Data centers control:
challenges and opportunities

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Aug. 24th, 2015

First part: what is a datacenter and what is its importance in our society

Data centers control: challenges and opportunities

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What is a datacenter?
"a facility that centralizes an organization's IT operations and equipment, and where it stores, manages, and disseminates its data"
Google (Aug. 2015)

Datacenters are the pillar of our IT society: banks, hospitals, governments, everything that is IT-based relies on datacenters.

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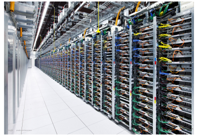
What is a datacenter?
TierPoint datacenters, Dallas



“a data center is a complex production facility, more similar to a chemical plant, power plant or other mission critical facility, than a simple building with a room full of servers” [ABB14].
A datacenter is a composition of IT systems and support infrastructure supplying power and cooling:

- IT systems: servers, storage devices, networking devices, middleware, software
- support infrastructure: backup power generators, UPSs, power distribution units, batteries and CT systems (server fans, CRACs, chillers, and cooling towers)

What is a datacenter?

TierPoint datacenters, Dallas

What is a datacenter?
Facebook, Luleå, Sweden

FB in Lulea = 60MW

What is a datacenter?

Facebook, Luleå, Sweden

What is a datacenter?
Sun Microsystems Modular Datacenter

What is a datacenter?

Sun Microsystems Modular Datacenter

Why do they exist?

- lower delays and high bandwidth between the servers
- easier to maintain
- higher level of data security and privacy

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What is their footprint?
In 2013 for EU-28:
- electrical energy consumption: 103.4 GWh (∼ 3% of the total generation)
- industry market: 18.85 billion €
- CO_2 emissions: 38.6 million tonnes (347g/kWh)
Pan European Datacenter Academy Project (2014)
Final Report Summary

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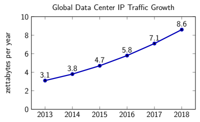
What will their footprint be?



Cisco Global Cloud Index 2013 - 2018

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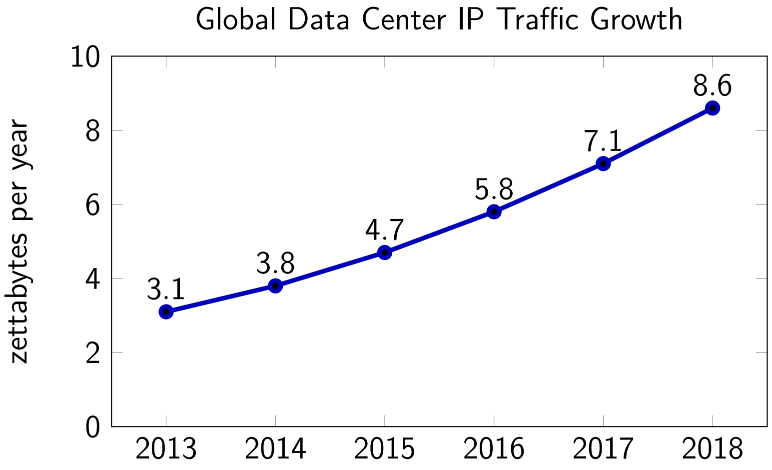

Cisco Global Cloud Index 2013 - 2018

What will their footprint be?

"forecasted energy savings from implementing ***best practices*** in datacenters in EU is 15,500GWh per year, approximatively equivalent to the energy consumed by 1M EU households yearly, 1.1 billion euro in electricity costs, 5.4 Mtonnes of CO_2"

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The best practices & Automatic Control
- Optimize Air Management
- Right-Size the Design
- Optimize the Central Plant
- Design Efficient Air Handling
- Improve Humidification Systems and Controls
- Specify Efficient Power Supplies
- Consider On-Site Generation
- Employ Liquid Cooling
- Reduce Standby Losses
- Improve Design, Operations, and Maintenance Processes
Best Practices for Data Centers: Lessons Learned from Benchmarking 22 Data Centers
Greenberg et al. (2006)
ACEEE Summer Study on Energy Efficiency in Buildings

Automatic control is important for the datacenters industry because modern and extremely efficient data centers are a minority in the global panorama of data centers.
In this presentation we do not touch the concepts of:

- "green cloud computing", i.e., how to improve algorithms so that they require less CPU efforts for solving the same task
- how to remove useless AC/DC conversions
- where to locate the datacenter
- how to design the datacenter

