Moore is Less

Since writing *Predicting the Degree of a Curve From Empirical Data,* I have applied the tool I described in that essay to a wide range of databases. While all the results are interesting, my quarry in this hunt has been the elusive high-degree curves, exemplified by the Weimar inflation. Between early 1918 and mid-1923, the Reichsmark-to-gold exchange rate was increasing, and the rate of that increase was increasing, and the rate of *that* increase was increasing, and so on through another fourteen degrees of increase (for a total of seventeen). At each level, we can show by Spearman's rho that the increase is statistically significant to a given alpha level. Put together this constitutes a Bethel Test, and I use the notation {+,+,+,+,+,+,+,+,+,+,+,+,+,+,+,+,+ at 0.01} for this result.

In vernacular, we would say that the Weimar data is an "exponential curve", though strictly speaking an exponential curve has an infinite Bethel sequence {+,+,+....}. All the same, it seems significant that while we can speak of linear, quadratic, or cubic curves with some familiarity, and there are official names for polynomials up to the tenth degree, there is simply no name for a seventeenth-degree curve, since it has never been necessary to distinguish such a curve from a true exponential.

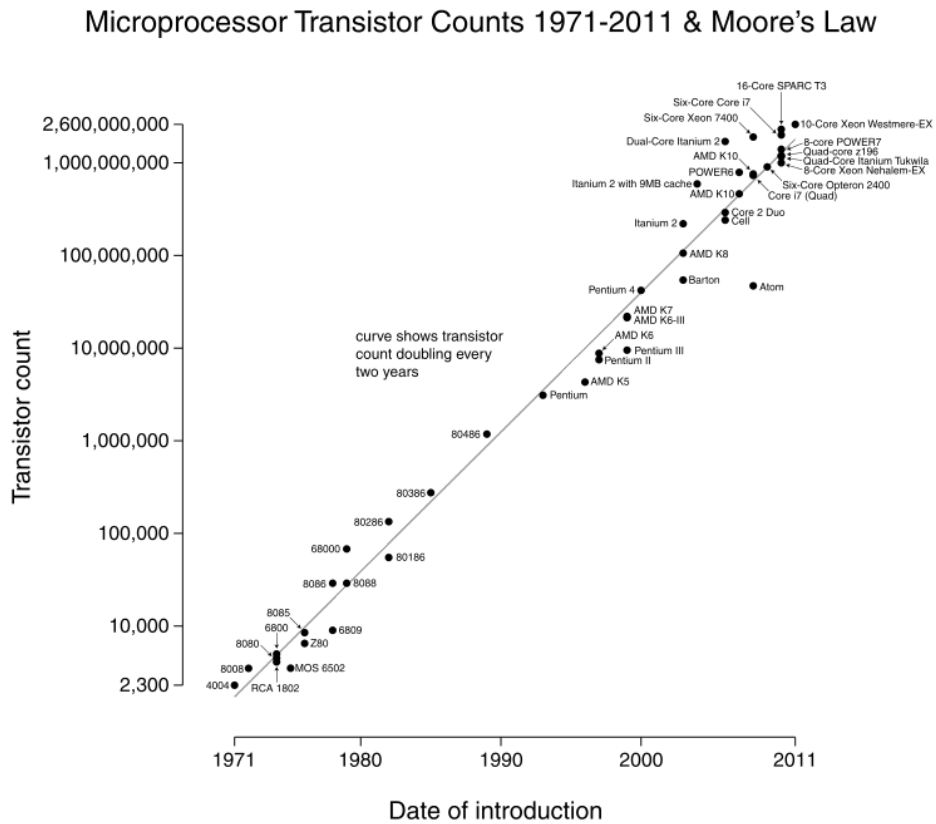
The Weimar hyperinflation is an extraordinary outlier, facilitated by the fact that it was not, ultimately, based in reality. By 1920, if not earlier, it was simply a question of maniacs adding zeroes to banknotes that no one was really using anymore. Similarly, we might find that the production of gold in a video-game universe has 23rd-degree curve, because why not? Adding zeroes is cheap.

If we constrain ourselves to reality—that is, to processes that involve meaningful amounts of entropy—I have never seen a growth pattern beyond quartic increase {+,+,+,+}. Yet we still speak of many curves as "exponential", and over the course of the last year or so I have begun to think of this as a major defect in our collective imagination, rather than an annoying statistical imprecision. The notion that a curve is exponential implies a strange kind of teleology. In reality, for a variable like steel production to shift a single degree (from linear to quadratic growth, say) requires a truly unusual effort, unusual circumstances, or both. If we think of the curve as exponential, we must assume that these prerequisites will keep being met, forever—which is to say we either stop thinking about them, or actively deny that they exist.

Several signature fallacies seem to grow in this environment. I have previously mentioned the tendency to reify average rates of growth (which all systems have) as permanent features of the system. Thus "during the late 1990s, the city of Austin was growing at 4.4%" becomes "Austin is projected to reach one billion people by the year 2170." This is a very common mistake, and it creates that the absurd conclusion that *all* systems are growing exponentially, when it is more nearly true to say that none of them are.

In a similar vein, there is a strong tendency to tweak the endpoints of a curve towards the exponential, usually by treating outliers selectively, or otherwise changing the test criteria. I routinely read things along the lines of "the fax machine is only fifty years old, and yet nowadays, with scanners and 3D printers, anyone can fax solid objects." It sounds good, and certainly implies a staggering momentum of industrial progress. But in fact, fax machines have existed in various forms since the 1840s. And in fact, 3D scanning and printing techniques are not common household technologies today. So both points of comparison have been tweaked to exaggerate the curve.

