Ruthless Extrapolation

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This is a guest post by Tom Murphy. Tom Murphy is an associate professor of physics at the University of California, San Diego. This post originally appeared on Tom's blog Do the Math.

We humans owe much of our success to our ability to recognize patterns and extrapolate trends to anticipate a future state. My cats, on the other hand, will watch a tossed toy mouse travel toward them across the room—getting ever-bigger—all the way until it smacks them between the eyes (no, they're not strapped down—I'm not *that* sort of scientist). But far beyond an ability to avoid projectiles, our ancestors were able to perceive and react to changes in local food and water supplies, herd movements, seasonal cues, etc. Yet this fine tool can be over-used, and I see a lot of what I call **ruthless extrapolation**. In almost every case, extrapolation works until it doesn't. When the fundamental rules of the game change, watch out!

As with many aspects of human behavior, some of the finest commentary on the matter is served up by *The Simpsons*. In one episode, Lisa Simpson is taken to the orthodontist to evaluate whether or not she needs braces. The "doctor" runs a simulation based on current growth rates, producing an alarming graphic of teeth gone wild.

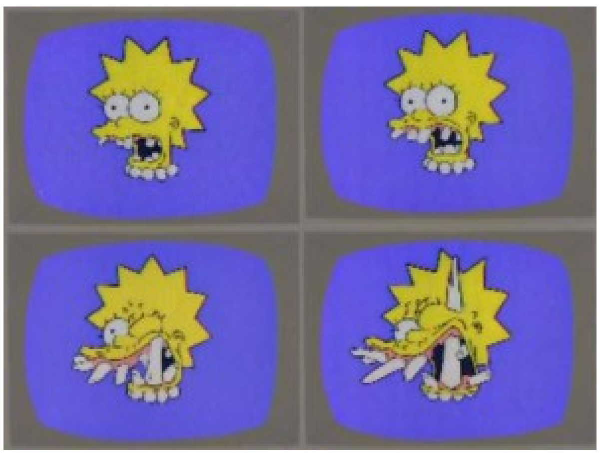
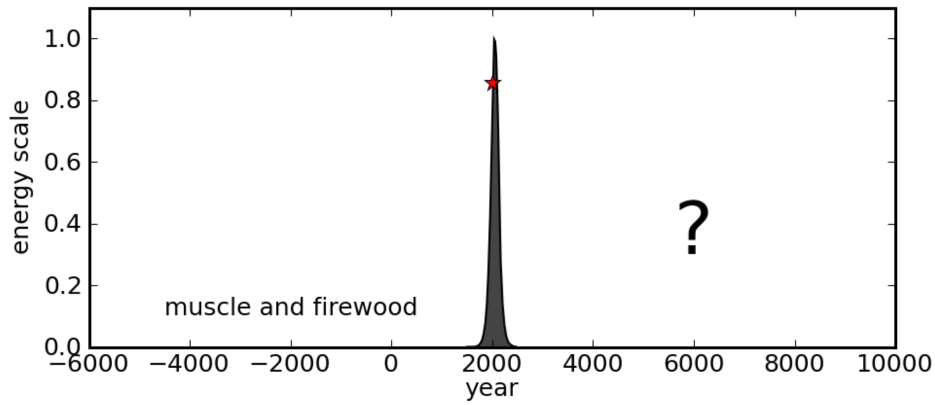


Image obtained from saucesome.net

Marge shrieks and is ready to do whatever it takes to protect her daughter against this cruel fate. Extrapolation can, of course, be used to argue both for impending doom *or* future prosperity—sometimes based on the same data. I started this blog with an extrapolative foil to demonstrate the insanity of continued physical growth, in fact. A tangential follow-up illustrated the hopelessness of differentiating a steady-state energy future from an energy crash using current data (although a continued exponential rise is already a poor fit).

The Problem with Extrapolation

The danger with extrapolation is that it can't work forever. Trends change. The picture I carry in my head is one I've shown before: the long-view history of fossil fuel energy use on Earth.



On the long view, the fossil fuel age is a blip, with a down side mirroring the (more fun) up side.

We found a one-time resource in the ground—like an inheritance—and are doing everything within our means to promote the fastest practical use of this finite deposit. By this, I mean that we have engineered a world that rewards economic growth—thus far carrying a nearly one-to-one physical/energy aspect, requiring ever more energy to keep the growth engine running. The finite nature of the underlying energy resource is not seriously under question. The overall impression of the figure above therefore *must* be approximately correct.

