Low Power System Design

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Course Introduction

- Master-level course that covers low-power system design
- Schedule
  - Monday, 11:30 to 13:45 (with a few exceptions)
- Instructor
  - Dr. Sangyoung Park + Guest lectures
  - sangyoung.park@tum.de
  - Phone: 23565
  - Office: Room 3993
  - Office hours: Monday, 13:45 to 15:00, but feel free to reach me any time

Course Introduction

- Homepage
  - Teaching page in RCS website
  - http://www.rcs.ei.tum.de/en/courses/lectures/lpsd/
- Information
  - 5 ECTS
  - All teaching, exams, presentation will be done in English
  - Final exam (50%)
  - Student presentation (30%)
  - Term paper (20%)

Course Introduction

- Textbook
  - There is no single textbook for this course
- References
  - Proceedings of relevant ACM/IEEE conferences
- Course materials
  - PDF format slides will be uploaded one by one

About the Instructor

- Dr. Sangyoung Park
  - PhD from Seoul National University, Korea
  - Postdoc @ TUM/RCS (Advisor: Prof. Samarjit Chakraborty)
  - Has been writing & reviewing papers in low-power area since 2009
  - Research areas
    - System-level low-power techniques
    - Energy management for mobile, grid-connected systems, electric vehicles, renewable sources
    - Embedded systems design

What to cover

- Review on prerequisite courses
  - MOSFET model
  - MOS capacitances
  - CMOS circuits
- Source of power consumption
  - Dynamic power of CMOS gates
  - Static power of CMOS gates
  - Power and energy consumption

What to cover

- Power estimation
  - Circuit-level estimation
  - Architecture-level estimation
  - System-level estimation
  - Architecture level simulators
  - Power measurement techniques
- Circuit-level low-power techniques
  - Transistor sizing, path balancing, don’t care optimization, technology mapping, state encoding
  - Body-biasing, multiple Vt, input vector control

What to cover

- Architecture-level low-power design
  - Low-power bus interconnect
  - Low-power memory architecture, cache
- System-level low-power techniques
  - Dynamic power management
  - Dynamic voltage and frequency scaling
  - Multicore processor power management
- Power generation and conversion for embedded systems
  - Battery characteristics
  - Power distribution network (DC-DC converters, etc.)
- Real-time systems and low-power
  - Wireless sensor networks
  - Power Management for Mobile Gaming

Why Low Power?

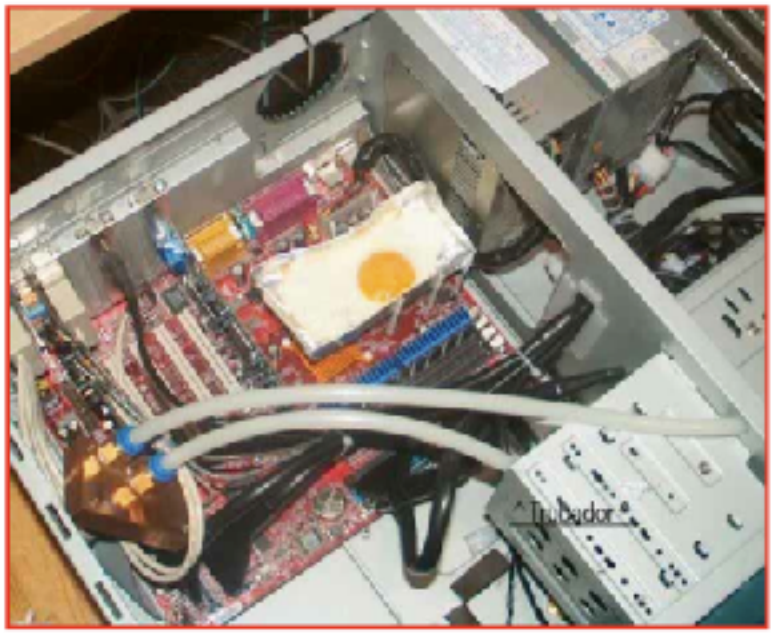
- Why do we want to decrease power consumption?
  - Longer battery life
  - Smaller battery size for portable devices
  - Lower power consumption decreases working temperature of the device
  - Lower electric bills (e.g. operating cost of data centers)

Why Low Power?

