Bill Calvin's Brainstorm

A GBN Interview with William Calvin

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The study of the human brain has led Bill Calvin to study evolution, the precariousness of civilization, and now, the possibility of abrupt climate change.

GBN Global Business Network

Bill Calvin studies brains, a vocation that has led him to explore countless other topics as well. For example, he decided to research evolution to understand how our brains developed over time. This sparked his curiosity about how past changes in climate might have contributed to the incredible increase in human brain size and complexity. His subsequent research on rapid climate shifts caused him to analyze what might happen if, or when, similar shifts happen in the future, perhaps even the near future. And so the brain researcher ends up being a climate expert—and the author of a provocative new book that describes why global warming may soon cause the next Ice Age.

That's Bill Calvin, whose brain is worthy of study in its own right. Technically, he's a theoretical neurophysiologist and affiliate professor of psychiatry and behavioral sciences at the University of Washington. But he's also known as a scientist with a wide-ranging intellect and a prolific (and accessible) writer who constantly offers remarkable insights about the world around him. As I sat down to interview Calvin in his book-lined Seattle home last Fall, I recalled the comments of someone who had come to GBN to hear Calvin speak. He said that he didn't know—or care—what Calvin was going to talk about because everything that Bill Calvin said was not only interesting, but worth learning about. After more than three hours of conversation with Calvin, I couldn't agree more.

Calvin starts the interview with the compelling argument advanced in his eleventh book, *A Brain for All Seasons: Human Evolution and Abrupt Climate Change*. Throughout this planet's history, the climate has flipped between cold and hot within the space of a decade and there's no reason to expect this to stop. In fact, accumulating evidence suggests that we may be on the verge of another shift towards an Ice Age, with humans probably contributing to the problem through global warming. In particular, this could affect the flow of the Gulf Stream in the Atlantic Ocean, which keeps Europe unusually temperate for land at such latitudes. If the Gulf Stream is redirected and the climate shifts, Europe could quickly come to resemble Siberia. As Calvin argues, the consequences of this scenario are dire.

Calvin goes on to describe the mounting challenges of a civilization that increasingly resembles a house of cards. The human population is so vast and our global society so complex that we are extremely vulnerable to any number of disasters: the spread of epidemics, economic collapse, and even the whims of a mad individual armed with weapons of mass destruction. Part of the problem is the mismatch between relative time-scales, with technological innovation far outpacing social evolution and institution building. Yet Calvin does

not wring his hands in despair, but focuses on what we can do to shore up our civilization's foundations.

Along the way, Calvin offers other gems that are equally profound. He believes that education today is analogous to the practice of medicine 100 years ago—based less on science and more on what works. But this will change as we capitalize on our growing understanding of the brain to create new and improved educational methods that accommodate differences. He also pushes back against advocates of artificial intelligence who claim that computers soon may approach the sophistication of humans. According to Calvin, human intelligence is not too refined; rather, it's so "buggy" that computers will never emulate it. That's a typical Bill Calvin insight. See for yourself in the following interview.

— Peter Leyden

Topics Covered in this Interview

Shifting Horizons

You can predict when a certain technology or science will take off. Just don't expect your predictions to be right.

Peter Leyden (GBN): How would you describe yourself?

William Calvin: I'm fundamentally a brain researcher. I came out of physics 40 years ago, but because I work on brain circuitry for higher intellectual functions, I've gotten very involved with the evolutionary aspects of how this all came about. I am now engaged not only with the whole community of great-ape researchers but also with all of the paleoanthropologists and archeologists who work on the problem. This led me to have considerable concern about what climates were like. That in turn has led to concerns about the future of our climate and how abrupt climate change can make things look very different from the gradual processes that everyone thinks in terms of. And like everyone else, I am embedded in the computer culture and am trying to figure out what its future is.

GBN: That's an interesting departure from the field of neuroscience.

Calvin: My futures horizons tend not to run next year as much as they do 10 or 100 years out. I naturally think in terms of this space. I've realized that over the last 10 years or so a lot of the things that I thought were 20 years out all happened in the last eight years. You just never know when things will be accelerated by other events.

To some extent, I think I presaged what happened in the 1980s with personal computers. I was embedded in computer stuff from the '60s onward, and I had a personal computer of my own since about 1964. I had some sense that it would expand, but I had no idea that spreadsheets would be the big thing that helped convert it. It didn't creep up from the techies below but came instead from the boss down, which I never would've guessed would spread things so rapidly.

In the early '90s, I was using the Gopher system and the early Web browsers. The fact that browsers would catch on, that search engines would revolutionize things, that everybody would have to have a high-speed line at home and that this would all happen in about seven years surprised me—I thought these things were 20 or 30 years out.

There are many other things I can look back on, like the attempts to grow neurocircuits in a culture dish. There's a news story about this every couple of years and there has been ever since the 1960s. Everybody thinks it's going to take off and happen next year, but it hasn't so far. It could happen tomorrow, but that would depend on how other things conspire to accelerate it.

GBN: Did that same kind of acceleration happen in the areas of neuroscience that you were most concerned with?

Calvin: No. Most areas in neuroscience have developed along a fairly steady and predictable pace. The techniques develop slowly. The concepts are well ahead of the techniques. There are a lot of people with good ideas who are waiting for the technology to improve to the point where they can use it, but the technology has been much slower than I would have thought.

My wife and I wrote about our ideas on how nerve cells work 25 years ago, and the questions are still current today. There's been very little progress. Now the techniques have arrived and people are starting to talk about those questions again. It's just hard to tell how quickly things will happen.

Most of the things I think about in terms of climate are low-probability events that happened so often in the past that you're pretty sure they're going to happen again. The question is when. All the things that we're doing, the way warming may accelerate some of these sudden lurches in climate, means it could happen at any time. We've probably known that for 10 years, but the public has not heard about it.

Dunes Today, Ice Tomorrow

Most people think that climate changes gradually; in fact, it can go from lush to barren in less than a decade.

GBN: Could you explain what you mean by "it could happen at any time"?

Calvin: There are both regional and worldwide climate changes that happen in just five to 10 years. They're like droughts that don't quit. They're widespread and pretty traumatic, the sort of thing where you go from a warm and wet climate like today's into a cool, dry climate, and it isn't the cold that hurts so much as the dryness, the dust storms, and the high winds that go with it. This cool, dry, windy, dusty mode of climate is rather typical of both Ice Ages, but you can flip into a warm and wet climate like today's worldwide in just five to 10 years.

You can also flip back. Since we're in the warm and wet today, the next flip is likely to go back. There are also regional modes of this. The Sahara is just a matter of decades. It could switch to a vegetated, almost lush, environment. There are some people who think that, at the same time, the Amazon Basin could dry up. This could happen in just a decade or two. So there are regional versions, but it's the worldwide ones that I've been most concerned with because that's what most of the debate is on.

GBN: How does it happen so quickly? People's general sense of climate is that it's a slow, regular process.

Calvin: People's general sense of climate is fixed on this global warming notion that we've been sold—that the climate ramps up like a dimmer switch rather than flipping from one mode to another, like an ordinary light switch. What we've been discovering is that there are a lot of flips. The notion that climate is gradual is based upon good physics in the sense of predictions about how greenhouses act. But it hasn't encompassed the knowledge that the earth often just flips into a new mode of operation. There are quasi-stable climate modes both regionally and worldwide and they are the real threat. They tend to happen so quickly that agriculture collapses, countries go to war with one another over the remaining resources and serious trouble can happen pretty quickly.

If the same change had taken 500 years and you knew it was happening, there would be all sorts of things you could do about it. When it happens in five or 10 years, there's no time to build roads, relocate agriculture, and resettle people. In the meantime it's sort of like the *Four Horsemen of the Apocalypse*. Even if no one sets out to make war, you get into a mode of operation where the population collapses with the agriculture. The whole world could resemble something like the Balkans today. The survivors all hate one another and for good reasons. Getting out of that could be very slow.

Ice Age Cometh

Simple physics say that global warming could trigger a worldwide chill. Welcome to planet Siberia.

GBN: I'd like to understand the physical side of it. You're talking about a planetary shift in climate, like the beginning of an ice age.

Calvin: The last one was about 8,200 years ago.

GBN: Could you describe the mechanics of how that works?

Calvin: Well, it's like most things in medicine. You have a long chain of causation. Let's take the global stuff. The Gulf Stream keeps the North Atlantic a lot warmer than it ought to be. There's nothing equivalent to it in the Pacific. This keeps Europe about 10 degrees Celsius warmer than it ought to be compared to, say, Canada or Siberia—other things at the same level of latitude.

