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Research infrastructures for a cloudy future Internet

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Goal of the talk

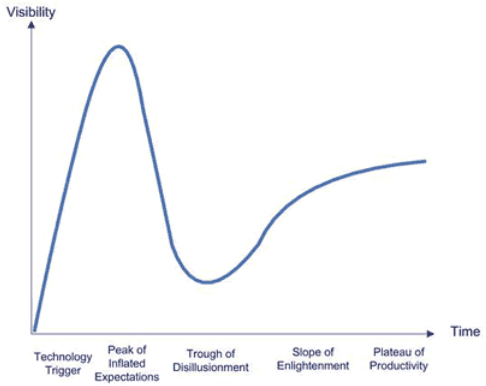
- OpenFlow
  - Enabling technology for the future Internet
  - Power of innovation, architectural implications, …
- New packet forwarding paradigms
  - LIPSIN: Line-Speed Publish/Subscribe Inter-Networking
  - SiBF: Data center networking with in-packet Bloom filters
- **Experimental Research on the Future Internet**

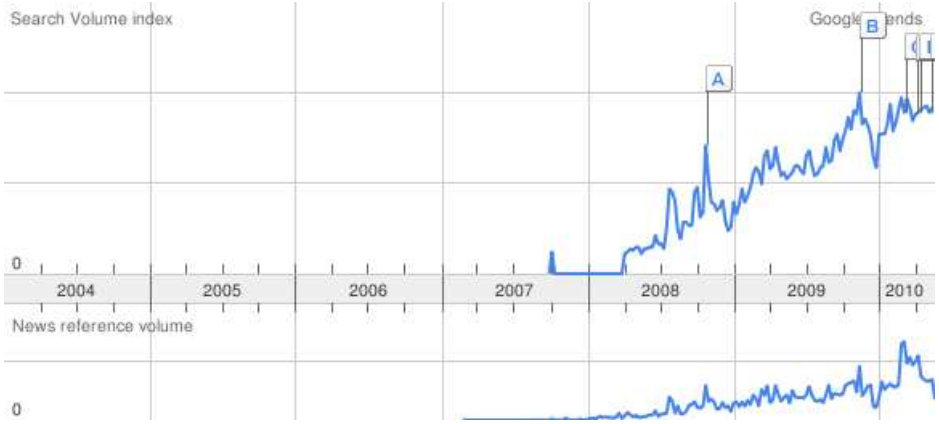
Message

- The Cloud is here to stay,
  - but how will it evolve and impact the Internet from an architectural point of view?
- The inter-networking requirements of the Cloud
  - main driving force shaping the so-called future Internet
- Develop Inter-Cloud use cases in the national infrastructures for Future Internet R&D
  - Towards a planet-scale, federated CloudLab

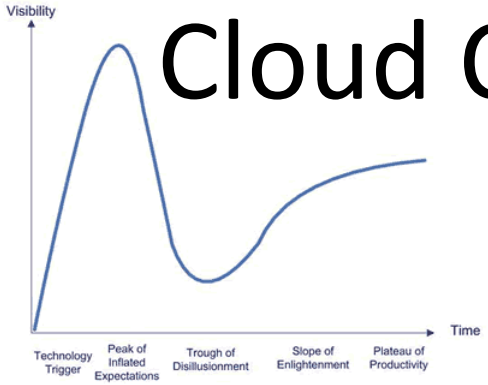
Disclaimer

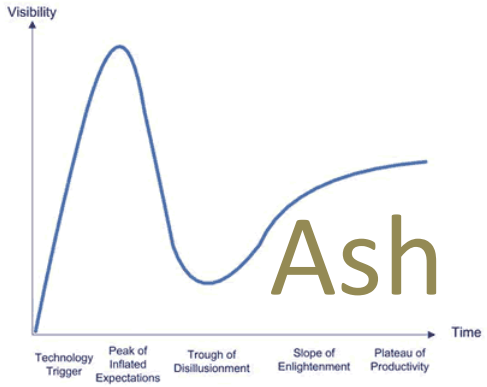
This presentation contains a mix of hype and speculation.





Cloud Computing





Ash Cloud Computing

- Interoperability
- Open market
- Low entry barrier
- Incentives for innovation at all layers
- Sustainable
- …

- Provider lock-in
- Performance hauls
- Security
- Privacy
- …

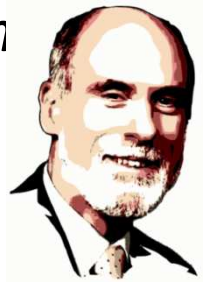
What is the Inter-Cloud?

- A marketing term?
- If the Internet is the network of networks, the Inter-Cloud is the cloud of clouds

- A federation of clouds
  i.e., an agreement to cooperate for the mutual benefit ($$$)

The Inter-Cloud

"The Cloud represents a new layer in the Internet architecture and, like the many layers that have been invented before, it is an open opportunity to add functionality to an increasingly global network" - Vint Cerf, 2009 [1]



Cloud Initiatives that have an analogue in the Internet's past:[1]

