the gridbus project

THE UNIVERSITY OF MELBOURNE

Market-Oriented Cloud Computing:
A Vision, Hype, and Reality of Delivering Computing as the 5th Utility

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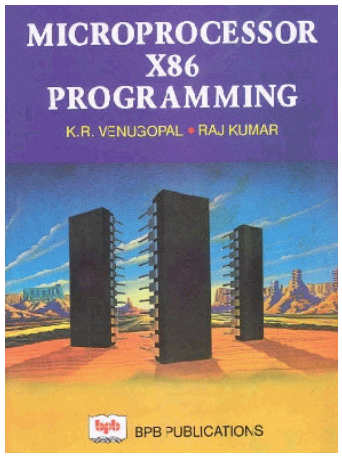
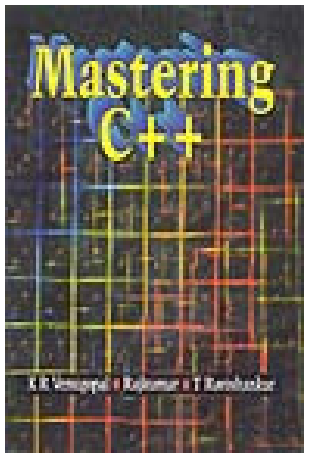
IEEE Medal for Excellence in Scalable Computing: Acknowledgements

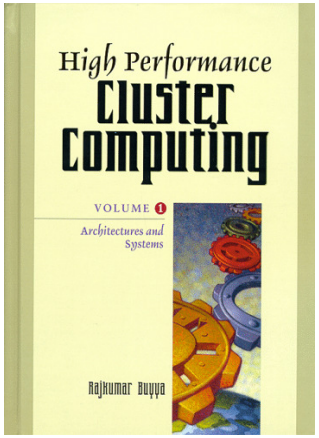
- GRIDS Lab and Ecosystem
  - Team
  - Sponsors
  - Collaborators
- International Community & Friends
  - IEEE Computer Society/Technical Committee on Scalable Computing (TCSC)
  - Colleagues who worked with me in many initiatives:
    - TFCC, TCSC and its events (e.g., CCGrid) and attendees
    - Edited Books
    - Offered access to their computing resources (clusters & supercomputers)
    - Nominated me for IEEE Medal and offered endorsements

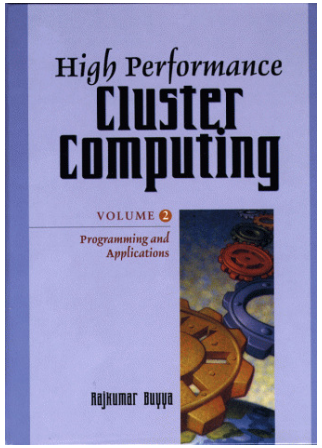
(1) team and collaborators: a glimpse

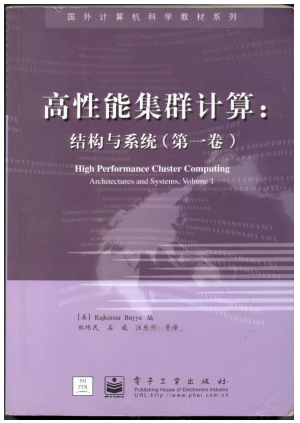
(2) Co-authors/editors

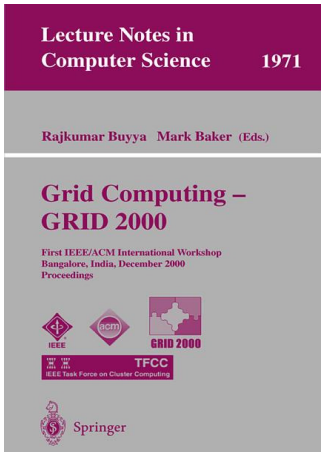


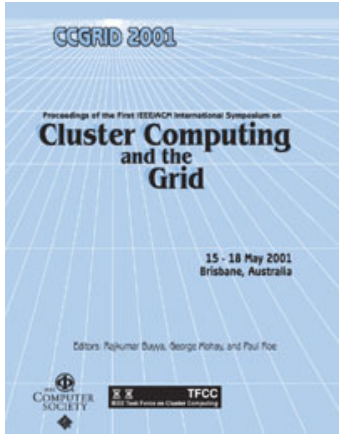


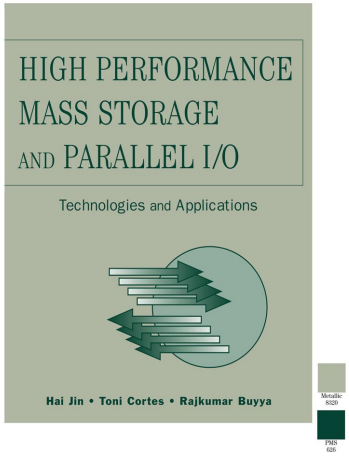


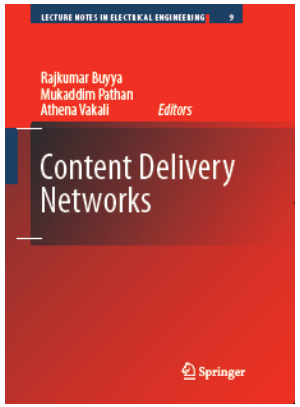


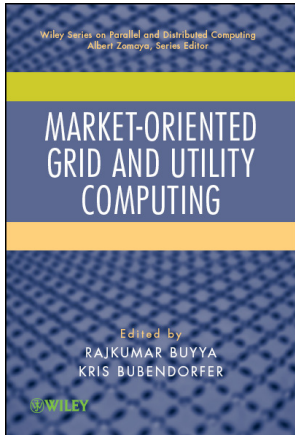












(3) Family

My wife Smrithi and our new born baby (Radha)

(first daughter Soumya)

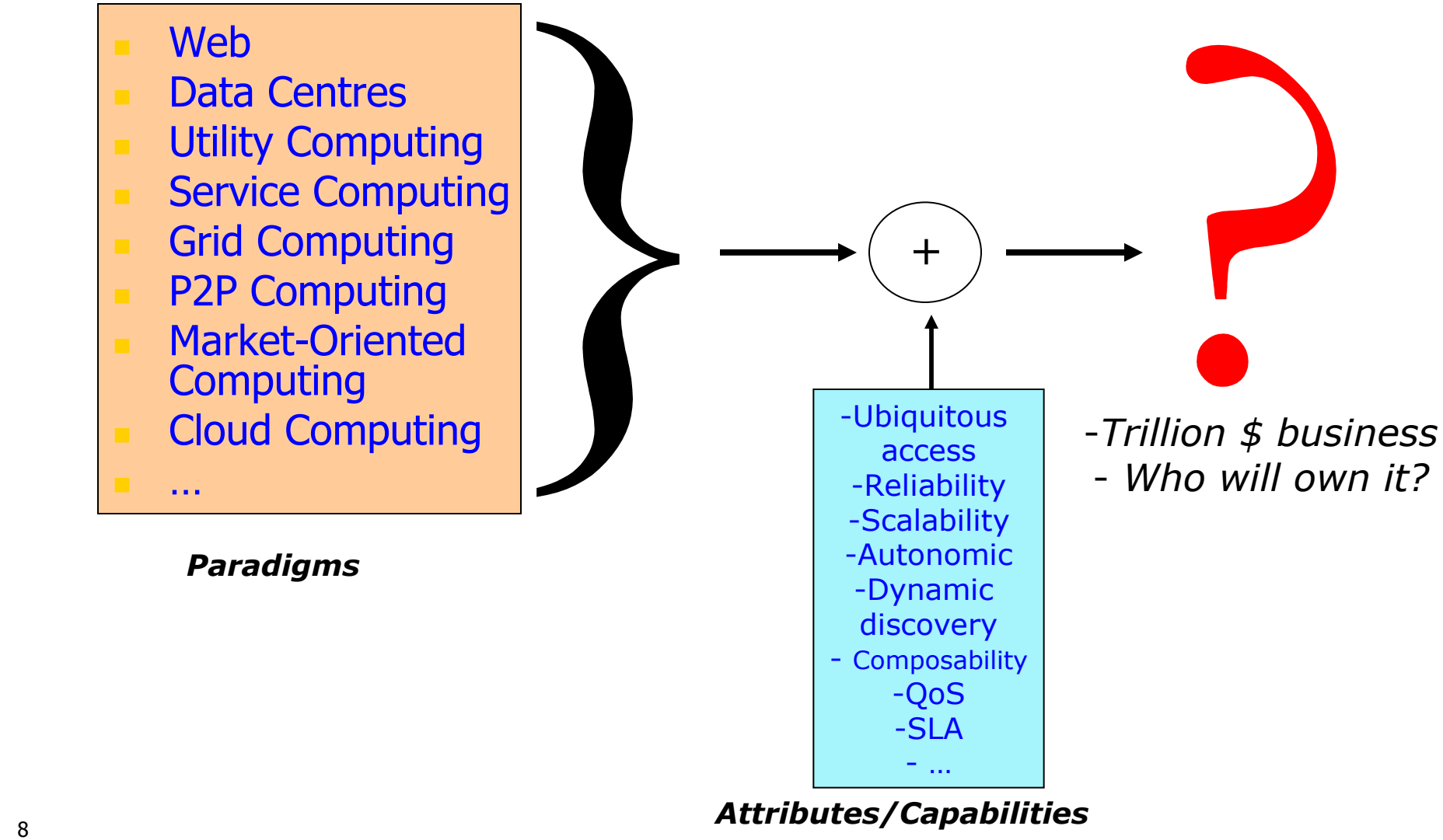
Outline

- "Computer Utilities"
  - Vision and Promising IT Paradigms/Platforms
- Cloud Computing and Related Paradigms
  - Trends, Definition, Cloud Benefits and Challenges
- Market-Oriented Cloud Architecture
  - SLA-oriented Resource Allocation
  - Global Cloud Exchange
- Emerging Cloud Platforms
- Megha: Melbourne Cloud Computing Initiative
- Summary and Thoughts for Future

"Computer Utilities" Vision: Implications of the Internet

- 1969 – Leonard Kleinrock, ARPANET project
  - "As of now, computer networks are still in their infancy, but as they grow up and become sophisticated, we will probably see the spread of 'computer utilities', which, like present electric and telephone utilities, will service individual homes and offices across the country"
- Computers Redefined
  - 1984 – John Gage, Sun Microsystems
    - "The network is the computer"
  - 2008 – David Patterson, U. C. Berkeley
    - "The data center is the computer. There are dramatic differences between of developing software for millions to use as a service versus distributing software for millions to run their PCs"
  - 2008 – "Cloud is the computer" – Buyya!

Computing Paradigms and Attributes: Realizing the 'Computer Utilities' Vision



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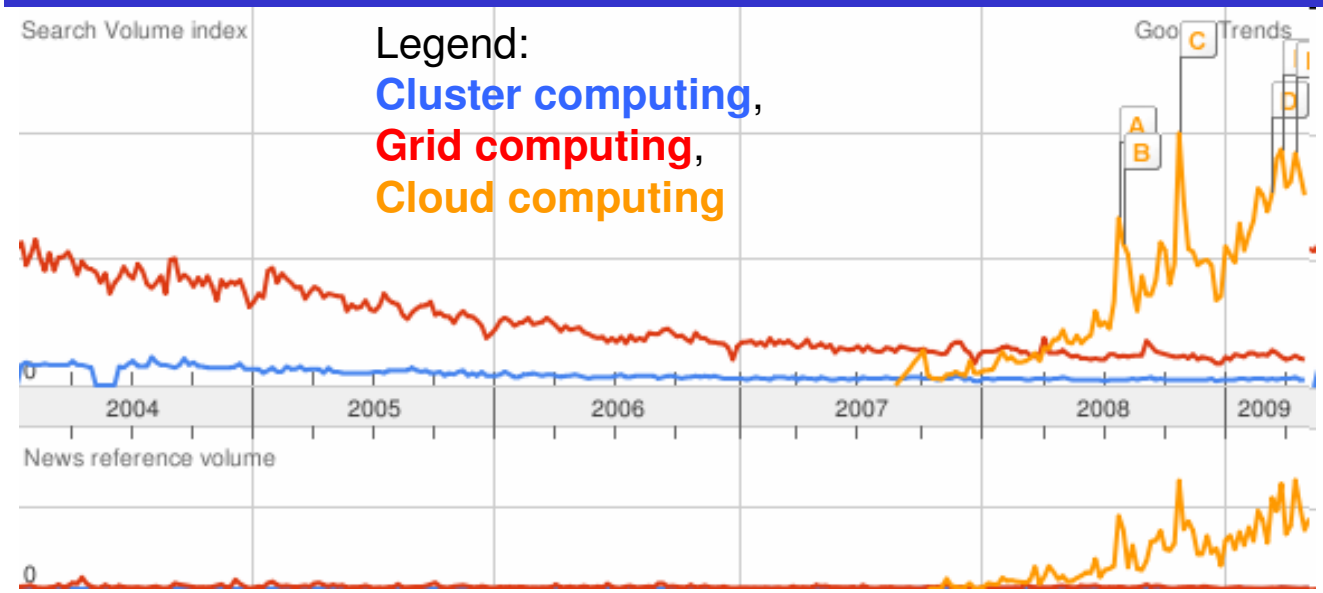
Web Search Trends & Hot News Items (ref: Google)



A Yahoo in 'cloud computing' research with HP-Intel
WA today - Jul 29 2008

B How Cloud Computing Is Changing The World
KMBC.com - Aug 4 2008

C Infrastructure Cloud Computing
SYS-CON Media - Oct 28 2008

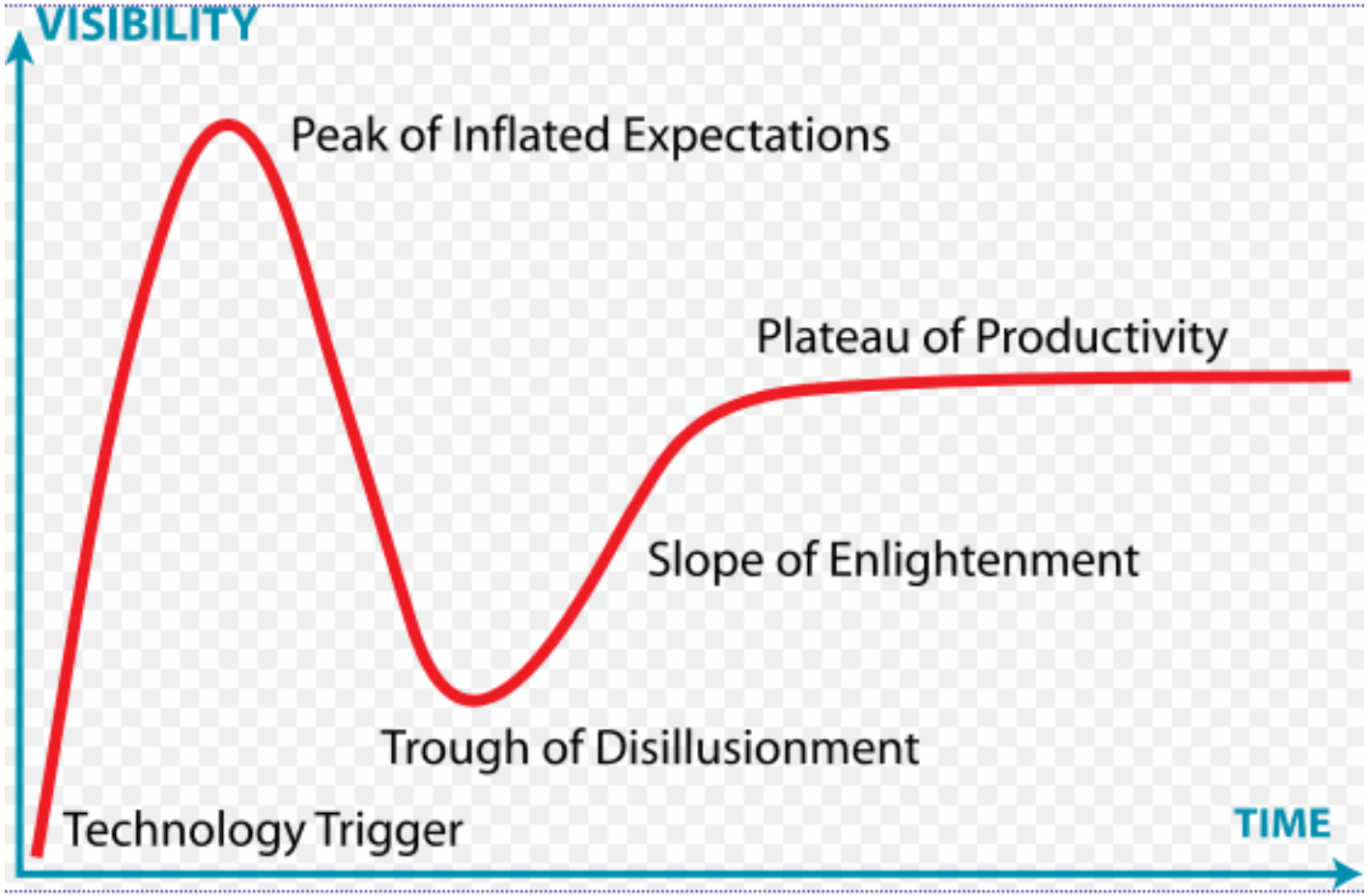
D Sun Shines on Cloud Computing
Sci-Tech Today - Mar 18 2009

