Key Factors Influencing Computer Costs

Time

Manufacturing costs decrease over time due to the learning curve, which is best measured by improvements in yield—the percentage of manufactured devices that survive testing.

Volume

Increasing volumes decrease costs by accelerating the learning curve and improving purchasing and manufacturing efficiency. Rule of thumb: cost decreases about 10% for each doubling of volume.

Commoditization

Products sold by multiple vendors in large volumes that are essentially identical. Competition decreases the gap between cost and selling price while also decreasing overall cost.

These factors have driven the computer industry to focus increasingly on cost-sensitive designs, particularly in high-volume market segments.

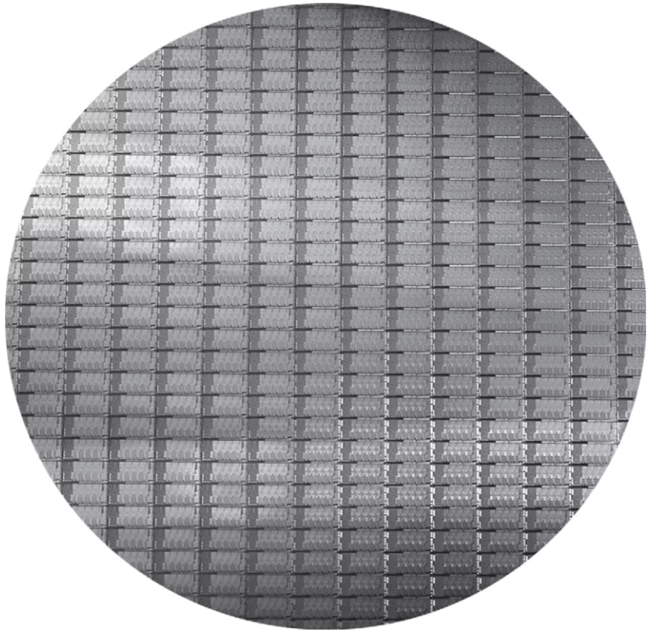
Integrated Circuit Economics

- Cost of a die

$$Cost\ of\ die = \frac{Cost\ of\ wafer}{Dies\ per\ wafer\ \times Die\ yield}$$

- Dies per wafer

$$Dies\ per\ wafer \approx \frac{\pi \times (Wafer\ diameter\ /\ 2)^2}{Die\ area} - \frac{\pi \times Wafer\ diameter}{\sqrt{2 \times Die\ area}}$$



- Example
  - 300 mm wafer
  - 20.7 by 10.5 mm die size
  - How many dies?
- Answer

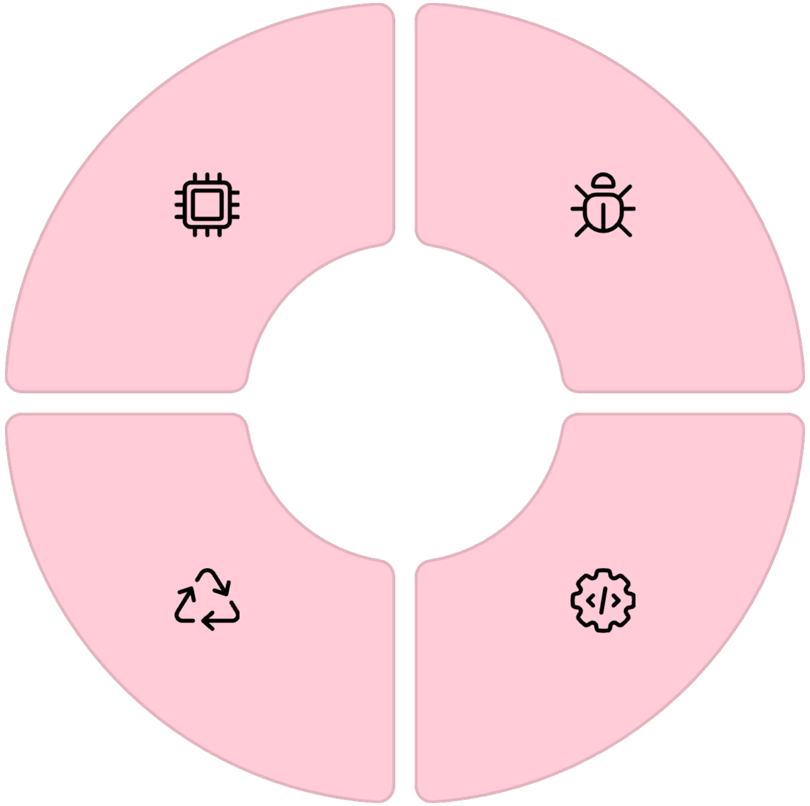
Die Yield and Cost Impact

Die Size

The critical factor controlled by designers. Cost per die grows roughly as the square of the die area due to yield effects.

