U – Understanding Ubiquitous Uncertainties

Dear: Before I show you what I review with the letter 'U' when I'm walking, let me mention a little story – which is relevant to what I review with 'U'. The setting was sometime in the early 80s when I was at a conference somewhere in Germany, maybe Hamburg. I had a little extra time (or took the time off, because scientific conferences can be draining – some because they're so boring and others because they're too stimulating!), and upon learning that the King Tut exhibition was in town and near the hotel where I was staying, I decided to visit it. You may know that King Tut's tomb was found relatively recently (in 1922); he's also known as the "boy king" and Pharaoh Tutankhamun; he seemed to have begun his "rule" when he was about 6 years old and "reigned" from c.1334–1325 BCE.

Incidentally, I put 'rule' and 'reigned' in quotes, because apparently it was the clerics who really ruled, for it was during the boy's "reign" that the clerics of the old gods obliterated the monotheism of his presumed father, Akhenaten (Amenhotep IV, 1352–1336 BCE, husband of Nefertiti).[1] This change in the "official" religion can be identified in the change in the boy's name, from Tutankhaten (referencing Akenaten's single god Aten or Aton) to Tutankhamun (or Tutankhamen, referencing the chief god, Amun or Amen). Thereby, it may be that, if Moses existed, he may have been merely one of the Egyptian clerics who worshiped the single god, Aten; if so, it would have been "politically expedient" for Moses to have left Egypt.

Anyway, I enjoyed the exhibit so much that I purchased (as a memento) a "poster" that depicted the Egyptian goddess of magic, Selket (or Serget, Serket, Selget, Selkit, or Selkis!), whose beautiful golden statue "guarded" King Tut's sarcophagus. At the bottom of this poster (which I subsequently hung in my office for at least a decade!) was the statement (in German, of course, because that's where the poster was being sold): "Ich habe das Gestern gesehen; ich kenne das Morgan." When I purchased the poster, I read the statement (in my stumbling German) as "I have seen yesterday; I know tomorrow", but dissatisfied with my ability to translate from German to English, I asked a German friend for help. His English is probably as good as mine. His translation was: *"I've seen the past; I know the future."*

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[1] His name is also spelled Akhenaton, and the years of his reign are sometimes given as 1379–1362 BCE; correspondingly, Tutankhamen's reign is given as c.1361–c.1352 BCE.

For years I really liked that saying. Not only because it was from roughly 3333 years ago but also because it contained a stimulating mixture of a little truth, a lot of arrogance, and substantial ambiguity: at most we can know a little of the past; at most this knowledge can provide us with some guidance for the future. It reminded me of a better statement by the philosopher George Santayana (1862–1952): "Those who ignore the past are condemned to repeat it." [I especially congratulate Santayana for his use of the word 'condemned'.]

And now, today, when checking on the internet to find the original source of the quotation on the poster, I find that it was neither from King Tut nor attributed to the goddess Selket but a statement attributed to the sun god Ra (or Re) in what is arguably the world's first book, the Egyptian *Book of the Dead*. I wrote "arguably the world's first book", because it appears that it was a "work in progress" for at least 1500 years: although Bartlett's gives its dates "only" during the 700 year period from ~1700–1000 BCE, you can find on the internet that some statements in the *Book of the Dead* are inscribed in the first pyramids, which date from ~2500 BCE. But of more relevance to my story, the translation from Egyptian hieroglyphics (in particular, from the *Papyrus of Ani*) to English by E.A. Wallis Budge, of the same statement (allegedly made by the sun god Ra "when he riseth in the eastern horizon of the sky") is: "I am Yesterday; I know Today. "

For me, that's rather shocking. It's hard (so it's said) to teach an old dog new tricks. It's difficult for old timers to abandon their old models. After more than a decade of my daily reading "I've seen the past, I know the future", my first reaction is to suggest: 1) For all I know, some archaeologists disagree with Budge's translation (certainly it's the case that Egyptian hieroglyphics permit many different interpretations!), and 2) For humans, as opposed to the sun god Ra, the "German form" ("Ich habe das Gestern gesehen; Ich kenne das Morgan") is, I think, more meaningful. Yet, all along I've known that there's something wrong with it: not only does the past not define the future, it's even a theoretical impossibility to know the future! It's only the ignorant and/or conniving clerics of the world who claim that their silly gods "know" the future. More defensible would be a statement similar to: "If I can learn principles from the past, I'll be more prepared for the future."

Which then brings me, finally, to at least the first part what I review with 'U' when I'm walking:

U: Ubiquitous Uncertainties – from random and various causes.

As sure as entropy increases, the past is certain, but the future isn't – from a variety of causes, including the variety of causes. Therefore, "Ich habe das Gestern gesehen; Ich kenne das Morgan" is wrong. More defensible would be: "If I can learn principles from the past, I'll be more prepared for the future." But be careful: nonlinear, nonequilibrium, complex systems can define their own principles.

To start trying to explain what I mean by the above, I'll return to the principle of causality.

PROBLEMS WITH THE PRINCIPLE OF CAUSALITY

As I've already written many times, the principle of causality – the concept that all effects have their causes – is the fundamental principle on which all scientific understanding depends. What I want to try to show you, first, is that there are some major problems (even "headaches") with this principle – and therefore with all associated understanding. To illustrate, I'll again imagine a certain set of five grandchildren (GCs), who seem to be simultaneously very bright and very argumentative.

One dark evening, near dinnertime, they hear a noise outside. Their dog, Sirius, begins to bark. He knows the cause and therefore his bark: "Intruder alert!" But the children have their own interpretations of the cause:

GC#1: "Pizza! Great! Mommy said that, last night on the phone, Daddy suggested she should skip making dinner and order some pizza. So, stop barking, Sirius: the cause of the noise isn't an intruder; it's the pizza delivery!"

GC#2: "Get real. The noise isn't from any 'pizza delivery'! The reality is that the noise came from the slamming of a car door; the cause is a poorly designed car; more padding is needed around the door frame; there wouldn't have been a bang if the car had been designed properly."

GC#3: "Always so mechanical! The obvious cause of the noise is love: between father and mother and between mother and at least some of her children. Without this love, no pizza would have been ordered, no car would have been outside, and no door would have been slammed."

GC#4: "What a dreamer! 'Love' isn't the cause; economics is. If Daddy didn't work to get money and if no one expected to make a profit selling pizza, then obviously there wouldn't have been any noise."

> GC#5: "Such astounding superficiality! Can't any of you see beyond your noses? If you want to understand the temporal chain of causality, then look with more depth: sure there was the phone call last night, but there wouldn't have been a call if there were no phones, no phone without scientific discoveries, no discoveries without humans, no humans without evolution, no evolution without the DNA molecule, no life here without the Earth, no Earth without our galaxy, and no galaxy without the Big Bang. Therefore, obviously the cause of the noise was the Big Bang. Similarly for the silliness about the cause being a poorly designed car door: on the one hand, think about the cause of cars, and on the other hand, think about the creation of sound and its transmission through the air: do you really think that any of that could have occurred without the Big Bang. And as for the silliness that the cause of the noise was love or economics, the superficiality is beneath comment. Can't any of you understand that what you heard was actually an echo of the Big Bang? And if you want to know the cause of the Big Bang, then…"

but then the doorbell rang, and the other kids started bickering about who would answer the door, leaving GC#5 talking to himself about the cause of the Big Bang (something about "the zigs and zags of zero", surprisingly similar to what I plan to write in **Z**).

Anyway, Dear, what I hope you see from the above (besides how much certain kids seem to like arguing!) are: 1) a little more about the nature of 'understanding' and 2) that something seems wrong with the principle (even the concept) of causality.

I'll comment first on some aspects of the nature of 'understanding'. In about 1600, the "father of modern science", Francis Bacon, summarized his concern about the propensity of our minds to take off in flights of fancy. He summarized his ideas in a large number of principles (or "aphorisms"), some of which are listed below (using his numbering system) and all of which you can find on the internet.

> 45. The human understanding, from its peculiar nature, easily supposes a greater degree of order and equality in things than it really finds… [Please think about that statement, Dear, in relation to the above story about the five grandchildren.]

> 46. The human understanding, when any proposition has been once laid down (either from general admission and belief, or from the pleasure it affords) forces everything else to add fresh support and confirmation; and although more cogent and abundant instances may exist to the contrary, yet [the human understanding] either does not observe or despises them, or gets rid of and rejects them by some distinction, with violent and injurious prejudice, rather than sacrifice the authority of its first conclusions… [Again, Dear… and think especially about the comments by GC#5.]

> 47. The human understanding is most excited by that which strikes and enters the mind at once and suddenly, and by which the imagination is immediately filled and inflated. It then begins almost imperceptibly to conceive and suppose that everything is similar to the few objects that have taken possession of the mind… [Again!]
>
> 51. The human understanding is, by its own nature, prone to abstraction… [And still again!]
>
> 54. Some [people] become attached to particular sciences and contemplations, either from supposing themselves the authors and inventors of them, or from having bestowed the greatest pains upon such subjects, and thus become most habituated to them…

Again, Dear, I encourage you to reread those aphorisms in conjunction with reconsidering the different thoughts of each grandchild to the same stimulus (i.e., hearing a car door slam). And I very much hope, Dear, that you'll consider Bacon's aphorisms carefully, especially the last one listed: when I re-read it, I recall errors I've made, I recall errors your father has made, and I very much hope that you can avoid similar errors – before you claim that you have reached some "understanding" (e.g., about God).