The Gulf Stream fails with some regularity. Over the past 100,000 years, there have been about two dozen failures. When this happens, not only does Europe get hit badly—which is what you'd expect given the way the winds blow and carry the warmth from the Gulf Stream to Europe, keeping it wet as well—but so does the whole earth. The Antarctic might be a slight exception, but the failure affects basically everything else.

It goes into a regime of about 25 percent less water vapor in the air, and that lowers the greenhouse into a new mode. The air/sea temperature contrast tends to become much greater, and you get high winds and a lot of dust blowing around. If you look at the ice cores in Greenland, you see that just within a few years, you can flip from a warm and wet regime like today into a cool, dry, windy, and dusty regime. There is dust in Greenland that came all the way from China. Dust storms in China will send dust all the way around the world.

At the same time, you see indicators that the tropics are changing. The wind strings around the equator have changed right in lock step with changes you're recorded in Greenland. The air bubbles that are trapped in the ice tell you what the atmospheric methane and CO2 are. The methane starts popping up very soon after the Greenland temperature does. Back before agriculture, methane was a gas produced in the tropics, showing you that the tropics are warming up and cooling down very quickly.

Like I said, this is a worldwide change. The impressive thing is that these have happened every few thousand years. There hasn't been a big one since about 12,000 years ago, although there was a minor one about 8,200 years ago.

GBN: Given that it's within recorded history, how did the one 8,200 years ago impact the planet?

Calvin: That's not clear. You can certainly see that its effects were widespread in the Western Hemisphere. It's not a classical one. Classic ones tend to cool down suddenly, stay down for centuries—sometimes as much as 1,500 years—and then pop back up faster than they cooled down. The warming is even faster than the cooling. No one knows quite how that works.

GBN: How the warming works, or how the cooling works?

Calvin: There are good models for the cooling. But the warming itself, why it happens so quickly, no one really knows. These kinds of real flips in the mode of operation, as I say, are widespread, last for varying lengths of time, and occur both in the Ice Ages proper and in the warm periods. If one happened today, with the population having expanded about 6,000-fold since the last one, just the sheer number of people would make it very different.

There's this old adage in geophysics that earthquakes don't kill people—buildings do. In essence, civilization has built a huge house of cards. We are very dependent upon efficient agriculture and an efficient transportation system to go with it, so that 2 percent of the population can feed all of the rest. This business of living in the cities could collapse almost completely under one of these. We could wind up with farmers able to provide for themselves or two or three times their population, but not 50 times their numbers.

GBN: Because of the transportation issue?

Calvin: Yes. Climate is not the only way that could happen. You could do it with an economic collapse. You could do it with a widespread disease. There are any number of things that make civilization precarious because of its sheer size. If you have 500 years to make changes, you can

survive all sorts of things. If things happen in five years, it's quite another matter. Things really do tend to collapse.

GBN: So how the climate flips to warm and wet is a mystery. Since there's more data available on the triggers for cooling, and since it's the next flip, can you describe its basic trajectory?

Calvin: It's certainly clear that global warming could trigger these abrupt chills. We've known that since 1987 or so, when the first computer simulations of the Gulf Stream failure were done, and there have been a half dozen simulations performed since then confirming it. The mechanism is very simple physics. It's not anything exotic. If you're going to bring all that warm water north on the surface, you've got to get rid of it somehow to bring more north. There is a mechanism that sinks the North Atlantic current, the Gulf Stream. Up in the area around Greenland the water falls to the bottom of the ocean and then it flows south. There's a sort of conveyer belt that brings warm water north and takes the cold water south. Basically, cold winds from Canada blow across the surface, and they evaporate a lot of water and take the heat with it.

This is what keeps Europe wetter and warmer than it ought to be. But in the process it cools down the surface water. Furthermore, because of all the evaporation, you leave a lot of salt behind. The surface waters become rather salty and cooler and because they are denser than the underlying water, they sink. They tend to sink as a giant blob of water to the bottom. In the late winter, you can see 15-kilometer-wide whirlpools in the North Atlantic that are funneling surface water down to the bottom in this big column. There are high efficiency mechanisms like that in both the Greenland Sea and in the Labrador Sea. Counting everything, the flow totals about 100 Amazon rivers.

This is the normal Gulf Stream operation. The problem is that it's vulnerable. You'd normally think rain falling into the ocean would not cause you any problem, and in most parts of the world it doesn't. But it can. If the surface waters don't get dense enough to sink, warm water can no longer flow north. The stuff just sits there instead of sinking and being flushed and gotten out of the way. Fresh water from rain or from floods out of Greenland or Norway or Iceland can affect it. So can increased rainfall in the northern latitude—that spills out into the north-flowing rivers and into the Arctic, then flows out into the Greenland or Labrador Sea. Any of those mechanisms are quite capable of killing the circulation.

It's not clear that this is how it typically happened in the past, but it's certainly clear that it's the way it might happen next time. So there's this interesting connection between global warming, which is thought to be a gradual thing, and it's role in triggering a sudden chill. It's not the cold, however, that hurts in most countries. It's the dryness and the winds. In northern Europe the cold hurts too. All the way around the earth you get substantial temperature and rainfall changes.

GBN: What is the climate of Europe like in an ice age?

Calvin: It's like Siberia. The vegetation's sort of like the scrublands. The German pine forests will be replaced by something basically Siberian—scrub, grasses, and such. Europe has a very efficient agriculture. They feed two or three times as many people as the U.S. and Canada. But it

depends upon all this rainfall off of the Atlantic and it depends on staying warmer than Siberia. It's unusual. It's not a general principle that applies in the oceans around the earth. It's peculiar to the North Atlantic.

Seeding the Sky

Whether or not it's our fault, we can still do something about global warming. But what?

GBN: Given the previous times and mechanisms, and the understanding that global warming is stimulated by human beings, are there other, natural mechanisms that we also have to watch for?

Calvin: Yes. The notion that global warming is caused by humans is probably the wrong way to frame the issue. Whether or not it's our fault we still have to do something about it. This is sort of like doing something about floods or smallpox—just because it's natural doesn't mean that something can't be done about it.

The mechanisms for doing something about it are not apparent yet. In the climate change mechanisms there are slow aspects and there are very fast aspects. We might actually be able to do something about the fast aspects even if we can't get a handle on the slower ones. For the fast ones, their mechanisms are crucially located—the Labrador and Greenland seas. We might actually undertake a regional climate project, just trying to make sure that the waters continue sinking even if we have to help them along.

GBN: You mean seeding them with salt?

Calvin: I prefer to talk in terms of cloud seeding, to make the rain fall elsewhere. I think that we'll probably have some high-tech ways of approaching this in the future. Right now, I tend to use analogies from nineteenth-century technology. If floods from Greenland are a problem, you can undertake to make sure that floods don't happen in Greenland. The floods occur because fjords get blocked by an ice dam, so they build up one or two years of melt water behind them. Then one day the dam breaks and it all comes sluicing out; you get 100 times the runoff in a week.

That's easy to prevent. You just make sure that the ice dams don't last very long. You send in helicopters and highway-construction amounts of dynamite, and a week after the dam forms you break it open and make sure that it keeps running. There are ways to prevent some of the causes and that buys us time to discover better ways. As I say, there are a lot of regional climate floats that are also possible, like the Sahara or the Amazon going in opposite directions, that we don't know very much about yet.

Vegetating the Sahara

How hotter summers can transform the Sahara from dusty desert to lush haven for wildlife.

GBN: It's really difficult to imagine the Sahara Desert becoming as lush as the Congo. Is that part of that same phenomenon? What triggers a regional shift like that?

Calvin: It's a totally different phenomenon. You have to understand that droughts and recovery from droughts are somewhat random events. A drought gets started in an area just because by chance the storm tracks don't go through the region for a few years, so the plants wither and dry out and the soil beneath them gets a lot hotter because it's not shaded. This is a sort of self-sustaining system of decline. Once it gets started, things can collapse down to where it really takes a couple of good years of rain, and all of a sudden everything recovers. Soon you go through the cycle of grasses to shrubs, from small trees to forests.

The Sahara is sort of like this. In the cooler-and-drier mode, there is a lot of dust being generated that blows off the continent. By drilling ocean cores off the Canary Islands, you can monitor what the changes have been like over the last 100,000 years. One of the things that you see is the winds and the dust can dramatically change within a century or so, and it corresponds to the Sahara getting vegetation back.

When the closest approach to the sun is in June (it's currently in January), the Sahara gets hotter summers and cooler winters. As afternoon temperatures increase, the monsoons penetrate further and further into the Sahel and Sahara. As perihelion drifted into May, about 14,500 years ago, it reached a point where all of a sudden the African Sahara got grass and grazing animals and elephants back. About 5,500 years ago, as summers cooled somewhat with autumn perihelion, all of a sudden things collapsed, apparently within just a few decades. When one of these drought cycles gets going it may be hard to reverse it—until by chance you get a lot more rain somewhere, and then it just stops happening. You can have these rapid flips in regional climate.

