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BEGIN TRANSCRIPTION

[00:00:11] COORDINATOR:

Since we're so late, I'll spare you my own compilations.

(audience laughing)

If you can have any case on this material an account of Professor Rolston's accomplishments, described quite rightly as the father of environmental ethics as more than academic discipline, his books out of those consultancies. I will just say that in a recent interview for the Denver Post, he was quoted for saying, "If you had asked me what honor I would most have liked, it would have been the Gifford Lectures.

(audience laughing)

But if you asked me did I think I would be asked? It came to me as a considerable surprise. I didn't think I was really in that league." Well sir, we who invited you assure you that we think

(unintelligible)

.

(audience laughing)

(audience applauding)

[00:01:20] PROF. HOLMES ROLSTON:

Thank you. And I apologize for the tardy start. We can't always predict electronics. I guess in a series of my lectures, part of the claim will be that the university is on occasion unpredictable.

(audience laughing)

I was surprised and pleased at this invitation. It comes in a bit of a curious, did come in a bit of a curious circumstance in that, I'm a graduate of the University of Edinburgh, and therefore I receive solicitations from time to time.

(audience laughing)

And they seem to come here from the provost, the principal's office regularly. And I usually toss them in the trash can. They come in brown envelopes.

(audience laughing)

So here came another one, such solicitation, and I, it was halfway into the trash can.

(audience laughing)

And I thought, well, that one looks a little different. Maybe I better open that one.

(audience laughing)

So I'm glad I did. Otherwise, I might not have been here today.

(audience laughing)

My memories of the Gifford Lectures do go back a number of years. That's one reason why I said perhaps it would be an honor in which I would be particularly interested, because I'm the son of a Presbyterian minister. My father was in Edinburgh in 1928-1929, when John Dewey gave the quest for certainty.

Dad didn't have all that high opinion of John Dewey. And as a child I remember his recalling the year before, when he was not here but the memory still lingered.

Alfred North Whitehead gave 'Process and Reality,' and Dad used to joke that Whitehead had a full audience in the start and nobody came for the last lecture.

(audience laughing)

'Process and Reality' perhaps is not the kind of book that lectures well. I hope that fate doesn't befall me here.

(audience laughing)

And the year before that, Arthur Eddington gave 'The Nature of the Physical World,' which was a book that I had greatly admired in my younger years. So those were good years, when Dad was here. And then I myself am a graduate of the University of Edinburgh.

I was here in 1956, 1957, and Austin Frerick gave 'The Freedom of the Will.' And then in '57, '58, Wolfgang Kalle gave lectures on 'The Psychology of Values.' So we go back, my memories of Gifford Lectures one way or another do go back quite a while. I also recall when I was in theological seminary reading a series that had been Gifford Lectures, and in particular, my seminary roommate, as being sort of unable to believe this might have happened has crossed the Atlantic to be here.

I think I'll ask him to stand. Bob, would you stand?

(audience applauding)

And he and I, I recall that he was a fan of William Temple, 'Nature, Man And God.' I remember his quoting that to me on several occasions when I was trying to make it through Richard Niebuhr's 'Nature and Destiny of Man,' which I was quoting in return. So that's a bit of memory of the past.

I do have, in addition to my seminary roommate, a few American followers that have thought it worthy to cross the Atlantic. I wonder if I could ask those people just briefly to stand, if you would, please. There, alright.

(audience applauding)

Thank you.

(audience applauding)

They want to make sure it actually takes place. I think yeah something of that sort. Okay. Well, my theme is 'Genetics, Genes, Genesis, and God,' and it'll take a while to develop that.

You might perhaps have seen, but let's look again at the sort of theme of these lectures today. Let's get this a bit better centered. We were here earlier, this light was not glaring quite like that.

I'm not sure what just happened.

[00:06:41] AUDIENCE MEMBER:

So we can see that.

[00:06:42] PROF. HOLMES ROLSTON:

Can you see it?

[00:06:43] AUDIENCE MEMBER:

Yes.

[00:06:43] PROF. HOLMES ROLSTON:

Let me put it down a bit lower. And I think that might work better.

