

The origins of purpose: the first metasystem transitions

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ABSTRACT

This speculative essay concerns the origins of purposive behavior and proposes that this is identically the origin of life. Negative feedback and control offer a self-selecting mechanism that accounts for the long-term stability of replication of the genome, and a related concept of reorganization offers a rationale for the progress of evolved forms into those which exert greater and greater control over the local environment. A picture emerges in which the basic principle of control runs like a unifying thread from the first living molecules to modern complex organisms.

Introduction

The concept of purpose has been in disrepute among scientists since they began to substitute a universe with properties for a universe run to suit the unfathomable purposes of a supernatural being. But science itself eventually rediscovered purpose—internal purpose—when it evolved the concept of negative feedback control. It is now possible to understand purpose as a natural phenomenon that emerges when a system attains a certain kind of organization in relation to its environment, the organization we know as that of a control system. The question I address here is when this phenomenon appeared in nature (whether understood by science or not). And the answer I propose is that it was the first phenomenon of life: the first step from a universe in which entropy and chaos held sway toward one in which purposes residing in organisms direct external physical processes and create new physical relationships.

Control

In the following I will employ a concept of control that is different from, but perhaps not inconsistent with, the concepts put forth by Joslyn, Turchin, and Heylighen in this compendium. The kind of control I mean is what Joslyn calls control-sub-2—closed-loop feedback control, not control-sub-1, which is merely the attainment of an equilibrium condition or the appearance of a causal dependency. There is certainly a principle of mutual constraint at work between a system that controls and an environment that is controlled. But this mutual constraint is not symmetrical. The reason for the asymmetry lies in a property of control systems called amplification.

A control system senses some aspect of its environment and produces actions bearing directly on that aspect. With only this much definition, it would seem that the environment affects the control system just as much as the control system affects the environment, and that this relationship is symmetrical.

But a control system is a dissipative system; not only that, it is a dissipative system with a continuously renewable source of energy. This allows amplification to take place, a process whereby a small cause has a large effect, achieved by drawing on the stores of energy and bringing them to bear on the creation of narrowly-focused effects in the environment. In general, the inanimate physical environment contains no such processes; for the most part, energy levels decrease as we follow processes of physical causation in the world outside of organisms. The prototypes of systems with the capability for amplification are living systems.

Amplification permits organisms to vary their actions by a large amount in response to small deviations of their inputs from neutral conditions called,

in control theory, reference levels. If those inputs represent outcomes of action, and if negative feedback is maintained, the control system can produce and defend against disturbance certain outcomes that then become relatively immune to the normal causal influences that otherwise would determine their states. Physical processes which are chaotic, which exhibit hypersensitivity to initial conditions, are forced into regularity and predictability by the varying actions of a control system, an organism. Organisms maintain certain aspects of their local environments at specific (but adjustable) reference levels, and by so doing, drastically alter the course of events, even much larger events, in the world around them. That world, on the other hand, is relatively incapable of altering the actions of organisms in an equally arbitrary way. This is the asymmetry of which I speak. It arises from the fact that organisms can draw on internal power supplies which are independent of the energy contained in disturbances. In a control system of Joslyn's type 1, all the restorative energy is put into the system by the very disturbance whose effects are afterward counteracted. A ball in a bowl, when deflected, contains exactly as much potential energy as the work done on it in deflecting it. That is the only energy available for restoring the original equilibrium. A type-2 control system begins expending energy on opposing disturbances long before the disturbance has done significant work on the control system.

I propose that the origins of control, which are identically the origins of purpose, lie in the development of this unique kind of asymmetrical relationship between a system and its environment.

The evolution of control: a speculation

In the beginning, control, in my sense of the term which is the meaning of Joslyn's control-2, did not exist. I have tried to imagine how it came into being. While this argument is very short on chemical sophistication, it does not depend on any particular chemical story; rather, it purports to apply some principles that may have been effective for any (and perhaps for many) chemical beginnings of life.

The first step: negative feedback

Let us suppose that at some point there was a population of different chemical species in a common substrate. Species of the complexity needed (amino acids, for example) may well have developed in the manner

suggested by Prigogine (1972, 1984)—as “islands of stability” in a sea of chaos. But in this development I am looking forward perhaps a billion years (a guess) to a kind of molecule that is not only stable, but superstable—its interactions with its environment create enzymes that repair damage to the molecule. This is active rather than passive stability—stability that results from counteracting the destructive forces of nature. I am looking for principles that might show the presence of active stability from near the beginnings of life.