E 3Leaf Addresses Cloud Computing and On Deman Cloud Computing Expo
SYS-CON Media - Mar 30 2009

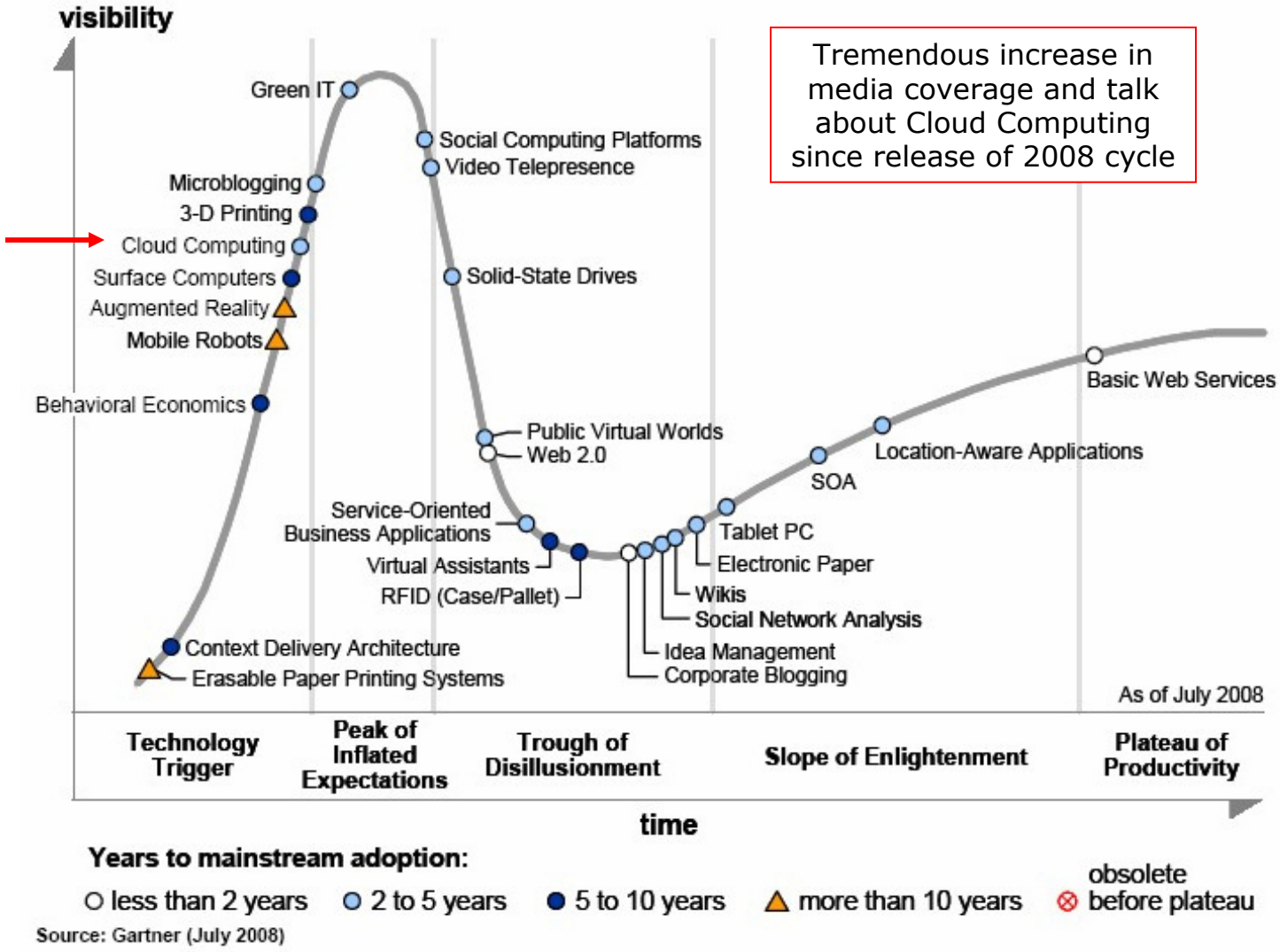
F Cisco Offering Cloud Computing Security
eWeek - Apr 21 2009

Regions	Cities	Languages
1. India	1. Bangalore, India	1. Korean
2. South Korea	2. Santa Clara, CA, USA	2. English
3. Singapore	3. San Jose, CA, USA	3. Dutch
4. Hong Kong	4. Chennai, India	4. Swedish
5. Taiwan	5. Seoul, South Korea	5. German
6. United States	6. Mumbai, India	6. Chinese
7. Ireland	7. San Francisco, CA, USA	7. Portuguese
8. Australia	8. Pleasanton, CA, USA	8. Italian
9. Canada	9. Singapore, Singapore	9. French
10. United Kingdom	10. Austin, TX, USA	10. Japanese

Where are we (Cloud Computing) in Gartner IT Hype Cycle ?



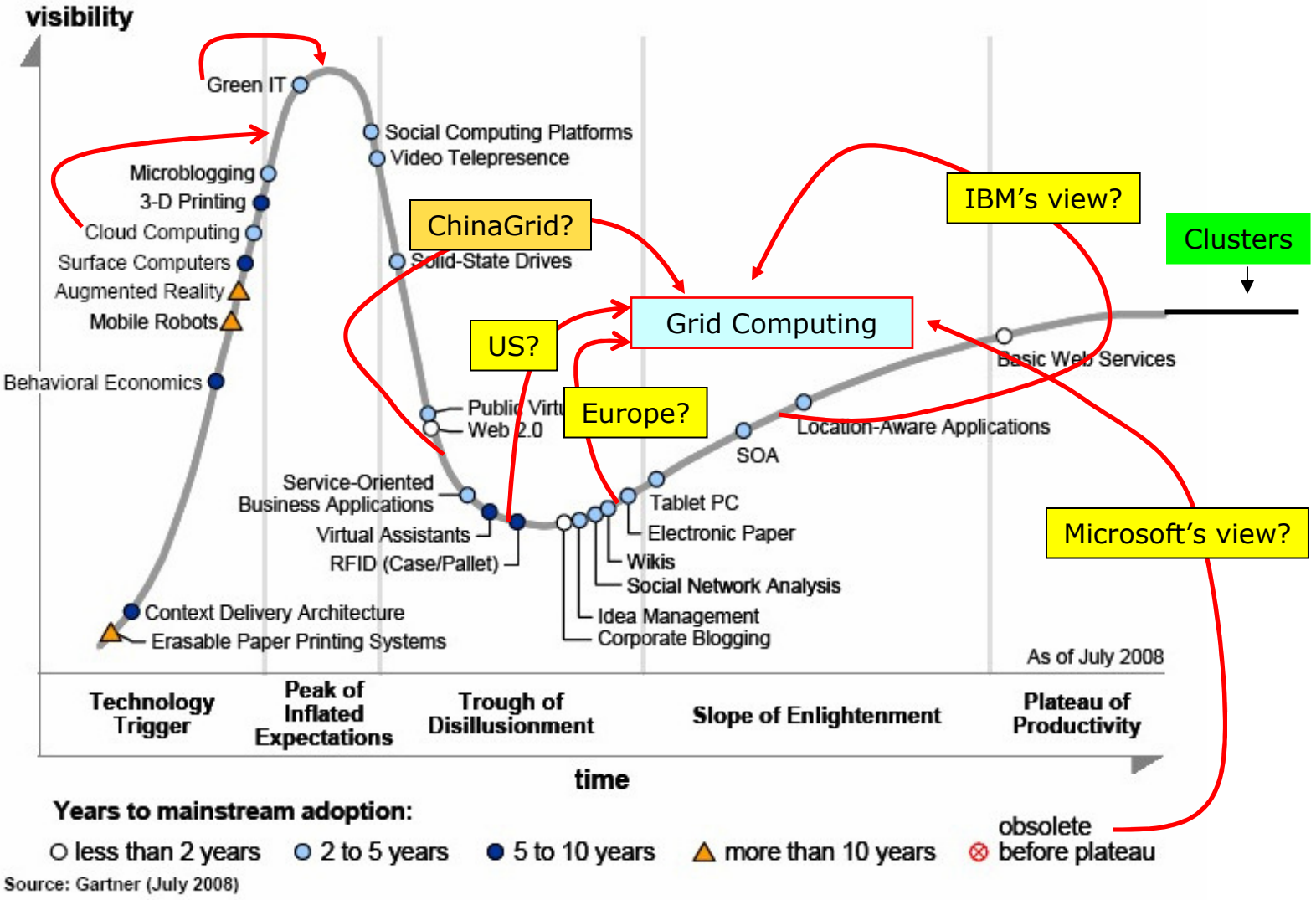
2008 Gartner IT Hype Cycle of Emerging Technologies



Tremendous increase in media coverage and talk about Cloud Computing since release of 2008 cycle

Source: Gartner (July 2008)

2009 Hype Cycle and where are Clusters and Grids ? Buyya's View!

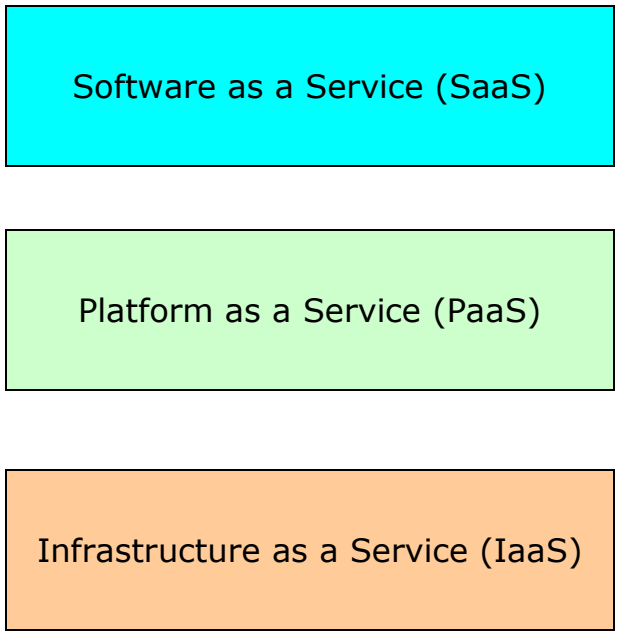


Defining Clouds: There are many views for what is cloud computing?

- Over 20 definitions:
  - http://cloudcomputing.sys-con.com/read/612375_p.htm
- Buyya's definition☺
  - "A Cloud is a type of parallel and distributed system consisting of a collection of inter-connected and **virtualised** computers that are **dynamically provisioned** and presented as one or more unified computing resources based on **service-level agreements** established through **negotiation** between the service provider and consumers."
- Keywords: Virtualisation (VMs), Dynamic Provisioning (negotiation and SLAs), and Web 2.0 access interface

Cloud Services

- Infrastructure as a Service (IaaS)
  - CPU, Storage: Amazon.com, Nirvanic, GoGrid….
- Platform as a Service (PaaS)
  - Google App Engine, Microsoft Azure, Manjrasoft Aneka..
- Software as a Service (SaaS)
  - SalesForce.Com



Clouds based on Ownership and Exposure

Public/Internet Clouds

3rd party, multi-tenant Cloud infrastructure & services:

*** available on subscription basis (pay as you go)**

Private/Enterprise Clouds

Cloud computing model run within a company's own Data Center / infrastructure for internal and/or partners use.

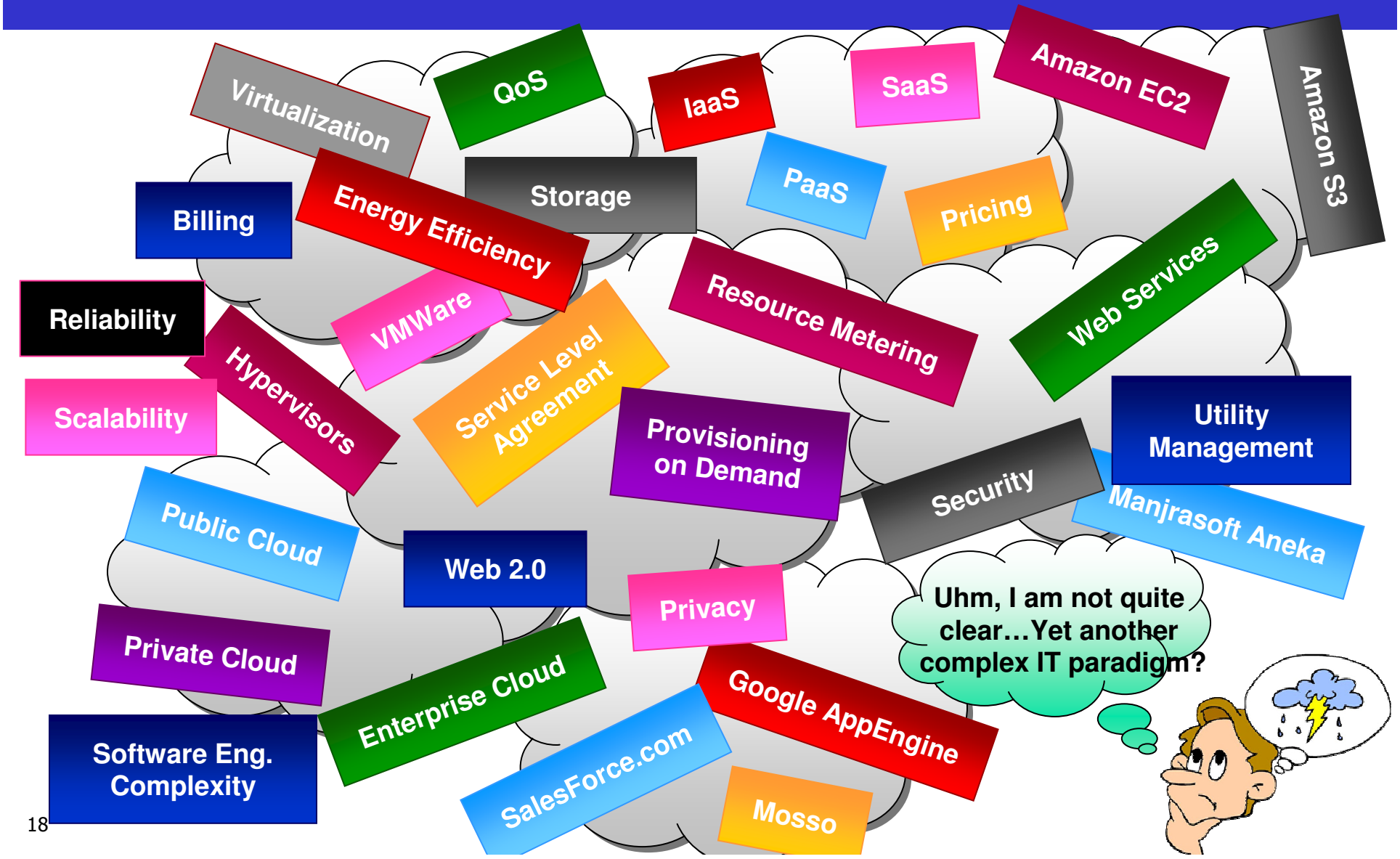
Hybrid/Mixed Clouds

Mixed usage of private and public Clouds: Leasing public cloud services when private cloud capacity is insufficient

Benefits of (Public) Clouds

- No upfront infrastructure investment
  - No procuring hardware, setup, hosting, power, etc..
- On demand access
  - Lease what you need and when you need..
- Efficient Resource Allocation
  - Globally shared infrastructure, can always be kept busy by serving users from different time zones...
- Nice Pricing
  - Based on Usage, QoS, Supply and Demand, Loyalty, …
- Application Acceleration
  - Parallelism for large-scale data analysis, what-if scenarios studies…
- High Availability
- Supports Creation of 3rd Party Services & Seamless offering
  - Builds on infrastructure and follows similar Business model as Cloud

Challeges: Dealing with too many issues and offerings



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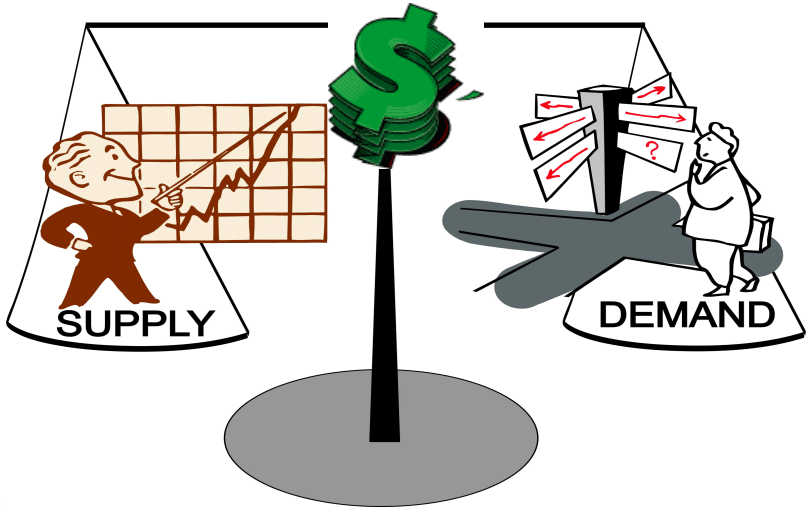
Realizing the 'Computer Utilities' Vision: What Consumers and Providers Want?