Today's lecture on really 'Diversity and Complexity in Natural History,' and then tomorrow a lecture on the theme of value, as I think values are in some way deeply connected with the capacity for genetic creativity and the genetic storing of information. Then on Thursday, genetic identity.

I think the philosophical questions of identity are of unusual interest in connection with genes. Just what different kinds and levels of identity are there.

And the theme of value returns and the conservation and integration and development of such values. Then there is the series of lectures on the intersection between genetics, natural history, and the human capacity for cultural history. And first on Monday, that will be a week from today, a general look at genes and the genesis of culture.

It does appear that with the appearance of culture, something novel occurs, unprecedented in previous genetic history. And then we will look at three particular domains of culture that are of special interest.

After all, genetics is a science, and on this planet we not only have genes, but we have the science of genetics, for instance, and other sciences and the question arises about the relationship between genetic creativity and the generation, as I put it, first of science. And then of ethics, another interesting human phenomenon. Ethics.

Two lectures on ethics, with an interest in the degree to which the ethical behavior can be naturalized. And there I think an interesting part, a challenge there particularly, is the question of universalism in ethics, part of which is the question of altruism, that makes it particularly challenging to naturalized ethics. Then we turn to religion.

We not only have science and ethics on this planet, but we have the interesting phenomena of religion across the millennia, and so we will look at that as the lectures begin to close. One of the ways in which biology and religion concur is that there's a kind of remarkable fertility on our planet, but they come at it sort of differently.

So the whole question of the prolific Earth will be the penultimate lecture, genes there, and then the final lecture on putting a summary overview of the course of lectures, genes, genesis, and God. So that's where we're headed.

(paper rustling)

Alright. Today's lecture then is dealing with the question of diversity and complexity in natural history. And at this point we find the biologists, I think, who are most familiar with this field, somewhat of a mixed mind.

And I can begin with an account given by Ernst Mayr. He is perhaps the best known, the senior American biologist at Harvard University. "Who can deny that overall there is an advance "from the prokaryotes that dominated the living world "more than three billion years ago "to the eukaryotes "with their well-organized nucleus and chromosomes, "as well as cytoplasmic organelles "from the single-celled eukaryotes "to plants and animals with a strict division of labor "among their highly specialized organ systems, "and within the animals from ectotherms "that are at the mercy of climate "to the warm-blooded endotherms from types of the small brain "and low social organization "to those with a very large central nervous system, "highly developed parental care "and the capacity to transmit information from generation to generation." Ernst Mayr though as we will presently see, quite a number of people do manage to deny that there is an advance in evolutionary history.

Or if we look at another spokesman, John Bonner, in the book on 'The Evolution of Complexity,' Bonner summarizes his findings, this is toward the end of his book, "There has been an extension of the upper limit of complexity "during the course of evolution. "There's also been an increase in complexity "of the plant and animal communities. "That is, there's been an increase "in the number of species over geological time.

"And this has meant an increase in species diversity "in any one community. "One can conclude that "evolution usually progresses by increases in complexity.

"As evolution proceeded on the surface of the Earth, there's been a progressive increase in size and complexity." Now anyone who looks at the record, will realize that there are setbacks in vicissitudes, notably in the Permian-Triassic, and again in a wave of mammal extinctions at the middle of the quaternary.

And yet there's recovery after these extinctions. There are many factors figure in, which include such things as climate change, continental drift.

Sometimes the developments in organic evolution are masked, swamped out by the climatic cooling or drying out. The continents may drift together and now there are different results.

Sometimes when continents drift together, there's a bigger area that supports more species, but then sometimes competition seems to pick up and eliminate species that evolved on separate continents. Another biologist, R.H.

Whitaker, finds that despite saturation, as he calls it, on some islands, that on continental scales there is increase of species diversity as a self-augmenting evolutionary process without any evident limit. A tendency toward what he calls 'species packing,' somewhat after that a term 'bootstrapping' in ecosystems, kind of a feed-forward loops that generate new niches that reinforce each other and open up opportunities for development. I'm using two words, one is complexity and one is diversity, and many think those can be independent variables.