- Higher performance and longer battery life are conflicting demands in system design
  - Sophisticated design techniques are needed to meet both of them
- Power management is one of the most critical design issues
  - Power consumption has become the limiting factor
  - Thermal design power requirement
  - Meet the demands of the market
  - Keep the working temperature at an acceptable level

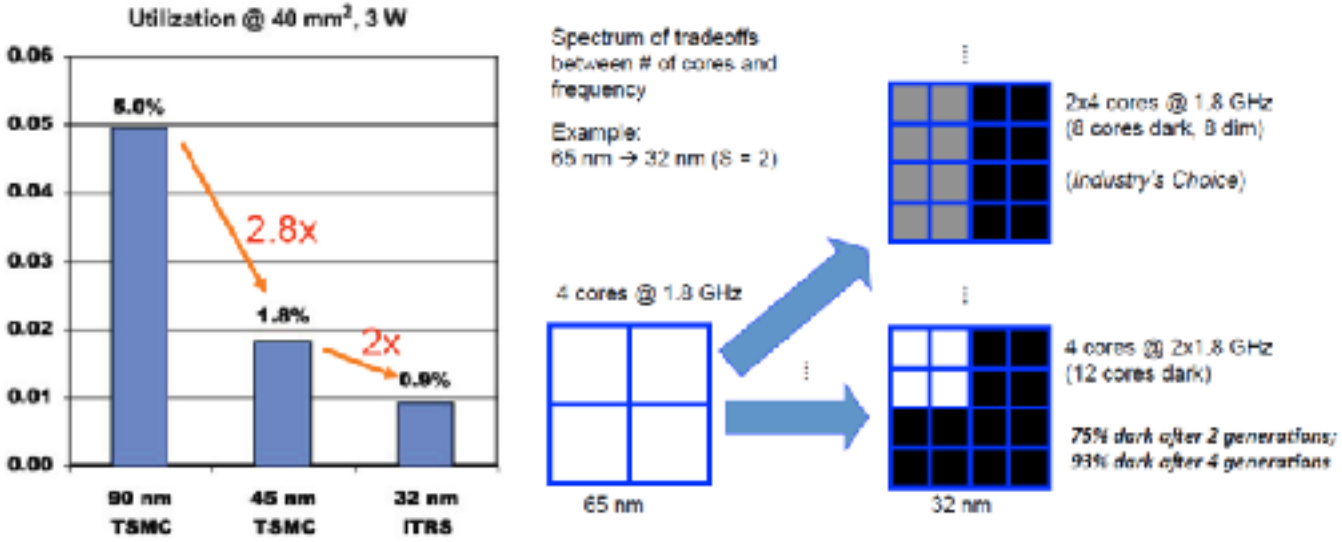
Why Low Power?

- Thermal issues
- Energy issues
- Power issues



Why Low Power?

- Power consumption has been the bottleneck over the last decade
- Thermal design power (TDP)
  - Maximum amount of heat generated by the CPU
- Dark silicon era
  - Parts of a chip should be turned off due to TDP



Source: Borkar, De Intel

Why Low Power?

- Designing within limits: power & energy
  - Thermal limits (for most parts self-heating is a substantial thermal issue)
  - Package cost (4-5W limit for cheap plastic package, 100W/ cm^2 air cooled limit, 7.5kW 19” rack)
  - Device reliability (junction temp > 125oC substantial reduction in reliability)
  - Performance (25℃ to 105℃: loss of 30% of performance)
- Distribution limits
  - Substantial portion of wiring resource, area for power distribution
  - Higher current - lower R, greater dI/dt needs more wire, decoupling capacitors
  - Package capable of low impedance distribution

Why Low Power?

