: The Control of Perception (2005) p. 191
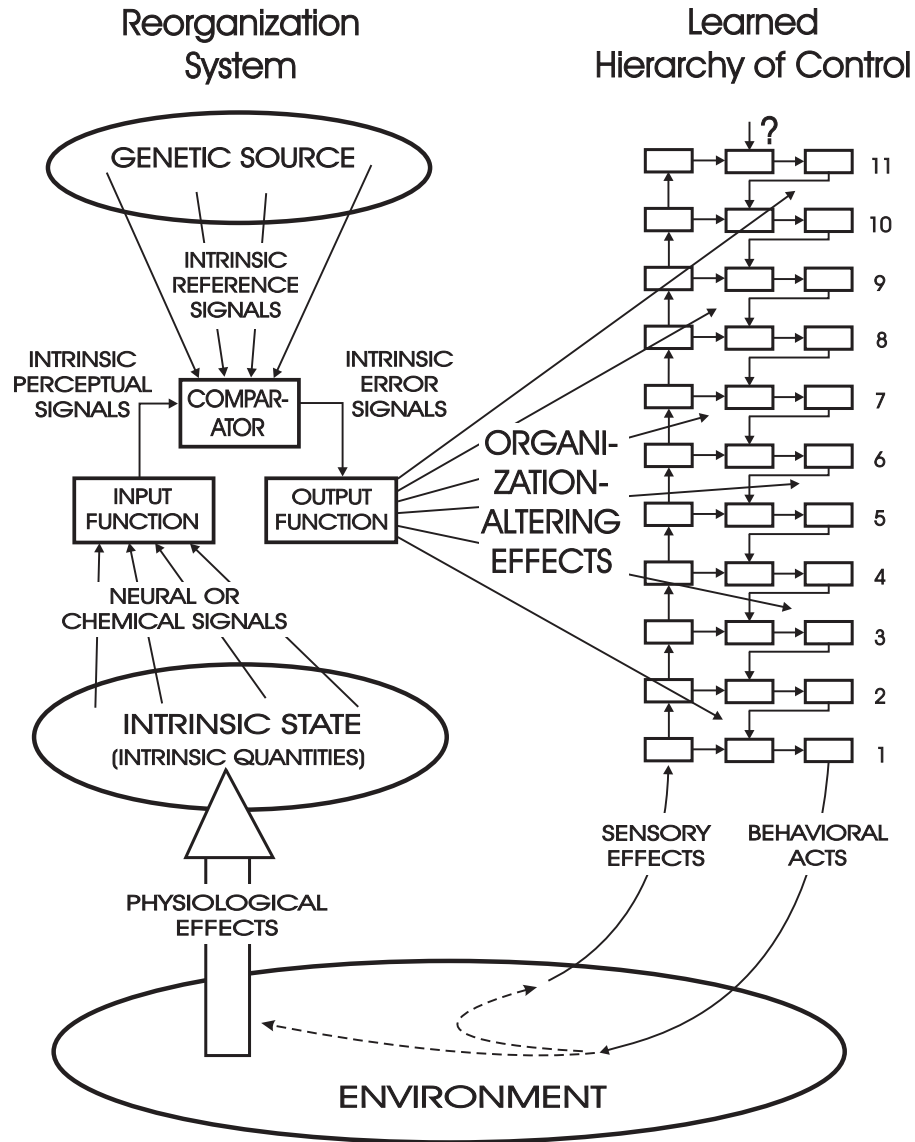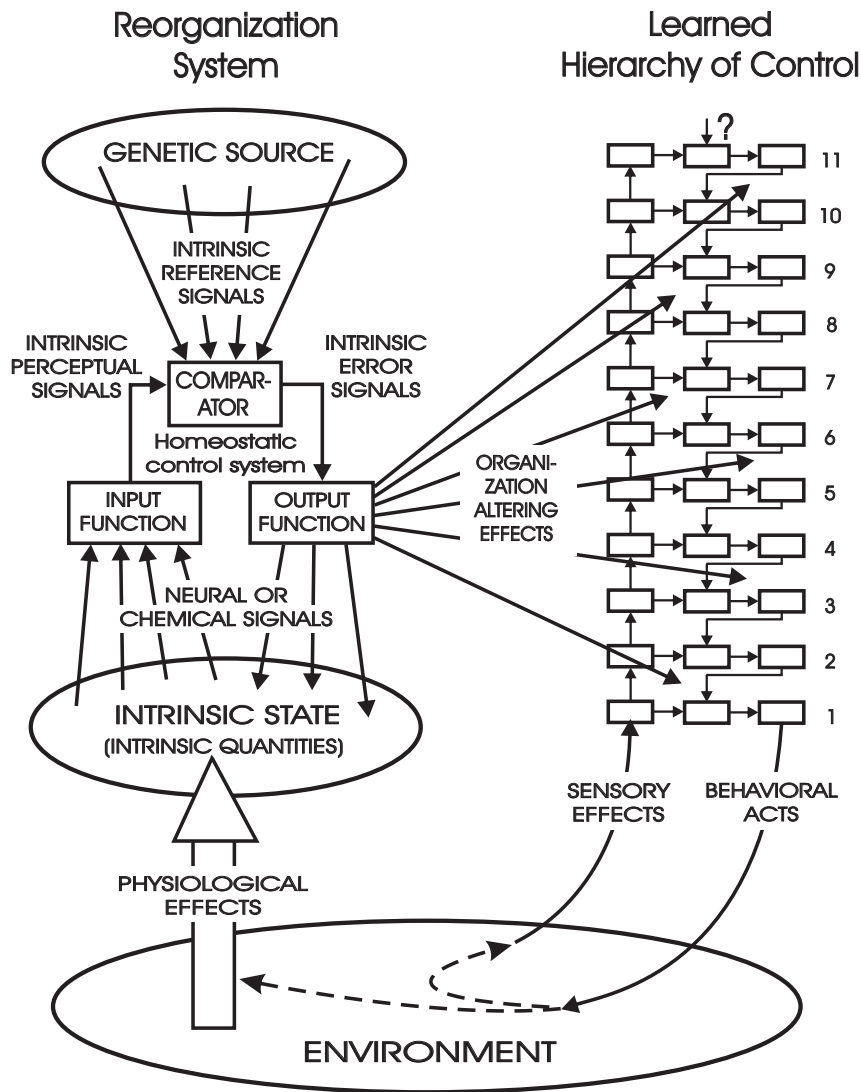Redrawn by Dag Forssell per Powers' instructions.