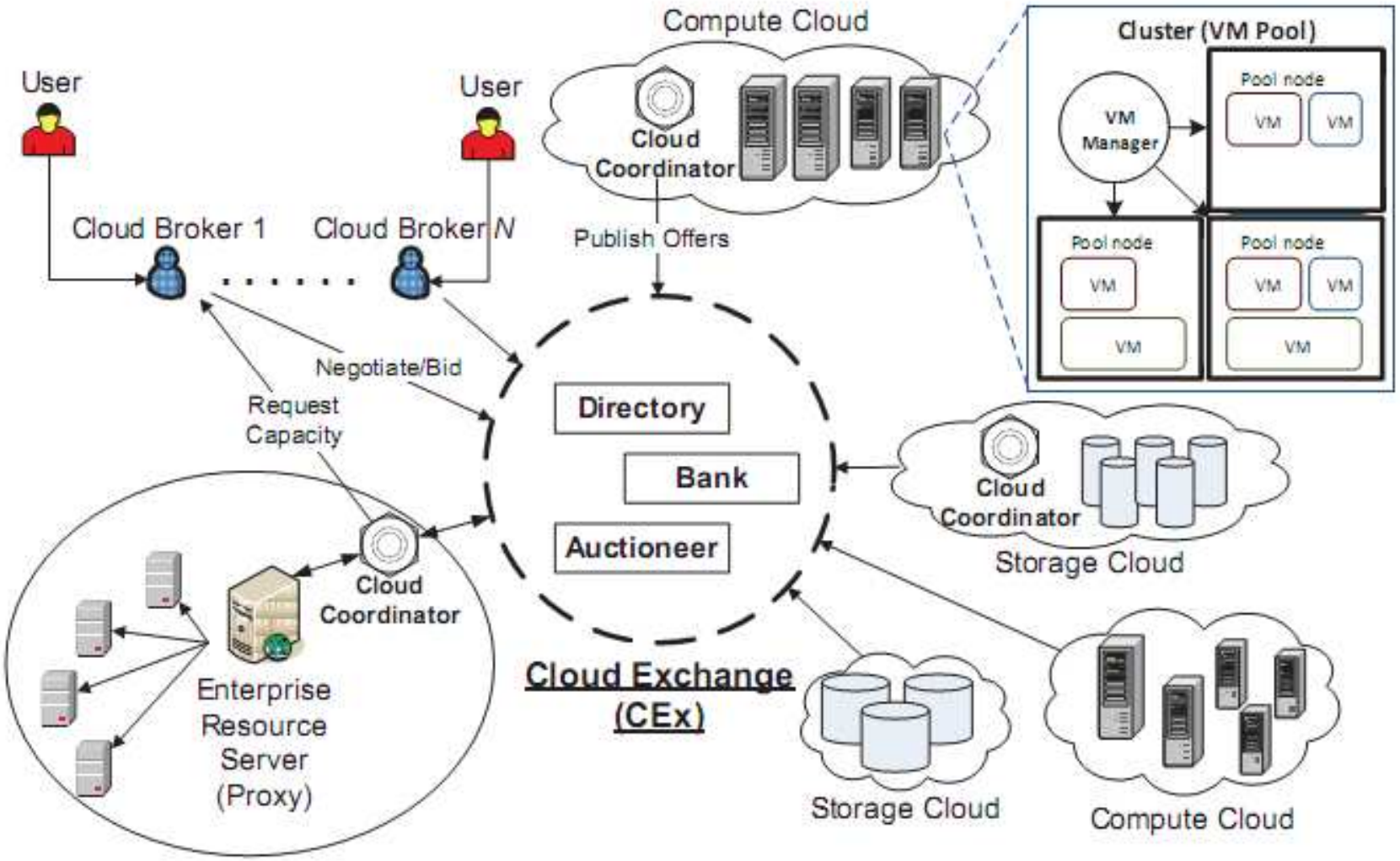
- The rising importance of *academia*.
- Increasing interest in *interoperability* among cloud vendors.
  - Today's clouds like network islands before IP
- *Carrier* interest in new service opportunities.

[1] http://googleresearch.blogspot.com/2009/04/cloud-computing-and-internet.html
[2] http://blogs.cisco.com/datacenter/comments/is_the_intercloud_history_repeated/

The Inter-Cloud as an Utility

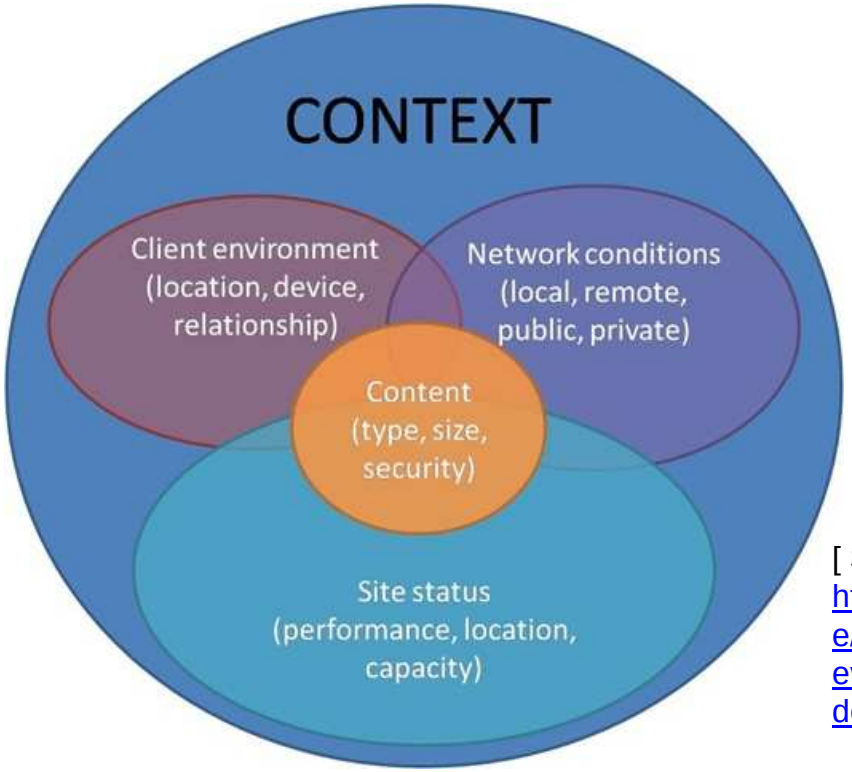
- Learn from other utilities (energy, water, transport) and anticipate the emergence of an utility-driven *Cloud resource market*
  - Utility-Oriented Federation of Cloud Computing Environments
- What is the role of the (inter-)networking substrate?

The emergence of a Cloud market



[Buyya *et al*. InterCloud: Utility-Oriented Federation of Cloud Computing Environments for Scaling of Application Services]

Research in the Inter-Cloud



[Source: http://devcentral.f5.com/weblogs/macvittie/archive/2009/06/30/intercloud-the-evolution-of-global-application-delivery.aspx]

- It is all about *context* (again, i.e., like mobility),
  but strongly driven by business (aka BGP but on a higher level)

Networking the Inter-Cloud

Re-examination of cost/control trade-offs & adoption incentives:

- Mature protocols (VPN, IPv6, IP Multicast, Sec BGP, DNSsec, …)
- Novel routing mechanisms (e.g., LISP, energy-aware protocols, or even XML routing)
- Radical information-centric architectures (e.g., CCN, PSIRP).
- Virtual flash networks, Bandwidth-on-Demand, WAN acceleration (compression, packet deduplication), etc.

