TDDD50: Green Computing

Lecture 2: Power-aware computing

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Thanks to Jordi Cucurull and Ekhiotz Vergara for some slides

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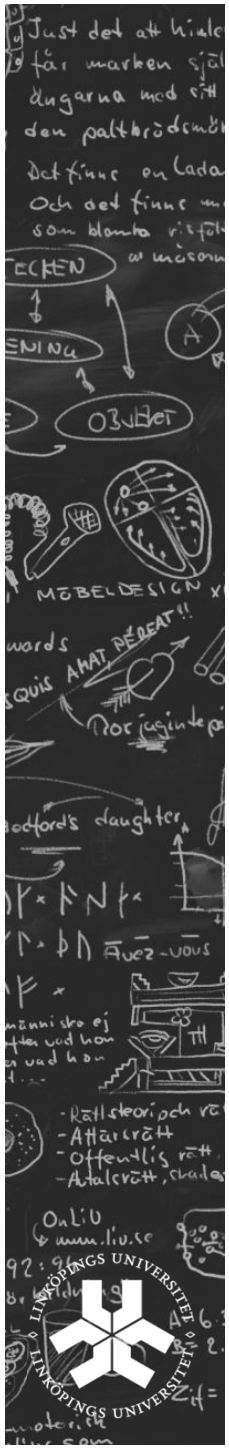
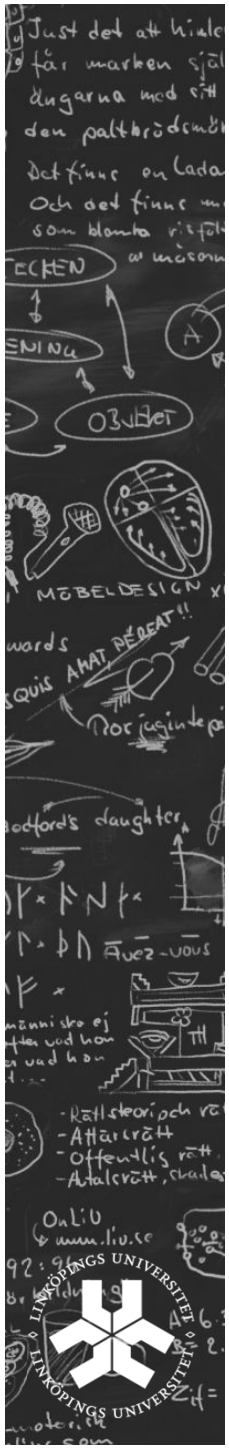
January 23, 2026

LiU expanding reality



Recap from Lecture 1

- Analysing sustainable products/services need a holistic approach
  - Lifecycle assessment
- Increasing energy efficiency may not be enough when the planet-scale constraints are considered
  - Computing within limits
- ICT is an essential ingredient in greening other sectors, but we need to keep its own footprint under control
  - This needs policy, corporate advocacy, knowledge



This lecture

- Power-aware computing

- Scientific articles
- Search for related works

Images:
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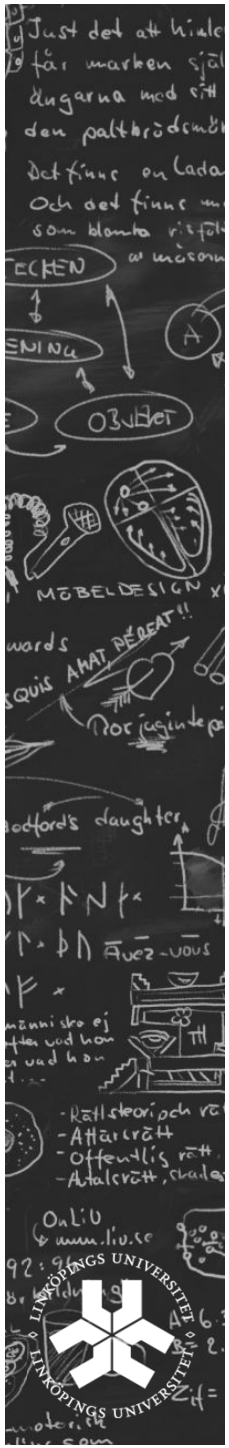
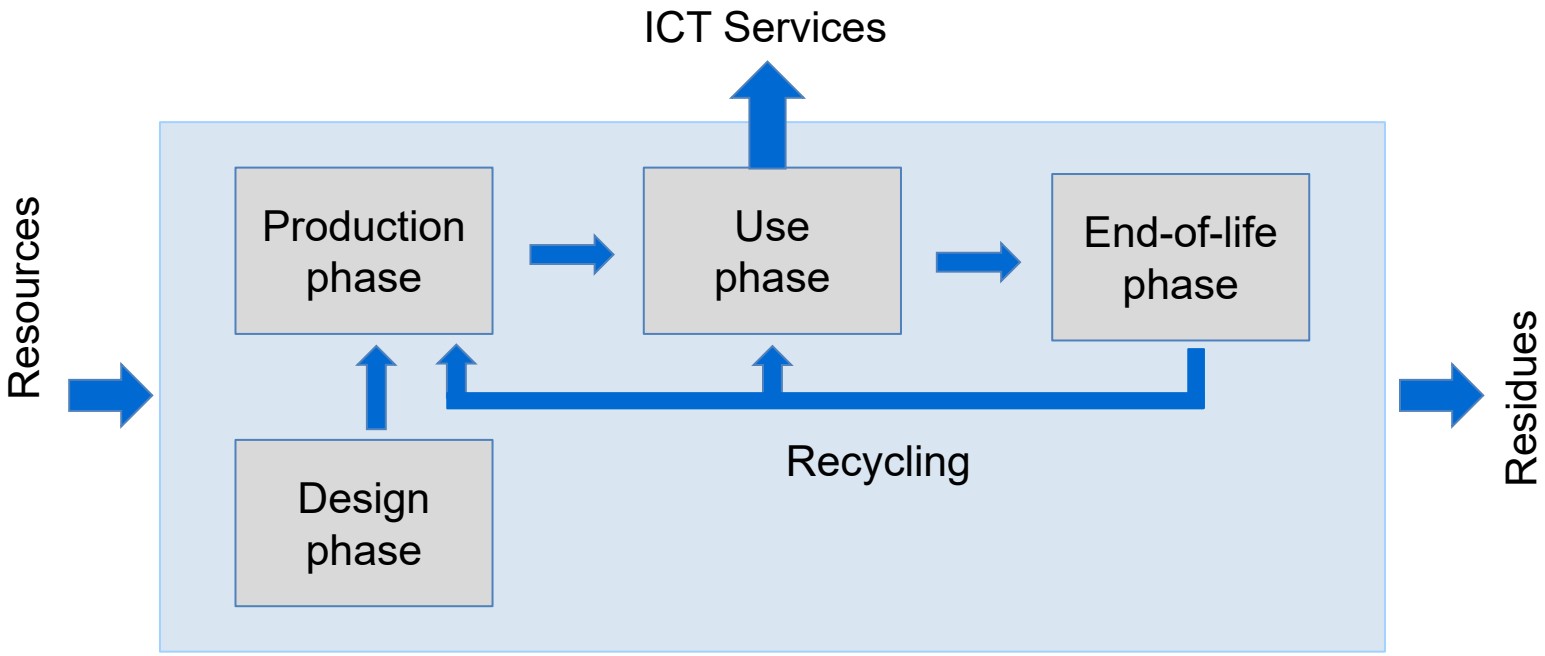


Power-aware computing

- Basic energy background
- Energy consumption in computing
- Sources of energy waste
- Reducing energy consumption

Recall: Green vs. power-aware computing

- Power-aware: focus is on design or use phase!

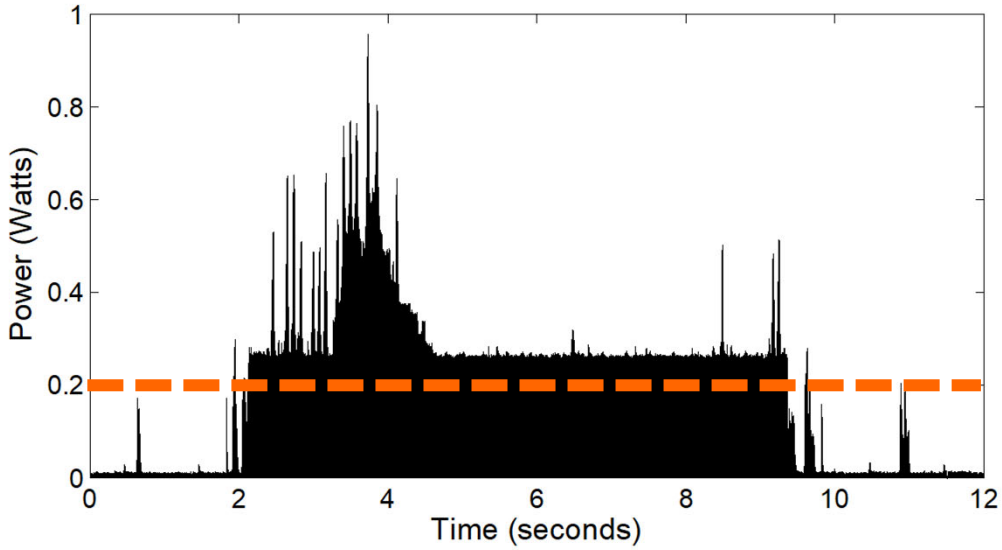


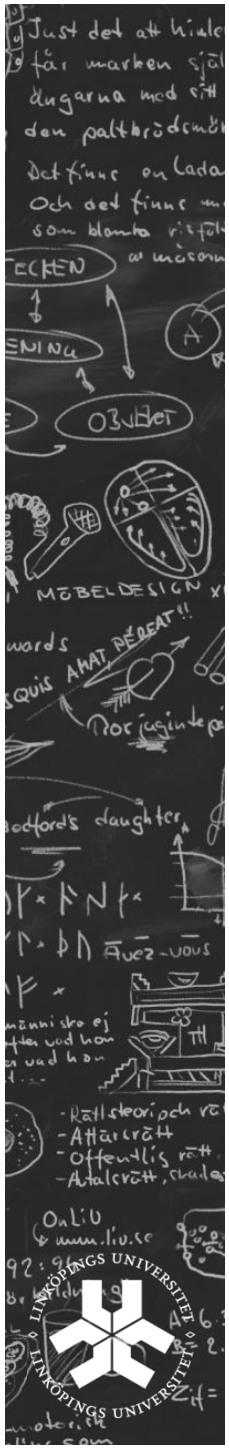
Lorenz M. Hilty. Information Technology and Sustainability: Essays on the Relationship between Information Technology and Sustainable Development, Books on Demand, 2008 ISBN: 978-3837019704

Power vs. Energy

- The cost of sending a SMS

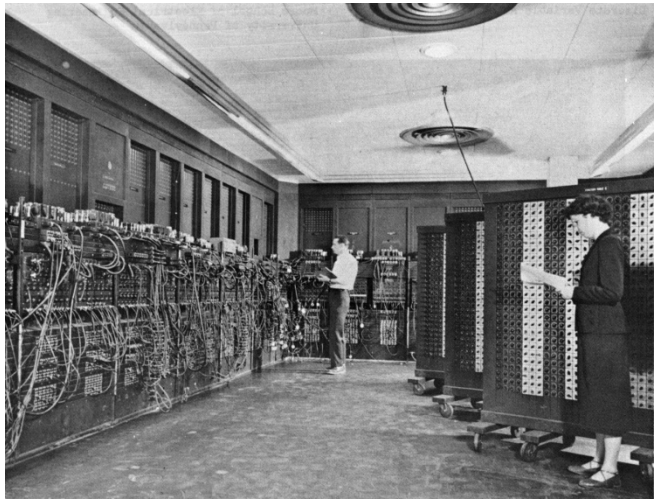
- Energy is power over time: 2.23 Joules
- Average power: 0.2 Watts