The best practices & Automatic Control

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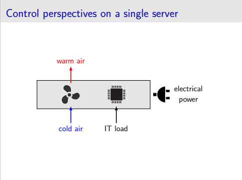
Datacenters Control

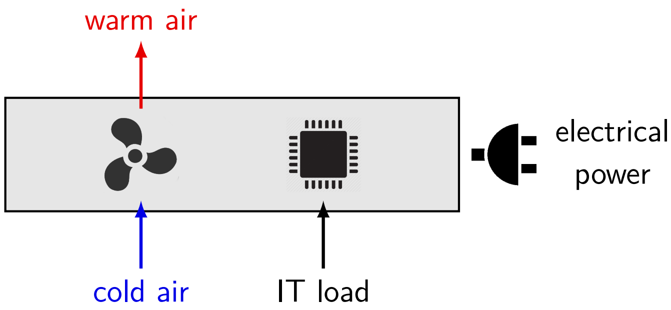
Next part: what is a datacenter from automatic control perspectives



"After the power draw from IT equipment, cooling the data center frequently consumes the largest amount of energy." [ABB14]

Liquid cooling has high installation costs and safety concerns, so it is not so widely used.

Control perspectives on a single server



Control perspectives on a single server
Control problem
Control aim
• maximize IT QoS + minimize electric consumptions
Inputs
Controllable: Non-controllable:
• CPUs frequencies • IT load
• number of VMs
• fan speed
Disturbances
• temperature of the air inlet

Problem: workloads are stochastic (and bursty and non-Gaussian at all). There is a need to predict them.

Most important thing for a datacenter is uptime and QoS.

Example of the importance of QoS: adding a 100 ms on the time to complete a user search requests induces a 1% of sales loss to Amazon.

Control perspectives on a single server

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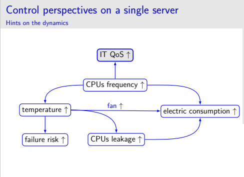
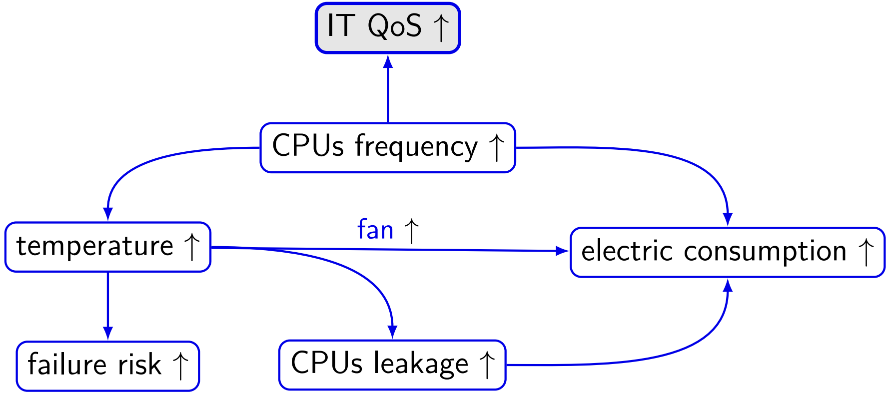


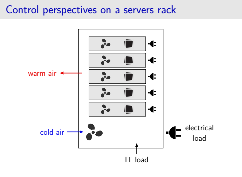
There are strong IT-CT couplings; thus operating IT and CT separately is suboptimal. Timescales: temperatures evolve in the order of minutes, while CPU power states can be changed as frequent as milliseconds.
Consequence of raising ambient temperatures too high:

1. as the ambient air temperature increases, the fan motor consumes significantly more energy to ensure the critical CPUs and memory modules stay within the acceptable operating temperature range
2. as soon as the ambient temperature rises to the point where the CPU chips enter the "leakage zone" leakage power grows exponentially with further increases in ambient temperature
3. acoustic noise from servers increases with the 5th power of the fan RPMs, and this implies indirect costs to face the additional noise
4. the time between a failure of the data center cooling system and the IT equipment reaching critical temperatures diminishes with increased starting ambient temperature