Second, relative to the possibility that there's something wrong with the principle of causality, what I hope you'll consider is that effects don't have a single cause: all effects have essentially an infinite number of causes – an "infinite regress" that can lead back to the Big Bang – and beyond! Each kid (and their dog as well!) correctly identified "a cause" of the noise: an intruder, a pizza delivery, a poorly designed car door, love, economics, and much more as well, back to (and including) the Big Bang. Thus, the problem with the "principle of causality" (as with the idea of God) is that by "explaining" too much, it explains nothing!

Once again it was apparently Aristotle who first saw that there was something wrong with the principle of causality, and without having a dictionary to which he could refer (at least, I assume that he didn't have a dictionary!), he set about solving the problem by defining four different types of causes. He gives a detailed explanation of these different types of causes in his book *Physics*, but his explanation contains too much detail to quote here. Instead, I'll first quote just his summary description of these causes, which he gives in his book *Metaphysics* (viz., "After Physics", Book or Chapter 1, Part 3)

> …causes are spoken of in four senses. In one of these we mean the substance, i.e., the essence…; in another the matter or substratum; in a third the source of the change; and in a fourth… the purpose and the good (for this is the end of all generation and change).

Next, I'll quote his further explanation given in Book II, Part 7 of his *Physics* (viz., "Nature")

> It is clear then that there are [four] causes… The number is the same as that of the things comprehended under the question "why". The "why" is referred ultimately either (1), in things which do not involve motion, e.g., in mathematics, to the "what" (to the definition of "straight line" or "commensurable", &c.), or (2) to what initiated a motion, e.g. "why did they go to war? – because there had been a raid", or (3) we are inquiring "for the sake of what?" – "that they may rule", or (4), in the case of things that come into being, we are looking for the matter.

Now, Dear, I grant you that it's rather difficult (at least for me!) to follow his language; so next, I'll do what Aristotle couldn't, namely, just check my dictionary for the meaning of the word 'cause'!

If you similarly check – but in an abridged dictionary – then I expect you'll be disappointed. For example my copy of *Webster's New World Dictionary of the American Language* gives only the common meanings for the word 'cause', e.g., "**1.** anything producing an effect or result…" But if you'll look in an unabridged dictionary, such as your grandmother's copy of *Webster's New Twentieth Century Dictionary Unabridged* (which, as you might remember, she keeps on a stand in our dining room), then the point Aristotle was tying to make is clearly displayed, defining four different types of causes (identified with the different adjectives introduced by Aristotle, although this dictionary neglects crediting Aristotle with either the distinctions or introducing the adjectives):

formal cause:	the ideal *form* according to which any thing or event is produced or brought about, as the *form* of a painting in the mind of an artist
material cause:	the *means* employed to produce a formal cause, as the oils, watercolors, etc. used in a painting
efficient cause:	the *power* or agent that effects a result [the artist]
final cause:	the *purpose* or end for which anything is produced [e.g., the purpose of a particular painting]

Now, Dear, my experience has been that, even with the above detail, it's still rather difficult to understand what Aristotle was trying to explain. Furthermore, it's not easy to see from the above (or even from what Aristotle wrote in his books) that for each of these four types of causes, there are multiple levels of understanding. Perhaps he didn't see these multiple levels. For you, however, it's probably obvious.

For example, if you were asked to identify the cause (or reason) for you (!), I could imagine that you would answer with something similar to the following.

> Well, using Aristotle's classification, there are four reasons for my existence – or, as you apparently want to say, "four reasons for me".
>
> First is the *formal cause;* i.e., the cause of the 'form' that I take. Those indoctrinated with any of the Abrahamic religions (i.e., Judeo-Christian-Islamic-Mormon indoctrination) claim that the formal cause of my existence is God, in that they claim that I'm made in the image of God, but no data support this contention. On the other hand, scientists provide evidence to support the contention that the cause of these two hands, arms, legs, eyes, etc., are the specifications in my genes; i.e., *my formal cause* is the information encoded in my DNA. As for details of how this information is encoded, I'll leave those levels of explanation for discussions other times.
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> Second is my *material cause,* which also has different levels of explanation, regardless of one's philosophical orientation. From a scientific perspective (i.e., from a perspective based on data rather than on myths), then at the most superficial level, my material cause is the food, drink, and oxygen that I consume. At a more advanced level, my material cause is the energy that the Earth receives from the Sun, because without it and the action of chlorophyll molecules, I wouldn't exist. At a still more advanced levels, my material cause is those physical processes that led to the formation of stars, the production of heavy elements, the collapse and then explosion of stars, and so on, and if you want to go back still farther, my material cause was the Big Bang that created this universe (and even the original symmetry-breaking quantum-like fluctuation in the void that led to the Big Bang).
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> Third is the *efficient cause* that led to me, but whereas communications with grandfathers are the original G-rated variety, and besides, whereas I'm reluctant to describe my parents as being "efficient" in any of their undertakings, let me skip further description of the efficient cause of my existence.
>
> And fourth is Aristotle's *final cause* (or purpose) for my existence. Here, again, different philosophies propose different causes and there are different levels of understanding within each of these different formal causes. Thus, people of various religious persuasions (or perversions, depending on your perspective) advocate that the reason for my existence is any of many possibilities, from serving as a sacrifice to

placate the volcano god to doing whatever else some clerics say is their god's purpose for me (which usually includes giving them a substantial portion of my salary). Other philosophies propose that my purpose ranges anywhere from "party 'til you drop" to "get the other guy before he gets you" and from "making hay while the sun shines" to "eat or be eaten". And of course there are the Humanists who suggest that my reason for being is to help knowledge, understanding, and wisdom expand – and within any one of these (and other) "final causes" are various levels of "understanding" (e.g., my grandfather-with-the-beard goes on and on about what he calls "our trio of survival goals"), but if you don't mind, I'm rather bored by the whole business.

Okay, Dear, so I see that I'm wasting your time trying to explain Aristotle's four causes, but maybe I can help by showing you that, actually, there are many more than four causes, and that, in practice, all of this classification of causes is rather a waste of time.

First, with respect to "other causes", to me it's amazing that Aristotle didn't list, also, the "cause" that he spent so much mental effort investigating, namely, what he called "the first cause". Aristotle's thoughts, alone (i.e., with no support from data), led him to conclude that this "first cause" was God, who after "setting everything in motion", allegedly then spends the rest of eternity contemplating his navel (although those aren't his exact words). And though clerics of different religions have assumed different alleged activities of their god(s), they commonly assume that one of their gods, similarly, was the "first cause" – thereby admitting that they don't know the formal, material, efficient, or final cause (i.e., purpose) of their gods!

Meanwhile, as I'll be showing you, some data do suggest that the "first cause" of this universe was the Big Bang – but then, of course, just as deeper understanding would develop if religious people would explain "the cause" of their gods, investigations are now underway to try to understand what caused the Big Bang, e.g., as I suggested in Chapter **A** and will show you more in **Z**, its cause may have been a quantum-like fluctuation in the original void that broke some fundamental symmetry and thereby split the "original zero" into positive and negative components of, e.g., energy.

As for other types of "causes", Dear, if you'll look on the internet, you'll probably find most references to two particular "causes" (bringing the total number, now, to seven causes!) called "the proximate cause" and "the ontological cause" (meaning, respectively, "near in space or time" and "reason for being", which maybe is the same as Aristotle's "final cause").

Later in this chapter, I'll introduce another "cause", one that I'll argue is most important for modeling and that I call "the dominant cause". And as for listing still more types of causes, let me return to the imagined argument among a certain group of grandchildren about "the cause" of the noise, and ask you to consider the following identification of more types of "causes", bringing the total to (I think) an even dozen: GC#1's "temporal cause", GC#2's "physical cause", GC#3's "emotional cause", and GC#4's "economic cause" (not counting, again, GC#5's "first cause"). From all of which, Dear, maybe I hear you say: "What's the cause of all these causes?"

Dear, when you can't seem to find a sufficient number of adjectives to describe (i.e., to develop a verbal model of) some process or thing, then take care. For example, there might be a certain someone whom you can't describe adequately before you run out of adjectives – and I admit that I would have difficulty adequately describing the best strawberry milkshake I've ever enjoyed. But in other cases, Dear, be careful that the reason for your inability to find adequate adjectives to qualify a noun might be: because your conceptual model for the noun is inadequate.

For example, if the "model" for God requires such adjectives as all-powerful (omnipotent), all-knowing (omniscient), existing-everywhere (omnipresent), all-good (omnibeneficent?), the creator of the universe, love, the one who listens to your prayers, the one who designed you and all life, the one who works in mysterious ways, and yet whose presence can't be detected by our senses or instruments, then with that many (and more!) adjectives required for the noun's specification, I hope that you'd entertain the possibility that the conceptual model is inappropriate. Similarly with the concept of "cause": rather than invent still more adjectives to try to specify "the cause", consider the possibility that the conceptual model is wrong.