When we realize that this incredible surge—of planes, trains, and automobiles; of radio, television, and the internet; of industrialization, industrialized agriculture, and swelling population; of supersonic, nuclear, and space capabilities—in the past century or so are all reflections of the scale of surplus energy derived from fossil fuels, we come to understand that we need to stare the plot above directly in the face and recognize the peril of extrapolation.

We sit near the peak of the fossil fuel saga (the star on the plot). Our tendency is to note the incredible slope of the past century and expect more of the same phenomenal performance for the foreseeable future. It's not a *bad* model. It has a pretty decent chance of being right over the coming years and possibly decades. Alternative forms of energy may take up some or all of the fossil fuel slack. But even this state of affairs does not look much like a continued skyward trajectory, even if it *were* possible.

I recently became aware of a story that highlights the degree to which the Earth has already been scoured for resources. In the remote, glacier-ridden Wrangell mountains of Alaska, prospectors found a certain copper-rich deposit in 1900. By 1911, a railroad was constructed and the copper bonanza began, discovering ores that were as rich as 70% copper. Compare this to typical copper ore mined today containing 0.3–6% copper (usually less than 1%). Production from the Kennecott mines peaked in 1916, declining more sharply after 1927, becoming uneconomic from 1932–1935, and reopening from 1935–1938 after which the resource was depleted. The mines and town of Kennecott were hastily abandoned. No ores this rich have been found since. It's hard to get more remote and inaccessible than the interior mountains of Alaska a century ago. Yet if the rich resources were found and exploited so efficiently so long ago, I am left with lowered expectations for low-hanging fruit elsewhere in the resource world. Seems a bit picked-over.

Examples of Ruthless Extrapolation

We have no shortage of examples, but I'll throw out a few to give a flavor of what I'm talking about. I think it would be fun to have readers contribute other glaring instances of ruthless extrapolation in the comments section.

To Infinity, and Beyond!

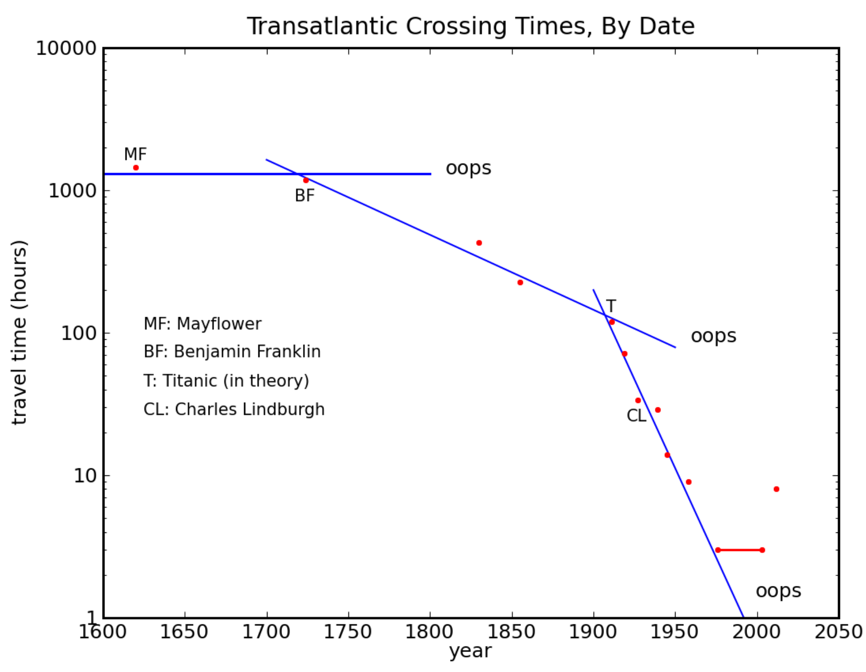
I have commented previously on the disappointment of space. Shouldn't we be living on Mars right now? Ask an American in 1962 where they think we would be fifty years hence with respect to space travel. How many would say: "grounded, without a means to launch humans even into low-earth orbit"? No, only a lunatic would say that: the trend was clear. The space race was on, and we were tooling up for our first trip to set foot on another planetary body. Common sense (another term for ruthless extrapolation) would demand that the answer be far more ambitious than the Moon—millions of miles from the correct answer of "grounded."

More generally, the extrapolation often goes that our evolutionary ancestors crawled out of the ocean onto land, so the next "logical step" (often substituted for "ruthless extrapolation" in casual conversation) is for us to take to the cosmos. Gibberish.

Science fiction—as inspiring and entertaining as it may be—is largely an exercise in ruthless extrapolation. Even less constraining, obeyance of the laws of physics (or grammar, in my case) is optional in this genre. For sure, I would be the *last* person to claim that we know all there is to know about physics. But any deviation from what we *do* know presently is a pretty substantial extrapolation.