That is to say that beetles can become more diverse without becoming more complex. And that seems to be true with beetles.

On the other hand, there are ways in which diversity and complexity can sometimes be interrelated. That is to say, if you have a diverse environment, then complexity may enable you to cope better in diverse environments, sometimes wet, sometimes dry, or with different kinds of predators. In that sense, they may be related. Reptiles can cope with a broader spectrum of humidity conditions than can amphibians for example.

Mammals in turn can cope in a broader spectrum of temperature than can reptiles. Once upon a time there was no smelling or swimming or hiding or defending a territory, making mistakes. Once upon a time there were no eggs hatching or mothers nursing young. Once there was no instinct and no conditioned learning, no pleasure, no pain.

Once there was no intentional reference but all these capacities arise, for example, when vervet monkeys learn to give different kinds of alarm calls to indicate the approach of different kinds of predators, leopards, eagles, and snakes. That gives them an improved coping ability. Diversity and complexity then can at times at least be interrelated.

Here is the conclusion of a well-known text in paleontology by J.W. Valentine. "A major Phanerozoic trend among the invertebrates "at the moment, invertebrates, "invertebrate biota of the world's shelf "and epicontinental seas "has been towards more and more numerous units "at all levels of the ecological hierarchy. "This has been achieved partly by the progressive partitioning "of ecospace into smaller functional regions "in which things can specialize, "partly by the invasion of previously unoccupied biospace.

"At the same time, "the expansion and contraction of available environments "has controlled strong "but secondary trends of diversity. The biosphere has become a splitter's paradise."

Valentine continuing says, "A sort of moving picture of the biological world "with its selective processes "that favor increasing fitness "and that lead to biological improvement "is projected upon an environmental background "that itself fluctuates. "The result of ecological images expand and contract, "but when measured at some standardized configuration "have a gradually rising average complexity and exhibit a gradually expanding ecospace." Those are the words.

If you wanna see this in a graph form, it can, a few of these. Here's an example, of dealing in this case with invertebrates, marine invertebrates, and there are, as you see, a number of ups and downs.

The geological timescale would be there coniferous on the left-hand side and the more recent on the right-hand side. And if you add in the marine, still in the marine, if you add the vertebrates and the invertebrates, that can look something like this. This by David Raup and John Sepkoski at the University of Chicago. Again, this is precambrian on the left, the geological time scale, the more recent, is the rising curve.

And yet there are ups and downs. And in this case, we have the five catastrophic extinctions numbered, and you do notice a somewhat flat middle part of the portion of the graph.

However, this is a graph about the seas, marine life, and it was at this time, so the flat part of the curve here, that life did move on to the land, and greatly diversified there from the Silurian period onward, which is not shown here. If you wanna take a look at how things do look on the land when plants first move onto the land, here's a curve of that sort. This is an old curve at Harvard University.

And there you see again, if you like, a bit flat perhaps in the middle, but a good deal of rising in the numbers of species and sort of spectacular climbs in the latter parts of evolutionary history. If you wonder about the animals, now let's see, that was one graph with plants. Let's look first at another graph with plants that separates out the different kinds of plants a bit. This might be a bit small for some of you to read, but we have the pteridophytes are ferns at the bottom and then the gymnosperms like pine trees were once more prominent than they are in the present flora, though they still continue.

And then the angiosperms, when the numbers of different kinds of plants considerably increase. And if we look at the animals here, the curve will look something like this. Sometimes these are numbers of orders I might add, and sometimes numbers of species, which we think would be correlated, but that's not always that straightforward. And again, once upon a time there were more amphibians, that's the bottom line, and then the reptiles sort of come into their own.

And the mammals are more in recent times, as well as birds, presumably developing in some way from reptiles. But we have a graph of that sort. If you add all these up, it's not always that easy to do, but nevertheless, some have attempted these kinds of things. Here is a graph by Norman Newell

(paper rustling)

from the Journal of Scientific American, both on land and in the seas fern is a fossil. These are animals, not plants.