- Energy capacity limits
  - Limits on volume and weight of batteries (portable applications)
  - Energy for IT equipment significant fraction of total cost of ownership

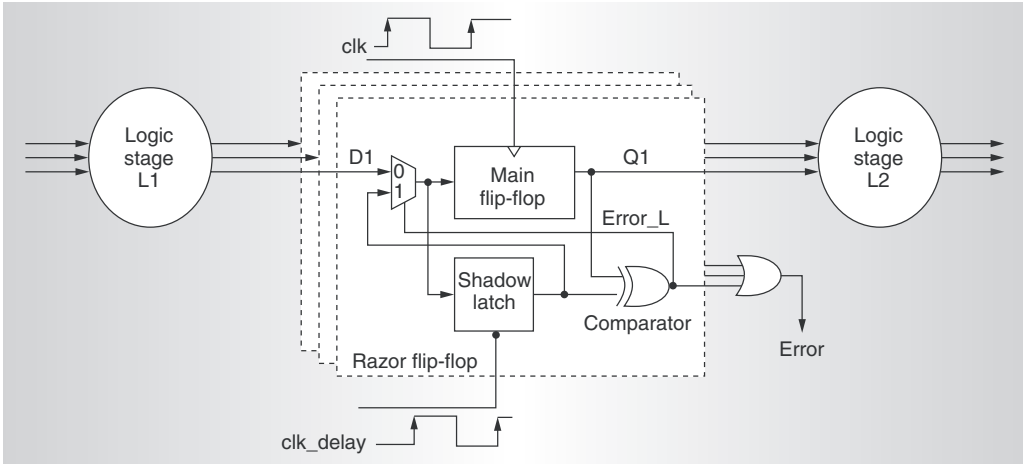
Why Low Power?

- Wearable devices
  - Limited size/weight
  - Energy harvesting
  - Use times

source: http://www.chinabbb.com/ckfinder/userfiles/images/devices.jpg

Low-Power Design & Abstraction

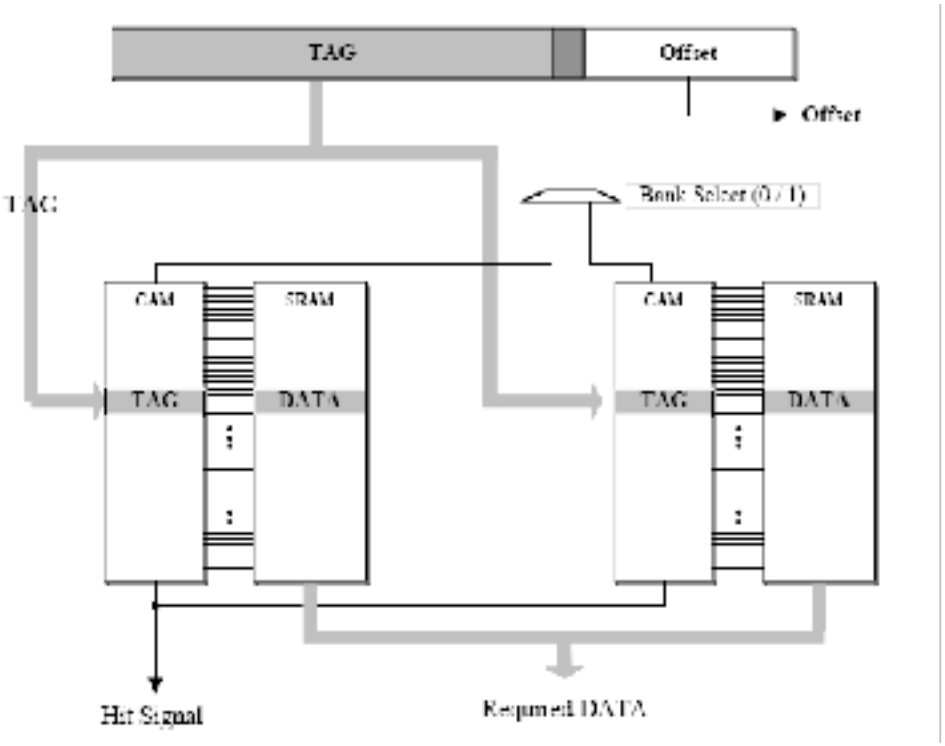
- Low-Power Design @ various abstraction layers
- Circuit-level
  - Low-power techniques applicable at circuit-level
  - Clock-gating, body-biasing, etc.