*Figure 14.1. Relationship of the reorganizing system to the behavioral
hierarchy and physical environment. The control loop for the
reorganizing system is closed via physiological results of
behavior, not through sensory effects. —Powers, 2003*

Reorganization System

Learned Hierarchy of Control

As requested by Bill in a post to CSGnet on August 20, 2009, this is an update of Figure 14.1 in *Behavior: The Control of Perception* (2005) page 191.

Added:

1) Down arrows from Output function to Intrinsic state.

2) Labeling the Homeostatic control system.

In a private email March 27, 2013, Bill made this comment about the diagram shown above:

The new diagram suggests something to me, coming from the two different effects of the homeostatic output functions. This suggests perhaps that there should be two different output functions associated with a homeostatic system, one having to do with performance and the other with learning.

However, one factor makes me hesitate. As modeled, reorganization is driven by error, but the reference condition is irrelevant. It doesn't matter to the reorganizing system as currently conceived what condition the homeostatic system is trying to bring about. All that matters is that there is error, and reorganization will continue until the error is gone. As far as I can see, that's all that's required. If the specific reference condition doesn't figure into reorganization, then the perceptual signal and reference signal don't figure in, either. Only the error signal is monitored by the reorganizing system.

If that's the case, then we can ask whether the reorganizer thing is just a separate system that has the goal of reducing error signals, without regard to what they mean. It doesn't have to be an inherent part of a homeostatic system.

How would it know that a signal is an error signal? I don't know. But error signals as we model the system now do have a special relation to control systems: they are the outputs of comparators, and comparators are simple subtractors. much the same in any control system. Is that enough to make them recognizeable? Again, I don't know. But let's leave that question open until some sort of data comes our way to help us decide.