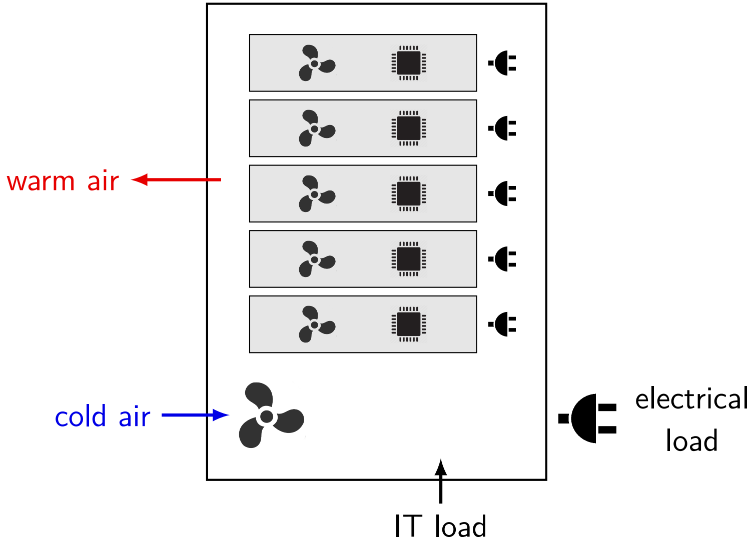
Control perspectives on a single server

Hints on the dynamics





Control perspectives on a servers rack



Control perspectives on a servers rack
Control problem
Control aim
- maximize IT QoS + minimize electric consumptions
Inputs
Controllable: Non-controllable:
- CRAC fans speed
- servers & VMs ON / OFF
- IT loads assignment
- IT load
Disturbances
- temperature of the air inlet
- thermal couplings

Again strong IT-CT couplings, so that operating IT and CT separately is suboptimal. Racks are modular, and this suggests the implementation of hierarchical / distributed estimation and control strategies.
One can decide which servers should be turned on / off and where the loads should be served; this is not negligible because different servers are more or less close to the internet fibers ⇒ different latencies and energy efficiencies.
Idle servers consume about 60% of their peak power consumption but operate between 10% and 50% of their maximum utilization. Aim is thus make active servers run at 100%, turn off the other ones.
Problem: setup time (time required to turn a server back on) is on the order of minutes, while migrating VMs is on the order of seconds.

Turning on / off things make the control problem a mixed-integer control problem.

Moreover thermal dynamics are nonlinear and costs are non convex, so the problem is

the worst possible →need for simplifications and intelligent approximations.

Control perspectives on a servers rack

Control problem

Control aim

- maximize IT QoS + minimize electric consumptions

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Controllable:

- CRAC fans speed
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Non-controllable:

- IT load

Disturbances

- temperature of the air inlet
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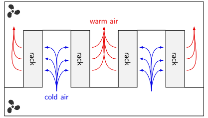
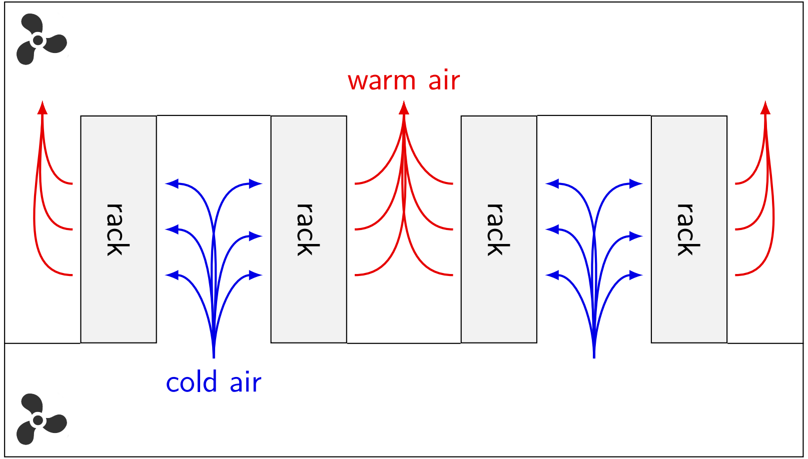
Control perspectives on a whole datacenter

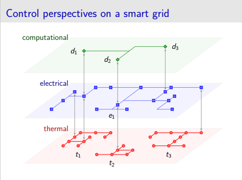


Again strong IT-CT couplings, so that operating IT and CT separately is suboptimal. Both how and where the workload is executed affect the total energy consumption: the way workload is executed impacts the efficiency at which IT operates, while the location where the workload is executed impacts the efficiency at which CT operates.
Datacenters are modular, and this suggests the implementation of hierarchical / distributed estimation and control strategies. Nonetheless this is problematic because cooling resources are usually shared, so distributed controllers need data from a whole-datacenter-level point of view.
Datacenters are also large-scale systems: the number of state variables ranges in the order of ten of thousands for a medium-size data center, since it is useful to let each CPU's temperature, workload, and amount of resources used be part of the state of the system.
Every different datacenter has very specific thermal dynamics, and there is no general "whole datacenter model". This complicates the development of general-purpose MPCs – one should learn each model of each single datacenter independently.