Energy consumption in computing

- Is it a new problem?
- ENIAC computer (1946)
  - Electronic Numerical Integrator And Computer
  - 150 kW
- Technology changed when its power was excessive
- Semiconductor device era



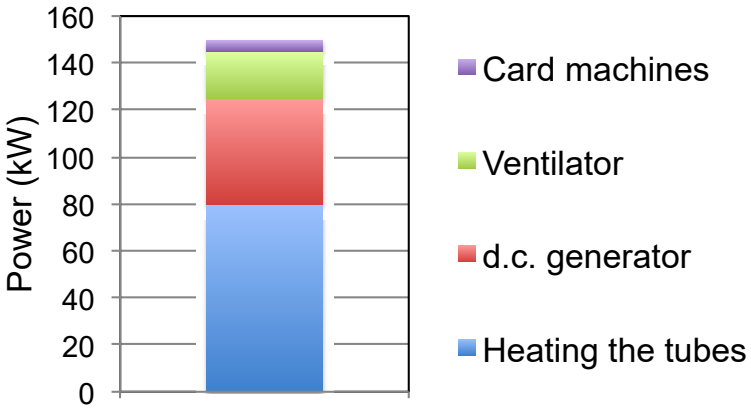
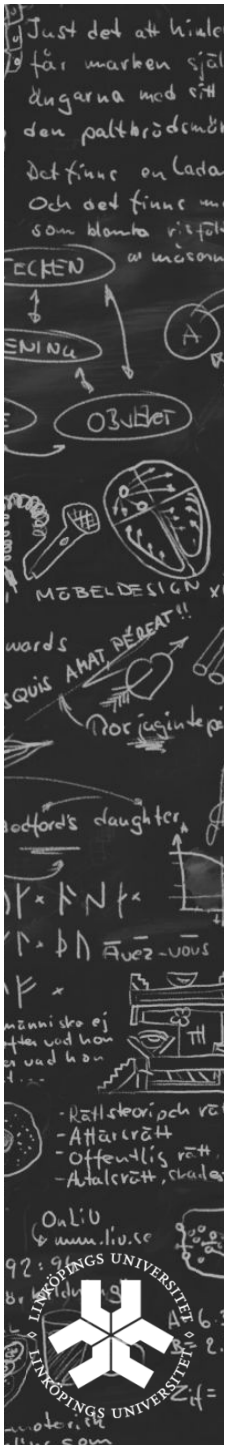


Image: http://en.wikipedia.org/wiki/ENIAC

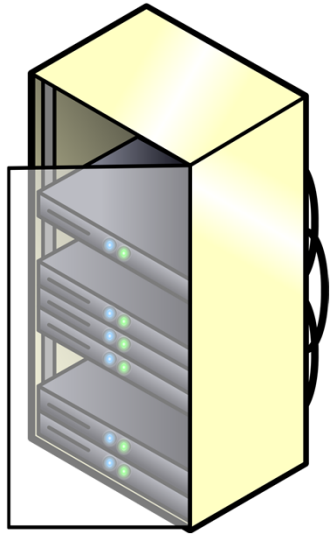


Computing has many different forms…

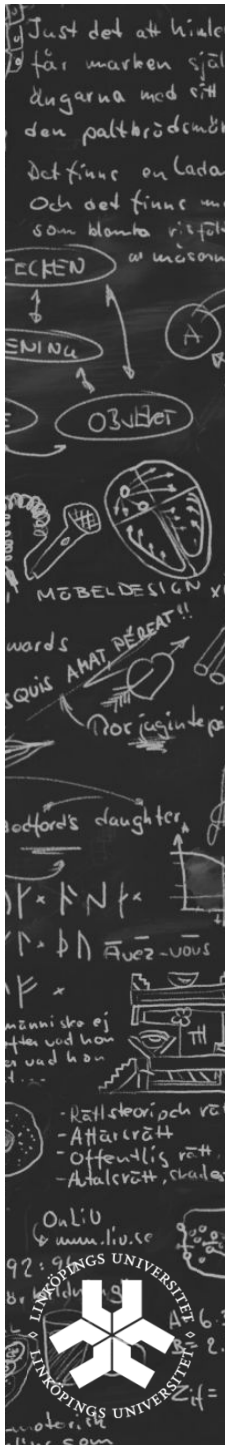
- … but often these forms share common characteristics





- Energy-performance tradeoffs
  - The result of different design requirements
- Where to compute?
  - Within a single system (e.g., single device)
  - In a distributed system thanks to connectivity and networks



AI (machine learning) needs attention

- New architectures and hardware designs are explored

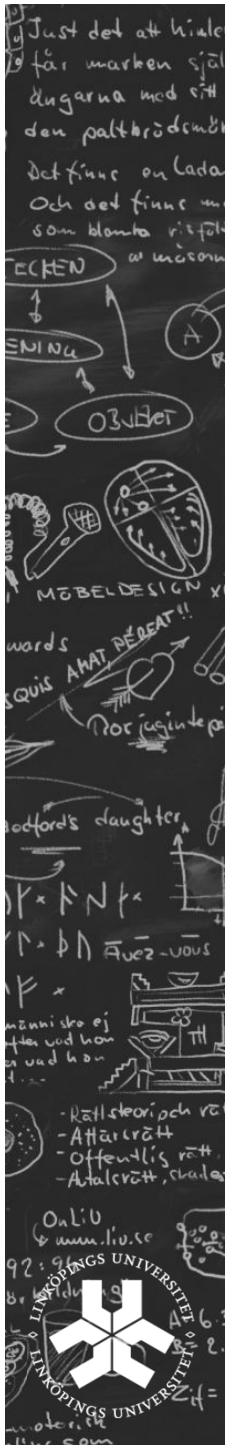
  Mehonic and Kenyon 2022
  https://doi.org/10.1038/s41586-021-04362-w

- One bottle of water for writing a 100 word mail by ChatGPT4
  https://fortune.com/article/how-much-water-does-ai-use/

- Nuclear fusion energy may not be adequate

  Crawford 2024
  https://www.nature.com/articles/d41586-024-00478-x

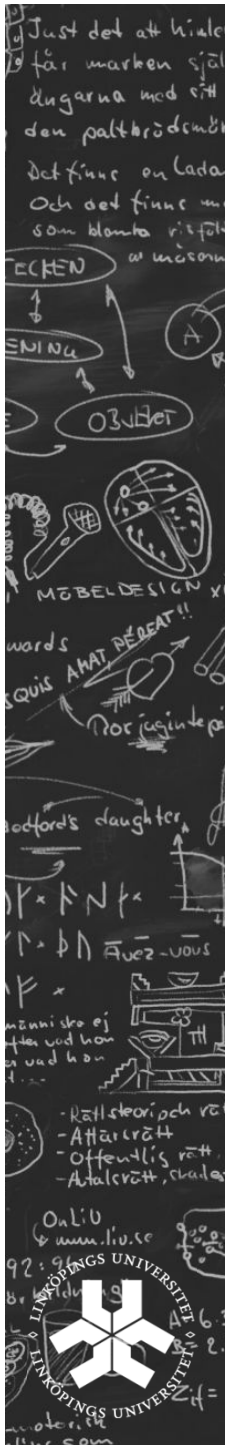
- More on AI in seminar 2 (new article for this year)!



IoT end-point devices

- Used to collect data
- Other research disciplines are needed to improve hardware

Rahmani et al. 2024
DOI: 10.1109/JMW.2022.3228683



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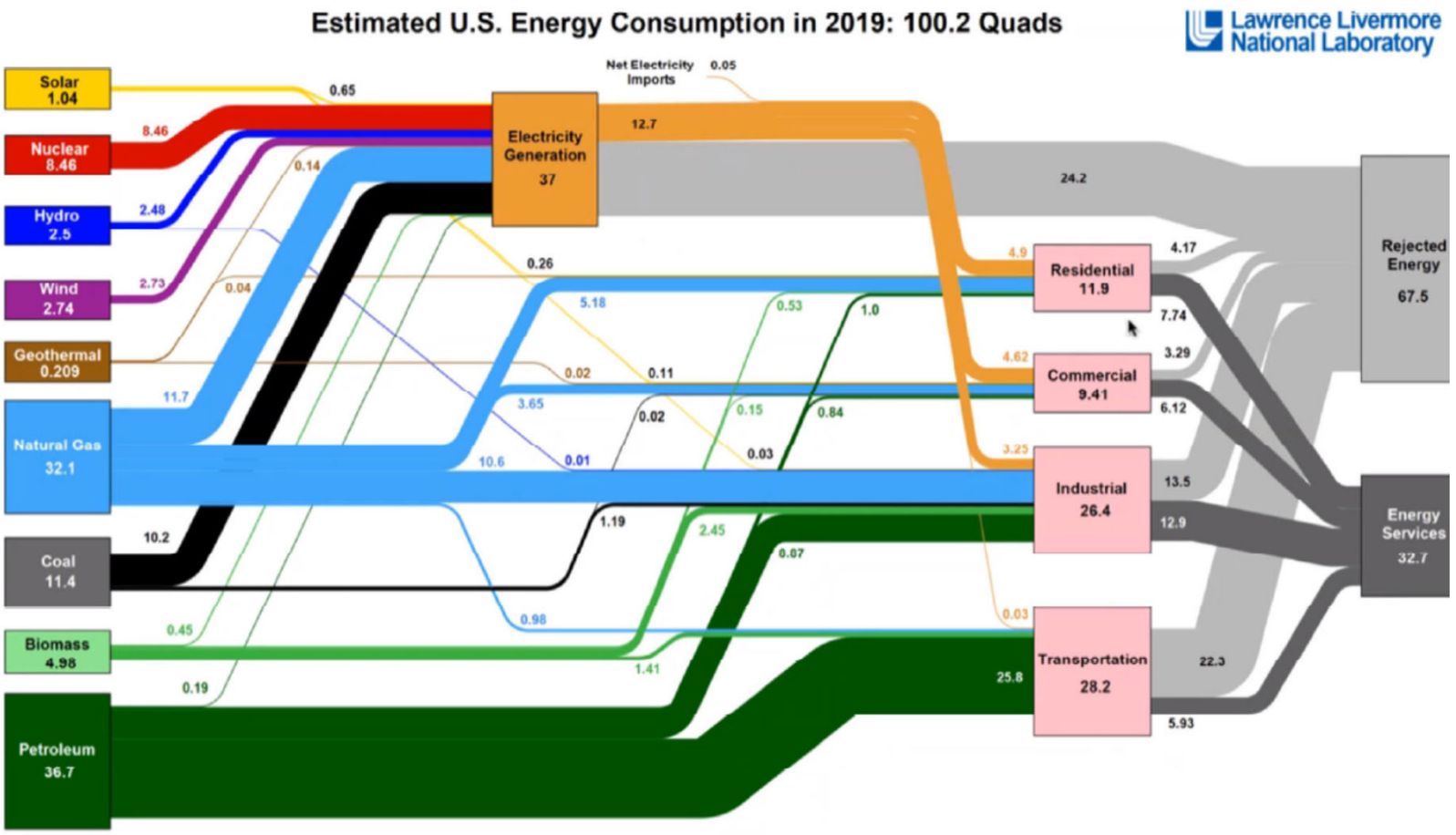
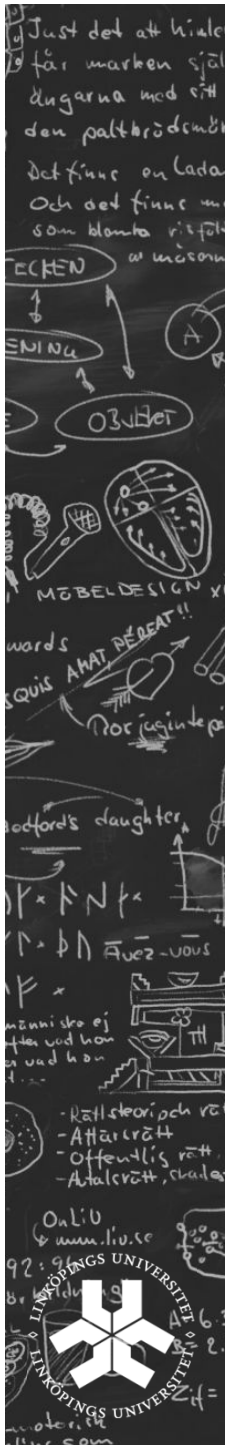
Energy Supply and Consumption: Most Energy is Lost