- Consumers – minimize expenses, meet QoS
  - How do I express QoS requirements to meet my goals?
  - How do I assign valuation to my applications?
  - How do I discover services and map applications to meet QoS needs?
  - How do I manage multiple providers and get my work done?
  - How do I outperform other competing consumers?
  - …
- Providers – maximise Return On Investment (ROI)
  - How do I decide service pricing models?
  - How do I specify prices?
  - How do I translate prices into resource allocations?
  - How do I assign and enforce resource allocations?
  - How do I advertise and attract consumers?
  - How do I perform accounting and handle payments?
  - …
- Mechanisms, tools, and technologies
  - value expression, translation, and enforcement

Market-based Systems = Self-managed and self-regulated systems.

- Manage
  - Complexity
  - Supply and Demand
- Enhance Utility

1



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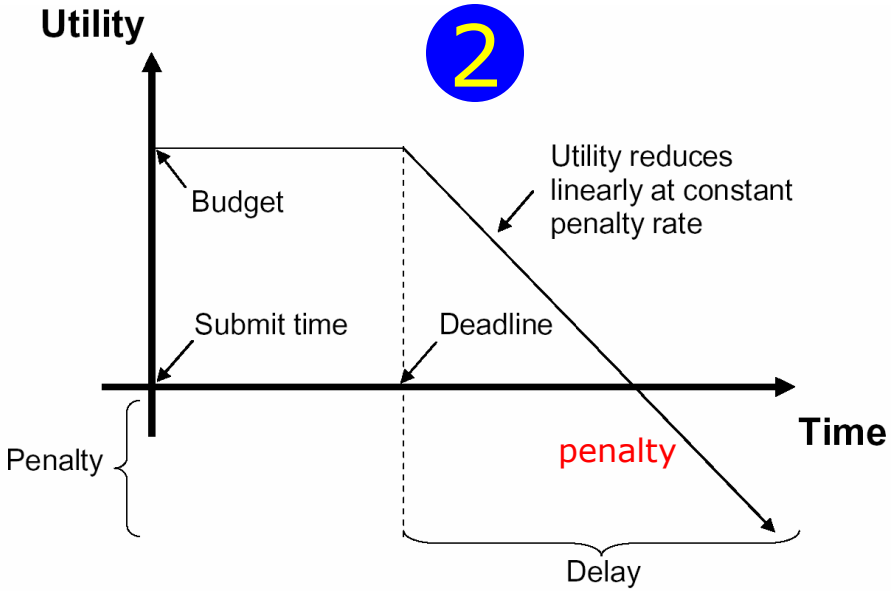


3

(Layered) Cloud Architecture

User level

Cloud applications
Social computing, Enterprise, ISV, Scientific, CDNs, ...

User-Level Middleware

Cloud programming: environments and tools
Web 2.0 Interfaces, Mashups, Concurrent and Distributed Programming, Workflows, Libraries, Scripting

Apps Hosting Platforms

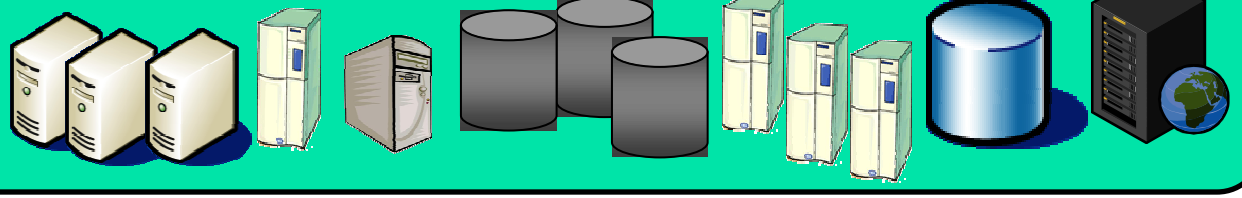
Core Middleware

QoS Negotiation, Admission Control, Pricing, SLA Management, Monitoring, Execution Management, Metering, Accounting, Billing

Virtual Machine (VM), VM Management and Deployment

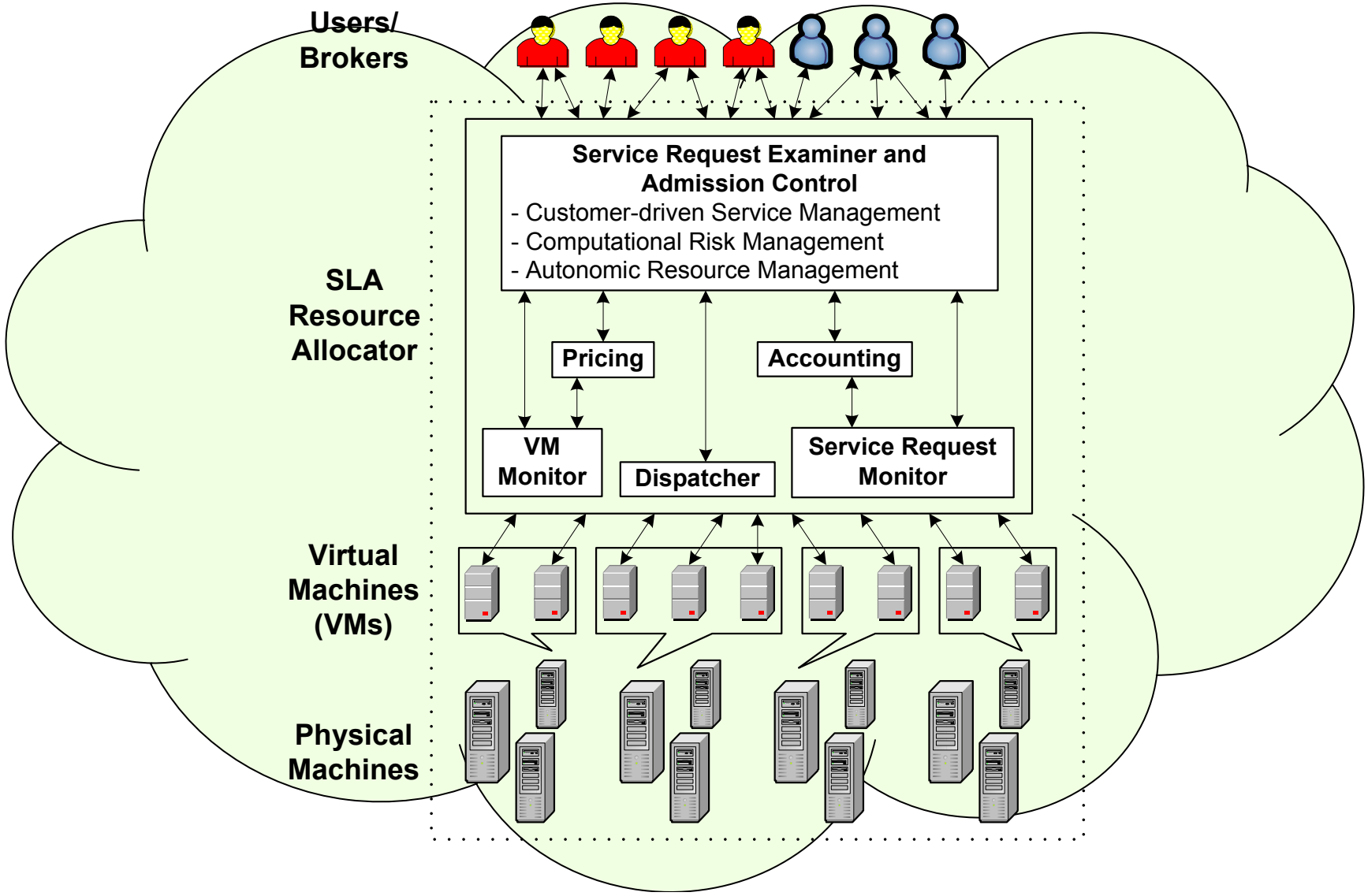
System level

Cloud resources

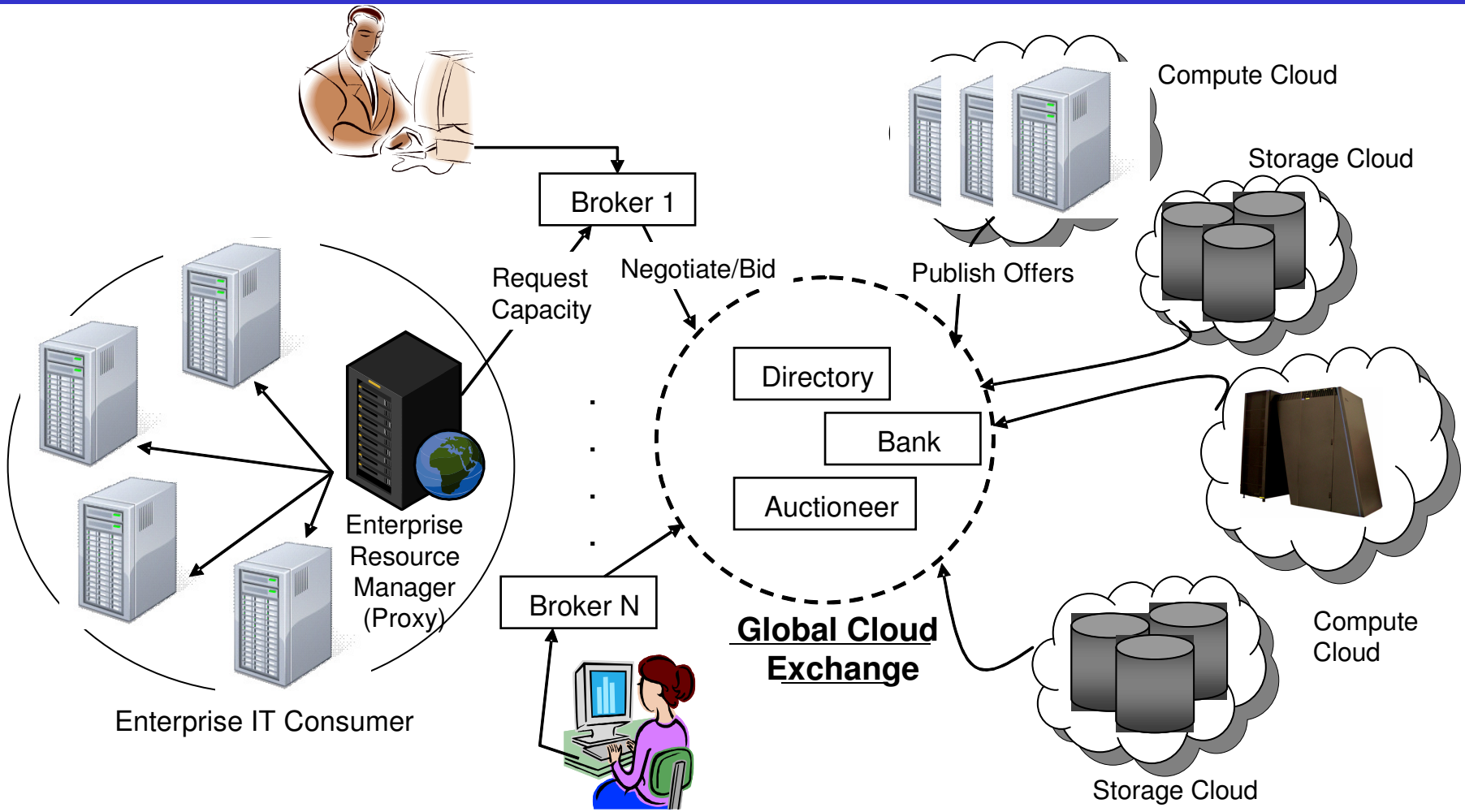


Autonomic / Cloud Economy
Adaptive Management

Market-oriented Cloud Architecture: QoS negotiation and SLA-based Resource Allocation



InterCloud: Global Cloud Exchange and Market Maker



Outline

- 21st Century Vision of Computing
  - Promising Computing Paradigms
- Cloud Computing and Related Paradigms
  - Trends, Definition, Characteristics, Architecture
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Some Commercial-Oriented Cloud platforms/technologies

System Property	Amazon Elastic Compute Cloud (EC2)	Google App Engine	Microsoft Azure	Sun Network.com (Sun Grid)	Manjrasoft Aneka
Focus	IaaS	IaaS/PaaS	IaaS/PaaS	IaaS	PaaS
Service Type	Compute, Storage (Amazon S3)	Web application	Web and non-web application	Compute	Compute
Virtualisation	OS Level running on a Xen hypervisor	Application container	OS level through Fabric controller	Job management system (Sun Grid Engine)	Resource Manager and Scheduler
Dynamic Negotiation of QoS Parameters	None	None	None	None	SLA-based Resource Reservation
User Access Interface	Amazon EC2 Command-line Tools	Web-based Administration Console	Windows Azure portal	Job submission scripts, Sun Grid Web portal	Workbench, Web-based portal
Web APIs	Yes	Yes	Yes	Yes	Yes
Value-added Service Providers	Yes	No	Yes	Yes	No
Programming Framework	Customizable Linux-based Amazon Machine Image (AMI)	Python	.NET framework	Solaris OS, Java, C, C++, FORTRAN	APIs supporting different programming models in C# and other .Net supported languages

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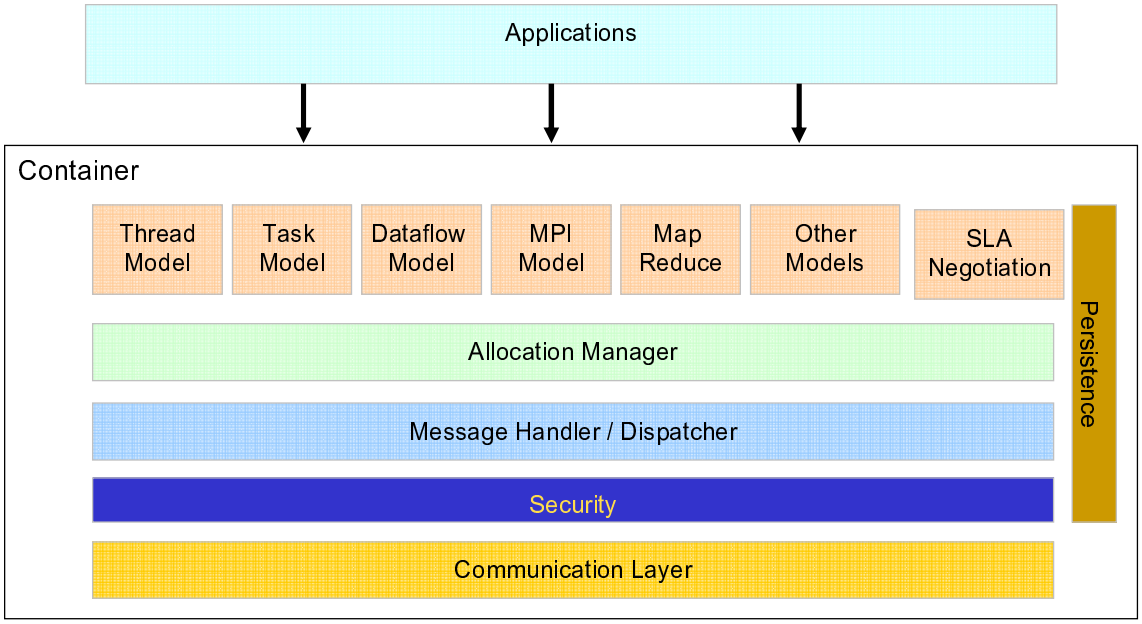
GRIDS Lab's Cloud Computing Initiatives

