# *E-COLI*
# *E-coli reorganization principle*

Part of PCT is a proposal that certain basic error signals drive a process of reorganization. The process itself is modeled after the way the bacterium E. coli finds its way up gradients of chemical attractants. E. Coli cannot steer, but it can periodically tumble, changing its swimming direction at random. By tumbling sooner when the chemical concentration decreases and postponing tumbles when it increases, E. coli can make its way toward the source of the chemical very successfully. This demo allows the user to play the part of E. coli, tapping the space bar to change the direction of movement of a spot on the screen to "steer" it to a target circle.
The changes of direction are completely random, yet the moving spot can be directed toward a goal-position quite reliably. There are implications of this principle for concepts of self-directed evolution, where the timing of mutations rather than the specific mutation is the important aspect of responses to selection pressures.

## Introduction

A central problem in Perceptual Control Theory is to explain how the hierarchy of control systems becomes organized to work in whatever environment a human baby finds when it is born. Theories that assume everything to be genetically determined have (supposedly) no problem with this, but a theory that assumes only a basic skeleton of levels or orders of control must account for how they come to be organized into their adult forms. Since these levels cover all kinds of control from elementary to abstract and complex, the organizing principle can't include any skills, knowledge, or means of action belonging to higher levels in the hierarchy that do not become functional until much later in life. However the processes of organization and reorganization happen, they must be in working order from the very beginning, perhaps even prenatally.

This means that we are looking for a very unintelligent system, one so simple that it needs no intellectual aid and is inheritable. The proposed solution has been presented in my other works, actually even in the first one (1960) as a "reorganizing system" that monitors critical variables in the body. When these variables depart from genetically-given reference levels, the reorganizing system starts a process called, generically, "reorganization". This process is applied to the brain and continues until the result of changes in brain organization is to produce behavior that happens, as a side-effect, to restore the critical intrinsic variables to their reference levels. Then, of course, reorganization ceases, and the organization existing at that time functions without change until reorganization is caused to start again by more intrinsic errors.

With this much on the table, the question then becomes "What kind of reorganizing process could such a reorganizing system possibly use that would have the necessary effects?" As a first guess, 40-odd years ago, I proposed that this process consisted simply of random changes in synaptic weightings (a weighting of zero implying that a connection is broken). That is certainly a minimal process requiring neither intelligence nor knowledge of any kind; unfortunately, it also seems maximally inefficient and unfocused.

If we leave the inefficiency aside for a moment, however, we can see that this solution has a certain elegance and novelty to it, and that it is very different from previous theories about changes in behavior, particularly the idea of reinforcement.

The operant-conditioning hypothesis proposes that some mysterious quality of stimuli has reinforcing effects that increase the probability of behaviors that produce those stimuli., Reorganization theory proposes almost the opposite: that deficits or problems of basic kinds cause change to start, and the changes simply continue at random until whatever problem is causing them is corrected. In both cases, random variations in behavior are assumed, but the way these changes are connected to permanent changes in behavior is quite different. Reinforcement theory has a problem explaining what it is that causes random changes in behavior to begin, and what prevents them from happening once a specific form of behavior has been produced by reinforcements. Also, reinforcement theory can't explain what is probably the simplest and most obvious fact about this kind of learning: what is reinforcing depends on what type of prior deprivation exists, so that one cannot reinforce a hungry animal or person by using water as a reward, or anything else beside food. Reorganization theory handles these questions easily.

But we are still faced with the fact that random reorganization ought to produce random changes in behavior, unrelated to anything including whatever problem caused reorganization to start. How can random changes lead to any systematic effects? That is the question we will answer here using the demonstration called ecoli.exe. This will point to a new principle that has actually been used before but without recognition of its generality. It also happens to answer the question of how random mutations could produce systematic evolutionary effects under control of a species rather than just being blindly instigated by the environment. But that is a different story.

## Escherischia coli

The name of this program, and the principle of reorganization, comes from studies of bacterial chemotaxis, specifically those done and written about by Daniel E. Koshland (1980). The bacterium Escherischia coli, or E. coli for short, normally swims in straight lines by spinning its 7 or 8 flagellae. Periodically, however, some of the flagellae reverse, creating a messy mop-like arrangement of filaments and making the body of the bacterium tumble. When the flagellae start to spin in the same direction again, swimming proceeds in a new direction demonstrably unrelated to the previous direction. The tumbles select new directions of swimming at random.

E. coli senses various chemicals in the soup through which it swims. In particular, it can sense the time rate of change of concentration of these chemicals, showing whether the direction of swimming is leading more or less up a concentration gradient or down it.

If the substance is an attractant, then swimming up the gradient results in postponement of the next tumble. If the direction is down the gradient, the next tumble occurs sooner. A moment's thought will show that this results in traveling a smaller distance down the gradient than up it (the bacterium swims at constant speed), and the bacterium must inevitably (barring a long run of bad luck) make its way up the gradient, presumably toward the source of some nutrient. Simply adjusting the timing of the tumbles in relation to the sensed gradient is sufficient to convert the purely random changes in direction into a systematic effect on something that is important to E. coli. Order out of chaos.

## The program Ecoli.exe

The program Ecoli.exe illustrates this principle, with the user playing the role of E. coli. When the program starts, somewhere on the screen is a circle indicating a target, and somewhere else is a moving dot that leaves a trace behind it. The moving dot is you, and your aim is to reduce the distance between you and the target to zero. This uses your visual system instead of E. coli's chemosensors, but the effect is the same (this also works with a one-dimensional display).

Your only means of steering the dot is to tap the space bar. Each tap produces a new direction of motion, selected at random. You will very quickly learn how to manage the taps so that the dot ends up inside the circle, stopping the run. Sometimes many "tumbles" in a row are unfavorable; sometimes you get lucky right away. But you always get to the circle. On the average, you do this at least half as fast as if you could simply turn and swim toward the target.

## Conclusions

This demonstration tells us that random reorganization, carried out in the context of the right strategy, becomes an exceedingly powerful way of producing systematic changes without any knowledge at all of how these changes work. No assumption is made about possible effects of any change. Neither is there any calculation of what change will be most likely to have a beneficial effect. All the changes ( in this case, changes of direction) are completely random with no bias toward any one direction good or bad. Simply through observing the effects of changes and adjusting their timing, a strong systematic bias is imposed, not by biasing the actions of the system but by performing a biased selection of the consequences of tumbling. If the result is unfavorable, change again right away. If favorable, postpone the next change.

It should be pointed out that this is not a random selection of positions in space, but a random selection of directions of movement. We can think of this demonstration as a two-dimensional example of a principle that can be applied in any number of dimensions. In three dimensions, we would have directions of movement (vx, vy, and vz) and on each "tumble" we would select the velocity in any direction at random. In a larger number of dimensions we can't visualize the "tumbles" spatially, but we can imagine changing each "hyperdirection" of velocity at random between, say, +1 and –1 unit per second, and then between tumbles letting the positions vary at whatever velocity exists until the next reorganization, while monitoring whatever criteria we use to determine whether the direction is still favorable.

It turns out that this approach has long been known as one "method of steep descent" for numerically solving large sets of linear or nonlinear equations. It is guaranteed to converge to the best possible solution—eventually. I have tried it as a method of solving simultaneous equations, and while it slows as the number of variables increases, it is still respectably fast for system with as many as 50 variables. It will not work under all conceivable conditions, but just what the practical limits in the present application are, if any, remains to be determined.