Principles of Energy-Aware Computing

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Introduction

- 4,1 zettabytes of data at the end of 2015
- Expected to double in 2016

Contents

- Different Computer Systems
  - Importance
  - Power Consumption
- Why try to improve?
- Examples
- The Future
- Conclusion

Computers!

How much power do different systems actually consume?

Why are they important?

Power Consumption

- Smartphones
  - Mobile Network
- Embedded Systems
- General-Purpose Computers
- Servers & Data Centers
- Supercomputers

Smartphones

- End-user
- Large market, growing in importance
- A new era of ICT

Smartphones – How much?

Suspended	Idle	Video	Wifi Browsing	Phone call
68.6 mW	268.8 mW	453.5 mW	352.8 mW	1054.3 mW

2-3 kWh per year for charging.

Mobile Connections

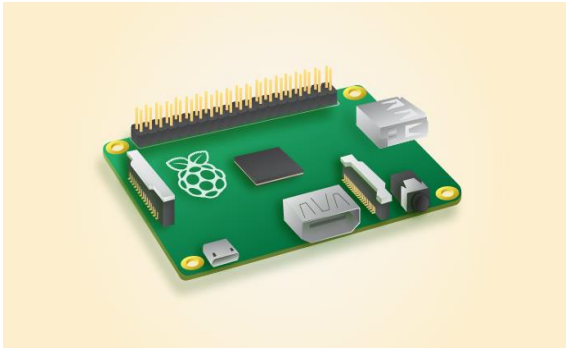
- Energy is consumed by the remote networks, too!
- 1 GB of data uses 0.4-0.8 kWh (4G)
- Using a smartphone for one year: ~ 14 kWh for mobile data.
- Efficiency doubling every two years.

Embedded Systems

- A computer integrated into a larger system.
- Designed for few, predefined tasks.

Embedded Systems – How much?

- Varies strongly (duh…)



Pacemaker	Radio Alarm Clock	Rasperry Pi A+	Xbox One
Few mW	1-2 W	~1 W	>100 W

General-Purpose Computers

- End-user
- Designed for unknown purpose (more or less)
- Varying workload
- Overprovisioned with resources

General-Purpose Computers – How much?

Laptop	Desktop	High-End GPU/CPU
65-90 W	100-300 W	~150 W

Servers & Data Centers

- Very important infrastructure
- Every website needs a server to run on!

Servers & Data Centers – How much?

- An average, refrigerator-sized server rack uses 5-6 kW.
- A large datacenter (50000 sq.ft.) consumes ~5 MW.
- Worldwide, data centers use about 2% of all electricity.

Supercomputers

- Very large computational power
- Used for large simulations
  - Weather forecasts, spaceflight, science…

Supercomputers – How much?

Sunway TaihuLight	Tianhe-2	Titan	Sequoia	K Computer
93 PFlops	33,9 PFlops	17,6 PFlops	17,2 PFlops	10,5 PFlops
15371 kW	17808 kW	8209 kW	7890 kW	12660 kW
6050 MFlops/W	1903 MFlops/W	2143 MFlops/W	2180 MFlops/W	829 MFlops/W

Power Consumption

Smartphone	Mobile Network	Laptop	Desktop
<0.1W - 1W	0.4 - 0.8 kWh/GB	65 W - 90 W	100 - 300 W

Embedded Systems	Large Data Center	Supercomputer	ICT
Vary	5 MW	1-20 MW	10% of worldwide electricity use

Improving Efficiency – Why?

Why try to improve?

- Environmental Concerns
- Performance
  - Heat
- Limitations
  - Battery
  - Power Budget
- Money