Let us suppose that these pre-life chemical species have somehow developed to the point where they form a group: their interactions with the substrate result in reaction products which influence the manner in which further molecules in that same group are formed out of the energy-rich soup. At this stage we do not have permanent or even long-lived molecules; combination and dissociations are going on simultaneously, for these complex organic fragments are fragile. But in the manner that Prigogine has suggested, they keep forming and reforming, with some probability.

The probability that any particular individual species in this group would exist in some numbers would depend on the state of the substrate, the external energy input, and the energies that influence dissociation. After some time, an equilibrium condition would result, with a more or less stationary population of molecules of each species—continually forming, continually being broken up again, although not necessarily into the same fragments from which they formed. We can think of this as a primitive process of replication; each population, reified as an entity, would have some success, however small, in reproducing itself through time.

For any given population, the interaction with the substrate both determines the relative reproductive success of that population, and contributes (through dissociation, and in conjunction with the external energy input) to the state of the substrate. This is a feedback relationship, albeit with no significant amount of amplification in it. Let us focus on the effect of this feedback process on just one aspect of the situation: the accuracy of replication.

Local variations in the chemical composition of the substrate will clearly affect the reproductive success of each population of molecules. Likewise, the dissociation products of each population, perhaps upgraded again through external energy inputs, will affect the substrate's chemical composition, and

thereby will affect the reproductive success of all species. If these influences on the local substrate are unrelated to each other, there will be no net change in populations. Two other possibilities, however, exist: positive feedback and negative feedback.

If a local variation in chemical composition of the substrate results in a change in a given molecular species such that its reaction products increase that variation in the same direction, the local variation will be exaggerated and the change in the molecular species will accelerate. This regenerative process will quickly alter that population of molecules to the limit: it may cease to exist.

On the other hand, if a local variation in the substrate results in a change in a particular species such that the reaction products oppose that variation, the result will be that changes in that population of molecules will be slowed. The result is a bias that increases the relative numbers of that species of molecule. The original probability of formation remains, but now the conditions that favor formation are somewhat protected against disturbance, which reduces the probability of failure to form.

The rest of this story is not hard to foresee. If the interaction of any species of molecule with its substrate is such as to oppose natural disturbances that tend to reduce the accuracy of replication, that species of molecule will be favored over others in which the feedback effects are neutral or positive. Through a straightforward process of natural selection, we must eventually arrive at populations of molecules whose interactions with their environments oppose, where possible, all

kinds of disturbances that tend to alter the process of replication for the surviving species. We are thus led to consider a subject that evolutionary theory has not directly addressed: not the variability of species, but their extraordinary stability over long periods of time. This proposition does not contradict Prigogine's general picture; it simply makes the probability of formation of islands of stability much higher than it would be on the basis of chance or thermodynamics alone. It gives us an example of what an island of stability might amount to.

At this point we have chemical species that protect themselves against disturbances of replication to some degree, through these negative feedback effects. Just what kinds of molecules would have to be present for this result to occur is unknown, at least to me. We are most likely speaking of organic molecules, because

a certain amount of complexity must be needed to provide the variety of interactions with the substrate that is implied. The probability of a negative feedback relationship between molecular population and substrate may initially be very low. But it would seem that all we require is that it not be zero.

The second step: amplification

While simple negative feedback can tend to favor a given population of molecules, this stabilization of replication against disturbance remains weak as long as the interactions do not entail any amplification processes. For amplification to exist, there must come into being some process that can systematically draw on external energy sources to make energetically small causes into larger effects. In the chemical world, this would seem to suggest that the next step would be the appearance of catalysts. More likely, as catalysts would initially be only those that naturally occur, it would be the appearance of molecular species in which association and dissociation processes are catalyzed by existing substances, and whose reaction products (or other properties) affect the participation of catalysts in the reactions.

Now we can imagine that when a disturbance of replication occurs, it affects some molecular population in a way that influences a catalyzed reaction, so that only a small disturbance can result in a much larger change in the interaction between molecule and substrate. This feedback relationship does not, of course, hold for a particular molecule, but only over the population. If a disturbance alters the way molecules are formed, and this alteration results in the right kind of dissociation products as individual molecules break up or recombine, the result will be a much larger net change in the substrate in the direction opposed to the initial disturbance. Molecules creating amplified effects in the opposite direction immediately disappear from the population.

