A Scientific Scandal

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IN SCIENCE, as in life, it is always an excellent idea to cut the cards after the deck has been shuffled. One may admire the dealer, but trust is another matter.

In a recent essay in COMMENTARY, "Has Darwin Met His Match?" (December 2002), I discussed, evaluated, and criticized theories of intelligent design, which have presented the latest challenge to Darwin's theory of evolution. In the course of the discussion I observed that the evolution of the mammalian eye has always seemed difficult to imagine. It is an issue that Darwin himself raised, and although he settled the matter to his own satisfaction, biologists have long wished for a *direct* demonstration that something like a functional eye could be formed in reasonable periods of time by means of the Darwinian principles of random variation and natural selection.

Just such a demonstration, I noted in my essay, is what the biologists Dan-Erik Nilsson and Susanne Pelger seemed to provide in a 1994 paper.[1] Given nothing more than time and chance, a "light-sensitive patch," they affirmed, *can* "gradually turn into a focused-lens eye," and in the space of only a few hundred thousand years—a mere moment, as such things go.

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Nilsson and Pelger's paper has, for understandable reasons, been widely circulated and widely praised, and in the literature of evolutionary biology it is now regularly cited as definitive. Not the least of its remarkable authority is derived from the belief that it contains, in the words of one of its defenders, a "computer simulation of the eye's evolution."

If this were true, it would provide an extremely important defense of Darwin's theory. Although a computer simulation is not by itself conclusive—a simulation is one thing, reality another—it is often an important link in an inferential chain. In the case of Darwin's theory, the matter is especially pressing since in the nature of things the theory cannot be confirmed over geological time by any experimental procedure, and it has proved very difficult to confirm under laboratory conditions. The claim that the eye's evolution has been successfully simulated by means of Darwinian principles, with results falling well within time scales required by the theory, is thus a matter of exceptional scientific importance.

And not just *scientific* importance, I might add; so dramatic a confirmation of Darwinian theory carries large implications for our understanding of the human species and its origins. This is no doubt

[1] "A Pessimistic Estimate of the Time Required for an Eye to Evolve," *Proceedings of the Royal Society*, London B (1994) 256, 53-58. In my essay I twice misspelled Susanne Pelger's name, for which I apologize.

why the story of Nilsson and Pelger's computer simulation has spread throughout the world. Their study has been cited in essays, textbooks, and popular treatments of Darwinism like *River Out of Eden* by the famous Oxford evolutionist Richard Dawkins; accounts of it have made their way onto the Internet in several languages; it has been promoted to the status of a certainty and reported as fact in the press, where it is inevitably used to champion and vindicate Darwin's theory of evolution.

In my essay, I suggested that Nilsson and Pelger's arguments are trivial and their conclusions unsubstantiated. I also claimed that representations of their paper by the scientific community have involved a serious, indeed a flagrant, distortion of their work. But in a letter published in the March issue of COMMENTARY, the physicist Matt Young, whom I singled out for criticism (and whose words I have quoted here), repeated and defended his characterization of Nilsson and Pelger's work as a "computer simulation of the eye's evolution." It is therefore necessary to set the matter straight in some detail.

I hope this exercise will help to reveal, with a certain uncomfortable clarity, just how scientific orthodoxy works, and how it imposes its opinions on the faithful.

HERE IN their own words is the main argument of Nilsson and Pelger's paper:

> Theoretical considerations of eye design allow us to find routes along which the optical structure of the eye may have evolved. If selection constantly favors an increase in the amount of detectable spatial information, a light-sensitive patch will gradually turn into a focused-lens eye through continuous small improvements in design. An upper limit for the number of generations required for the complete transformation can be calculated with a minimum number of assumptions. Even with a consistently pessimistic approach, the time required becomes amazingly short: only a few hundred thousand years.

And here is how they arrived at their conclusions. The setting is "a single circular patch of light-sensitive cells"—a retina, in effect—"which is bracketed and surrounded by dark pigment." A "protective layer" lies above these light-sensitive cells, so that the pigment, the light-sensitive cells, and the protective layer form a kind of sandwich. Concerning the light-sensitive patch itself, Nilsson and Pelger provide no further details, indicating neither its size nor the number of cells it might contain.