An other problem: there is no algorithm that accurately models the air flows and that is fast enough to be used for real-time control.

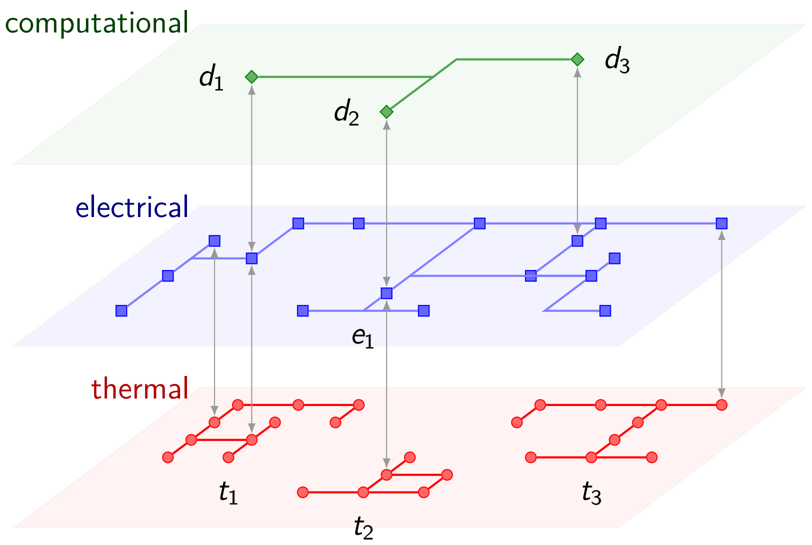
Control perspectives on a whole datacenter





Exchanging IT loads enables exploiting geographically-varying electricity prices.
Interacting with the power-grid enables taking advantage of a time-varying electricity prices and performing ancillary services like demand response for electrical networks (but this requires predictive control approaches).
Interacting with the district heating enables selling the exhaust thermal power and performing ancillary services like demand response for thermal networks.

Control perspectives on a smart grid



Datacenters Control

Next part: current states of practice and art, and research directions

State of the practice
control level
single server
servers rack
whole datacenter
smart grid

Big need for monitoring: ("you cannot improve what you are not measuring").

Importance of model predictive approaches is that preemptive over-cooling may be used to take advantage of time-varying electricity prices, external weather and variability of the load.

Problem is that to develop a model predictive controller one must first have the models, and the models should be learned automatically.

State of the practice

control level

single server

servers rack

whole datacenter

smart grid

State of the practice
control level
control technology
single server
servers rack
whole datacenter
no IT-CT couplings
IT, CT control: mostly PIDs
no learning, no robustness
big focus on DCIMs
smart grid

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State of the practice
control level | control technology
single server, servers rack, whole datacenter | no IT-CT couplings; IT, CT control: mostly PIDs; no learning, no robustness; big focus on DCIMs
smart grid | some experiments on demand response and district heating integration

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State of the art
control level
single server
servers rack
whole datacenter
smart grid

Load shedding can be done via temporarily changing the settings of the CT and exploit the buildings thermal dynamics.
Geographical load balancing routes user requests to locations with cheaper and cleaner electricity; should also account for the status (i.e., current load and temperature) of the various datacenters.

State of the art

control level

- single server
- servers rack
- whole datacenter

- smart grid

State of the art
control level
control technology
single server
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big focus on IT-CT couplings
IT-CT control: MPCs
some robustness & learning
(Bodik, Kliazovich, Lee, Parolini, Zhou, . . .)
smart grid

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smart grid | load shedding, geographical load balancing, integration with renewables

