Principles of Green Computing

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Abstract

Computers are everywhere around us. We live in the Information Age and the digital world continues to grow. This leads to new challenges, since these devices consume a great deal of energy. This paper is intended to introduce the subject of energy-efficient computing, why it is necessary and how better efficiency can be achieved.

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1 Introduction

As of the end of 2015, humanity has generated about 4.2 zettabytes of data – 4.2 billion terabytes. And while this number is enormous by itself, it is already outdated: In 2016 alone, this amount is expected to double. All this information needs to be gathered, stored, and processed; consuming a great deal of power along the way. The efficiency of computer systems is becoming more and more important. To understand this process better, I will give an overview of some of the most common types of computer systems and their power consumptions, followed by a more specific look into why increasing efficiency is desirable. Then I will consider the ongoing developments in this field.

2 Power Consumption of Computer Systems

Computers exist in all sizes and forms and are made for very different purposes, from embedded computers in a digital watch to a supercomputer for scientific research. Their power consumption differs just as wildly. Yet even the power consumption of small devices adds up to astonishing amounts when considering the sheer number of them.

2.1 Computers around us

We encounter various computer systems every day, such as Smartphones, Laptops or Desktops. These computers are designed as end-user products, which we use to access the internet with. They are typically designed for an unknown purpose and varying workload – after all, the designers don't know what programs are going to run on the computer, or if several programs may run at once. This makes design more inefficient.

But how much power do these systems actually use? Tests showed that smartphones typically consume less than one watt, even below 100 mW when in stand-by mode (Carroll & Heiser). Laptops generally consume less power (65-90W) than their non-mobile Desktop counterparts, the latter using mostly between 100 and 300 W.

But there are also many embedded computers that we do not see: they may be controlling our traffic lights or tell us when our car needs service. These computers are tailored specifically to a few, predefined tasks. Their power consumption varies accordingly – an airplane avionics system uses more power than a pacemaker, of course.

2.2 Large-Scale Computers

Besides these small computers that we interact with, there are also many larger computers such as servers and supercomputers. They are not as visible but still as important as other computing systems.

Every website requires a server to run on, and every company has important data to store. Servers and Data Centers are critically important infrastructure in today's world. Without them, neither the internet nor our economy could function. Many are simply small server racks in the back of an office room, but Data Centers of incredible size exist around the planet, their power consumption being correspondingly high. A Data Center with 50000 sq. ft. of IT area uses about 5 MW, (Kanellos, 2008) which is as much as a large wind turbine can generate. Worldwide, servers and data centers cause about 1.5% of the total electricity consumption. (Koomey, 2011) But already a small, refrigerator-size server rack uses about 6 kW, (Emerson Network Power, 2013) more than a family household.

Supercomputers are very large computers with extreme computational power. They are mainly used for scientific purposes in fields such as quantum mechanics, astrophysics or molecular chemistry. But they are also used for cryptography purposes, nuclear weapons simulations, or, more peacefully, weather forecasts.

The power consumption of these computers is very high, often being above 10 MW. Nonetheless their very different capacities must be considered – a twice as powerful computer can use twice as much power. To measure efficiency, one looks at the floating point computations per Watt consumed. Modern and efficient supercomputers reach an efficiency of about 6 MFlops/W. (Green 500, 2016)

3 Reasons to Improve Efficiency

While designers were mostly focused on performance in the last decades, efficiency is becoming more and more important. There are a number of reasons for this, which I will introduce in this section.

One important aspect is the environment. Computers do use a lot of electricity in total – Information and Communication Technology makes up 8-10% of worldwide electricity consumption. (Vertatique, 2013)

Another reason is performance. Efficiency and performance do not counteract each other, in fact, efficiency can enhance performance. Processor performance is reaching its limits mainly due to critical heat dissipation. Heat is wasted energy, so increasing processor efficiency can push their limits further. A lower operating temperature also increases hardware reliability, resulting in a better mean time to failure.

This is very relevant for embedded systems, since they are designed to be as cheap as possible, while still performing as well as necessary. This minimalistic design concept includes efficiency, since these systems often have a very limited power budget. The designers try to use the smallest, cheapest and most efficient hardware components available to make their product better than others.