What they do assume, if only implicitly, is that changes to the initial patch involve either a deformation of its shape or a thickening of its cells. The patch can be stretched, dimpled, and pulled or pushed around, and cells may move closer to one another, like bond salesmen converging on a customer.

So much for what changes. What is the change worth? Assuming (reasonably enough) that an eye is an organ used in order to see, Nilsson and Pelger represent its value to an organism by a single quantitative character or function, which they designate as "spatial resolution" or "visual acuity"—sharp sight, in short. Visual acuity confers an advantage on an organism, and so, in any generation, natural selection "constantly favors an increase in the amount of detectable spatial information."

There are two ways in which visual acuity may be increased in an initial light-sensitive patch: a) by the "invagination" of the patch, so that it becomes progressively more concave and eventually forms the enclosed interior of a sphere; and b) by the constriction of the sphere's aperture (the two rounded boundaries formed as the flat patch undergoes invagination). These changes may be represented on sheets of high-school graph paper on which two straight lines—the x and y axes of the system—have been crossed. On the first sheet, representing invagination, visual acuity moves upward on one axis as invagination moves to the right on the other; on the second sheet, visual acuity moves upward as constriction moves to the right. The curves that result, Nilsson and Pelger assert, are continuous and increasing. They do not hurdle over any gaps, and they go steadily upward until they reach a theoretical maximum.

The similar shape of the two graphs notwithstanding, invagination and aperture constriction exercise different effects on visual acuity. "Initially, deepening of the pit"—i.e., invagination—"is by far the most efficient strategy," Nilsson and Pelger write; "but when the pit depth equals the width, aperture constriction becomes more efficient than continued deepening of the pit." From this, they conclude that natural selection would act "first to favor depression and invagination of the light-sensitive patch, and then gradually change to favor constriction of the aperture."

THE RESULT is a pin-hole eye, which is surely an improvement on no eye at all. But there exists an aperture size beyond which visual acuity cannot be improved without the introduction of a lens. Having done all that it can do, the pin-hole eye lapses. Cells within the light-sensitive sphere now obligingly begin to thicken themselves, bringing about a "local increase" in the eye's refractive index and so forming a lens. When the focal length of the lens is 2.55 times its radius—the so-called Mattiessen ratio—the eye will have achieved, Nilsson and Pelger write, the "ideal solution for a graded-index lens with a central refractive index of 1.52."[2]

Thereafter, the lens "changes its shape from ellipsoid to spherical and moves to the center of curvature of the retina." A flat iris "gradually forms by stretching of the original aperture," while the "focal length of the lens . . . gradually shortens, [until] it equals the distance to the retina . . . producing a sharply focused image." The appearance of this spherical, graded-index lens, when placed in the center of curvature of the retina, produces "virtually aberration-free imaging over the full 180 degrees of the visual field."

The same assumptions that governed invagination and aperture constriction hold sway here as well. Plotted against increasing lens formation, visual acuity moves smoothly and steadily upward as a graded-index lens makes its appearance, changes its shape, and moves to center stage. When these transformations have been completed, the result is a "focused camera-type eye with the geometry typical for aquatic animals."

One step remains. Nilsson and Pelger now amalgamate invagination, constriction, and lens formation into a single "transformation," which they represent by juxtaposing, against changes in visual acuity, changes to the original patch in increments of 1 percent. The resulting curve, specifying quantitatively how much visual acuity may be purchased for each 1-percent unit of change, is ascending, increasing, and straight, rising like an arrow at an angle of roughly 45 degrees from its point of origin. Transformations are "optimal" in the sense that they bring about as much visual acuity as theoretically possible, with the "geometry of each stage [setting] an upper limit to the spatial resolution of the eye."

It is the existence and shape of this fourth curve that justify their claim that "a light-sensitive patch will gradually turn into a focused-lens eye through continuous small improvements in *design*" (emphasis added). This is not the happiest formulation they could have chosen.

HOW MUCH does the initial light-sensitive patch have to change in order to realize a focused camera-type eye? And how long will it take to do so? These are the questions now before us.

