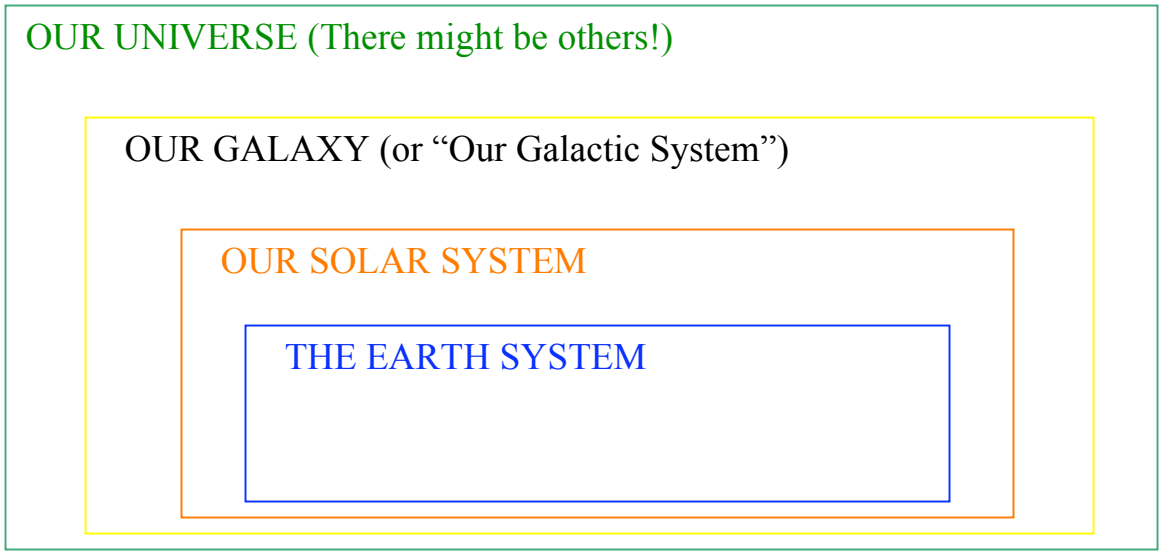
X5 – EXchanging Worldviews, 5: EXamining Interactions of the Human System with Its Environment

Dear: As I emphasized in the **T**-chapters, dealing with "Truth", it's important to distinguish two types of systems: those that interact with their environments (called "open system") and those that don't (called "closed systems"). The Human System (better known as 'humanity') is definitely an open system, not only interacting with its environment, but without such interactions (e.g., air to breath, water to drink, food to eat…), humanity would quickly disappear. In this chapter, I want to try to show you a little about how the Human System interacts with its environment, since such interactions are so critical to humanity and since modern humans are modifying the interactions so dramatically.

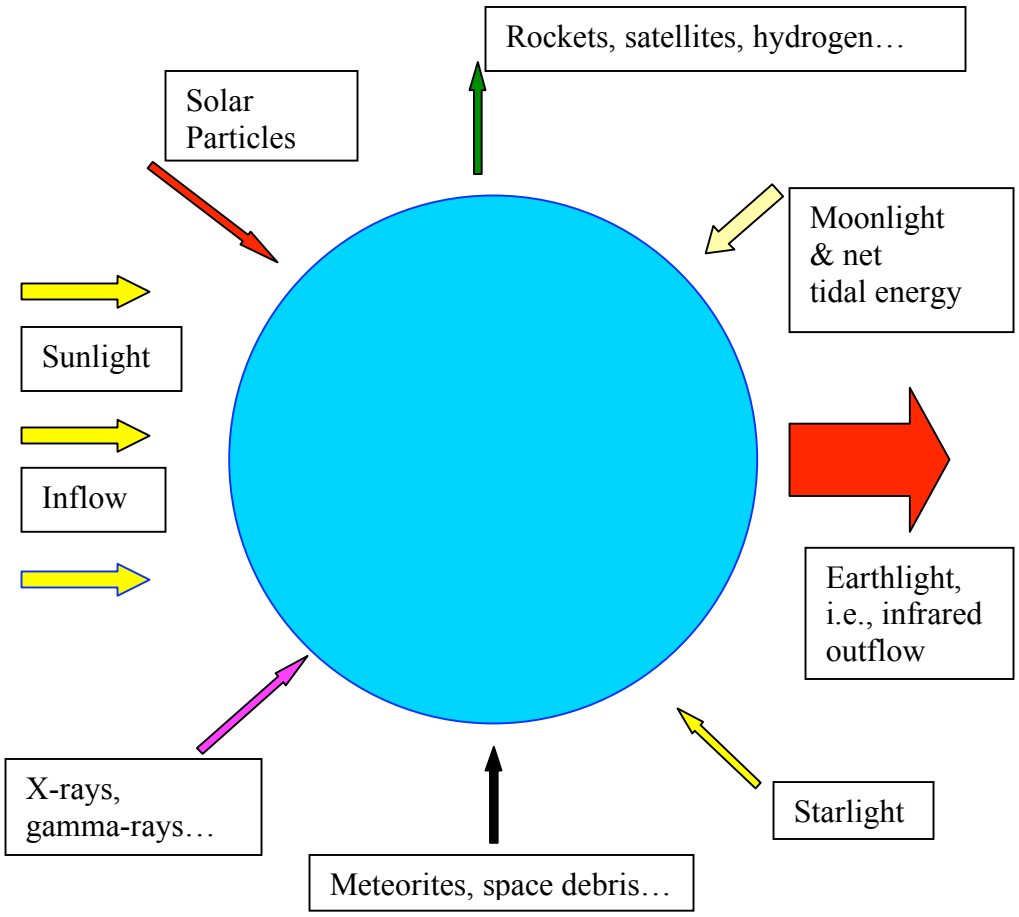
To examine the interactions of the Human System with its environment, it's instructive to look, first, at how the Human System fits within larger systems. In the sketch below, I've tried to show you what I mean by indicating where the Earth System (which currently constrains the Human System – except for space flights!) fits within "the entire system" – which for reasons I sketched in Chapter **A** and will describe more in **Z**, I think is "Total Nothingness".

TOTAL NOTHINGNESS
Split into "positives" and "negatives", still summing to "zero", yielding:



Next (and more to the point of examining interactions between the Human System and its environment), consider how the Earth System interacts with its environment. In the sketch below, I've shown some of these interactions (in particular, exchanges of mass and energy).

MASS & ENERGY TRANSFERS FOR THE EARTH SYSTEM



Of the energy fluxes shown in the above sketch, the one that might seem most strange to you is the "net tidal energy" (associated with the Earth-Moon system) – not that you're unfamiliar with oceanic tides (and there are similar tides in the atmospheric and the magma), but as you might expect, the system isn't like a frictionless pendulum, swinging back and forth (perpetually transferring energy between potential and kinetic forms). Instead and like a real pendulum, energy is dissipated, causing the Earth to rotate more slowly and the Moon to speed up and recede (at a rate of ~4 cm per year), with the energy lost to space via thermal radiation.

Thereby, Dear, you should be alert to something important. Thus, in all cases of "systems analyses" (such as those that I'll be getting to), be alert to the analyzer's choices of inflows and outflows, because almost invariably, analyzers choose to focus only on those exchanges that appear to be of most significance to the inquiry under investigation. A case that illustrates the importance of only energy transfer for the Earth System is the "greenhouse effect", with its resulting warming of the Earth's climate. For the Earth's climate, the two principal energy flows are the inflow of (mostly visible) radiation from the Sun and the outflow of (infrared) radiation from the Earth. As you know, with the addition of anthropogenic (i.e., "human generated") greenhouse gases, the Earth's atmosphere has become more opaque to infrared radiation. Consequently, the effective height from which the infrared radiation leaves the Earth for outer space has increased to where the temperature is lower. As a result, with the infrared radiation from cooler, greater heights being less than from warmer, lower heights, less radiation would leave the Earth, causing it to become warmer (leading to a warmer climate) – until the Earth's atmosphere regains thermal equilibrium, heating the entire Earth System (and therefore it becomes warmer at the effective height from which the atmosphere radiates thermal energy). But the tidal energy between the Earth-Moon system may also be important to the climate, because as you can find on the internet, the tides may provide some of the energy that drives the thermal-haline circulation of the oceans.

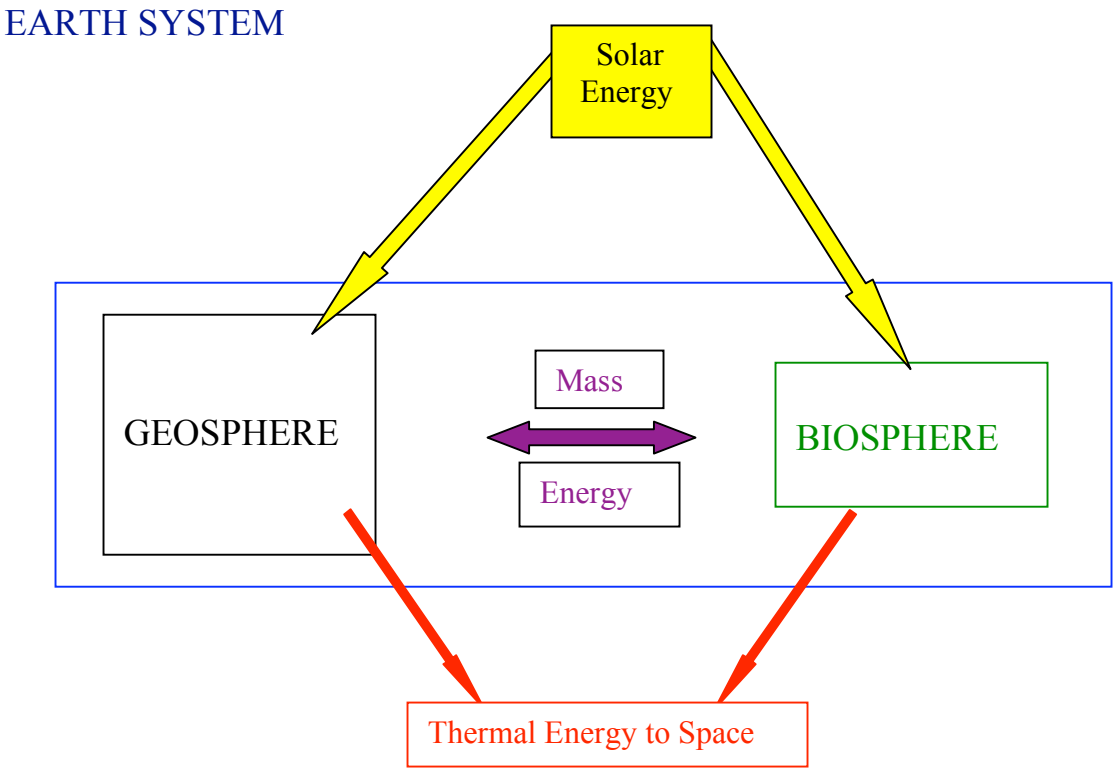
All of which was my attempt to illustrate that "system analyzers" focus on inflows and outflows most germane to the issue being addressed – and those indicated in the above sketch are sufficient (or actually, more than sufficient!) for present purposes. And if you're now thinking something similar to, "Grampa, where the devil are you going with this?", then my first response would be "Patience, child." Thus,

- My immediate goal is to provide you with at least some indication of how the "Human System" interacts with its environment; to do that, I need to describe inflows and outflows for the Human System; and to do that, I need to show you at least a little about the other systems (especially the Earth System) in which the Human System is embedded.

- Besides that, by commenting on such systems, I'm trying to at least expose you to some worldviews developed by scientists, worldviews that don't include any exchanges with or influences (or interferences) from any magic man in the sky.

- In addition, I'm trying to give you at least a hint of what scientists really do: however their endeavors might be camouflaged by mathematical formulae and Hollywood-promoted white lab-coats, what they really do is develop various types of models (from simple sketches, such as those drawn above, to the most elaborate computer models), attempting to account for the dominant features and processes of the system under investigation – and then, to complete the scientific process, of course they must determine what their models predict and compare those predictions with data from new experiments.

Consequently, Dear, please be patient: I realize that my presentation is slow, but eventually I'll get to showing you some recently developed models of the Human System – models that unfortunately are so new that they haven't yet been adequately tested experimentally.[1] For now, let me continue to try to build some features into a model for the Human System. For example, my next schematic suggests interactions between two commonly identified components of the Earth System, namely, the Geosphere and the Biosphere (the latter of which of course includes humans):



[1] Actually, you'll need to be especially patient (or diligent!) if you want to see results from experiments designed to test such models: maybe by the time you're my age, you'll learn which models were well conceived! Will the predicted global warming occur? Will the population bomb explode? Will critical resources become depleted? I don't know!

In what follows, I won't go into details about either 1) these two "spheres" [i.e., the Geosphere (the atmosphere, oceans, lands) or the Biosphere (all living organisms)] or 2) interactions between them. If you're interested, there are textbooks and graduate courses available, e.g., dealing with biogeochemical cycling. In what follows, I'll use only "simple stuff" related to such "cycling", such as the fact that components of the Biosphere (e.g., humans!) import mass and energy (minerals, coal, oil, wind energy…) from the Geosphere and subsequently export other forms of mass and energy (mill tailings, carbon dioxide, thermal pollution) back to the Geosphere. Thereby, Dear, I'm finally getting close to starting the task of examining the interactions between the Human System and its environment!