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2015-08-21

Datacenters Control

└Research & Development directions

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Operation & Maintenance
plug & play
zero touch

environmental footprint
zero carbon
zero energy overhead

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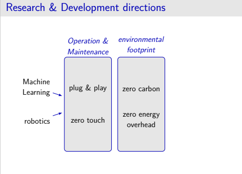
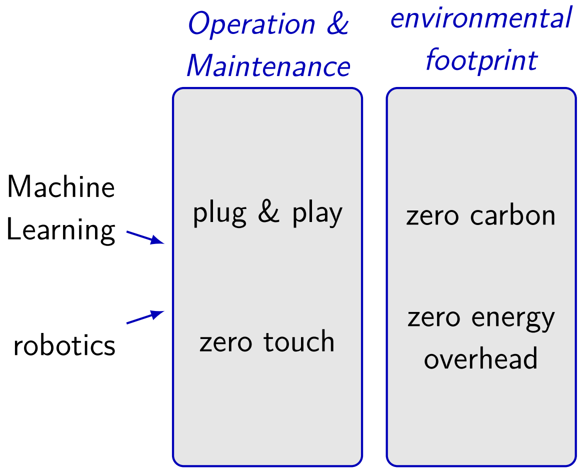
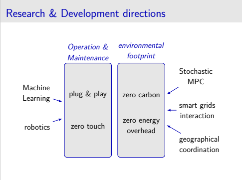


Research & Development directions





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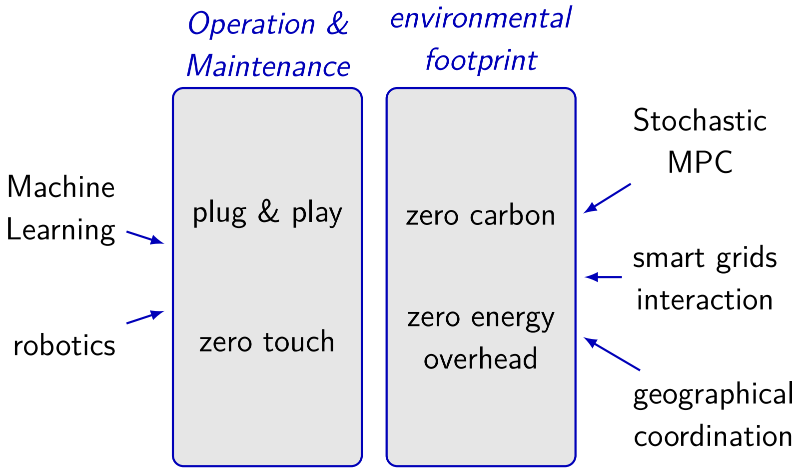
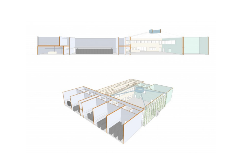