Increasing through time, you get a picture that looks something like that. Alright. This is the kind of thing then that the genetics on our planet has produced, and now perhaps we need to philosophize about it a bit.

A word coined by two South American biologists to explain this kind of creativity over evolutionary history is autopoiesis from the root for self-production or self-organizing. It is, I think, an idea that's old although it is an idea which in scientific circles has sort of come back in the style. I remember it to some extent, the idea from the New Testament phrase 'the earth produces of itself,' where the Greek language is something somewhat resembling at least the idea of automatic. And that is, as a matter of fact, in a way the meaning, the very meaning of the word nature.

And we have to watch the word self here because I don't think there is any biological self in an ecosystem that kind of, I think it would be better more accurate to speak of spontaneously organizing. But the root idea and the meaning of the word nature is a process of springing forth or of giving birth. In the United States we have a group called the Santa Fe Institute that are big on studying this self-organizing and one of their prominent figures is a man named Stuart Kauffman, and here is his summary.

"Since Darwin, biologists have seen natural selection "as virtually the sole source of that order. "Darwin could not have suspected "the existence of self-organization, "a recently discovered innate property "of some complex systems.

"Selection has molded, "but was not compelled to invent "the native coherence of ontogeny "or biological development. "We may have begun to understand evolution "as the marriage of selection and self-organization.

"Such order has beauty and elegance, "casting an image of permanence "and underlying law over biology. "Evolution is not just chance caught on the wing, "it's not just a tinkering "of the ad hoc, of bricolage, or contraption. It is emergent order honored and honed by selection." Almost a poetic conclusion to that book on 'The Origins of Order.' One of our best-known geneticists in the United States is Francisco Ayala.

He was president in recent years of the American Association for the Advancement of science. Ayala says, "Progress has occurred in non-trivial senses "in the living world because of the creative character of the process of natural selection." And he defines progress here as increase in the ability to gather and process information about the environment. We can do graphs, I think, of counts of orders and species, I'm not so sure it is easy to do a graph of increasing complexity.

Complexity might not be the sort of thing that graphs that well. It may be that it's not so much a statistical affair as more something like what a historian would call a narrative affair to tell the story of unfolding complexity in natural history. In nature, if one takes physics only, physics and chemistry perhaps, which is where I began once upon a time, there are two kinds of things, I think matter and energy, or if you're a follower of Einstein, matter and energy are related.

But nevertheless, physics sort of deals with those two kinds of states in the world, matter and energy. But when we pass to biology, and here's the key with genetics, something else has entered, really a third kind of thing in formation. And all three are required for this spectacular biological diversity and complexity in our evolutionary history. There's then a kind of challenge to make sense of this element of genesis that's deeply embedded in the genetic capacities that so far as we presently know exist only on this planet.

If we were worried about genesis at an astronomical level, we might wanna know about the Big Bang and various events there. But that's not my focus in this series of lectures because in addition, whatever we may come to believe about astrophysics, we have a planet, Earth, on our hands to make sense of, and there the creativity is deeply embedded in the genetics. I've given you a number of biologists who do draw this kind of conclusion about the increasing development of complexity and diversity of evolutionary history, and yet biologists are puzzled about this.

Let's look at a statement by a person that I consider one of the best biologists in the United Kingdom, theoretical biology, John Maynard Smith, who says, isn't this interesting, "There's nothing in neo-Darwinism "which enables us to predict "a long-term increase in complexity "to put an arrow on evolutionary time. "It is, in agreeing with Ernst Mayr, "in some sense true that "evolution has led from the simple to the complex. "Prokaryotes precede eukaryotes.

"Single-celled precede many-celled organisms. "Taxes and kineses precede complex instinctive "or learnt acts. "I do not think that "biology has at present anything very profound "to say about this. "We can say little about the evolution of increasing complexity."

Natural selection, I mean there are local trends. Hair will grow whiter when the climates grow colder, for example.

Horns will repeatedly evolve. But natural selection theory by this account, is unable to predict any long-term or big-scale outcomes.