As we have learned from the analysis of control systems, this amplification does not necessarily result in instability (if it does, of course that chemical species will succumb; selection effects by this stage are very pronounced). Under a few quite probable conditions, the reaction dynamics can see to it that changes in concentration are slowed enough to make the whole feedback loop stable. In that case, amplification does not result in a vastly larger amount of effect on the substrate, but in more exact cancellation of the effects of any disturbance. In fact, as long as dynamic

stability and negative feedback are preserved the result will be that the effects of external disturbances on the local substrate decrease in proportion to the amount of amplification.

Thus the participation of catalysts in the molecule-substrate interaction can have an enormous effect on the accuracy of replication in any chemical species so favored. And because they can, they will. The size of disturbances that can be resisted increases dramatically, and the variations in replication shrink correspondingly.

An example of catalyzed biochemical negative feedback

In relatively recent times, there has been an interest in negative feedback phenomena at the biochemical level of organization. While certain biases among biologists have prevented any concerted adoption of the paraphernalia of control theory, some biochemists have nevertheless uncovered chemical systems in which the basic phenomena of feedback can be demonstrated. Some relatively informal control-system analyses were done early (Jones, 1973). Further developments by Savageau (1976) extended the concept of feedback even to genetic processes, although without specifically involving control theory. Modern modeling of dynamic biochemical systems has revealed complete control systems with high amplification factors.

An example appears in Hayashi and Sakamoto, *Dynamic analysis of enzyme systems* (1986)

See Fig 1.

One model of particular interest shows how an allosteric enzyme catalyzes a reaction that produces an output concentration X_4 from substrate precursors. The concentration X_4 feeds back through an intermediate product Y_1 to affect the transition of the enzyme between an inactive (E_i) and an active (E_a) form. This same transition is affected by another substance, Y_2 , which acts in the opposite direction. The state of the enzyme passes vary rapidly from active to inactive and back again as the two substance, Y_1 and Y_2 , vary in the neighborhood of equal concentration. The concentration of Y_1 , in the feedback path, is increased by an increase in the product X_4 , and this results in a highly amplified decrease in the activity of the enzyme population that facilitates formation of X_4 . The negative feedback is very strong. Fig. 1 shows the reaction, with some added labels to suggest identifications of function in a general control system type of organization..

The authors modeled this reaction and plotted the behavior of the various substances involved. Being most interested in large changes in the variables, they started the system far from equilibrium and plotted the rather violent oscillations that took place, interpreting these as the “behavior” of the chemical system. But just at the end of the simulation run, the system approached a final state in which the activity of the enzyme population abruptly stopped changing, at a value between the extremes, and in which $Y_1 = Y_2$ as precisely as the plot could show. This was, in fact, the stable state of the control system. See Fig 2.

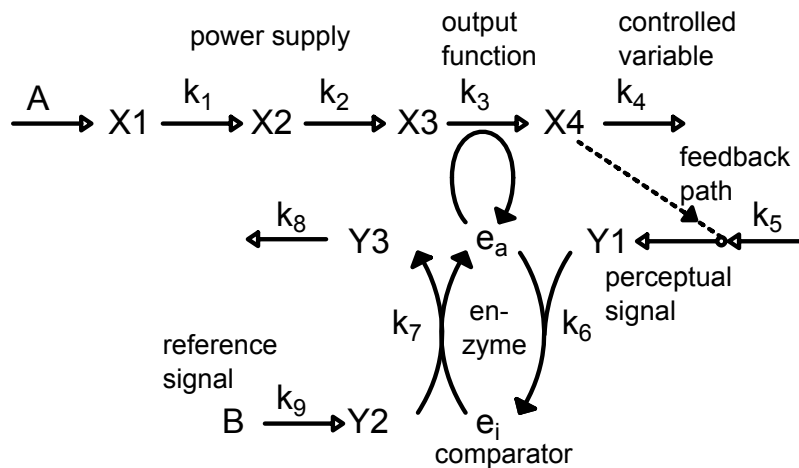


Fig. 1. Biochemical system with annotations suggesting functions in a standard negative feedback control system. X_4 is the controlled variable. Redrawn from Hayashi and Sakamoto.