CONSTRUCTING CONCEPTUAL MODELS OF CAUSALITY

The most common "conceptual model" (or analogy) for "causality" is the chain of cause and effect. That is, causality (like a chain) is imagined to link an observed effect to a prior cause, which in turn is linked to an earlier cause, and so on (back to God's setting the universe in motion, according to Aristotle and most clerics, or continuing backwards without end, in an never ending cycle, according to Hindu clerics, or back to the Big Bang, and to whatever caused the Big Bang, according to GC#5).

Instead, Dear, consider the analogy that causality is like a pyramid. Like in a movie that I recently saw with some actors climbing to the top of an Egyptian pyramid, it's as if the present moment is at the top of huge pyramid of causality. Aristotle apparently wanted to label the four sides of the pyramid (as "formal cause", "material cause", "efficient cause", and "final cause"), but as far as getting to the top of the pyramid is concerned, the naming of the sides is irrelevant: the actors who climbed to the top of the pyramid wound their way up, stone by stone, in whatever way seemed to satisfy their fancies (or their climbing abilities, or the movie director's instructions, or whatever). Similarly, each of the argumentative grandkids (and their dog, as well) had their own ideas of the best "trail" up "the pyramid of causality" to get to the top, i.e., to the present (when they all heard the slam of a car door).

I therefore suggest, Dear, that "the chain of causality" is a poor analogy. I suggest that inadequacies of this analogy lead to the need for so many adjectives (to try to identify the "causality chain" one is talking about). Instead, I suggest not only that causality is like a pyramid and not only that there's little point in continuing to use Aristotle's adjectives to identify the four sides of the pyramid, but also that you can trace backwards how you (or anyone) got to the top of the pyramid (i.e., the current moment) through any of essentially an infinite number of "trails" up the pyramid: if in each step along any "causality trail" you could step on either of only two stones (although normally there are many more than two choices), then after N steps, you could take any of 2^N trails, so that after only 100 steps, that's already $2^{100} \sim 10^{30}$ trails – and to get back to the base of the pyramid, to the Big Bang, requires how many steps?! With so many "causality trails" available, it's then easy to see why a certain set of grandkids could find something to argue about – as if they needed a reason – or a cause (☹)!

But if one concludes that it's then "pointless" to talk about "the cause" of anything, such a conclusion misses the point. To see "the point", Dear, I hope that you'll become accustomed to asking (almost as frequently as you say "Show me the data!"): *"What's the objective?"*

In the case of tying to identify "the cause" of anything, I trust you agree that the objective is to understand. In turn, the objective of understanding some current "set of circumstance" is usually to be able to predict what will occur should a similar set of circumstances occur in the future.

By trial and error, we've learned that a good method of developing predictive capabilities is first to develop some model (mental, verbal, physical, graphical, mathematical, or whatever) that's capable of describing what happened on specific "causality trails" in the past – and then test the ability of the developed model to predict future consequences. For example, returning to the argumentative grandkids and their dog, all of them were attempting to fit the identification of "the cause" (of the noise) within their separate "models". In addition, all of them probably had some plan or plans (probably unknown to the others) to use the identification of "the cause" as the basis for their future actions:

- The dog's identification of a particular "trail of causality" led to his barking,
- GC#1's identification of a particular "trail of causality" led to her preparing for dinner,
- Somehow or other, GC#2 seemed to use his identification of a particular "trail of causality" to support his model for improving the design of car doors,
- GC#3's identification of a particular "trail of causality" supported her "psychological model", and GC#4's, her "economic model", and
- No doubt GC#5's tracing the "trail of causality" all the way back to the Big Bang promoted his own "cause" (which seemed to be demonstrating the importance of determining "the cause" of the Big Bang).

That is, Dear, almost invariably, the objective is, not to identify "the cause", but to use whatever information is available to develop, apply, test, promote… some model.

AN EXAMPLE OF A SICK MODEL!

To try to make my point clearer, let me sketch another example. Suppose that, the day after eating the pizza, you had a stomachache. You were pretty sure that "the cause" was the pizza, but no doubt you considered that identification to be superficial – and I guarantee you that, with your stomach aching, you would consider even more superficial any suggestion that "the true cause" of your stomach ache was the intruder, your dad's phone call, the design of car doors, love, economics, or the Big Bang! That is, if you were ill, I'm sure you'd take quite seriously the need to develop a reliable model of how you became ill – so you could avoid such illness in the future.

If the other kids were also ill, then your model might be that there was something wrong with the pizza, but suppose they were feeling fine. So, you'd probably reject the "pizza model" of your illness, and instead, you'd consider a model that proceeded from the hypothesis that, somewhere-or-other, you picked up a bug, nothing to do with the pizza.

But suppose that, the next time you had pizza, again only you became sick. Then, no doubt you'd also reject "the bug model", and search for another "cause". And to cut the story shorter, suppose that after trying and testing various other possibilities (using a process of elimination to identify "the cause" called Mill's method, which you found described on the internet), you finally went to the doctor, and after umpteen tests, she found that you (and only you in the family) are allergic to oregano, which was one of the spices in the pizza sauce.

So, then, would you know "the cause" of your illness? Would you then be satisfied with your "oregano model"? Again, that depends – on your objective. If your objective was to avoid being sick after eating pizza, then "the cause" would have been identified satisfactorily – in fact, your model would provide you with amazingly good predictive capability. Not only would you know that, if you ate a certain type of pizza, you'd be sick, but you'd know that you probably wouldn't be ill if you ate pizza that had no oregano and that you would be ill if you ate anything else that contained oregano. But, then, what if you had other objectives?

For example, what if you were "just" curious? Suppose you wanted to know why your body reacted so violently to oregano. Or what if, more than curious, you were worried? Suppose the idea started wandering through your mind that your body's reaction to oregano might be a signal that something more serious was wrong with you? What if you started thinking about your own, future children? Suppose you began to wonder if you had a genetic malfunction that you could potentially pass on to your own children – but that might be curable. And so, away the grandchild went, obtaining a Ph.D. in biochemistry, to determine the genetic "cause" of the production of some protein that went berserk when it was exposed to oregano. And I'm sorry that I can't end this story, Dear, not only because I don't know enough about biochemistry but also because you have yet to tell me "the cause", i.e., you have yet to finish constructing your model.

MODELING FOR UNDERSTANDING

Anyway, Dear, I hope you're beginning to develop a "model" of what "understanding" is all about: we develop "models" of what we encounter in this world, then try to fit new information into our models, test them, and if appropriate, use them to guide our lives. Even the kids' dog used his own "model", and consistent with his "model", his reaction to the noise was to start barking, to protect his property. GC#1 had a model about dinner, and the noise fit perfectly within that model – and so on, for the rest of the kids. That is, the practical application of the "principle of causality" is to determine if a newly observed effect can fit within one of our existing models – or if we need to improve it or develop a new model.

Thus, to "understand" your illness, your first model (when you realized that the pizza didn't make the other kids sick) was that "the cause" must have been a bug that you had picked up. But when you became ill from eating pizza again, your new model described "the cause" as something in the pizza that your metabolism couldn't handle. And so on it went: you kept changing your models until you were satisfied that you had a model with which you could confidently describe what happened and predict what would occur for similar events in the future.

Now, Dear, it's easy to argue that any such model is incomplete. It's easy to argue that a complete model would need to describe not just your reaction to eating oregano but also everything back to and including the Big Bang. But although that's easy to argue, it's also easy to dismiss such suggestions, simply by asking: "What's the objective?" It may be GC#2's objective to build better car doors and GC#5's objective to relate everything to the Big Bang (just as it seems to be some people's objective to relate everything to their gods), but the objective of a certain sick grandchild was much more "down to Earth": to try to avoid future stomachaches!

Further, Dear, notice that, given a particular, observed effect, yet in practice, there isn't a unique cause: *"the cause" is model specific.* For example, all the grandkids (and their dog as well), "correctly" related the observed and agreed-upon effect (the slamming of a car door) to a "cause", but there was no agreement about a unique "cause". In general, there are as many "causes' (of a particular effect) as there are models capable of "adequately explaining" the effect (where by "adequate" I mean capable of predicting similar effects if there are similar "causes").

In fact, as is obvious to any grandchild who reads the story rather than participates in it, a model can be built that describes the entire process and that includes each grandchild's model as a sub-model (or "module"). Thus, starting from the Big Bang (to placate GC#5) but skipping over many details, the grandkids and their dog were sitting around the house just before dinner. Suddenly they heard a car door slam… and I'll skip describing the rest of the model, here, because basically it's what I've already written! That is, one can obviously build a model that "explains" why there were so many models and therefore so many identified "causes".

THE "DOMINANT CAUSE" DEPENDS ON THE MODEL!

But further – and importantly – *for each model, there's a "dominant cause".* For example, in the first reliable model of your illness, you found that the "dominant cause" was oregano. With your model that incorporated this "dominant cause", you had the knowledge that you shouldn't eat anything with oregano. Then, though, you wanted to develop a model of why you were allergic to oregano. For this case, you have yet to tell me the "dominant cause" of your allergy, but I suspect that it's a defective gene. If you then want to find the "dominant cause" of why you have a defective gene, let me just say: "Don't blame me, kid; I'm not allergic to oregano!"