In general, we humans are a (particularly troublesome!) component of the Biosphere. We're "troublesome" in that:

- With all the aerosol particles that we're putting into the atmosphere, we're interfering with the incoming visible solar radiation,

- With all the ozone destroying chemicals we've put into the atmosphere, we've permitted more ultraviolet solar radiation to reach the Earth's surface (potentially damaging other components of the Biosphere),

- With the "greenhouse gases" that we've put into the atmosphere, we're interfering with the outgoing thermal radiation to space, and

- With our huge consumption of resources, we've significantly modified the mass and energy exchange between the Geosphere and the Biosphere.

Thus, although the Human System is enormously complex, behind the complexity there appears to be a general "organizational principle" for the Human System that appears to govern its operation, in turn because it governs the behavior of every human. Specifically (and similar to all animals), we humans are exploiters – and similar to most natural systems, the Human System functions by exploiting Nature. In fact (or at least as far as I know), all systems (at least all systems that come to mind – correct me if you can think of an exception!) transform inputs to outputs by *exploiting* something, usually including energy.

For example, our bodies exploit energy stored in food such as edible plants, plants exploit the sun's energy to produce biomass, and the Sun exploits gravity and the energy "congealed" in mass (i.e., mass is transformed into energy during the building of carbon nuclei from hydrogen and helium).

Even the entire universe (viewed as a system) may do the same: although you'll probably not understand the following statement until after you read Chapter **Z** (and maybe not even then!), let me say that I wouldn't be surprised if the universe "operates" by exploiting the positive energy that's split off from the negative energy of "space", and this exploitation continues to occur as our universe expands into total nothingness.

But more "down to Earth" – and most seriously – the Human System is facing a huge number of extremely dangerous problems, derived from our exploitive nature, exploiting Nature. Specifically, we are encountering a huge number of excruciating, potentially explosive, and exploding problems, because there are too many people exploiting too many natural resources (such as water, soil, minerals, and irreplaceable energy resources).

Thus, currently in the world, hundreds of millions of people are starving, have inadequate water, shelter, etc., and are dying of controllable diseases. Also, pollution contaminates air, land, and water (including the oceans), which threatens the well being of future generations. In addition, ecosystems are being destroyed and species have been (and continue to be) driven to extinction. And although I don't plan to go into details about such problems – in part because I know that you're aware of many of them – let me at least add some summary statements dealing with the scope of the problems and the "immorality" (the idiocy!) of the current behavior of the vast majority of humans.

As for the scope of the problem, regardless of differences in opinions about "prosperity", one thing is almost indisputable: there's no way that this poor old world of ours can tolerate worldwide acceptance of the crazy concept of prosperity held by most American consumers – at least, not for a human population anywhere near its current size (of about 6 billion people). There's the familiar line: "Comprising about one twentieth of the world's population, Americans consume about one third of the world's resources." Then, think how much Americans would consume if there weren't so many "poor" Americans! Consequently, given that many of the world's resources are currently strained to their limits (or beyond), then for everyone to live in the relative prosperity enjoyed by most Americans, more than about seven more Earths would be needed – and if environmental problems are to be solved, more than ten Earths would be needed (or more realistically, the population would need to be reduced by a factor of about ten).

In 1992, to make the point known to more people, "more than 1500 of the world's most distinguished scientists, including 99 of the 196 living Nobel laureates", signed a *World Scientists' Warning to Humanity*, which was sent to governments throughout the world. The statement includes:[2]

> The earth is finite. Its ability to provide for growing numbers is finite. And we are fast approaching many of the earth's limits… Pressures resulting from unrestrained population growth put demands on the natural world that can overwhelm any efforts to achieve a sustainable future. If we are to halt the destruction of our environment, we must accept limits to that growth…

And although the above is "almost indisputable", apparently it's not accepted by some. For example, consider the following quotation from an article by Glenn Scherer entitled "Religious wrong: a higher power informs the Republican assault on the environment" [to which I've added the notes in brackets].[3]

> In *America's Providential History,* a "religious right" high-school history textbook, the authors (Mark Beliles and Stephen McDowell) write:
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> > "The secular or socialist has a limited-resource mentality and views the world as a pie… that needs to be cut up so everyone can get a piece… In contrast, the Christian knows [cough, cough] that the potential in God is unlimited and that there is no shortage of resources in God's Earth. The resources are waiting to be tapped… While many secularists view the world as overpopulated, Christians know [cough, cough] that God has made the Earth sufficiently large with plenty of resources to accommodate all of the people. "

Talk about the need to "get real"! Talk about living in a dream world! Talk about problems caused by crazy worldviews! And realize, Dear, that such ignorance is taught to American children "home-schooled" by their "evangelical" religious parents, brainwashing their children in the same idiocy that destroyed their own ability to think.

Yet, such idiocy isn't confined to textbooks for the "religious right" (better, "religious wrong" or "religious Reich"). For example, consider the following quotation from the "Review & Outlook" section of the 17 July 2007 issue of *The Wall Street Journal*, dealing with Norman Borlaugh's

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[2] Dear: If you want to read the full "Warning", you can find it at the homepage of the Union of Concerned Scientists: http://www.ucsusa.org/ucs/about/page.cfm?pageID=1009.

[3] Copied from http://www.encyclopedia.com/doc/1G1-101763356.html; the original article was published in *E: The Environmental Magazine*, May-June, 2003.

award of the Congressional Gold Medal.[4] In 1970, he was awarded the Nobel Peace Price for his contributions to the "Green Revolution."

> The late economist Julian Simon was in the habit of claiming that natural resources are basically infinite. His refrain: "A higher price represents an opportunity that leads inventors and business people to seek new ways to satisfy the shortages. Some fail, at cost to themselves. A few succeed, and the final result is that we end up better off than if the original shortage problems had never arisen." As anti-development environmentalists preach the gospel of limits and state coercion, here is a question worth asking: How many millions of people might have perished had Norman Borlaug heeded their teachings?

The science-fiction writer Douglas Adams summarized such stupidity well:[5]

> It's rather like a puddle waking up one morning – I know they don't normally do this, but allow me, I'm a science fiction writer – A puddle wakes up one morning and thinks: "This is a very interesting world I find myself in. It fits me very neatly. In fact it fits me so neatly… I mean really precise isn't it?… It must have been made to have me in it." And the sun rises, and it's continuing to narrate this story about how this hole must have been made to have him in it. And as the sun rises, and gradually the puddle is shrinking and shrinking and shrinking – and by the time the puddle ceases to exist, it's still thinking – it's still trapped in this idea that – that the hole was there for it. And if we think that the world is here for us we will continue to destroy it in the way that we have been destroying it, because we think that we can do no harm.

Let me comment a little on the immorality of such consumption. To begin, consider the meaning of the verb *exploit.* My copy of Webster gives the definitions:

> **1.** to make use of; turn to account; utilize productively, **2.** to make unethical use of for one's own advantage or profit; specifically, to make profit from the labor of (others).

The dictionary that comes with this word processor (**Word**), gives the meanings for *exploit* as:

> **1.** to take selfish or unfair advantage of a person or situation, usually for personal gain, **2.** to use or develop something in order to gain a benefit.

The suggestion in these definitions that exploitation is "selfish" or "unfair" or "unethical" (or immoral) is, of course, rather tenuous without evaluation of objectives and alternatives.

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[4] The url is http://online.wsj.com/article/SB118461857225767963.html; the author isn't identified.
[5] Copied from http://www.knowprose.com/node/1188.

Thus, if the "greatest good" recognized by life is for it to continue, then one would be hard pressed to criticize plants for "exploiting" the sun's energy (especially since, otherwise, the energy would be "wasted" in space) or to criticize animals for eating plants and other animals. Besides and importantly, the process of devouring other species normally keeps their populations from reaching other natural constraints, such as starvation or in some cases, some type of communicable disease (made worse by overpopulation). In the case of humans, however, unless we use our brains as best we can (i.e., be moral), starvation and communicable diseases (such as AIDS) are the only near-term constraint on our population – although devastating wars "help", and certainly an impact from a large asteroid could drastically reduce our numbers (if not eliminate us).

I'll not address the morality of Americans consuming (say, on average) 100 times more than people in Bangladesh do. If that topic is addressed, concepts such as "finders keepers, loser weepers" will cloud the important point, and a person can then be led, for example, to question the "ownership" of the vast oil reserves in Saudi Arabia, Iran, Iraq, and elsewhere. Instead, I think that the "important point" about American consumerism is the immorality of robbing one's family members (including one's descendants), i.e., the topic of "intergenerational morality".

You can read much about the topic of intergenerational morality, but you don't need to – because it's all rather obvious. Let me assume that you agree with what I've been arguing for many chapters: that the prime goal of all life is to continue, that morality has meaning only relative to some objective, and that the only known absolute morality is for each of us to use our brains as best we can. Accepting those ideas, then not much brainpower is needed to conclude that, relative to the prime goal of helping humanity to continue, it's immoral (it's dumb) to impoverish future generations by using more than our "fair share" of natural resources.

Instead of impoverishing future generations, each of us should adopt the goal to try "to put the future in debt to ourselves." That means, in general, that we should make great efforts to ensure not only that all our economic activities are "sustainable" but also that they add to our descendants' inheritance. When examined, that doesn't mean that we can't use exhaustible resources (such as oil and coal, for example), but the only morally defensible way to use them is to apply our resulting economic strength (and our ingenuity) to ensure that future generations are

compensated, e.g., with better energy supplies (e.g., via nuclear fusion, with the ocean's supply of the deuterium fuel being essentially inexhaustible). In contrast, the way that the vast majority of Americans are consuming exhaustible resources is decidedly and despicably immoral: it would be totally understandable if our descendants spit on our graves.

But certainly such craziness and such immorality aren't confined to American religious kooks and industrialists. And certainly it's not just "American consumerism" that's the root problem. Substantial data are available to support the assertion that, given the opportunity, the vast majority of humans would consume as much as Americans. Instead, as was stated in the above quoted *World Scientists' Warning to Humanity*, "unrestrained population growth put demands on the natural world that can overwhelm any efforts to achieve a sustainable future." And yet, rather than supporting constraints on population growth, leaders of Catholic, Muslim, and Mormon religions preach utter stupidity.

As an example is the Mormon leaders' statement:[6]

> We seriously regret that there should exist a sentiment or feeling among any members of the [Mormon] Church to curtail the birth of their children. We have been commanded to multiply and replenish the earth that we may have joy and rejoicing in our posterity…

"Joy and rejoicing in our posterity"? Mormons are to have more children because they'll be happy, living with their children in paradise for eternity? And the worldview that produced this goal and therefore such values is what? That some magic man in the sky is in control and "commanded" us "to multiply"? That He's gonna solve all our problems? And this speculation is based on what data? What? It's all based on the speculations of savages that are promoted in some old books concocted by con artists? Surely you jest! Surely there's some small amount of sanity still flickering in your brains!

And of course I'm not alone in criticizing such idiocy. For example, approximately 2,000 scientists at a meeting of the American Association for the Advancement of Science signed the following statement in response to Pope Paul VI's *Humanae Vitae* "encyclical" dealing with birth control:

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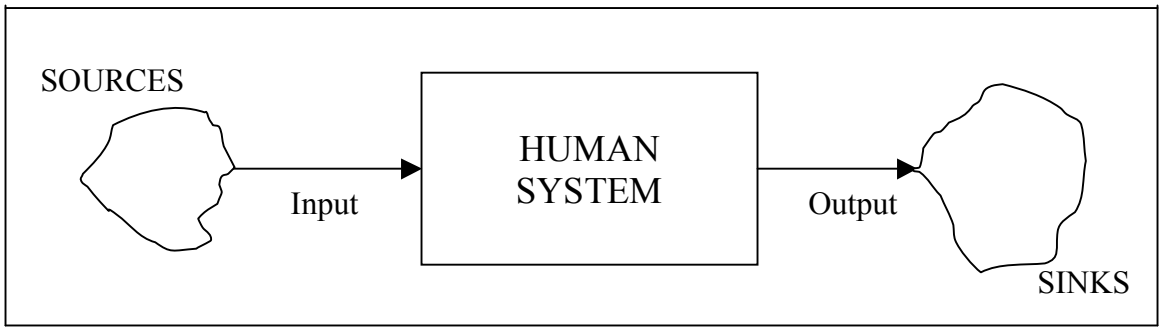
[6] First Presidency (David O. McKay, Hugh B. Brown, N. Eldon Tanner), *Letter to presidents of stakes, bishops of wards, and presidents of missions*, 14 April 1969.

> More than half the world is hungry and the environment of the world is deteriorating rapidly because of over-population. Any action which impedes efforts to halt the world population [growth] perpetuates the misery in which millions now live and promotes death by starvation of millions this year and many more millions in the next few decades… It has been stated by Roman Catholics that the Pope is not evil, but simply unenlightened, and we must agree. But, whatever the motives, the evil consequences of his encyclical are manifest…

"Evil", Dear, because of ignorance – that is, recall Socrates' summary: "There is only one good, knowledge, and one evil, ignorance."

