Key Research Challenges in Cloud Computing

Ignacio M. Llorente

Head of DSA Research Group
Universidad Complutense de Madrid

dsa-research.org

Project co-Lead and Director
OpenNebula Open-source Cloud Community

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Acknowledgments
## A Model for Delivering IT Capabilities as a Service

<table>
<thead>
<tr>
<th>What</th>
<th>Who</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-demand access to any application</td>
<td>End-user</td>
</tr>
<tr>
<td></td>
<td>(does not care about hw or sw)</td>
</tr>
<tr>
<td><img src="skype.png" alt="Skype" />, <img src="gmail.png" alt="Gmail" />, <img src="facebook.png" alt="Facebook" /></td>
<td></td>
</tr>
<tr>
<td>Platform for building and delivering web applications</td>
<td>Developer</td>
</tr>
<tr>
<td></td>
<td>(no managing of the underlying hw &amp; sw layers)</td>
</tr>
<tr>
<td><img src="windows_azure.png" alt="Windows Azure" />, <img src="salesforce.png" alt="Salesforce" /></td>
<td></td>
</tr>
<tr>
<td><strong>Raw computer infrastructure</strong></td>
<td>System Administrator</td>
</tr>
<tr>
<td></td>
<td>(complete management of the computer infrastructure)</td>
</tr>
<tr>
<td><img src="gogrid.png" alt="GoGrid" />, <img src="flexiscale.png" alt="Flexiscale" />, <img src="amazon_web_services.png" alt="Amazon Web Services" /></td>
<td></td>
</tr>
</tbody>
</table>
Key Research Challenges in Cloud Computing

Cloud Deployments

Public Cloud
- Simple Web Interface
- Pay-as-you-go (On-demand access)
- Elastic & “infinite” Capacity

Private Cloud
A “Public Cloud behind the firewall”
- Simplify internal operations
- Dynamic allocation of resources
- Higher utilization & operational savings
- Security concerns

Hybrid Cloud
- Supplement the capacity of the Private Cloud
- Utility Computing dream made a reality!
Cloud Computing as an Enabler for the Internet of Services

**SaaS**
- Software applications are available as a service in the Internet

**PaaS and IaaS**
- The tools to develop applications and the infrastructure are available as a service

**Cloud Computing as an Enabler**
- Reduce infrastructure management complexity
- Automatic scalability
- Cloudbursting
- Reduce infrastructure costs

- Pay-per-use (utility) models
- Reduce development time
- Speed-up time-to-market of services
Open Research Issues

- PaaS Cloud Management
- Cloud-enabled Applications and Platforms
- Cloud Aggregation
- IaaS Cloud Management
- Cloud Enablement

Cloud Interoperability
Platform Management

Challenges in **delivering middleware capabilities** for building, deploying, integrating and managing applications in a multi-tenant, elastic and scalable environment

- **Scalability** and **multi-tenancy** of application containers
- **Placement optimization algorithms** of containers in resources
Cloud-enabled Applications and Platforms

Challenges in building cloud-enabled applications and platforms to take advantage of the scalability, agility and reliability of the cloud

- **Elastic** and **scalable** applications and frameworks on very large-scale environments
- **Self-scaling, self-awareness, self-knowledge, and self-management** capabilities of services
- **Novel applications** of cloud computing
- **Power-efficient** applications and platforms
Cloud Aggregation

Research challenges in the **aggregation of resources from diverse cloud providers** adding additional layers of service management

- **Novel architectural models** for aggregation of cloud providers
- **Brokering algorithms** for high availability, performance, proximity, legal domains, price, or energy efficiency
- **Sharing of resources** between cloud providers
- **Networking in the deployment of services** across multiple cloud providers
- **SLA negotiation and management** between cloud providers
- **Additional privacy, security and trust management** layers atop providers
- **Support of context-aware applications**
- **Automatic management of service elasticity**
Cloud Management

Research challenges in **delivering infrastructure resources** on-demand in a multi-tenant, secure, elastic and scalable environment

- **Scalable management** of network, computing and storage capacity
- **Scalable orchestration** of virtualized resources and data
- **Placement optimization algorithms** for energy efficiency, load balancing, high availability and QoS
- **Accounting, billing, monitoring** and **pricing** models
- **Security, privacy** and **trust** issues in the cloud
- **Energy efficiency** models, metrics and tools at system and datacenter levels
Cloud Enablement

Research challenges in enhancing platform infrastructure to support cloud management requirements

- **Technologies for virtualization** of infrastructure resources
- **Virtualization of high performance** infrastructure components
- **Autonomic and intelligent management** of resources
- Implications of Cloud paradigm on networking and storage systems
- Support for **vertical elasticity**
- Provision of service related metrics
Cloud Interoperability

Challenges to ensure that the available cloud services can work together and interoperate successfully.

- **Common and standard interfaces** for cloud computing
- **Portability of virtual appliances** across diverse clouds providers

Diagram:

- Public Cloud
- Private Cloud
- Hybrid Cloud
- Cloud Management
Ongoing Research Projects

CumuloNimbo

PaaS Cloud Management

Cloud-enabled Applications and Platforms

Cloud Aggregation

IaaS Cloud Management

Cloud Interoperability

Cloud Enablement

Vision Cloud

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Non-Technical Challenges to Boost Adoption

Boost Adoption of Cloud Technologies

Technology Gap
- Research Initiatives
- Promote OSS
- Focused Innovation

Usability Gap
- Standards
- Interoperability
- Legalistic issues, trust and security

Cultural Gap
- Educate users
- Provide exp. testbeds

Main Areas for EU-Japan Collaboration
Building an Open Cloud Ecosystem

**Openness**
- Open architectures
- Open interfaces
- Open code

**Adaptability**
- Modular architectures

**Key Principles to Maximize Value**

**Standardization**
- Use standards
- Implement standards

**Re-use**
- Re-use existing open-source components
- Contribute to existing communities
The OpenNebula Case

Flagship International Project in Cloud Computing
Result of many years of research and development in efficient and scalable management of virtual machines on large-scale distributed infrastructures.

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Open-source Toolkit
Open platform for innovation to research the challenges that arise in cloud management, and production-ready tool in both academia and industry

• Started in 2005, first release in March 2008
• Open-source released under Apache v2.0, packaged for main Linux distributions
• Mailing lists for best-effort support and open development framework
• Development and roadmap definition driven by the community and projects
• Active and engaged open community and ecosystem
• > 3,000 downloads/month (not including code repository and Ubuntu)
Reference Open Source Stack for Cloud Computing

Open Source Community
- Open architecture and interfaces
- Open code
- Open community and ecosystem
- Very liberal license

OpenNebula.org

Adopt Standards

Avoid Software Fragmentation
Re-use sw Components

Wide Adoption
- Tool for innovation
- Build a commercial service
- Build a commercial product
References, Questions and Comments

Reports


Research References

• B. Sotomayor, R. S. Montero, I. M. Llorente and I. Foster, “Virtual Infrastructure Management in Private and Hybrid Clouds”, IEEE Internet Computing, September/October 2009 (vol. 13 no. 5)