Power in Microprocessor Designs

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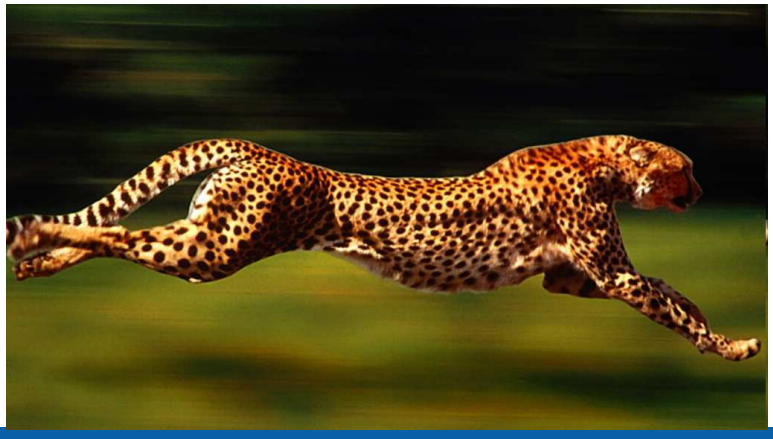
First….

Who Am I ?

Until a few years ago ..

Emphasis had been **solely** on improving performance



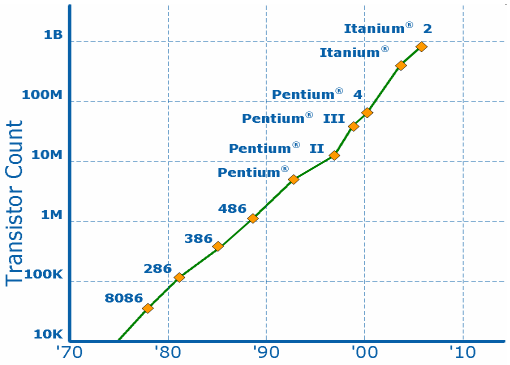
Times have changed

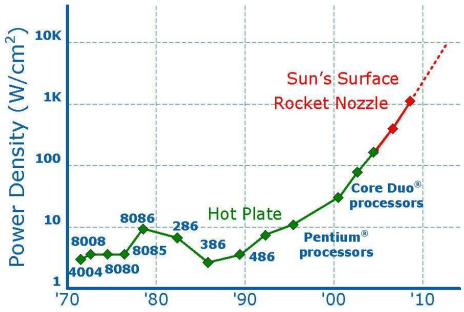
No longer sole emphasis on performance ….

Power & reliability concerns have become huge !!

Technology Trends: Moore's Law

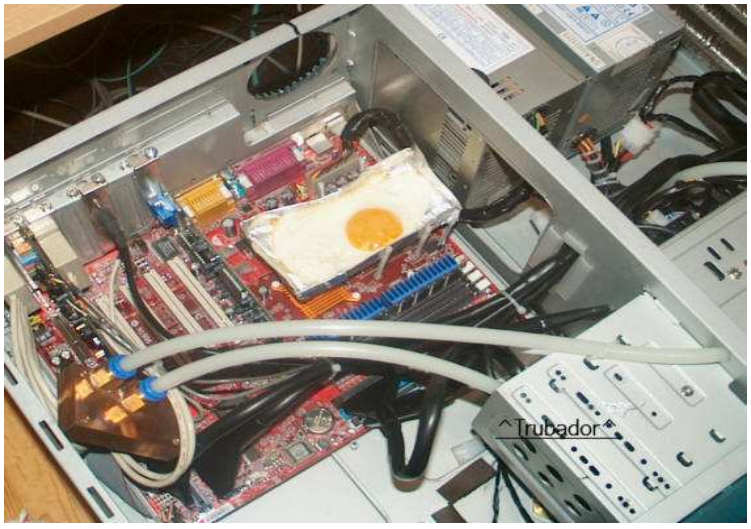
- More and faster transistors with higher power demands
  - Gate delay ⬇30% every process generation (2 years)
- Area of a transistor roughly scales by 50% per generation
  - Transistor density doubling
  - Power density increasing





Technology Trends

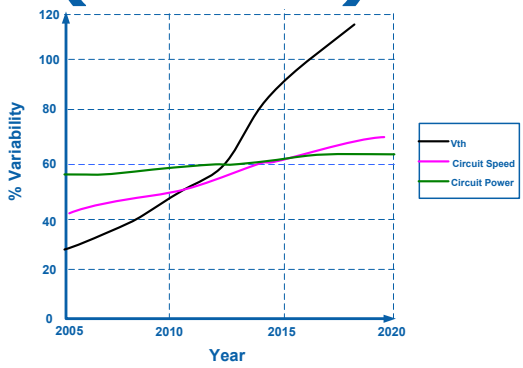
Traditional cooling solutions reaching physical limits



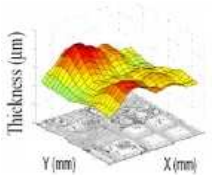
http://www.phys.ncku.edu.tw/~htsu/humor/fry_egg.html

Technology Trends (contd.)