GBN: It would seem there's not a lot we can do about this.

Calvin: No, but I use that as an example to show how gradual drivers can cause revolutionary changes. The feedbacks in the system are such that you can really flip. It's like pushing on a light switch slowly, slowly, slowly. All of a sudden it pops into the on position. That's the climate. It's not at all like the picture we've been carrying around of global warming making things gradually different like a dimmer switch ramping up.

Think Fast

The reasons most people wrongly believe that global climate trends evolve slowly are scientific skepticism and a dearth of public information.

GBN: What do you make of the misconception that climate changes gradually?

Calvin: In some sense the whole story of the sudden changes, which were discovered only in the mid-'80s and then nobody quite believed them, began in 1998. It was about the same time that my "Great Climate Flip-Flop" article came out in the *Atlantic Monthly* that the *New York Times* started covering the story. The information had been in *Science* and *Nature* for 10 years before that. So it was very clear that all of the science reporters and presumably their editors knew about this story, but it was never reported. I don't know why. Perhaps the editors thought that people just couldn't absorb that much complexity, that the gradual greenhouse was all they could absorb, so that's what they emphasized. It's really an interesting study of how things get known. It's just in the last few years that there's been much public knowledge outside of the scientific community on the subject.

GBN: The core samples and computer models changed things in the mid-1980s?

Calvin: Yes. Since 1957, we've had ice cores from places like Antarctica, but the Antarctic has a very slow rate of ice accumulation; there's just not much snowfall, so you can't see the individual years in the record. It's a little bit better than ocean-floor cores, where a thousand years have been averaged together by stirring because the bottom fish and the worms stir about a thousand years' worth. It's like having a two-year running average on the stock market during the periods when fortunes were made or lost—you get lost in it and miss seeing a lot of important things when you have a running average. Well, that's what worms have done to us.

It wasn't until ice cores were studied in regions of Greenland that have a very high snowfall rate, where you can see annual layers—summer, winter, summer, winter, and count your way down a ways—that it became clear that some of these fast changes occurred. Of course, everybody looked at them and said that it must be a peculiarity of Greenland. It took a half dozen years before people were willing to say, "No, it looks like it's at least Europe and maybe the rest of the Earth."

Part of it is science as usual. Part of it is the very slow aspect of getting the news out. It was unaffected by news stories in *Science* and *Nature*. It was not affected by some of the players getting big prizes. It was very clear that the scientific community was paying attention but nobody else was.

A Preventative Medicine Climate

Climatic changes are set off by complicated chains of events; the good news is it may be possible to head off disaster at any number of points.

GBN: Give us more detail on what happens to the rest of the world. It's clear what happens to Europe, but does China turn into a dust bowl?

Calvin: So far, no place has been discovered that does better in this regime. This is not like the usual drought, where your rain falls someplace else and improves things. In the worldwide stuff, it's really a downshift into a cool, dry, dusty, and windy mode of operation.

GBN: Across the board?

Calvin: It's like tipping a table. At some point everything slides off of it. Tip it a little bit further and it crashes into a new configuration. Climate is like that. It's understanding all those feedbacks. The thing is never in some steady-state mode of operation that balances out. They're a little out of balance, and so it creeps. That's been our model of climate and greenhouse warming. There are vast nonlinearities in the system due next to all the feedbacks, so it really can flip the mode of operation both regionally and worldwide. That's where we are now. Scientifically, we realize that happens. The news mostly hasn't gotten out.

GBN: In the global warming scenario, the permafrost areas of the planet get warm enough that they release methane in ways that they hadn't before. Is that a similar dynamic?

Calvin: That's another one of the feedbacks you have to work back into the system. There's a series of positive feedbacks; there are some negative ones that might stabilize. We have no idea how things will balance out. We don't know about the feedback cycles. It's the notion that things are tippy rather than slow. That is where we are now, but we don't understand the tippiness enough to predict.

We can say that this is nothing new. This is not like greenhouse warming in that sense. This has happened many times in the past and there's no reason for it not to happen again, except that we have 6,000-times more people now than when it happened last time.

GBN: But we have a knowledge and a control over our environment that we didn't have then. For example, what if we get hit by an asteroid? We could perhaps find a way to nudge it away or blow it up. There is a different threshold we've crossed here of actually having the capability to solve it. You indicate that even climate problems could possibly be solved.

Calvin: Possibly some of them. We can almost certainly do something to make sure that the water leaks out of Greenland slowly rather than as a flood with 100 years' accumulation. But other aspects— like the rainfall into the North Atlantic or the rainfall into the north-flowing rivers—it's much less clear how to go about managing that.

We're discovering a lot of climate cycles that we didn't realize existed. To call them cycles lends more of a notion of predictability than they deserve. It's like El Niño. Yes, they happen every few years, but they can also go for decades. The climate cycle that's driving all of this may be a 1,500-year cycle and no one knows where it comes from yet. There's a whole batch of real scientific uncertainties.

These things are always Rube Goldberg chains in causation, but that also allows you to intervene at any number of points. Even though you may not understand the basic mechanism that's setting off a cancer in the first place, you may understand how to intervene to slow things down and head it off. I think that we're heading toward a preventative-medicine of climate. I am not sure that anybody in the climate business sees it that way, but that's my analogy. I think that we'll have the knowledge to at least buy time in the same way we do in medicine. Everybody dies of something someday, but lifespan has been more or less doubled in the last century. I think we might be able to slow down at least the rapid parts of climate change and make them more survivable.

GBN: So you're saying that the preventative-medicine side of climate change is just dawning. There aren't many people thinking that besides you.

Calvin: No, and the scientists are mostly saying, "We don't understand this yet." The people in climate science are not used to thinking in terms of interventions. They don't think like physicians. They're quite right, we do need to understand it, but consider this adage from medicine: "If you wait until you're dead-certain about the diagnosis, you may wind up with a dead patient." There's a problem with waiting for scientific certainty; you just can't let yourself get distracted by that.

This sort of thing is happening with global warming. As far as I can tell, the oil people and everyone else whose pockets might be hurt by doing something about climate have discovered that the science is uncertain, so they say we have to wait until we're more certain about it. I think they understand that the way science normally works is that for every question you answer you turn up two new questions. The thing is never finished. If you have to act, you're going to do it on the basis of uncertain knowledge. It's going to be just like medicine, and you're going to have failures along with the obvious successes.

The Human Factor

If civilization is going to stabilize itself, it will first have to stabilize the climate.

GBN: In your interpretation of global warming, there seems to be some human impact on climate change.

Calvin: My attitude about CO_2 is that it's not so much a matter of whether it's our fault or not. It may be that in addition, but CO_2 is the only handle we've got on the system. If we want to do something about all of the climate changes that will result if CO_2 levels keep going up, then CO_2 controls and reduction are at the moment the only way we can grab hold of the system. So even if it weren't our fault, CO_2 reductions would still be the name of the game.

This may change as we understand a little bit more about pollution of the atmosphere and the extent to which we can turn some of it to our own gain to stabilize systems. Industry has been throwing an awful lot of stuff into the atmosphere and we have been relatively lucky up to this point. If industry had been producing bromides for various processes rather than chlorides, for example, that would have wiped out the ozone layer long ago. If we wiped out all the atmospheric ozone, there would be a worldwide hole. We're just incredibly lucky that industry, by chance, didn't happen to use bromides.

GBN: Which was a possibility?

Calvin: Yes. Nobody really realized until the study of the atmospheric chemistry progressed to where it has today just what a catastrophe it would have been if bromides had been used. We don't know how many other things like that are brewing. There are an awful lot of things you can get away with in a world where you don't have this huge house of cards that is so vulnerable to just a couple of bad years. It's like that phrase attributed to Woody Allen: "Time was invented to keep everything from happening at once. Space was invented to keep everything from happening to you."

As it stands, the East Coast bails out the West Coast when it has earthquakes and the West Coast bails them out after hurricanes. These events have this virtue that they're over and done with and the next day people can start recovering. In a situation where crises aren't over the next day, and they happen everywhere all at once, nobody can bail out the others.

GBN: Could this all-at-once scenario happen within the next 10 years? If so, what should we be thinking about doing?

Calvin: It's like what I said about the Web and Internet access. You can say these things are possible and they'll probably happen someday, but your ability to estimate when they'll happen is poor. I see no collapse about to happen next year, but on the other hand, I also know that we're not monitoring the North Atlantic very intensively. There's been a 20 percent decline in the Gulf Stream over the last 50 years. That data just came out a couple of months ago. If that's confirmed by other kinds of studies, then maybe we are on a downward trajectory that we didn't realize.