But let me temporarily get down from that soapbox and return to investigating how the Human System interacts with its environment. In the above I tried to give you at least a few hints of what may be a common "operating principle" of all systems, namely, exploitation. This exploitation of the Earth System by the Human System can be depicted schematically as shown in the following sketch, in which not only have I given up on the pretty colors (☹) but also I've simplified "the model" by distinguishing neither interactions with larger systems (e.g., the Solar System) nor separately the Geosphere and the Biosphere, lumping all such details into the categories of either "sources" or "sinks".

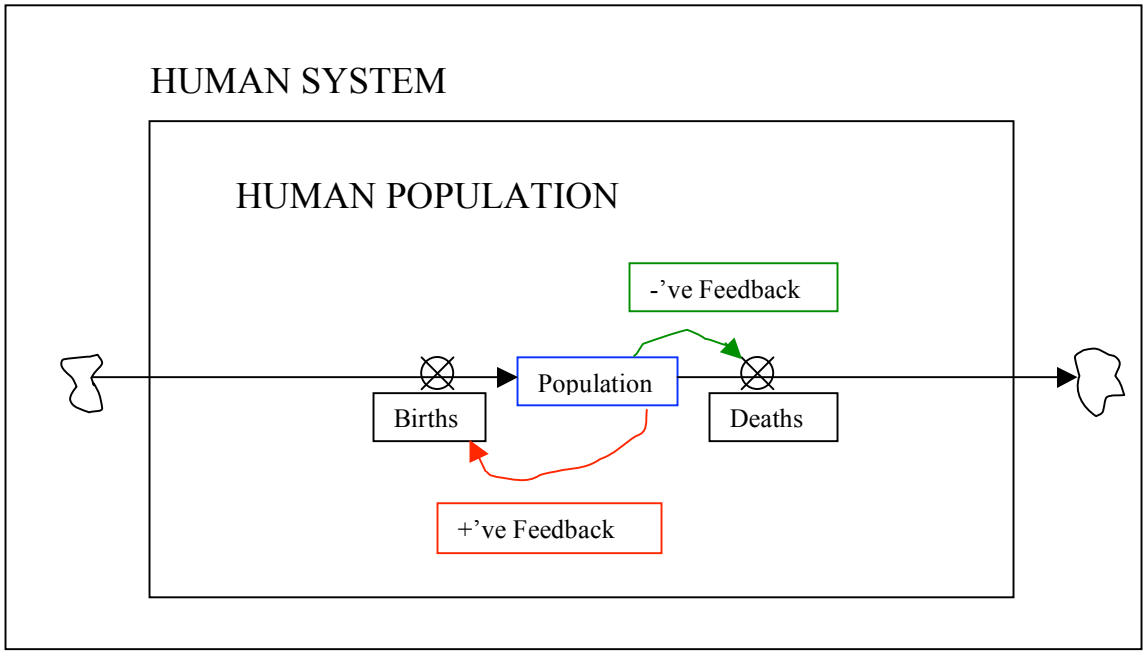
EARTH SYSTEM



In addition, though, within complicated systems such as the Human System there are "feedback loops" (which feed information about the output back to the input) and various "control mechanisms" (which respond to the information fed back).

As I mentioned in the previous chapter (and as you probably know, anyway), such feedback is termed "positive" if information from changes in the output causes the control mechanism to enhance the same direction of change; "negative", otherwise. For the Human System, a particularly important positive feedback (causing overpopulation) is that: the more babies born, then without adequate "birth control mechanisms", still more babies will be born. On the other hand, there is a negative feedback on the population: the more people there are, the more there are who die. These two feedbacks are indicated schematically in the sketch below, in which the two "valves" (circles with crosses through them, labeled "births" and "deaths") are used to represent the two identified "control mechanisms" on the population.

EARTH SYSTEM



In principle, it's easy to develop mathematical models to describe changes in the human population. Symbolically, using the symbol Δ (read "delta") to represent "change", then during any change in time (or "time interval") Δt, the change in the number of people, ΔN, is the difference between the number of births *per unit time* and the number of deaths *per unit time* multiplied by the time interval:

$$\Delta N = [(\text{Births/unit time}) - (\text{Deaths/unit time})]\, \Delta t \ .$$

In turn, if the average birth rate (people born per unit time interval and expressed as a fraction or percentage of the current population, e.g., 2% of the current population per year) is written as the Greek letter "b", i.e., β (read "beta") and similarly if the death rate is taken to be the Greek letter "d", i.e., δ (read "[lower case] delta"), then the above equation becomes

$$\Delta N = (\beta - \delta)\, N\, \Delta t \ .$$

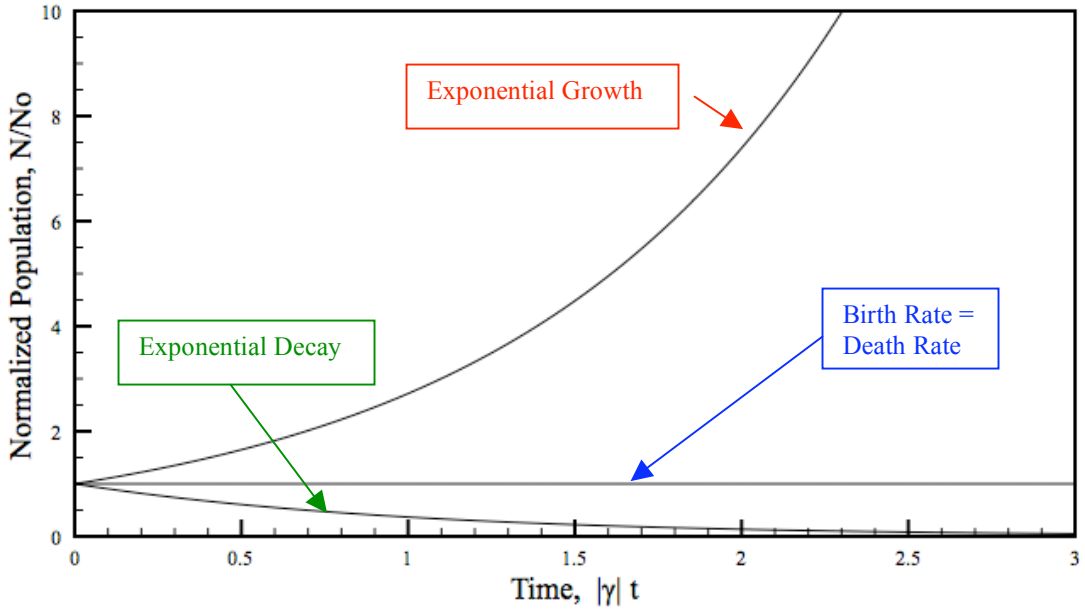
With such a description of the change in the population at every time step, then the population at subsequent times can be found, basically by addition.

Equivalently (as you'll learn when you're older!), the above "difference equation" can be written as a "differential equation" (i.e., the difference equation in the limit as the time interval becomes very small, and then $\Delta N/\Delta t$ is written as "the derivative" dN/dt, which represents the rate of change of the population at any time), i.e.,

$$[\text{Limit as } \Delta t \rightarrow 0,\ \Delta N/\Delta t\ ] \ \Rightarrow\ dN/dt = (\beta - \delta)\, N = \gamma\, N \ ,$$

in which the Greek letter "g", i.e., γ (read "gamma") is $\gamma = (\beta - \delta)$, i.e., the net birth rate.

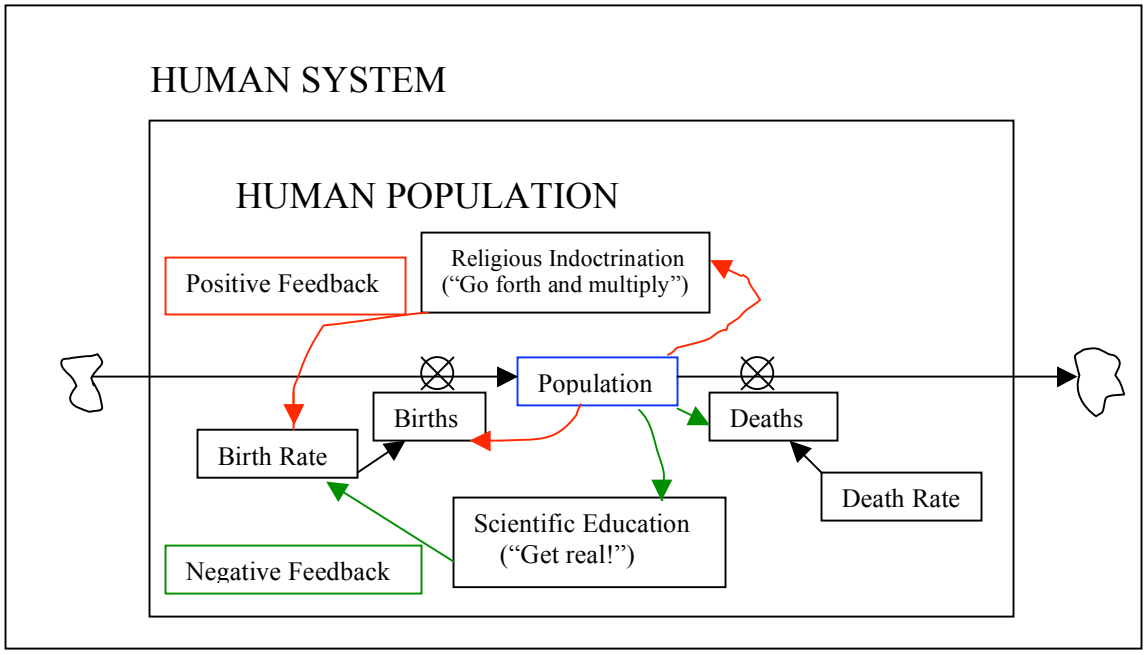
The above differential equation can be solved, e.g., numerically (in essentially the same way as the difference equation is solved), but in the special case that the net birth rate is independent of time, then this differential equation has the simple "analytic" solution $N = N_o \exp(-\gamma t)$, in which N_o is the population at $t = 0$ and exp (also written "e") is the irrational number 2.718… Plots of this solution are shown below for three values of the net birth rate, γ: the top curve is for the case when the birth rate is greater than the death rate (leading to "exponential growth"), the horizontal line is for the case when the birth rate is equal to the death rate (no growth) and the bottom curve is for the case when the birth rate is smaller than the death rate ("exponential decay").



For the above plot, I forced the numerical values on both axes to be dimensionless, by "normalizing" both the population (by dividing it by the initial population, N_o) and the time (by multiplying it by the magnitude of the net birth rate, $|\gamma|$); thereby, the above curves are appropriate for all birth and death rates. For example, if the death rate is 2%/yr (or 0.02/yr) and the birth rate is 5%/yr (or 0.05/yr) (i.e., if the net birth rate $\gamma = +0.03$/yr), then, e.g., in two-thirds of a century (~67 years), i.e., with $\{|\gamma| t\} = 2$, then the "exponentially growing curve" in the figure gives an N/N_o value of about 7 (more accurately, $e^2 = 7.39\ldots$); that is, the population will have increased more than 7-fold.

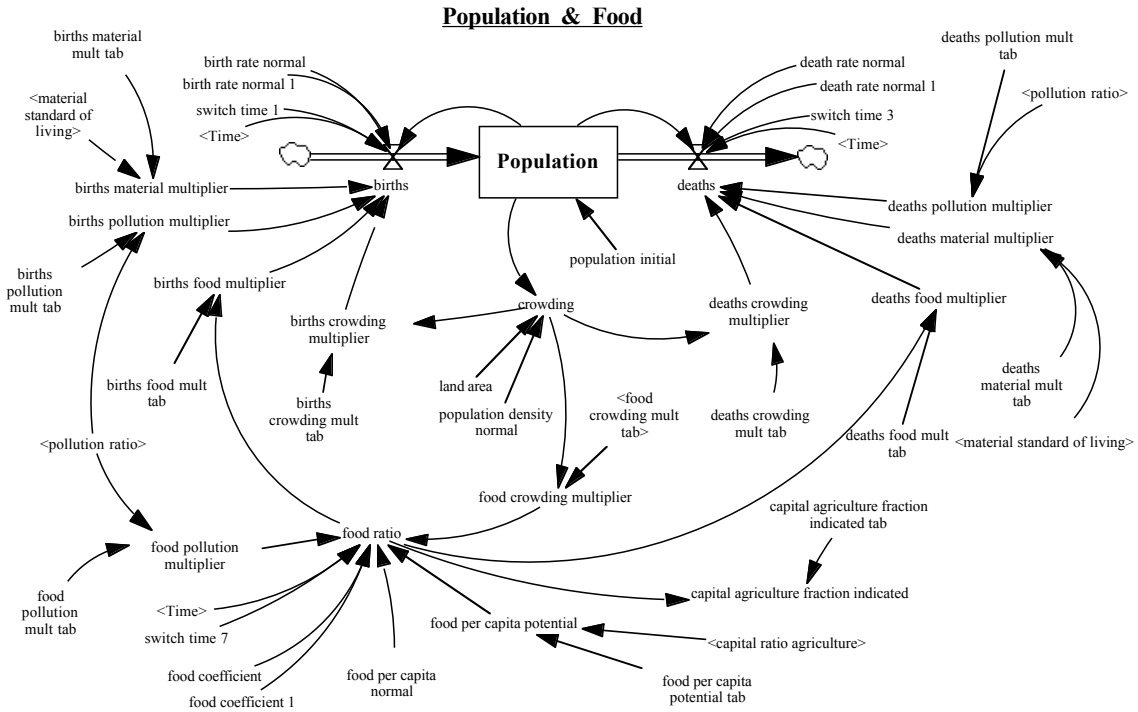
In reality, however, processes that influence the size of the human population are vastly more complicated than suggested by the above solution (with its plot), which is appropriate only if the birth and death rates are constants. As a first indication of such complexity, the "control mechanisms" (and associated "information flows" controlling the feedback) can themselves be identified as various subsystems. For example, various religious fundamentalists can be viewed as subsystems that deal with information and control, unfortunately stimulating positive feedback to the Human System, e.g., by preaching such idiocy as "Go forth and multiply." Meanwhile, birth control policies can provide negative feedback.