General sources of energy waste

- System design is full of complex tradeoffs
  - General-purpose vs. dedicated
  - High vs. best-effort availability
  - Peak vs. average performance
  - Peak vs. average load

Images:
http://openclipart.org/detail/3402/tachometer-by-digitalink-3402
http://openclipart.org/detail/120691/business-people-siluete---by-systemedic

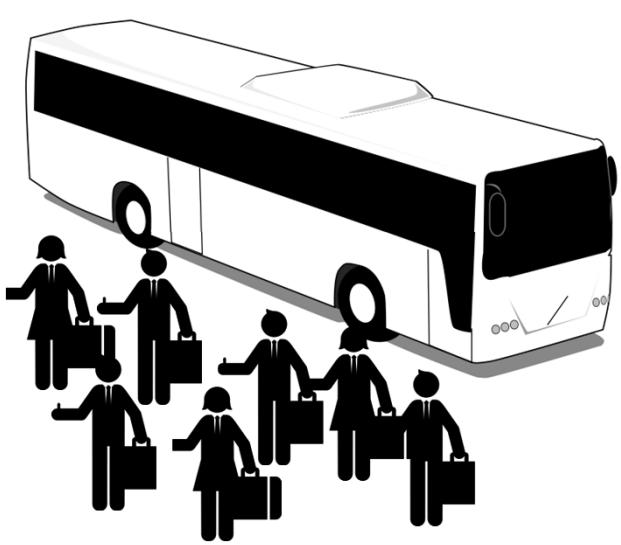
General-purpose solutions

- Good performance for a multitude of different applications

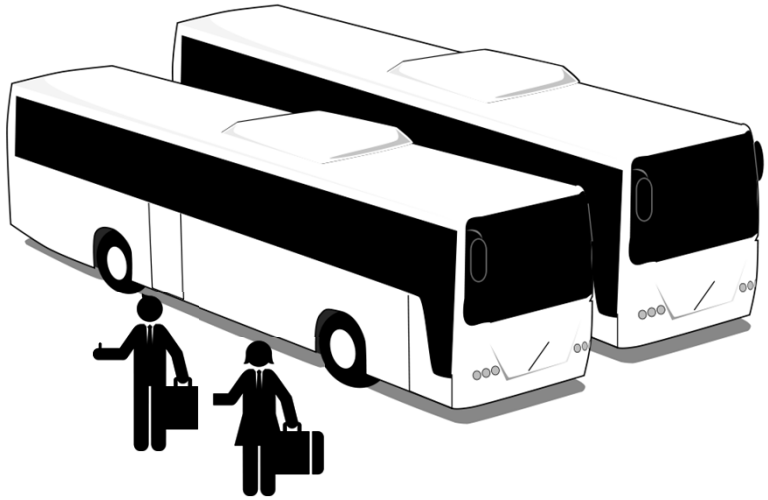
  - Union of maximum requirements of each application class
  - Smartphone vs. MP3 player
  - Legacy solutions

Growth and availability

- Overprovisioning to plan for the future
  - Ensure enough capacity
- Redundancy to increase availability



vs.



Images:
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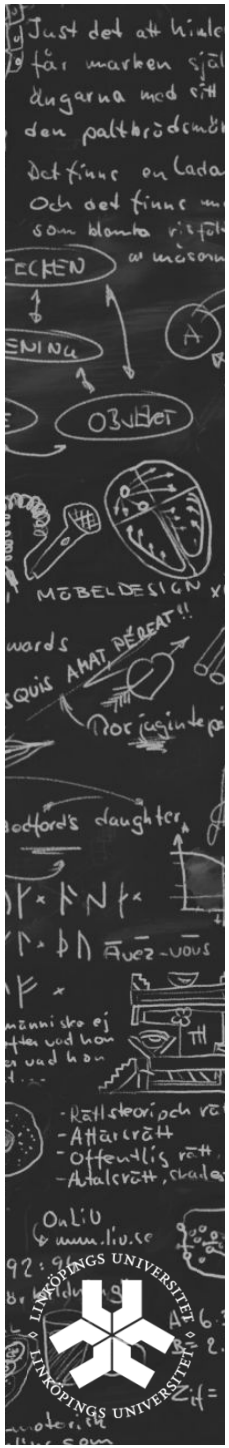
http://openclipart.org/detail/173172/people-hitchhiking-by-vlodco_zotov-173172

Peak performance and worst-case tolerance

- Optimisation for peak performance scenario

  - Low average system utilisation
  - Benchmarks stress worst-case performance workloads
    - Systems optimised for these scenarios



Another source of energy waste

- System functionality as independent modules
  - Modularity and interaction
  - System components designed separately
    - CPU, network interface…

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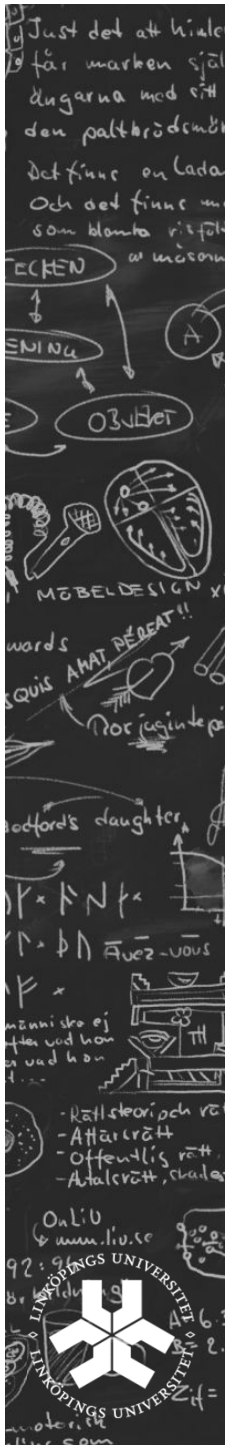
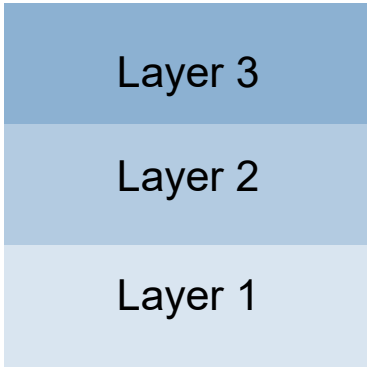
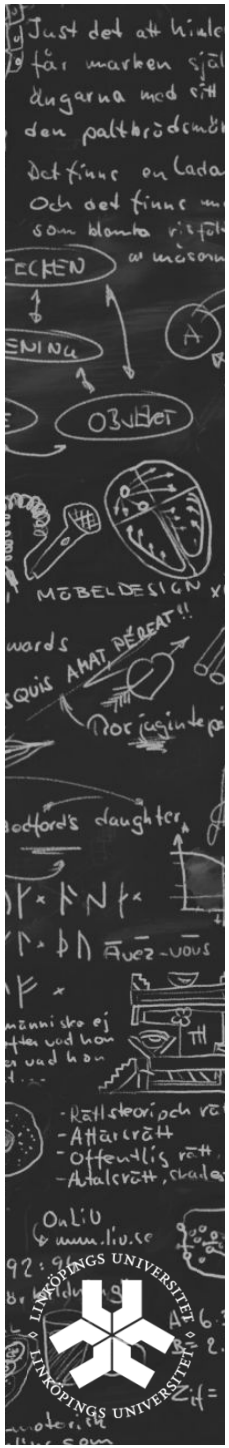


Design process structure

- Hardware and software separately
- Divided system functionality across components
- Layers
  - Local optimisations not optimal for global efficiency
  - Worst-case assumption at each layer



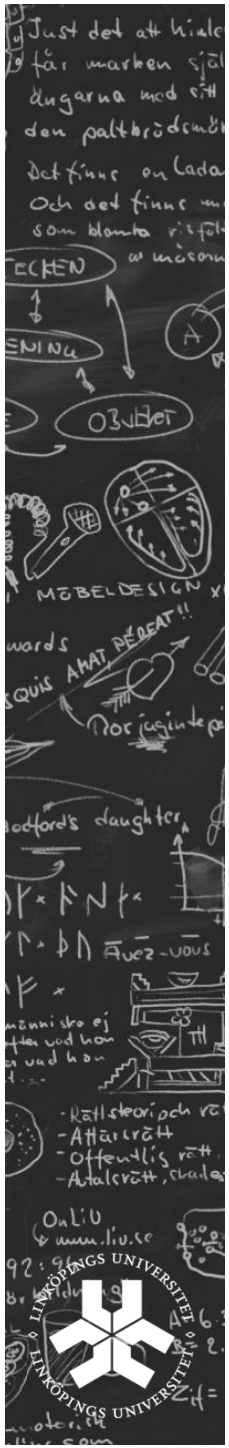


First, we need to discover waste

- Analysis tools to predict resource usage trends
- Energy awareness
  - Monitoring infrastructure

- Then …
  - Control algorithms and policies

http://openclipart.org/detail/35353/tango-utilities-system-monitor-by-warszawianka
http://openclipart.org/detail/160057/machine-control-blue-by-zxmon21



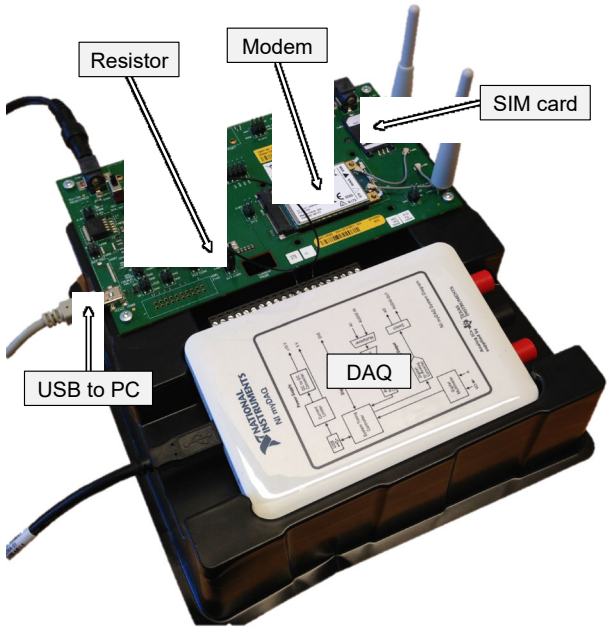
Energy awareness is the first step

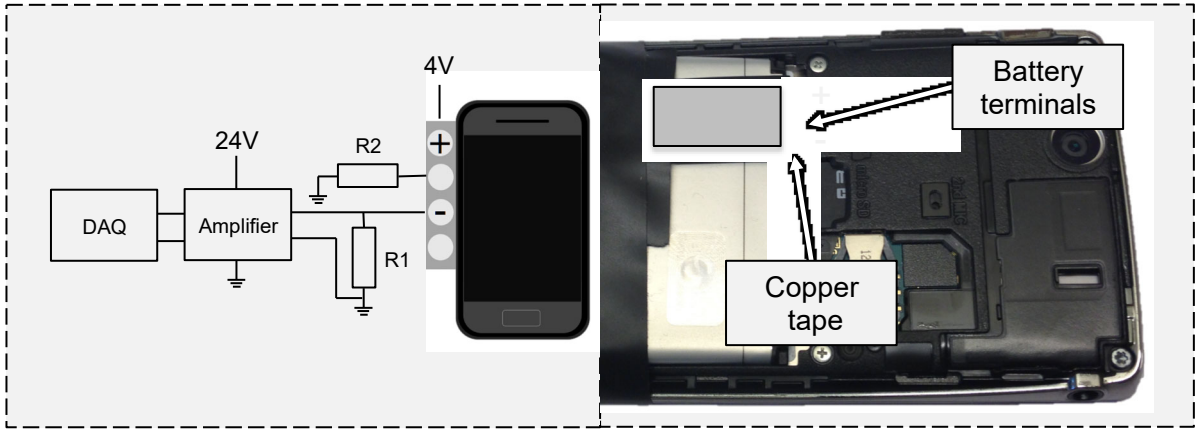
- “Measurement is the first step that leads to control and eventually to improvement. If you can’t measure something, you can’t understand it. If you can’t understand it, you can’t control it. If you can’t control it, you can’t improve it.”