GBN: What do you mean by a 20 percent decline?

Calvin: A decline in volume. Basically, somebody installed some flow meters on the ocean bottom around the Faroe Islands. These showed over the course of a decade what the changes were. They have older data that you can now interpret in terms of the newer stuff, and that's what's led to this conclusion that there's been a 20 percent decline. The cold bottom water is

flowing out of the Greenland Sea, which should be proportional to the amount of Gulf Stream coming in.

No one knows how fast these things can go. It's certainly clear that civilization, if it wants to help stabilize itself, is going to have to do something to stabilize climate. There's now a lot of knowledge about the challenges that lie ahead in that area. Certainly our record of dealing with these things has been mixed. We detected the chlorofluorocarbons early, even before the ozone hole was detected, and managed to do something fairly effective internationally about decreasing CFC production. That's one of the success stories.

Gas mileage, in terms of efficient uses of resources, has been completely reversed in the last 10 years, with SUVs and other gas hogs becoming more popular and cheap gasoline becoming a religion in this country. When compared to Europe, it's just amazing how successful the automotive industry and the petroleum industry have been in doing things that are completely opposite any conservation ethic or any environmental concerns. They all take out full-page ads showing beautiful natural scenes around their appliance, when in fact the history is a rather sorry one. A lot of it is simply that American voters are reluctant to do anything that has an immediate impact on their pockets, like higher gasoline taxes.

GBN: You could imagine that a crisis could galvanize people. Having been in California for the so-called electricity crisis, it was amazing how quickly people ramped down their use of electricity and developed all kinds of efficiencies.

Calvin: But it's not really creating efficiencies—it's postponing use. Creating real efficiency, like installing regulators with motors that consume less electricity, things that would really have a long-term impact and not just fluctuate with the climate, has been much harder.

Weird Weather

The weather does seem to swing more wildly than even a decade ago, but that's nothing compared to the dry, dusty cooling that's coming.

GBN: There is a common perception starting to build that the weather is getting weirder. Is that perception wrong, or do you think there are demonstrable changes in localized climate attributable to the massive change going on?

Calvin: There are some people who believe that global warming is making El Niños more frequent or prolonged. I think that the climate changes that we've been having, whatever their cause, are sort of a taste of it. You can't just measure climate with a simple half a degree temperature change in your index. In the Little Ice Age, it wasn't that half a degree that hurt people; what hurt them were the crop failures, the unseasonable weather—big rainfalls in July

flattening the wheat crops, stuff like that. It was a few really severe winters in a row along with the presence of hot summers. The average temperature didn't change that much, but you had these unsettled extremes of climate. That was pretty much the history of the Little Ice Age from 1300 to 1850. It wasn't that it was a half a degree cooler—it was those variations that really hurt.

I think we could be in for a lot more of that. People will have to get away from thinking that temperature is the be-all and end-all of this discussion. The abrupt drying and the high winds and all the dust and so forth are equally a part of it. When we say that it's like ice age conditions, that also misleads people because it doesn't come back instantly. The ice may take tens of thousands of years to build up. It's not as if you get a wall of ice outside your town tomorrow—it's the crop failures and droughts that just don't go away that tend to hurt people.

GBN: Has the planet roughly been equally cold and warm, or is the norm a situation in which cold is occasionally punctuated by warm, or vice versa?

Calvin: The ice age cycle is about 100,000 years. Following an ice age, you get a period that is relatively warmer and certainly wetter and less windy, and these are called interglaciations. They're no more than 10 or 15 percent of the whole cycle, so on average things are in this cool, dry, windy, dusty mode and they just pop up into a warm and wet one. They don't necessarily stay there; they may chatter up and down, like a florescent light that won't stay on or off.

We are in what is, on average, one of the warmer periods. We are probably near the end of it. The warm periods don't end gradually—they end with a jump into a cool, dry, windy, dusty regime. That could happen to us at any time. My guess is that we'll get one of these abrupt coolings and may pop back up. Sometimes these things chatter three or four times, which makes it even harder to adapt. It's just a constant whiplash of conditions where nothing stays, so you can't make a living any which way before it really settles back down into a cool, dry state and stays there much longer.

It's all a matter of time scale. That is to say, if you smooth the curve, you can miss all the important things where people made fortunes and lost them. We're now getting the time resolution to see that the past has been very jerky, it really flips. Both regionally and worldwide, it flips into modes of operation where all of a sudden within one generation's lifetime, all bets are off for how you make your living. All the old ways won't work anymore.

Bad Weather, Big Brains

Some thoughts on the interesting connection between droughts, floods, and human brains.

GBN: One of your ideas is that drastic shifts in weather are what caused the brain capacity of humans to evolve.

Calvin: It is, but it has to be tempered by the notion that all land mammals were subjected to the same regime. This is not a universal principle for improving intelligence. There's no sign that the other great apes and the bears and the other omnivores have gained anything by being subjected to this. Because of that, one of the things I've been driven to look for is whether, in the aftermath of the big downsizes of population, there are any opportunities our ancestors had that the other great apes and omnivores didn't have. That's actually what my new book is about. It's called *A Brain for All Seasons: Human Evolution and Abrupt Climate Change.*

GBN: So it seems you're saying there was an opportunity.

Calvin: Well, first of all, I think that at least after about 2 million years ago, our ancestors were fairly good predators of grazing animals. One of the things about a drought is that it focuses the resources on waterholes. If you're a waterhole predator, like lions, not only do the animals have to come there to drink but the rim of the remaining lake is where all the good grass is. I visited Kenya last year. They're in the middle of a drought. I saw all these waterholes, these lakes that are shrinking down. They had this glorious rim of green grass all around them and mudflats. Even if the animals didn't need water, if they were desert-adapted, they'd still come there for all of the green grass.

To the extent that our ancestors were waterhole predators, they would actually survive these droughts somewhat better as long as they hadn't expanded beyond the waterholes to try to make a living elsewhere. Furthermore, when you recover from one of these droughts or abrupt flips, grass suddenly grows in areas that were formerly arid. The grazing animals again experience a temporary boom.

In essence, for every one of these coolings there are two boom times that follow. One boom time is associated with all of the land clearing. When you get an abrupt drought, you get a lot of forest fires. The forests burn down. The next year they grow a lot of grass, and so the herd sizes really expand. There's also a lot of anthropogenic fire. For about 100,000 years or more, people have set fires to clear the brush so there will be more grass to attract grazing animals for eating. I think these abrupt coolings probably did exactly the same thing on a wide scale. They created an enormous boom in grasslands and grazing animals, and to the extent that our ancestors could successfully make a living on them, I think those who survived the downsizing would experience a boom along with the grazing animals.

Later, when you get the abrupt warming out of the cool and dry condition, you get a second boom time because of all the arid areas that now get grass. I think our ancestors were subjected to hundreds of these episodes, all fairly alike in many respects. It's a crash, then a boom, then a second boom. You don't have to have much advantage; it could be 1 percent per episode in terms of creating a bigger brain or more behavioral versatility. The notion is that you've got hundreds of episodes giving you this kind of compound interest. That's a lot of what the book is about. It brings together my interests in climate and evolution and brains. This book led me to think we have to do a serious planning job.

GBN: You mean plan for the screwed-up climate development?

Calvin: I mean on just the short-time scale of ballistic movement—throwing and clubbing and kicking and so on. These are actions that are over and done with in just a quarter of a second. The feedback loops from your limb back to your spinal cord and back out again take nearly an eighth of a second to operate. A dart throw is over and done with in an eighth of a second. That means you can't just guide it by corrections. You've got to make a perfect plan, because any feedback that arrives that tells you that you're doing it wrong will arrive too late. For hunting with projectiles or for hammering, to the extent that these are novel situations and not set pieces like a basketball free throw, you need to be able to create a movement plan for something you've never done before in exactly that way. You have to create a high-quality plan because if you miss, dinner is likely to run away. There is a real premium on being right the first time.

Twenty years ago, I started thinking about the brain circuitry that it takes to do this. It has webbed into all of these other things that I've been talking about. If you can plan on that eighth-of-a-second time scale, you may be able to use the same brain machine to plan a week or a career. Evolution does not really operate by making small special-purpose compartments that do only one thing. They operate by giving you a general capability that may operate on different time scales, with different muscle groups. For example, language overlaps a lot with hand and arm movement. They share the same parts of the cortex.

The Multipurpose Brain

Thanks to the nature of the brain, developing an ability to plan quickly could lead to an ability to plan on other time scales.

GBN: Is this overlap why people speak with their hands?