Isolated Clouds over IP

Users

Data Centers

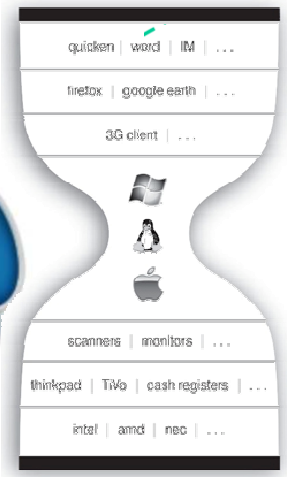
naming DNS

routing BGP

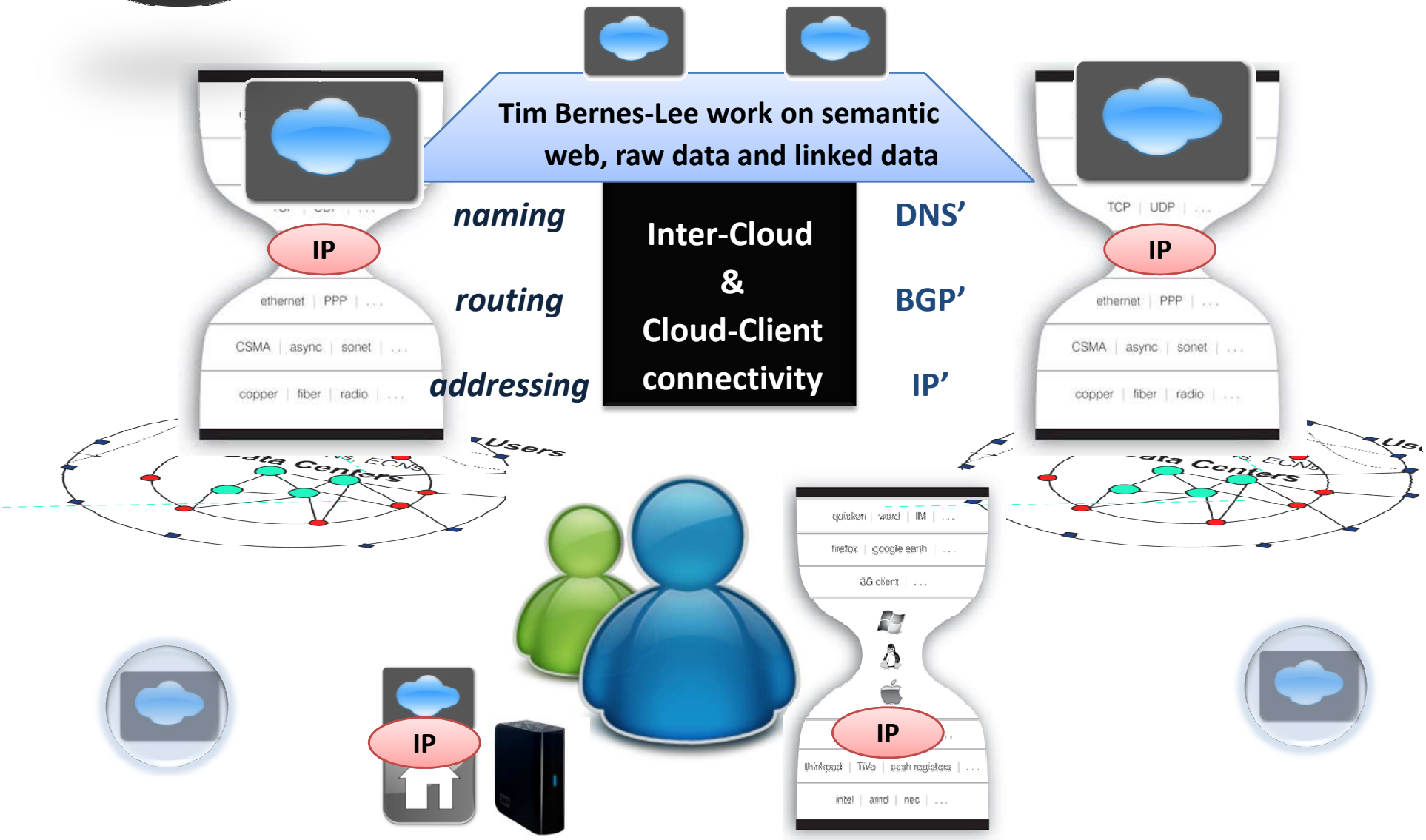
addressing IP

Users

Data Centers



Cloud-oriented connectivity?



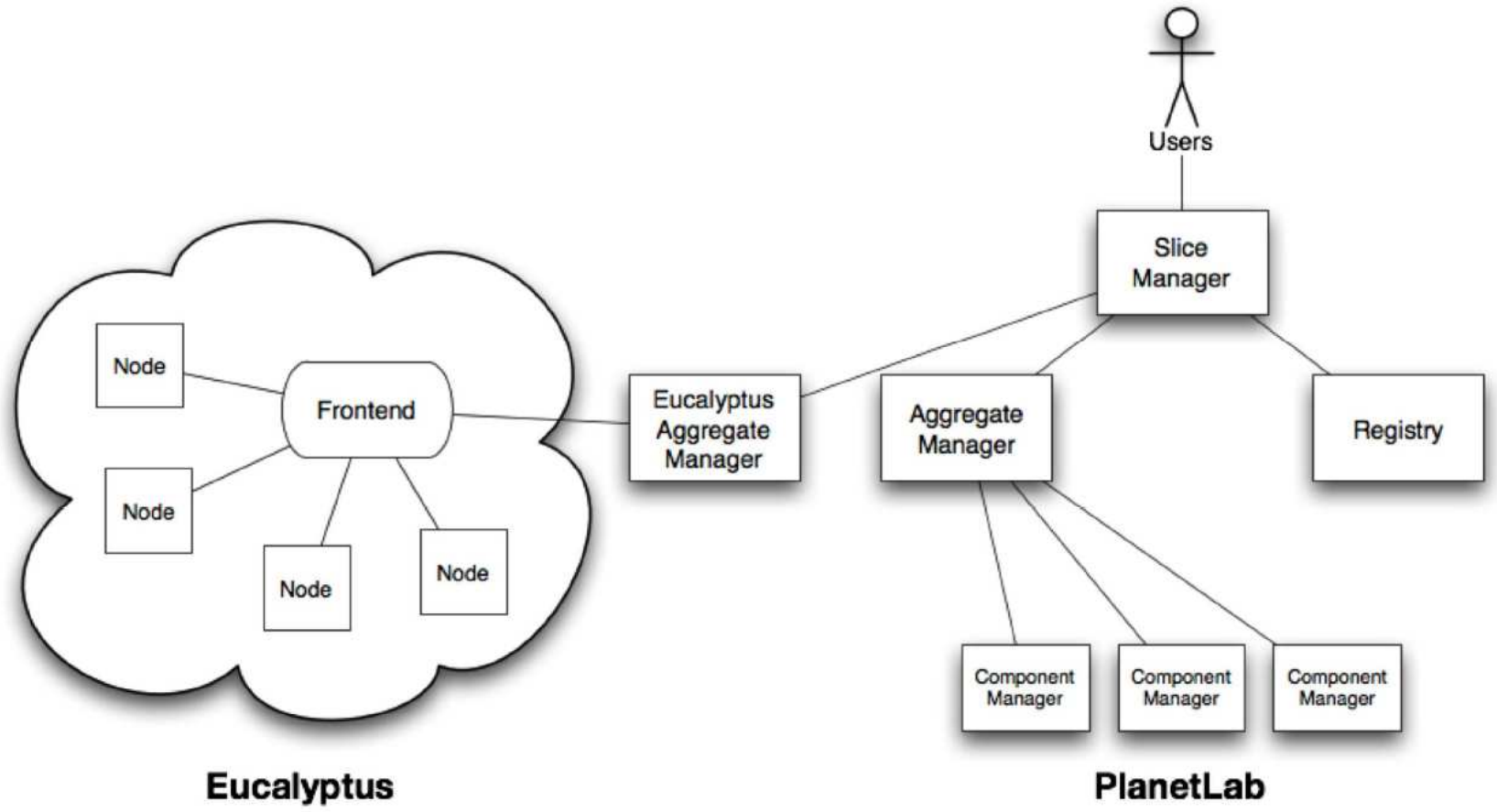
Towards a CloudLab

Table 2. Comparison of cloud computing testbeds.