All of these tendencies seem very much in evidence in discussions of Moore's Law, which is arguably the most important "exponential curve" in modern thought. Moore's Law has been so heavily reified that many commenters will happily posit multiple generations increasingly unlikely quantum computing, rather than abandon the idea their beloved exponential curve. Both the technooptimists and the robot-apocalypse-singularity crowds (who are oddly overlapping) are heavily invested in the idea of Moore's Law. This gets displayed in a variety of little biases, many of which get showcased in graphics like this one:



For starters, we should note that most of the data points on this chart are not relevant to Moore's law, which focuses by definition on our *maximum* capacity, rather than the modal integrated circuits in actual use. Thus a relatively “low-tech” chip like the 2008 Intel Atom can be overlooked, because in 2008 we were also able to produce the Core i7. This makes the narrative of Moore's Law partially an artifact of the way it is phrased. To use an example that is perhaps more intuitive, the curve for the tallest buildings on earth, since Ancient Egypt, is cubic {+,+,+ at 0.05}. Yet the modal human being lives in a one- or two-story house, as we have since we invented housing. And even if we stop building skyscrapers altogether and start living in the sewers, the curve for the tallest buildings *ever built* will remain cubic. Again, our most distant spacecraft is voyaging outwards at almost a million miles a day, but that does not mean our space program is doing much.

Similarly, there is the suggestion of an apples-and-oranges comparison between ubiquitous workhorse chips, like the 4004 and the 8088, and some of the highly specialized, state-of-the-art chips on the right, which few people ever encounter in daily life. That we can produce such chips is miraculous, but it is not necessarily indicative of our overall appetite for technology. And looking a bit closer, we notice something odd: despite the fact that the 4004 is often referenced as the starting-point for Moore's-Law narratives, it is not used as the benchmark for the supposed line of doubling. Rather, the line seems to be benchmarked on either the 8088, the Pentium 4, or the six-core Opteron 2400. In all events, this cheats the line slightly to the right, so that recent microprocessors like the Itanium Tukwila look like they are much closer to the putative trend-line than would be the case if this diagram were benchmarked on the 4004.

This is a very minor issue, to be sure, but it does suggest the direction that the wind is blowing. Whether it is Moore or Malkiel or myself, I am suspicious of people's abilities to eyeball curves like this and make bold pronouncements with much assurance. "Exponential" is not a word we ought to use lightly, especially if we are going to base our utopian / apocalyptic fantasies around it.

So I ran the numbers myself. Maximum transistor counts since 1971 have a Bethel score of {+,+,+,+ at 0.05}. That's a quartic curve, which is extremely impressive, and in this data I see no signs of it slowing down (although I note that both the industry pundits and their critics are now predicting that the slowdown is already occurring). It is not, however, an exponential curve. Nor is it unique. I have found two other quartic curves: the number of cell phone subscriptions from 1985 to 2001, and the number of Walmarts from 1962 to 1981. Both of these are situations where an exceptional number of social and economic factors were all converging, as is true of semiconductor technology. Both of them, pointedly, are also examples of explosive market saturation. There are still cell phones and Walmarts today, god knows, but they are not growing at quartic rates, let alone exponentially. And it is easy to see why not: at some point everyone is living across the street from a Walmart and has five cell phones. The industry keeps moving at a breakneck speed, but there is no longer an incentive for it to *accelerate.* And a quartic curve implies accelerated accelerated acceleration.

Presumably integrated circuits will also reach a saturation point. Discussions of Moore's law have tended to phrase this in mechanical terms: *when will our inexorable progress reach the limits of physical engineering?* But I suspect economics is a closer and higher hurdle. New microchip plants are not inevitabilities, they are multi-billion-dollar decisions that grow increasingly hard to justify. The two major driving forces have, to date, been gamers and spies (by which I mean, catholically, the NSA, Google, and their lesser kin). Gamers no longer seem to have a strong demand for better chips, and the spies have no need for miniaturization, since they can happily cover Kansas or wherever with whatever the best-value storage happens to be. The last-chance-saloon for miniaturization is probably wearables, and/or the tech on microdrones, but these are being developed in a cloud-computing environment, which again tends towards server racks in Kansas.

It is hard to tell how far along this curve we've already come. There is every reason to think that we are already wasting much of our microchip capability, at least as far as home computing is concerned. How much of what we store ever gets instantiated? How many devices get scrapped before they ever max out their RAM? This gap between what we are producing and what we are actually using is likely to grow, and it is—to use our earlier metaphor, like the "vanity space" at the top of skyscrapers, useless except for making the building a bit taller.

Every high-degree curve, from the inside, feels exponential, inevitable, teleological. It is easy to view it as a kind of law of nature, and reify it until other laws of nature—quantum mechanics, in this instance—feel flimsy by comparison. From the outside (which is to say, *afterwards*), these curves always seem like relatively brief anomalies. What is most striking about them, from the outside, is how much *work* goes into generating such an anomaly.

It would be a fool's bet to say when we will start looking back at the era of Moore's Law from the outside. "Exponential" is a fairy tale, but a quartic curve is nothing to sneeze at, and even if chip production slacks off to a quadratic curve, it will be an enormous part of our social reality. Television sets, after all, have grown quadratically since the 1940s, and their social influence is hardly trivial. But the numbers on microchips do not bear out the kind of magical thinking—optimistic or pessimistic or both—to which they are too often applied.