Power Consumption

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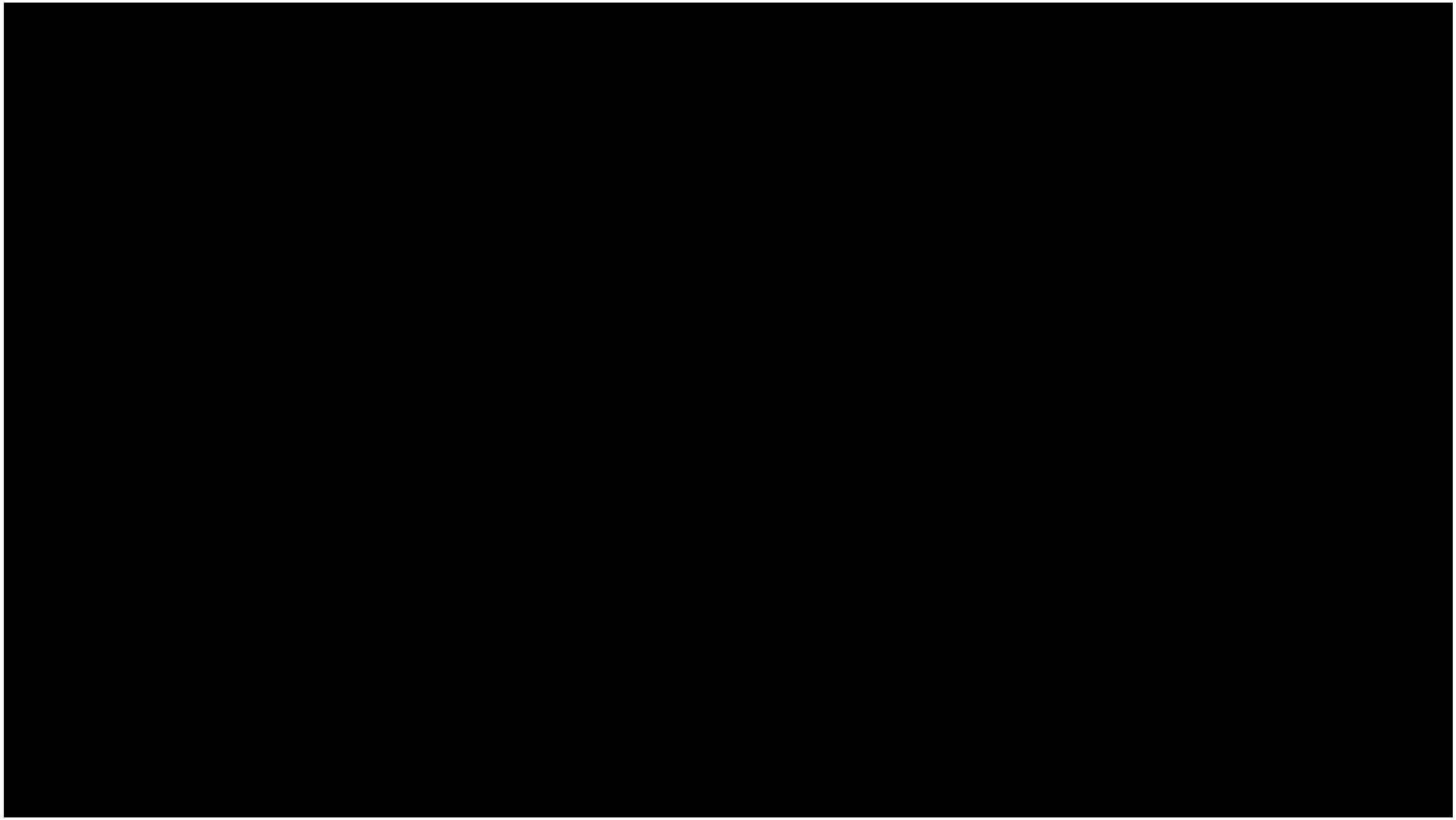
Electricity Costs

Smartphone	Mobile Network	Laptop	Desktop
<1€ per year	4 - 8 ct/GB	~20€ per year	30 - 90 € per year

Embedded Systems	Large Data Center	Supercomputer	ICT
Vary	500€/hour	1000€/hour	100s of billions €/year

Improvements *are* possible!

Examples



Some more information

- 27.000 sq.m.
- Consumes 120 MW.
- Excess heat used to warm up offices at the data center.
- Second data center being built.

What are they doing differently?

- Location
  - Renewable and reliable power source.
  - Cold climate = free cooling.
  - Cheap land, cheap electricity.
- Architecture
  - Easy maintenance.
  - Airflow.
  - Excess heat is used
- Servers
  - Joint design by the largest internet companies
  - “vanity-free”: function & efficiency over aesthetics

- 1 MHz
- 64 kB memory
- 32 kg
- 55 W

It can steer a spaceship and land on the moon.

Apollo Guidance Computer

- Slow and inefficient in todays terms
  - State-of-the-Art in the 60‘s
- It did what it was supposed to very well.
- Extreme design limitations.

The Future

What does it hold?

Processors

- Koomey‘s Law
  - Number of computations per Joule dissipated doubling every 1.57 years
- Processor Scaling leads to new problems

Improving Server Efficiency

- Operating efficiency
  - Average server operates only at 12-18% capacity.
  - Still using 30-60% of max power.
- Cooling Techniques
- Power Distribution

Power Usage Effectiveness (PUE)

- $PUE = \frac{Total\ facility\ energy}{IT\ equipment\ energy}$
- Average PUE of 1.8-1.9
- <1.1 is possible

Improving Server Efficiency

- Data centers use a lot of energy
- Yet huge energy savings would be easily possible

Half of technologically feasible savings would save estimated 40% electricity in data centers!

Future Supercomputers

- International competition to reach 1 exaflops
  - China and Japan: before 2020
  - US: before 2025
- >60 MW
- But: Performance gains are slowing

The Internet of Things

- "the infrastructure of the information society."
- 98% of processors made are for embedded systems
- Expected to contain 50 billion devices by 2020

Conclusion

Conclusion

- ICT is rapidly growing…
- High power consumption
- and is indispensable!
- But improvements are possible on all levels!

Thank you for listening!

Here, have a cookie.