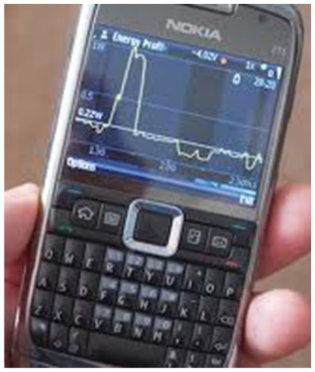
  H. James Harrington

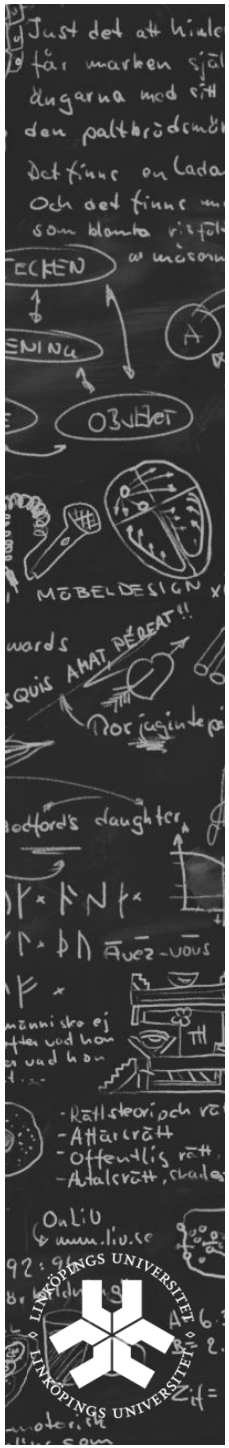
- **Measurements**
  - Battery interfaces
  - External measurement tools
  - Development hardware

Measurement platform examples



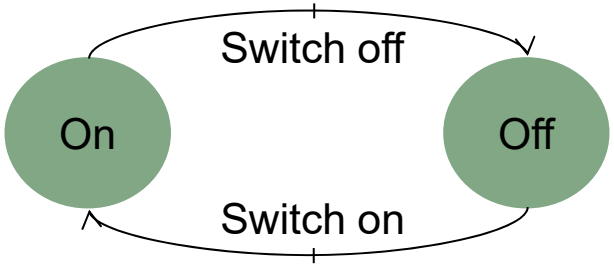






Then, we need to build models

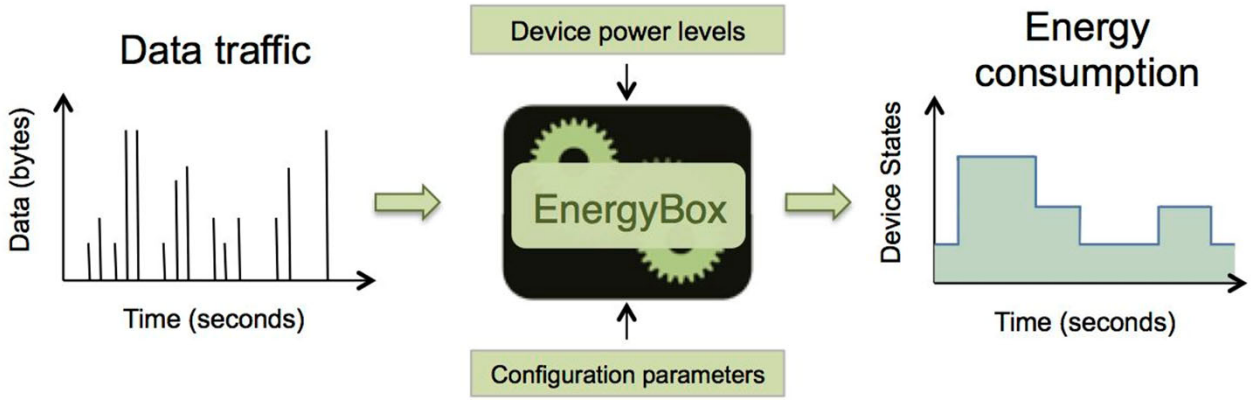
- **Models**
  - **Input:**
    - Power measurements
    - Performance counters
  - **Examples:**
    - Statistical regression of measurements
      e.g. : P = a * CPU_load + b * CPU_freq
    - Finite state machines
    - Analytical models



P_On = 100 W P_Off = 10 W

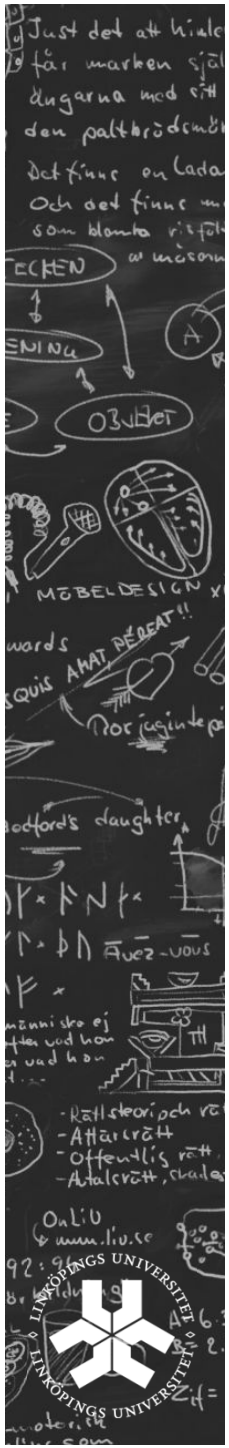
EnergyBox

- Models the energy consumption of 3G/4G and WiFi interfaces
  - Finite state machines
- Decouples device power parameters and network



https://github.com/rtslab/EnergyBox/

E.J. Vergara, S. Nadjm-Tehrani, M. Prihodko, EnergyBox: Disclosing the wireless transmission energy cost for mobile devices, Sustainable Computing: Informatics and Systems, DOI: 10.1016/j.suscom.2014.03.008.



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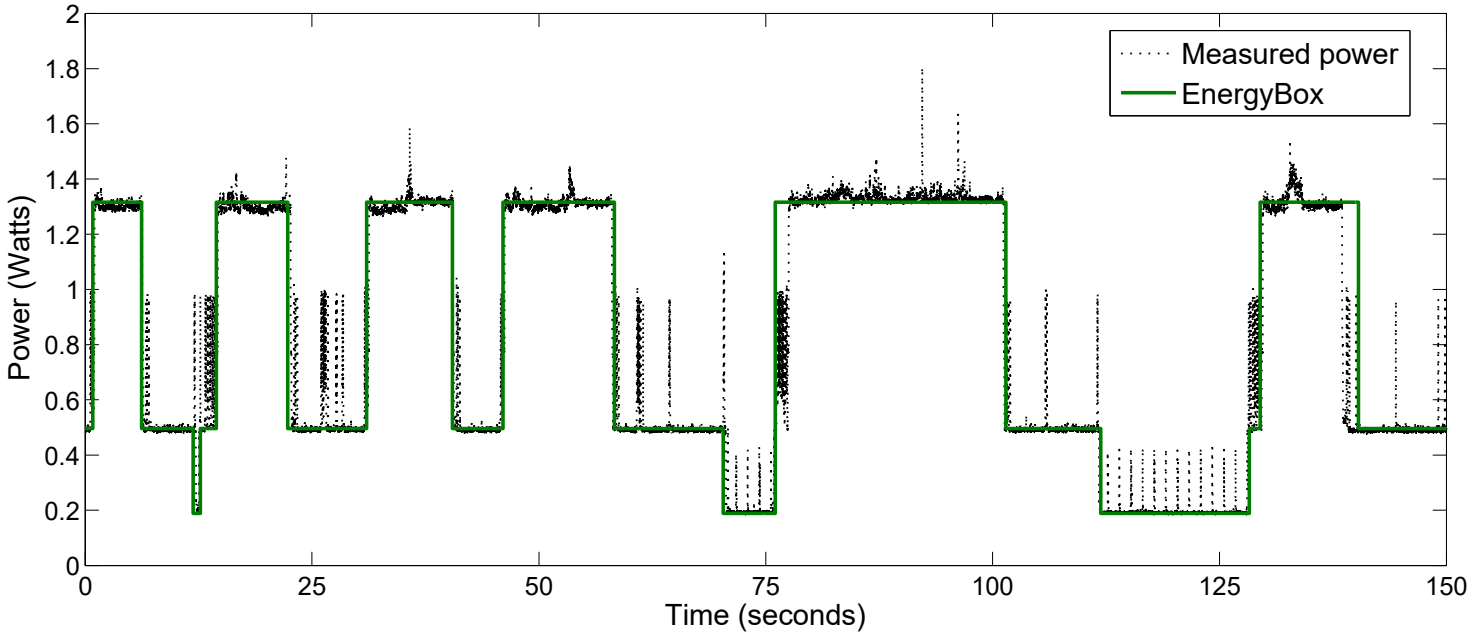

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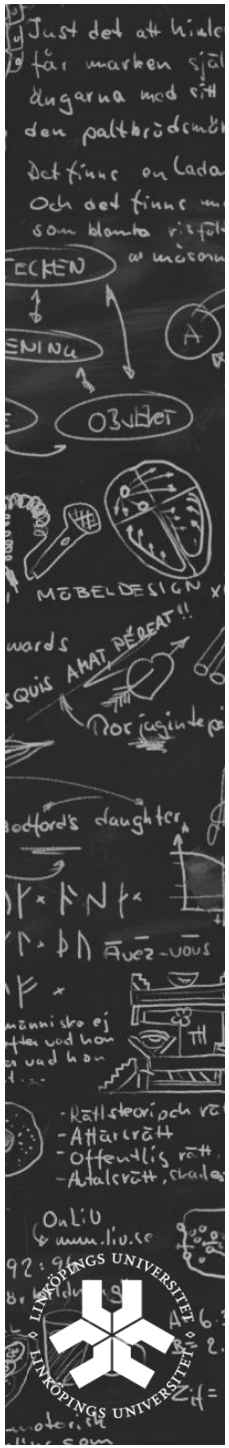

