Algorithms and Software Systems for Resource Management in Clouds

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Outline

- Brief Biography
- Geographical Load Balancing (GLB)
- Resource Provisioning for Data-intensive Applications on Hybrid Clouds
- A Low-Cost Micro Data Center for Software-Defined Cloud Computing
- Summary
Biography and Research Overview

- **PhD, University of Melbourne, 2010-2014**

- **Postdoctoral Research Fellow, University of Melbourne, 2014-2018**
  - Renewable Energy, Data intensive application Scheduling, Software-defined Clouds

- **Lecturer, Faculty of Information Technology, Monash University, May 2018**

- **Research Interests**

- **Publications**
  - 29 publications, 17 Journal Articles (11 A/A* ERA Ranking, ACM CSUR,TCC, JCNA, FGCS, TAAS), 11 Conference papers (CloudCom, UCC, HPCC), 1 Book Chapter,
  - h-index: 16 and 1200+ citations (SRC: Google Scholar)
Geographical Load Balancing for Web Applications
Cloud Computing

3.4 MILLION EMAILS ARE EXchanged\(^{a}\)

6,000 TWEETS ARE SENT ON TWITTER\(^{b}\)

100,000 SEARCHES ARE MADE ON GOOGLE\(^{c}\)

600 ITEMS ARE SOLD ON AMAZON\(^{d}\)

250 SONGS ARE DOWNLOADED VIA ITUNES\(^{f}\)

70,000 LIKES ARE GENERATED ON FACEBOOK\(^{e}\)

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\(^{a}\) https://www.lifewire.com/how-many-emails-are-sent-every-day-1171210
\(^{b}\) http://www.internetlivestats.com/twitter-statistics/
\(^{c}\) http://www.statisticbrain.com/google-searches/
\(^{d}\) https://www.inc.com/tom-popomaronis/amazon-just-eclipsed-records-selling-over-600-items-per-second.html
\(^{e}\) https://www.brandwatch.com/blog/47-facebook-statistics-2016/
Power Hungry Clouds

- Cloud data centres consume large amounts of electricity
  - High operational cost for the cloud providers
  - High carbon footprint on the environment

- US Data Centres
  - 70 billion kilowatt-hours of electricity in 2014
  - = Two-year power consumption of all households in New York
  - = The amount consumed by about 6.4 million average American homes that year
  - Projected nearly 50 million tons of carbon pollution per annum in 2020.

  – Source: US Natural Resources Defense Council (NRDC)

Photo Source: http://nycyoungmen.tumblr.com/
Renewable Energy and Challenges

- **Cloud providers aims**
  - Reduce energy consumption
  - Abate dependence on brown energy

- **Renewable energy**
  - Google, Microsoft and Amazon

- **Challenges:**
  - Non-dispatchable, Intermittent and Unpredictable
  - Powering data centres entirely with renewable energy sources is difficult

- **Mixed sources of energy for data centres:**
  - Grid power or brown energy
  - Renewable energy sources or green energy

- **Challenges:**
  - Minimising brown energy usage
  - Maximising renewable energy utilisation

Source: https://aws.amazon.com/about-aws/sustainability/
Geographical Load Balancing (GLB)

- Geographical load balancing (GLB) potentials:
  - Follow-the-renewables
- GLB approach benefits cloud providers but it raises an interesting, and challenging question:

  “With limited or even no a priori knowledge of the future workload and Dynamic and unpredictable nature of renewable energy sources, how to optimise the overall renewable energy use and cost?”
System Architecture for Web Applications

Diagram showing the architecture with layers of load balancers and autoscalers, connecting to web servers and database servers.
Workload Traces

![Graph showing workload traces over time with peaks and valleys]

Wikipedia
A Prototype System
Renewable Power and Electricity Prices

**Solar**

- Solar Power Generation (Watt)
- Time (Hour)

**Wind**

- Wind Power Generation (Watt)
- Time (Hour)

**Combined**

- Normalized Renewable Power
- Time (Hour)