For Smartphones and other mobile devices, power efficiency is important due to mobility reasons. After all, their limited battery power makes efficiency an important factor when designing both hardware and software, since battery lifetime otherwise limits the capabilities of the product.

Lower capabilities of course result in lower sales, and this leads to the last point: money. Not only is efficiency a desirable quality of every electronics device: for large computer systems like data centers or supercomputers the operating costs are very high due to their power consumption, so every provider is interested in better efficiency. By today, the operating costs of a computer – not only large-scale systems – generally exceed the acquisition costs. Thus it becomes economically smart to invest more money into a new and more efficient system than sitting on a higher electricity bill.

But another very simple reason to work on power efficiency is that improvements are possible, if not even easy.

4 The Future

4.1 Servers and Data Centers

What are the ongoing developments in this field? Especially large internet companies are working on efficient servers and building more and more advanced data centers. These data centers are increasingly being supplied from renewable power sources and boast very good PUE values, which is the most common way of measuring server efficiency: The PUE (Power Usage Effectiveness) is the amount of power going into the entire facility divided by the power the IT equipment consumes.

$$PUE = \frac{Total\ facility\ energy}{IT\ equipment\ energy}$$

For example, a PUE of two would mean that for every watt used by the servers, another watt was used for cooling, power supply etc. A PUE of one would be an ideal data center, where the entire power is used on IT equipment. The average PUE of servers and data centers is at about 1.8-1.9, (Miller, 2011) while some state-of-the-art data centers have PUEs of about 1.1. (Google)

But, the problem lies not within the large data centers used by the internet giants or cloud providers – these are generally the most efficient. But there are many woefully inefficient servers around the world, often maintained by small companies, that add up to contribute strongly to the overall server electricity consumption. (Whitney & Delforge, 2014) These servers mostly are not working at full capacity. Actually, the average server only works at 12-18% of its maximum workload, while still consuming a great deal of power – 30-60% of its intake at full capacity. (Whitney & Delforge, 2014)

This problem may be solved by means of virtualization, ergo having one physical server simulate several servers by running several operating systems: For example, five servers running at 20% each may be substituted by one running at 100%. But, of course, this requires extensive coordination. Just half the technologically feasible savings in servers and data centers could cut the overall power consumption by these computers systems by 40%. (Whitney & Delforge, 2014)

4.2 Supercomputers

The field of supercomputing is in constant development, and the research into even more powerful computers is driven not only by the more and more complex calculations necessary in science, but also national prestige: Supercomputers often get government funding so that they can reach new milestones. As of now, with the avant-garde supercomputers having performances on the scales of tens of petaFlops, several countries are working toward a supercomputer boasting a performance of one exaFlops, or 1000 petaFlops. China and Japan have scheduled theirs to be built before 2020, while the US aims to complete their exascale computer by 2023. Experts estimate their power consumption at at least 60 MW. (Baraniuk, 2015)

But some experts note that the gains in supercomputer performance have been slowing down in the past years, and doubt that the computers will get done on time. Problems occurring are for one the complexity of such a massive parallel processing system, but also the low mean time to failure, which might shrink to 30 minutes on an exascale system. (Hsu, 2014)

4.3 The Internet of Things

Another currently very important development in IT is the Internet of Things, or IoT. The IoT is the network of embedded devices around us, which collect and analyze data. It has even been called “the infrastructure of the information society”. (ITU) What is certain is that it is rapidly growing – by 2020, it is estimated that 50 billion devices will be online. (Evans, 2011) Already today, 98% of processors produces are made for embedded systems, with the amount of CPUs produced yearly increasing anyway. (Barr, 2009)

5 Conclusion

The ICT sector is growing rapidly, and is already now consuming a lot of energy. In today's information society, computer systems have become indispensable. This means that we need to look for possibilities to increase efficiency. Luckily, this is possible on all levels: every computer, from a smartphone or embedded device to a giant datacenter, can be made more efficient, and often, the obstacles aren't as great as one would imagine. Increasing computer efficiency is both necessary and possible.

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