Scalable Data Management in the Cloud: Research Challenges & New Opportunities

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A Voice from the Above

…Cloud Computing? What are you talking about? Cloud Computing is nothing but a computer attached to a network.

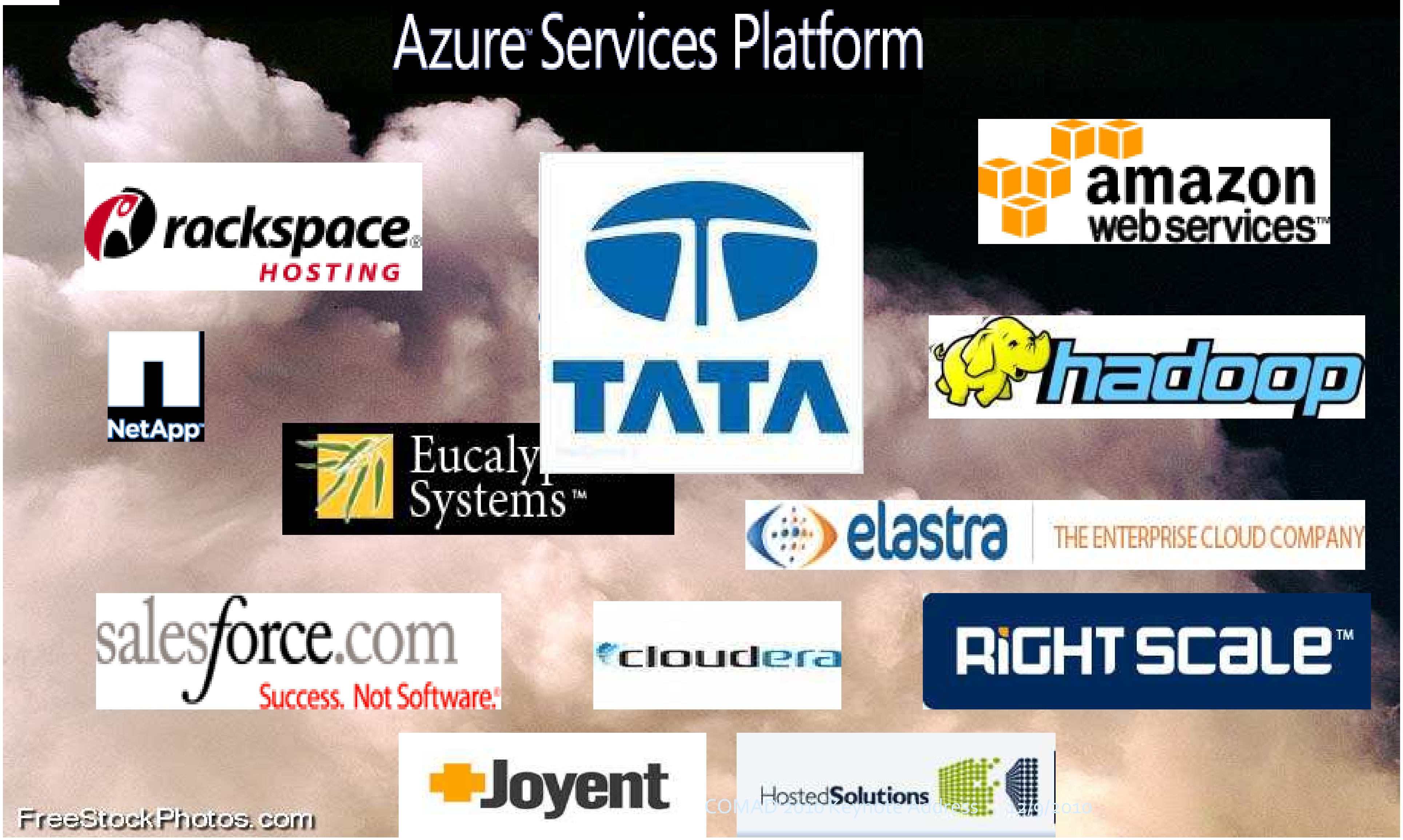
-- Larry Ellison, Excerpts from an interview

Outline

- Infrastructure Disruption
  - Enterprise owned ➔ Commodity shared infrastructures
  - Disruptive transformations: Software and Service Infrastructure
- Clouded Data Management
  - State of the Art lacks “cloud” features
  - Transactional systems (Application Development)
  - Decision support system (Data Analysis)
- Cloudy Application Landscape
- Gen-next Data Management (UCSB)
  - Design Principles
  - Data Fusion and Fission
  - Elasticity