As I have mentioned, Nilsson and Pelger assume that their initial light-sensitive patch changes in 1-percent steps. They illustrate the procedure with the example of a flat one-foot ruler that also changes in 1-percent steps. After the first step, the ruler will be one foot plus 1 percent of one foot long; after the second step, it will be 1-percent longer than the length just achieved; and so forth. It requires roughly 70 steps to double a one-foot ruler in length. Putting the matter into symbols, $1.01^{70} \cong 2$.

Nilsson and Pelger undertake a very similar calculation with respect to their initial light-sensitive patch. But since the patch is a three-dimensional object, they are obliged to deal with three dimensions of change. Growing in steps of 1 percent, their blob increases its length, its curvature, and its volume. When all of these changes are shoehorned together, the patch will have increased in magnitude along some overall (but unspecified) dimension.

The chief claim of their paper now follows: to achieve the visual acuity that is characteristic of a "focused camera-type eye with the geometry typical for aquatic animals," it is necessary that an initial patch be made 80,129,540 times larger (or greater or grander) than it originally was. This number represents the *magnitude* of the blob's increase in size. How many *steps* does that figure represent? Since $80{,}129{,}540 = 1.01^{1{,}829}$, Nilsson and Pelger conclude that "altogether 1,829 steps of 1 percent are required" to bring about the requisite transformation.

These steps, it is important to remember, do not represent *temporal* intervals. We still need to assess how rapidly the advantages represented by such a transformation would spread in a population of organisms, and so answer the question of how long the process takes. In order to do this, Nilsson and Pelger turn to population genetics. The equation that follows involves the multiplication of four numbers:

$$R = h^2 \times i \times V \times m$$

Here, R is the response (i.e. visual acuity in each generation), h is the coefficient of heredity, i designates the intensity of selection, V is the coefficient of variation (the ratio of the standard deviation to the mean), and m, the mean value for visual acuity. These four numbers designate the extent to which heredity is responsible for visual acuity, the intensity with which selection acts to prize it, the way its mean or average value is spread over a pop-

[2] A graded-index lens is a lens that is not optically homogeneous; the figure of 1.52 is "the value close to the upper limit for biological material."

ulation, and the mean or average value itself. Values are assigned as estimates to the first three numbers; the mean is left undetermined, rising through each generation.

As for the estimates themselves, Nilsson and Pelger assume that $h^2 = .50$; that $i = 0.01$; and that $V = 0.01$. On this basis, they conclude that $R = 0.00005m$. The response in each new generation of light-sensitive patches is 0.00005 times the mean value of visual acuity in the previous generation of light-sensitive patches.

Their overall estimate—the conclusion of their paper—now follows in two stages. Assume that n represents the number of generations required to transform a light-sensitive patch into a "focused camera-type eye with the geometry typical for aquatic animals." (In small aquatic animals, a generation is roughly a year.) If, as we have seen, the mean value of visual acuity of such an eye is $1.01^{1,829} = 80,129,540$, where 1,829 represents the number of steps required and 80,129,540 describes the extent of the change those steps bring about; and if $1.00005^n = 1.01^{1,829} = 80,129,540$, then it follows that $n = 363,992$.

It is this figure—363,992—that allows Nilsson and Pelger to conclude at last that "the time required [is] amazingly short: only a few hundred thousand years." And this also completes my exposition of Nilsson and Pelger's paper. Business before pleasure.

NILSSON AND Pelger's work is a critic's smorgasbord. Questions are free and there are second helpings.

Every scientific paper must begin somewhere. Nilsson and Pelger begin with their assumption that, with respect to the eye, morphological change comes about by invagination, aperture constriction, and lens formation. Specialists may wish to know where those light-sensitive cells came from and why there are no other biological structures coordinated with or contained within the interior of the initial patch—for example, blood vessels, nerves, or bones. But these issues may be sensibly deferred.