Calvin: It's one of the reasons, I suspect. About two-thirds of the people with aphasia have a cognitive disorder of hand and arm movement planning. They can make ordinary movements OK, but if you ask them to do a task that's the equivalent of putting a key in a lock and turning it and pushing the door, they can't put it together right compared to normal people. There's a big overlap in the brain between areas that handle planning in the sense of ballistic movement and planning what sentence to speak next. The sort of shaping up of quality before it comes out for language is the same as that for throwing and ballistic movement in general.

It's very much like curb cuts. Curb cuts were made for wheelchair consideration, but 99 percent of their use is for things that would never have paid for them, like wheeled suitcases, skateboards, bicycles, and grocery carts. Sometimes one of those things will pay for an improvement. For example, wheeled suitcases have paid for widening of the curb cuts at airports. There used to be queues of suitcases waiting to get through the curb cut, so the newer airports have curb cuts as wide as crosswalks. Wheelchairs didn't pay for that, suitcases paid for it.

GBN: So your saying that if the path in the mind is already there, you just…

Calvin: Yes, but basically this is the way that evolution works. The brain is so multipurpose that you don't get these little specialized modules that only do one thing. If you get a planning ability for one time scale, you can probably use it on other time scales. You can probably use it for hand and arm movement as well as mouth and lip movement and so on. That's certainly what the neurophysiologists have been telling us.

GBN: That planning capacity, in a very literal way, is what a lot of businesspeople and organizations try to do. Are there any insights that you draw from brain function that you can actually put into an organizational concept?

Calvin: Organizational planning is certainly in the general tradition of trying to project the past into the future, imagining a number of paths, then shaping up the quality of your guesses. It's much like the problem of creating a new sentence to speak that you've never spoken before. You need, pretty early on in speaking the sentence, to have figured out how it's going to end to make it all hang together. Say that planning ability in the brain is not restricted to language, that it's a much more general ability. That's the sort of thing business executives have to do constantly. They have to know where they are and how they got there, but they have to be able to see all these new paths in the future and make increasingly good guesses as to where they're going without getting blindsided. It's on a longer time scale than constructing sentences, but I think it's fundamentally the same brain machine being used.

GBN: When you think of sentence construction, it's improvisational. But when you think of planning in terms of a business, it's so rationalized. It doesn't seem like the same thing.

Calvin: Perhaps the analogy should not be spoken but written language, where you've got more time to fiddle with it. There are some aspects of language that happen almost automatically. Telling a word from a non-word, for example, is something that's done early and very automatically in the brain; you can't stop yourself from doing it. Seeing a collection of letters that don't make a word versus ones that do make a possible English language word is just a completely automatic process. It's not one we were genetically born with. It's one that's only been used for the last 5,000 years since writing was invented, and there's been very little genetic change in that time. It's only in the last couple of hundred years that so many people on the planet have had this automatic ability in their brain to tell words from non-words.

Education Over Evolution

Genetic engineering certainly could improve human intelligence, but education can do it more quickly.

Calvin: Our culture and, in particular, our early education enables us to do all sorts of things that evolution didn't really equip us to do. They're like the curb cuts and the wheeled suitcases and skateboards making use of them—something is paid for in evolution by something more immediate and compelling.

People are always asking me about the sort of genetic engineering you could do to improve intelligence and so forth. My usual answer is that it's possible but I bet education gets there sooner. Education is where medicine was about 100 years ago. A hundred years ago, most of medicine was empirical—somebody tried it and figured out whether it worked or not. Of course, it didn't work very often but they couldn't figure that out. They were trapped into thinking it worked, like with bleeding and purging.

Gradually, over the last century, medicine became half-scientific and half-empirical. Over the next few decades I suspect the same thing will happen with education. In its present state of affairs, science is not really contributing very much to the subject. We're going to understand a lot more about how the brain works, how brains develop, and what the critical windows of opportunity are for introducing concepts. We are going to understand a lot more about the strategy of introducing new material versus rehearsing what you've already been exposed to versus sprouting out the creativity. We will know at some point the basis for about how half of these different aspects—of the way we try to get children to learn—really work.

Understanding them will lead us to making considerable improvements. They will suggest to us new empirical things to try out, and it will go a lot like medicine has gone. We'll be able to educate children to grow up and be better thinkers.

For example, there are some basic limitations that you see now. It's a lot about what the IQ tests are measuring. Most people can juggle at least a half-dozen different concepts simultaneously. For example, a multiple-choice question, "A is to B as C is to D or E is to F," is juggling six things at a time. You remember seven-digit telephone numbers, but you have a lot more trouble with 10-digit telephone numbers. Some people can handle nine, while other people can only handle five. That surely is amenable if that's one of your goals, to make everybody capable of doing a dozen at the same time. I suspect that with the right kind of childhood education we could probably achieve that.

The second big part of IQ tests is the speed with which you can make decisions and move on to the next one. That, too, is probably amenable. Modern physicians have to make decisions quickly, bear a lot of possibilities in mind at the same time, and sort through them within a 15-minute office visit. You really can't practice medicine without being good at both speed and the number of balls you must keep in the air. I think that the educational system will produce many more

people who are capable of operating at that level. It won't be genetic changes that do it. It will be changes in the way you go about education.

GBN: Do you expect that kind of understanding within the next 10 years?

Calvin: This is one of those things that could take awhile but could also happen very quickly. I can easily envisage somebody developing the technology in all the private schools. There are some feedbacks in the system that might make something like that happen very quickly. It could also, of course, produce a catastrophe. I don't want to present this as something that is inevitably good, because people operating faster and faster can dig themselves into deep, dark caves.

GBN: Once we understand how a child multitasks or how he or she starts to imprint things and stores them in memory, the next step will be developing technologies and methodologies to expand and enhance that.

Calvin: Exactly. A lot of it will be taking advantage of individual variability. The school systems are not very well adapted to handle very bright students or the retarded. They make an attempt at it, but they're obviously not tuned in to what the problems really are. I think that one of the things that will come with this knowledge of how the brain works, particularly in development, will be a much better understanding of individual variability—how to make use of it, and how to work around the problems. If you have somebody who can't juggle a half-dozen things at the same time, we'll be able to bring them up to speed quickly. If you've got somebody who is particularly gifted in one area, we'll be able to use that to help them develop related skills quickly because they use common machinery.

Humans are enormously variable compared to, say, chimpanzees, both in brain size and behavior. It's not generally appreciated how variable the brain is. A good example is the primary visual cortex in the back of the brain, which is the brain area most easily identified, because even without a microscope you can see a broad stripe that defines it. It's very easy to measure the surface area of Area 17. In normal adult humans the size of Area 17 varies threefold. There's an enormous range of variance.

GBN: Does that physical differentiation correlate to actual capability?

Calvin: Nobody knows. Nobody's made the correlation yet. It probably gives them better visual acuity, better color vision. I don't know. That's one of the things that hasn't been pieced together. That's about the only brain area where it is really easy to see where it starts and stops; most of the others have too much overlap.

The other areas, say Area 19, have turned out to be many smaller functional areas that aren't really a unit in the way that Area 17 is. It will be much harder to figure out the others. The notion is that people are born quite variable and that in life they develop specialized areas, like areas for reading. Those surely didn't exist 5,000 years ago; nobody had one. Today some people can have strokes that selectively interfere with reading and not much else. It sort of says that in their

childhood, on the fly, they specialized a region for reading. As adults, if they lose it they can't improvise very well.

GBN: Rather than a genetic interpretation you're saying that you "work out" your brain.

Calvin: Thanks to DNA sequencing we can get a much better handle on it. The major source of variability in humans is recombination—having a mother's and a father's genes to choose between and to use in combinations for different things. As the sperm and ova are made, the grandparents' genes get shuffled, and these two different recombination steps produce a wide range of variability that makes everybody except identical twins highly variable.

On top of that you have an environment that is highly variable. People get exposed to reading, for example, and it soft-wires what one might call reading areas, except for the fact that these areas are also doing other things. It's not a simple chain of causation in that it's something we can often do something about. It's like the fallacy of thinking that if something is natural you can't do anything about it. You may not be able to do much about the color of your eyes, but in general the brain is highly multifunctional and quite capable of being wired up in youth in a number of different modes of operation.

Parents will do the experimentation for us. Parents will happily experiment on their children by playing classical music in the crib and such. My guess is that as these techniques begin to become available, parents will pick them up and run with them and produce various disasters along the way. Instead of speaking in complete sentences by age three, maybe some of the kids will do this by 11 months. But the side effect of doing it may turn out to be that they can't think straight about anything else. You just don't know how these things hang together. Just trying to shape things up for earlier language, which would be the most obvious thing for parents to tune in to, may have all sorts of side effects. Just what it does to their later development we don't know. Science probably won't be able to predict it.