Adding just those two complications yields the following modification to the earlier sketch – in which I've added only two feedbacks (one positive and the other negative) to the Birth Rate and no feedbacks to (or other influences on) the Death Rate.



But trying to get still closer to modeling reality, one needs to add that both the birth and death rates are influenced by a large number of other factors (including customs, education, food, health services, pollution, the current population, etc.). As an illustration of such complications, below is shown what was used in the first "World Model" to describe only the human population portion of the model, which was the first attempt to use a computer model to describe the world system and was developed at the Massachusetts Institute of Technology (MIT) under the direction of J.W. Forrester.[7] Relative to the sketch below, it actually emphasizes only the influence of food supply on the "human population" component of Forrester's World Model.

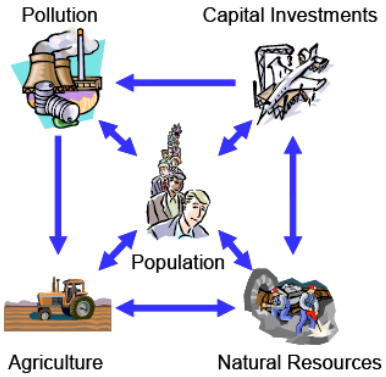
[7] I copied this sketch from the version of J.W. Forrester's World Model that's contained in the freely available version of the System Dynamics software at Ventana Systems, Inc., called "Vensim PLE" and available at http://www.vensim.com/download.html. On the internet, you can find the description of this World Model at many sites (e.g., by "googling" with the search words "World Model").



And if your immediate reaction is close to

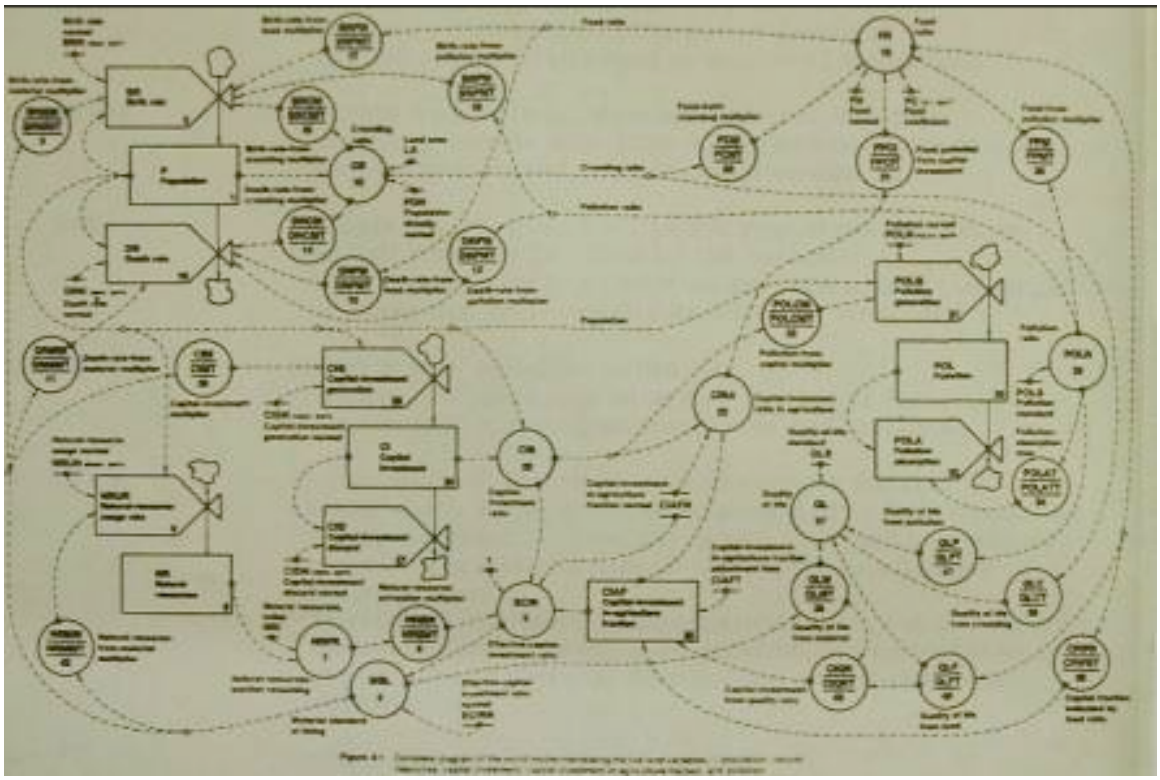
> Hey, wait a minute: not only is that so complicated I can barely read the fine print but also, what gives with all the unattached arrows?

then to begin to respond, let me first show you the interconnections among the major components of the MIT World Model:[8]



[8] I copied this figure from a Ph.D. thesis (submitted to the University of Bergen, Norway) that you can find on the internet entitled *The World Model Controversy* by Magne Myrtveit.

Now, in response to your imagined complaint about the unconnected arrows in the earlier figure, the following shows how all the components were connected in the first version of the MIT World Model:[9]



And if your response is close to

> Grampa! What are all those chicken scratches?! Not only are you losing me, I'm beginning to think that you're losing it!

then Dear, let me try to justify my leading you into that briar patch (or "chicken coop") by providing you with some "rewards" for your "hanging in there" this far!

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[9] I copied the above figure from the September 1971 article entitled "World Dynamics and Psychodynamics: A step towards making abstract 'world system' dynamic limitations meaningful to the individual", which you can find on the internet and whose authorship is identified only as "Distributed by the Union of International Associations and Mankind 2000 as Study Paper ORG/2". In turn, this article identifies the original source of the figure as follows: "This is a complete diagram of the world model described in Jay Forrester's [book] *World Dynamics*. The model interrelates the five-level variables: population, natural resources, capital investment, capital-investment-in-agriculture fraction, and pollution." In the upper left-most rectangle (or reservoir) in this figure, the word is "Population"; i.e., this reservoir represents the population component of the model.

As a first "reward", Dear, maybe you're gaining a better appreciation for the many "linkages" that exist in the Human System – and thereby, how so many of our problems are interconnected. For example, many of our environmental problems are derived from population problems, many of which (in turn) are derived from cultural problems (codified by religions), which in turn are linked to ignorance, in turn linked to poor education, in turn linked to governance problems (including laws permitting parents to brainwash their children in supercilious nonsense about "the supernatural").

In turn, such linkages among problems cause huge difficulties in trying to solve them. For example, health problems are commonly related to economic problems (e.g., poverty) and sometimes environmental problems (e.g., pollution), which in turn are commonly related to economic problems (e.g., exploitation of natural resources), which in turn are commonly linked to governance problems (e.g., dealing with social "safety nets" and with environmental laws), which in turn are again commonly linked to economic problems (e.g., wealthy individuals or corporations able to influence legislatures *via* campaign contributions and other lobbying), which in turn are sometimes linked to other governance problems (e.g., because the wealth of some individuals and corporations is, in some cases, derived from the government's funding of its military). And in turn, much of all such problems is derived from lack of knowledge, i.e., poor education. Thereby, Dear, if you tried to show all such linkages, you'd probably end up with something similar to what's in the MIT model – which critics would probably describe as "chicken scratches"!

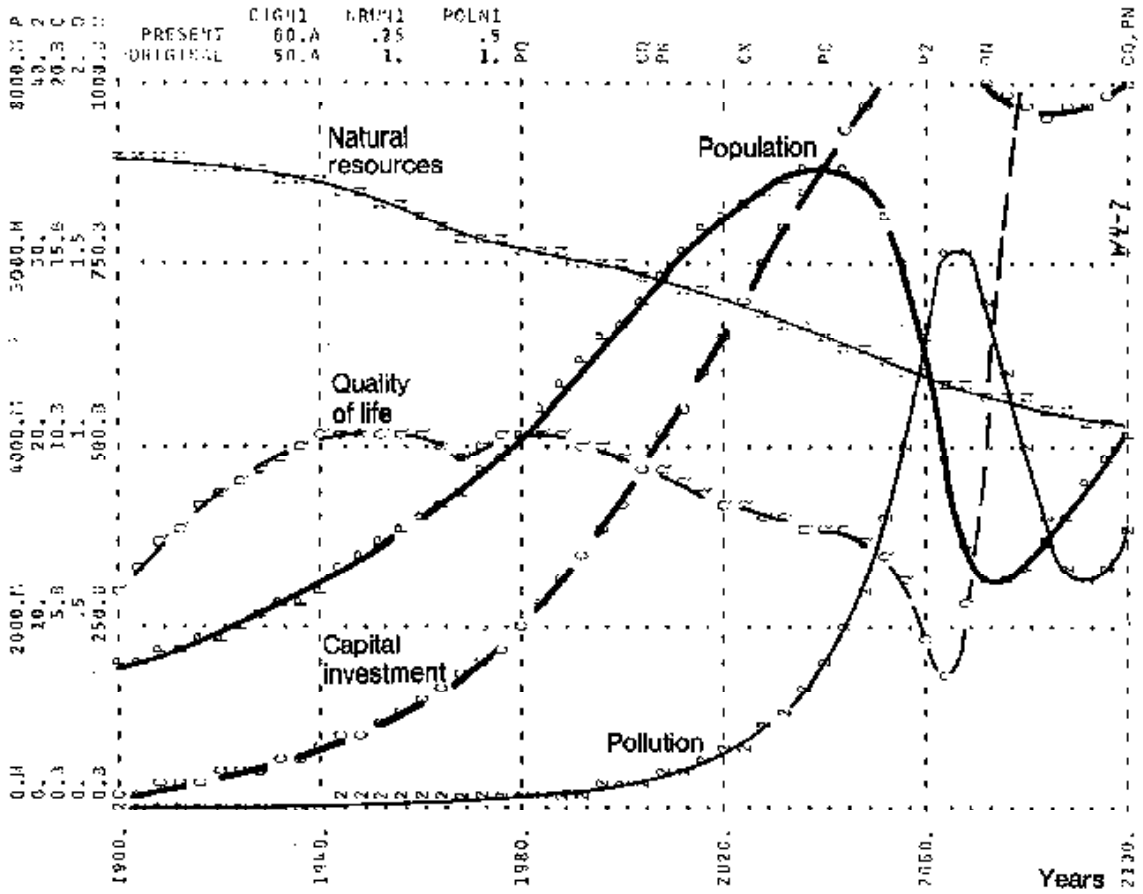
A second "reward" for "hanging in there", Dear, is to show you at least a few results from Forrester's original model and its subsequent modifications. You can find many examples on the internet; here, I'll show you just a little, first as described by Forrester himself.[10]

> The model of world interactions showed different alternative futures depending on whether social policies are adopted to limit population growth while a high standard of living is still possible or whether the future is ignored until population is suppressed by pollution, crowding, disease, water and resource shortage, social strife, hunger…

[10] Quotation taken from Forrester's 7 October 1970 testimony before the Subcommittee on Urban Growth of the Committee on Banking and Currency, US House of Representatives; you can find his full statement on the internet using his name and the title: *Counterintuitive Behavior of Social Systems.*

> It is certain that resource shortage, pollution, crowding, disease, food failure, war, or some other equally powerful force will limit population and industrialization if persuasion and psychological factors do not. Exponential growth cannot continue forever. At present population growth rates, there would remain only one square yard per person in less than 400 years.
>
> Our greatest challenge is to guide the transition from growth to equilibrium. There are many possible mechanisms for limiting growth. That current growth rates of population and industrialization will stop is inevitable. Unless we choose favorable processes to limit growth, the social and environmental systems by their internal processes will choose for us. The natural mechanisms for terminating exponential growth appear the least desirable. Unless the world understands and begins to act soon, civilization will be overwhelmed by forces we have created but can no longer control.

An illustration of what Forrester was warning about is shown below.



In the above figure (a better copy of which I couldn't find on the internet), the most important (but almost illegible) numbers are the dates along the

horizontal- or x-axis (or "abscissa"): these dates are indicated in 40-year intervals from year 1900 to 2100. The numbers along the vertical- or y-axis (or "ordinate") aren't so significant: "parameters" (i.e., adjustable values) in the model were manipulated so that generally the curves follow historical data between 1900 and the then-current date of 1970. The most important features of the "scenario" depicted by the above figure (i.e., with specific values chosen for the many parameters) are the huge increase in pollution that could occur during your lifetime and (especially because of pollution's influence on agriculture) the associated "population plunge" around the middle of this century.