Note that I'm not saying that all extrapolation is *wrong*—just flimsy to sometimes extraordinary degrees.

Faster than a Speeding Bullet



Logarithmic plot of transatlantic crossing time in hours. A straight line represents an exponential (compound) function on this plot. Select data points are labeled above or below the associated point. The red bar represents the era of the Concorde. Some data are from here.

Traveling between Europe and the U.S. used to take months by sailing ship. Improvements in ship design and navigation trimmed this down slowly over time, but a decent model would have been "it will always take about two months." Enter the steamer—a game changer, thanks to fossil fuels—and suddenly a new field opened up, ripe for development and improvement. The old extrapolation broke down. For a few hundred years, crossing speed improved at a rate of 1.2% per year. Extrapolate to now, and we would expect to be able to cross in 37 hours. Oops. This extrapolation fails in two respects. Not only is a 37 hour ship crossing not possible today, but more importantly we missed another game-changer called the airplane. After the airplane entered the picture, improvements came fast and furious, at a whopping rate of 5.7% per year! This culminated in the supersonic Concorde, crossing in typically three hours and change.

Extrapolate the progress of the aeronautical age to 2012, and we should expect crossing time to now be 19 minutes. By 2050 it would take a cool 2 minutes, and our crossing would exceed the speed of light by the year 2200. Another big oops. Not only did we *saturate* at 3 hours with the Concorde, *we don't achieve even **that** any more!* Why? It was too expensive to operate: beyond our means.

Sometimes we step backwards: the space program and the Concorde are two striking examples. There are several oopses on the plot above: sometimes missing game changers that improved things; and sometimes missing the exhaustion or saturation of a technology. Moore's Law is today's celebrated joy ride of amazing progress. Physical limits are bringing this ride to a stop too. Note that the new mode of CPU expansion is in multiple cores, not intrinsically faster chips.

Visionary Virus

I attended a conference (the Compass Summit; talks viewable online) in October 2011 aimed at mapping out our future path. Its subtitle was: "what's possible, what matters, what's ahead." It was here that I first put the words "ruthless" and "extrapolation" together, in reaction to many of the talks. The boiler-plate talk was: look at the tremendous advances we've seen in the last decades; what amazing, mind-blowing futures await if we extrapolate these trends forward? Only a few speakers rung alarm bells about soils, monetary systems, and the impossibility of maintaining growth indefinitely (ahem).

Virtually all talks failed to acknowledge the fundamental role that surplus energy has played in the amazing trajectory we've seen. Unlimited energy availability seems to be an *unexamined assumption* for most. This might be fine if we did not *know* that our primary energy resources are finite and are expected to peak this century. We can hope for a seamless replacement, but as I have worked to illustrate in the past, this extrapolation is far from guaranteed.

Meanwhile, we are attracted to stories of optimism. They are *infectious*. It's fun to dream of a world where everyone can live like Bill Gates does today (or even better than Bill—why not?). Moreover, optimism for the future inoculates the market economy against loss of confidence—which is vital to maintain a growth trajectory. In so doing, optimism helps propagate itself—like a good little virus.

I recently listened to a radio segment on 3-D printing and the arbitrarily complex structures and devices whose fabrication by this method may soon be possible. In response to the question about whether there is anything that *can't* conceivably be made by this technique, the answer was the familiar refrain that human ingenuity is unlimited—so no—nothing is out of bounds. A lovely sentiment that is all well and good in the absence of physical limitations. Again, the allure of ruthless extrapolation wins out.

The Trajectory of Physics

Okay, this one is a little obscure as a form of extrapolation, but it's one I relate to professionally in the world of physics. Physics has a marvelous track record of *reductionism*. The same thing that pulls an apple from the tree keeps the Moon moving about the Earth. Electricity and magnetism—seemingly much different—are in fact different shades of a unified theory of electromagnetism. In the latter half of the 20th century, all fundamental particles and forces (including nuclear flavors) were bundled into the symmetry-group-fashioned "Standard Model"—leaving only gravity in the lurch as a thing unto its own. But the sense of imminent grand unification (theory of everything) was palpable. String theory pounded out many-dimensional mathematics in an attempt to provide a coherent framework for uniting gravity and the quantum domain of the Standard Model.