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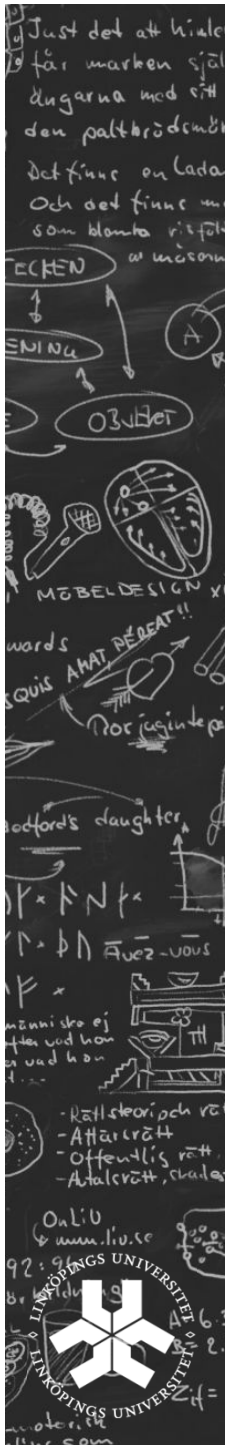
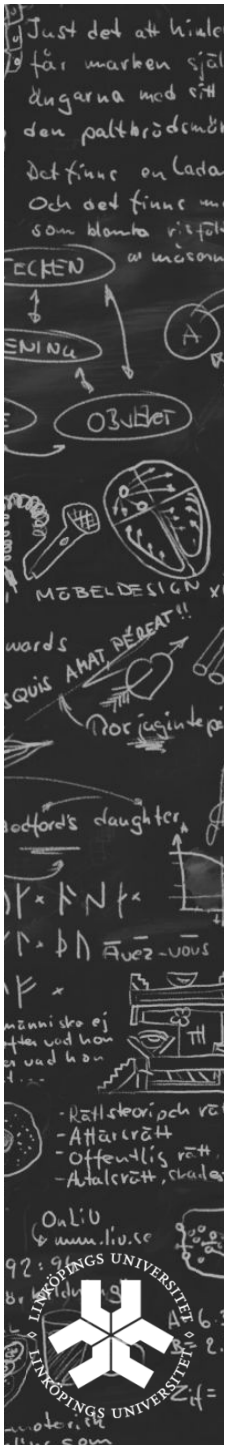


Energy efficiency at **design stage**

- Replacement with a more power-efficient alternative
- Holistic solutions
  - Consider cross-layer interaction
- Optimise energy efficiency for the common case
- Design only for required functionality and requirements

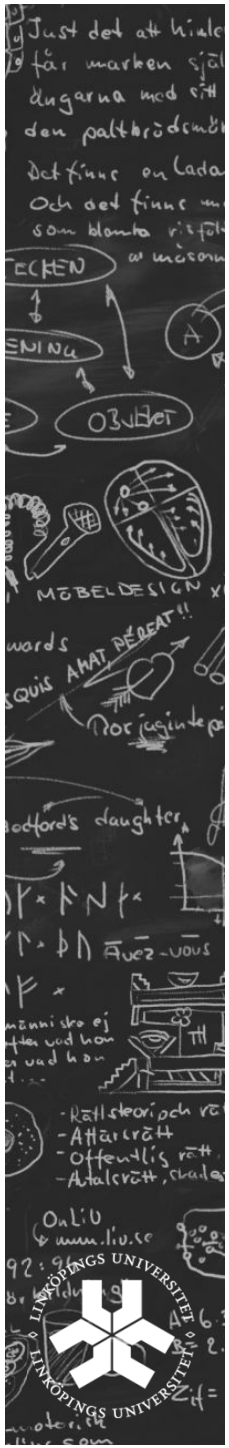
Image from: https://openclipart.org/detail/201475/recipe-book-by-bnsonger47-201475



Energy efficiency at **run-time**

- Trade off some other qualities for energy
- Disable or scale down unused resources
- Combination of multiple tasks in a single energy event
- Spend someone else's power
- Spend power to save power

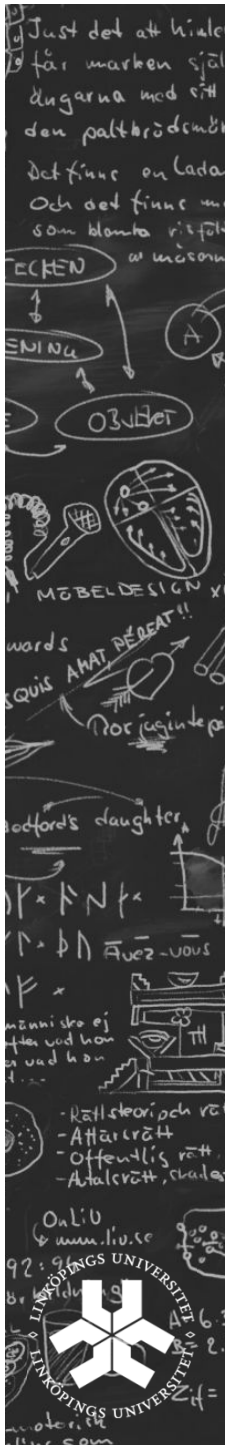
Find instances of these in the seminars!



Concepts/approaches

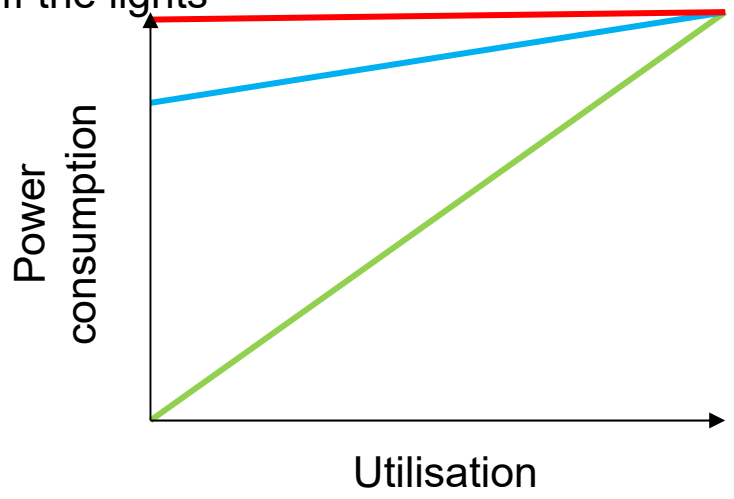
- Energy proportionality
- General approaches to power management
  - On/off approaches
  - Load consolidation
  - Scaling approaches

https://openclipart.org/detail/38827/netalloy-gears-by-netalloy



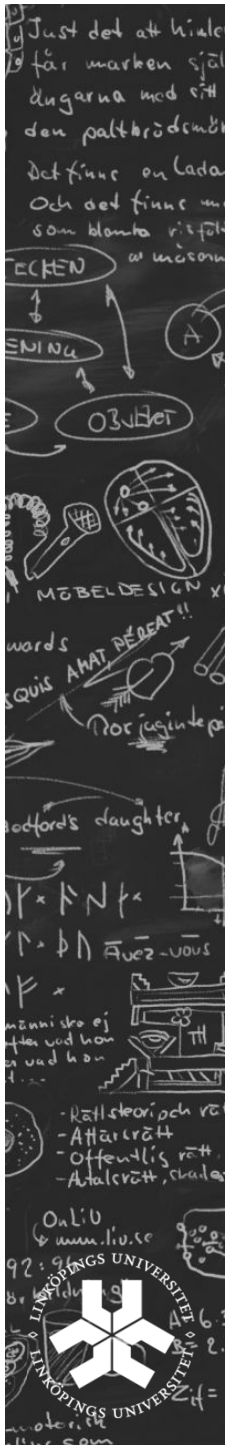
Energy proportionality

- Definition: Power consumption that is proportional to resource utilisation
- A system must have:
  - Wide dynamic power range
  - Low base power
    - If the room is empty, turn off the lights
- Most systems present low energy proportionality



Proportional consumption
High idle consumption
Constant consumption

L. A. Barroso and U. Hölzle, The Case for Energy-Proportional Computing, IEEE Computer, vol. 40. 2007



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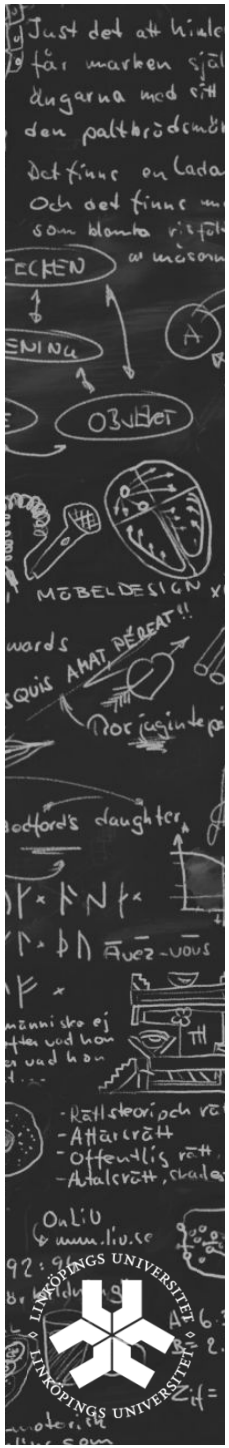
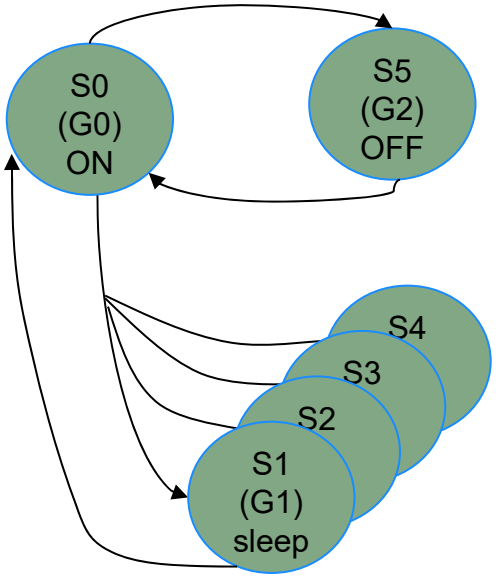


ON/OFF techniques

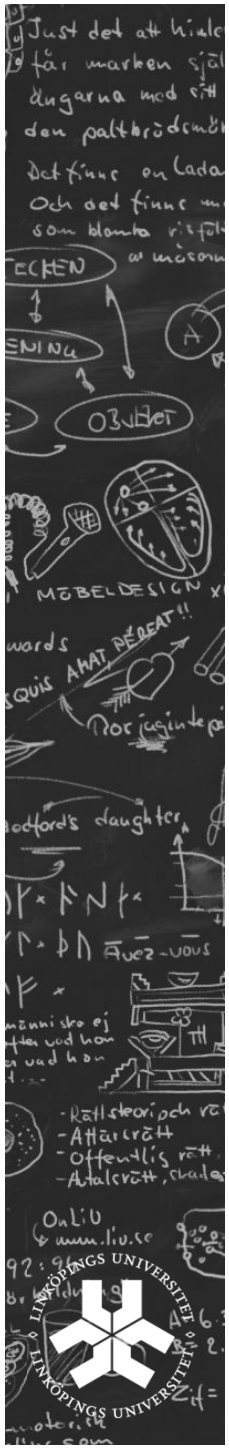
- Advanced Configuration and Power Interface (ACPI)
  - Operating system controls the power management

- System power states
  - Power consumption vs. retained context



- Power states
  - S0: On state
  - S1: Power on Suspend
    (CPUs on but not executing)
  - S2: CPUs off
  - S3: Standby, Sleep or Suspend to RAM
  - S4: Hibernation or Suspend to disk
  - S5: Off state. All context is lost.