Maynard Smith's conclusion as I give to you here, is I think a rather modest one. We have biologists that are less modest, and one of our most vociferous such biologists in the United States is Stephen Gould, Stephen Jay Gould, a biologist at Harvard University.

If you ever wanna look at the diversity in biology, just look at the staff of biologists at Harvard University. They disagree with each other as radically as any group of theologians I ever met.

Now Stephen Gould has emphasized the contingent nature of things. "We are," he says, "the accidental result of an unplanned process, "the fragile result "of an enormous concatenation of improbabilities, not the predictable outcome of any definite process."

And from his book 'A Wonderful Life,' which is a marvelous book, almost every interesting event of life's history falls into the realm of contingency. "This is," he says, "a claim about the nature of reality, "denying that progress characterizes "the history of life as a whole, or even represents an orienting force in evolution at all."

So, Gould is impressed with the contingent character of evolutionary history, and he shares that opinion with Michael Ruse. Michael Ruse is the editor of the Journal of Philosophy and Biology in Canada.

Michael Ruse has a recent Harvard University Press book on the idea of progress, which he thinks is a great illusion. However, he admits that most biologists share this illusion.

A major conclusion of his study is that some of the most significant of today's evolutionists are progressionists. You can watch that capital P, you know, something's at work.

And we find absolute progressivism alive and well in their work. But, says Michael Ruse, this is pseudoscience. He believes that this capacity to read progress into the evolutionary record is really, it's a kind of a European bias that's been read into biology.

For nigh two centuries, evolution functioned as an ideology, a secular religion that of progress, mature scientists, now he claims, the unbiased ones have expelled progress from evolutionary history. Michael does have a way of being rhetorical about this, and so he says evolution is going nowhere, and rather slowly at that.

(audience laughing)

Evolutionary history wanders, we are told, for a number of reasons. It wanders because of atomic and molecular chance, which is where the genetic mutations arise, which are unrelated to the needs of the organism, as most of you learned in your biology classes. But it wanders also because on the retention side there is the drifting about of continental masses or climate changes, those kinds of things, so it's a kind of a twice-compounded randomness. One can say that if life starts out simply, there's nowhere to go but up in that sense.

So you would expect some things to develop that are more diverse and complex, but then there's nothing in the theory that seems to say that must happen or will inevitably happen. And it doesn't happen in many cases.

Grasses are no more complex than they once were. Horseshoe crabs off the coast of North America are no more complicated than they were many millennia ago in that sense. And yet, this idea that the theme is essentially the play of contingency has been challenged, and I incline myself to challenge it, but let's look at the challenge to it by a prominent biologist, again, at the University of Chicago, Leigh Van Valen.

Here's the idea that if you look at the fortune of one species, that may come and go. Much of the metaphor of this kind of goes play the tape over again. What would happen if we could imagine it were to happen all over again? Would we see the same thing?

And nearly everybody says that no, we wouldn't see the same thing if we played the tape over again. But Van Valen says, "Well, suppose you played the tape a number of times now." Now he thinks there would be certain melodic elements, as he puts it, that reappear.

Play the tape a few times more. We see similar melodic elements appearing in each, and the overall structure may be quite similar.

When we take a broader view, the role of contingency diminishes. Look at the tape as a whole. It resembles in some way a symphony, although its orchestration is internal and caused largely by the interactions of many melodic strands.

For example, if we had to do all over again, in all probability that by this account, eyes would arise again. Eyes have arisen more than once already in evolutionary history. If we had to play it over again in all probability, ears would arise again or something like that.

Some forms of perception somewhat similar on our planet, somewhat similar to the kinds of perception that we have on our own planet. Alright. I want to develop the idea that in view of this evolutionary record, the genes that have made this possible, the genes represent some kind of search program.

That the life process is drifting through, I'm willing to put it that way, drifting through an information search and locking on to certain discoveries, and these discoveries then are hereditary, so it's a kind of cybernetic process that's hereditary. Now that seems to me to be something that's not present in the geology, not present in the meteorology, it's not present in physics and chemistry, as far as we know, it's not present on the moon or Jupiter, Saturn, and Mars, but it is present on this planet. And in this search program, there's a kind of discovery of what I, tomorrow at least, will be calling values that are gained and dynamically transformed over time.