- Electricity Price per KWh (£)
- Time (Hour)
Results

Lyon

Reims

Rennes
## Results

<table>
<thead>
<tr>
<th>Site</th>
<th>Metric</th>
<th>RR</th>
<th>Capping</th>
<th>GreenLB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyon</td>
<td>Power Consumption (kWh)</td>
<td>36.3</td>
<td>42.9</td>
<td>41.2</td>
</tr>
<tr>
<td></td>
<td>Brown Consumption (kWh)</td>
<td>13.3</td>
<td>19.0</td>
<td>16.9</td>
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<tr>
<td></td>
<td>Cost (€)</td>
<td>1.71</td>
<td>2.31</td>
<td>2.01</td>
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<td>Reims</td>
<td>Power Consumption (kWh)</td>
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<td>Brown Consumption (kWh)</td>
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<td></td>
<td>Cost (€)</td>
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<td>Rennes</td>
<td>Power Consumption (kWh)</td>
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<td></td>
<td>Brown Consumption (kWh)</td>
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<tr>
<td></td>
<td>Cost (€)</td>
<td>1.23</td>
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<tr>
<td>Total</td>
<td>Power Consumption (kWh)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brown Consumption (kWh)</td>
<td>25.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost (€)</td>
<td>3.36</td>
<td></td>
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</tr>
</tbody>
</table>

**Brown Energy:**
-17% and 7%

**Cost Saving:**
-22% and 8%
Resource Provisioning for Data-intensive Applications on Hybrid Clouds
Background

- **Data-intensive applications**
  - Analysis of large datasets
  - Explosive growth of data
    - Smart cities, Social networks, Internet of Things (IoT), …

- **Cloud computing**
  - Preferred platform

- **Common Scenario**
  - Data is available in local IT infrastructure with limited processing capacity

- **Cloud bursting**
  - Hybrid Cloud (PaaS, Middleware)
Scheduling Problem

- **Locality**
  - Location of the data relative to the available computational resources

- **Network bandwidth**
  - Can become the bottleneck

- **Data transfer**
  - Not ideal to move the entire data set to the public cloud

- **Data-intensive application**
  - Data transfer time to the external cloud is often comparable to the computational time
Our Contribution

- **Data-aware provisioning and Scheduling algorithm**
  - Minimising cost while meeting the deadline requirements of applications
  - Hybrid cloud environments.
  - Data transfer time, available bandwidth, locality

- **Plugged into PaaS**
  - Aneka platform
  - Support dynamic resource provisioning for Microsoft Azure

- **Experiments in actual hybrid cloud environment**
  - Local resources and Azure virtual machines
  - Compared with existing approaches
  - A real-world case study
    - A data-intensive application in the smart cities context
Aneka

Application Development and Management
- Software Development Kit
  - API
  - Tutorials
  - Samples
- Management Kit
  - Management Studio
  - Admin Portal
  - Web services

Middleware - Container
- Execution Services
  - Thread Model
  - Task Model
  - MapReduce Model
  - ...

Foundation Services
- Persistence
  - Licensing
  - Membership
  - Accounting
  - Reservation
  - Storage
  - ...

Fabric Services
- Resource Provisioning
- Hardware Profiling
- ...

Platform Abstraction Layer (PAL)

Infrastructure
- Desktop Cloud
- Data Center
- Cluster
- Cloud
Walkability Index – Melbourne Neighbourhoods
Hybrid Cloud Testbed
Some Experimental Results

- **Execution Time (mins)**
  - Data-aware
  - Default
  - Enhanced

- **Total running time of VMs (mins)**

- **Number of launched VMs**
A Low-Cost Micro Data Center for Software-Defined Cloud Computing
Software-Defined Networking

- Separation of control plane from data forwarding plane
- Platform is decoupled from infrastructure
- Centralized controller, network-wide control by controller SW that performs routing and traffic engineering

**Traditional Networking**

- Control Plane
- Data Forwarding Plane

**Software-Defined Networking**

- Controller Software
- Control Protocol

Credit: Jungmin Son
Network Function Virtualization (NFV)

- **Migration of network functions to the software layer**
  - Firewalls, Network Address Translation (NAT), Intrusion Detection Systems (IDS)

- **Virtualized Network Function (VNF)**
  - Deployable elements of NFV

- Enables better interoperability of equipment and more advanced network functions
Software-defined clouds

- **Virtualization in networking**
  - Software-defined networking (SDN) and Network Functions Virtualization (NFV).