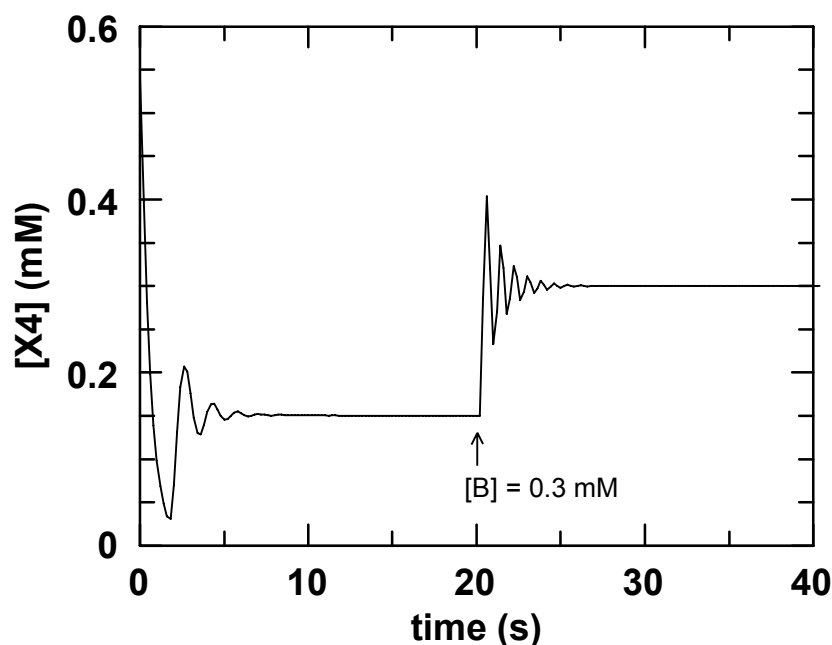


Fig. 2. Simulation of system in Fig. 1.

Once in this state, the system would maintain the value of concentration X4 (the product) at a value corresponding exactly with the concentration of another substance, Y2 (or its precursor, B), which bears no direct chemical relationship to X4. Disturbances—reactions directly affecting the concentration of X4—would automatically and quite precisely be counteracted by the control system, so the concentration of X4 would not appreciably change. A drain on X4 would cause the reaction forming it to speed up; a buildup of X4 would shut down the reaction. Hayashi and Sakamoto demonstrated that the concentration of X4 was completely insensitive to changes in the substrate concentration over a range of 10:1.

The enzyme, in fact, combines a perceptual function, a comparator, and a very high-gain amplifier in a control system of standard design, which the non-chemical labels are meant to suggest. The perceptual or sensor signal in this control system is the substance Y1, whose concentration depends directly on X4—thus making X4 into a controlled variable adjustable by variations in another chemical signal, Y2. Y2 and its precursor B set the reference level for X4.

The point of this example is to show that catalyzed chemical reactions can indeed form control

systems of very high precision, and render reaction product concentrations stable against large and unpredictable disturbances. This active stability is very different from and much greater than the stability conferred by chemical bonds. If a reaction product like X4 happened to be a determinant of the accuracy of replication of a molecule, this control system, by shielding X4 from environmental disturbances that alter concentrations in the substrate, would also protect against external influences tending to alter the accuracy of replication.

Of course enzymes are not natural catalysts in our story of the primordial soup—they are manufactured by the very system in which they operate, a system that develops only much later in the sequence. We can, however, be encouraged in a belief that chemical control processes at a more fundamental level in a proto-living system can render the aspects of its local environment that affect replication almost immune to external disturbances. The possibility of such feedback processes essentially guarantees, because of natural selection, that they will eventually predominate.

Punctuated Equilibrium

We have now reached a place in this story where molecules exist in a strong negative-feedback relationship with the substrate, their environments. Disturbances of the kind that can alter the process of replication are strongly resisted by changes in the dissociation products of the molecules. These “output” changes tend to be one-way because of catalysis—the direct reverse effects (recombination) are small compared with the forward effects, which is just another way of describing power amplification. The catalysts function, in part, as sensors, in that their action can be modified by feedback information. All such control systems, however, have limits on the range of output variations they can produce. Up to a point, an increase in disturbances will be met by an equal

and opposing change in the output process, so the net result remains stable. In this case, the process of replication will remain relatively undisturbed.