Not so the issues that remain. Nilsson and Pelger treat a biological organ as a physical system, one that is subject to the laws of theoretical optics. There is nothing amiss in that. But while theoretical optics justifies a *qualitative* relationship between visual acuity on the one hand and invagination, aperture constriction, and lens formation on the other, the relationships that Nilsson and Pelger specify are tightly *quantitative*. Numbers make an appearance in each of their graphs: the result, it is claimed, of certain elaborate calculations. But no details are given either in their paper or in its bibliography. The calculations to which they allude remain out of sight, if not out of mind.

The 1-percent steps: in what units are they expressed? And how much biological change is represented by each step? Nilsson and Pelger do not say. Nor do they coordinate morphological change, which they treat as simple, with biochemical change, which in the case of light sensitivity is known to be monstrously complex.

Does invagination represent a process in which the patch changes as a whole, like a balloon being dimpled, or is it the result of various local processes going off independently as light-sensitive cells jostle with one another and change their position? Are the original light-sensitive cells the complete package, or are new light-sensitive cells added to the ensemble as time proceeds? Do some cells lose their sensitivity and get out of the light-sensing business altogether? We do not know, because Nilsson and Pelger do not say.

Biologists commenting on Darwin's theory have almost always assumed that evolution reflects what the French biologist François Jacob called *bricolage*—a process of tinkering. Biological structures are put together out of pieces; they adapt their function to changes in their circumstances; they get by. This suggests that in the case of eye formation, morphological change might well purchases *less* visual acuity than Nilsson and Pelger assume, the eye being tinkered into existence instead of flogged up an adaptive peak. But if, say, only half as much visual acuity is purchased for each of Nilsson and Pelger's 1-percent steps, twice as many steps will be needed to achieve the effect they claim. What is their justification for the remarkably strong assertion that morphological transformations purchase an optimal amount of visual acuity at each step?

Again we do not know, because they do not say.

More questions—and we have not even finished the hors d'oeuvres. The plausibility of Nilsson and Pelger's paper rests on a single number: 1,829. But without knowing precisely how the number 1,829 has been derived, the reader has no way of determining whether it is reasonable or even meaningful.

If nothing else, the number 1,829 represents the maximum point of a curve juxtaposing visual acuity against morphological transformation. Now, a respect for the ordinary mathematical decencies would suggest that the curve is derived from the number, and the number from various calculations. But all such calculations are missing from Nilsson and Pelger's paper. And if the calculations are not given, neither are any data. Have Nilsson and Pelger, for example, *verified* their estimate, either by showing that 1,829 1-percent steps do suffice to transform a patch into an eye, or by showing that such an eye may, in 1,829 1-percent steps, be resolved backward into an initial light-sensitive patch? Once again, we do not know because they do not say.

Still other questions suggest themselves. Although natural selection is mentioned by Nilsson and Pelger, it is a force that plays no role in their reasoning. Beyond saying that it "constantly favors an increase in the amount of detectable spatial information," they say nothing at all. This is an ignominious omission in a paper defending Darwinian principles. An improvement in visual acuity is no doubt a fine thing for an organism; but no form of biological change is without cost.

Let us agree that in the development of an eye, an initial light-sensitive patch in a given organism becomes invaginated over time. Such a change requires a corresponding structural change to the organism's anatomy. If nothing else, the development of an eye requires the formation of an eye socket—hardly a minor matter in biological terms. Is it really the case that an organism otherwise adapted to its environment would discover that the costs involved in the reconstruction of its skull are nicely balanced by what would initially be a very modest improvement in sensitivity to light? I can imagine the argument going either way, but surely an argument is needed.

Then there is Nilsson and Pelger's data-free way with statistics. What is the basis of the mathematical values chosen for the numbers they use in assessing how rapidly transformation spreads in a population of eye patches? The coefficient of variation is the ratio of the standard deviation to the mean. The standard deviation, one might ask, of *what*? No population figures are given; there are no quantitative estimates of any relevant numerical parameter. Why is selection pressure held constant over the course of 300,000 years or so, when plainly the advantages to an organism of increasing light sensitivity will change at every step up the adaptive slope? Why do they call their estimates pessimistic (that is, conservative) rather than wildly optimistic?