D. Ernst, et al., “RAZOR: CIRCUIT-LEVEL CORRECTION OF TIMING ERRORS FOR LOW-POWER OPERATION”, IEEE Micro 04

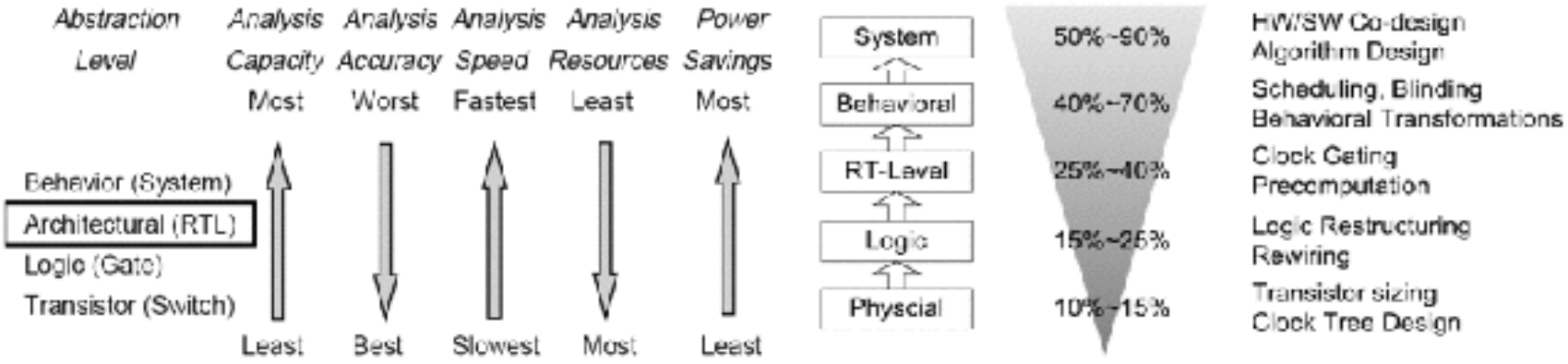
Low-Power Design & Abstraction

- Architecture-level
  - Cache/memory architecture
  - Interconnects



System-level energy optimization

- High-level energy reduction
  - RTL or higher level
  - Suitable for complex systems
  - Higher energy gain
  - Based on high-level energy model.
    - High-level energy characterization.
  - Abstraction progressively degrades the quality of power estimation

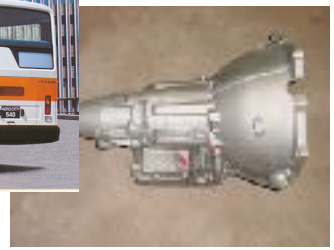


System-level energy optimization

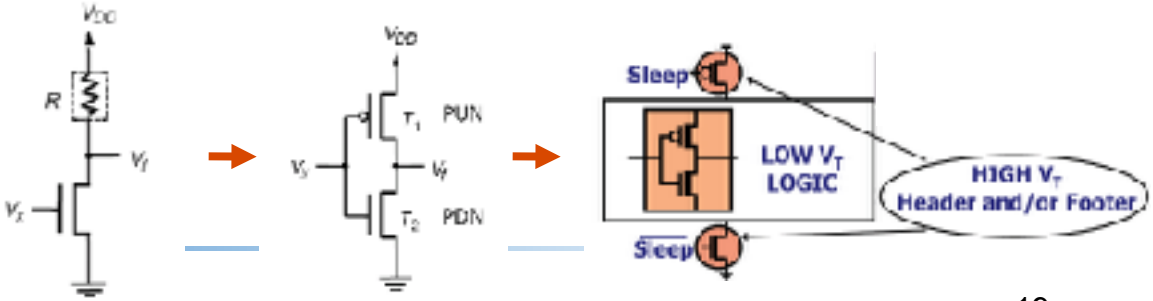
- Low-level energy optimization
  - Has been contributing over dozens of years
  - Enhancement of devices and components
  - General solution applicable to almost all kinds of use
  - City bus service example
    - Objective: more gas mileage
    - New buses, engine swap, aluminum bodies, new transmissions, etc.
  - In the semiconductor world
    - NMOS
    - CMOS
    - MTCMOS

