5.3 Money, Markets, and Management

5.3.1 Moore's Law and what it Means

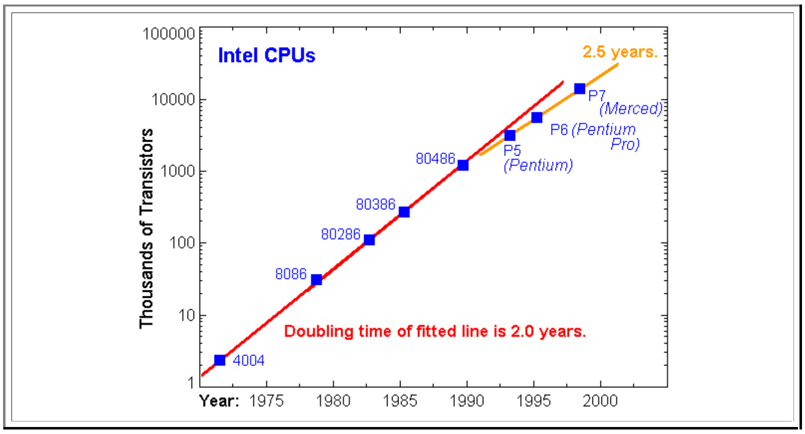
- This module more or less continues chapter "4.3 Infrastructure" - it is essentially about money!
  - Semiconductor technology thrives because it makes money by offering products that become exponentially cheaper and / or better. That is the *only* criterium for a new product that will make money; it is the **central credo**:

Cheaper and / or better!

- Let's look at a simple example: You have already spent something like **2 × 10^{9} €** when you produce your very frist **1 Bbit DRAM** memory that you can actually sell to a customer. It has four times more bits that the **256 Mb DRAM** presently on the market. It is definitely *better* in the eyes of your engineers; it's just so much cooler, smaller, faster; uses the latest materilas and so on.
  - However, for you customers it's a memory. If the price is not substantially smaller than **4** times that of the tried-and-proven **256 Mb DRAM**, they are not going to buy it. All they care for is the *price per bit*!

- You may be the foremost *materials* expert in the world, but if you try to leave your mark on chip development without regard to some boundary conditions of a more *economical* nature, you will not achieve much. And if you are the *manager* (which you should be with the kind of education you get here), you better be aware of the following points that are special to research, development and manufacture of (memory) chips.
  - There is no other product with quite such brutal requirements, even considering that *all* technical product development must follow similar (but usually much more relaxed) rules.

- ***1.** A new generation with four-fold capacity will appear on the market every three years.*
  - That is an expression of "**Moore's law**". It is, of course, not a "law" but an extrapolation from observation and bound to break down in the not so distant future (with possible disastrous consequences to the economy of the developed countries).
  - The original observation made in **1965** by Gordon **Moore**, co-founder of **Intel**, was that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data density has doubled approximately every **18** months, and this is the current definition of Moore's Law, which Moore himself has blessed. Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades.
  - Here is a graphic representation for microprocessors:

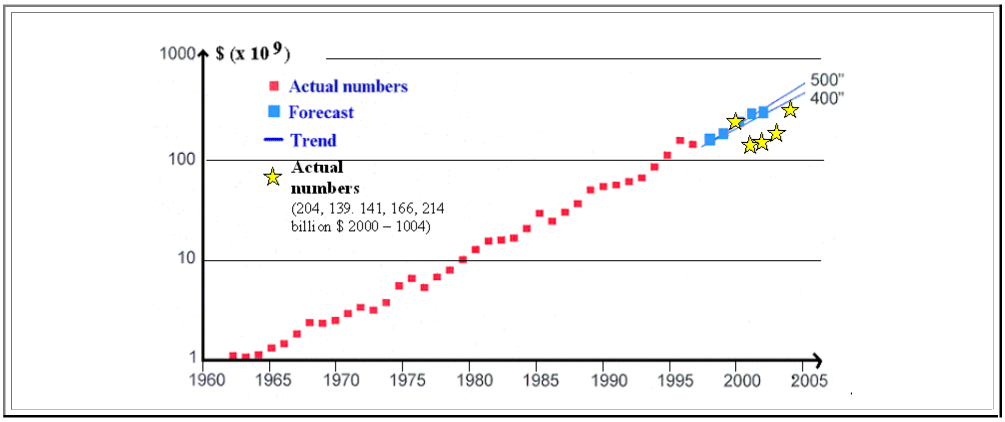


  - Not bad - but of course Moore's law must break down sometime (at the very latest when the feature size is akin to the size of an atom (when would that be assuming that the feature size of the **P7** is **0,2 µm**?). This is illustrated in a separate module.
  - Still, as long as it is true, it means that you either have your new chip generation ready for production at a well-known time in the future, or you are going to loose **large amounts of money**. There are some immediate and unavoidable consequences:
  - You must spent *large amounts of money* to develop the chip and to built the new factory **2 - 3** years before the chip is to appear on the market, i.e. at a time were you do not know if chip development will be finished on time. And *large* means several billion **$**.