Finally, Nilsson and Pelger offer an estimate of the number of *steps*, computed in 1-percent (actually, 1.00005-percent) intervals, that are required to transform their initial patch. At one point, they convert the steps into generations. But a step is not a temporal unit, and, for all anyone knows, each step could well require half again or twice the number of generations they suggest. Why do Nilsson and Pelger match steps to generations in the way they do? I have no idea, and they do not say.

We are at last at the main course. Curiously enough, it is the intellectual demands imposed by Darwin's theory of evolution that serve to empty Nilsson and Pelger's claims of their remaining plausibility.

Nilsson and Pelger assert that only 363,992 generations are required to generate an eye from an initial light-sensitive patch. As I have already observed, the number 363,992 is derived from the number 80,129,540, which is derived from the number 1,829—which in turn is derived from nothing at all. Never mind. Let us accept 1,829 *pour le sport*. If Nilsson and Pelger intend their model to be a vindication of Darwin's theory, then changes from one step to another must be governed by random changes in the model's geometry, followed by some mechanism standing in for natural selection. These are, after all, the crucial features of *any* Darwinian theory. But in their paper there is no mention *whatsoever* of randomly occurring changes, and natural selection plays only a ceremonial role in their deliberations.

At the beginning of their paper, Nilsson and Pelger write of their initial light-sensitive patch that "we *expose* this structure to selection pressure favoring spatial resolution" (emphasis added), and later that "[a]s the lens approaches focused conditions, *selection pressure* gradually appears to . . . adjust its size to agree with Mattiesen's ratio" (emphasis added). But whatever Nilsson and Pelger may have been doing to their patch, they have not been exposing it to "selection pressure." The patch does only what they have told it to do. By the same token, selection pressures play no role in adjusting the size of their lenses to agree with Mattiesen's ratio. That agreement is guaranteed, since it is Nilsson and Pelger who bring it about, drawing the curve and establishing the relevant results. What Nilsson and Pelger *assume* is that natural selection would track their results; but this assumption is never defended in their paper, nor does it play the slightest role in their theory.

And for an obvious reason: if there are no random variations occurring in their initial light-sensitive patch, then natural selection has nothing to do. And there are no random variations in that patch, their model succeeding as a defense of Darwin's theory only by first emptying the theory of its content.

An example may make clearer both the point and its importance. Only two steps are required to change the English word "at" to the English word "do": "at" to "ao" and "ao" to "do." The changes are obvious: they have been *designed* to achieve the specified effect. But such design is forbidden in Darwinian theory. So let us say instead, as Darwin must, that letters are chosen randomly, for instance by being fished from an urn. In that case, it will take, on average, *676* changes (26 letters times 26) to bring about the same two steps.

Similarly, depending on assessments of probability, the number of changes required to bring about a single step in Nilsson and Pelger's theory may range widely. It may, in fact, be anything at all. How long would it take to transform a light-sensitive patch into a fully functioning eye? It all depends. It all depends on how *likely* each morphological change happens to be. If cells in their initial light-sensitive patch must discover their appointed role by chance, all estimates of the time required to bring about just the transformations their theory demands—invagination, aperture construction, and lens formation—will increase by orders of magnitude.

If Darwin were restored to pride of place in Nilsson and Pelger's work, the brief moment involved in their story would stretch on and on and on.

FINALLY, THERE is the matter of Nilsson and Pelger's computer simulation, in many ways the gravamen of my complaints and the dessert of this discussion.

A computer simulation of an evolutionary process is not a mysterious matter. A theory is given, most often in ordinary mathematical language. The theory's elements are then mapped to elements that a computer can recognize, and its dynamical laws, or laws of change, are replicated at a distance by a program. When the computer has run the program, it has simulated the theory.

Although easy to grasp as a concept, a computer simulation must meet certain nontrivial requirements. The computer is a harsh taskmaster, and programming demands a degree of specificity not ordinarily required of a mathematical theory. The great virtue of a computer simulation is that if the set of objects is large, and the probability distribution and fitness function complicated, the computer is capable of illustrating the implications of the theory in a way that would be impossible using ordinary methods of calculation. "Hand calculations may be sufficient for very simple models," as Robert E. Keen and James Spain write in their standard text, *Computer Simulation in Biology* (1992), "but computer simulation is almost essential for understanding multi-component models and their complex interrelationships."