http://www.acpi.info/DOWNLOADS/ACPIspec10.pdf



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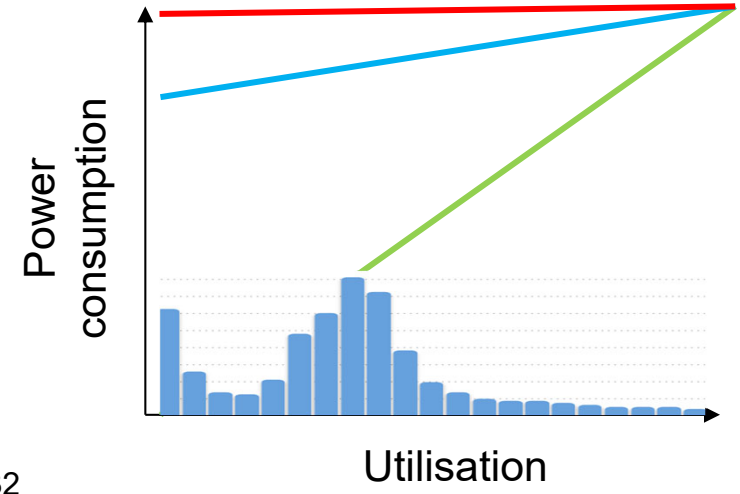
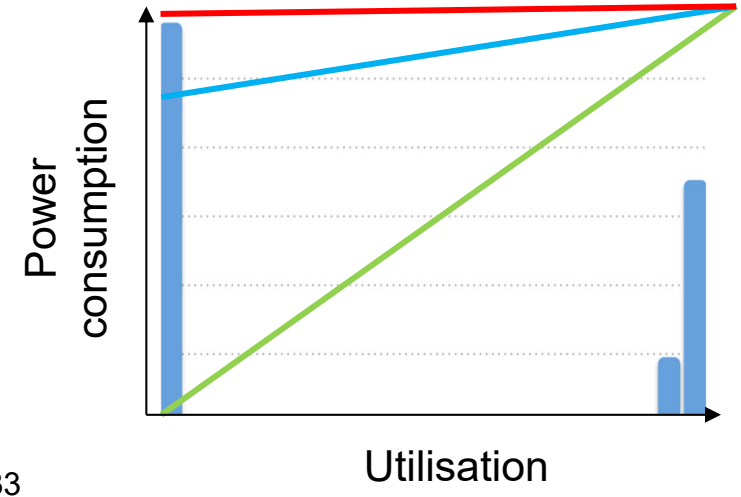
Load consolidation

- Switching off the light is not enough!
- Efficiency of the ON/OFF is increased by interaction with "consolidation":
  Group people in one room to switch off other rooms' lights
- Systems usually work at low utilisation,
  which means low efficiency

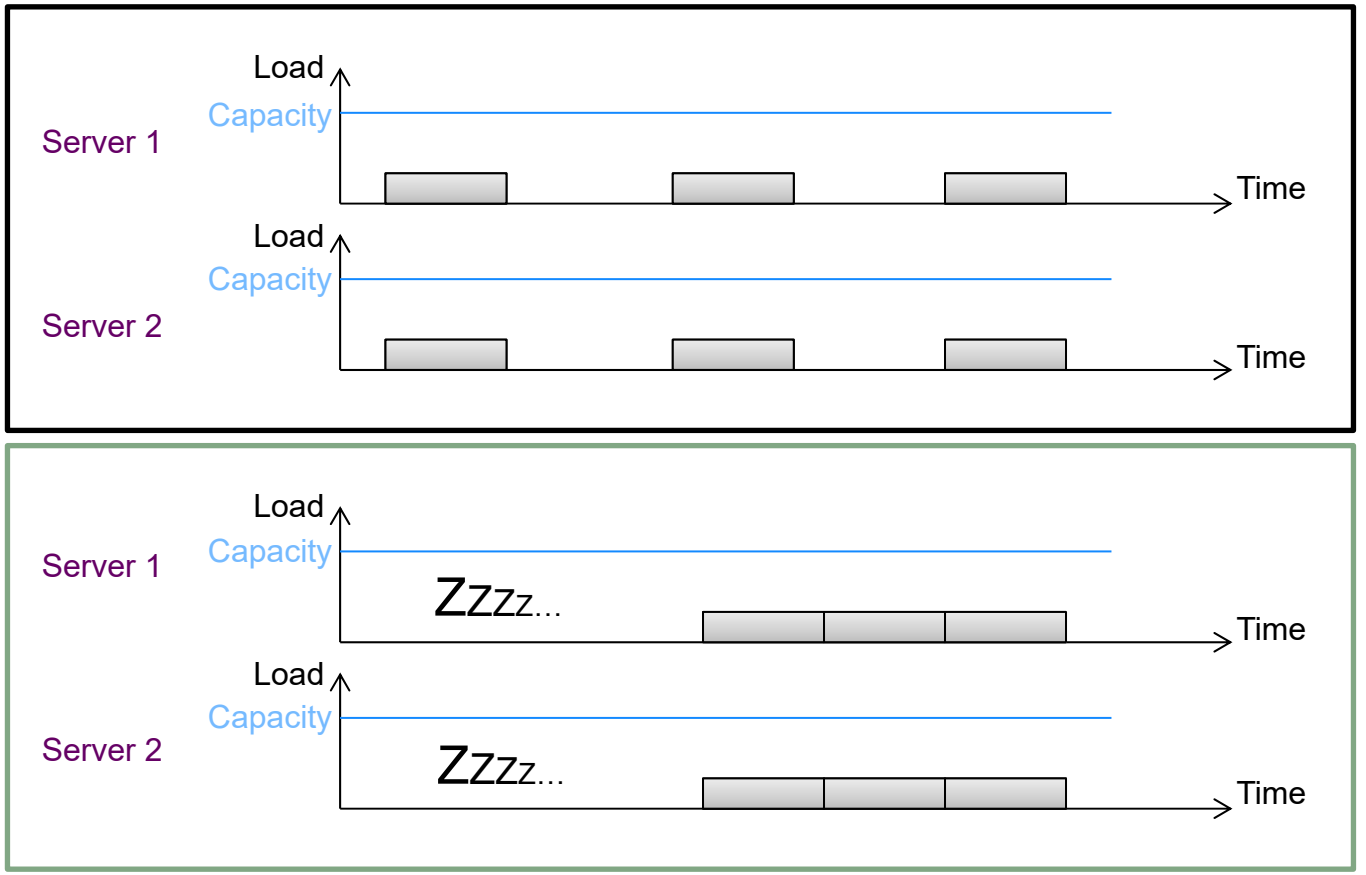


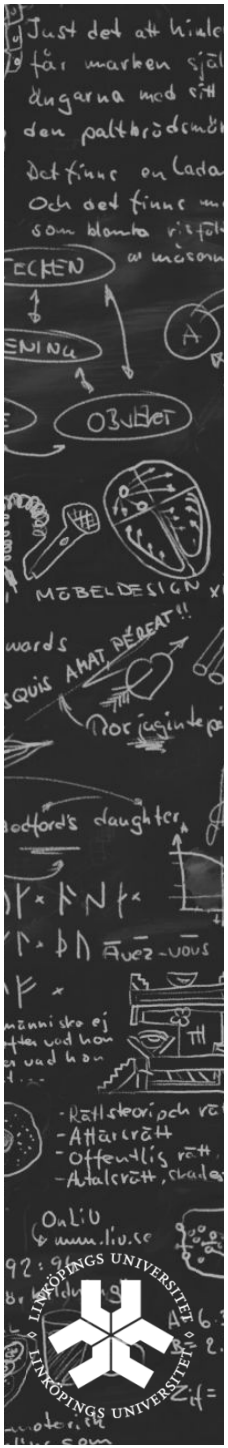
Load consolidation

- Switching off the light is not enough!
- Efficiency of the ON/OFF is increased by interaction with "consolidation":
  Group people in one room to switch off other rooms' lights
- Systems usually work at low utilisation, which means low efficiency
- Change the utilisation!

