Is Power Consumption Important?

“The internet and wireless services are getting married”, Simon Segars
Motivation
Why should a digital designer care about power consumption?

• Portable devices:
  – handhelds, laptops, phones, MP3 players, cameras, … all need to run for extended periods on small batteries without recharging
  – Devices that need regular recharging or large heavy batteries will lose out to those that don’t.

• Power consumption important even in “tethered” devices.
  – System cost tracks power consumption:
    • power supplies, distribution, heat removal
  – power conservation, environmental concerns

• In a span of 10 years we have gone from designing without concern for power consumption to (in many cases) designing with power consumption as the primary design constraint!
Battery Technology

- Battery technology has moved very slowly
  - Moore’s law does not seem to apply
- Li-Ion and NiMh still the dominate technologies
- Batteries still contribute significant to the weight of mobile devices

**Nokia 61xx - 33%**

**Handspring PDA - 10%**

**Toshiba Portege 3110 laptop - 20%**

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Basics

- Power supply provides energy for charging and discharging wires and transistor gates. The energy supplied is stored and dissipated as heat.

\[ P \equiv \frac{dw}{dt} \]

**Power:** Rate of work being done w.r.t time.

Rate of energy being used.

Units: \( P = \frac{E}{\Delta t} \) Watts = Joules/seconds

- If a differential amount of charge \( dq \) is given a differential increase in energy \( dw \), the potential of the charge is increased by: \( V = \frac{dw}{dq} \)
- By definition of current: \( I = \frac{dq}{dt} \)

\[
\frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = P = V \times I
\]

\( w = \int_{-\infty}^{\infty} P dt \) total energy
Basics

- **Warning!** In everyday language, the term “power” is used incorrectly in place of “energy.”
- Power is **not** energy.
- Power is **not** something you can run out of.
- Power can **not** be lost or used up.
- It is **not** a thing, it is merely a rate.
- It can **not** be put into a battery any more than velocity can be put in the gas tank of a car.

Metrics

How do we measure power consumption?

- One popular metric for microprocessors is: **MIPS/watt**
  - MIPS, millions of instructions per second.
    - Typical modern value?
  - Watt, standard unit of power consumption.
    - Typical value for modern processor?
  - MIPS/watt is reflective of the tradeoff between performance and power. Increasing performance requires increasing power.
  - Problem with “MIPS/watt”
    - MIPS/watt values are typically not independent of MIPS
      - techniques exist to achieve very high MIPS/watt values, but at very low absolute MIPS (used in watches)
    - Metric only relevant at reasonable performance range
      - One solution, **MIPS²/watt**. Puts more weight on performance.
Metrics

- How does MIPS/watt relate to energy?
- Average power consumption = energy / time

\[
\text{MIPS/watt} = \frac{\text{instructions/sec}}{\text{joules/sec}} = \frac{\text{instructions}}{\text{joule}}
\]

- therefore an equivalent metric is energy per operation (E/op)

- E/op is more general - applies to more than processors
  - also, usually more relevant, as batteries life is limited by total energy draw.
  - This metric gives us a measure to use to compare two alternative implementations of a particular function.

Power in CMOS

Switching Energy:
energy used to switch a node

Calculate energy dissipated in pullup:

\[
E_{sw} = \int_{t_0}^{t_1} P(t)dt = \int_{t_0}^{t_1} (V_{dd} - v) \cdot i(t)dt = \int_{t_0}^{t_1} (V_{dd} - v) \cdot c \cdot (dv/dt)dt = cV_{dd} \int_{t_0}^{t_1} dv - c \int_{t_0}^{t_1} v \cdot dv = cV_{dd}^2 - \frac{1}{2}cV_{dd}^2 = \frac{1}{2}cV_{dd}^2
\]

An equal amount of energy is dissipated on pulldown.
Switching Power

- Gate power consumption:
  - Assume a gate is switching its output at a rate of:
    \[ P_{avg} = E/\Delta t = \text{switching rate} \cdot E_{sw} \]
  - \[ P_{avg} = \alpha \cdot f \cdot cV_{dd} \]

- Chip/circuit power consumption:
  \[ P_{avg} = n \cdot \alpha_{avg} \cdot f \cdot c_{avg} V_{dd}^{2} \]
  number of nodes (or gates)

Other Sources of Energy Consumption

- "Short Circuit" Current:
  \[ I_{off} \]
  \[ V_{out}=V_{dd} \]
  \[ V_{in}=0 \]
  \[ \approx 1 \text{nWatt/gate} \]
  \[ \text{few mWatts/chip} \]

- Junction Diode Leakage:
  \[ I_{off} \]
  \[ V_{out} \]
  \[ V_{in} \]
  \[ \approx 1 \text{nWatt/gate} \]
  \[ \text{few mWatts/chip} \]

- Device Ids Leakage:
  \[ I_{off} \]
  \[ V_{th} \]
  \[ V_{gs} \]
  Transistor s/d conductance never turns off all the way.
  \[ \approx 3 \text{pWatts/transistor} \]
  \[ \approx 1 \text{mWatt/chip} \]
  Low voltage processes much worse.
Controlling Energy Consumption

What control do you have as a designer?

- Largest contributing component to CMOS power consumption is switching power:

\[ P_{avg} = n \cdot \alpha_{avg} \cdot f \cdot c_{avg} V_{dd}^2 \]

- Factors influencing power consumption:
  - \( n \): total number of nodes in circuit
  - \( \alpha \): activity factor (probability of each node switching)
  - \( f \): clock frequency (does this affect energy consumption?)
  - \( V_{dd} \): power supply voltage

- What control do you have over each factor?
- How does each effect the total Energy?

In EECS150 design projects, we will not optimize for power consumption.

Power / Cost / Performance

- In lecture 23 we discussed using parallelism to trade cost for performance. As we trade cost for performance what happens to energy?

\[
\begin{align*}
4 E_{MUL} + 3 E_{ADD} + E_{Wires} & \\
2 E_{MUL} + 3 E_{ADD} + E_{Wires} & \\
2 E_{MUL} + 3 E_{ADD} + E_{MUXES} + E_{CNTL} + E_{Wires} &
\end{align*}
\]

- The lowest energy consumer is the solution that minimizes cost without time multiplexing operations.