There will always, however, be some amount of disturbance that will bring the opposing output of the system to its maximum possible level. That defines the limits of normal operation of the control system. Any further increase in the disturbance will not elicit a corresponding increase in the opposing output. That last increment in the disturbance will affect the system just as if no control existed. The local substrate will begin to change.

As we are speaking of control of variables affecting the accuracy of replication, the result will be that precisely accurate replication of this population of molecules will cease: the offspring of the current population will be different in some respect from the parents. The chances would seem rather large that the difference will detract from the control process. As a result, protection of replication against disturbance would become less effective, and the final outcome would seem inevitable: collapse of control followed by extinction.

There would, however, be some probability that random changes in the process of replication would result in better control, an increase in the ability to counteract disturbances that affect replication. The resulting sub-population of molecules would survive; in fact, they would be even more capable of resisting disturbances of replication than were their parents. In effect, another and more disturbance-resistant island of stability would be found.

So when disturbances grow to the point where they exceed the capacity of the old population of molecules to cancel their effects, the immediate result will be a burst of mutation, for mutation means not replication but variation. Out of this burst of variation will, or may, come new molecules capable of greater resistance to disturbance: this result might even amount to a metasystem transition (Turchin 1977), the addition of a new layer of control.

The overall picture will be one of long periods of stability, punctuated by brief episodes of rapid mutation ending either in extinction or in a new level of capacity to protect replication from disturbances. There are, of course, evolutionary theorists who maintain that this is exactly the appearance of the evolutionary record (at more advanced state of progress than we are considering here).

Reference signals

When a negative feedback system is set up so as to resist disturbances of a controlled variable, it tends strongly to maintain that variable near the zero-disturbance state, the “natural” state of that variable. But it is possible for such control systems to contain a bias, such that the error-correcting efforts will cease not when the controlled variable is in its natural state, but when it is in some other state. Then the control process will maintain that variable in a specified state not only against disturbances, but against the natural tendency of that variable to return to its lowest-energy or otherwise natural configuration.

Such a bias can be introduced in many ways and in many places inside the structure of the controlling system. As a representative model, it can be thought of as a reference signal, a variable signal that determines the momentary bias of the system, like the substance B in Fig. 1. If the input to the system is such as to match the reference signal, the output will be zero. The action of the system will then depend on departures of the input from the reference state implied by or specified by the reference signal. And most important, the state of the controlled variable will be determined by the setting of the reference signal, external influences on the controlled variable being automatically canceled by the negative feedback process. A bias inside the control system will determine the state of a physical variable outside it quite independently of external influences on that variable.

In a population of molecules (by now getting rather complex), there could be variations in the effective reference signal, the bias on control processes. The substrate conditions that enter into the feedback process would, accordingly, be maintained not at the natural zero-disturbance level but at a variety of levels distributed around that point. Of these levels, some would result in better replication than others. The result: the appearance and propagation of non-zero reference signals as intrinsic parts of the control systems.

Now these hypothetical control organizations would not only be capable of resisting changes in the substrate deleterious to accurate replication, but would actively maintain aspects of that substrate in conditions best favoring accurate replication.

The first purposes

In a control-system model, a purpose is simply a reference signal. The reference signal determines the state to which an input, a sensory signal, will be brought and at which it will be maintained. In nearly all control systems, the sensory input represents the state of some external variable affected by the system's action, so whatever action brings the sensory signal to a match with the reference signal perforce brings the sensed external variable to some specific reference state. In very primitive systems we do not really think in terms of specialized sensors, but if we think a little more generally, we can see a sensor-like function in certain sensitive input processes (see Fig. 1)

The purpose of a control system, in the final analysis, is to control some effect of the environment on it, via its sensors, around a specific state or condition or level. We observe this from outside the system as controlling some external variable. The preferred state of that observed variable, the state toward which action always tends to return it after any deviation, is the observable reflection of the control system's purpose.

This concept of purpose, of course, does not entail any cognitive abilities or any ability to symbolize the purpose, to think about it. It is simply an inherent property of a control system, whether simple or complex.

Even in the absence of an explicit reference signal there is a purpose in a control organization. Absence of an adjustable reference signal is completely equivalent to presence of a reference signal set to zero. So even before non-zero reference signals appear in our story, purpose exists.