Newton seemed to have a similar idea about "dominant cause". I assume he was trying to put an end to Aristotle's nonsense, when he gave for his Rule 1 of *Rules of Reasoning in Philosophy* (Book II of his *Principia*):

> We are to admit no more cause of natural things than such as are both true and sufficient to explain their appearances.

One problem with this "rule", however, is that Newton neglected to mention that the "true and sufficient cause" is model dependent: in the case of the banging car door associated with the pizza delivery, for example, there's a "true and sufficient" or "dominant" temporal cause – and a physical cause, psychological cause, economic cause, and so on, for as many models as are proposed.

A second problem with Newton's Rule 1 is that he didn't explain what he meant by 'explain'. And to explain what I mean, I should first comment on:

"CRITICAL-POINT" DECISIONS

Dear, from this point in this chapter, I could proceed in any of many different directions. For any process in any system (such as my writing this chapter), such a point is called a "critical point", a "branching point", a "forking point", or a "furcation point" (where *furca* is Latin for 'fork', and if there were only two dominant branches, it's called a "bifurcation point").

As I'll be trying to show you in a number of places throughout the remainder of the book, the existence of such "critical points" is typical for all "nonlinear systems" (such as life!), and the path that such systems take leading away from these "branching points" depends extremely sensitively on even extremely small stimulations (or "perturbations"). For example, Dear, at the "critical point" when you must decide on whether or not to try some illegal drugs, hearing a bird sing might stimulate you to decide "No!" – and if you don't hear a bird sing, then remember your grandfather's plea that you not damage our brain!

But of very much less significance than your never trying brain-damaging drugs, let me list and briefly describe at least three of the paths that could be taken from this branching point for my writing.

1. I could now proceed down a path to try to explain the concept that "the cause" of so many "causes" is that humans have developed so many models (physical, chemical, biological, physiological, economic, social, religious, political, and so on), but I want to delay showing you some of these different models until later chapters.

2. A second path I could now take is to try to explain when it's useful to try to identify "the first cause", following in the footsteps of Aristotle, all clerics, and even GC#5. In fact, very soon this path bifurcates. One of the branching paths is the religious path (with dangerous traps and pitfalls, and hopelessly entangled with broken limbs, fallen trees, and rotting stumps). As I'll try to show you later, uncertainties make this path hopelessly impassible. But on the other branching path, a science path, there apparently are some cases when it's useful to try to identify "the first cause", namely, those cases in which the "first cause" may be the "dominant cause". For example, to try to understand why momentum and mass-energy are conserved for isolated systems or to try to understand the nature of elementary particles (e.g., quarks), then it's been found useful, first, to identify some fundamental "symmetry principles" that appear to exist in this universe of ours. And what some scientists are now exploring is "the cause" of this symmetry, which may be related to "the first cause" of this universe (i.e., the Big Bang may have been caused by a breaking of at least one of the potential symmetries, destroying the original "nothing").

3. And a third path from this branching point in this chapter is the one that I plan to take. Specifically, on this third path (as if this were a "trifurcation point", although, actually, more than three paths from this branching point are available), I plan to focus less on "causes" and want to emphasize more the influence of uncertainties even in simple models, such as those developed and used in mathematics, physics, and engineering.

And if you think, Dear, that once again I'm being silly (by describing models in math, physics, and engineering as "simple"), I assure you that I'm not! Let me put it this way. If you're thinking that you might want to gain sufficient education for a career in building, testing, and using models in economics, psychology, sociology, or similar fields, then I'd recommend that you first obtain at least your master's degree in a simpler field, such as computer sciences, mathematics, engineering, or physics. Then, when you have developed competence in developing models in one of these fields that deal with relatively simple processes, start over, to work on your Ph.D. in one of the fields that deals with the much more complicated "nonlinear, nonequilibrium human systems."

An important reason for starting with modeling "simple stuff" (such as the weather, climate, turbulence, and subatomic processes!) is: you can then begin to see some limitations of all models. Then, Dear, if you take care, you won't go off "half-cocked" (as have so many economists, psychologists, sociologists, and similar people) using models far beyond the inherent capabilities of any model. These "inherent limitations" of models are related not only to the fact that "causes" are model specific but also to inherent and unavoidable uncertainties.

SOME SOURCES OF UNCERTAINTIES

There are at least three sources of these uncertainties, even in relatively simple fields of study such as physics and engineering. Correspondingly, three "theories" have been developed (and are still being developed) to try to understand these uncertainties. As I hope to show you, progress in each of these cases has been made (permitting some progress in understanding), but in each case, we're confronted by erosion of "certainty". These three sources of uncertainty and how they're studied are crudely as follows.

1) *Randomization*: studied using probability theory to relate cause and effect only statistically. Thereby, it's impossible for any model to predict the outcome of a "randomization event" with any more detail than is dictated by "the laws of

probability" (e.g., if you make a decision based on a single toss of a "honest coin", there's a 50% chance that you'll… and a 50% chance that you'll…); consequently, direct "linkages" between a cause and its effect are obliterated.

2) *Quantum Uncertainty* (e.g., Heisenberg's uncertainty principle): studied using the theory of quantum mechanics (QM). QM is specifically applicable to the "microscopic world", but its consequences appear in our "macroscopic world" – as you verify whenever you turn on your computer or play a CD.

3) *Complexity and Nonlinearity*: studied in nonlinear mechanics and chaos theory. Such studies demonstrate that many (and maybe even most) systems (e.g., the weather, the human brain, evolution…) are so complex and nonlinear that it's impossible (even theoretically) to discern linkages between initial causes and their effects. The leap of a single grasshopper in the Sahara desert can indeed cause a hurricane to hit Florida. Thereby, the common scientific procedure of reductionism (e.g., trying to understand atoms by studying interactions among elementary particles, trying to understand human biology by deciphering information coded in the DNA molecule, trying to understand the human brain by analyzing brain circuitry, etc.) may be methodologically flawed. And perhaps most amazingly, sometimes only very weak external influences can lead to amazing order in complex, nonlinear systems (e.g., subjected only to an extremely weak gravitational force between dust particles, a star can be born, and subjected only to a single "off-hand" remark from her grandfather when she was four, a grandchild can become a…).

Now, Dear, I assume you'll be pleased to know that I don't plan to go into much detail about any of these three sources of uncertainty. If you want, then after you've earned your Bachelor's degree, you can go after your Ph.D. specializing in probability theory, quantum theory, or nonlinear (or chaos) theory. In fact, to make contributions to any one of these theories, it would help if you'd take graduate courses in all of them! But here, to try to give you at least some idea about "what the devil I'm talking about", I'll start with a simple example, even though it may at first appear to deal with quite complicated systems, i.e., people!

In particular, in the scenario dealing with the delivery of pizza, how do you expect the grandkids would decide who would answer the door? Given the "certain knowledge" that certain grandkids always minimize the work that their slave masters (also known as parents) tell them to do, suppose that none volunteered for the job. Further, suppose there were agreement among them (and "I know, I know" – but this is a hypothetical example) that the question of who would answer the door would be settled by tossing coins, "odd person out" (i.e., the one whose coin is in the minority, or is different, answers the door) – a horrible, "age-old" method of promoting conformity!

Suppose that, in the first toss of all five coins (assuming that each kid had a coin), there were two 'heads' and three 'tails'. So then, the two who tossed 'heads' (being the "odd people", i.e., in the minority) toss again, and the first one whose coin comes up 'tails' (being the "nonconformist", having then switched from 'heads' to 'tails') answers the door. If they both get 'tails', then they toss again, and the first one who tosses 'heads' answers the door (now being the nonconformist), and if they both toss 'heads', then… etc. Now, the challenge to you: develop a model, with predictive power (and whose predictions can be tested!) to describe who answers the door.

No doubt you can immediately develop such a model (assuming, rather brazenly, that, for a change, no grandchild cheated). A sound, reliable model is that, for the five children, there's a 20% chance that any one of them will lose and therefore be required to answer the door. And my point? It's just this: some processes have inherent uncertainties (e.g., randomness); in such cases, the best we can do is incorporate probabilities in our models.

Knowing you (at least somewhat!), you might object to that conclusion. You might argue (I know that much!) that there's no such thing as randomness. You could mount a defensible argument that, for example, there's nothing "random" about a coin toss: once a coin is placed on top of your thumb with a certain side up and then flicked with your thumb, then the coin's subsequent spinning motion until it's caught is perfectly defined. And of course I would agree with you that, if you could develop a perfectly calibrated thumb and catching hand, then in theory at least, there's nothing random about a coin toss.

But, Dear, how about coming back to reality: show me the data. Show me that you can calibrate both your thumb and your catch that well. I've tried it and I can't do it: after many attempts, my average is 50% 'heads' and 50% 'tails'. Besides, to "defeat" the randomization process to decide who would open the door to get the pizza, you'd need to know the outcomes of the tosses by the other kids (which I suppose you could do if you were the final one to flip your coin – but I bet at least one kid would claim that you were cheating). Furthermore, even if you could beat the randomization of coin tossing, there are so many randomization processes available (drawing straws, drawing cards, spinning a pointed object, choosing a random number…) that I'm certain that even you couldn't beat them all.