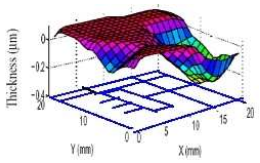
- In-die process variations
  - V_{th} variation
  - Variation in parasitics
  - Variations in die ageing
  - **Impact:** Alters impedance, current demand, hurts reliability



Data extracted from ITRS 2005



Cu Thickness Variation

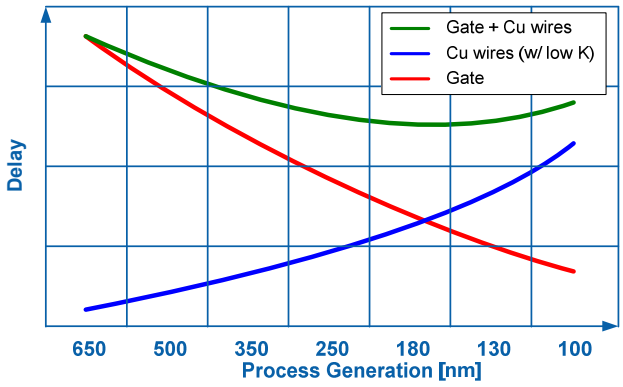


ILD Thickness Variation

Technology Trends (contd.)

- Delay Trends
  - ⬇ Gate delay, ⬆ Wire delay
  - ⬆ Cross-chip communication

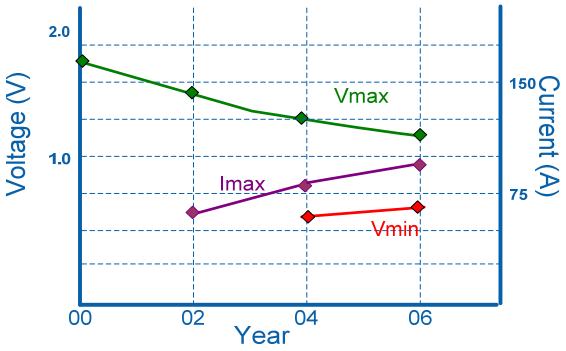
Performance demands continue



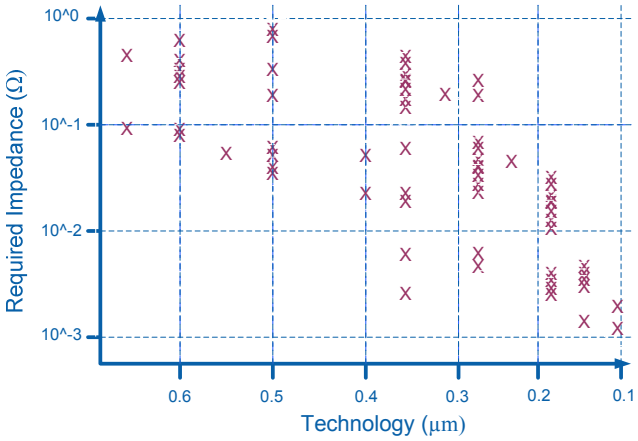
Wire & gate delay trends

Technology Trends (contd.)

- Intel's "Right Hand Turn"
  - Power is $$
  - "Power Wall" driving reduction in voltage
    - Dynamic power = α C V^2 F
- V_{MIN} relatively constant
  - ⬇ Operating range
  - ⬇ Noise margins



Technology Trends (contd.)



Impedance Rqmts. For High Performance MicroProcessors

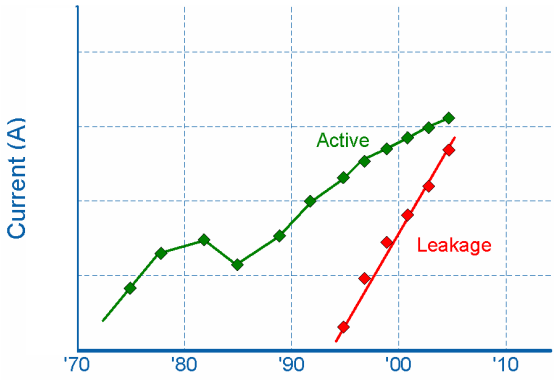
ISTR RoadMap
July 31st 2007

- Impedance scaling:
  - Drastic drop in supply impedance
  - Even at constant power
    - Vdd ⬇, Imax ⬆

    ➔ |Zrequired| ⬇ ⬇
  - Today's chips: |Zrequired| ≈1 mΩ
    - Supply voltage becoming noisy as result

Technology Trends (contd.)