An organism arrives in the world with what's called the genome, it's a genotype which has been shaped by a long evolutionary history. That's the past delivered to the present. So the organism is what it is because it contains a record of the evolutionary past. And yet the organism with that evolutionary past is given its moment in evolutionary history with a perhaps slightly modified evolutionary program tested to cope with the future.

So I'm going to try and interpret survival of the fittest, if you like, as a kind of subroutine in a program of the survival of the searchers. Since you think that might be philosophical speculation, and perhaps is, let's enlist the support of a well-known philosopher of science, Mr. Karl Popper. "Animals and even plants are problem solvers, "and they solve their problems "by the method of competitive tentative solutions "and the elimination of errors. "Just like theories, organs, and their functions "are tentative adaptations to the world we live in.

"A new tentative solution, a theory or an organ, "a new kind of behavior "may discover a new virtual ecological niche "and thus may turn a virtual niche into an actual one. "New behavior or organs "may lead to the emergence of new problems.

"And in this way plants and animals "may influence the further course of evolution, including the emergence of new biological values." Plants and animals then with their genes as a kind of a problem-solving technique.

Now, I need to set that against a fairly widespread interpretation of genes as being, to use Richard Dawkins' phrase, blind, as in the blind watchmaker. That's a metaphorical claim, but it has a certain plausibility because there's no intentionality in the genes.

The genes don't see where they're going. And by the standard account, there are these random mutations that bubble up from the genetic level, unrelated to the needs of the organism. And that kind of lack of intentionality or blindness is frequently dwelt upon by the philosophers of biology, or here in this case by a well-known American biologist, George Williams, who can put it with sort of the rhetoric of Michael Ruse.

"The evolutionary process "is immensely powerful and oppressive. It is abysmally stupid."

It's kind of blind groping of evolutionary history. But other biologists have different accounts.

Let's look at Donald Cram when he was accepting the Nobel Prize for his work, deciphering how biological molecules recognize and interlock with each other in these processes. He said, "A few scientists acquainted with the chemistry "of biological systems at the molecular level "can avoid being inspired. "Evolution has produced complex chemical compounds "that are exquisitely organized "to accomplish the most complicated "and delicate of tasks, "organic chemists can hardly dream of designing and synthesizing such marvels."

Well, when we have a biologist disagreeing in ways like that, philosophers take an interest. Now, when we begin to look especially at the molecular biologist nowadays, here's the kind of thing we begin to hear. A genetic system is a cybernetic program where we've all learned to use computer language, how we think of things sort of depends on what our latest gadgets are, and so it's a bit handy to think perhaps of the DNA as a kind of program which would be blind in the sense that it's not intentional, and yet a computer program can have a kind of know-how to it, in this case the know-how for life.

And we said a moment ago that these genetic systems are problem solvers. So there's not just this inherited past, but this past brought to the present and tested for the future. Now, how does this take place? Now here I think the molecular biologists may be teaching us something that the paleontologists can't see so well.

And what they're impressed with is the way in which the genetic system is almost pre-adapted to do something sort of like genetic engineering. That is to say there are various enzymes that cut and splice this kind of material, mutators, anti-mutators that may step up or suppress the mutation rates at different loci so that whereas the specific place of mutation may not be directed, there are still certain tendencies for the genes to sort and regroup in tested blocks.

Here is from a genetics textbook currently in use at my university. A statement of this kind, "Components for feedback "exist between the generators of genetic diversity "and the environment that selects among the variants."

It seems to be the case that when a species goes into stress, for example, the mutation rate is increased. "Natural selection acts beyond particular alleles. "It also favors genetic metabolism "that generates alleles, that's a type of gene, "with a high probability of passing the test of environmental selection." And another molecular geneticist John Campbell is, I think, almost overly enthusiastic about this, but we have to listen to what these people are saying.