- Aneka – .NET-based Cloud Computing
  - PaaS for Enterprise and Public Clouds
- Market-Oriented Clouds
  - SLA-based Resource Management
  - Global Cloud Exchange Elements: Brokers
- 3rd Party Cloud Services (MetaCDN) – Harnessing Storage resources
  - Building Content Delivery Networks using different "vendors" Storage Clouds
- Scaling Across Clouds (Meta Brokering) – Harnessing Compute resources
  - Extending our existing Market Oriented Grid computing ideas…
  - Federation of clouds for application scaling across distributed resources
- CloudSim: Toolkit for Simulation of Clouds
  - Design and evaluation for resource management policies & algorithms
- Green Clouds / Data Centers
  - Energy Efficiency and QoS Oriented Resource Allocation

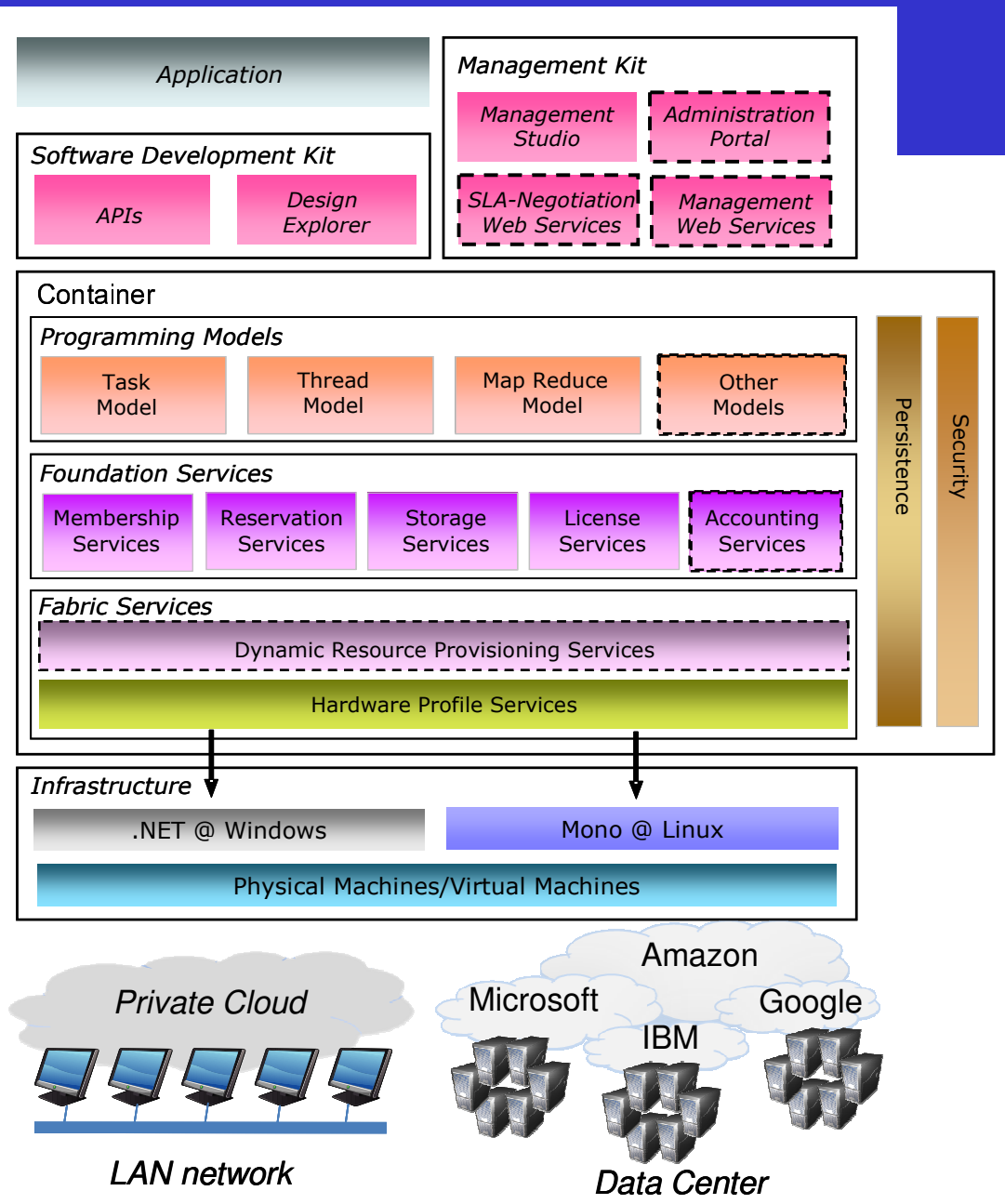
Aneka – Product Overview

- .NET based service-oriented platform for Cloud computing
- **SDK** containing APIs for multiple programming models and tools
- **Runtime** Environment for managing application execution management
- Suitable for
  - Development of Enterprise Cloud Applications
  - Cloud enabling legacy applications
- Ideal for Corporate Developers, ISVs, Hosting Vendors and Application / System Integrators

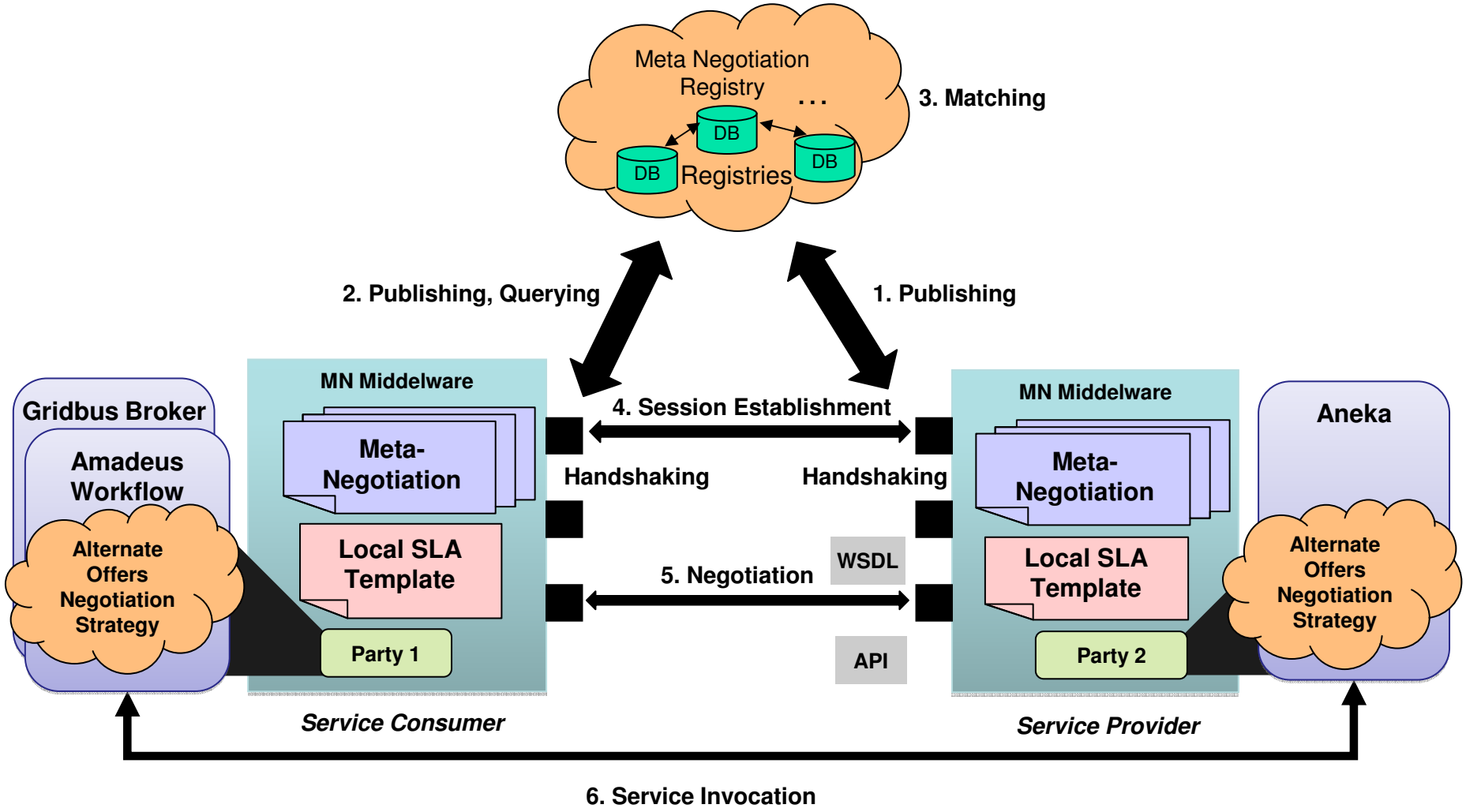


ANEKA Product Architecture

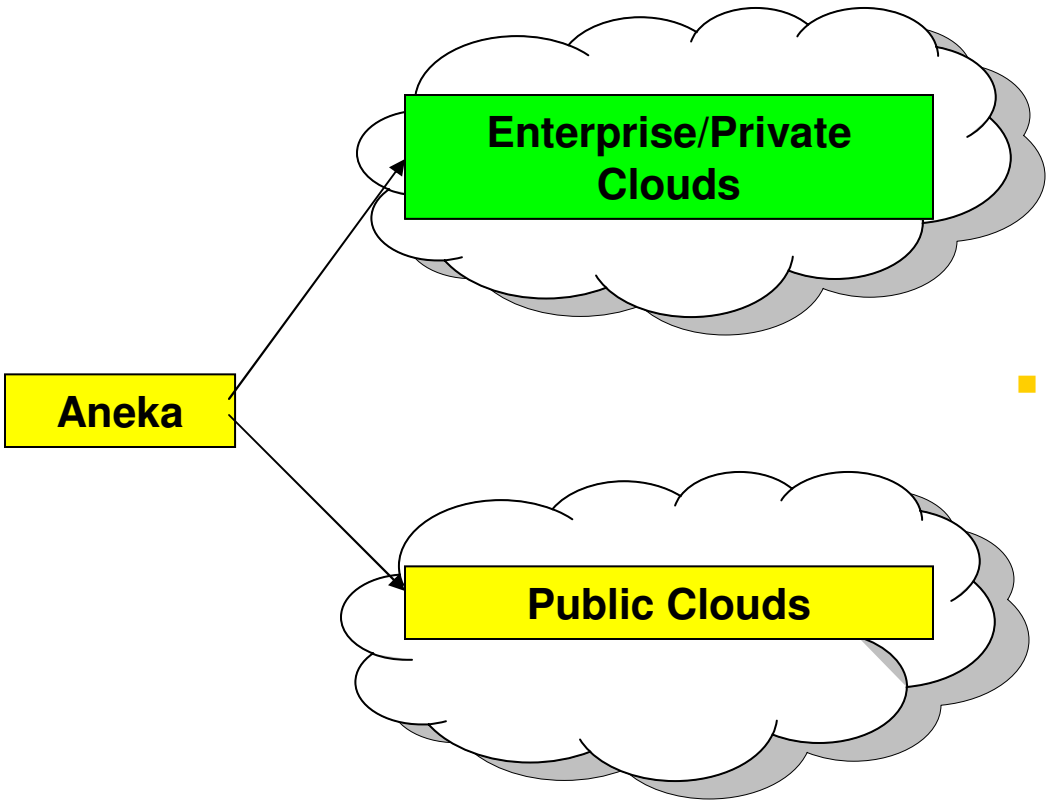
Aneka Engineering Architecture



QoS Negotiation in Aneka



Aneka Deployment Models

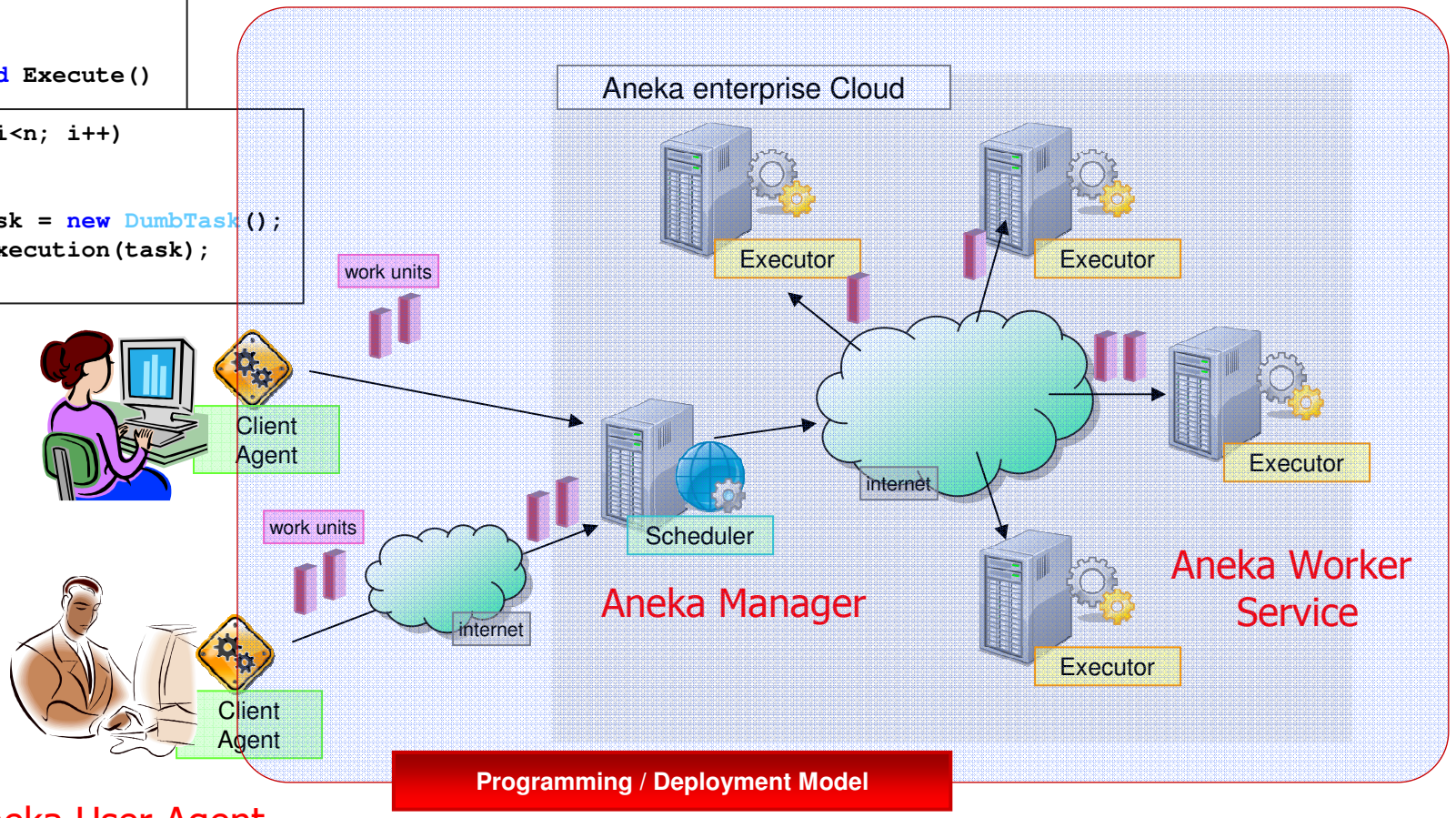


- Enterprise/Private
  - Harness LAN connected resources
  - Application Development, Testing, Execution
  - Teaching and Learning
  - Sensitive applications
- Public
  - Hosted by a 3rd party service provider owning a large Data Center (1000s of servers)
  - Offers subscription-based services to their **shared** infrastructure on “pay-as go” model.to many users from **different organisations**.
  - Amazon.com, Microsoft Azure
  - **Aneka** SDK + Execution Manger