- The time allowed for developing the new chip generation is a constant: You can't start early, because everything you need (better lithography, new materials,) does not exist then. But since chip complexity is ever increasing, you must do more work in the same time. The unavoidable conclusion is more people and *shift work*, even in research and development.
- It follows that you need ever increasing amounts of money for research and development of a new chip generation (there is a kind of Moore's law for the costs of a new generation, too). Look at it in another way in a separate module.

2. The market for chips grows exponentially

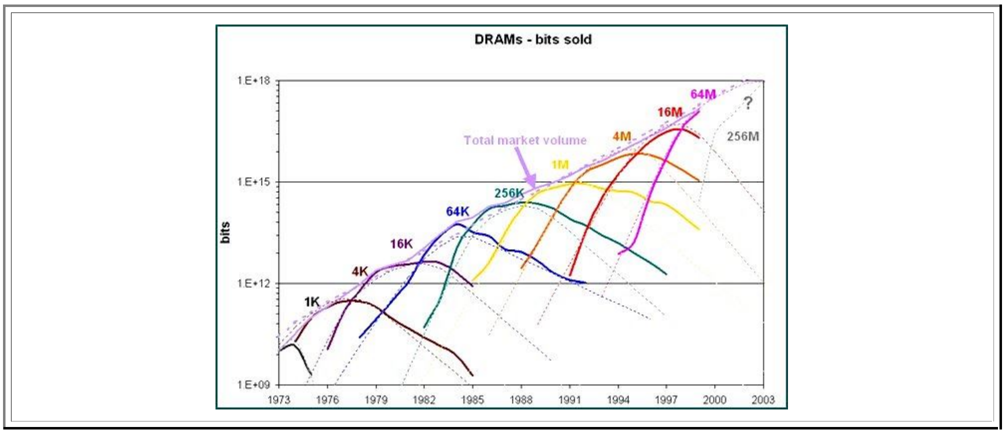
- That is an expression of the insatiable demand for chips - as long as they provide more power for less money! That this statement was true is shown below. Note *that the scale is logarithmic*!



Shown is the total amount of money grossed in the semiconductor market from **1960 - 2000** (Source: Siemens / Infineon).

- The essentially straight line indicates exponential growth - including the foreseeable future. Extrapolations, however, are still difficult. The two extrapolated (in **2000)** blue lines indicating a difference of **100.000.000.000 $** of market volume in **2005** are rather close together. The error margins in the forecast thus correspond to the existence or non-existence of about **10** large semiconductor companies (or roughly **150.000** jobs).
- We also see the worst downturn ever in **2001**. Sales dropped from **204** billion $ in **2000** to **139** billion $ in **2001**, causing major problems throughout the industry.

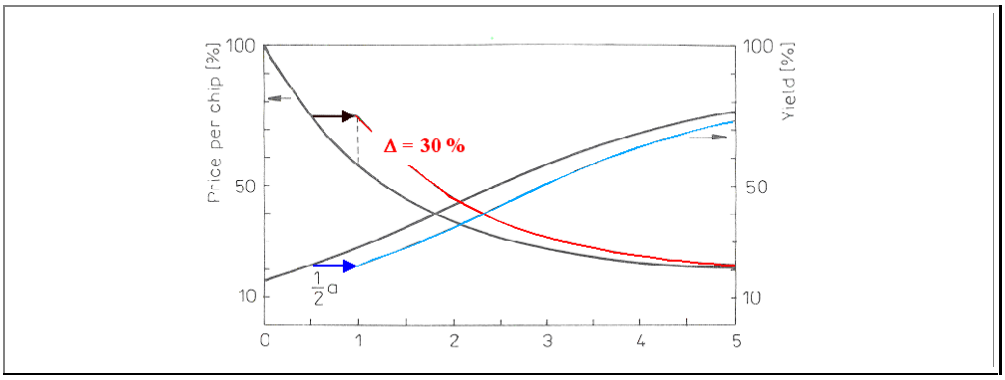
More specific, we can see the exponential growth of the market by looking at sales of **DRAMs**. Shown is the total number of memory *bits* sold. Note that just a fourfold increase every three years would keep the number of *chips* sold about constant because of the fourfold increase of storage capacity in one chip about every three years.