So, going on, suppose there were no arguments ("That'll be the day!") and suppose that GC#5 lost the coin toss. GC#5 therefore answered the door, the pizza-delivery girl stepped into the house (and tracked some mud into the house, for she had stepped off the sidewalk into the flower bed), exchanged the pizza for some money (confirming GC#4's economic model), and then left. Suppose further that, a few minutes later, your mother came downstairs (she had been resting, taking a break from a certain set of argumentative children), saw the mud on the floor, all five kids sitting at the table, and wanted to know what was going on.

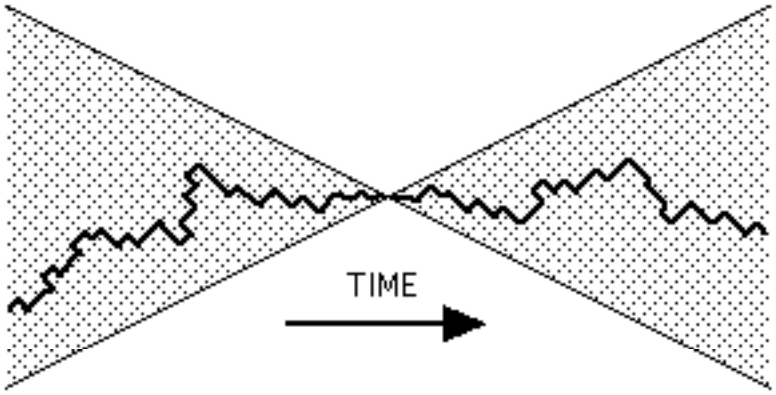
Of course, all kids disavowed responsibility for the mud on the floor and claimed that their hands had been washed. Additionally, your mother received the following reports:

- GC#1 reported that, as daddy had suggested, the pizza came, and whereas she didn't lose the coin toss, she had gone to the table (of course after washing her hands);
- GC#2 talked about the noise caused by a poorly designed car door, he didn't lose the coin toss, so he went to the table (after washing his hands);
- GC#3 talked of love, GC#4 talked of economics, and both described their luck at the coin toss and the cleanliness of their hands); finally,
- GC#5 described that he had lost the coin toss, the pizza girl had tracked the mud into the house, and he would have proceeded to describe his model of the Big Bang, but he saw that the other kids were already eating, so he decided that he'd better cut his story short and start eating.

Now, Dear, notice what the kids did: continuing to promote their own models, they all looked back down their model-defined "causality trail" and described what they considered to be the important events (even "dominant causes") along their "causality trails". Looking backwards in time, the steps that each kid took seem perfectly ordered and connected (described by the word "deterministically") – even though, on the way "up the causality trail", an important step was determined by the outcome of a coin toss (i.e., determined only "probabilistically"). Thus, for example, "the cause" of GC#5 going to the door wasn't just the Big Bang: it was determined by his losing the coin toss, but at the time of the randomization, the future couldn't be modeled deterministically, only probabilistically.

Now, Dear, I know that the above was "totally obvious", but the consequences aren't. To begin to see them, consider the "double-headed

pyramid" that I've sketched below (sketched in only two dimensions). *On the left-hand side of the sketch*, I've indicated by the jagged, dark line the particular "causality trail" that, say, you took between the time you heard the car door slam and when you started eating the pizza, or it could represent the "causality trail" that you've taken during the past few days, the trail you've taken since you were born, the trail that your DNA has taken during the past billion-or-so years, or to placate GC#5, it could represent the path all the way back to the Big Bang. The "background pattern", on both sides of the sketch, is meant to represent all possible "causality trails", only one of which was taken (the jagged, dark line).



On the right-hand-side of the sketch, the jagged, dark line is meant to represent a "causality trail" that, say, you will take into the future. Each "jag" in the path is meant to represent one of the huge number of choices or decisions that you will make (at various "critical" or "branching" points) – some possibly defined by "randomizations" such as coin tosses – whose outcomes will dictate the "causality trail" that you'll take. And the point of the "picture" is contained in the word "TIME".

Two reasons why I included the word TIME are the following. First, time is the essence of causality: 'causality' means that something occurs ("the cause") and then – AT A LATER TIME – something related occurs (called "the effect"). But, Dear, look again at the sketch and ask yourself if you would be able to tell the direction of time (in the sketch) if I hadn't shown the direction with the arrow. Then, Dear, my second reason for indicating the word TIME on the sketch is to ask you to please consider what's meant by "the direction of time", and for that matter, what is meant by 'time'.

CAUSALITY, TIME, IRREVERSIBILITY & ENTROPY

If you're thinking that you doubt anything could be stupider than to ask what 'time' is, then I hope that you'll think again. I know you've been able to "tell the time" since you were four years old, but I also know that most people know what time is only "intuitively"; few people know what time is "conceptually". Certainly, most people have learned to "tell time" [by looking at their watch, by counting the number of "times" that the Sun has come up since (whenever), by counting the number of moons or summers since they were born, and so on], but that demonstrates only that people know how to count changes and to conform to convention, not that they know what time is.

That is, Dear, time isn't some arbitrary "counter" (the number of "times" that the Sun, or the Moon, or whatever did whatever). To illustrate, suppose you could talk to an electron, whirling around a nucleus, keeping perfect "time" (i.e., counting the number of revolutions it has made around its nucleus). Ask him (or her, as the case may be!) what "time" it is. His response: "Well, I've made umpteen googles of revolutions around that stupid nucleus, but whereas nothing changes, there is no time." That is, first, time has meaning only if there is some change.

But, Dear, time isn't just a measure of change. To see what I mean, look again at the above sketch, and suppose that I hadn't indicated on the sketch the direction of time (with the arrow). Then, how would you know which "direction" was "the past" and which was "the future": for the "causality trails" in both directions, changes occur (indicated by the jagged lines). So, "change", alone, doesn't define the direction of time: from the sketch, you can't tell which is cause and which is effect.

What defines the direction of time is randomization and (in the case of life) choice. To see this, Dear, suppose that the entire episode with the grandkids had been put on a silent video tape, that an observer was asked to view the tape to identify the correct direction of time, and that the observer was convinced that the grandkids were superb actors who could act out all motions in reverse if requested to do so. Yet, I trust you agree, a sufficiently attentive observer could still identify "the correct" direction of time by paying attention to all randomization processes: the floor boards of a normal house won't have a "collective fluctuation" that will lift mud up into the air and have the mud land exactly on a pizza-delivery girl's shoe; it's highly

doubtful that even five abnormal kids could all start with coins in their hands, throw the coins in the air, and catch the coins exactly lying flat on their thumbs; a footprint in the flower garden will not disappear when a person walks backwards through the mud!

That is, Dear, there are a huge number of processes in this universe that, on their own, aren't reversible (i.e., normally, they're "irreversible", unless work is done to reverse them), and it's this irreversibility – or randomization – that defines the direction of time. This observation, this experimental result, that "left to their own devices", things become more random (a more uniform probability distribution) and/or that energy degrades into a less useable form (e.g., because of friction) is known as the second principle of thermodynamics (the first principle of thermodynamics being that the total energy is constant, even in those irreversible processes in which the energy becomes less available for "useful" work). The quantity developed to provide "a measure" for this energy degradation and randomness is called the entropy. Thereby, "entropy [increase] is time's arrow."

Now, Dear, I don't want to take the space, here, to show you how entropy is defined and can be used as a quantitative measure of irreversibility and why, when any system reaches equilibrium, the entropy reaches a maximum. If I get around to writing an "excursion" for this book dealing with scientific principles, I'll sketch at least a little of "the story" of how the concept of entropy was developed – after more than a century of thought by some of the brightest people who have ever lived, from Fourier through Carnot, Kelvin, Maxwell, Boltzmann, Gibbs, Shannon, and including the 1977 Chemistry Nobel Prize winner Ilya Prigogine, whom I'm pleased to have had two chances to meet and talk with.

For now, I hope you'll let me get away with just stating that, for most processes (and at least theoretically, for all processes), there's a way to measure the amount of irreversibility that occurs – using a quantity called entropy. Consequently, rather than the "qualitative statement" that "irreversibility defines the direction of time", it's at least theoretically possible to specify for any process how much the entropy increases. In all cases, irreversibility "causes" entropy to increase, and the direction of time is in the direction of increasing entropy, i.e., increasing randomization.

Furthermore, what's truly amazing (at least to someone who spends his time writing a chapter on "uncertainties and unknowns" ☹) is that the concept of

entropy ties together all the pieces: uncertainty, probabilities, knowledge, and time! In fact, it's all summarized on Boltzmann's tombstone with the inscription: S = k lnW, in which S is the entropy, k is one of the most famous constants in physics (known as Boltzmann's constant), and W is a probability that basically measures the uncertainty of our knowledge about the system under consideration.

Meanwhile, though, everyone understands "intuitively" that "time's direction" is indicated by increasing randomization and energy degradation. That understanding (even wisdom!) is contained in the familiar (pessimistic but realistic) expression: "Things always go from bad to worse!" Yet, Dear, I expect you'd be amazed to learn how few people have conceptualized it and used it in their models.