Aneka: components

```
public DumbTask: ITask
{
  …
  public void Execute()
  {
```

```
for(int i=0; i<n; i++)
{
  …
  DumbTask task = new DumbTask();
  app.SubmitExecution(task);
}
```

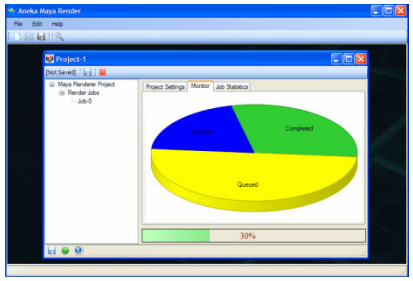


Aneka User Agent

User scenario: GoFront (unit of China Southern Railway Group)

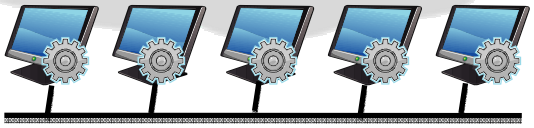
Application: Locomotive design CAD rendering

Aneka Maya Renderer

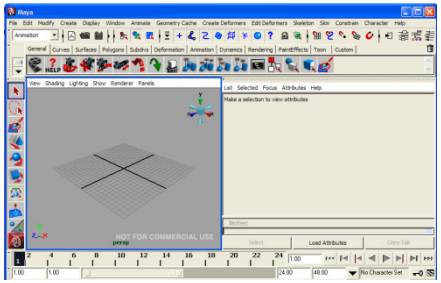


Use private Aneka Cloud

GoFront Private Aneka Cloud



LAN network
(Running Maya Batch Mode on demand)



Raw Locomotive Design Files
(Using AutoDesk Maya)

Case 2: Aneka Enterprise Cloud

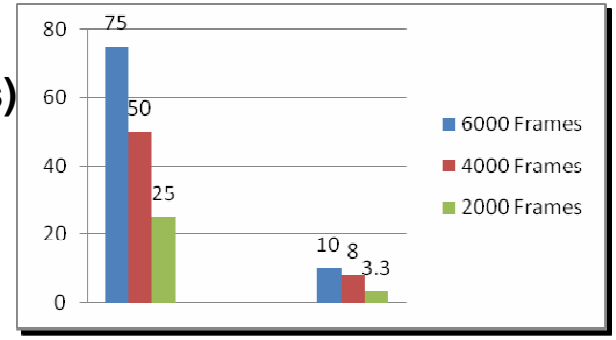
Manjrasoft

Case 1: Single Server

Using Maya Graphical Mode Directly

4 cores server

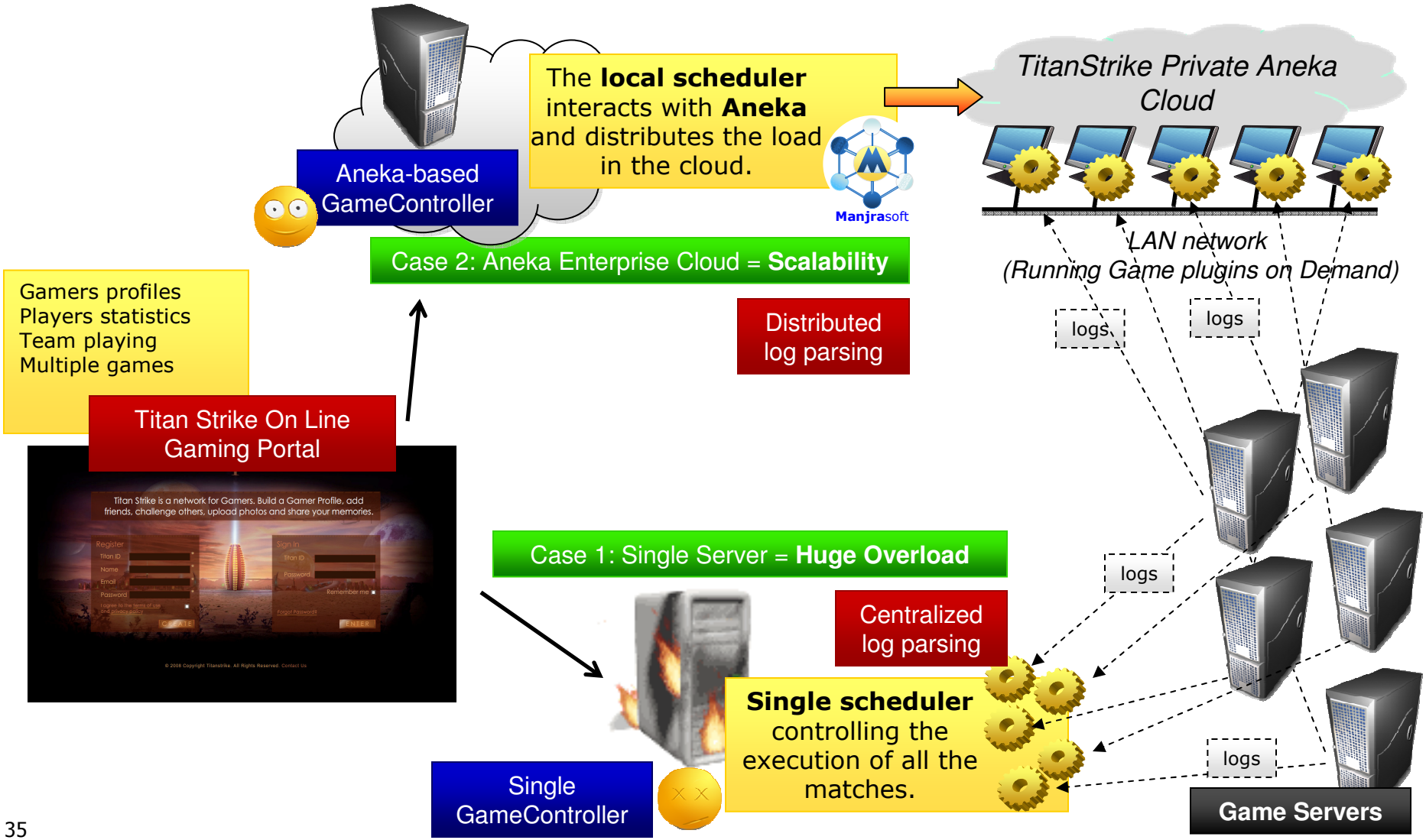
Time (in hrs)



Single Server **Aneka Cloud**

Aneka utilizes idle desktops (**30**) to decrease task time from days to **hours**

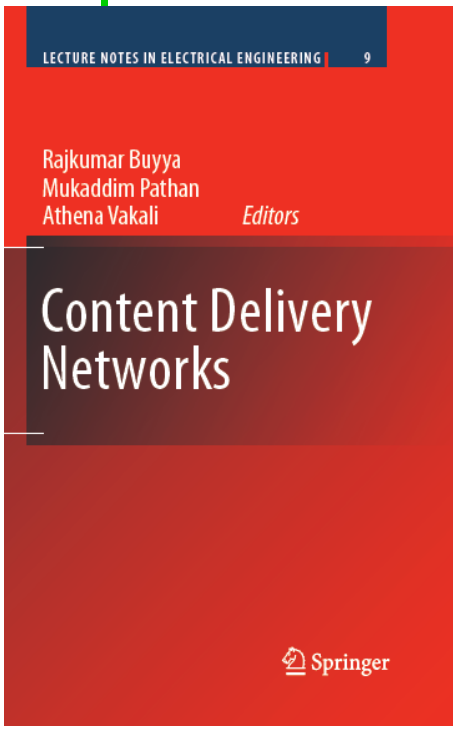
Providing a scalable architecture for TitanStrike on-line Gaming Portal



Aneka on Public Cloud (Amazon)

- **Application Demonstration:**
  - **Microarray Gene Expression Data Analysis for Cancer Diagnosis**
  - SCALE 2009 (Scalable Computing Challenge) Demos:
    - **Wednesday: 20 May 2009**
    - **14.00-16.00 (Room 1)**
- Play with Aneka:
  - Build your own Private Cloud:
    - Download Aneka: http://www.manjraosoft.com
  - Use it as a Platform for running apps on Amazon

Building 3rd Party Cloud Services – Harnessing Storage Clouds



Building Next-Gen "Content Delivery Networks"

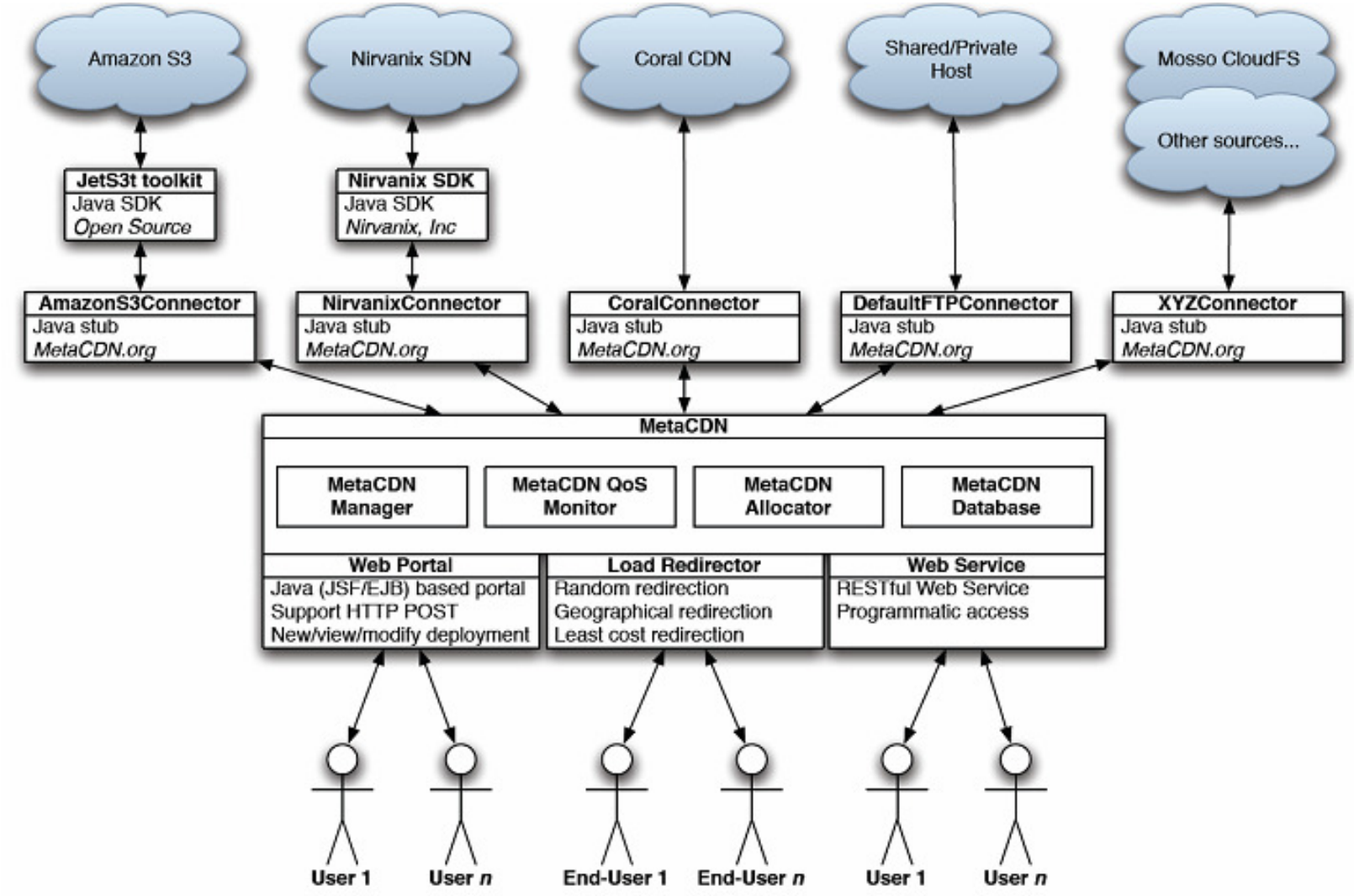
Motivations

- Content Delivery Networks (CDNs) such as Akamai place web server clusters in numerous geographical locations – ”huge upfront investment”
  - to improve the responsiveness and locality of the content it hosts for end-users.
- However, their services are priced out of reach for all but the largest enterprise customers.
- Hence, we have developed an alternative approach to content delivery by leveraging infrastructure ‘Storage Cloud’ providers at a fraction of the cost of traditional CDN providers – “pay as you go”

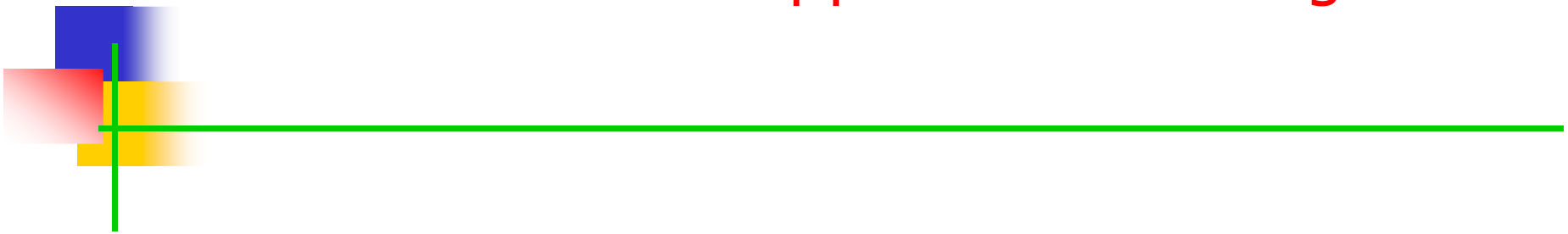
Commercial Storage Clouds & Pricing

Feature \ Provider	Nirvanix US/EU	Nirvanix SDN	Amazon S3 US	Amazon S3 EU	Mosso CloudFS
Incoming Data ($/GB/month)	0.18	0.18	0.10	0.10	Unkn
Outgoing data ($/GB/month)	0.18	0.18	0.17	0.17	Unknown
Storage ($/GB/month)	0.18	0.25	0.15	0.18	0.15
Requests ($/1,000 PUT)	0.00	0.00	0.01	0.01	Unknown
Requests ($/1,000 GET)	0.00	0.00	0.01	0.01	Unknown
SLA	99.9	99.9	99-99.9	99-99.9	Unknown
Max. File Size	256GB	256GB	5GB	5GB	5GB
US PoP	Yes	Yes	Yes	N/A	Yes
EU PoP	Yes	Yes	N/A	Yes	No
Asia PoP	No	Yes	No	No	No
Australasia PoP	No	No	No	No	No
Automatic Replication	Yes	No	Yes	No	No
Developer API	Yes	Yes	Yes	Yes	Yes

MetaCDN: Harnessing Storage Clouds for Content Delivery (Broberg, Buyya, Tari, JNCA 2009)