Characteristics	Open Cirrus	Google/ IBM cluster	TeraGrid	PlanetLab	Emulab	Open Cloud Testbed	Amazon EC2	LANL cluster
Type of research	Systems and services	Data-intensive applications	Scientific applications	Systems and services	Systems	Interopera-bility across clouds using open APIs	Commercial use	Systems
Approach	Federation of heterogeneous data centers	Cluster supported by Google and IBM	Multisite heterogeneous clusters for super-computing	Nodes hosted by research institution	Single-site cluster with flexible control	Multisite het-erogeneous clusters	Raw access to virtual machines	Reuse of LANL's retiring clusters
Participants	CMU, ETRI, HP, Intel, IDA, KIT, MIMOS, RAS, UIUC, Yahoo!	Google, IBM, MIT, Stanford Univ., Univ. of Washington	Many universities and organizations	Many universities and organizations	Univ. of Utah	Four centers	Amazon	CMU, LANL, NSF
Distribution	10 sites	Central-ized—one data center in Atlanta	11 partners in US	More than 700 nodes worldwide	More than 300 machines	480 cores dis-tributed in four locations	Several unified data centers	Thou-sands of older but still useful nodes at one site

[Source http://www.cs.cmu.edu/~droh/papers/opencirrus-ieeecomputer.pdf]

GENICloud

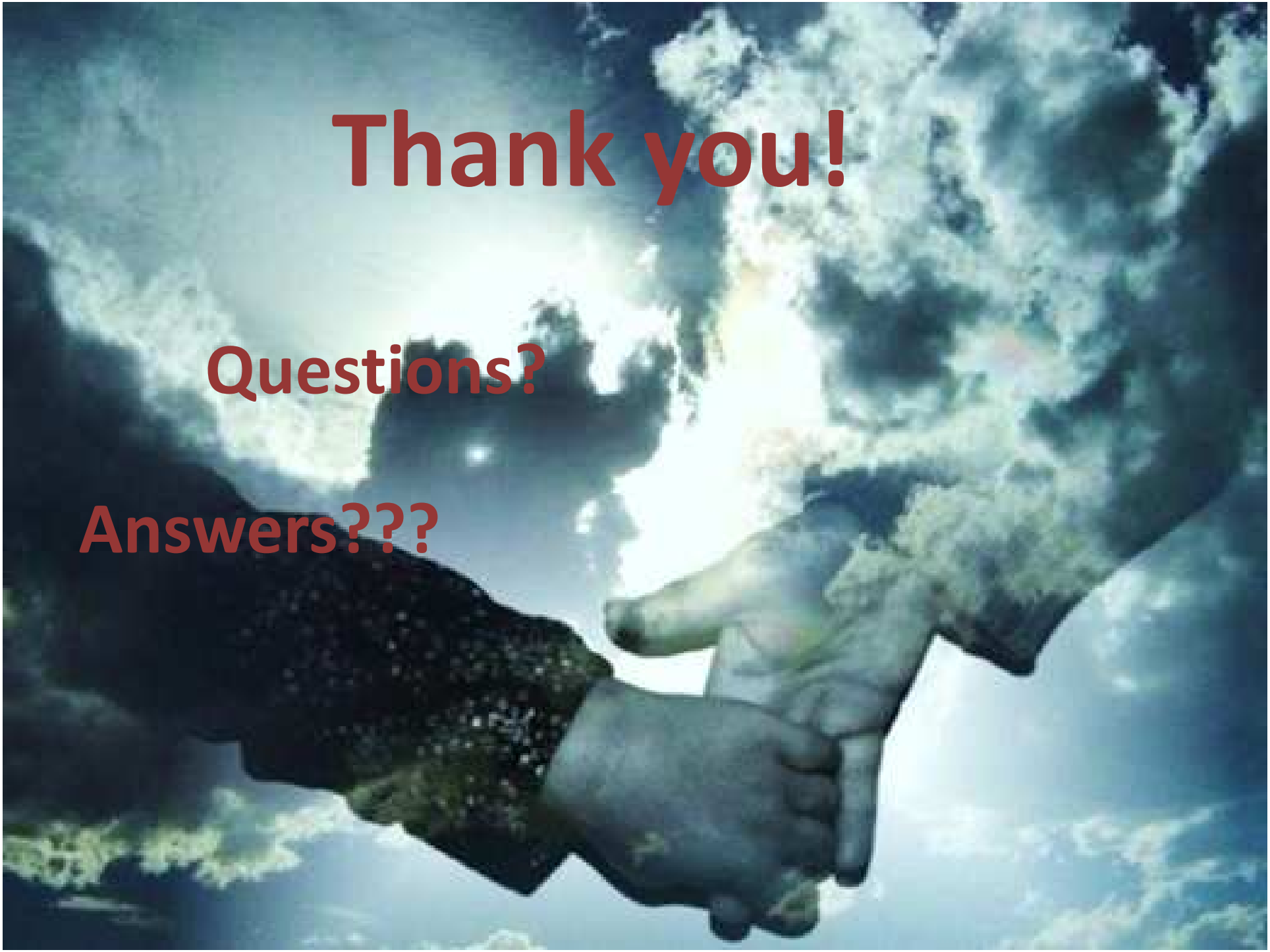


[Source: http://groups.geni.net/geni/attachment/wiki/GENICloud/GEC7Poster.pdf]

Thank you!

Questions?

Answers???