Thus, everyone knows by experience (even without thought) that "the past is certain; the future isn't", but few people seem to realize what's certain is uncertainty (if you don't mind my teasing your mental alertness by writing it that way!) and this "certainty of uncertainty" is what's used to define time, to distinguish past from future. But again, I don't plan to go into many details about this definition of entropy (i.e., basically, of time). If you want to investigate them yourself, then sometime (perhaps not until you have your bachelor's degree in some branch of science) read the book *Order out of Chaos* by Ilya Prigogine and Isabelle Stengers. Instead, and of more current significance to you, you should realize that your mother knows all this stuff – and more.

LIVING WITH UNCERTAINTIES

To show you what I mean, I'll return to those five kids, who have now almost devoured the pizza. There was relative peace and quiet when their mouths were full with food, but with the pizza almost gone, the squabbling resumed. Now, apparently no one actually saw GC#2 try to hit GC#1 (as GC#1 alleges): the only thing clear to everyone was that GC#2's milk was splattered all over the table and was starting to drip onto the floor, irreversibly. Of course the mother yelled at him and then ordered someone to get a towel (and both GC#3 and GC#4 responded to her request and then tried to stop the spreading mess), but unless you were there, you probably wouldn't believe the subsequent "conversation".

"I didn't do it," was GC#2's claim, "I was sitting here, doing nothing but eating my pizza, as innocent as the day I was born, when all of a sudden and all by itself, my glass tipped over and spilled its milk. The cause must have been a quantum mechanical fluctuation of my glass! Everyone knows Heisenberg's uncertainty principle: it's impossible to specify, simultaneously and perfectly accurately, the position, say x, and the momentum, p, of anything."

"Consequently," added GC#2, "if anyone is to be blamed for the spilled milk, it should be her ," pointing at his big sister. "When she set the table, she went to such lengths to specify the exact location of the bottom of the glass, exactly where she wanted it, that as a result, it's momentum became uncertain, the bottom of the glass moved, and so the glass tipped over."

"Riiiiiight," responded the mother, "I could tell you stories about your 'innocence' on the day you were born. But for now, let me just point out that you neglected to mention that the product of those uncertainties,

$$\Delta x \, \Delta p \geq h/2\pi$$ (in which h is Plank's constant),

is astounding small (h is approximately 6.626×10^{-34} in SI units). Consequently, the probability is essentially zero that quantum mechanical uncertainties would lead to a fluctuation in the momentum of your glass large enough to spill your milk."

"Mother Dear," GC#2 responded (I think he was being sarcastic), "although far be it for me to claim that my mother is anything but correct, let me say that I think my innocence at birth should be a subject of another discussion and that with respect to quantum mechanical uncertainties, you neglected to emphasize three important points. One is that, in Heisenberg's uncertainty principle, $\Delta x \, \Delta p \geq h/2\pi$, '$\geq$' means exactly what it says: '*greater than* or equal to'; therefore, the fluctuation in the momentum can be very large, especially if you have a sister who's so picky about exact positions of everything. Second, although I'd agree that the probability of a quantum fluctuation sufficient to spill my milk is small, it's not zero, and the spill could equally well occur today as a billion years from now. And third, surely you agree that coherent quantum phenomena can easily lead to observable effects in this macroscopic world; otherwise, there would be no lasers and no CDs."

"Ah come off it," chirped in GC#1, "substantial care and effort is needed to excite a laser into a coherent state. What was it, pray tell, that stimulated your milk into such a coherent state?"

"Actually," added GC#5, "the explanation in terms of quantum fluctuations seems not too bad. Certainly we're all aware of the ability of quantum mechanical systems to penetrate energy barriers (witness radioactivity); therefore, it's not impossible that his milk could penetrate its gravitational potential, sufficient to tip his milk. Yet, a more likely explanation is not in terms of quantum fluctuations but in terms of macroscopic nonlinearities."

Surprised that GC#5 would be on his side, GC#2 urged him on (which he probably didn't need to do, because GC#5 was obviously just winding up).

"I would suggest," GC#5 continued, "that another cause of the milk spill is more likely. Just before the incident, I noticed that someone must have bumped the table, because I noticed its slight vibration. In turn, that vibration probably stimulated a wave in the glass of milk. Now, as we all know, the equations describing the motion of fluids are nonlinear (in contrast to the linear equations of quantum mechanics), and as at least some of us know, the least uncertainty in the initial conditions for any nonlinear system will grow so large that, in time, the consequences will be totally unpredictable. That, of course, is why weather predictions can't be made beyond a few days. I therefore suggest not only that the consequences of kick to the table are unpredictable, but also that the resulting nonlinear wave in the milk grew sufficiently to tip over the glass."

"What a pair the two of you are", the mother exclaimed, addressing the boys. "To bolster your arguments, the two of you focus on minute details while ignoring the obvious: the probability that a quantum fluctuation caused the milk to spill is vanishingly small, and the possibility that the cause was a nonlinear wave totally ignores not only dissipation (particularly viscosity) that suppress such waves but also that no such wave occurred in anyone else's glass, and in fact, no one even noticed that the table was vibrating. In summary, your arguments are as messy as your rooms – which then brings to mind what I want done: right after dinner, I want both of you to go to your rooms and clean up your rooms."

"Mother Dear," started GC#5 (now it was his turn to be sarcastic), "your suggestion that we should clean up our rooms, although no doubt made with the best of intentions, should be seriously questioned. As the Seven Sages said, more than 2500 years ago: 'Not even the gods fight against necessity.' And the obvious 'necessity' is that disorder must increase, for without an increase in entropy, time itself couldn't advance. And although every day, Dear Mother, you're looking younger and more beautiful than ever, nonetheless, time must advance, entropy must increase, and therefore the disorder of our rooms is necessary."

"Hear! hear!" seconded GC#2 (although it was unclear if he was seconding the statement about their mother's appearance or the necessity of not cleaning up his room).

"The two of you better 'hear, hear' me", she responded, perhaps a bit angrily. "When you talk of quantum uncertainties, pay attention to their sizes; when you talk about uncertainties from nonlinearities leading to chaos, pay attention to dissipation; and when you talk about the necessity of entropy increase, pay attention to energy flows: it does appear to be correct that entropy of isolated system can't decrease (this is, after all, the second principle of thermodynamics), but neither you nor, unfortunately, your rooms are isolated systems."

"Thus, after dinner," she continued, "I want you to go to your rooms, straighten them out, thereby bring order to your rooms, and thereby decrease their entropies. I agree that you will need to supply energy (and I mean, lots of energy!) to decrease your rooms' entropies and I agree that the entropy of the universe will increase when you expend that energy, but on the other hand, why do you think you've been fed. So, if you want to get philosophical about it, think of this: each of you is merely a conduit of energy; some of the energy that the Sun had expelled in the form of radiation was temporarily interrupted by some chlorophyll molecules, leading to the pizza that you just ate, and what I want you to do is use some of the Sun's energy to decrease the entropy in your rooms."

After a brief quiet-period (certainly the boys remained quiet), a perplexed GC#4 responded methodically: "Mother, I don't understand. Something seems wrong. I know that time increases, I realize that what we mean by time increasing is that randomization and dissipation have occurred, I can accept the use of the word entropy to describe this, and I can appreciate that the entropy of open systems (such as the boys' rooms) can decrease by application of energy, while the entropy of the universe increases – but something still doesn't make sense. How is it that some systems, such as babies, seem to be able to generate a huge amount of order in themselves (such as grow and think and learn), while other systems, such as a certain old grandparents (who take in even more energy in the way of food!), seem to grow more feeble, become smaller, think less, and learn little? It seems as if there's more to life than just the second principle of thermodynamics."

"Precious daughter," responded her mother, "your perceptions are perfect, and it's time to tell you some of the facts of life. As you perceived, some systems (including all living systems) are able to bring order out of chaos, by themselves. The details of the way that a human body or any living thing (such as a flower or even a single cell) manages to bring order out of chaos are not yet known, usually because the chemical reactions involved are too complicated. But we are beginning to see how simpler – yet still complex – systems evolve. It's an amazing balancing act: such complex systems are held away from equilibrium (i.e., in a state of nonequilibrium) in a balance between energy inflow (such as from the Sun or from food) and energy outflow because of dissipation (with the energy eventually returned to the universe). Apparently what happens in such systems (called complex dissipative systems) is that they're able to tap into the energy flow to reorganize themselves – but in the case of living systems, eventually this ability wanes and the systems finally tend toward equilibrium, which for living systems means death."

"Mother," interjected GC#3 thoughtfully, "for me that doesn't explain enough. I can understand that complex dissipative systems can be held away from equilibrium and I can understand that the systems, themselves, can change (so that, for example, babies grow stronger while old people grow weaker), but I don't understand how such systems understand what they're supposed to do!"

"I agree, Dear," responded the loving mother, "that's the hardest part to understand. And although I'm sure it will be a long time before we understand more complicated systems, such as how human cells learn to read the information in their DNA molecules, yet we're beginning to understand how simpler systems, such as stars, 'know' how to progress through their life cycles."