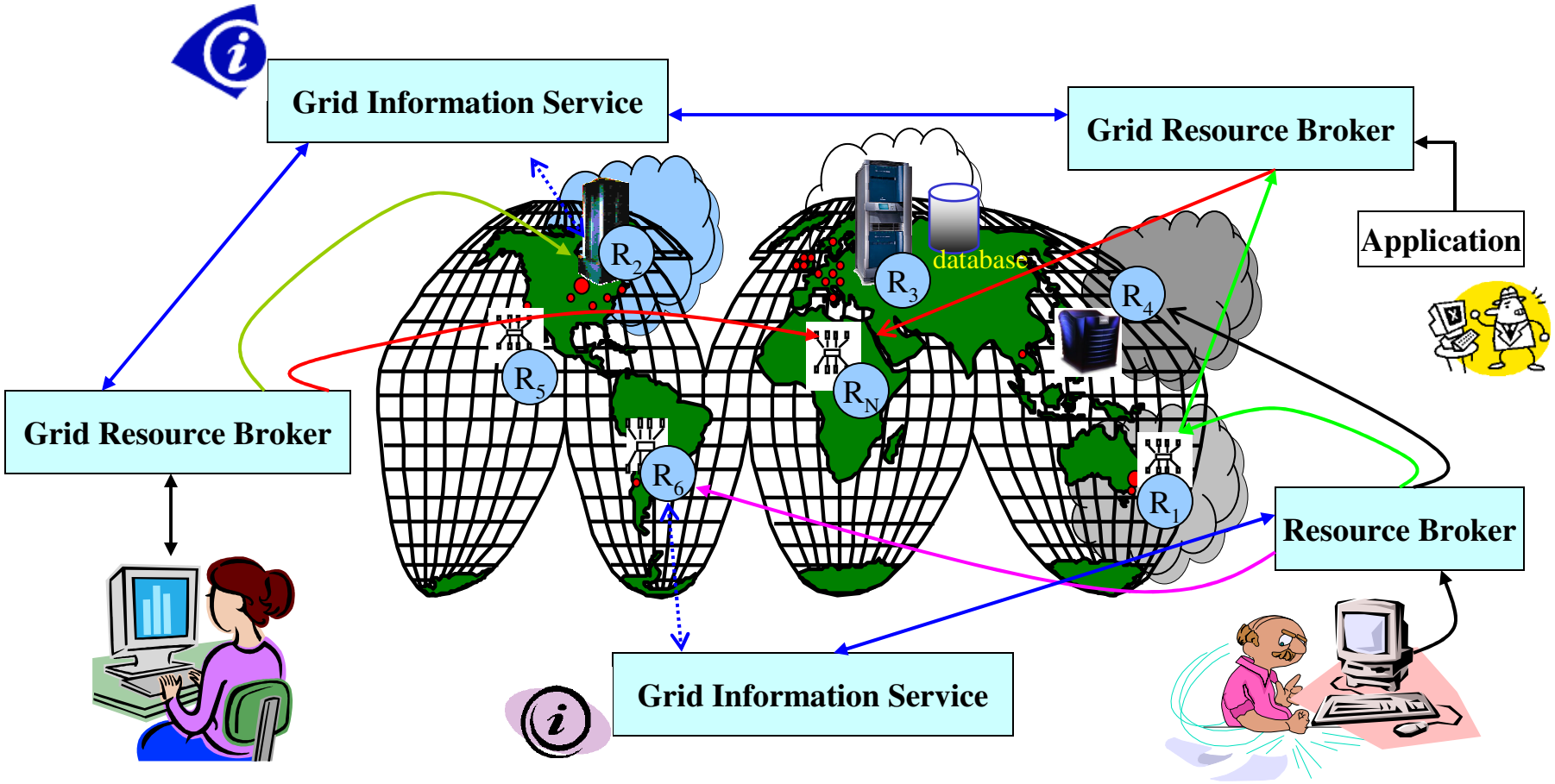


Meta Brokering – Harnessing Compute Clouds for Application Scaling



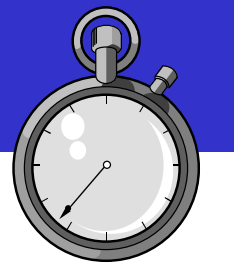
Extending market-oriented Grid Ideas with Cloud computing

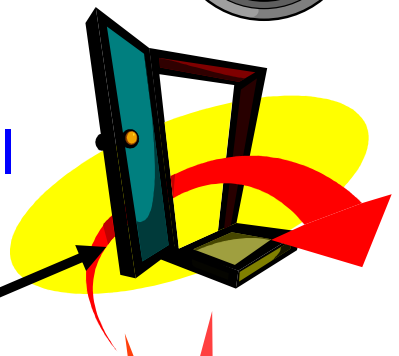
Building a Grid of Clouds → Global Utility Computing

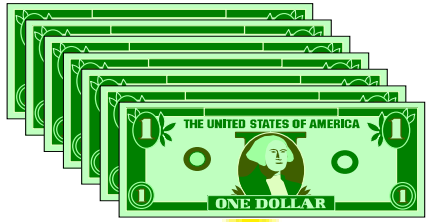


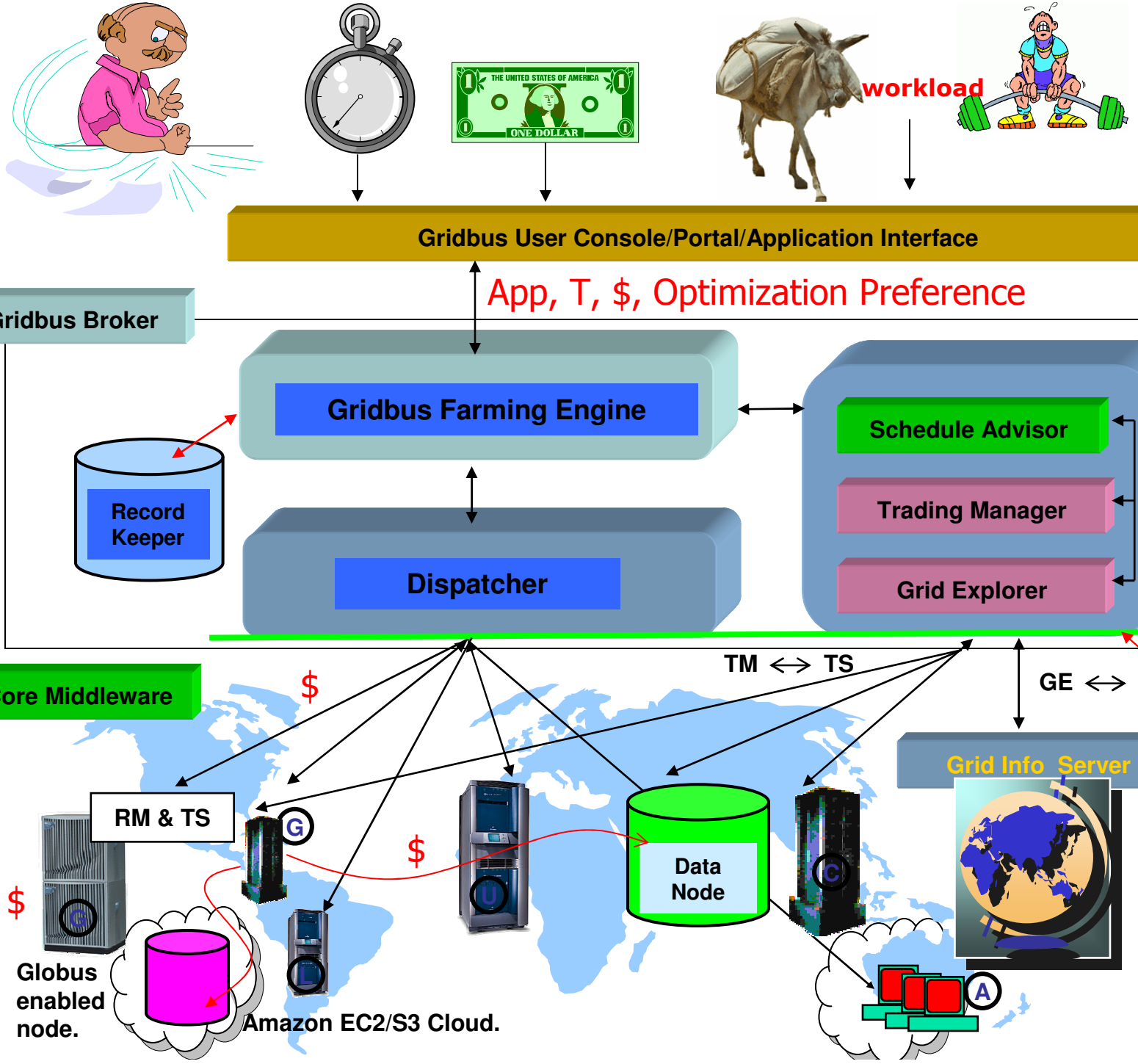
Gridbus Service Broker (GSB)

- A resource broker for scheduling task farming data-intensive applications with static or dynamic parameter sweeps on global Grids and Clouds.
- It uses computational economy paradigm for optimal selection of computational and data services depending on their quality, cost, and availability, and users' QoS requirements (deadline, budget, & T/C optimisation)
- Key Features
  - A single window to manage & control experiment
  - Programmable Task Farming Engine
  - Resource Discovery and Resource Trading
  - Optimal Data Source Discovery
  - Scheduling & Predications
  - Generic Dispatcher & Grid Agents
  - Transportation of data & sharing of results
  - Accounting

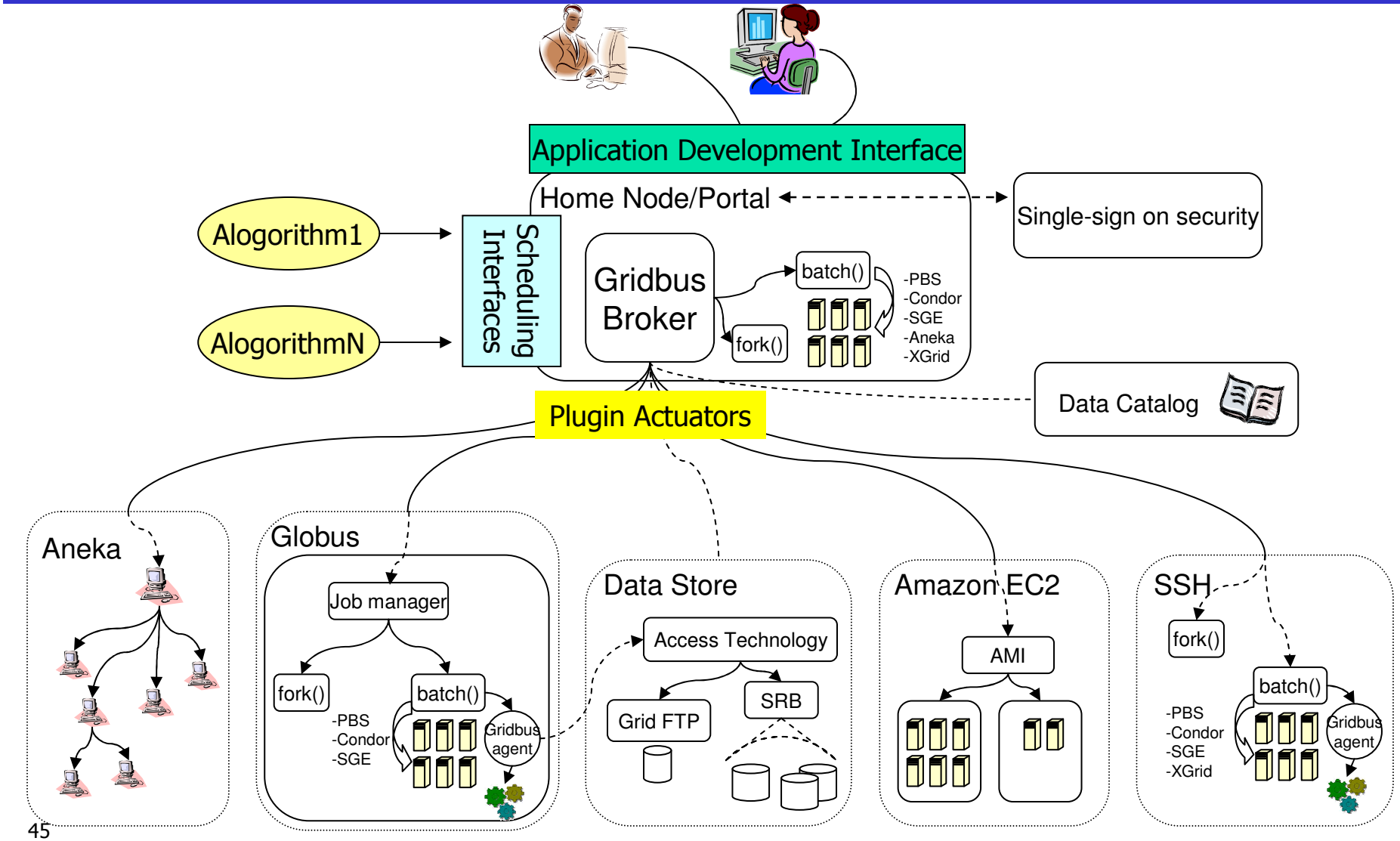







workload
Gridbus User Console/Portal/Application Interface
App, T, $, Optimization Preference
Gridbus Broker
Gridbus Farming Engine
Record Keeper
Dispatcher
Schedule Advisor
Trading Manager
Grid Explorer
TM ↔ TS
GE ↔ GIS, NWS
Core Middleware
Grid Info Server
RM & TS
Data Node
Data Catalog
Globus enabled node.
Amazon EC2/S3 Cloud.

Gridbus Broker: Separating "applications" from "different" remote service access enablers and schedulers



THE UNIVERSITY OF MELBOURNE

the gridbus project

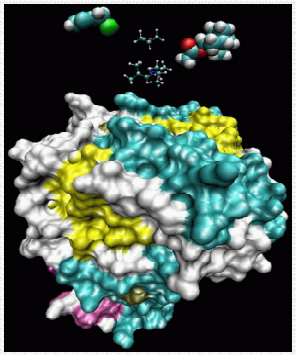
http://www.gridbus.org

Australian Government
Australian Research Council

A Sample List of Gridbus Broker Users

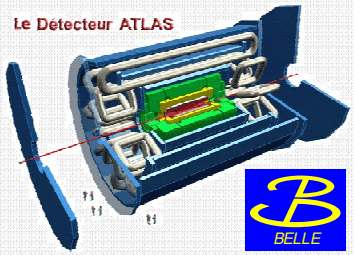
Molecular docking for drug design on Australian National Grid