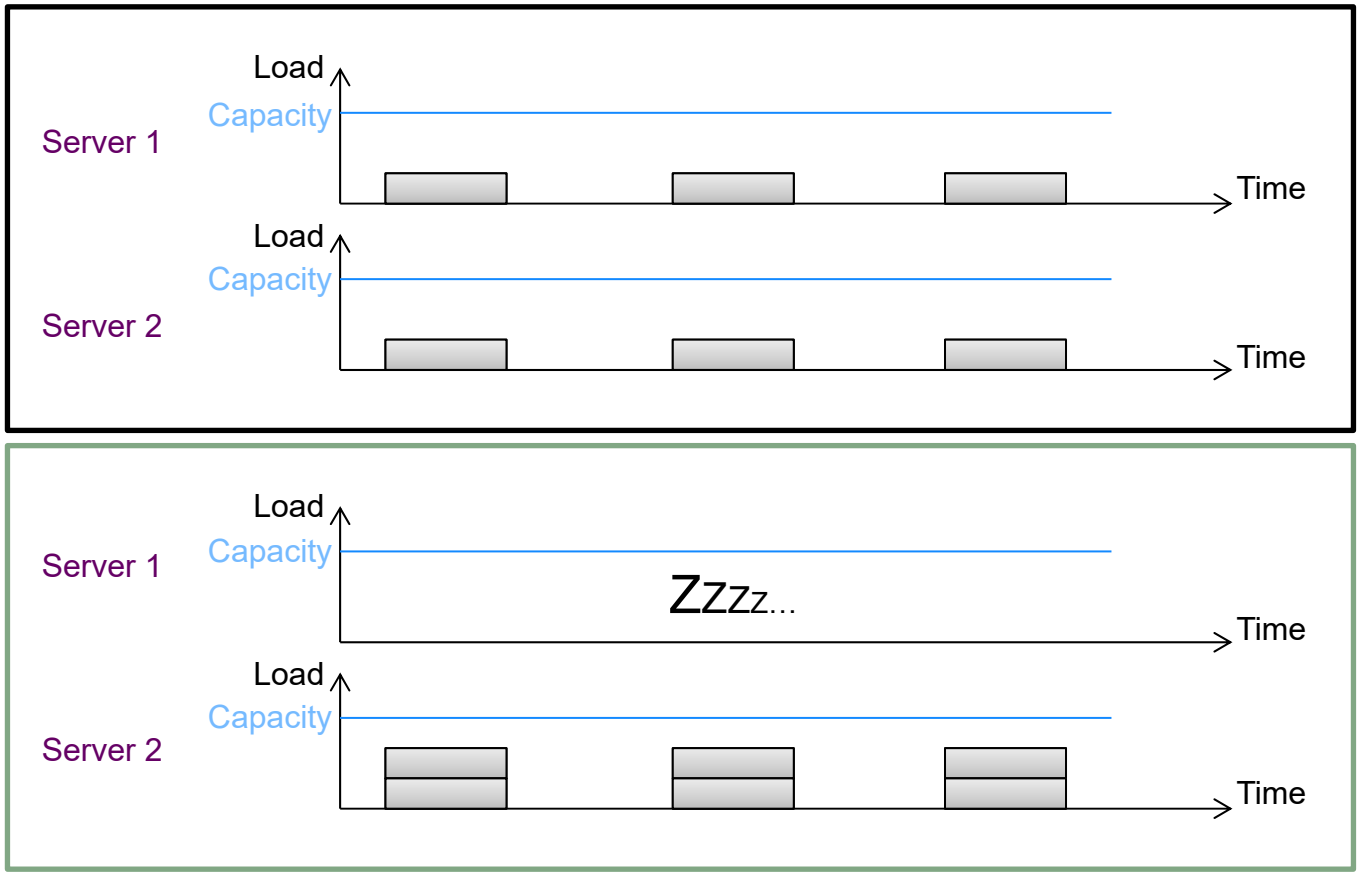


Consolidation in time



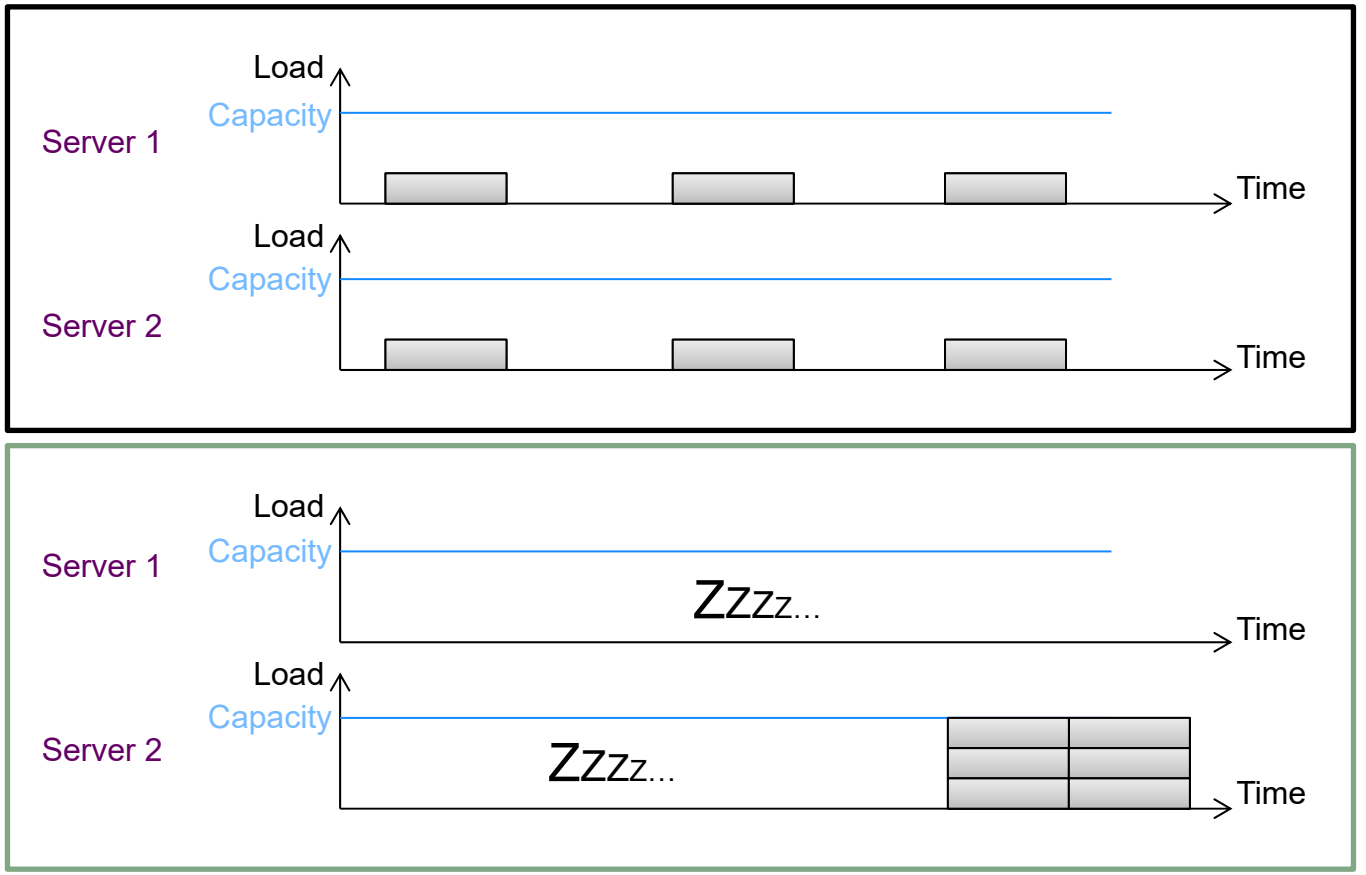


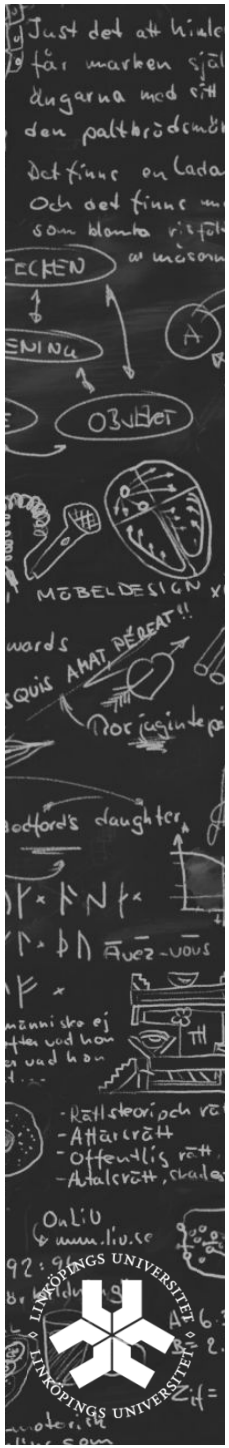
Consolidation in space



Sleep = Zzzz...

Consolidation in time and space

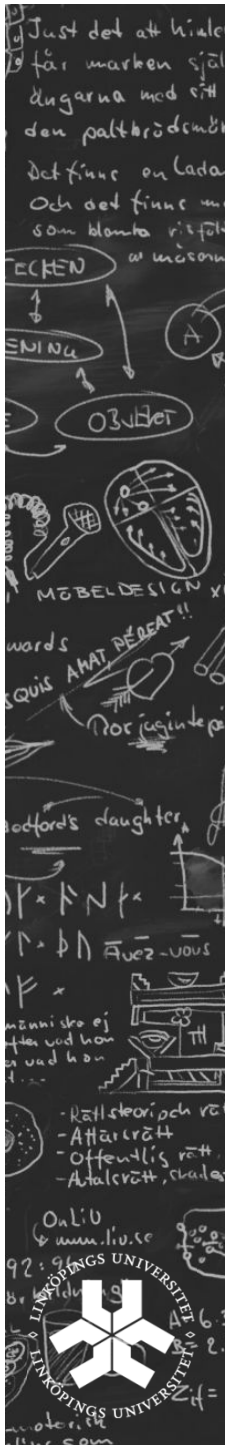




Concepts/approaches

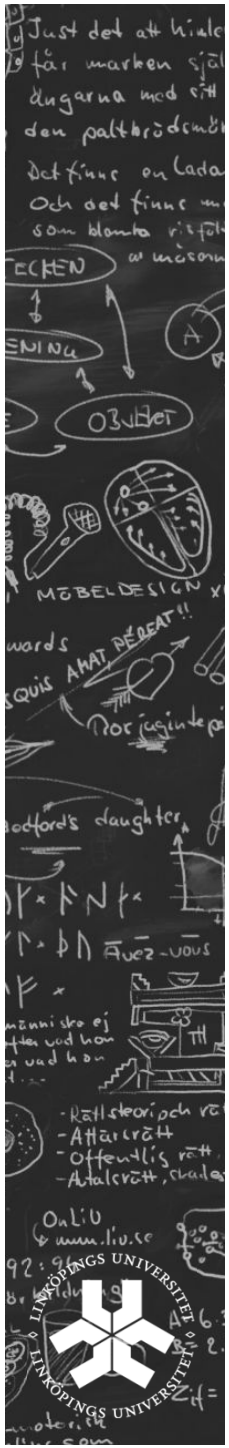
- Energy proportionality
- General approaches to power management
  - On/off approaches
  - Load consolidation
  - Scaling approaches

https://openclipart.org/detail/38827/netalloy-gears-by-netalloy



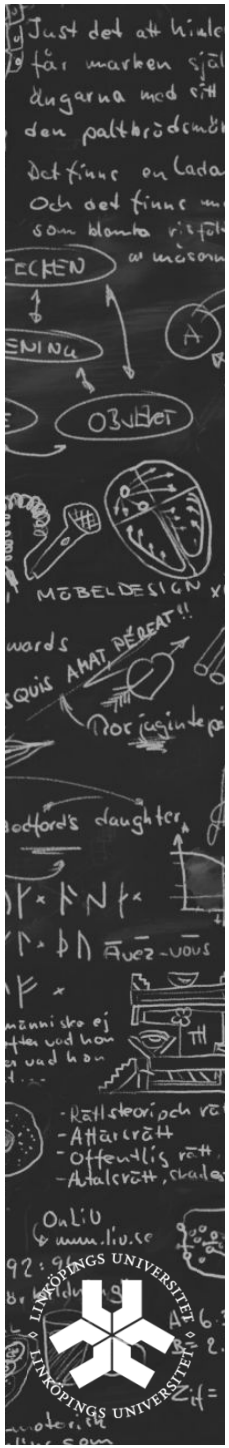
Switch off or scale down?

- Example: Processor
- Does not run at 100% capacity all the time
- Architecture techniques
  - CPU frequency and voltage scaling (P-states in ACPI)
  - Low power mode states (C-states in ACPI)
  - Tickless kernel (dynamic tick)



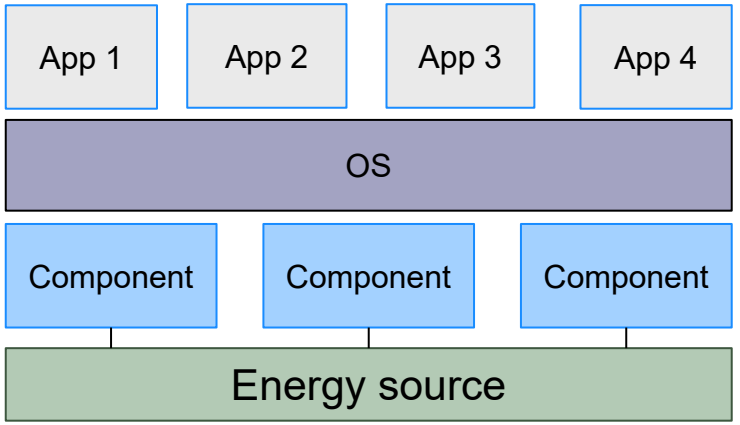
Dynamic voltage and frequency scaling (DVFS)

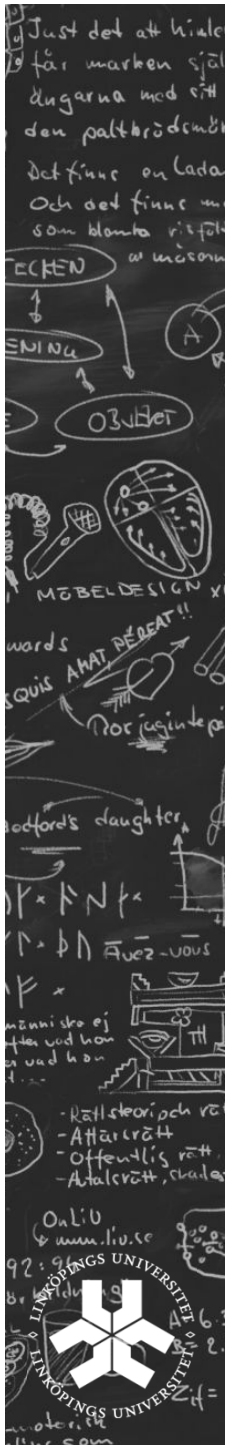
- Dynamic adjustment of voltage/frequency of the processor
  - Trade-off power dissipation against performance
- Decision
  - Program level
    - Program behaviour drives the decision
    - e.g., scale down when program knows it has to wait
  - System level (OS)
    - Idleness of the system drives the decision
    - Voltage/frequency scaled to eliminate idle periods
  - Hardware level
    - Exploits different timings of hardware components and system techniques
- Used in one of the articles that you will present!