He says, "Cells are richly endowed with special enzymes to tamper with DNA structure." These are the same enzymes used in genetic engineering, but they're already there in the gene, and our genetic engineers are isolating them and putting them to further use. Gene processing enzymes also engineer, that's his word. Comparable changes in genes in vivo, comparable to the genetic engineering that our humans are doing.

Cells deliberately, that's the kind of word I wish he hadn't used, but still it's the word he uses, cells deliberately manipulate the structures of their gene molecules for phenotypic and possibly evolutionary goals. We have discovered enzymes and enzyme pathways for almost every conceivable change in the structure of genes.

The scope for self-engineering of multi-gene families seems to be limited only by the ingenuitive control systems for regulating these pathways. Now there is a great deal of this kind of activity in a genetic set. Much of it suppresses the genetic novelty. There are these various repair mechanisms that sort of come along and proofread genetic translation, and they snip out these errors and fix them.

And in that sense, they can alter, these repair mechanisms can alter the mutation and the shuffling rates with crossovers by up to five orders of magnitude, for example. And the genetic repair mechanism seems to have the capacity to eliminate many of the trials. But they do not pump out all the disorder, or else there would be no sufficient shake-up of the genes to permit evolution toward novel forms.

Natural selection has the problem of leaving sort of twin optima in place. That is there's a selective advantage in keeping as much past information as possible. That may be by keeping many different alleles in the population.

That may be by keeping a trait recessive, which means it's not normally expressed, but it's there if the climate shifts and it's helpful to have this recessive trait, for example. On the other hand, there's an advantage in the right circumstances in being able to adapt swiftly, in being flexible.

So there's a kind of trade-off between keeping in place past information and being flexible for the future. There do seem to be a vast array of enzymes to splice and digest and rearrange and mutate and reiterate and edit and correct and translocate.

These are standard vocabulary out of genetics text these days. Translocate, invert, truncate particular gene sequences. Something then in that sense creative seems to be going on in the genetics. In a study of species as historical lines, Jonathan Schull presents what I think is an extremely interesting claim.

This in the target article in behavior and brain sciences, to which a number of critics are invited to reply. Jonathan Schull makes the claim that a species, not an organism, but a species which represents the genetic package going from generation to generation to generation ought to be considered intelligent. "Plant and animal species "are information processing entities of such complexity, "integration, and adaptive competence "that it may be scientifically fruitful "to consider them intelligent.

"Plant and animal species process information "by way of multiple nested levels "of variation and selection "in a manner that's surprisingly similar "to what must go on in intelligent animals. "These information processing capacities "of these massively parallel distributed processing systems "surpasses that of even the most sophisticated man-made systems. "It seems likely that an evolving species "is a better simulation of real intelligence, "than even the best computer programs likely to produce by cognitive scientists for many years." That's interesting.

And that takes us to what will be my closing thought for today, and that is to the question of what's called a genetic algorithm. Christopher Wills, another molecular biologist, says, "There is an accumulated wisdom of the genes "that actually makes them better at evolving, "sometimes better at not evolving "because one does need to be conservative at times. "Then were the genes of our distant ancestors.

"This wisdom consists both of the ways "the genes have become organized "in the course of evolution "and the ways in which the factors that change the genes have actually become better at their task." Now, some years back, I took a class at my university in artificial intelligence. And we had a member of the computer science department there, and I was struck by a lecture.

He was a guest lecturer for part of the series. I was struck by a phrase he used to call 'genetic algorithm.' That's the first acquaintance I had with that.

And so I asked him about what in the world a genetic algorithm could be. Let me tell you what I know about them, which is not a lot, but I think I can give you the main idea. An algorithm is a set of instructions or rules that's repeated to solve a problem.

You play tic-tac-toe. You don't play tic-tac-toe very long before you realize it's an algorithmic kind of thing, right?

But you play chess much longer before you find the algorithm. There are no algorithms. It's too complicated. There's this combinatorial explosion of options.

So there are rules of thumb by which you play, but there's no priest or no computer can program all the possible moves ahead. Now, so then certain kinds of problems are too big to have any set of algorithms that will solve. So what did the computer program in this case do to, in that case, they invented what they call genetic algorithms. And a genetic algorithm is a kind of computer program modeled after, guess what, natural selection.