FIAT·LUX QUT apac



High Energy Physics: Particle Discovery

CERN

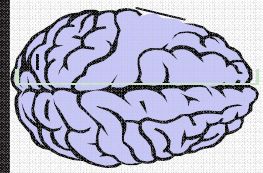


BELLE

ATLAS

School of Physics
Melbourne University

NeuroScience: Brain Activity Analysis



HOWARD FLOREY INSTITUTE

EU Data Mining Grid

DaimlerChrysler
Mercedes-Benz
CHRYSLER

DATAMINING grid

DaimlerChrysler,
Technion, U. Ljubljana,
U. Ulster

Kidney/Human Physiome Modelling

EuroPhysiome

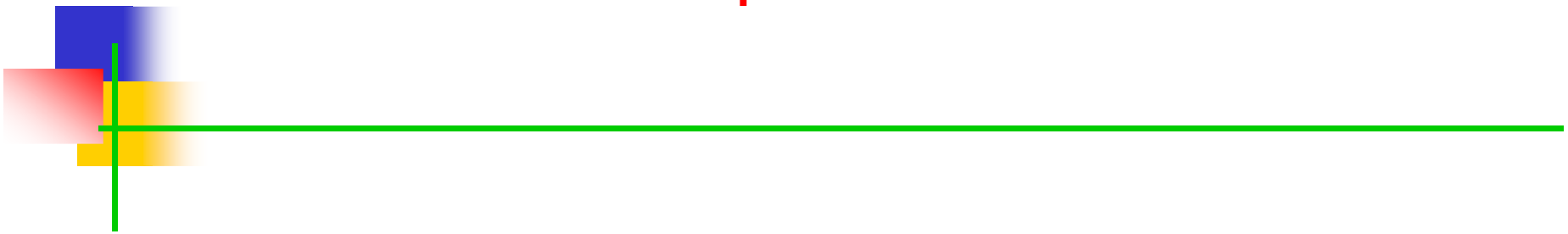
UNIVERSITÉ D'EVRY VAL D'ESSONNE

Melbourne Medical Faculty,
Université d'Evry, France

Finance /Investment Risk Studies: Spanish Stock Market

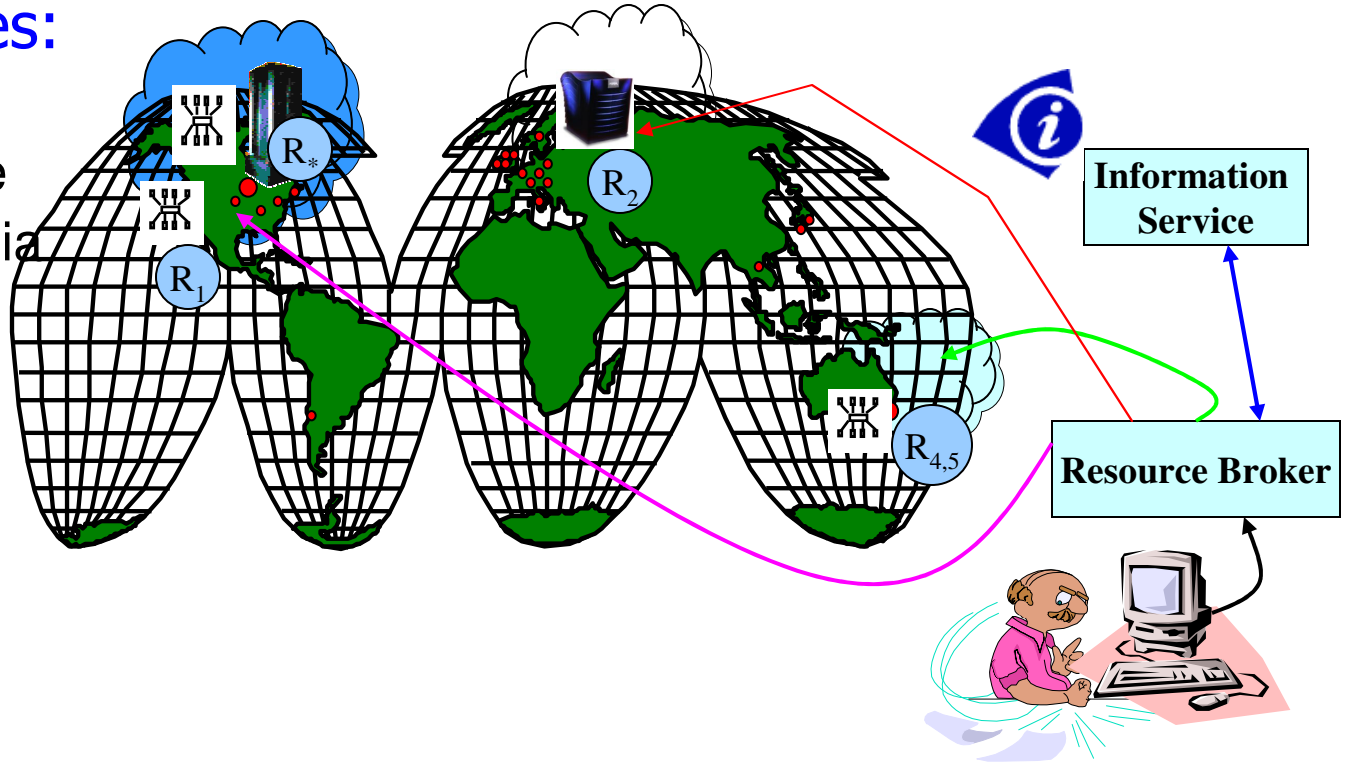
Universidad Complutense de Madrid, Spain

Market-Oriented Scheduling Experiments



Experiment Setup: DBC Scheduling with Optimize for (1) Time & (2) Cost

- Workload:
  - A parameter sweep “synthetic” application (100 jobs), each job is modeled to execute ~5 minute with variation of (+/-20 sec.).
- QoS Constraints: Deadline: 40 min. and Budget: $6
- Resources:
  - US
  - Europe
  - Australia

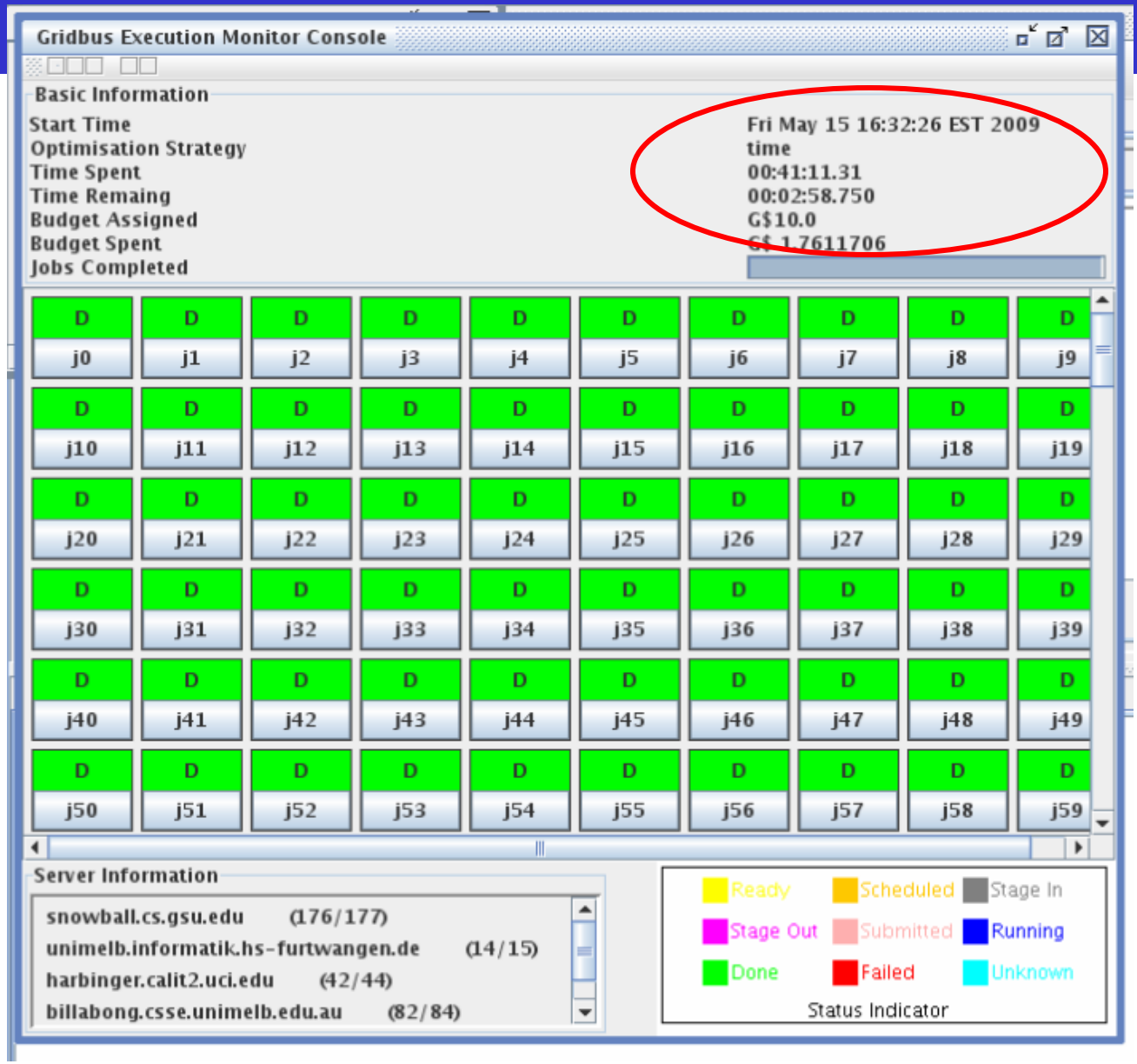


Resources & Price (*multiplier for clarity*)

Organization	Resource Details	Rate (Cents per second*1000)
Georgia State University, US	*snowball.cs.gsu.edu* 8 Intel 1.90GHz CPU, 3.2 GB RAM, 152 GB HD, Linux	90 (0.09)
H. Furtwangen University, Germany	*unimelb.informatik.hs-furtwangen.de* 1 Athlon XP 1700+ CPU, 767 MB RAM, 147 GB HD	3
University of California-Irvine, US	*harbinger.calit2.uci.edu* 2 Intel P III 930 MHz CPU, 503 MB RAM, 32 GB HD	2
University of Melbourne, Australia	*billabong.csse.unimelb.edu.au* 2 Intel(R) 2.40GHz CPU, 1 GB RAM, 35 GB HD	6
University of Melbourne, Australia	*gieseking.csse.unimelb.edu.au* 2 Intel(R) 2.40GHz CPU, 1 GB RAM, 71 GB HD	6
Amazon EC2 *	*ec2-Medium instance* 5 EC2 Compute Units*, 1.7 GB RAM, 350 GB HD	60
Amazon EC2 *	*ec2-Medium instance* 5 EC2 Compute Units, 1.7 GB RAM, 350 GB HD	60
Amazon EC2 *	*ec2-Small instance* 1 EC2 Compute Unit, 1.7 GB RAM, 160 GB HD	30
Amazon EC2 *	*ec2-Small instance* 1 EC2 Compute Unit, 1.7 GB RAM, 160 GB HD	30
	Total Price / Budget Consumed	
	Time to Complete Execution	

* Amazon charges for 1 hour even if you use VM for 1 sec. We should force Amazon to change Charging Policy from 1hr block to actual usage! Or invent a 3rd party service that manages this by leasing smaller slots.

Execution Console: Setting QoS



Results of Execution on Cloud and other Distributed Resources

Organization	Resource Details	Rate (Cents per second*1000)	Total Jobs
Georgia State University, US	*snowball.cs.gsu.edu* 8 Intel 1.90GHz CPU, 3.2 GB RAM, 152 GB HD, Linux	90 (0.09)	
H. Furtwangen University, Germany	*unimelb.informatik.hs-furtwangen.de* 1 Athlon XP 1700+ CPU, 767 MB RAM, 147 GB HD	3	
University of California-Irvine, US	*harbinger.calit2.uci.edu* 2 Intel P III 930 MHz CPU, 503 MB RAM, 32 GB HD	2	
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Amazon EC2 *	*ec2-Medium instance* 5 EC2 Compute Units*, 1.7 GB RAM, 350 GB HD	60	
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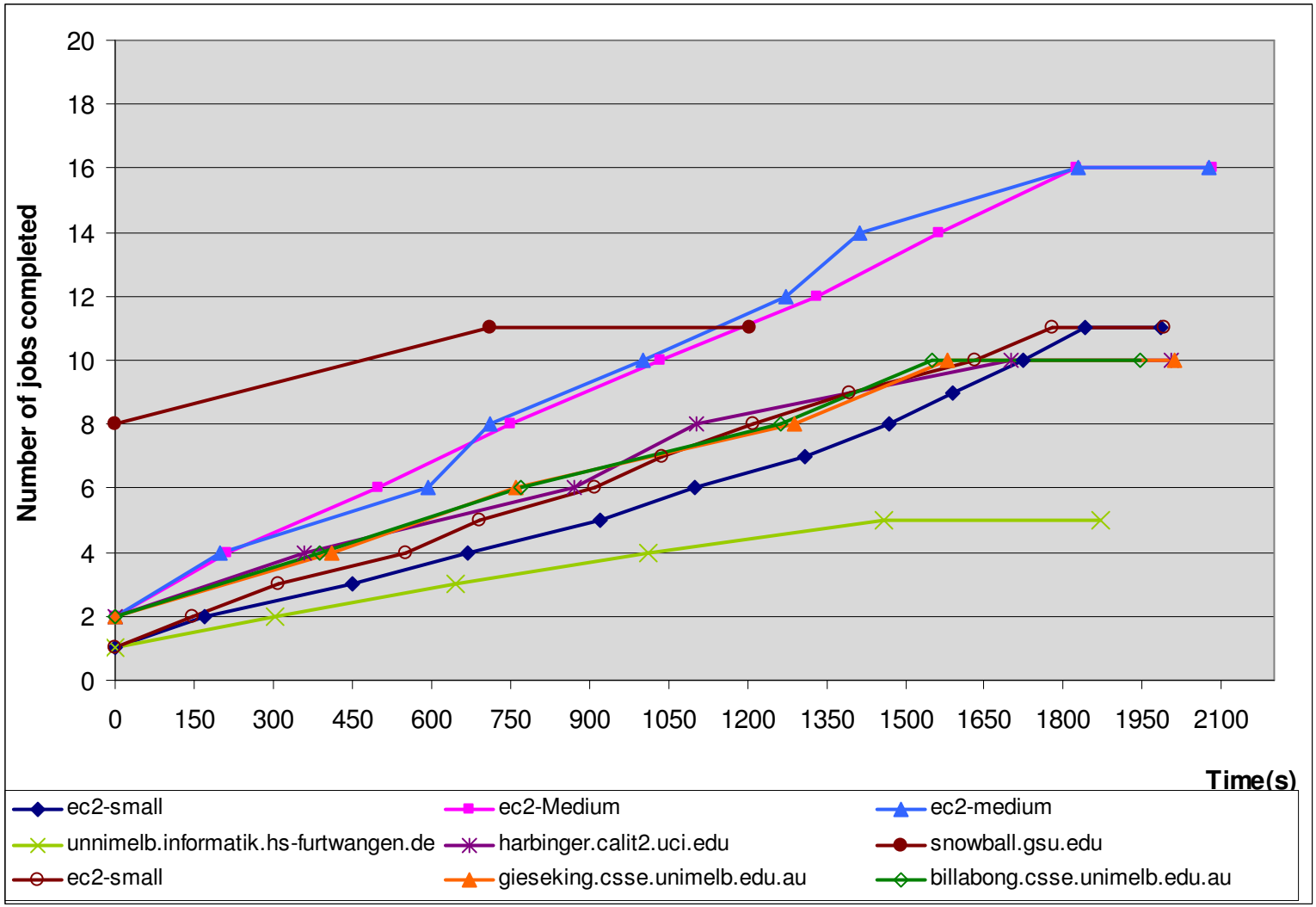
Amazon EC2 *	*ec2-Small instance* 1 EC2 Compute Unit, 1.7 GB RAM, 160 GB HD	30	
	Total Price / Budget Consumed		
	Time to Complete Execution		

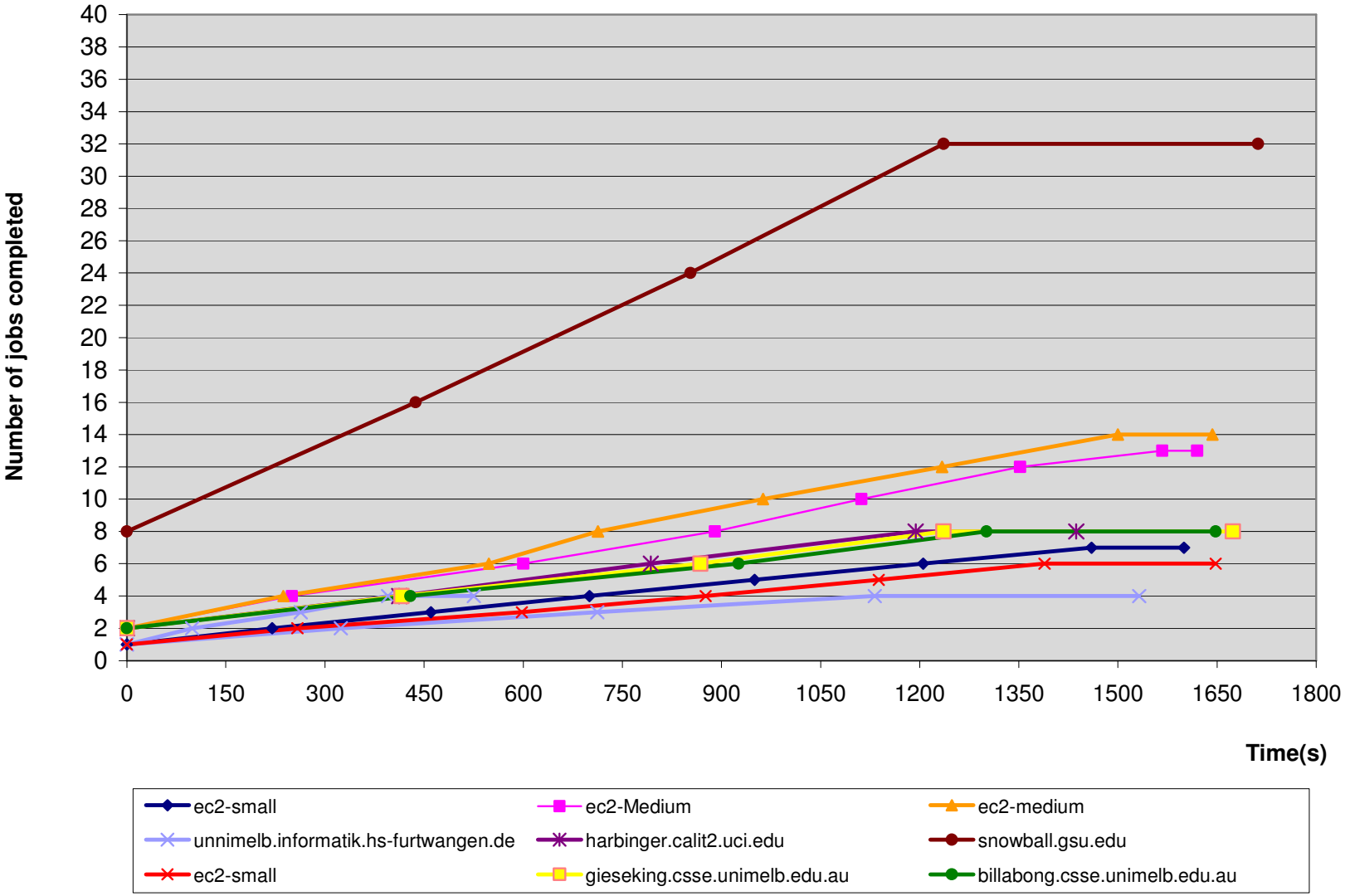
** Amazon charges for 1 hour even if you use VM for 1 sec.*