And still another "reward" for "hanging in there", Dear, is that, now, you might better appreciate the writings of Donella (or "Dana") Meadows, who was one of the principal researchers of the first two major applications of the MIT model and the lead author of the two popular books that describe the results.[11] The following is from the Preface to the second book:[12]

> Twenty years ago we wrote a book called *The Limits to Growth*. It described the prospects for growth in the human population and the global economy during the coming century. In it we raised questions such as: What will happen if growth in the world's population continues unchecked? What will be the environmental consequences if economic growth continues at its current pace? What can be done to ensure a human economy that provides sufficiently for all and that also fits within the physical limits of the Earth?… Newspaper headlines announced: A COMPUTER LOOKS AHEAD AND SHUDDERS… STUDY SEES DISASTER BY YEAR 2100… SCIENTISTS WARN OF GLOBAL CATASTROPHE.
>
> The book was interpreted by many as a prediction of doom, but it was not a prediction at all. It was not about a preordained future. It was about a choice. It contained a warning, to be sure, but also a message of promise. Here are the three summary conclusions we wrote in 1972. The second of them is the promise, a very optimistic one, but our analysis justified it then and still justifies it now. Perhaps we should have listed it first.
>
> 1. If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years. The most probable result will be a sudden and uncontrollable decline in both population and industrial capacity.

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[11] *The Limits to Growth* (Donella H. Meadows *et al.,* New York: Universe Books, 1972 – which reportedly sold more than 9 million copies!) and *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future* (Donella H. Meadows *et al.,* Chelsea Green Press, Post Mills, VT, 1992).

[12] Copied from the webpage of the Context Institute at http://www.context.org/ICLIB/IC32/Meadows.htm.

2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his or her individual human potential.

3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.

To us those conclusions spelled out not doom but challenge – how to bring about a society that is materially sufficient, socially equitable, and ecologically sustainable, and one that is more satisfying in human terms than the growth-obsessed society of today.

In one way and another, we've been working on that challenge ever since. Millions of other people have been working on it too. They've been exploring energy efficiency and new materials, nonviolent conflict resolution and grassroots community development, pollution prevention in factories and recycling in towns, ecological agriculture and international protocols to protect the ozone layer. Much has happened in twenty years to bring about technologies, concepts, and institutions that can create a sustainable future. And much has happened to perpetuate the desperate poverty, the waste of resources, the accumulation of toxins, and the destruction of nature that are tearing down the support capacity of the earth.

When we began working on the present book, we simply intended to document those countervailing trends in order to update *The Limits to Growth* for its reissue on its twentieth anniversary. We soon discovered that we had to do more than that. As we compiled the numbers, reran the computer model, and reflected on what we had learned over two decades, we realized that the passage of time and the continuation of many growth trends had brought the human society to a new position relative to its limits.

In 1971 we concluded that the physical limits to human use of materials and energy were somewhere decades ahead. In 1991, when we looked again at the data, the computer model, and our own experience of the world, we realized that in spite of the world's improved technologies, the greater awareness, the stronger environment policies, [yet] many resource and pollution flows had grown beyond their sustainable limits.

That conclusion came as a surprise to us, and yet not really a surprise. In a way we had known it all along. We had seen for ourselves the leveled forests, the gullies in the croplands, the rivers brown with silt. We knew the chemistry of the ozone layer and the greenhouse effect. The media had chronicled the statistics of global fisheries, groundwater drawdowns, and the extinction of species. We discovered, as we began to talk to colleagues about the world being "beyond the limits", that they did not question that conclusion. We found many places in the literature of the past twenty years where authors had suggested that resource and pollution flows had grown too far, some of which we have quoted in [our] book.

But until we started updating *The Limits to Growth* we had not let our minds fully absorb the message. The human world is beyond its limits. The present way of doing things is unsustainable. The future, to be viable at all, must be one of drawing back, easing down, healing. Poverty cannot be ended by indefinite material growth; it will have to be addressed while the material human economy contracts. Like everyone else, we didn't really want to come to these conclusions…

As far as we can tell from the global data, from the World3 model, and from all we have learned in the past twenty years, the three conclusions we drew in *The Limits to Growth* are still valid, but they need to be strengthened. Now we would write them this way:

1. Human use of many essential resources and generation of many kinds of pollutants have already surpassed rates that are physically sustainable. Without significant reductions in material and energy flows, there will be in the coming decades an uncontrolled decline in per capita food output, energy use, and industrial production.

2. This decline is not inevitable. To avoid it, two changes are necessary. The first is a comprehensive revision of policies and practices that perpetuate growth in material consumption and in population. The second is a rapid, drastic increase in the efficiency with which materials and energy are used.

3. A sustainable society is still technically and economically possible. It could be much more desirable than a society that tries to solve its problems by constant expansion. The transition to a sustainable society requires a careful balance between long-term and short-term goals and an emphasis on sufficiency, equity, and quality of life rather than on quantity of output. It requires more than productivity and more than technology; it also requires maturity, compassion, and wisdom.

These conclusions constitute a conditional warning, not a dire prediction. They offer a living choice, not a death sentence. The choice isn't necessarily a gloomy one. It does not mean that the poor must be frozen in their poverty or that the rich must become poor. It could actually mean achieving at last the goals that humanity has been pursuing in continuous attempts to maintain physical growth.

We hope the world will make a choice for sustainability. That is why we have written our book. But we do not minimize the gravity or the difficulty of that choice. We think a transition to a sustainable world is technically and economically possible, maybe even easy, but we also know it is psychologically and politically daunting. So much hope, so many personal identities, so much of modern industrial culture has been built upon the premise of perpetual material growth…

The ideas of limits, sustainability, sufficiency, equity, and efficiency are not barriers, not obstacles, not threats. They are guides to a new world. Sustainability, not better weapons or struggles for power or material accumulation, is the ultimate challenge to the energy and creativity of the human race.

We think the human race is up to the challenge. We think that a better world is possible, and that the acceptance of physical limits is the first step toward getting

> there. We see "easing down" from unsustainability not as a sacrifice, but as an opportunity to stop battering against the earth's limits and to start transcending self-imposed and unnecessary limits in human institutions, mindsets, beliefs, and ethics. That is why we finally decided not just to update and reissue *The Limits to Growth*, but to rewrite it completely and to call it *Beyond the Limits*.

The above, however, provides you with just a first and perhaps not an adequate sample of Donella Meadows' writing; for the above, her writing was necessarily put through her co-authors' filters. In the next chapter, I'll show you some "unfiltered Donella"; to read more, I encourage you to explore on the internet. In 1985 she resigned her professorship in environmental studies at Dartmouth College to become a newspaper columnist. At http://www.pcdf.org/meadows/default.htm are assembled all her newspaper columns; she died in 2001 at the relatively young age of 59.

Still another "award" for "hanging in there", Dear, is that, with the above, I've presented you with at least a glimpse at the applications of "systems analysis" to social problems. The following quotation shows you Forrester's assessment of the potentials of such methods:[13]

> We are on the threshold of a great new era in human pioneering. In the past there have been periods characterized by geographical exploration. Other periods have dealt with the formation of national governments. At other times the focus was on the creation of great literature. Most recently we have been through the pioneering frontier of science and technology… The next frontier for human endeavor is to pioneer a better understanding of environmental, economic, and social systems. The means are available. The task will be no easier than past development of science and technology. For the next 50 years we can expect rapid advance in understanding the complex dynamics of social systems…

In fact, Dear, if you're wondering about what career to choose, I'm sure that the challenges of trying to develop better models of the Human System would keep you busy for the rest of your life – assuming you could obtain funding! If such a research career interests you, then I'd recommend that you get a broad education in many fields and an in-depth education in at least one. To explain why, let me show you a two-part figure from the online book[14] *Dynamics of Complex Systems* by Yaneer Bar-Yam (who obtained his Ph.D. from and now teaches at MIT). The first part of this

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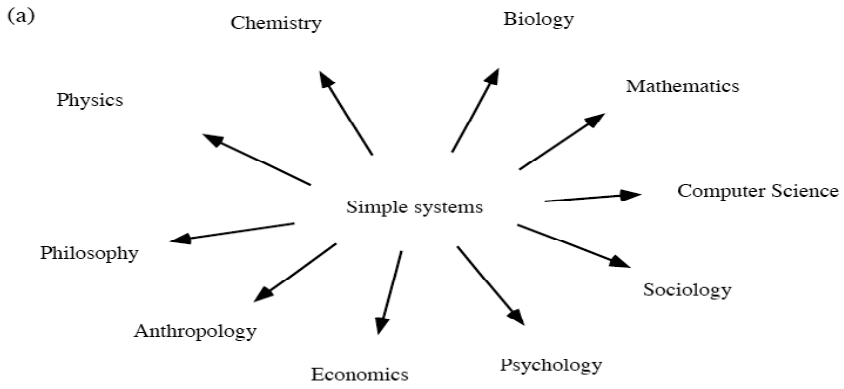
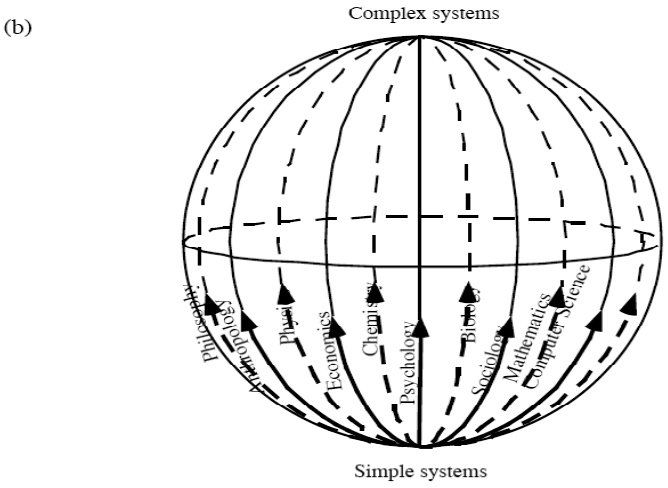
[13] Quotations from Jay W. Forrester's article "Counterintuitive Behavior of Social Systems", *Technology Review*, Vol. 73, No. 3, Jan. 1971, pp. 52-68.

[14] Available at http://necsi.org/publications/dcs/.

figure, i.e., "(a)", below, schematically shows how "simple systems" are analyzed (commonly via reductionism) in various "disciplines" such as physics, chemistry, etc.



The second part of the figure, i.e., "(b)", shown below, schematically suggests how different disciplines must be integrated to develop models of complex systems (such as the Human System). In this figure, if you can't read the labels leaving the "south pole", they're the same as in the first part of the figure [i.e., in (a), above].



Yet, Dear, if you desire to pursue such research, it doesn't follow that you must become an expert in many fields, which would be an essentially impossible task! Instead, you must be an expert in at least one discipline and you should learn enough about other disciplines so you at least know some of their vocabularies (and additionally, you should learn some of the basic principles in their fields). Consequently, if you choose to seek expertise in a specific field such as computer sciences (emphasizing, e.g., artificial intelligence or numerical methods) or physics or economics or… then while you're obtaining at least your M.S. in your chosen specialty, simultaneously take introductory courses in other relevant fields (such as anthropology, biology, chemistry, economics, psychology, etc.). Then, for your Ph.D., you could "get serious" and seek degrees in specific aspects of system science or sustainability.[15]

As for my concern expressed by "assuming that you could obtain funding", be aware that, especially since President Reagan in the US and Prime Minister Thatcher in the UK, conservatives in general and the "Religious Right" in particular have been hostile to systems analysis. For example, Richard W. Chadwick writes:[16]

> My understanding is that sometime after Margaret Thatcher took office as prime minister, the SARU [the UK Systems Analysis Research Unit] team was asked to come in and tell her what global modeling was about and why it was useful. As I have been given to understand it, the team members present began to explain to her the systems dynamics approach. After patiently listening for perhaps 15 minutes, I understand that she told them they were all fired, but they had a year to find jobs, and she got up and left the room.

If that actually occurred, it probably reveals only one of several types of criticisms of system modeling – and in any case, it might be useful to you if I provided at least a few details of these different types of criticism.

The Reagan-Thatcher type of criticism was probably derived from their hostility to Communism, which to them probably meant (at least in part) "central planning". Attempts at central planning of the economy were certainly a dominant feature of the USSR, and apparently (e.g., from

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[15] See the article by C.H. Deutsch in the 25 Dec. 2007 issue of *The New York Times* entitled "A Threat So Big, Academics Try Collaboration"; http://www.nytimes.com/2007/12/25/business/25sustain.html.

[16] You can find Chadwick's interesting article on the internet. It's entitled *Global modeling: origins, assessment, and alternative futures;* originally it was published in SIMULATION & GAMING, Vol. 31, No. 1, March 2000, pp. 50-73.

Chadwick's article, referenced above), some "central planners" of the Soviet Union tried to develop and use models of their economic system. I suspect that, consequently, when Thatcher saw that economists in the UK were developing similar models, she immediately terminated their work (and their employment). In my opinion, that was "knee-jerk" stupidity: so long as the UK (and similarly the US) remains representative democracies, there's no harm in trying to understand how economic systems operate! Data support the concept that understanding can lead to control, but so long as the people control the government and have access to all relevant information, then modeling should be encouraged not terminated.