Demystifying the Brain

It's not just the map of the brain that scientists are working to reveal; it's also the way the brain re-maps itself.

GBN: Your sense is that ultimately the brain is knowable and scientifically understandable. All the mystery could be clarified and leveraged in ways we haven't before. Is that fair to say?

Calvin: It doesn't wind up with anything very deterministic. As Steven J. Gould would say about evolution, it's all highly contingent. Yes, there are some general principles of operation, and understanding those is very important, but it's not going to save you from learning all the history of how things have happened in the past. The brain is going to be that way too. Yes, we will

discover the general principles of operation, but unless cloning takes hold in a big way, people are going to remain highly variable. To some extent we will celebrate it and in other cases we will regret it. But as long as sexual recombination continues to be around, every generation will have a highly diverse group of capabilities. It's just part of evolution's way of spreading its bets.

GBN: Do you anticipate identifying the location of certain genes that would actually enhance, say, the visual cortex? If a larger one does prove to be better, could we find genes that could produce that?

Calvin: In principle, but that's a long way off. The number of genes that control brain development is not terribly clear yet. One of the major things that is understood about bigger brains is that the whole thing tends to scale up together—with the exception of the olfactory parts, which scale separately. You can get a big olfactory part without an enlargement of the rest of it. This is true across large groups of mammals. By and large, if something needs a bigger visual cortex, you get a bigger brain in general; you don't just get a bigger visual cortex.

That finding came out in about 1995. It really does have some interesting implications, at least in the way genes ordinarily operate in mammals. There's not a whole lot of differential control in terms of sheer size. The relative size varies within that, and it may nonetheless be shiftable. I think it's certainly shiftable by experience. We understand the cortex well enough now for us to be very clear that use makes a big difference in the map. You can make changes within a week in the map. This is quite unlike the visual cortex, where everything stays put after childhood.

It was a big surprise 20 years ago when people discovered that there's a lot of plasticity, a sort of a dynamic remapping of the brain where the boundaries are not fixed. You shift them back and forth with use. Training a monkey to hold his hand against a rotating phonograph record that's got a bump on it, so the tip of the finger gets bumped regularly, will cause the whole finger map in the cortex, and not only that finger but of all the other fingers, to shift. It's not as if you just enlarged that third fingertip; it moves over the second and the fourth and the thumb. The thumb is right next to the jaw representation. It will move that boundary between the jaw and the thumb, even though you're just tapping the third finger.

In fact, it turns out that if you don't do anything and just pre-sample the monkey's boundaries regularly over a course of weeks, there's a constant dynamic tension between whether the given cell represents the thumb or the jaw. One week it's one; one week it's the other. There's a constant boundary war going on. It's not a no-man's land; its cells that are wired to both jaw and thumb. They're really like Alsace-Lorraine or something.

GBN: On one level, it seems like it could be a 100- to 200-year project. On the other hand, it seems like there may be breakthroughs in understanding that could have profound consequences in a very short time.

Calvin: It could. It's very hard to predict how fast these things will go. You can be much surer about saying that in 100 years we will understand this and we might be able to do something about some parts of it, then you just get surprised because it only took five years. There are other

things, like I was saying about growing cells in a culture dish and hooking them up to a computer, that have been going on for 40 years with very slow progress. There are two or three generations of scientists that have tried these ideas. Every few years you'll find a newspaper story on the subject. Somebody will surprise me one day by succeeding, but it turns out to be a harder job than anyone thought.

Artificial Intelligence

A.I. technology certainly has its bugs, but so does the human brain.

GBN: Where do you fall on the artificial intelligence debate? Some people are telling us that our computers will surpass us, like Ray Kurzweil and Vernor Vinge. They don't give precise dates, but in their trajectories it's close.

Calvin: I generally like the projects and the concerns A.I. has had about understanding complex systems. I think they've been very worthwhile. They're always limited by their technology in terms of what they can try out. They tend to go for a straight line of cause and effect and they don't really take advantage of all the redundancies and multifunctional stuff. They'll get better as the technology improves.

I don't take the general extrapolations of Moore's Law applied to competing with brains terribly seriously. So many of the people who comment on it have very little conception of where the modern mind has come from on the anthropological time scale. They just don't understand how recent it is and how buggy it is. Psychiatry shows you an awful lot of the bugs. They also tend not to understand the stability considerations of why this thing doesn't just go into seizures all of the time. It's operating much more closely to the edge than most animal brains do in terms of getting hung up and crashing.

GBN: You mean like psychosis?

Calvin: Petit mal and grand mal seizures, in that case, but a lot of the obsessions and so forth in the psychiatric area probably qualify. Just in everyday psychology, simple reasoning and decision-making is obviously very buggy. For example, you can sway a logical chain of decision. Say you evaluate what car to buy next with careful analysis of all the frequency of repair records, and you've really got it down. You go to a party and somebody complains about their experience with this top-rated car you were about to go buy, and instead of factoring that in you go out and you buy the second-rated car. Your ability to skew things by a vivid example or by the last thing you heard is so great that it really confounds a lot of the attempts to reason about it more abstractly. Ronald Reagan was very good at being able to override logical evaluation of a subject, which itself fails often enough.

The brain sciences are going to be very interesting. I think that the most interesting parts will probably be a whole new aspect to education that no one's thinking very much about. I think the genetic stuff will be interesting, but it probably will not affect very many people. I think the educational stuff will affect lots of people. It's not as if you uniformly will bring them up to standard; in fact, the rich will get richer and the poor will get poorer, at least initially. But I think the ability to do something about the people who really can't care for themselves effectively in this world, to bring them up to an acceptable standard, might be possible.

GBN: You don't think that understanding the human brain will result in advances in artificial thinking?

Calvin: There are some obvious aspects. If you can handle twice as many novel objects at the same time, those improvements make it much more possible to do logical reason. The problem is how do you develop judgement? It's easy enough to make new combinations of things, but most of them are nonsense. They are like your nighttime dreams, a jumble of people, places, and times that don't fit together very well. They're incoherent.

In waking hours, we make those things coherent by enough trial and error and refitting the pieces so we can speak sentences that aren't nonsense. Our ability to do that is a combination of how many things we can hold on to. To use a metaphor, there's a real house of cards in the head. Can we stage the operation so that we can build a house of cards? Can we shore up the house of cards so that it doesn't blow over so easily, so that we can maintain higher levels of abstract thinking for longer times? I think we are capable of educating for these things, with the aid of technology that allows you to detect and work with individual differences.

We have to make a lot of snap judgments that are most often just best guesses. That, in fact, is how we're always throwing up these new, probably digitally coded schemes on the fly of how things might fit together. But the way we're judging whether they fit together is this old analog system of memories and instincts and feelings. That's something that is probably a lot harder to understand. It's a much more fuzzy logic kind of thing compared to the on-the-fly motor plans, which in my theory are a largely digital operation. It's sort of a hybrid, an analog computer with a digital computer operating on top of it.

GBN: So we can borrow from digital environment methodologies that might work in machines.

Calvin: All the judgments about whether it really fits together or not, whether it's desirable and so forth—it's memory-based, it's emotion-based, it's instincts that come through. It's a whole series of much older and slower and fussier things. What we can conjure up in our imaginations obviously has changed a lot. It changes with all the cultures. We have words or tools. You have a word that means a particular constellation of things and it enables you to engage in much fancier operations in your head with your limited machinery. You may only be able to juggle a half-dozen things at one time, but they're now complicated things, not simple things. At any rate, that would be my guess as to where it's going.

Much of my neural circuitry work involves the whole issue of creativity—how you do something you've never done before and not have it turn out to be completely nonsense, even though you start with complete nonsense as your raw material; how you do a Darwinian process that increases the quality generation after generation and does it quickly enough to be able to speak your next sentence. Language is to my mind the really fast and really automatic part of creativity. It's the same neural machinery that you can use to operate on longer time scales of writing papers and thinking about the future.

GBN: If you have competing thoughts about what might happen, is there some kind of evaluation process through which the fittest notion gets sifted out?

Calvin: It's just like Darwin's natural selection: It's not just one aspect of the environment, it's the combination. For example, bluegrass and crabgrass are competing for my backyard. What makes bluegrass do better than crabgrass is how often you water it, how often you fertilize it, how often it gets walked on, how often it gets frozen in the winters. No one thing decides the issue. It's the combination that makes crabgrass, in my case, do better than bluegrass.