That is to say it's a computer program in which the computer generates trial solutions, tests them against certain problems needed to be solved, saves the best ones, and crisscrosses, mates as they put it, different provisional solutions to the computer program. And then when they test that series in turn and picks the best of those. And so the computer in essence, by sort of random trial and error in which the best are selected and reiterated in the next round of trial and error are kept.

And the language these computer scientists use is bit strange, as they call it, sort of like a DNA program, genotypes, mutations. They test them, as they say, for their fitness They breed them, as they say, or mate them one to another. And so the computer in that sense is run to solve problems that are too complex for engineers to write the algorithms for.

The computer discovers its own algorithms. Computer searches for optimal solutions where there are many possible variables that would take a computer an estimated billion years, if done completely at random, can be accomplished by genetic algorithms in a few hours. Genetic algorithms have been used to find the most effective management of complex cross-country gas pipelines, to engineer better jet engine turbines, the jet engines that I flew across the Atlantic with, were modeled in part at least with genetic algorithms, in one case analyzing 100 different variables, each with a range of values that led to what they call a search space of ten, 10 raised to the 387th power points.

They are being used in the United States to design the information superhighway. The reason that my particular gentleman in my class knew about it is the computer science department at my university had a grant from the defense department. They needed to be able to recognize a pattern at great distance of what would perhaps be an incoming missile from an enemy, and at great distance it's hard to separate a significant signal from a noise, static, right?

And so they were using these, they had the programs in genetic algorithm to enable them to detect, to let the computer figure out what might be the difference between the significant signal and noise at a great distance away. All this to just give them another half a minute of early warning in case we were attacked, for example.

But there's a spin-off, I think, perhaps of this kind. Now, in that sense, it strikes me as quite interesting that computer science these days is using part, it's not the only way to do computer science, but one way it's being done at my university, of using a program that's not unlike the searching capacity of the genes in natural selection. In the last stage of this, which I just read about six weeks ago, the previous programs, all that the computer does, it remakes its software. The hardware is fixed, but different software programs are worked out by the computer itself to solve these problems.

But the next round is that the software will design and propose experimental chips, hardware, that then will be conserved and used and tested there. That's in the experimental stage, but some of that is being done. Now, here's Herbert Simon, a great computer guru in the United States, is liking the process of natural selection to the process of human problem solving.

"The process," he says, "involuntarily involves much trial and error. "Various paths have tried.

"Some are abandoned. "Others are pushed further.

"Before a solution is found, "many paths of the maze may be explored. "The more difficult and novel the problem, "the greater is likely to be the amount of trial and error "required to find the solution. "At the same time, "the trial and error is not completely random or blind. "It is, in fact, rather highly selective.

"Human problem solving "from the most blundering to the most insightful "involves nothing more than varying mixtures of trial and error selectivity." A principal figure in the production of genetic algorithms in the United States is John Holland. And here is John Holland's account. After studying genetics, he's been working, he was one of the pioneers he's been working on these algorithms for 40 years.

He concludes comparing his program, his way of problem solving with genetic problem solving. "Living organisms are consummate problem solvers.

"Pragmatic researchers see evolution's remarkable power "as something to be emulated. "By harnessing the mechanisms of evolution, "researchers may be able to breed programs "that solve problems "even when no person can fully understand their structure. "Maybe one day, perhaps, we'll be able to make computers that are more complex than we ourselves can understand."

Now, the conclusion that I hope to have reached at this point is that Earth is the scene of a remarkable genetic creativity, a genesis that results in a dramatic diversity and complexity. The genes are a phenomenon of searching.

And they're quite ingenious about this, comparable to, if not surpassing, the capacities we humans ourselves have realized. And now is where I'm ready to invite you back tomorrow, genes are of great value because they embody the genesis of value. And tomorrow I will turn to a more detailed analysis of that question of genetic value.

Thank you and good night.

(audience applauding),

END TRANSCRIPTION