Note that the purpose of a molecular population organized to oppose disturbances is not to stabilize reproduction. It is to maintain the substrate in a particular condition. That purpose emerges as the result of failures to stabilize reproduction. There is nothing that tells the molecule to reproduce faithfully. Faithful reproduction is not a goal of the system of molecules. It is rather the consequence of failing to reproduce accurately that leads to changes, and those changes continue until the molecule begins to control aspects of the substrate that otherwise would lead to further changes. To the extent that the substrate is maintained near the optimal state for accurate reproduction in the relevant respects, further generations

will continue to do the same thing. They do so not by intending to reproduce accurately, but by intending that the substrate shall remain in a given state.

Knowing control theory, we can freely use such terms as intending, having a purpose, willing, and desiring, because we can now see that the fundamental meaning of such terms is defined by a particular relationship between a system and its environment, a relationship that has nothing to do with verbalizations, reasoning, or cognitions of any kind. Purpose is a far more fundamental phenomenon than any of its various manifestations. It is, I propose, the very basis of life.

Metasystem transitions

It may be that some of the processes in our story that lead to the first molecules (or molecular structures) with high amplification and nonzero reference signals amount to metasystem transitions. But I would prefer to reserve that term to mean the construction of more layers of control into a hierarchical system (it's not my term, however, so I will use it as others dictate).

I would see a metasystem transition when one molecule begins to control its local environment not by directly affecting it, but by affecting the reference signal of another molecule, or even a set of other molecules. We would then have one control system acting by adjusting what other control systems are controlling.

There is a large gap in the story here, skipping over what may be many levels of organization and certainly skipping over geological stretches of time. In this gap there are unknown stages of development, perhaps many metasystem transitions. I will not try to guess what they are. Instead I will push the fast-forward button and pick up the story at a later stage.

Behind this concept of metasystem transitions, I think, is the same kind of process that led to the first negative feedback system, the first spark of life. D. T. Campbell called it, long ago, "blind variation and selective retention." In the story as so far developed, the blind variation is due entirely to external disturbances, and the selective retention comes about simply from the fact that achievement of control puts an end to, or at least slows, certain of these forces of variation. We could call this the stage of blind variation and blind retention.

We now will skip to what would seem to be the last great development, which is the introduction of blind variation and purposive retention. Certain metasystem transitions may have preceded this development, but after it the progression of evolution toward greater and greater control, and toward vastly more complex metasystems, would have taken a completely new turn.

What I visualize is this: the evolution of a system that internalizes evolution. Instead of waiting for the external world to impose new and more threatening kinds of blind variation, this system instigates such variations spontaneously. It does not wait for failures, but detects them before they can result in extinctions. It retains the basic power of the evolutionary principle: the use of random change to break out of local minima and discover illogical and improbable but superior solutions to the problem of accurate replication. But it is now an organized system, a control system, emergent from the very process that it emulates.

It is likely that this process exists even at the level of DNA. A simple version of it may be involved in physical development of advanced organisms. I think it is, in its most advanced form, the major source of metasystem transitions that develop within the lifetime of single higher organisms.

Reorganization

In my theorizing I have embodied this process as a “reorganizing system.” We can visualize this as a system that monitors certain variables that are critical to continued viability of an organism; W. Ross Ashby (1952) called them “critical variables,” meaning essentially what I mean. My concept of reorganization was taken directly from Ashby and the “uniselector” in his Homeostat. These variables are a sketch of the state of the organism, represented in signals (or, I suppose, as the variables themselves, initially). In addition to the signal-representations of these variables (skirting any more exact definition), there are reference signals that are inherited. The reference signals now represent far more complex variables than those described for the primitive pre-cellular molecules; in a human being, such a reference signal might specify the pH of the stomach fluids, or the CO₂ tension in the carotid arch, or even global states of the brain. The reorganizing system compares the sensed states of these “intrinsic variables” with the genetically-given

reference states, and converts the difference into the rate at which deliberate random changes are made in the basic organization of the behaving system.

This reification of the processes associated with the beginnings of life can be seen in a convenient form in the mode of locomotion of the intestinal bacterium *E. coli*. This bacterium can move itself in two ways: by spinning its flagellae all in the same direction and swimming at constant speed in a straight line; or by reversing some of its flagellae, creating a picture of a shaken mop and tumbling randomly in space. These two acts constitute its sole method of steering. Yet *E. coli*, placed in a gradient of an attractant, will find its way up the gradient (and presumably toward the source) with better than half the speed it could achieve if it had a continuous means of steering (Koshland, 1980).