A second type of criticism of economic- and world-system modeling is more basic, more serious (and more sad), and more prevalent in the US, especially among the "Religious Right". In essence, this type of criticism is that the worldview depicted by computer models conflicts with their own worldview, e.g., "The world (population and/or economy and/or climate and/or…) isn't governed by a set of a few thousand equations but by God!" Thereby, for example, they don't fear sea-level rise caused by global warming, because they fear only their God, e.g., at *Jeremiah 5,* 22:

> "Should you not fear me?" declares the Lord. "Should you not tremble in my presence? I made the sand a boundary for the sea, an everlasting barrier it cannot cross. The waves may roll, but they cannot prevail; they may roar, but they cannot cross it."

So, who cares about global warming?! – especially since the Lord apparently doesn't recognize tsunamis! Stated differently, the criticism by such people is that their own model (originally developed by prehistoric savages!) is better than any computer model described objectively, programmed on a computer, and solved numerically! Such criticism was addressed in a 1988 article by John Sterman (director of the MIT System Dynamics Group):[17]

> Fortunately, everyone is already familiar with models. People use models – mental models – every day. Our decisions and actions are based not on the real world, but on our mental images of that world, of the relationships among its parts, and of the influence our actions have on it.
>
> Mental models have some powerful advantages. A mental model is flexible; it can take into account a wider range of information than just numerical data; it can be

[17] You can find his complete article on the internet. Its title is *A Skeptic's Guide to Computer Models*. In what I've quoted, I've suppressed his references, replacing them with "…".

adapted to new situations and be modified as new information becomes available. Mental models are the filters through which we interpret our experiences, evaluate plans, and choose among possible courses of action. The great systems of philosophy, politics, and literature are, in a sense, mental models.

But mental models have their drawbacks also. They are not easily understood by others; interpretations of them differ. The assumptions on which they are based are usually difficult to examine, so ambiguities and contradictions within them can go undetected, unchallenged, and unresolved. That we have trouble grasping other peoples' mental models may seem natural. More surprising, we are not very good at constructing and understanding our own mental models or using them for decision making. Psychologists have shown that we can take only a few factors into account in making decisions… In other words, the mental models we use to make decisions are usually extremely simple. Often these models are also flawed, since we frequently make errors in deducing the consequences of the assumptions on which they are based.

Our failure to use rational mental models in our decision making has been well demonstrated by research on the behavior of people in organizations (e.g., families, businesses, the government). This research shows that decisions are not made by rational consideration of objectives, options, and consequences. Instead, they often are made by rote, using standard operating procedures that evolve out of tradition and adjust only slowly to changing conditions… These procedures are determined by the role of the decision makers within the organization, the amount of time they have to make decisions, and the information available to them. But the individual perspectives of the decision makers may be parochial, the time they have to weigh alternatives insufficient, and the information available to them dated, biased, or incomplete. Furthermore, their decisions can be strongly influenced by authority relations, organizational context, peer pressure, cultural perspective, and selfish motives. Psychologists and organizational observers have identified dozens of different biases that creep into human decision making because of cognitive limitations and organizational pressures… As a result, many decisions turn out to be incorrect; choosing the best course of action is just too complicated and difficult a puzzle.

The value in computer models derives from the differences between them and mental models. When the conflicting results of a mental and a computer model are analyzed, when the underlying causes of the differences are identified, both of the models can be improved. Computer modeling is thus an essential part of the educational process rather than a technology for producing answers. The success of this dialectic depends on our ability to create and learn from shared understandings of our models, both mental and computer. Properly used, computer models can improve the mental models upon which decisions are actually based and contribute to the solution of the pressing problems we face.

In his article entitled *Counterintuitive Behavior of Social Systems* (already referenced), Forrester was more blunt about the inadequacy of such "mental models" when applied to social systems:

> It is my basic theme that the human mind is not adapted to interpreting how social systems behave. Our social systems belong to the class called multi-loop nonlinear feedback systems. In the long history of evolution it has not been necessary for man to understand these systems until very recent historical times. Evolutionary processes have not given us the mental skill needed to properly interpret the dynamic behavior of the systems of which we have now become a part…
>
> Until recently there has been no way to estimate the behavior of social systems except by contemplation, discussion, argument, and guesswork. To point a way out of our present dilemma about social systems, I… sketch an approach that combines the strength of the human mind and the strength of today's computers…
>
> Our social systems are far more complex and harder to understand than our technological systems. Why, then, do we not use the same approach of making models of social systems and conducting laboratory experiments on those models before we try new laws and government programs in real life? The answer is often stated that our knowledge of social systems is insufficient for constructing useful models. But what justification can there be for the apparent assumption that we do not know enough to construct models but believe we do know enough to directly design new social systems by passing laws and starting new social programs? I am suggesting that we now do know enough to make useful models of social systems. Conversely, we do not know enough to design the most effective social systems directly without first going through a model-building experimental phase. But I am confident, and substantial supporting evidence is beginning to accumulate, that the proper use of models of social systems can lead to far better systems, laws, and programs… It is now possible to construct in the laboratory realistic models of social systems. Such models are simplifications of the actual social system but can be far more comprehensive than the mental models that we otherwise use as the basis for debating governmental action.
>
> Before going further, I should emphasize that there is nothing new in the use of models to represent social systems. Each of us uses models constantly. Every person in his private life and in his business life instinctively uses models for decision making. The mental image of the world around you which you carry in your head is a model. One does not have a city or a government or a country in his head. He has only selected concepts and relationships which he uses to represent the real system. A mental image is a model. All of our decisions are taken on the basis of models. All of our laws are passed on the basis of models. All executive actions are taken on the basis of models. The question is not to use or ignore models. The question is only a choice among alternative models.

The mental model is fuzzy. It is incomplete. It is imprecisely stated. Furthermore, within one individual, a mental model changes with time and even during the flow of a single conversation. The human mind assembles a few relationships to fit the context of a discussion. As the subject shifts so does the model. When only a single topic is being discussed, each participant in a conversation employs a different mental model to interpret the subject. Fundamental assumptions differ but are never brought into the open. Goals are different and are left unstated. It is little wonder that compromise takes so long. And it is not surprising that consensus leads to laws and programs that fail in their objectives or produce new difficulties greater than those that have been relieved.

For these reasons we stress the importance of being explicit about assumptions and interrelating them in a computer model. Any concept or assumption that can be clearly described in words can be incorporated in a computer model. When done, the ideas become clear. Assumptions are exposed so they may be discussed and debated.

But the most important difference between the properly conceived computer model and the mental model is in the ability to determine the dynamic consequences when the assumptions within the model interact with one another. The human mind is not adapted to sensing correctly the consequences of a mental model. The mental model may be correct in structure and assumptions but, even so, the human mind – either individually or as a group consensus – is most apt to draw the wrong conclusions. There is no doubt about the digital computer routinely and accurately tracing through the sequences of actions that result from following the statements of behavior for individual points in the model system. This inability of the human mind to use its own mental models is clearly shown when a computer model is constructed to reproduce the assumptions held by a single person. In other words, the model is refined until it is fully agreeable in all its assumptions to the perceptions and ideas of a particular person. Then, it usually happens that the system that has been described does not act the way the person anticipated. Usually there is an internal contradiction in mental models between the assumed structure and the assumed future consequences. Ordinarily the assumptions about structure and internal motivations are more nearly correct than are the assumptions about the implied behavior.

The kinds of computer models that I am discussing are strikingly similar to mental models. They are derived from the same sources. They may be discussed in the same terms. But computer models differ from mental models in important ways. The computer models are stated explicitly. The ‘mathematical’ notation that is used for describing the model is unambiguous. It is a language that is clearer, simpler, and more precise than such spoken languages as English or French. Its advantage is in the clarity of meaning and the simplicity of the language syntax. The language of a computer model can be understood by almost anyone, regardless of educational background. Furthermore, any concept and relationship that can be clearly stated in ordinary language can be translated into computer model language.

> There are many approaches to computer models. Some are naïve. Some are conceptually and structurally inconsistent with the nature of actual systems. Some are based on methodologies for obtaining input data that commit the models to omitting major concepts and relationships in the psychological and human reaction areas that we all know to be crucial. With so much activity in computer models and with the same terminology having different meanings in the different approaches, the situation must be confusing to the casual observer. The key to success is not in having a computer; the important thing is how the computer is used. With respect to models, the key is not to computerize a model, but instead to have a model structure and relationships which properly represent the system that is being considered.
>
> I am speaking here of a kind of computer model that is very different from the models that are now most common in the social sciences. Such a computer model is not derived statistically from time-series data. Instead, the kind of computer model I am discussing is a statement of system structure. It contains the assumptions being made about the system. The model is only as good as the expertise which lies behind its formulation. Great and correct theories in physics or in economics are few and far between. A great computer model is distinguished from a poor one by the degree to which it captures more of the essence of the social system that it presumes to represent. Many mathematical models are limited because they are formulated by techniques and according to a conceptual structure that will not accept the multiple-feedback-loop and nonlinear nature of real systems. Other models are defective because of lack of knowledge or deficiencies of perception on the part of the persons who have formulated them.
>
> But a recently developed kind of computer modeling is now beginning to show the characteristics of behavior of actual systems. These models explain why we are having the present difficulties with our actual social systems and furthermore explain why so many efforts to improve social systems have failed. In spite of their shortcomings, models can now be constructed that are far superior to the intuitive models in our heads on which we are now basing national social programs.
>
> This approach to the dynamics of social systems differs in two important ways from common practice in social sciences and government. There seems to be a common attitude that the major difficulty is shortage of information and data. Once data [are] collected, people then feel confident in interpreting the implications. I differ on both of these attitudes. The problem is not shortage of data but rather our inability to perceive the consequences of the information we already possess. The system dynamics approach starts with the concepts and information on which people are already acting. Generally these are sufficient. The available perceptions are then assembled in a computer model which can show the consequences of the well-known and properly perceived parts of the system. Generally, the consequences are unexpected.

But even if such responses can suppress naïve criticism of computer models of social systems, it's not so easy to suppress more serious criticism about

the adequacy of such models. In fact, responding to such criticism, attempting to improve the models, will probably require close to a century of work by extremely intelligent, competent, and diligent people – such as you!

If you think that someday you might like to try to contribute to improving models of the Human System, then, Dear, please be aware of a number of "ground rules". One of these "ground rules" is: there's "no way" that anyone will ever develop a "complete" model of the Human System. Not only is the Human System far too complex to be modeled "completely", but someone smart enough to be able to come close to being able to do it wouldn't try!

But that a complete model can't be developed doesn't matter, because a second "ground rule" concerns the nature of all useful models: they're simplifications capable of capturing the essence. For example, Newton's model for the Solar System was obviously wrong (it included the gravitational force between only the Sun and the Earth), but it captured the essence of the dynamics of the Earth-Sun System. In fact, to this day, there's no way – even if all the computers on Earth were slaved together – that the "complete" equations describing the dynamics of the Solar System could be solved (even if the equations could be specified, which they can't, because the masses and locations of all asteroids aren't known). Correspondingly, in developing models of the Human System, the goal is not to describe the behavior of every human – but to attempt to model the essence of the "dynamics" of the system, and from that "essence", perceive general features.

Consistent with the second "ground rule" of modeling (viz., to try to capture the essence of the system), a third ground rule applicable to all attempts at modeling is: don't confuse the map with the territory. That is, Dear, don't confuse models of reality with reality. Three important "corollaries" of this "rule" are:

1) The results of any model are always an approximation to reality,

2) The goal of all modeling is not to describe reality but to try to describe important and relevant features of reality – or alternatively, to disregard unimportant details, thereby to be able to discern, describe, and simulate important behavior, and

3) If you propose to use a map to help you find your way through some territory, then first, make sure that you know where you want to go!

I'll shortly try to explain what this third corollary means; in short, it means: build models appropriate for specific applications.

My fourth and final "ground rule" is: models evolve. That is, current computer-models of the Human System are just the next stage in a long evolution of "world models" – and certainly this evolution will continue. To see what I mean, consider the following overview:

- "In the beginning", primitive people concocted "world models" (for their "worlds") that typically didn't extend beyond their visual or hunting-and-gathering range and that included the imagined presence of spirits in essentially everything (the wind, the forest, streams, lakes, mountains…).

- Starting about 5,000 years ago, the ancient Sumerians, Egyptians, Mesopotamians, Hindus, Persians, Jews, Arabs, etc., developed various "flat-Earth models" that contained various imagined "deifications" of laws, customs, morals, social order, peace, justice, love, etc. – as still depicted in their descendants' "holy books" (e.g., in the Vedas, the Bible, the Quran, etc.); thereby, these silly books depict gods of war, gods of vengeance, gods of justice, gods of love, and so on.

- About 500 years ago, when scientific humanism began to gain strength, improved models were developed that depicted a spherical Earth and the concept that customs and laws were made not by "the gods" but by people. Perhaps this was best enshrined when the authors of our Constitution wrote "We the people…"

- Then, about 50 years ago, space travel needed a more accurate model of the physical form of the Earth (an oblate spheroid), and computer models of human interactions and their exploitation of the environment began to be developed.

- Fifty years from now, my grandchildren will have contributed to this evolution by developing models that ____ (Those, kid, are more blanks for you to fill in!)