- The unavoidable consequence is: Your production capacity must grow exponentially, too, if you just want to keep your share of the market. You must pour an *exponentially growing amount of money* into investments for building factories and hiring people, while the returns on these investments are delayed for at least **2 - 3** years. In other words: the difference of what you must spent and what you earn increases, very roughly, exponentially. This is not a healthy prospect for very long, and you must make *large amounts of money* every now and then (e.g. by being the first one on the market with a new chip or by having a quasi monopoly).
- You must make (and sell at a profit) an *exponentially increasing number of chips* (since the prize per chip is roughly constant) to recover your ever increasing costs. Since chip sizes increase and prices must stay halfway constant, you must use larger wafers to obtain more chips per processing. This puts a lot of pressure on developing larger **Si** crystals and equipment to handle them.
- You must produce as many chips as you can during the product life time (typically **5** years). Continuous shift work in the factory (**7** days a week, **24** hours a day) are absolutely mandatory!

3. Chip prices for memories decay exponentially from the time of their market introduction (roughly $60) by two orders of magnitude within about 5 years (i.e. at the end you get $1).

- The prize development up to the **16 Mbit DRAM** can be seen [in an illustration] via the link. Microprocessors may behave very differently (as long as Intel has a quasi monopoly). The rapid decay in prizes is an expression of fierce competition and mostly caused by:
- **1.** The "**learning curve**", i.e. the increase of the percentage of good chips on a wafer (the **yield**) from roughly **15%** at the beginning of the production to roughly **90%** at the end of the product life time (because you keep working like crazy to improve the yield).
- **2.** Using a "**shrink strategy**" . This means you use the results of the development efforts for the next two generations to make your present chip smaller. Smaller chips mean more chips per wafer and therefore cheaper chips (the costs of making chips are mostly the costs of processing wafers).
- An immediate consequence is that if you fall behind the mainstream for **6** months or so - you are dead! This can be easily seen from a simple graph:



- The descending black curve shows the expected trend in prizes (it is the average exponential decay from the [illustration]). The ascending curve is the "learning curve" needed just to stay even - the cost of producing one chip then comes down exactly as the expected prize.
- Now assume you fall behind **6** month - your learning curve, i.e. your yield of functioning chips does not go up. You then move on the modified blue learning curve. The prize you would have to ask for your chip is the modified red prize curve - it is **30 %** above the expected world market prize in the beginning (where prizes are still moderately high).
- Since nobody will pay more for your chips, you are now **30 %** behind the competition (much more than the usual profit margins) - you are going to loose *large amounts of money*!
- In other word: You *must* meet the learning curve goals! But that is easier said then done. Look at [real yield curves] to appreciate the point

To sum it up: If you like a quiet life with just a little bit of occasional adrenaline, you are better off trying to make a living *playing poker in Las Vegas*.

- Developing and producing new chip generation in our times is a quite involved gamble with billions at stake! There are many totally incalculable ingredients and you must make a lot of million **$** decisions by feeling and not by knowledge!
- So try at least to know what can be known. And don't forget: *It's fun*!

To give a few more data, here is a table with many numbers:

Type	**4 kb**	**16 kb**	**64 kb**	**256 kb**	**1 Mb**	**4 Mb**	**16 Mb**	**64 Mb**	**256 Mb**	**1 Gb**	**4 Gb**
Begin of production	1974	1976	1979	1982	1985	1988	1991	1994	1997	2001	2004
Equivalent of type written pages	0,23	1	4	16	64	250	1000	4000	16000	64000	250000
	Growth per year about **+ 60 %**										
Prize for 1 Mbit memory (DM)	150000.-	50000.-	10000.-	800.-	240.-	60.-	10.-	1.-	0.25.-	0.11.-	0.05.-
	Growth about **– 40%** per year										
Chip size (mm^2)	24	16	25	45	54	91	140	190	250	400	?
Structure size (µm^2)	6	4	2	1.5	1.2	0.8	0.6	0.4	0.3	0.2	0.15
Number of process steps	70	80	8	120	280	400	450	500	600	?	?

Size of "killer" particles (>µm^2)	1.5	1.3	0.8	0.6	0.4	0.2	0.15	0.1	0.07	0.05	0.03
Total development costs (M$)	(90)	(140)	200	450	650	1000	2000	3500	5000	7000	?