- Leakage power
  - Increasing
  - Constant demand on power delivery system
    - Reliability impact



Leakage & Active Current Trends

Challenge: Efficient power delivery while:
- Minimizing power consumption
- Optimizing heat dissipation

Some Other Trends

Economy

- Electronic device presence multiplying
- Energy consumption increasing
- Energy costs rising
  - We all have an electricity bill to pay at the end of the month

Sociology & environment

- Global warming awareness

What exactly is Power & Energy ?

Power

- Rate at which work is done, expressed as amount of work per unit of time in Watts
- In a microprocessor:
  - Power consumed = dynamic power + leakage power
  - P = (Pswitch + Psc + Pcont + Pglitch) + Pleak
  - P = (α C V^2 F + Psc + Pcont + Pglitch) + VI_{leak}

    α activity factor — C switching capacitance
    V power supply voltage — F clock frequency
    Vt threshold voltage — $I_{leak} \sim \exp(-qVt/kT)$ leakage current

Energy

- Total amount of work done expresses in Joules
  - Power * Time = Energy

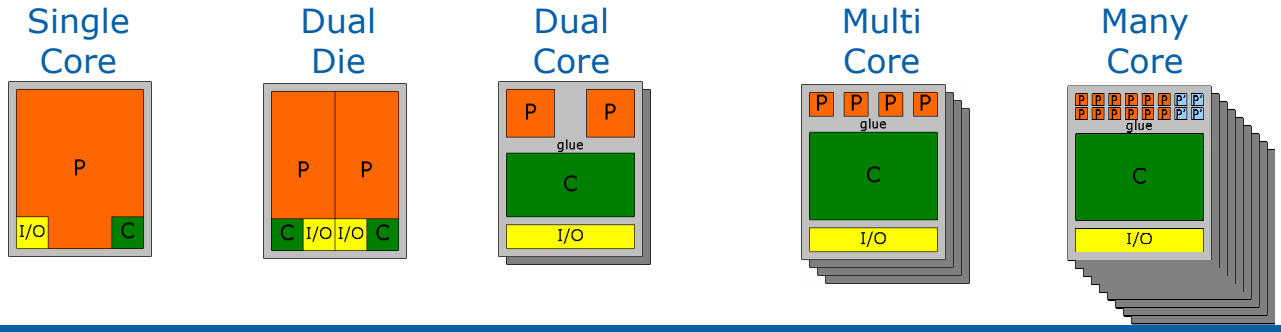
Which one do we aim at lowering: Energy or Power or BOTH?

Current Design Solutions

- Multiple voltage domains on-die
  - Trick used to reduce power while maintaining performance
  - Cache voltage lower than core/uncore voltage
    - Cache mainly needs to hold state
    - Speed critical for execution units, overall communication etc ➔ leads to higher voltage requirements here
  - Impact
    - Overall grid metal available per domain reduced
    - May need to compromise grid requirements depending upon distribution of voltage domains

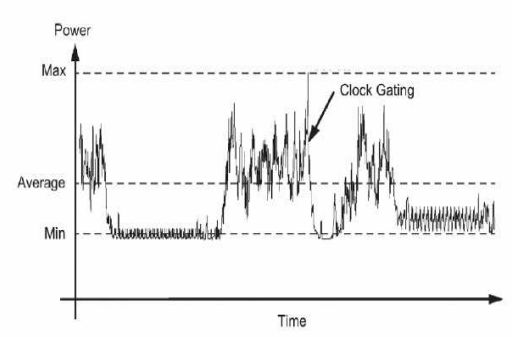
Current Design Solutions

- Multi-core trend
  - Attractive for throughput based solutions
  - Enables reduction in power consumption while maintaining throughput
  - Dynamic power = CV^2F
    - Power = 1Core @ V,F ~ 2 Cores @ 0.8V,0.8F



Current Design Solutions

- Active power management techniques
  - V/f scaling
    - Multiple operating modes for various benchmarks
  - Clock gating & power down mechanisms
    - ➡ Higher I_{STEP} (I_{MAX} - I_{MIN})
  - Power gates



SUN Microsystems CPU Sample Current Profile

Source: Harris, Addison-Wesley '05

Is it sufficient ?

2015 Likely Scenario

5 Billion Connected People

Always On

In Pursuit of Killer "Experiences"

Network Capacity?
100 Tbits/sec Today. 100,000 Tbits/sec Needed.
*That is **1000x** Increase!*

That's a lot of power!

Summary

- Technology trends in nano-era have elevated our power and reliability challenges
- Call for action: We need to be able to develop easy and revolutionary techniques to counter this in the increasing world of complicated microprocessor design
  - Plenty exist….but not sufficient
- Plenty of opportunities for research

Talk to/email me for further input/questions

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