Abstraction of Complexity

Design complexity

- 10's of transistors
  - full custom
- 100's of Ts
  - tedious for full custom
- 1000's to 100,000's of Ts
  - must find or create regularity + exploit it
- millions to billions
  - high level structure
  - SoC - system on a chip
  - IP "intellectual property"

Ex: Clock distribution
- skew is critical

Ex: 32-bit register
Ex: Power distribution
- low R for a small voltage drop

Cost

Metrics
- Energy to perform a function Ex.: $pJ/\text{add}$
- Performance
  - max clock freq.
  - throughput
- latency
- Cost $\leftarrow$ chip area

- Design time
  - Power dissipation (peak, power)
  - Scalability
  - Reliability

Ex: heart pacemaker - reliable, energy
Ex: RFID tag
Ex: GPU - perf.

\[
\text{Cost} = \frac{\text{cost/Chip}}{\text{chip}} = \text{fixed per design} + \text{variable cost per chip}
\]

1) Fixed: non-recurring engineering (NRE)
   - design time
   - masks
   - CAD tools
   - company costs - sales, building

2) Recurrent costs
   - chip
   - package
   - testing
Modern ASICs ~ $50 million NRE

18-24 months

large + talented design team

Dies per wafer = \( \frac{\pi \left( \text{wafer dia} / 2 \right)^2}{\text{die area}} \) - \( \frac{\pi \text{wafer dia.}}{\sqrt{2 \cdot \text{die area}}} \)

Die Yield = \( \frac{\# \text{ good chips}}{\text{total \# chips}} \times 100\% \)

\[ \alpha = \left[ 1 + \frac{\text{defects per area} \times \text{die area}}{\alpha} \right]^{-\alpha} \]

\( \alpha \) roughly proportional to \# mask layers

\( \alpha = 3 \) for modern CMOS

0.5 - 1 defects/cm² modern CMOS
<table>
<thead>
<tr>
<th>Year</th>
<th>Water Cost</th>
<th>Die</th>
<th>Area</th>
<th>Die Cost</th>
<th>Yield</th>
<th>Good Die Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>386 DX</td>
<td>0.90 mm</td>
<td>$900</td>
<td>1.0</td>
<td>43</td>
<td>360</td>
<td>71%</td>
</tr>
<tr>
<td>Power PC 601</td>
<td>0.80 mm</td>
<td>$1700</td>
<td>1.3</td>
<td>121</td>
<td>115</td>
<td>28%</td>
</tr>
<tr>
<td>Pentium</td>
<td>0.80 mm</td>
<td>$1500</td>
<td>1.5</td>
<td>296</td>
<td>40</td>
<td>99%</td>
</tr>
</tbody>
</table>

Die cost = f(Die Area)