Whatever the merits of computer simulation, however, they are beside the point in assessing Nilsson and Pelger's work. In its six pages, their paper contains no mention of the words "computer" or "simulation." There are no footnotes indicating that a computer simulation of their work exists, and their bibliography makes no reference to any work containing such a simulation.

Curious about this point, I wrote to Dan-Erik Nilsson in the late summer of 2001. "Dear David," he wrote back courteously and at once,

> You are right that my article with Pelger is not based on computer simulation of eye evolution. I do not know of anyone else who [has] successfully tried to make such a simulation either. But we are currently working on it. To make it behave like real evolution is not a simple task. At present our model does produce eyes gradually on the screen, but it does not look pretty, and the genetic algorithms need a fair amount of work before the model will be useful. But we are working on it, and it looks both promising and exciting.

These are explicit words, and they are the words of the paper's senior author. I urge readers to keep them in mind as we return to the luckless physicist Matt Young. In my COMMENTARY essay of last December, I quoted these remarks by Mr. Young:

> Creationists used to argue that . . . there was not enough time for an eye to develop. A computer simulation by Dan-Erik Nilsson and Susanne Pelger gave the lie to that claim.

These, too, are forthright words, but as I have just shown, they are false: Nilsson and Pelger's paper contains no computer simulation, and no computer simulation has been forthcoming from them in all the years since its initial publication. Sheer carelessness, perhaps? But now, in responding to my COMMENTARY article, Matt Young has redoubled his misreading and proportionately augmented his indignation. The full text of his remarks appears in last month's COMMENTARY; here are the relevant passages:

> In describing the paper by Nilsson and Pelger . . . , I wrote that they had performed a computer simulation of the development of the eye. I did not write, as Mr. Berlinski suggests, that they used nothing more than random variation and natural selection, and I know of no reference that says they did.

> . . .The paper by Nilsson and Pelger is a sophisticated simulation that even includes quantum noise; it is not, contrary to Mr. Berlinski's assertion, a back-of-the-envelope calculation. It begins with a flat, light-sensitive patch, which they allow to become concave in increments of 1 percent, calculating the visual acuity along the way. When some other mechanism will improve acuity faster, they allow, at various stages, the formation of a graded-index lens and an iris, and then optimize the focus. Unless Nilsson and Pelger performed the calculations in closed form or by hand, theirs was, as I wrote, a "computer simulation." Computer-*aided* simulation might have been a slightly better description, but not enough to justify Mr. Berlinski's sarcasm at my expense. . . .

And here is my familiar refrain: there is *no* simulation, "sophisticated" or otherwise, in Nilsson and Pelger's paper, and their work rests on no such simulation; on this point, Nilsson and I are in complete agreement. Moreover, Nilsson and Pelger do *not* calculate the visual acuity of any structure, and certainly not over the full 1,829 steps of their sequence. They suggest that various calculations have been made, but they do not show how they were made or tell us where they might be found. At the very best, they have made such calculations for a handful of data points, and then joined those points by a continuous curve.

There are two equations in Nilsson and Pelger's paper, and neither requires a computer for its solution; and *there are no others*. Using procedures very much like Nilsson and Pelger's own, Mr. Young has nevertheless deduced the existence of a missing computer simulation on theoretical grounds: "Unless Nilsson and Pelger performed the calculations in closed form or by hand, theirs was, as I wrote, a computer simulation." But another possibility at once suggests itself: that Nilsson and Pelger did not require a computer simulation to undertake their calculations because they made no such calculations, their figure of 1,829 steps representing an overall guess based on the known optical characteristics of existing aquatic eyes.

Whatever the truth—and I do not know it—Mr. Young's inference is pointless. One judges a paper by what it contains and one trusts an author by what he says. No doubt Matt Young is correct to observe that "computer-*aided* simulation might have been a better description" of Nilsson and Pelger's work. I suppose one could say that had Dan-Erik Nilsson and Susanne Pelger rested their heads on a computer console while trying to guess at the number of steps involved in transforming a light-sensitive patch into a fully functioning eyeball, their work could also be represented as computer-aided.

