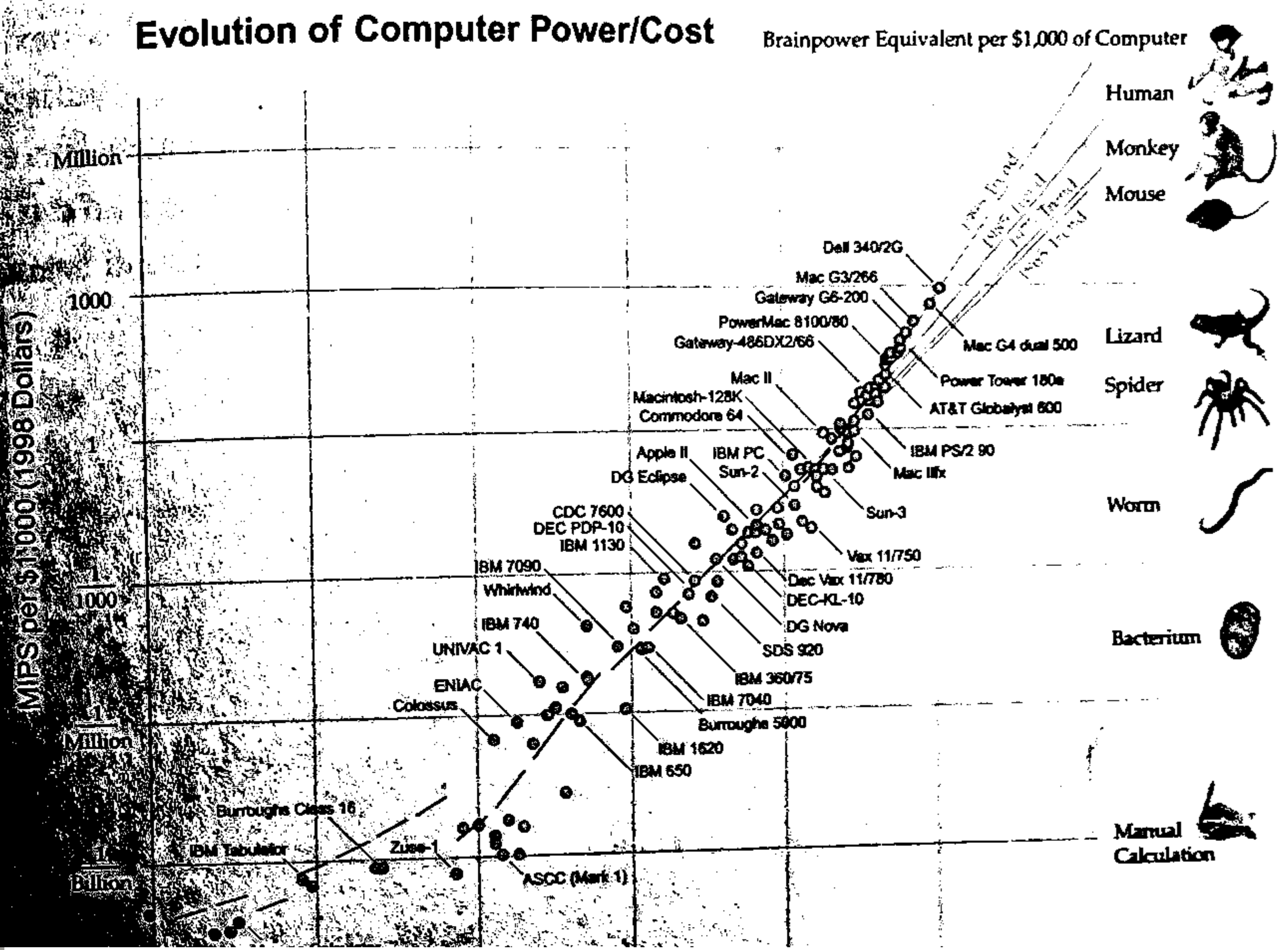
Fractal Dimensions and the Brain

Note that the use of the third dimension in computing systems is not an either-or choice but a continuum between two and three dimensions. In terms of biological intelligence, the human cortex is actually rather flat, with only six thin layers that are elaborately folded, an architecture that greatly increases the surface area. This folding is one way to use the third dimension. In "fractal" systems (systems in which a drawing replacement or folding rule is iteratively applied), structures that are elaborately folded are considered to constitute a partial dimension. From that perspective, the convoluted surface of the human cortex represents a number of dimensions in between two and three. Other brain structures, such as the cerebellum, are three-dimensional but comprise a repeating structure that is essentially two-dimensional. It is likely that our future computational systems will also combine systems that are highly folded two-dimensional systems with fully three-dimensional structures.

Notice that the figure shows an exponential curve on a logarithmic scale, indicating two levels of exponential growth.[36] In other words, there is a gentle but unmistakable exponential growth in the *rate* of exponential growth. (A straight line on a logarithmic scale shows simple exponential growth; an upwardly curving line shows higher-than-simple exponential growth.) As you can see, it took three years to double the price-performance of computing at the beginning of the twentieth century and two years in the middle, and it takes about one year currently.[37]

Hans Moravec provides the following similar chart (see the figure below), which uses a different but overlapping set of historical computers and plots trend lines (slopes) at different points in time. As with the figure above, the slope increases with time, reflecting the second level of exponential growth.[38]



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Doubling (or Halving) Times[33]

Dynamic RAM "Half Pitch" Feature Size (smallest chip feature)	5.4 years
Dynamic RAM (bits per dollar)	1.5 years
Average Transistor Price	1.6 years
Microprocessor Cost-per-Transistor Cycle	1.1 years
Total Bits Shipped	1.1 years
Processor Performance in MIPS	1.8 years
Transistors in Intel Microprocessors	2.0 years
Microprocessor Clock Speed	3.0 years

Moore's Law: Self-Fulfilling Prophecy?

Some observers have stated that Moore's Law is nothing more than a self-fulfilling prophecy: that industry participants anticipate where they need to be at particular times in the future, and organize their research and development accordingly. The industry's own written road map is a good example of this.[34] However, the exponential trends in information technology are far broader than those covered by Moore's Law. We see the same types of trends in essentially every technology or measurement that deals with information. This includes many technologies in which a perception of accelerating price-performance does not exist or has not previously been articulated (see below). Even within computing itself, the growth in capability per unit cost is much broader than what Moore's Law alone would predict.

The Fifth Paradigm[35]

Moore's Law is actually not the first paradigm in computational systems. You can see this if you plot the price-performance—measured by instructions per second per thousand constant dollars—of forty-nine famous computational systems and computers spanning the twentieth century (see the figure below).

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As the figure demonstrates, there were actually four different paradigms—electromechanical, relays, vacuum tubes, and discrete transistors—that showed exponential growth in the price-performance of computing long before integrated circuits were even invented. And Moore's paradigm won't be the last. When Moore's Law reaches the end of its S-curve, now expected before 2020, the exponential growth will continue with three-dimensional molecular computing, which will constitute the sixth paradigm.