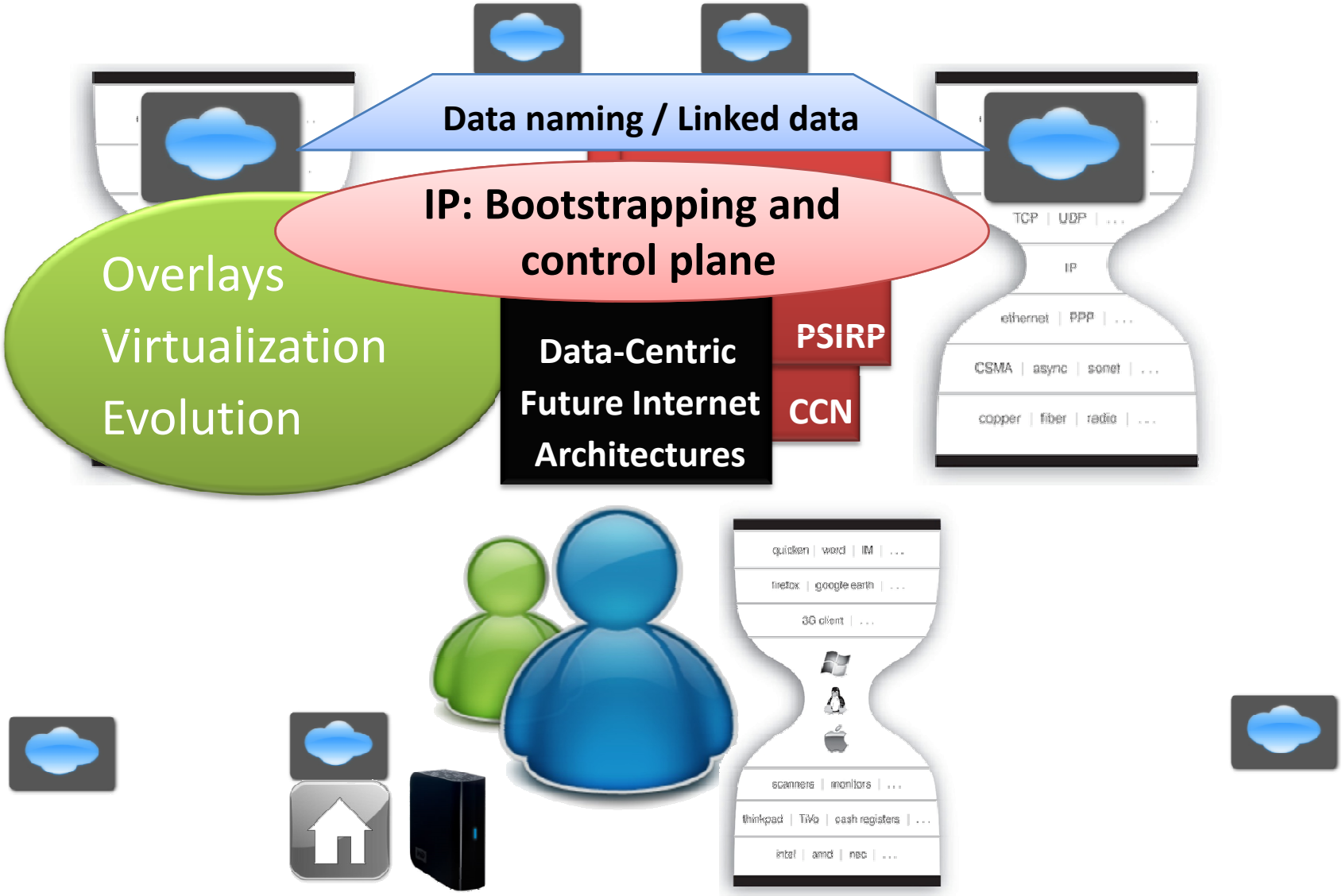

Thank you!
Questions?
Answers???

BACKUP

Impacts of the cloud data center footprint on the Future Internet?