"We just finished studying that in school," an excited GC#4 interjected, "and it's neat. It's driven by gravity. For any of a number of reasons, clouds of mostly hydrogen plus some star debris start to condense. Gravity eventually manages to collect enough material to start the fusion of hydrogen nuclei into helium, then later, helium into carbon, and for some stars, the fusion continues, producing oxygen and other nuclei, all the way out to iron, with each fusion changing mass into energy. For stars more massive than the Sun, eventually the core collapses into a neutron star, the outer region explodes in a Supernova in which even heavier nuclei such as uranium are formed, and the remnants of the explosion are then used in the formation of new stars."

"Well," pounced in GC#5, "they've taught you the outline, but they sure preached the party line. In my view, the driving force is totally different. In my view, the driving force isn't gravity but the negative energy background, which we call 'space' or 'the vacuum', ridding itself of positive energy, especially the positive energy that's congealed in mass. If you'll think about it for yourself, rather than adopt the party line, you'll see that the entire life-cycle of stars is nothing but space's successfully turning positive energy into light and then expelling the positive energy as fast as possible and as far as possible toward the edge of the universe."

"That's an interesting idea," responded the patient mother, "but whatever model is promoted, I'd have you think about other aspects of the life cycle of stars. First, notice that during each stage of its life cycle, a star is a system held away from equilibrium in a balance between energy inflow from fusion and energy outflow (or dissipation) by radiation."

"So in some sense," added GC#1, "it's as if equilibrium never occurs – maybe even the eventual death in a Supernova plus a Black Hole, isn't really death (that is, equilibrium), because the remnants of the Supernova are used in the condensation of new stars and who knows the contribution made by Black Holes."

"That's what I hoped you see, Dear," responded the mother, "and more toward responding to the question, see that the 'knowledge' possessed by such systems is extremely primitive and, for that matter, barely noticeable to 'individuals' participating in the process. For example, a hydrogen nucleus 'knows' it should respond to gravity, even though the force on an individual hydrogen nucleus is extremely weak, too small for scientists to detect with their most sensitive instrument. Thereby, see that a simple and almost undetectable guiding principle can have an enormous influence on complicated systems."

"And I wonder why", GC#2 added, rather sarcastically, "I get the sneaking impression that the real message here is that the behavior of even more complicated systems, such as certain humans, can be dominated by a 'guiding principles' provided in gentle hints from their mothers."

"Well, earlier I could have told you about the fate of Black Holes," interjected GC#5, "namely, that they return the universe to its original state of nothingness, but now, it's more important to point out how easy it is to miss or misconceive the 'guiding principles' – especially those guiding principles dealing with entropy. In particular, left unexamined is how mass 'knows' that it's attracted to other masses, how it 'knows' it can fuse with some other masses and release energy in the process *via* $E = mc^2$, and how the released energy, in the form of light, 'knows' that it's supposed to leave, at a fantastic speed (actually, in its own rest frame, it reaches the edge of the universe instantaneously, since time travels at the speed of light). And what I suggest is that the single guiding principle is that 'space' (i.e., the negative energy background of our universe) is trying to rid itself of positive energy."

"What's that got to do with entropy?" GC#1 injected sarcastically.

"Plenty", GC#5 quickly responded. "Look: given the fact that, in total, there's no energy in this universe of ours (all of the positive energy, e.g., congealed as mass, is exactly balanced by the negative energy of 'space' or 'the vacuum'), then in total, there's also no entropy in the universe. The positive entropy on this 'positive side' of reality (where all the mass 'exists') is exactly balanced by negative entropy on the 'negative side' of reality, i.e., the entropy of space. We think that the positive energy dissipates, increasing entropy, but all that energy "dissipated" actually roars off to the edge of the universe as electromagnetic energy, instantaneously, and no doubt, it there forces the continued expansion of the universe, which increases the magnitude of the negative entropy of space. So, not only does space have negative entropy (and therefore time is going in the opposite direction in space), but the total entropy of the universe stays at zero. "

"Whoa! Slow down! You're losin' it!" yelled GC#1, adding "What's this about time going backwards in space?!"

"I don't know why I bother," GC#5 drawled sarcastically, "when I know that you'd sooner read romance stories than papers by John Cramer of the University of Washington. But I'll try. Look, for any wave equation, there are solutions that go both ways in time, but for electromagnetic waves, for example, we discard the retarded-wave solution, because we know that, in reality, there's dissipation and therefore exponential decay of the wave in time. But for the wave equation of quantum mechanics, there's no dissipation of the wave function; therefore, both the retarded and advanced waves must be kept. But if we do that only on the positive side of reality, all the familiar "paradoxes" of quantum mechanics arise, which is why Einstein could never accept Schrödinger's equation as being correct: it predicts signals transferring faster than the speed of light. Cramer proposes the resolution that

the Schrödinger equation also describes what's occurring in the negative-side of reality, i.e., in the vacuum, in which time goes in the opposite direction: its past is our future."

"Well," coughed GC#1, "it sounds to me like both you and Cramer are in the negative side of reality."

"If you're so smart," GC#5 angrily responded to GC#1, "then tell me what an antiparticle is – like an anti-electron (or if you want, call it a 'positron')."

"I know what a positron is," GC#1 shot back, "it's a hole in the vacuum."

"Riiiight," GC#5 responded drolly, "so then, why do physicists describe a positron as an electron traveling backward in time?"

"Only backward physicists do that", GC#1 tried to joke.

"Riiiiight", GC#5 again responded. "The real reason is because it's right: time (and therefore entropy) do increase on the positive-energy side of reality, where we live, but the negative side of reality (that is, within the vacuum, itself), energy, entropy, and time are negative."

"That's strange and interesting," GC#3 interjected thoughtfully, "but have there been any experimental confirmations of such ideas."

"Yes, Dear sister," GC#5 responded in an uncharacteristically friendly manner, "they resolve long-standing (and paradoxical) experimental results in quantum mechanics."

"Children," injected the mother, "how about moving on past quantum mechanical studies? In the main, they deal with small-scale and short-duration phenomena. Instead, consider again large-scale and long-duration phenomena, specifically the life cycle of stars. Obviously there's much to discuss about the 'information' possessed by such systems and how we gain knowledge and understanding of that information, but instead of my addressing those issues, let me ask all children to notice a third feature of the life cycle of stars: what a star becomes (be it a dwarf star, which never accomplishes much more than burn some hydrogen, or a Supernova giant, which produces the carbon, oxygen, and even the iron needed for growing children) depends entirely on certain 'critical points' during their growth, which in turn were reached from what are essentially imperceptibly small variations during their lifetimes."

"So maybe I see what your saying, mother," GC#3 mentioned methodically, "not only that there are critical points in our own lives (from which the outcomes will be as obvious as the fates of stars) but also that the branch that we take from each critical point depends on a host of previous choices we've made, the consequences of each of which could never have been foreseen. "

"For example, Dear, " responded her mother, "it's more than I could have ever foreseen that I would have a child who could see so much so well."

"Mother," added GC#4, "perhaps your analogy can be applied to more than just individuals. Perhaps the life cycles of stars is similar, also, to the life cycle of even societies: even gentle guiding principles (such as maximizing kindness and freedom) can dominate the growth of entire social systems, but their behavior, too, depends on choices made at critical points, where the choices made, in turn, can depend on earlier choices, whose consequences could never have been foreseen."

"Your ideas seem sound," mother answered, "but I admit that you're going beyond my understanding – just as all children's understanding should surpass their parents'. For now, all I was hoping you'd see was that the evolution of even enormous systems such as stars and galaxies can be governed by extremely limited 'knowledge' and what otherwise might be viewed as extremely weak forces. Thereby, maybe you can see why it's so difficult to understand how humans and other life forms evolve, individually and collectively, when the governing forces may be extremely small and the relevant 'knowledge' may be very primitive."

"What bothers me about your analysis", said GC#1 addressing her mother, "is the hint that reductionism can easily miss the point. In the case of living systems, for example, no doubt we'll soon be able to decipher their complete DNA and maybe even the chemical reactions in every protein, but it may be centuries before we uncover the guiding principles, not only because they may be associated with such weak forces but because (quite likely) they are obliterated when we look at details. It's a classic case of failure to see the forest amongst all the trees."

"I couldn't have said it better," added the mother, "and maybe it's even more complicated: not only can the guiding principles be weak, but for nonlinear systems held away from equilibrium in a balance between energy consumption and dissipation (for example, living systems), their responses can be extremely sensitive to even small perturbations."

"Well, I know some nonlinear systems that aren't responsive even to rather strong perturbations," added GC#2 glaring at GC#1, "but I agree that, in some cases, what you say may be correct. For example, I remember hearing someone say that a grasshopper's jump in Africa can cause a hurricane to hit Florida."

"Oh, let's not go down that path again", scoffed GC#1. "You've gotta focus on the dominant cause of hurricanes. It may be that a particular perturbation that led to a particular hurricane was a particular grasshopper, but if it hadn't been that perturbation, it would have been another. The important point about hurricane generation is that IF the dominant cause is present, that is, IF the temperature of the ocean is high enough and the upper-level winds support the growth, then a hurricane will result. Let me put it this way: you can never model backwards in time, through the generation of a hurricane, to the jump of particular grasshopper."

"Well then, why don't you similarly attack all the talk about the Big Bang?" GC#2 defensively responded, while glancing at GC#5. "If nonlinearities in weather systems wipe out the memory of a particular grasshopper, then certainly any memory all the way back to the Big Bang will be completely obliterated."