Consequently, Dear, my response to Thatcher's firing all the UK system modelers would be something similar to:

> Don't fire the modern model-makers; fire all the damn clerics! Computer based models are a helluva lot better than the word-models describing a flat Earth controlled by some magic man in the sky! Which model is better: that $dN/dt = \gamma N$ or that if you strap explosives around your waist and blow yourself up amongst a crowd of bystanders, then you'll go directly to Paradise?!

All of which was a preamble to my comments on "improving… (world) models".

Dear: It'll be an enormous task, probably requiring a century of substantial effort, to significantly improve models of the Human System – to the point where they can be trusted to describe reality "adequately". Simultaneously, comparable effort will be needed to "test the models" (to see if, in fact, they do "adequately" describe reality). Further, experience (based on data from essentially all other branches of science) leads to the strong recommendation that, to improve models of the Human System, by far the best way is almost certainly to demand that modeling efforts be led by data.

Of course it's difficult to test existing world models – the only way to test them is to determine if their dire predictions were correct! Yet, such models can be tested by applying them to historical events and to cases with smaller spatial and temporal scales, and by separately testing various parts of the models ("submodels"). Similar is done for climate models, and for that matter, many current economic models (being tested for companies, cities, states, and nations) can be viewed as submodels of world models. Further, given the comments re. the 2005 World Environment Day by Klaus Toepfer, the chief of the UN's Environment Program, that "the battle for sustainable development, for delivering a more environmentally stable, just and healthier world, is going to be largely won and lost in our cities," it would seem wise to apply versions of "world models" to various cities throughout the world, to test abilities to model such "simpler" situations.

Still another way to test such models and submodels (and at various spatial and temporal scales) is to apply them to what I describe as "otherwise-uncontrolled social experiments", by which I mean the following. Today, there are I-don't-know-how-many "social experiments" being conducted throughout the world – but surely there are many millions of them. As a few examples, almost certainly (I hope!) the UN will soon change Security Council membership, the US Congress has recently approved the Central America Free Trade Agreement (CAFTA), the government in our state has approved a plan to reduce "welfare rolls", the Board of Education for our county has approved year-round school (to alleviate school crowding), and in our little town, the City Council has given approval for a new Wal-Mart and a new "distribution center" (for building supplies). All such activities are "social experiments", and from a scientific viewpoint, all are "uncontrolled" – not only in the sense that essentially no one seems to be carefully monitoring and attempting to model the consequences but also in the sense that usually no "control" study is initiated to permit comparison.

Let me separately address those two aspects of "control". First, as for "monitoring and modeling consequences", almost certainly there will continue to be a huge number of commentaries on such "social experiments", e.g., "The advantages of the changes in Security Council membership were…", "CAFTA has led to…", "Now that there are fewer people on welfare…", and so on. Currently, however, such commentaries are typically little more than attempts to push some political agenda.

In contrast, what I would advocate is that a small fraction (~ 1%) of the cost of any "social experiment" be competitively awarded to anthropology (and other relevant) departments in nearby universities for monitoring, attempting to model, and producing a readable public report on the consequences of any such experiment. And certainly I'd admit that, from a scientific perspective, there are huge inadequacies in the "design" of such experiments (commonly there are a huge number of uncontrolled and even unmonitored variables), but studies of the Human System must start somewhere! If the behavioral sciences are allotted appropriate financial resources, then over time (many decades!), I'm certain that they will develop knowledge as well as have the physical and biological sciences.[18]

With respect to attempts to develop some "controls" for such social experiments, although the controls couldn't match the completeness of "laboratory controls", yet in most cases, some measure of control would be possible – even while satisfying the widespread and supportable demand that no human (either individually or in groups) ever be used as a "guinea pig". For example, in most social experiments (which humans will conduct anyway!), usually some other situation or circumstance could be monitored

[18] Incidentally, Dear, I'd strongly argue against any suggestion that the research be done anywhere else than at universities (not, e.g., by private consulting firms), because "the bottom line" at any private firm is necessarily financial profitability; any consultant who can't be profitable will almost certainly soon be out of a job. At universities, in contrast, the bottom line is to increase knowledge – and any faculty member who can't do that should soon be out of a job. Thereby, one can see (once again) the enormous benefits available to the public from universities (at least, from "real" universities, not the "fake" ones in this country that are run by various religious organizations, such as Bob Jones "University", Brigham Young "University", Notre Dame "University", Regent "University", etc., whose "primary mission" is not to pursue "truth" but to promote their organization's dogma *via* propaganda). And with that thought, I'm reminded of Thomas Jefferson's suggestion for his tombstone: "Here was buried Thomas Jefferson, author of the Declaration of American Independence, of the Statue of Virginia for Religious Freedom, and Father of the University of Virginia." For this university, the creation of which was his prime passion during the final 10 years of his life (he died at age of 83), he strove that it be "based on the illimitable freedom of the human mind to explore and to expose every subject susceptible of its contemplation."

to provide some measure of comparison. To see what I mean, consider some possibilities for some of the cases mentioned above.

- If the aforementioned Wal-Mart store and "distribution center" are built in our town, then almost certainly, similar won't be built in our neighboring town (about 30 miles to the West); thereby, that town could be used to provide some measure of comparison of consequences (to smaller retailers, to employment, to traffic, etc.) of such developments.

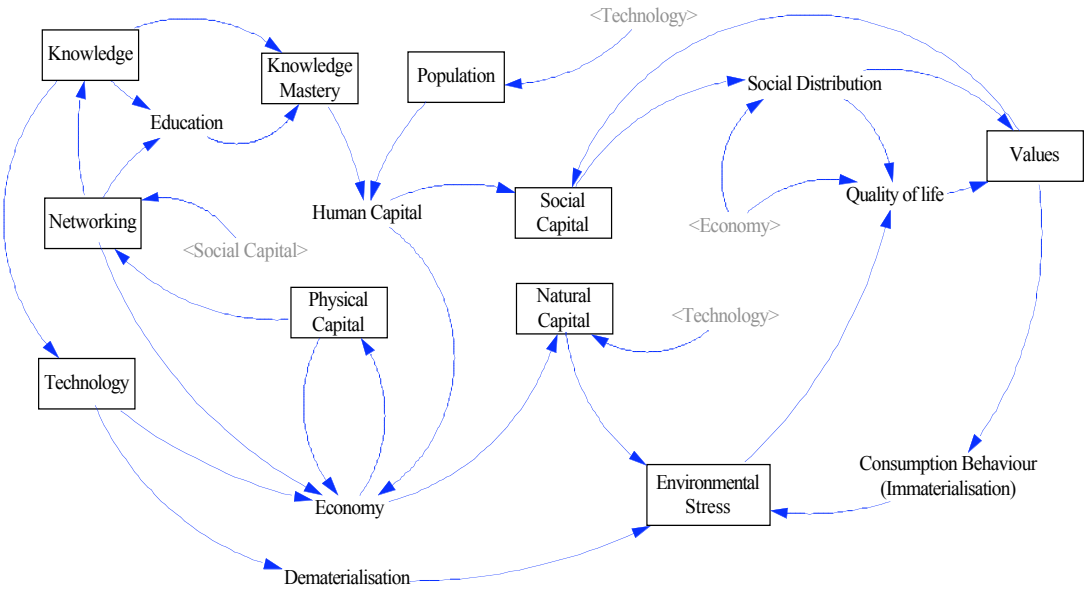
- If our county does proceed with year-round schooling, it needn't be done everywhere in the county. For example, whereas the schools in our town aren't so crowded as elsewhere in the county, our town's schools could continue with their current schedule and be used to provide some measure of comparison of consequences of the "experiment", e.g., to student achievements, student health, juvenile delinquency rates, etc.

Similar could be done for essentially all such experiments. Thus, to gain some understanding about the possibility that the UN would function better with different membership (and maybe different rules) in the Security Council, then try it out, e.g., by incorporating into any modification, rules for an "experimental period". For example, a ten-year experiment could proceed as follows. For the first three years, let Australia, Brazil, Germany, India, and Japan have "veto power" in the Security Council – and see what happens; then for the next three years, replace the veto powers of all members of the Security Council with majority rule – and monitor what happens; and then for the next four years, try my recommendation (!): let all nations be members of the Security Council but weight each nation's vote proportional to the amount they pay to maintain the UN (and simultaneously, in the General Assembly, weight each nation's vote proportional to the number of people represented – allotting essentially zero weight for autocrats and dictators who represent only themselves or some ruling clique). Then, for the next decade, chose a method based on experience rather than speculation.

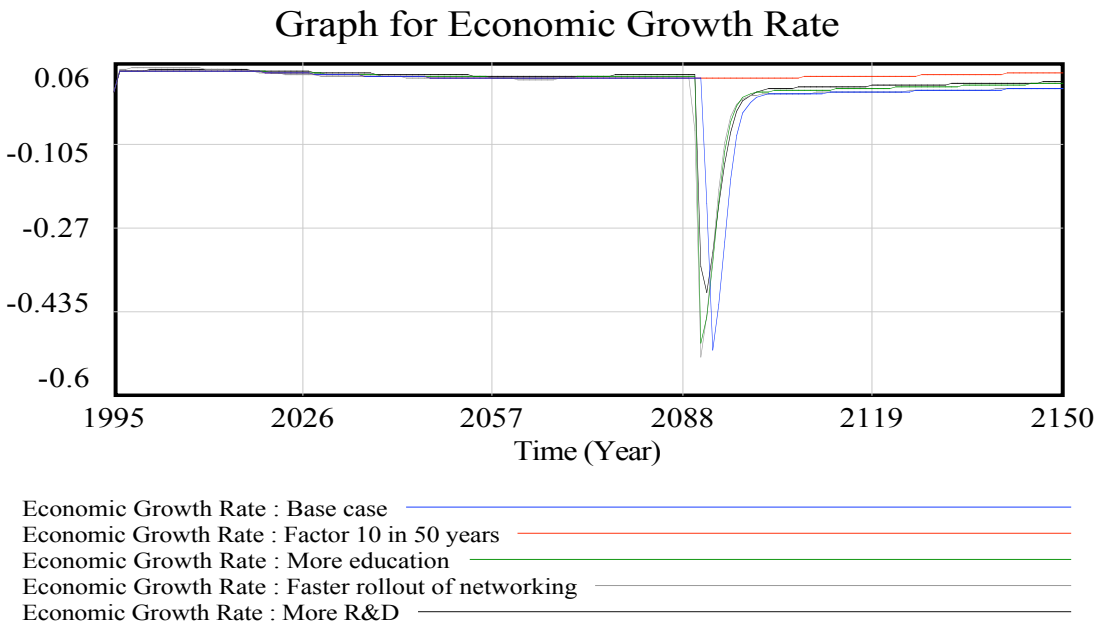
Of course there would be screams of protests (from both liberals and conservatives) against such experiments. Liberals will continue to demand change, and conservatives will continue to defend the *status quo*. But "for crying out loud", the only way to learn is by experience, so conduct experiments – and monitor and try to model them. And of course I'd agree that inadequacies in any such "controls" will cause knowledge to be gained slower than desired, but any increase in knowledge is better than continued ignorance!

All of which leads me to summarize that it's difficult to imagine how humans can be so dumb – except if one becomes as skeptical as I have about the real motives of power-mongering "leaders" (in religions, other businesses, and politics). Some consolation is available, however, in expecting that, a few centuries from now, we might provide historians some comic relief when they see how silly humans were!

Meanwhile, in addition to model testing *via* monitoring all the social experiments now being conducted throughout the world, huge efforts are needed to try to improve current world-models. For example, one obvious area of needed improvement is to try to incorporate the ability of humans to learn – a topic that I'll emphasize in subsequent chapters. For now, and setting aside doubts that probably all of us have, I'll just say that humanity is a "self-organizing" or "emerging" system, capable of modifying its future behavior by learning from past experiences. Humans have done so in the past, as a huge number of examples could illustrate (from learning how to fashion stone tools to the case of terminating atmospheric releases of chlorofluorocarbons that destroy stratospheric ozone). One attempt to incorporate such "learning" into Forrester's world-model is depicted schematically below, along with representative "predictions" of the model.



As you can see from the figure[19] shown below, this world model predicts (for almost all simulations) that there'll be a dramatic decrease in economic growth rate (throughout the world) when you (with a little luck) will be about 100 years old – finally satisfying the condition "when you're older"!



An exceptional case is labeled in the above figure with "Economic Growth Rate: Factor of 10 in 50 years", which is a case in which humans learn and by which the authors mean:

> The "factor 10 scenario" is a popular one amongst "green" thinkers… [It] represents the transition to an economy where the material flows associated with the generation of one monetary unit in the economy is reduced by a factor 10. This transition is done over a 50-year time span.

About the "economic crash" predicted, the authors write:

> The factor 10 framework is the only [one] to avoid the economic crash in the 2090s. This crash is of a scope never experienced before, and the consequences of this catastrophe (compared to which the Black Plague will be a trivial occurrence) are such that any attempt to model what would happen after it is probably doomed to fail. Indeed a drop back of the economic output by nearly 50 percent would be the cause of massive civil unrest, wars over the remaining resources, etc.