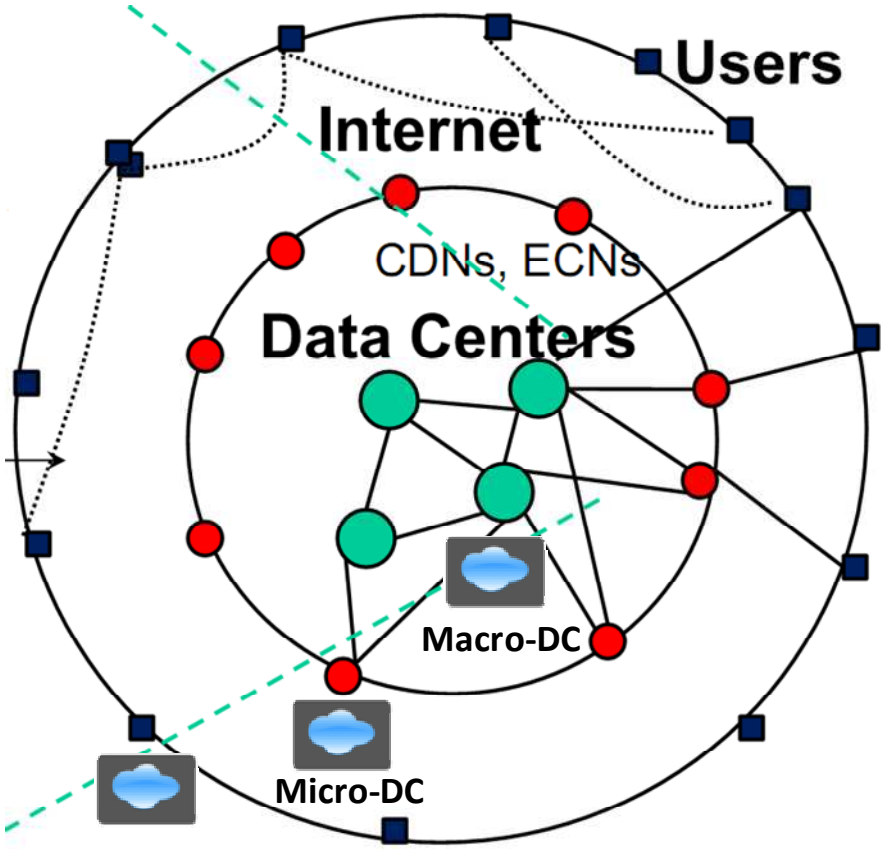
THE INTER-CLOUD

Emergence of data-centric architectures



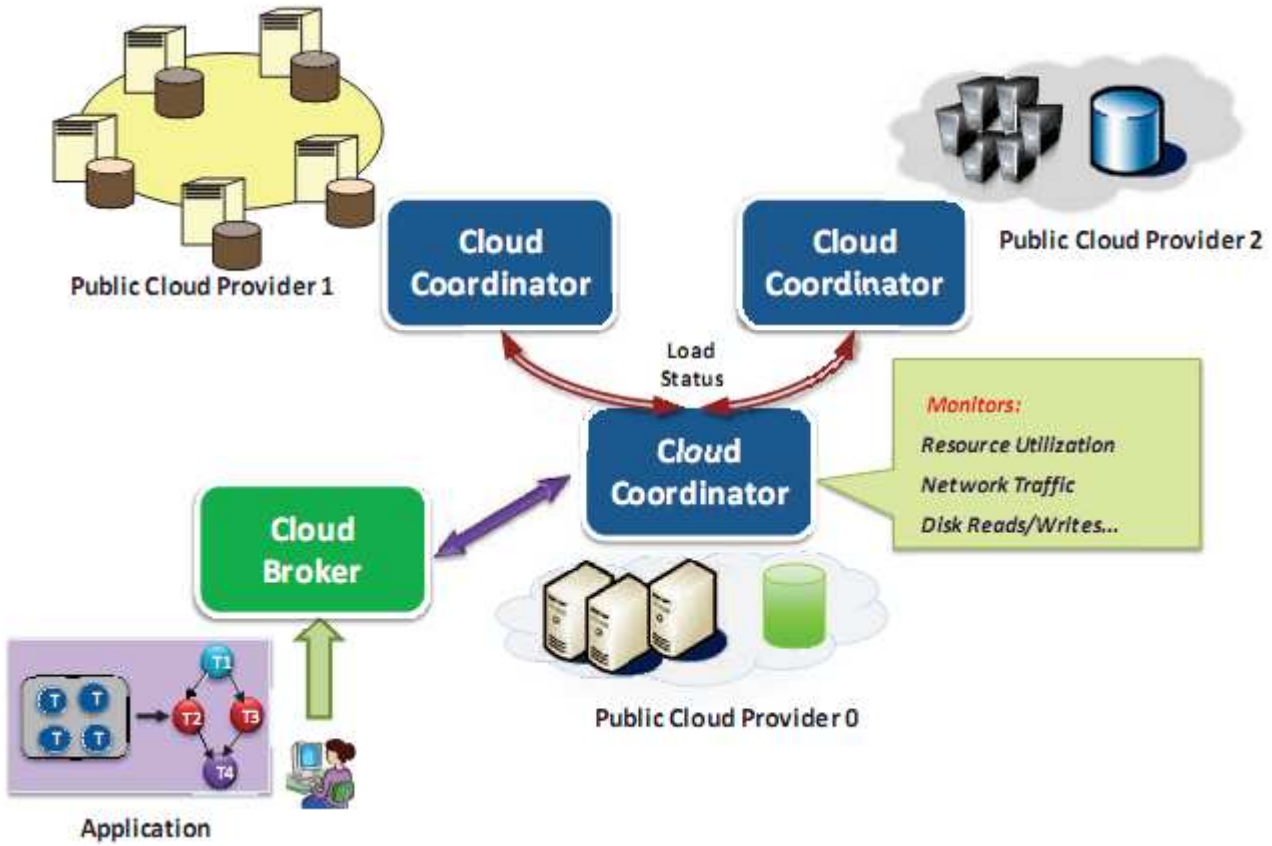
Impacts of the Inter-Cloud?

Flattering of the Internet topology



[Core image adapted from A. Greenberg SIGMETRICS 09 Tutorial]