QoS Constraints: Deadline: 40 min. and Budget: $6

Scheduling for DBC Cost Optimization

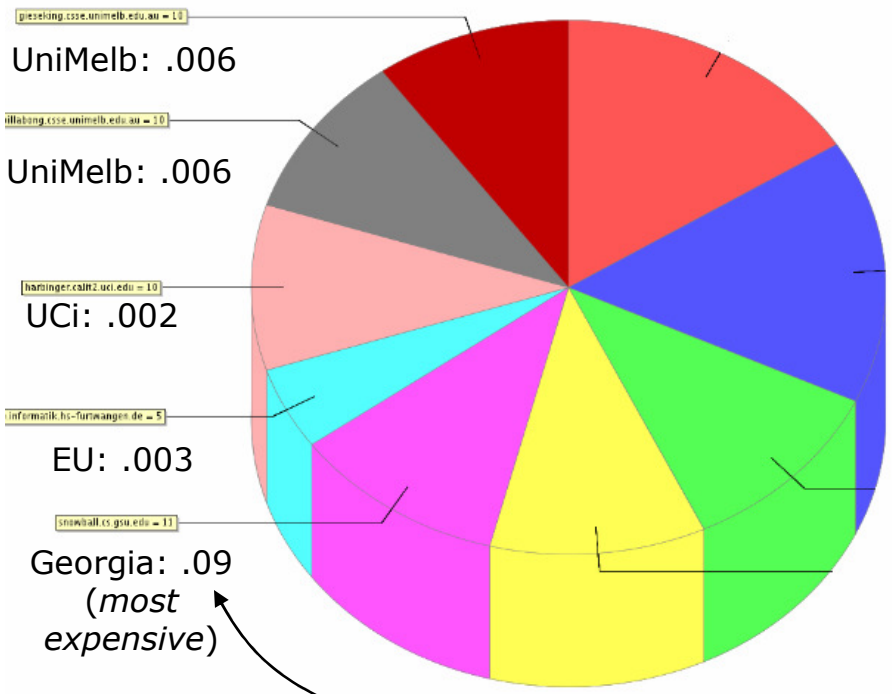


Resource Scheduling for DBC Time Optimization

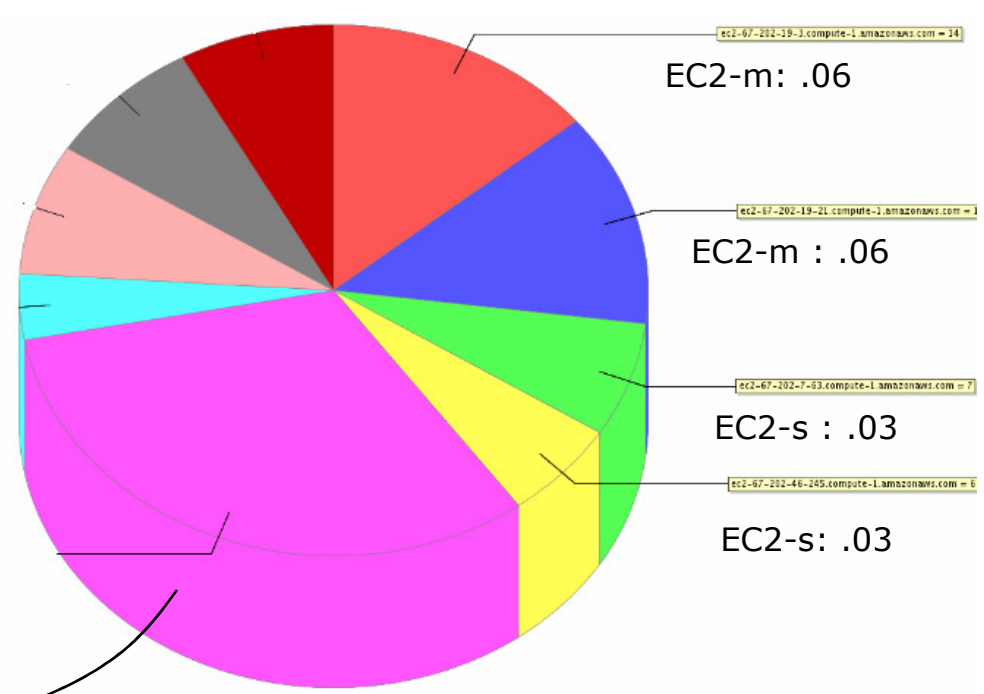


Resources Consumed by Cost and Time Opt. Strategies

Cost-Opt



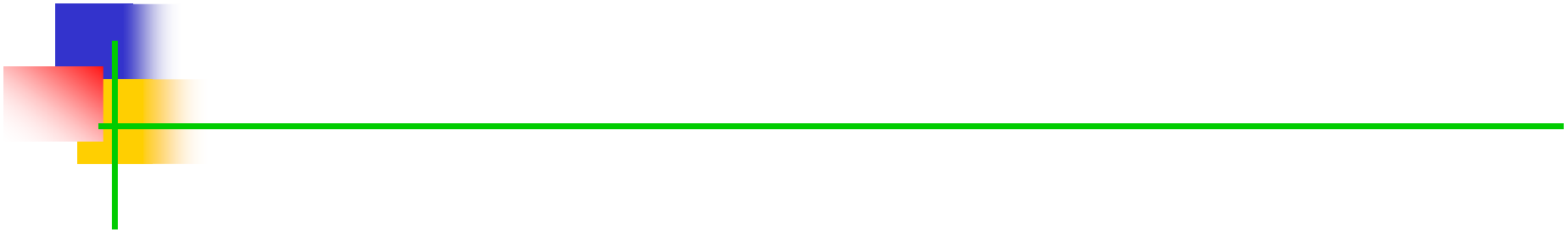
Time-Opt



QoS Constraints: Deadline: 40 min. and Budget: $6

	Time	Cost
Budget Consumed	5.04$	3.71$
Time to Complete	28 min	35 min

Experimental Evaluation is too much of work and "expensive" for computing researchers?

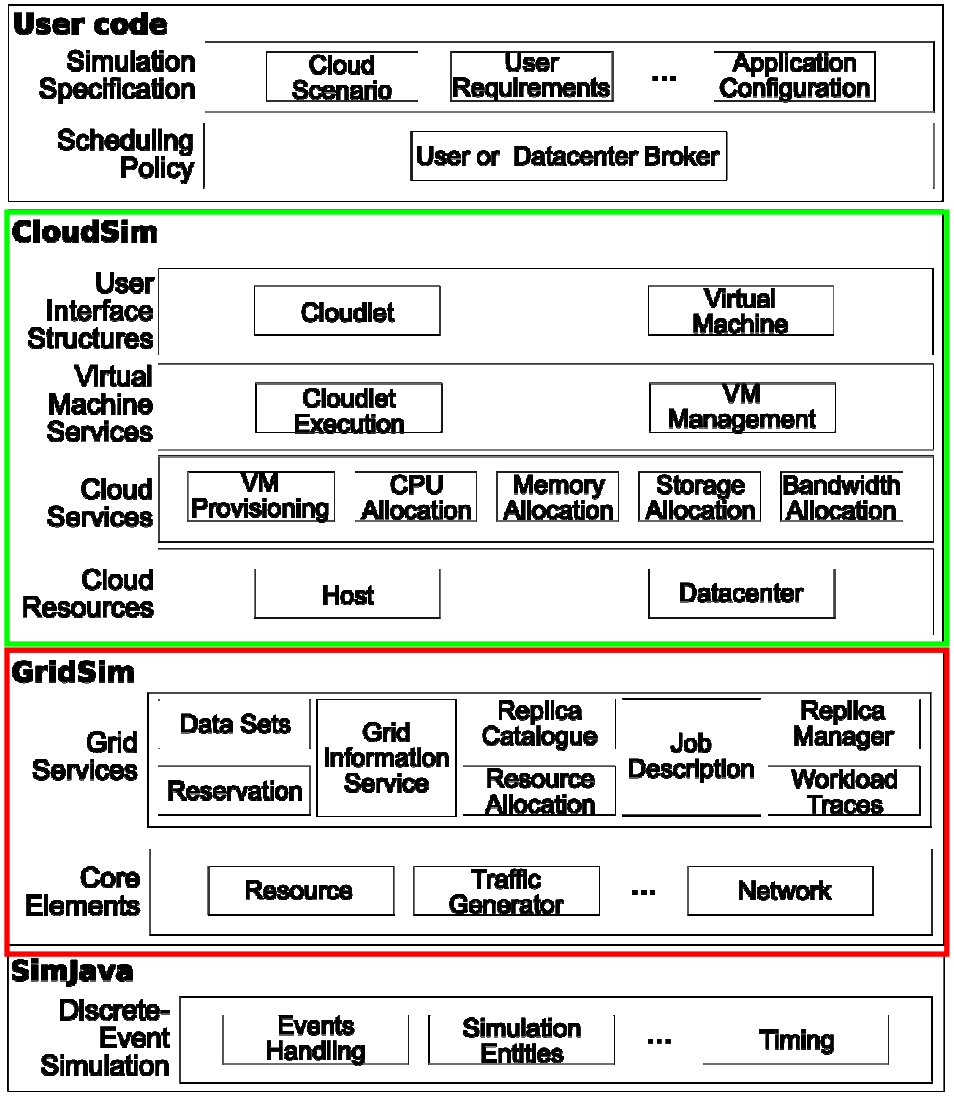


CloudSim: Performance Evaluation Made Easy

*Repeatable, scalable, controllable environment for modelling and simulation of Clouds

* No need to worry about paying IaaS provides + CloudSim is FREE!

The CloudSim Toolkit
http://www.gridbus.org/cloudsim/



Outline

- "Computer Utilities"
  - Vision and Promising IT Paradigms/Platforms
- Cloud Computing and Related Paradigms
  - Trends, Definition, Cloud Benefits and Challenges
- Market-Oriented Cloud Architecture
  - SLA-oriented Resource Allocation
  - Global Cloud Exchange
- Emerging Cloud Platforms
- Megha: Melbourne Cloud Computing Initiative
- Summary and Thoughts for Future

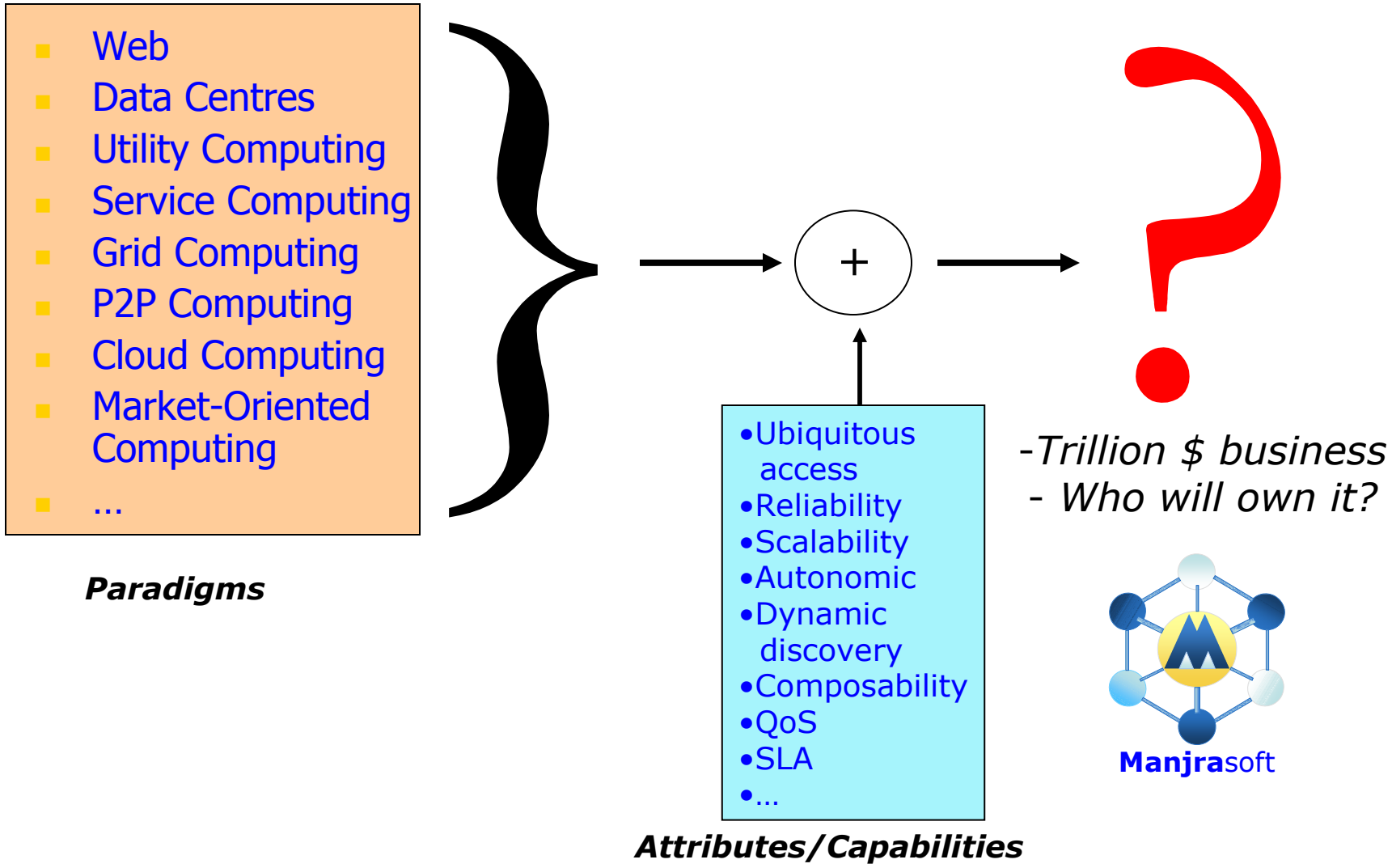
Summary

- Several Computing Platforms/Paradigms are promising to deliver "Computing Utilities" vision
  - Cloud Computing is the most recent kid in the block promising to turn vision into reality
  - Clouds built on: SOA, VMs, Web 2.0 technologies
  - Many exciting business and consumer applications enabled.
- Market Oriented Clouds are getting real
  - Need to move from static pricing to dynamic pricing
  - Need strong support for SLA-based resource management
  - 3rd party Composed Cloud services starting to emerge
- Building Grids using Clouds is much more realistic.
  - Extension of idea can lead to → "Global Cloud Exchange"

Dozens of Open Research Issues

- (Application) Software Licensing
- Seamless integration of private and Cloud resources
- Security, Privacy and Trust
- Cloud "Lock-In" worries and Interoperability
- Application Scalability Across Multiple Clouds
- Clouds Federation and Cooperative Sharing
- Global Cloud Exchange and Market Maker
- Dynamic Pricing
- Dynamic Negotiation and SLA Management
- Energy Efficient Resource Allocation and User QoS
- Power-Cost and CO_2 emission issues
  - Use renewable energy: follow Sun and wind?
- Regulatory and Legal Issues

Convergence of Competing Paradigms/Communities Needed



Thanks for your attention!

- Are there any
  - Questions?
  - Comments/ Suggestions

Manjrasoft

We Welcome Cooperation in R&D and Business!

http:/www.gridbus.org | www.Manjrasoft.com

rbuyya@unimelb.edu.au | raj@manjrasoft.com

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