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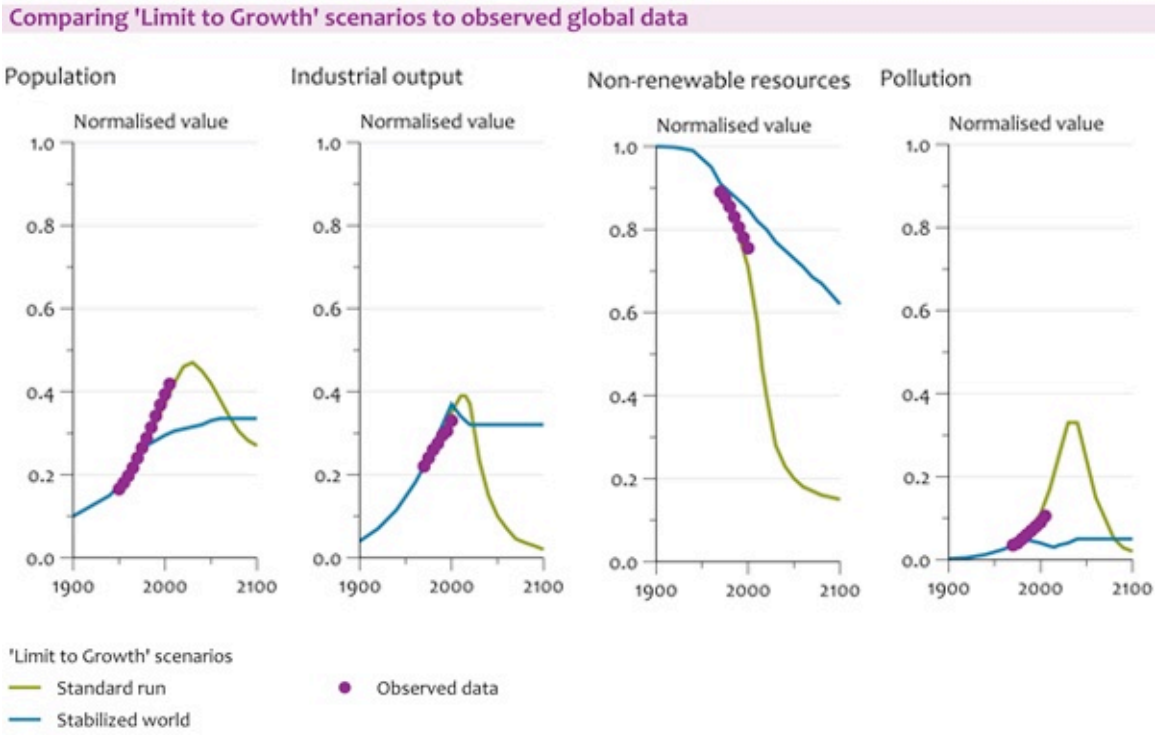
[19] I copied these two figures from the internet; they're from a report entitled *Modelling the Dynamics of our Common Future; the Sustainability Simulation in the TERRA2000 Project* authored by Tom Tesch, Pol T. Descamps, Barry Hughes, and Raoul Weiler; I haven't provided a web address, because recently I found that the one I was using no longer works; to learn more about this model, then in an internet search, use "key words" of the title or any of the authors' names or start at http://www.terra-2000.org/.

But in reality, will such a "crash" occur? Well, Dear, I'm sorry to respond, "I dunno." Some more recent predictions are shown below, copied from the 23 May 2012 Scientific American article[20] by Madhusree Mukerjee entitled "Apocalypse Soon: Has Civilization Passed the Environmental Point of No Return?" The article reviews a 2012 book by Jorgen Randers entitled *2052: A Global Forecast for the Next Forty Years.* In the figure below, all the plots have been normalized to unity (i.e., the curves show fractions of the maximum values); the curves labeled "Stabilized world" are those if controls were in place; the circles show data (for population, industrial output, etc.), and by "Pollution", I think the authors mean carbon dioxide concentrations.



In any case, what I'd bet on is: the scenarios outlined above are a helluva lot more realistic than the "prophecies" found in all the so-called "holy books" – which continue to pollute humanity and which were concocted by various, ignorant, power-mongering clerics. Stated differently, with the growth of population promoted by clueless clerics, the probability that humanity is heading for hell ("compared to which the Black Plague will be a trivial occurrence") is a helluva lot higher than the probability that any human is (or ever has been) heading for heaven!

[20] Available at http://www.scientificamerican.com/article.cfm?id=apocalypse-soon-has-civilization-passed-the-environmental-point-of-no-return.

Now, Dear, although I'm sure that much better submodels are needed (than the one sketched above) to incorporate the abilities of human to learn – and our failures to learn! – yet as for how to develop such submodels (if it's possible!), I must leave the details to brilliant, resourceful, conscientious people such as you. Yet, let me at least "chat a bit" about a few points dealing with possible model limitations. I'll start by just mentioning a few points that you won't understand "until you're older" (☹) – by which I mean, until you've obtained your B.S. in mathematics (with a minor in computational methods), an M.S. in physics, and you're working on your Ph.D. in systems science (with minors in economics and psychology)!

- My first point deals with computational methods and is: don't trust them! If you study them, I bet you'll be amazed to see how, for nonlinear equations, the computational methods, alone, can generate absolutely stunning results that have absolutely nothing to do with the system that you think you're modeling. That is, once you modify your equations so that they can be evaluated using a computer (e.g., using finite differences), then you're dealing with an entirely different system.

- Another point that will take substantial study to understand is that, courtesy developments since pioneering work by von Neumann and John Nash (who was the portrayed in the movie "A Beautiful Mind"), game theory is becoming a unifying tool for many areas of behavioral science, and with more empirical results to define "preferences" of people in different cultures, the potential for modeling the behaviors of different people will correspondingly improve.

- My third point, one that I don't know if you'll appreciate, is this: what a job it will be to develop realistic models of "the human system"! Let me put it this way. Your father is probably one of the most intelligent and diligent people you'll ever meet. You know how hard he works trying to model various oceanic subsystems. If you ask him how hard it would be to develop a realistic model of the ocean, I'm sure he'll tell you that it appears to be essentially impossible – but of course, it depends on what's meant by "realistic". Then, Dear, consider models for "the climate system". They're at least an order of magnitude more complicated that models of the ocean, a large number of the most brilliant and resourceful people in the world are working on climate models, and if you ask them how realistic their models are, they'll respond that it depends on what you mean by "realistic". Now, move up by one or two (or more!) orders of magnitude in difficulty to the case of modeling "the human system". You want a realistic model of the human system? And when would you like that? By next Tuesday – or will three centuries from now be soon enough?!

There is, however, another point dealing with potential model limitations; this one is fairly easy to understand – even for a kid! It deals with the "butterfly effect", which is common for all nonlinear systems (e.g., the

Human System or the Earth's ocean or atmosphere or – combining them – the climate system). In the case of the atmosphere, it's impossible (even theoretically) to forecast atmospheric conditions (i.e., the weather) for more than a few days, because of the "butterfly effect"; that is, because "noise" in the initial conditions, no matter how small (even from a butterfly flapping its wings!) will grow exponentially, eventually becoming larger than any "signal". Yet, it does seem possible to develop models capable of predicting the Earth's climate (i.e., weather conditions averaged over a long time period, customarily taken to be 30 years).

Although that result may seem paradoxical, the resolution is that, in the construction of climate models, long-term averages are take from the outset, i.e., the method used is, not to develop a model for the weather and then average the results to get the climate, but instead, to develop a model for the climate, describing long-term average winds, temperatures, precipitation, radiation, etc. Such models are crude, of course, but apparently they're capable of describing important features of the climate (as verified, for example, by testing the model's ability to simulate ice-age climates). Thereby, the "butterfly effect" is suppressed by taking long-term averages – over the effects of all butterflies!

A similar "butterfly effect" makes it impossible (even theoretically) to predict the motions of all asteroids in the Solar System; yet the motions of the planets are predictable – even if it's impossible (even theoretically) to predict when an arbitrary asteroid might hit the Earth.

In the case of the nonlinear Human System's ability to learn, a similar "butterfly effect" almost certainly occurs. As example:

- During the 1700s, there was an amazing crop of "butterflies" whose ideas dramatically changed humanity's future: in Edinburgh, Scotland, alone, there were the economist Adam Smith, the engineer James Watt, the philosopher David Hume, and the poet and Humanist Robert Burns; in America, there were Thomas Paine, Thomas Jefferson, and Alexander Hamilton; and in France there was, for example, Voltaire (whose penetrating, witty remarks were perhaps the most important reason why Europe, today, is so far ahead of the US in rejecting the silly idea of god).

- In the 1800s there were butterflies such as Charles Darwin, Michael Faraday, and James Maxwell – and locusts such as Karl Marx (who didn't appreciate that hypotheses needed to be tested), and

- Certainly the 1900s had plenty of both butterflies (Plank, Einstein, Bertrand Russell, Mahatma Gandhi, Martin Luther King, Nelson Mandela, Mikhail Gorbachev, Kofi Anan…) and locusts (Hitler, Stalin, Pope John Paul II, Billy Graham, Pat Robertson, James Dobson, Osama bin Laden…).

The challenging question (to be answered by brilliant people such as my grandchildren!) is then: Can the average response of the Human System to such butterflies (and locusts) be predicted (in a manner similar to predictions of the climate)?

It's not at all obvious to me that the answer to that question will be "yes" – in part because the "butterfly analogy" may be inadequate for the Human System. In the case of climate models, the influences of all butterflies (e.g., on the generation of hurricanes) can be "averaged out", because the dominant cause of hurricanes is not the initial disturbance but the temperature of the ocean and the intensity and turning-with-height ("directional shear") of the winds. Consequently, given average descriptions of ocean temperature and winds, an average number of hurricanes is (at least theoretically) predictable.

But in the case of the Human System's ability to learn, it may be, not that some "average behavior" of the people is dominant, but instead, special characteristics of each butterfly! But I leave it to you to "fill in the blanks", to determine which is dominant! Would humanity be in roughly the same state today without David Hume, Robbie Burns, James Watt, Adam Smith, Jefferson, Voltaire, Darwin, Einstein…? Was each of them just "in the right place at the right time"? If they hadn't "flapped their wings", would others have flapped theirs, leading to similar results? I dunno, Dear – and that "I dunno" is meant to be not an abbreviation for "only god knows" but a challenge to you to figure it out for yourself!

Should you choose to accept that challenge, Dear, then you may want to delve into the literature on what's called "counterfactual history". It summarizes speculations by historians on possible consequences if outcomes of historical events had been different, e.g., if Julius Caesar hadn't been murdered, if Emperor Constantine had been defeated, and so on. Another example (which I don't think has been considered) is: if Sydney Rigdon hadn't fallen off his horse as a child, would Mormonism ever have been concocted?

I also haven't seen such speculations applied by historians of science, but nonetheless, let me add my speculations that, if there hadn't been Newton, Maxwell, Boltzmann, Einstein, Plank, Schrödinger, or Heisenberg (and maybe even Dirac), I bet that physics would have developed pretty much the same without them – although undoubtedly delayed by a decade or so. That is, in each case, especially experimental results posed such quandaries that, sooner or later, someone would have proposed the current interpretations. Historians describe such occurrences as "inevitable"; my mother would have said "the fruit was ripe for picking."

Some other events, however, appear to be "the accidental consequences of contingent events" – which is a historian's way to describe the butterfly effect. Further, even if it's possible to develop something similar to a climatological model of the influences of all "human butterflies", then another obvious question is: Would such a model be of much value?

There's value knowing (if it's correct!) that, if greenhouse gases continue to increase, then on average, more hurricanes will hit the US, but there's little value of a model prediction such as: whereas, on average, humanity develops a new energy source every century-or-so, therefore, there's a 50% probability (say) that someone will develop a new energy source before the world's oil resources are exhausted. That is, humanity won't experience "average conditions" – only one "scenario" will be realized!

Thereby, a major change in all such world models seems needed. Currently, it's common to run the models using different values for their many "parameters" to generate various "scenarios"; e.g., if the birth rate becomes xx, then… or if the economic growth rates becomes yy, then… and so on. Examples were given in the figure shown a few pages ago. But in contrast, more useful would be, first, specifications of "realistic" probability distributions for each of the (in some models, thousands of) parameters, and then (Monte Carlo) simulations to yield probabilities of resulting scenarios.[21] Then, if the probabilities of the parameters were reliable, the result would be something similar to: there's a 98% chance that humanity is heading for hell on Earth – assuming that the model is reliable!

[21] They're called "Monte Carlo simulations", Dear, because similar to the case in gambling (e.g., at Monte Carlo), the outcome of each simulation depends on the probability distributions of all variables.

Which again points to the pressing need for testing all submodels or "modules". To test any proposed "learning module", for example, surely historical case studies should be investigated. For example, Dear, how about developing and testing a model to simulate how various people "learned" and adopted Mormonism? How is it that, given the recent data showing Joseph Smith's *Book of Abraham* is a total fabrication, yet Mormons continue to "believe"? How does habit and emotional commitment override common sense? In what cases do people refuse to learn? Are they unable? Correspondingly, will humans continue to devour the Earth's resources until we're stopped by the "catastrophe… compared to which the Black Plague will be a trivial occurrence"?

And oh yes, there is another important test of another model: would you feel better if you got more exercise?