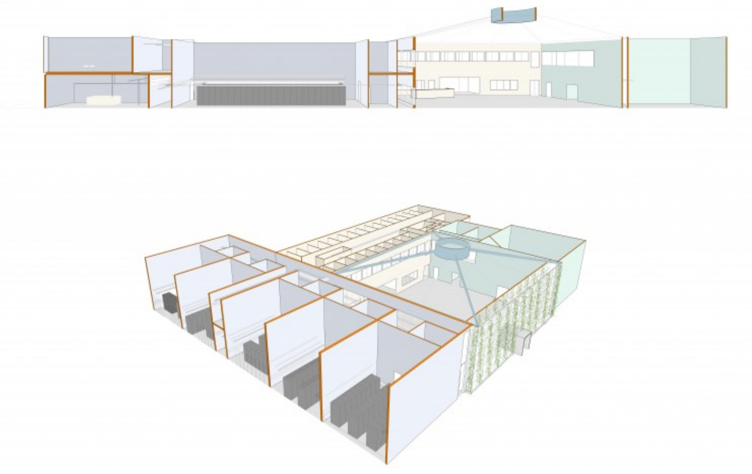
Datacenters Control

Next part: the SICS ICE testbed

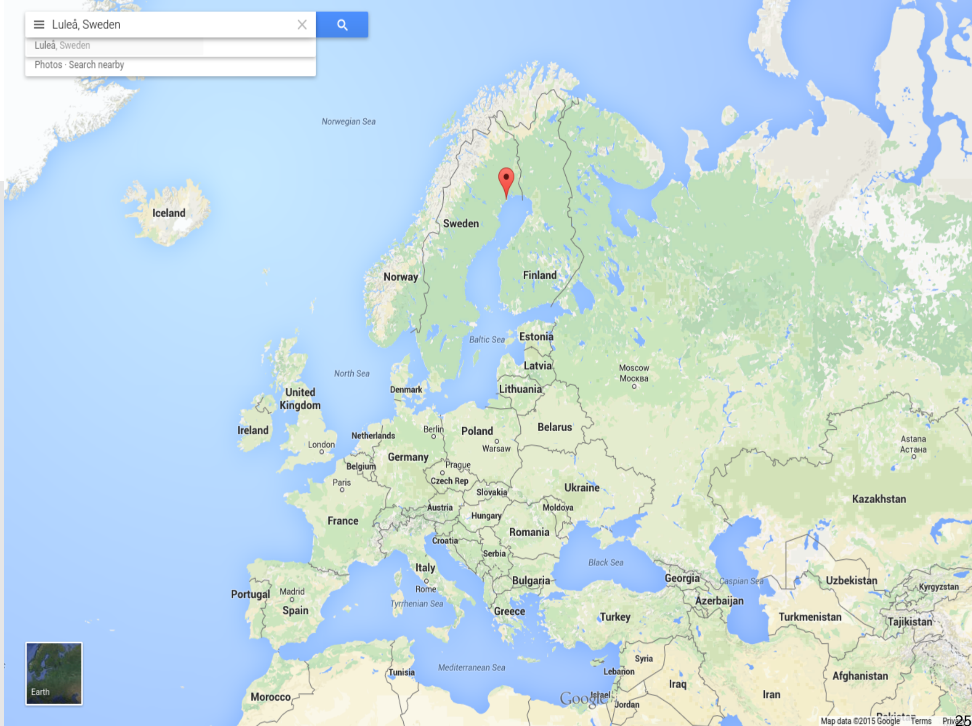


Infrastructure to enable both small and large scale experiments.
Supports growing datacenter industry and research efforts.

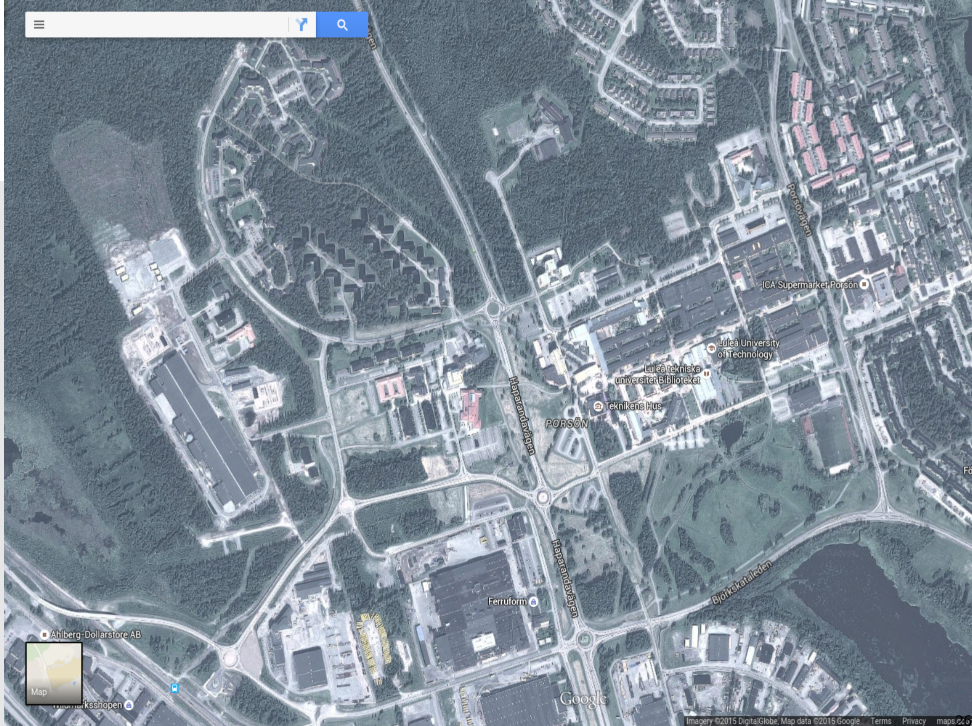
The SICS ICE datacenter



Datacenters Control



Datacenters Control



The SICS ICE datacenter
Characteristics

- 3000 - 4000 servers (2MW)
- 160 m^2 lab
- biogas back up generators
- connections with the urban district heating network
- Generality, Flexibility and Expandability

"Experiment-as-a-Service" is a way to describe the value delivered by the facility: different kinds of experiments have different costs. E.g., experiments on a single server for one hour will cost less than experiments on the whole datacenter for a month.

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Experiment-as-a-Service

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