E. coli's secret is not in any bias on the direction of the random tumbles, but in a bias on when the random tumbles are performed. The tumbles themselves are truly random; they leave the bacterium pointed in a new direction unrelated to anything else—the old direction or the direction of the gradient. If, however, *E. coli* senses a positive time rate of change of concentration of the attractant (produced by its swimming), it postpones the next tumble; if the rate of change is negative, it shortens the interval to the next tumble (there is a continuum of these effects). Thus if it comes out of a tumble and finds itself swimming in a direction that reverses or even lessens the rate of change of concentration, it tumbles again right away. If the result is a positive rate of change, it swims longer before tumbling again. The result is that it spends a lot less time and energy, very much less, swimming in the wrong direction than in the right one.

Note that *E. coli* does not have to starve to death in order to discover than a change is called for. It does not have to eliminate itself before reproducing so that other bacterial offspring will swim in the right direction. This is because it can sense a variable critical to its continued existence, and before the state of that variable becomes life-threatening institute a random change that has a chance of improving matters—all within its own lifetime, and in fact countless times within its own lifetime. It has truly internalized and greatly streamlined the basic process of evolution, with respect to one aspect of its behavior. It can, by this method, move appropriately with respect to over 20 kinds of attractants or repellents.

There have been suggestions, controversial of course, that *E. coli* can do something very similar at the genetic level (Cairnes, Overbaugh & Miller, 1988). There are two strains of *E. coli*, one that can live only on fructose and one that can live, I believe, only on galactose. A population raised on one substrate and then switched to the other apparently begins to mutate much more rapidly than the normal rate, and produces enough variants of the opposite kind to survive (as a population). This does, of course, require the death of individuals, but the point is that the DNA being passed along apparently carries with it a kind of reorganizing system that responds to the stress by shortening the interval between “tumbles”—random but internally instigated changes of genetic organization. *E. coli*’s method of steering would seem to be an embodiment of the same principle through which it controls, or at least strongly influences, its own evolution.

A reorganizing system is concerned only with the states of certain basic variables. What it creates in the process of maintaining these variables near their genetically-specified reference states is the organization of behavior. If we imagine that each human being begins life with an intact reorganizing system and a “kit” of neurons capable of being connected in a large number of different ways, we can explain how each individual comes to have just that organization, at all the required levels, that will preserve life in a randomly-chosen environment replete with unpredictable variations and disturbances. Ontogeny, at this level, does not just recapitulate phylogeny: it replaces it.

I have proposed 11 levels of behavioral organization in the adult human being. Turchin has proposed others, and the literature of the past abounds in still more proposals for hierarchical organizations. Quite aside from the question of what levels of organization exist, however, there is the question of how they come into existence. If we are not to believe that natural selection can account for environment-specific adaptations of suspicious appropriateness, such as learning to drive a tractor, we must rely on some principle of reorganization to account for learning of basic survival skills by an individual. The one I propose carries on the spirit of the evolutionary principle, but in the form of a system that has itself evolved to imitate evolution without the crudity of Darwin’s Hammer.

Conclusions

The thread that runs through this story of life from its beginning to the present is that of control and purpose. I have not tried to account for the appearance of living systems as a passive consequence of external forces, or for the stability of living molecules simply as a matter of the strength of chemical bonds. Instead I have looked for a way in which stability could have resulted from an active process, one that counteracts disturbances that, unopposed, would alter the organization of a living system. In a way I have backtracked from the present-time appearance of living systems, which beyond doubt control aspects of the environments in which they live and on which they depend for continued life. There is a case to be made for the assertion that the same principle of negative feedback control has been at work all the time; at first in a simple form growing naturally out of the possible interactions among molecules and the substrate in which they form (*and which, dissociating, they affect*), and as time went on, in more elaborate and powerful forms leading to greater and greater control over the environment.

I have represented this development as a story, and a story it is, based more on imagination than fact. But the principles seem sound, and subject to test at least in simulation. I have, provisionally, a certain amount of confidence in this picture, even though that confidence is matched or exceeded by my ignorance. Perhaps others with more information, bigger computers, and more youth on which to draw will find these suggestions worth exploring further.

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