Gas-efficient engine

Light-weight bus

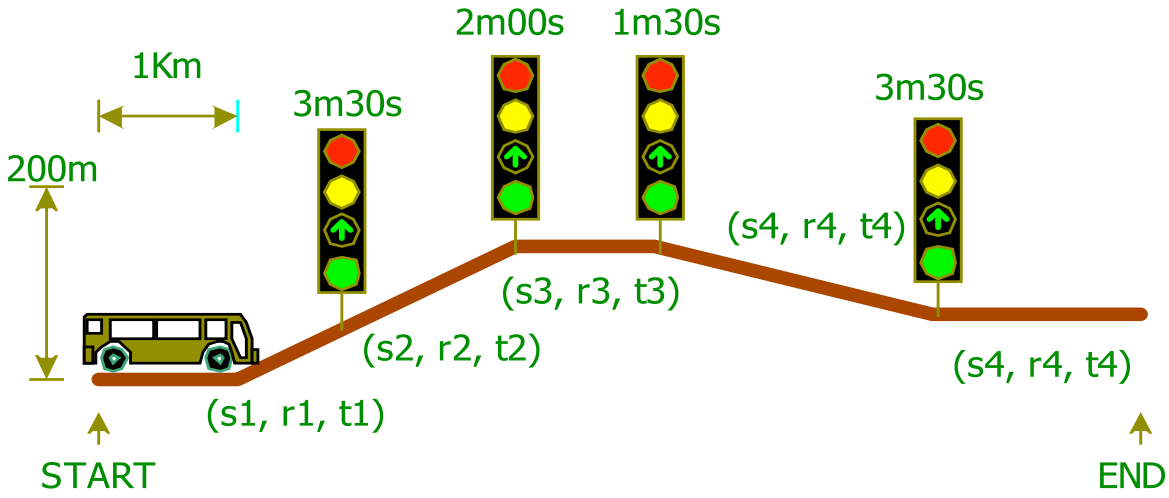


Low-loss transmission



System-level energy optimization

- System-software-level energy optimization
  - City bus service example
    - Optimal speed, engine rpm, shift position scheduling w/original hardware
      - Analysis of a target route
      - Use of component characteristics



System-level approaches give us bigger chance to minimize energy consumption!

System-level energy optimization

- Level of abstraction: engine idle gas consumption
  - Model 1: linear gas consumption per speed: $g = mv$
  - Model 2: counting idle gas consumption when v=0: $g = mv + I$
  - Model 3: counting engine restarting cost
  - Applicable gas saving techniques when a vehicle is temporarily parked
- Technique 1: linear gas consumption model
  - No policy when a vehicle is stopping
- Technique 2: Idle gas consumption
  - Stop engine whenever a vehicle is stopped
- Technique 3: Restarting cost
  - Stop engine when stopping time is more than 2 minutes for instance

Proper energy characterization is a primary concern of quality high-level power saving approach

Student Presentations

- Study of state-of-the-art low-power techniques and survey presentation
- Latter part of the lecture
  - End of Dec. ~ end of Jan.
  - Will be also an important part of evaluation (30%)
- List of candidate papers will be given and each student will choose based on their preference and topic coverage

Note

- Slides are modified from lecture notes of “Advanced Computer System Design” from Seoul National University (Lecturer: Prof. Naehyuck Chang)