It's the same thing in the head. You're trying to find the right word to fit into a sentence. This coherency judgment of yes, that word really fits better than this other candidate, that's what your brain has got to do on the fly, and it's got to do it pretty quickly. We don't understand much about all the give and take of that. If it weren't for the fact that we understand Darwin's process so well in evolution and in the human response, we'd really be waving our hands in the air with respect to how it works in the brain. But we do understand the principles. When you're really stuck and you've never done it before and you don't know how to proceed, the Darwinian process will enable you to shape up the quality of your initial guesses into something that is much higher quality. Once you've done it once or twice, you may get a subroutine; you may not have to do it the long way in the future. But whenever you're dealing with something really novel, you've got a Darwinian process.

GBN: Should we replicate that Darwinian process of many different projects, many different conjectures, and winnow them through?

Calvin: It's just like the old problem with artificial intelligence. People did the best they could with the computers they had. They couldn't afford very much redundancy or variability in 1960; now they can afford more. Organizations have the same problem. You've got to be constantly imagining scenarios. You've got to try constantly to improve, but you don't necessarily want to improve them at the expense of discarding the alternatives. You may need to think in a number of different directions all the time.

It's a hard problem. It's much easier to be a pessimist than an optimist in some sense because the things to be pessimistic about are so obvious and the things to be optimistic about require such a large amount of hope. While my work has led me into a consideration of a fair number of catastrophic things, I also recognize there's a much harder-to-find long boom, I hope, in operation here, which I don't think we can trust to happen all by itself. I think we've got to keep heading off the catastrophes in order to enable it. That means very serious planning as to how to stabilize

society against collapse, whether it's climate or economics or epidemics; any of those three things could produce widespread problems that could spiral up and out of control. It would be quite unlike the earthquake or the hurricane that's here one day and gone the next, when you've got somebody else to help out.

Runaway Technology

If society can't react in time to the changes wrought by technological advances, it's in for serious trouble.

GBN: Are you an optimist or a pessimist?

Calvin: I'm an optimist who's trying to warn people about the sudden problems they get into, the ones that are not at all like floods and earthquakes and hurricanes. We now know the world has been full of them and that the worms have conspired to hide them from us. Now that we have the records we can see that happen, but we can also see the mechanisms. We can really understand part of this Rube Goldberg chain of causation and how we can interfere with it, how we could head things off or slow them down to buy us the time to handle it.

The quickness would almost doom us to a large catastrophic failure. These are not things that I think will wipe out homo sapiens, but I think they could wipe out major aspects of civilization as we know it. It could lead us to where the whole world is the Balkans.

GBN: But the optimist side of you is saying that we can understand the mechanisms and figure out how to intervene.

Calvin: Understanding gives you a lot of power, but it doesn't guarantee results. The power often comes with significant downsides. Relative time scales matter enormously. For example, it took less than 10 years after physicists realized that an atomic bomb was possible to make it. It took 50 years for the European community to reach the point of having a common currency. The technological stuff and the political stuff that could be done to make the world safe for the technology operate on very different time scales. There's nothing in nature to guarantee that you won't shoot yourself in the foot. Changing the political time scale requires the old generation to retire and get out of the way, making political changes slow to happen. I think what the Europeans have done is perfectly miraculous in terms of bringing people together under a common framework that had not existed before, but it did take 50 years. Compared to the time scale of technological change, that's pretty slow.

Ruptures happen when things operate on different time scales. What makes an explosion an explosion is that other things can't get out of the way in time. You just have all these opportunities for our technology, whether it's science-driven or the usual improvisation. The

chances for our technology to dig us into deep holes are pretty considerable. Whatever general trends there might be, whether it's in computing power, economics, or whatever, I don't see us necessarily overriding any of these dangers. They're just different things, and you've got to deal with the things that could destabilize the whole system.

GBN: Can technology override what is essentially the human pace of change?

Calvin: I think we've obviously done some very interesting things, of which the European community is a good example. But I don't necessarily see technology solving more problems than it creates. It's not that technology is inherently evil or anything like that, but I have no faith in the ability of society to react in time to the changes it makes. Whether it's weapons of mass destruction or computer viruses, I think we are heading into a period of substantial technological instability, all this quite aside from nature's instabilities. It will take a large human effort to stabilize it, and so far we're not doing very well.

The Perils of Globalization

Globalization has clear advantages, but it also has its dangers: wiping-out culture, spreading fatalism, and increasing the chance that the disaffected will wreak havoc on the world.

GBN: Do you think that this globalization phenomenon is exacerbating the problem? It's difficult for human institutions to evolve and we are living in a world with no global institutions to speak of. Does that lack of governance make it more difficult for society to respond to change?

Calvin: I don't know how that's going to balance out. You've got to have a base of a good rule of law and you've got to have a kind of transparency. A whole batch of things that make globalization possible that is coming to a lot of countries. Its virtue of making everybody dependent on one another so that they don't go to war is more obvious, but whether this will wipe out and demoralize cultures is much harder to foresee.

I don't think that analyzing it in just economic terms of personal income and educational opportunity is enough. I think you really have to look at issues. What do you do when you're a country that is so far behind in terms of average education for your people and you still don't have a system of free schools? How do you bring a country like that up to a global standard? Even if you didn't have the problem of all the politicians pocketing aid money, you'd still have an enormous psychological problem. When people are in a position of not understanding how things work, all they can do is try to do what they're told and not improvise because they will get into trouble, which is sort of the colonial legacy. It's psychologically difficult.

I worry that the whole world could find itself in the position of the colonial-era Africans—feeling like they don't have any control over things, that there's no point in doing anything or planning for your future. Fatalism is about all you can do, and it makes for a very dull life if you have to be that resigned. If you have the rich getting richer in the educational sense, where there's a very smart class that tries to run things successfully for the rest of the world, you've still got the problem of a lot of smart people with no jobs to go to, and they probably will just get the world in trouble.

GBN: How so?

Calvin: It's just like Bill Joy's comment that we're lucky that the Unabomber wasn't a molecular geneticist, he was only a mathematician. There's a sense in which technology empowers the disaffected to do a lot of damage. The analogy that's the easiest is, if you're disgruntled and bare fists were all that you had, there's a limit to the damage you can do. But with a knife or with a gun, with a bomb on an airplane, you could do a lot more. With nerve gas, you could wipe out a whole city.

There are going to be people who are mad like that, no matter how good the economics get. The amount of damage that a single person can do is growing with our technology, even though their percentages are very small in terms of total numbers. I think people like the Unabomber don't come along every day, but the amount of damage they could do when they do come along is growing very rapidly. I don't see any way of heading them off in terms of genetics, that is to say the recombination. We will continue producing a lot of variability.

There are a lot of things about our technological confidence that I'm very impressed with. I also see that the opportunities that technology gives to people who would do damage. Society's responses to them operate on a slower time scale than the technology. That will create problems and is likely to get us into a lot of trouble. I don't know whether it will happen in the next 10 years or the next 50, but it's hard to imagine how we are going to head all of them off. [This interview took place a week before 9/11/01.]

House of Cards

"The chances for either economic collapse or epidemics are high. In the next 50 years, we'll get hit by one of them on a fairly broad scale."

GBN: Whether it's biotech or the human genome project or brain science, there seems to be this juggernaut of progress and trajectories that are roughly on track. If you had to think about it schematically, the technology took off in the 1990s, and in this decade we're coming to terms with the consequences of that other time scale. It seems that human institutions are getting stressed and are in some ways pushing back and in other ways floundering.

Calvin: I'm not sure if there's a change with the decades. Yes, the 1990s were very fast in some ways—what we thought would take decades to occur all happened in half a decade. But I don't see that this decade is necessarily different. There are a lot of longer-term consequences that I don't think we're at all prepared to deal with. I don't think that anybody is very tuned in to the technological dangers. The dangers are larger ones of unintended consequences, and society's reactions to them are a lot slower.

There are things about climate change that we know now but we didn't know in 1990. I was very lucky—I happened to go to a lecture in 1984—but almost no one else knew. At the time, the word was just beginning to come out of Greenland. Until about three years ago, the information had not made it out of the scientific community. I don't know of any similar problem in the neurosciences. It is going along a lot more slowly and predictably.

There's a chance that all the experimentation that I said that parents will do on their children will show us a lot about the roots to doing very well and a batch of new roots to doing dangerous things. I don't see this as being a uniformly good result. We don't like nature's way of handling these things, and with good reason. Nature's way is to produce an awful lot of variance, and the fact that half of kids died early is just the way nature works. Now we work very hard to add value to the individual and the individual life. If we're going to keep that, we've surely got to learn how to cope with some of the consequences.

GBN: The flip-flop of the climate, half of the human race perishing—it doesn't really bother nature. It's part of the cycle.