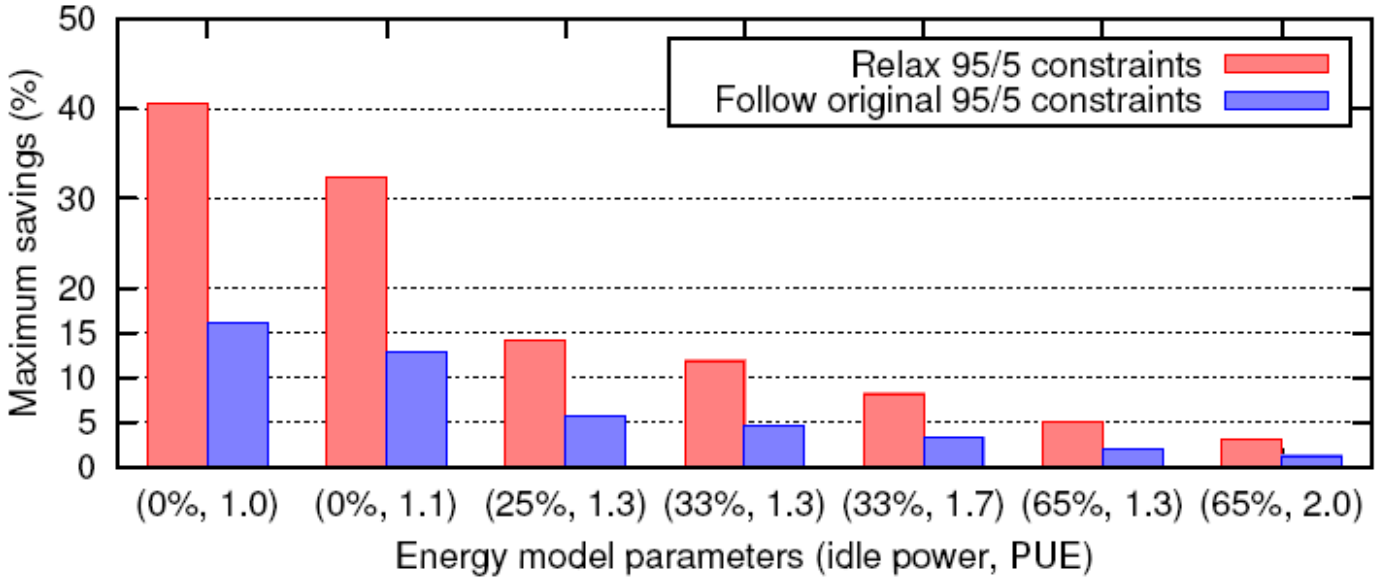
The role of Cloud brokers



Cost-Aware Internet Routing

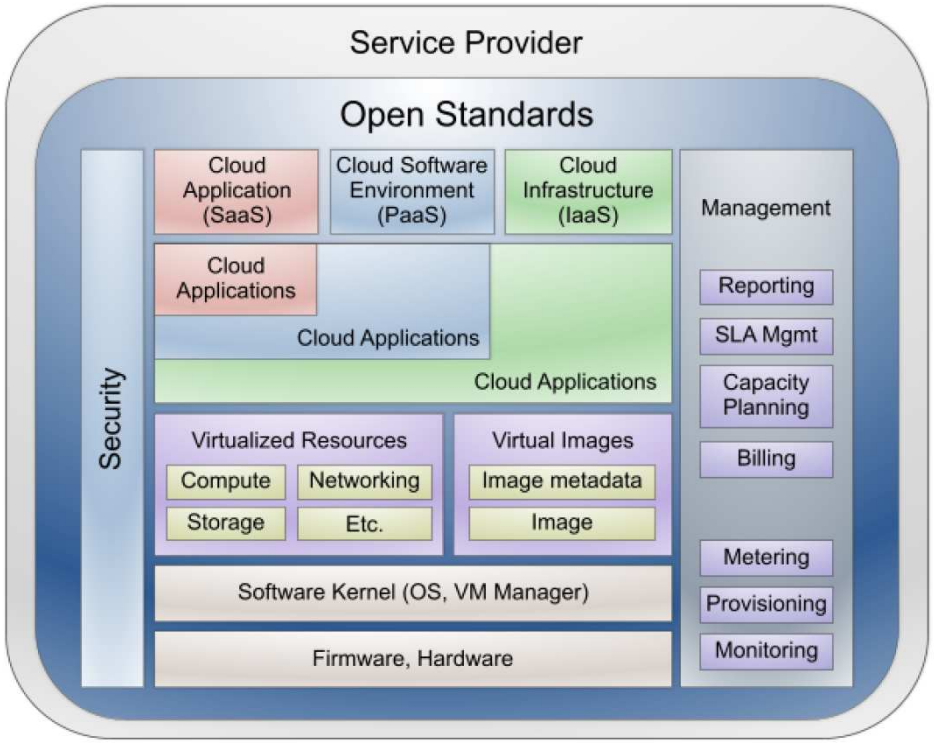
40% savings of a cloud computing installation's power usage by dynamically re-routing service requests to wherever electricity prices are lowest on a particular day, or perhaps even where the data center is cooler.

From "Follow the energy price! " to "Follow the wind, the sun or the moon!"



[Qureshi et al, "Cutting the Electric Bill for Internet-Scale Systems", SIGCOMM´09]

Cloud Standards

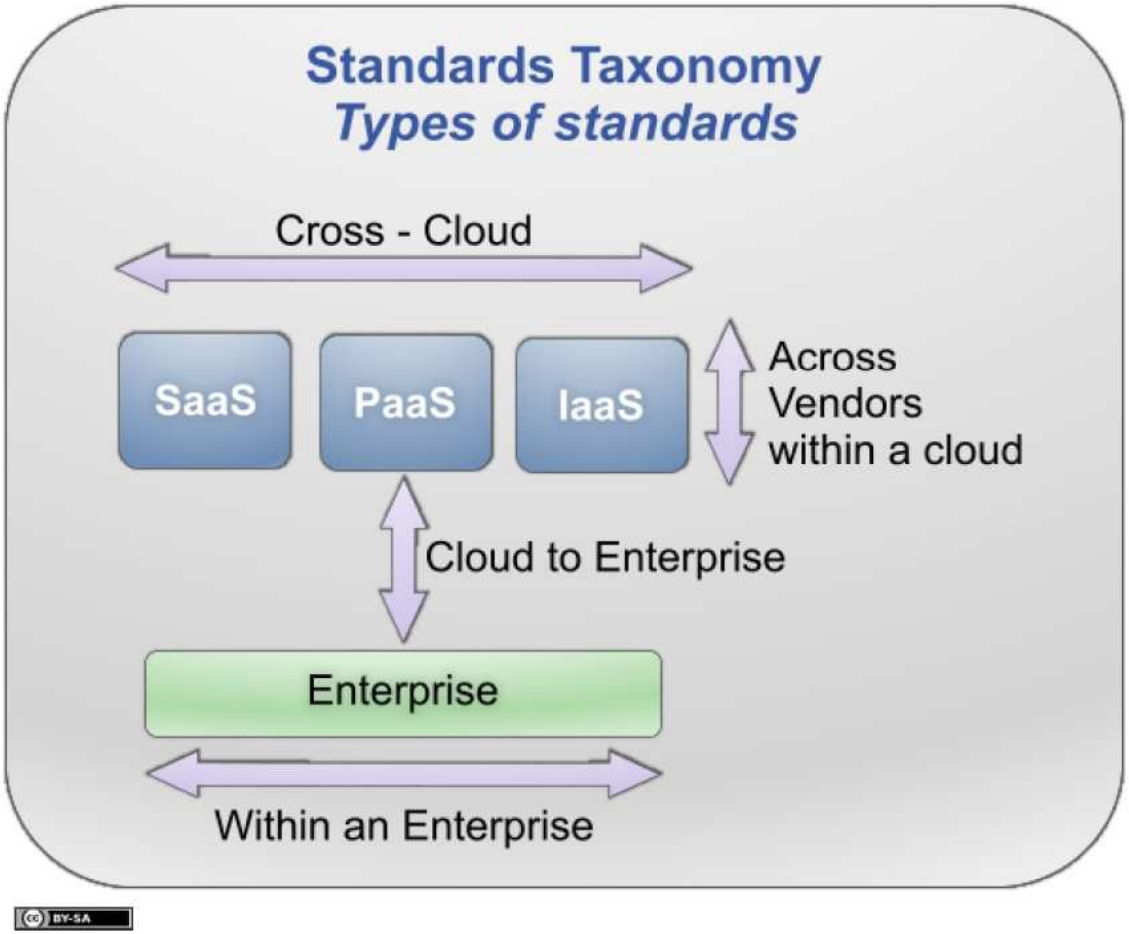


- VM image formats and metadata
- API to storage, DB, etc.
- Naming
- Security
- …

[Source: http://www.opencloudmanifesto.org/Cloud_Computing_Use_Cases_Whitepaper-2_0.pdf]

- Open Source developments (Eucalyptus, Ubuntu Enterprise Cloud) and de facto APIs (e.g., Amazon EC2 and S3)