To sum up: Energy management

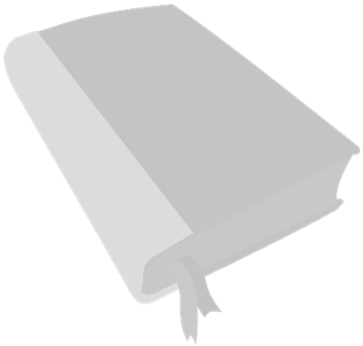
- Planning and operating the energy resource
  - Optimise the resource consumption (avoid waste)
- Is done at many layers
  - System components (e.g., CPU, memory or wireless interface)
    - Power management of components (DVFS, radio resource allocation)
  - Entities sharing system components (e.g., applications)
    - Allocate energy to software (tasks) to run





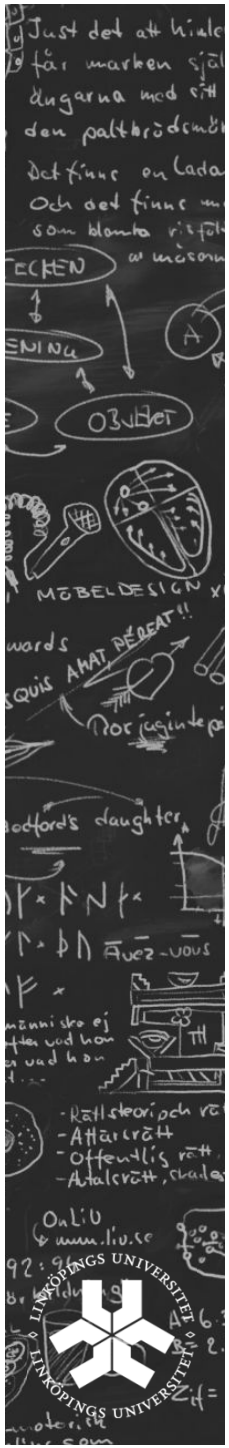
This lecture

- Power-aware computing



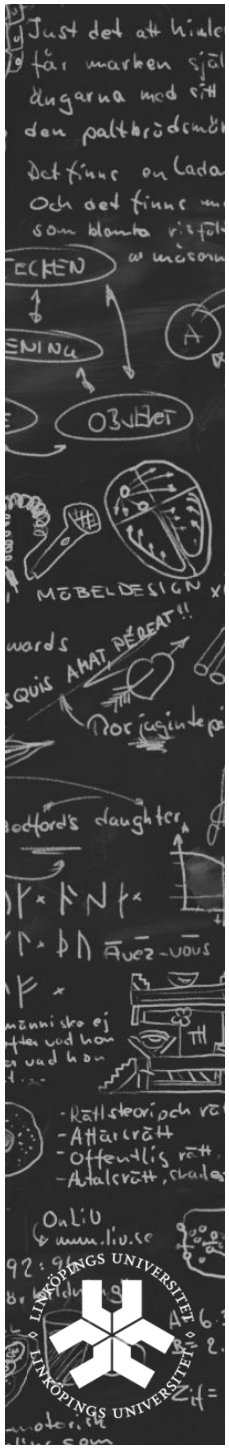
- Scientific articles
- Search for related works

Images:
http://openclipart.org/detail/75799/registry-book-by-wakro
http://openclipart.org/detail/28016/roadsign-keep-left-by-anonymous



What is a scientific article?

- Seminars centre on use of scientific articles
- Old or new?
  - If you look for a method/approach to design/measure then age does not matter
  - If you only look for facts (measurements/outcomes) all articles are old!
- Helps you train for finding advanced solutions later in life
  - Own reading
  - Discussion with peers
- But… Have you seen one before?



What is a scientific article?

A scientific article is a peer-reviewed and published document created by the research community, and reports scientific contributions or findings

CHARACTERIZING ELEGANCE OF CURVES COMPUTATIONALLY FOR DISTINGUISHING MORRISSEAU PAINTINGS AND THE IMITATIONS

Lei Yao, Jia Li, James Z. Wang

The Pennsylvania State University, University Park, Pennsylvania

ABSTRACT

Computerized analysis of paintings has recently gained interest. The rapid technological advancements and the expanding interdisciplinary collaboration present us a promising prospect of computer-assisted authentication. We focus on the characterization of curve elegance. Specifically, we propose measures of curve steadiness and neighborhood coherence from brushstrokes. The technique has been applied to the paintings of renowned aboriginal Canadian artist Norval Morrisseau. Through computerized analysis of his authentic works and the imitations, it is revealed that the curves in his authentic paintings exhibit his commanding painting skills. The smooth and steady flow of the curves show less hesitancy of the artist than the authors of counterfeit works. The tangent angles tend to be more consistent along curves in the authentic paintings than in the imitations.

***Index Terms*—** Image analysis, image line pattern analysis.

1. INTRODUCTION

The art forgery industry has become increasingly sophisticated to target the growing number of art collectors. Factories with assembly lines have been established to forge paintings from well-known artists. Relatively skillful painters and modern technologies are involved in making counterfeits. Despite the use of modern technologies, such as carbon dating, lead dating, X-rays, multispectral imaging, and cross-section microscopy, authenticating visual art is still an open problem.

A connoisseur can tell the authenticity of a painting by analyzing the emotions expressed by the artist. Authentic paintings often stimulate higher emotional responses than forgeries. Traditional painting authentication is a highly subjective and sophisticated appreciation process. Art historians utilize various heuristics and theories [1]. For instance, color, brushwork and composition are some important factors considered in artist attribution, dating, and painting style identification.

In computerized painting analysis, many problems lead to one main issue, that is, numerical characterization of paintings. The numerical features of paintings provide evidence for attribution and can be used for other purposes, e.g., retrieval. One type of digital signature of a painter is based on brushstrokes [1, 4, 6, 5]. The techniques of depiction, such as shading and glazing, suggest that texture-like features may be appropriate for brushstroke analysis [2, 1]. Existing work in the literature is mostly based on analyzing the characteristics of brushstrokes. However, some paintings, such as those by Norval Morrisseau (1932–2007), do not have clearly visible brushstrokes. A new technique has to be developed.

In this paper, we used curves as the main visual content clues. We developed an automated method to detect curves resulting from brushstrokes. Measures of steadiness and neighborhood coherence have been developed and tested on real-world paintings, both authentic ones and forgeries. We found that our measures are good indicators of elegance and skillfulness.

We applied our techniques to the works of Norval Morrisseau, an aboriginal Canadian artist, as well as some known imitations. Figure 1 shows some examples in the dataset. Morrisseau, known as "Picasso of the North," was arguably the greatest aboriginal artist ever to have lived in North America. His subject matter addressed the protection of the environment long before global warming entered our mainstream consciousness. We photographed dozens of authentic paintings and paintings which the artist himself stated as counterfeit using both a digital SLR camera and a medium-format slide film camera.

2. CHARACTERIZING ELEGANCE OF CURVES

Various traits of brushstrokes are by far the main subject for computational comparison of digitized fine art paintings, in large part due to the fact that brushstrokes have been

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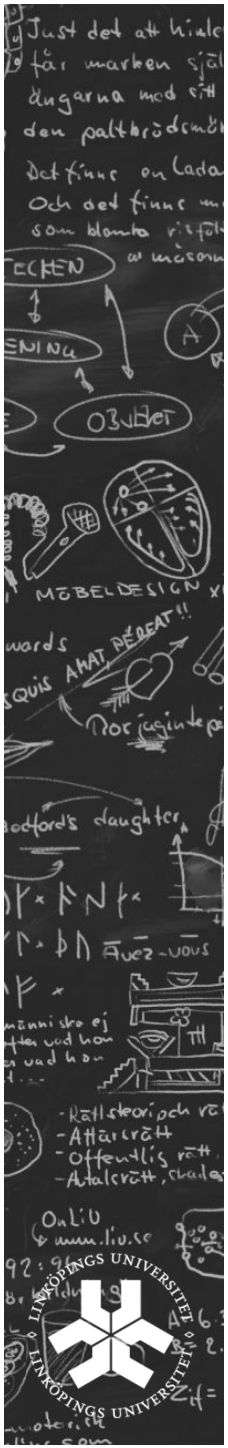
- Published in
  - Books
  - Scientific magazines, Journals
- Most commonly presented in conference proceedings published by a publisher and permanent link (DOI)
- Quality of content
  - Depends on the publishing forum
  - There are low quality ones Focus on the well-known publisher!



How is a scientific article organised?

Title of the article

Authors and affiliation

Abstract (summary)

Overview and Motivation

Background

DOI: --- where it is published

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How is a scientific article organised?

Which method did they use to arrive at these?

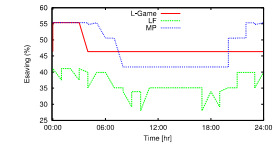
Outcomes/
Results

Study the style of writing for "Related works" sections!

Conclusions

Acknowledgments

Bibliography (References)



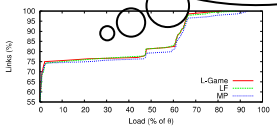


Fig. 6. Distribution of the link loads for the FT network scenario, for different link rankings, for the peak traffic request.

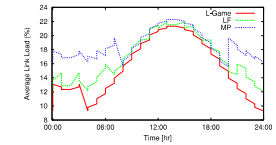
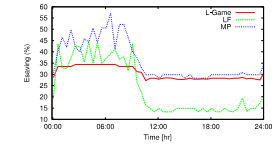


Fig. 4. Achievable energy saving (top), and corresponding average link load (bottom), for the TIGER network scenario, for different link rankings.

"L-Game". The adopted concept of criticality, based on a cooperative-game approach, is able to take into account at the same time both (i) the network topology, and (ii) the amount of traffic that the network is required to deliver, unlike previous approaches. Simulation results, on real network scenarios, show that the L-Game is able to achieve a better trade off between energy saving and QoS, with respect to classical solutions, being able to reduce the network energy consumption of about a half, and limiting, at the same time, the traffic load on links.

ACKNOWLEDGMENT

The work described in this paper was funded in part by FP7 ETICS, FP7 TREND (grant agreement n. 257740), and EuroNF.



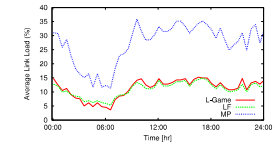


Fig. 5. Achievable energy saving (top), and corresponding average link load (bottom), for the FT network scenario, for different link rankings.

ranking accounts also for the position of link in the network, and for all possible network configurations.

V. CONCLUSIONS

We presented a novel approach to drive the resource consolidation process by the criticality of links in networks, namely

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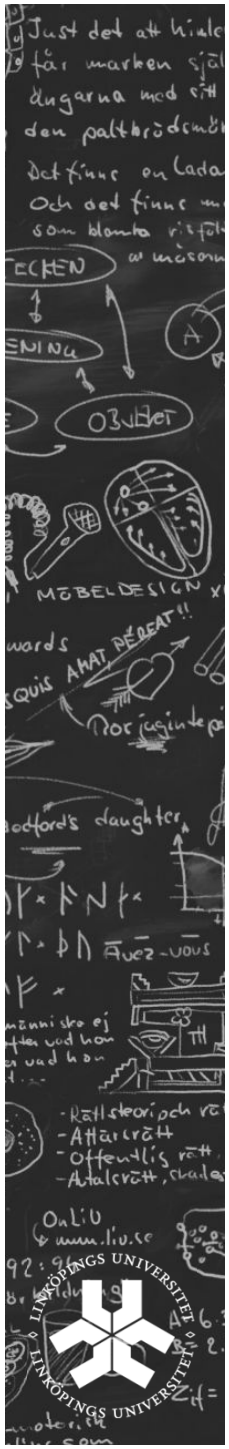
More on this in Seminar 0!



Questions?