"Ah come off it," GC#5 leaped back in, "you're missing the point. Certain principles can persist through even the most violent randomizations, such as the principles dealing with momentum and energy, in turn probably because certain symmetry principles persist. That's why, even though the weather can't be predicted beyond a few days, yet climate predictions are reasonably reliable."

"Your brother has a valid point," added the mother, "and the challenge is to identify the principles that can survive randomization. For example, even though the randomization in your room obliterates much, it's still your room – and it's still your mess."

"What I consider to be a challenge", GC#3 said (as if thinking out loud), "is to identify not just the principles that survive randomization but that guide people and their societies. Maybe that's what grampa tried to do, with all that stuff about our trio of survival goals, and maybe that's what my kid sister is trying to do, with all her talk about economics. And I guess that's what I'm trying to do, when I talk about kindness and love."

"Well, it's not that I recognize only economic principles," GC#4 defensively added, "it's just that it amazes me how many times the choices that we make can be expressed in economic terms. For example, I bet that a certain couple of messy boys I know would pay us plenty to clean up their rooms!"

"You're right, Dear," responded mother, "but in this case, I don't want them to be offered that choice: it's important for them to learn the principle that some things aren't for sale "

"Once again your point is well made, mother Dear," GC#2 replied, shifting in his chair, "but I think I see another principle, here, that seems to be quite important. It seems to me that some complex systems – and I'm especially thinking about humans – can be not only guided by some simple external principles (not that I consider mothers to be 'external'!) but also can, in fact, define their own principles."

"Oh, I absolutely agree," the mother quickly responded, "for many systems, perhaps even systems of stars, it's not just some external principles that govern their evolution, but the partial ordering can lead to the establishment of new principles, which then leads to further order."

"Well, what strikes me most significant in this conversation", added GC#1, "is the analogy between the life cycle of stars and of societies. Consider the contributions to

> our society by certain brilliant and productive people, from Aristotle and Euclid through to Galileo, Descartes, and Newton, as well as many others, including Locke, Hume, Burns, Smith, Jefferson, Boltzmann, Einstein, Dirac, and so on. It's as if the contributions from such 'stars', by themselves, are able both to define a society's critical points and then to stimulate society to take particular paths into the future."
>
> Mother was too flabbergasted to say anything more: she found her children speaking as if they were intelligent adults. And I think I saw her smile a bit to herself, maybe realizing the importance of mothers, maybe thinking that her children were acquiring sound principles, and maybe wondering about the future contributions of her own five stars.

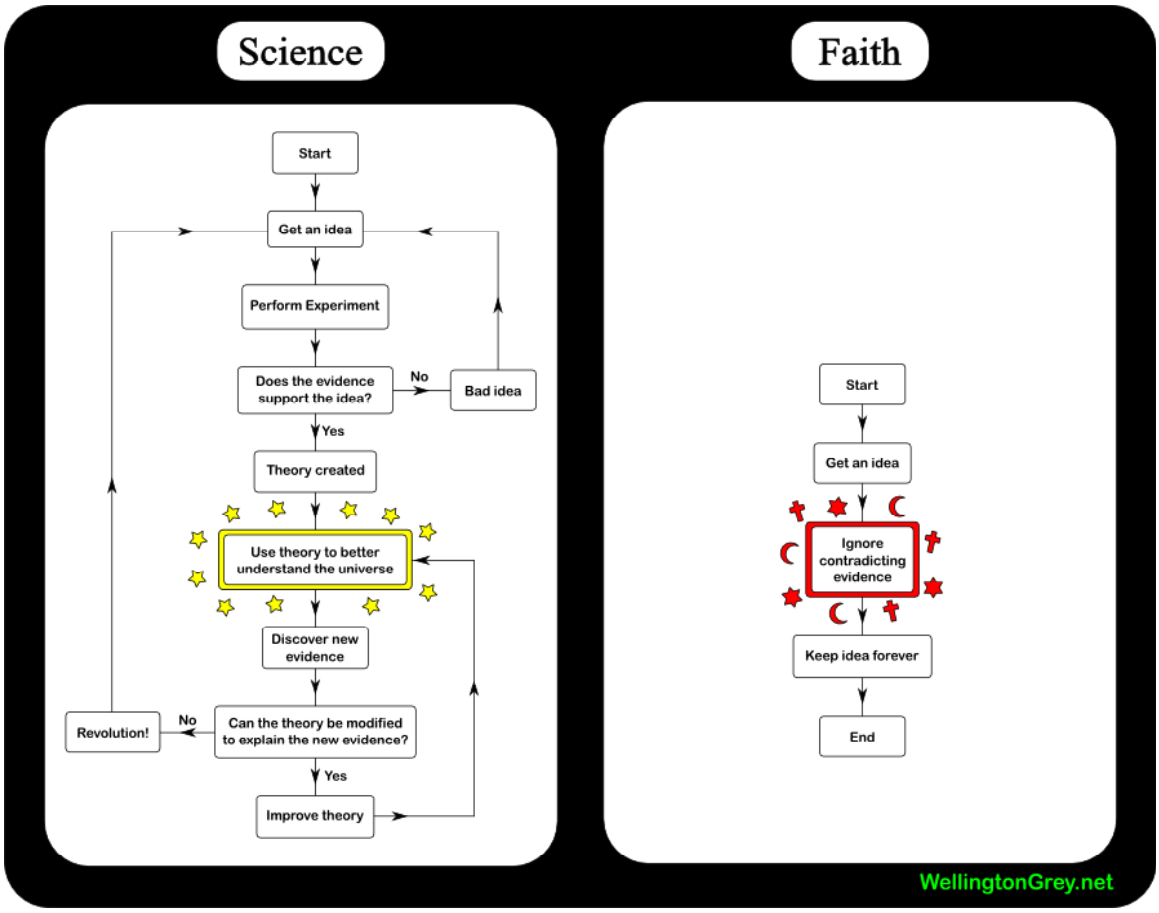
Discounting the bravado of the two boys, I, too, wonder about the contributions of those grandchildren. I wonder if they'll contribute as much as did the philosopher David Hume, whose remark from more than 200 years ago provides a great summary for this chapter: "All knowledge degenerates into probability."

Or how about their matching (if not surpassing!) the contributions of the philosopher Bertrand Russell (1872–1970) who wrote:

> Science tells us what we can know, but what we can know is little, and if we forget how much we cannot know, we become insensitive of many things of very great importance. Theology, on the other hand, induces a dogmatic belief that we have knowledge where in fact we have ignorance and by doing so, generates a kind of impertinent insolence towards the universe. Uncertainty in the presence of vivid hopes and fears is painful, but must be endured if we wish to live without the support of comforting fairy tales.

The same idea as expressed by Russell was recently conveyed well in the "flow charts" created by Wellington Grey and shown below. [2] In addition, if you'll study these flow charts, Dear, I think you'll agree that they provide a great way (in many ways, better than my "chicken scratchings" of the previous chapter that attempted to show the "demiverses" of ideas and how ideas change) not only to illustrate differences between the scientific and religious ideas but also to emphasize how scientific ideas change, asymptotically approaching "truth", while religious ideas stagnate in dogma.

[2] The original of this figure is at http://www.wellingtongrey.net/miscellanea/archive/2007-01-15%20--%20science%20vs%20faith.html; at http://www.wellingtongrey.net/about/ you can learn a little about the author (Wellington Grey).



In summary, Dear, and as I mentioned in the previous chapter, when we say we 'know' or 'understand' some thing or process, we simply mean that we have a "useful working hypothesis" about it, i.e., a hypothesis

1) that succinctly summarizes a substantial quantity of reliable data,

2) that's consistent with other hypotheses found to be useful,

3) that has predictive capabilities, and

4) whose predictions have been found experimentally to have a much higher probability of being right than being wrong.

And again, if you think it "rather pathetic" that satisfying the above criteria is all that's meant when we say that we know or understand something, then I'd tend to agree with you – but this pathetic meaning is far better than those

who claim they know or understand more! As Voltaire said more than 200 years ago: "Doubt is not a pleasant condition, but certainty is absurd. "

When I'm walking and come to the letter 'U', I remind myself of such ideas with something similar to the following.

> *As sure as entropy increases, the past is certain, but the future isn't – from a variety of causes, including the variety of causes. Therefore, "Ich habe das Gestern gesehen; Ich kenne das Morgan" is wrong. More defensible would be: "If I can learn principles from the past, I'll be more prepared for the future." But be careful: nonlinear, nonequilibrium complex systems can define their own principles.*
>
> *In general, useful working hypotheses, useful models, are the most we can achieve, and it's impossible to purge these of all uncertainties. Forget about Aristotle's four causes; it's difficult enough to figure out the dominant cause. And if the dominant cause is chaos (caused by anything from randomness to nonlinearity to complexity) or is quantum mechanical uncertainty, then admit the obvious: the best any model can do is describe probabilities, modeling the uncertainties.*

But actually, I don't usually spend much time with 'U' when I'm walking, because after spending a lifetime working in science, such ideas are more-or-less "old hat". Nowadays, more important to me is continuing to walk, to get more exercise – which brings to mind that you, too, should…