Cloud Standards



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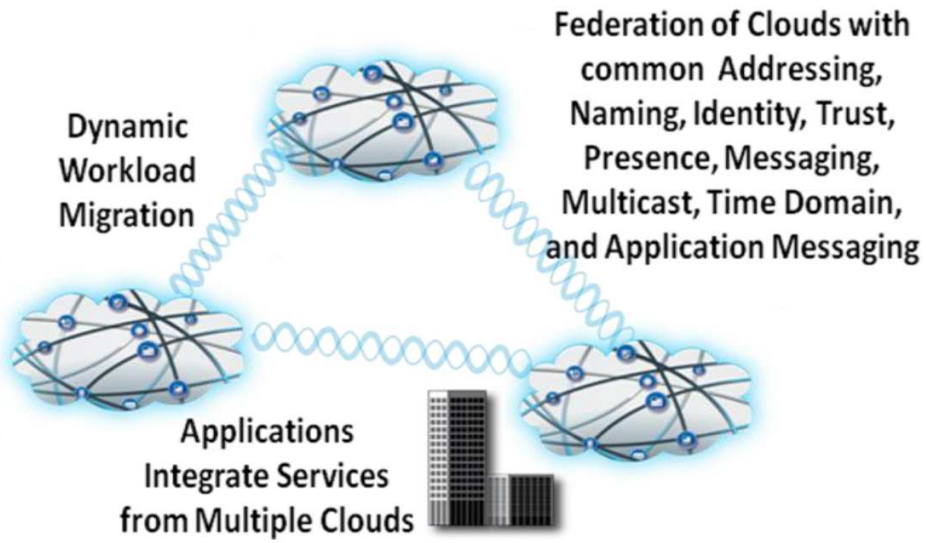
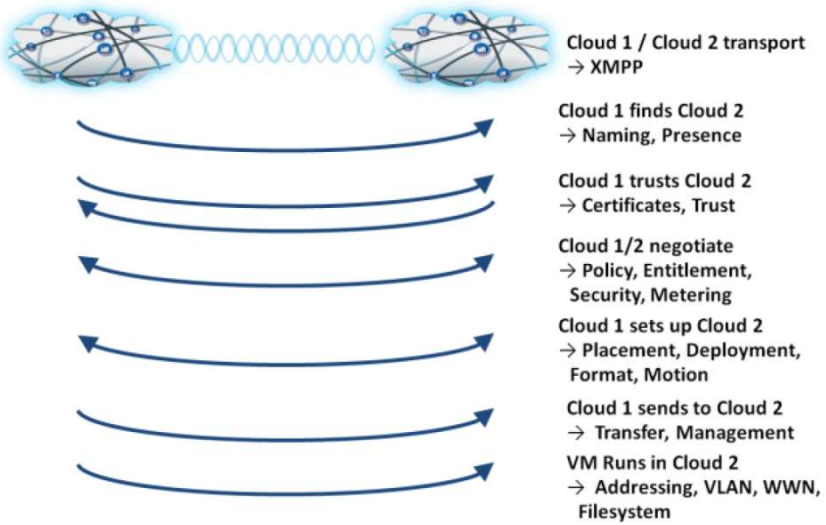
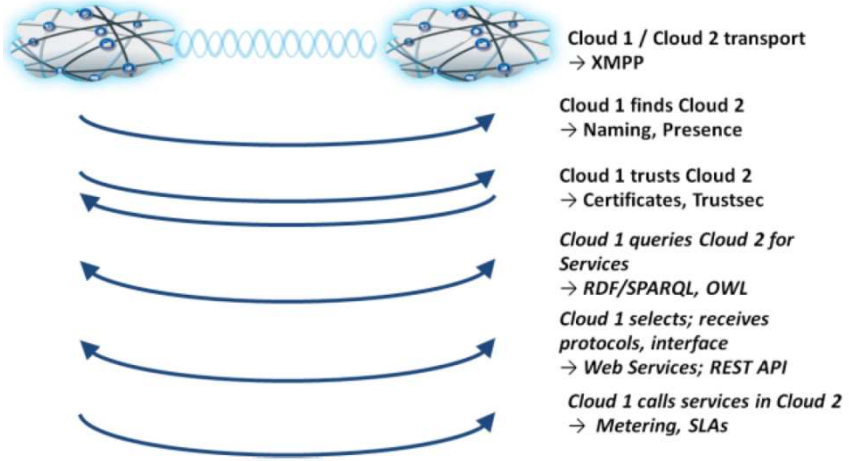
Inter-Cloud



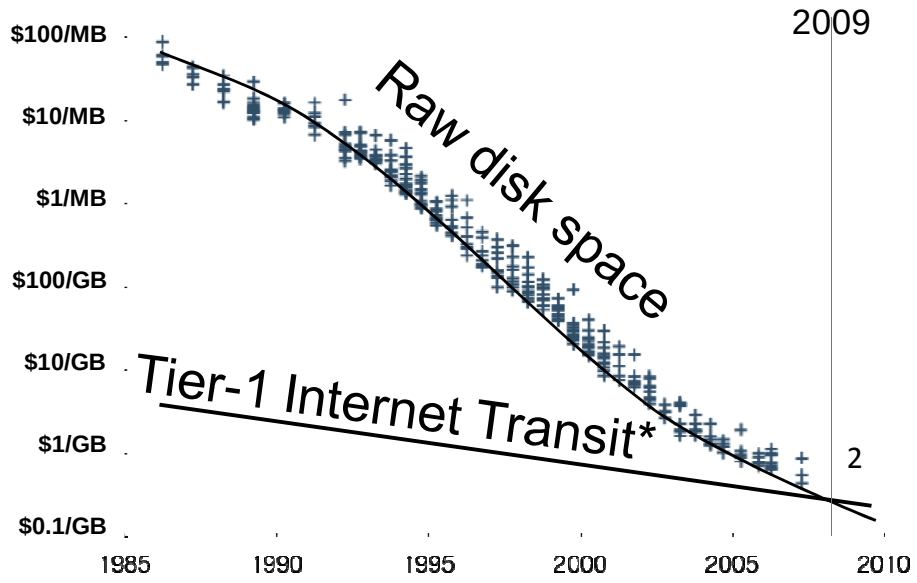


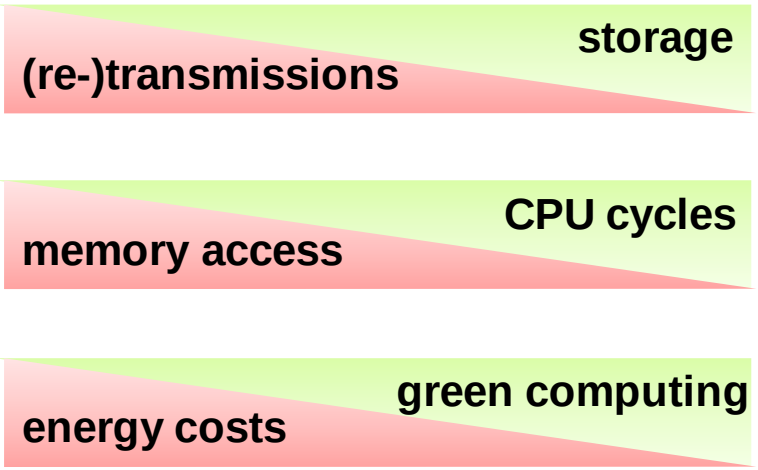


Bernstein *et al.* "Blueprint for the Intercloud - Protocols and Formats for Cloud Computing Interoperability,"

Network economics & Future Internet

- **Data Centers are like Factories[1]**
  - Number 1 Goal: Maximize useful work per dollar spent
- **And the future network of networks?**
  - Incentives for re-architeturing the Internet? DC-driven incentives???
- **Think like an economist/industrial engineer as well as a computer scientist**
  - Understand where the dollar costs come from
  - Use computer science to reduce/eliminate the costs / complexity





[1] cf. Greenberg SIGMETRICS tutorial