MATT YOUNG is hardly alone in his lavish misreadings. The mathematician Ian Stewart, who should certainly know better, has made virtually the same patently false claims in *Nature's Numbers* (1995). So have many other prominent figures.[3] But misreadings are one thing, misrepresentations another. More than anyone else, it has been Richard Dawkins who has been responsible for actively misrepresenting Nilsson and Pelger's work, and for disseminating worldwide the notion that it offers a triumphant vindication of Darwinian principles.

In a chapter of his 1995 book, *River Out of Eden*, Dawkins writes warmly and at length about Nilsson and Pelger's research.[4] Here is what he says (emphasis added throughout):

> [Their] task was to set up *computer models* of evolving eyes to answer two questions . . . [:] is there a smooth gradient of change, from flat skin to full camera eye, such that every intermediate is an improvement? . . . [and] how long would the necessary quantity of evolutionary change take?
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> In their *computer models*, Nilsson and Pelger made no attempt to simulate the internal workings of cells.
>
> . . . Nilsson and Pelger began with a flat retina atop a flat pigment layer and surmounted by a flat, protective transparent layer. The transparent layer was allowed *to undergo localized random mutations of its refractive index.* They then let *the model transform itself at random*, constrained only by the requirement that any change must be small and must be an improvement on what went before.
>
> The results were swift and decisive. A trajectory of steadily mounting acuity led unhesitatingly from the flat beginning through a shallow indentation to a steadily deepening cup, *as the shape of the model eye deformed itself on the computer screen. . . .* And then, *almost like a conjuring trick*, a portion of this transparent filling

[3] Among those who, by contrast, have raised (on the Internet) points similar to my own, I would single out especially Brian Harper, a professor of mechanical engineering at Ohio State University.

[4] A version of the same material by Dawkins, "Where D'you Get Those Peepers," was published in the *New Statesman* (July 16, 1995).

> condensed into a local, spherical region of higher refractive index.
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> . . . This ratio is called Mattiessen's ratio. Nilsson and Pelger's *computer-simulation model homed in* unerringly on Mattiessen's ratio.

How very remarkable all this is—inasmuch as there are no computer models mentioned, cited, or contained in Nilsson and Pelger's paper; inasmuch as Dan-Erik Nilsson denies having based his work on any computer simulations; inasmuch as Nilsson and Pelger never state that their task was to "set up computer models of evolving eyes" for any reason whatsoever; inasmuch as Nilsson and Pelger assume but do not prove the existence of "a smooth gradient of change, from flat skin to full camera eye, such that every intermediate is an improvement"; and inasmuch as the original light-sensitive patch in Nilsson and Pelger's paper was never allowed to undergo "localized random mutations of its refractive index."

And how very remarkable again—inasmuch as there are no computer "screens" mentioned or cited by Nilsson and Pelger, no indication that their illustrations were computer-generated, and no evidence that they ever provided anyone with a real-time simulation of their paper where one could observe, "almost like a conjuring trick," the "swift and decisive" results of a process that they also happen to have designed.

And yet again how very remarkable—inasmuch as Nilsson and Pelger's "computer-simulation model" did not home in unerringly on Mattiessen's ratio, Nilsson and Pelger having done all the homing themselves and thus sparing their model the trouble.

Each and every one of these very remarkable asseverations can be explained as the result of carelessness only if one first indicts their author for gross incompetence.

FINAL QUESTIONS. Why, in the nine years since their work appeared, have Nilsson and Pelger never dissociated themselves from claims about their work that they know are unfounded? This may not exactly be dishonest, but it hardly elicits admiration. More seriously, what of the various masters of indignation, those who are usually so quick to denounce critics of Darwin's theory as carrying out the devil's work? Eugenie Scott, Barbara Forrest, Lawrence Krauss, Robert T. Pennock, Philip Kitcher, Kelly Smith, Daniel Dennett, Paul Gross, Ken Miller, Steven Pinker—they are all warm from combat. Why have they never found reason to bring up the matter of the mammalian eye and the computer simulation that does not exist?

And what should we call such a state of affairs? I suggest that scientific fraud will do as well as any other term.