- **Software-defined Cloud Computing (SDC)**
  - Extending the concept of virtualization to all resources
    - compute, storage, and network

- **Evaluation and Experimentation**
  - Complexity, scaling, accuracy, and efficiency.

- **A low-cost experimental testbed/infrastructure**
  - Conducting practical research in the domain of software defined clouds.
CLOUDS-Pi

- Our recipe for constructing a platform for conducting empirical research in SDCs
  - Easily Repeatable
  - Low-cost (reusing existing servers and Raspberry Pis)
  - Open Source Software

- Hardware
  - Small scale cloud datacenters (9 physical servers, Fat-tree network)
  - Raspberry Pis as SDN Switches
  - Managed enclosure Power Distribution Units (ePDUs)

- Software
  - OpenStack
  - OpenDaylight (ODL)
  - Open vSwitch
Hardware

<table>
<thead>
<tr>
<th>Machine</th>
<th>CPU</th>
<th>Cores</th>
<th>Memory</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 x IBM X3500 M4</td>
<td>Intel(R) Xeon(R) E5-2620 @ 2.00GHz</td>
<td>12</td>
<td>64GB (4 x 16GB DDR3)</td>
<td>2.9TB</td>
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<tr>
<td>4 x IBM X3200 M3</td>
<td>Intel(R) Xeon(R) X3460 @ 2.80GHz</td>
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<td>16GB (4 x 4GB DDR3)</td>
<td>199GB</td>
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<tr>
<td>2 x Dell OptiPlex 990</td>
<td>Intel(R) Core(TM) i7-2600 @ 3.40GHz</td>
<td>4</td>
<td>8GB (2 x 4GB DDR3)</td>
<td>399GB</td>
</tr>
</tbody>
</table>

Eaton Managed Enclosure Power Distribution Units (ePDUs)

USB 2.0 to 100Mbps Ethernet adapters

Raspberry Pis (Pi 3 MODEL B)
System Architecture
More Photos
Dynamic Flow Scheduling for Virtual Machine Migration

“Is it possible to reduce live VM migration time and overhead by dynamically scheduling flows in a cloud data center with multiple paths available between a given pair of physical hosts?”
Acinonyx: Proposed Algorithm

- When multiple shortest paths are available between the source and destination
  - As long as the VM migration is in progress it exploit residual bandwidth on multiple available paths
  - Redirect the live VM migration traffic on a path with the lowest load
  - Find a path that has the highest residual bandwidth on its most utilized link
  - Push appropriate flow rules into the switches to redirect traffic
## Some Results

<table>
<thead>
<tr>
<th>Metric</th>
<th>Static Routing</th>
<th>Acinonyx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Migration Time (s)</td>
<td>287</td>
<td>256</td>
</tr>
<tr>
<td>Average Throughput (Mbs)</td>
<td>32.0</td>
<td>34.4</td>
</tr>
</tbody>
</table>

Migration time for two simultaneous migrations when Static and Acinonyx flow scheduling are used.
Summary

- **Cloud computing** is a critical building block of many ICT applications.

- **Geographical load balancing** for maximization of renewable energy usage.
  - Real traces of web requests for English Wikipedia
  - Meteorological data in the location of each data centre to model solar and wind power generation
  - Uses **17% less brown energy** and saves **cost** by almost 22% in comparison to round robin policy.
Summary

- **Deadline-aware Scheduling and Resource Provisioning Method for Data-intensive Applications on Hybrid Clouds**
  - The proposed method is able to meet strict deadlines for a sample data-intensive application to measure the walkability index.
  - It minimizes cost and the total number launched instances compared to other existing algorithms.

- **Recipe for constructing an economical testbed for Software Defined Clouds and conducting practical experiment**
  - Dynamic flow scheduling algorithm for live VM migration
  - Migration time is reduced by 12% and network throughput is increased by 7%.
THANK YOU

Questions?