Redundancy

Including redundant components (like memory cells) can significantly boost yield, especially for commodity products under price pressure.



Defect Density

Measure of random manufacturing defects. Typically 0.016 to 0.057 defects per square centimeter for a 40 nm process in 2010.

Process Complexity

Parameter N in the yield formula measures manufacturing difficulty. For 40 nm processes in 2010, N ranged from 11.5 to 15.5.

Yield

- Bose-Einstein empirical formula

$$Die\ yield = Wafer\ yield \times \frac{1}{(1 + Defects\ per\ unit\ area\ \times Die\ area)^{N}}$$

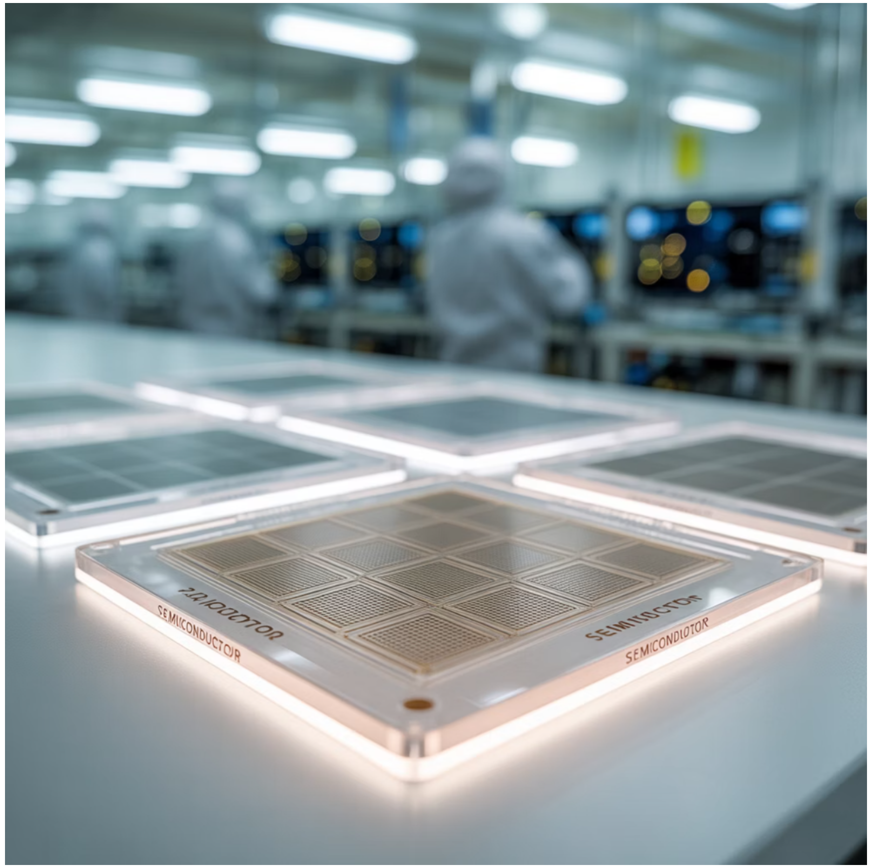
- Wafer yield accounts for wafers that are completely bad and so need not be tested.
- *N* is the process-complexity factor, ranging from 11.5 to 15.5.

- Example
  - 1.5cm by 1.5cm die size
  - 0.031 per cm^2 defect density
  - *N* is 13.5
  - 100% wafer yield
  - Die yield?
- Answer

$$Die\ yield = 1\ \times \frac{1}{(1 + 0.031 \times 1.5 \times 1.5)^{13.5}} = 0.40$$

Non-Recurring Engineering Cost

- For modern high-density fabrication processes with 4-6 metal layers, mask costs exceed $1M.
- This large fixed cost significantly affects:
  - Prototyping and debugging runs
  - Small-volume production economics
  - Design decisions for flexibility



Designers may incorporate reconfigurable logic or use gate arrays (with fewer custom mask levels) to reduce mask cost implications.

Operational Costs: The New Reality

- For large data centers with tens of thousands of servers, operational costs are now as significant as purchase costs.
- Monthly operational cost breakdown:
  - ~60%: Amortized purchase price of servers and networks (3-4 year lifetime)
  - ~30%: Power use and amortized infrastructure for power distribution and cooling (10 year amortization)
  - ~10%: Other operational expenses