Then things came off the rails a bit. Neutrinos turn out to have mass—in open defiance of the vanilla Standard Model. Cosmological observations indicate the existence of not only dark matter (new stuff not made of atoms on the periodic table), but also dark energy (providing a repulsive force and *accelerating* the expansion of the Universe). These have no place in the current Standard Model. Meanwhile, a sizable cadre of string theorists—in trying to understand the geometries of extra dimensions—stumbled on the concept of a *Landscape*: a near-infinite number of ways that the compactified extra dimensions of spacetime could be arranged/folded, each resulting in its own unique set of rules for physics. Most would be utterly unsuitable for the formation of atoms or stable nuclei—let alone stars, galaxies, chemistry, and life. A tiny subset of the myriad arrangements would host conditions likely conducive to life. Obviously, our Universe would have to be one of these. Because this line of thought involves the "selection effect" of humans in the mix, it is referred to as an "anthropic" view of physics (not to be confused as implying that humans are *required* for the Universe to exist—just that we can't overlook our presence—and that of nuclei, atoms, stars, galaxies—as an observational fact/constraint).

There is currently something of a schism in physics. Ask any particle physicist, cosmologist, astrophysicist, etc. where they come down on the anthropic view, and you're bound to get an earful of…gibberish (including from me). Why gibberish? *Because we don't* ***know*** whether physics unravels into random instances among a Landscape of choices in a multiverse, or whether the loose ends get tied together into a coherent picture with no freedom to be anything other than what it is. Some physicists believe one thing, and others believe another. But it's still **just belief** either way—a religion of sorts.

In the unification corner, the track record of success in reductionism makes a very persuasive "exhibit A." If early physicists had decided that the energy levels of atoms were somewhat random, then we would have missed the chance to understand something deeper and more fundamental (i.e., quantum mechanics). While there is no apparent rhyme or reason to the approximately 20 Standard Model parameters (masses of particles, coupling strengths, mixing angles), the hope is that one day not only will these be understood, but the current observational anomalies will also be incorporated and explained. In addition, the hope goes, there will be no mathematically self-consistent description by which the Universe could have ended up any other way—life and all. To the unificationists, the anthropicists are throwing in the towel prematurely. The anthropicists caution against blind extrapolation, and point to disturbing examples of fundamental constants that cannot be changed very much without destroying the life-support system of the Universe.

In this case, one could argue that there is little downside to assuming that the reductionist trend of physics will continue. The potential upside for discovery is rather large. A king of old could send a few ships over the horizon, accepting the comparatively inconsequential risk that the ships would disappear off the edge of the world in exchange for the possible huge gain of a newly discovered land. There will always be scientists to push into the unknown. The extrapolative view that physics may accomplish a "theory of everything" may well be *wrong* (and ultimately *feels* wrong to me, such is my bias). But unlike extrapolating societal growth/development trends, getting this one wrong doesn't pose a threat to humanity's happiness.

For me, I think there are questions that are too fundamental for physics to ever touch—like: why is there something rather than nothing? So I am not willing to embrace the ultimate extrapolation that physics holds all the answers to the how and why of our Universe. Meanwhile, physics certainly offers abundant opportunity to *describe* our world in a systematic and prediction-enabling way. And continued exploration is bound to be fun no matter what the ultimate end.

Human Boon; Human Bane

Our ability to extrapolate is indeed a valuable adaptation for our survival. I do not claim that it is *unique* to humans (other animals can anticipate and prepare), but we have abstracted the practice to a real art form. Many of our greatest accomplishments owe to this fundamental skill.

Yet we're a little too married to the concept. From a mathematical point of view, we're first-derivative machines. We sense and react to local gradients, or current trends. It's a powerful technique. Again speaking mathematically, Newton's Method, Runge Kutta Integration, the Method of Steepest Descent, and many other techniques are devastatingly effective using only first derivatives.

Yet sometimes the game changes, for better or worse, and our linear—or at least monotonic—extrapolations fail. We would do better with second-derivative sensitivity—to perceive "curvature," or the *trend of the trend*. But real-world complexity often throws distracting noise into the data, making it difficult to discern more subtle behaviors.

Evolutionary processes tend to satisfy minimal requirements to outperform the competition, or to edge out environmental impositions. Human cultural memes aside, there are no deluxe model organisms with far more "adaptiveness" than is needed to get the job done (and procreate). So why would we expect to leapfrog evolution and develop a subtle perceptive tool beyond simple extrapolation. The simple technique is enough to exert powerful anticipatory action relative to our surroundings.

But this human boon turns into a bane if we are collectively too shortsighted to spot abrupt and detrimental phase changes ahead, like the end of the fossil fuel age. We're smart enough to dip a stick into the ground and have it come up dripping with oil. But we may not be smart enough to realize that we shouldn't use the stuff (and all of it) as rapidly as our growth machine can manage. Right now, the wind's in our hair, we're flying faster and higher, and isn't that just the way it will always be?

Never mind. Don't answer that question. We're too poorly equipped to get the right answer.