Calvin: It isn't the fact that the earth's population might decline by 3 million over time, but the notion that it does that in a few years. The consequences for the survivors will be very different than if it slowly coasted down. To live with those consequences is quite terrible. If you value what civilization has brought us, you have to do things to help stabilize it and keep it from being so vulnerable. It's akin to realizing that buildings kill people in earthquakes, in which case you better not have shoddy construction, like they do in most of the world. You have to design buildings and bridges to be earthquake resistant.

I don't think we've even begun to do that in other areas. I don't think that economics has the brakes available. We're moving organisms around the world on airplanes and in ships, and most of them don't do very well in the new environment and just die out. But occasionally one of them will flourish, and without any natural predators or controls these things can take off pretty badly in the same way that smallpox and tuberculosis took off among American Indians. You can quickly wipe out nine-tenths of the population that way without warfare at all. The chances for either economic collapse or epidemics are high. In the next 50 years, we'll get hit by one of them on a fairly broad scale.

GBN: Do you think there's a decent possibility that something like this might come our way in the next 10 years, when we'd have to really scramble?

Calvin: If you speed things up as much as we have, the danger of out-driving your headlights is very high. You won't see the problems in time to stop for them. We almost got caught that way with ozone.

Most of the interesting things in nature have to do with two competing time scales. The body development in utero is very much a matter of two sheets of cells that grow at somewhat different rates; most of the interesting things about muscular movement have to do with two slightly different rates of change. Many of the things that give you problems in a societal way are simply due to one thing changing faster than something else. There's an awful lot we don't know about that. I think the danger of out-driving your headlights is very considerable as you go faster and faster. Yes, you could use brighter headlights, and science is one of our better headlights. But I don't see much sign that we're building better brakes or better alternative paths—all of the things that would allow you some flexibility that contributes to stability. We'll build a house of cards, but we need to shore it up so it doesn't fall down easily. I just don't see much shoring up going on.

The Long View (in Millions)

Culture, not genetics, is responsible for most human advances of the last 50,000 years.

GBN: You see time in terms of ice ages, and talk about the human brain in the context of 2 million years.

Calvin: The book I've just written covers the last 6 million years.

GBN: Can you situate the current moment on a really long time scale?

Calvin: Well, not in a way that makes this decade different than the last. Certainly our general progression during human evolution is not what we thought it was—a series of gradual changes in intelligence and brain size and cultural complexity. These things happened in a disjointed way; they just don't parallel one another in the way we thought.

We still don't know what upright posture is about. We don't really know what big brains are about because any of our modern human abilities, language and planning ahead and ethics and so on, probably haven't been around for more than about 50,000 years. We had a big brain for three times as long as that. We got the big brain, but there wasn't any evidence of what's called behaviorally modern humans. It's the sort of thing that kicks in with the cave art and the fishhooks and barbed spears and all the other use of antler and bone.

There's two and a half million years of occasional progress. You can go for a million years without much change in tool-making technology while the brain is growing. They just don't grow in parallel. Up until about 50,000 years ago, it is not clear from any of the evidence that our big-brained ancestors were thinking very much differently than chimpanzees. They could stage their tool-making and food preparation better than chimpanzees, but in terms of producing anything that you would look at and say, "Those people thought a lot like we do," you couldn't say that until about 50,000 years ago.

Six thousand years ago is when we started getting cities and differentiation of occupations, the subtle existence of civilization. There wasn't anything that looks like modern science or philosophy until about 2,500 years ago and then it was spotty until things took off about 400 or 500 years ago. The stage we're at in terms of total population, movement of people around the earth, movement of disease organisms around the earth, all these things have largely happened in the last 200 years.

Two hundred years ago there was almost no knowledge of medicine. It was all sort of bleeding and purging, no real understanding of how things work. We're really living in a time when there has been enormous acceleration in our capabilities, largely due to culture. This is not a genetic change. Culture has accelerated everything—particularly the technological aspects and the political organization. With a background like that, you have to look back and say, "Does 50,000 years ago represent the first worldwide distribution of the beta software?"

It looks like minds like ours first happened in Africa, then spread around the world immediately afterward. The major bugs that are left—psychiatric disorders, epilepsy, all these things that you just don't see in other animals—really suggest that we're on the edge. It's not just the threat of an ice age, though we'll have to overcome that too. If you can't improve things genetically, which I don't think is going to happen, you need to improve the situation culturally so that things are much more stable when the difficulties come along. You don't collapse the whole house of cards; you shore up everything except the top story and keep all of the big improvements that were made along the way. I just worry that we haven't shored up many of them at all.

GBN: On the other hand, you are quite impressed by cultural advances, though technology experiences a different pace of change than political organization.

Calvin: I'm using the word culture to cover education, technology, science, politics—the whole thing. Some of these operate on fast tracks and others operate slowly, and you can get into big trouble that way. Physical systems go into oscillation when you have setups like that, and there's no reason to assume that economics, epidemics, or the climate won't substantially collapse. The chances of losing an awful lot of what we've gained are high—much higher than they were 200 years ago. There's just an enormous increase in the population, which makes us very vulnerable. A hundred years ago, farmers made up 30–40 percent of the American population. Now it's 1.3 percent. That alone tells you how vulnerable we are.

GBN: So we are in a unique moment.

Calvin: I find the speed as exhilarating as other people do. This last decade has been a great ride and I have learned a great deal from it. But nonetheless, yes, it is a house of cards. It is rather vulnerable to the breezes. When you're moving people and disease organisms around the world as fast as we're doing it, you've just got to expect trouble.

Darwinian Dilemma

Human evolution doesn't operate the way it used to, making us increasingly vulnerable.

GBN: I don't know how you feel about the chances of intelligent life in other places, but isn't this a problem that a truly intelligent species has to solve at some point? Those that solve it get to move on, and those that don't, don't?

Calvin: In the SETI business, it's called the lifetime-of-civilizations factor—how long they'll last, what sort of window there is for communicating with other civilizations elsewhere. Does it flicker on and off for such short periods of time that it's essentially undetectable? The jury is still out on that.

We've always been aware that economics could go up and down and bust. We have some notion that epidemics could do that; we lost 30 percent of the population to the plague over a matter of a couple of decades. We now know that climate changes are not only just regional droughts and unseasonable weather but major changes that last for centuries before they pop back into a new mode of operation. Learning how to live with that is going to be a matter of figuring out how to slow them down as well as how to build for them.

GBN: So the indicator of true intelligence would be a lasting civilization.

Calvin: Civilization is not really a matter of going faster and faster; it's a matter of flying safer and safer. You've just got to assume that some idiot will do something wrong and you've got to figure out how to keep things from collapsing when they do it. I think with respect to dangerous people, we've got to figure that they're always going to be here and that they will have some sort of access to the highest technology. There will always be the problem of how to keep catastrophes from happening because somebody has a mean streak or is psychotic, and if they go down they will take as much with them as they can.

GBN: Yet on top of it all you are basically hopeful. Is that accurate?

Calvin: Yes, in part because I've seen a lot of progress in my lifetime. I know enough about the history of science, technology, and medicine to see that despite about the same collection of catastrophic possibilities there's been a lot of real progress in 500 years. I don't see it as inevitable. I think that once you get big and top heavy, you have to tend to the stability of the

house of cards. I'm generally optimistic by nature. It's only considering what our ancestors went through to become human that I've come to appreciate all the downsides. There are, paradoxically, downsides that have produced upsides. I don't necessarily see the next downside as having any of those saving graces.

GBN: Why not?

Calvin: Largely because evolution, ever since the invention of agriculture and transportation, has been slowed to a small fraction of the speed at which it used to operate. There's been very little human evolution in the last 10,000 years. There's a lot of natural selection that goes back and forth, but it doesn't necessarily result in any permanent change. If, off in your remote valley, you make some anatomical improvement in coping with the environment, it's easily destroyed when the climate improves and some immigrants from your old population arrive and dilute out all the change. Speciation is the only thing that prevents backsliding. It depends on isolation, small groups, and also a fair amount of downsizing by natural selection.

Agriculture has eliminated a great deal of that by providing surpluses that keep bad years from being so bad and a relatively better level of nutrition so that many few children die in childhood. It used to be what happened and it's still true in much of the world. Transportation has minimized isolation.

I don't think there's a silver lining to the next one. Civilization via education and standing on the shoulders of everybody has produced a much larger amount of progress than any 1 percent change in the genes ever did. The gain is one in civilization and culture, not in human evolution in the way that it used to operate. This isn't to say that some genetic engineering might not improve humans, but you just can't extrapolate the advantages of the evolutionary past into the future. You've got to look around and see that agriculture and transportation have just taken the whole edge off. It's not going to work the way that it did in the past. We're in a whole new ball game, with the need to invent a more stable future.

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