WEB is replacing the Desktop

Paradigm Shift in Computing

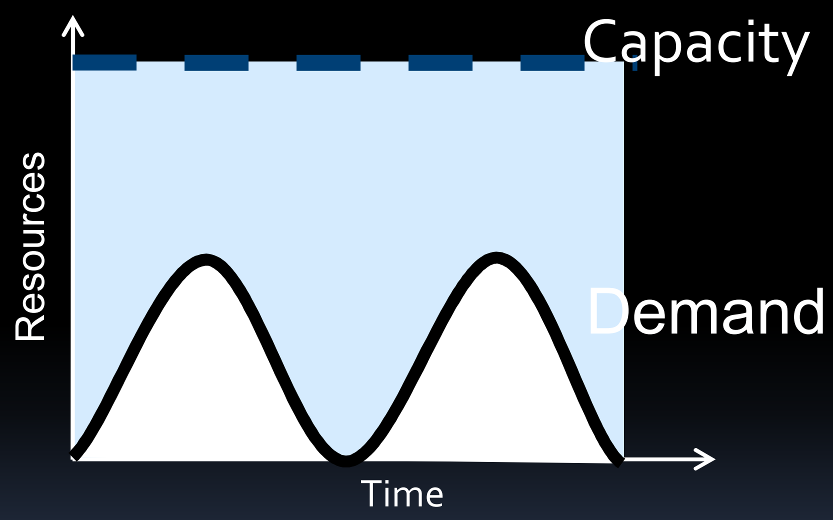


Cloud Computing: Why Now?

- Experience with very large datacenters
  - Unprecedented economies of scale
  - Transfer of risk
- Technology factors
  - Pervasive broadband Internet
  - Maturity in Virtualization Technology
- Business factors
  - Minimal capital expenditure
  - Pay-as-you-go billing model

Economics of Data Centers

- Risk of over-provisioning: underutilization



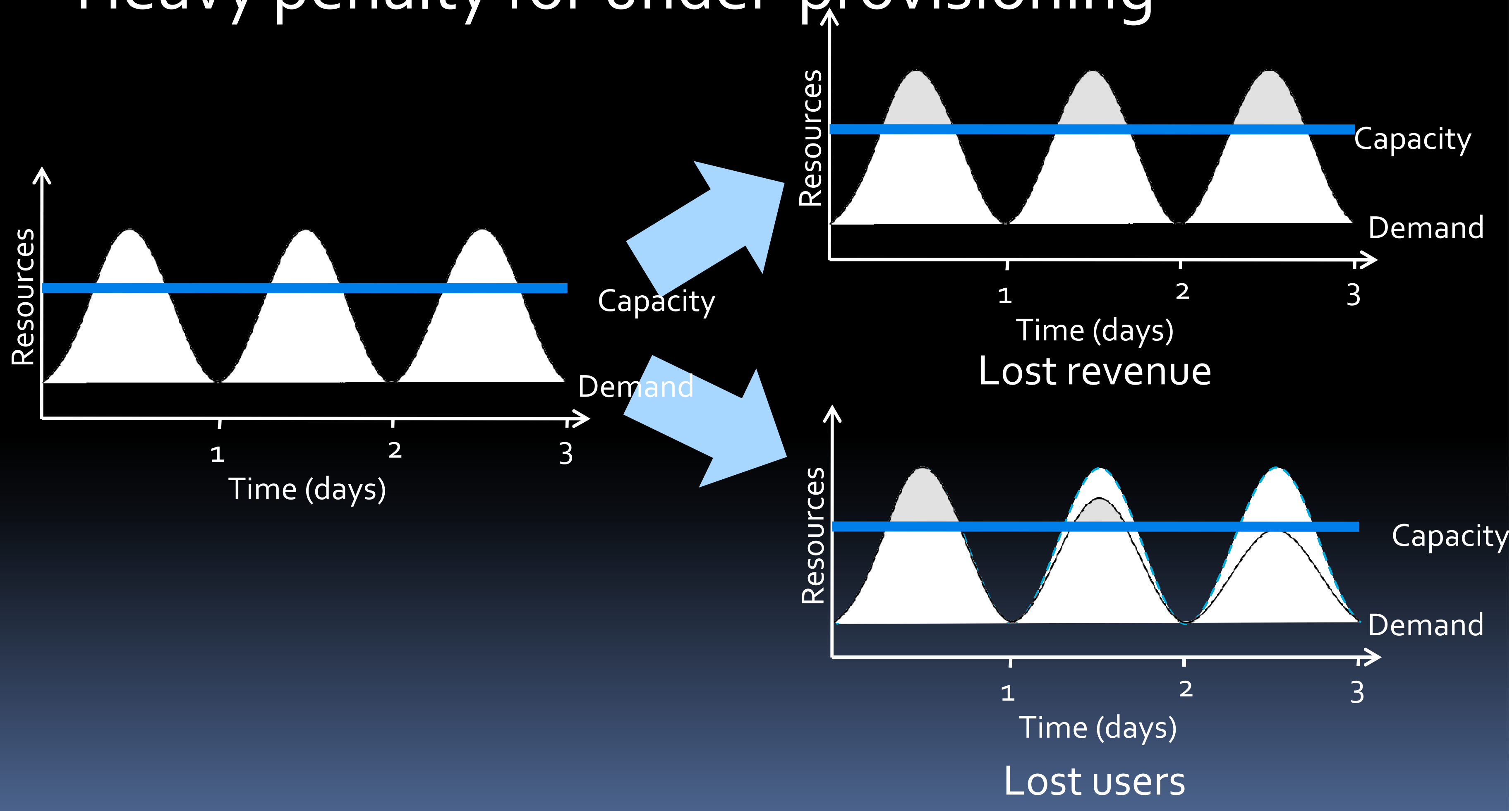
Static data center

Money & Time Questions:

1. How much?
2. How Long?

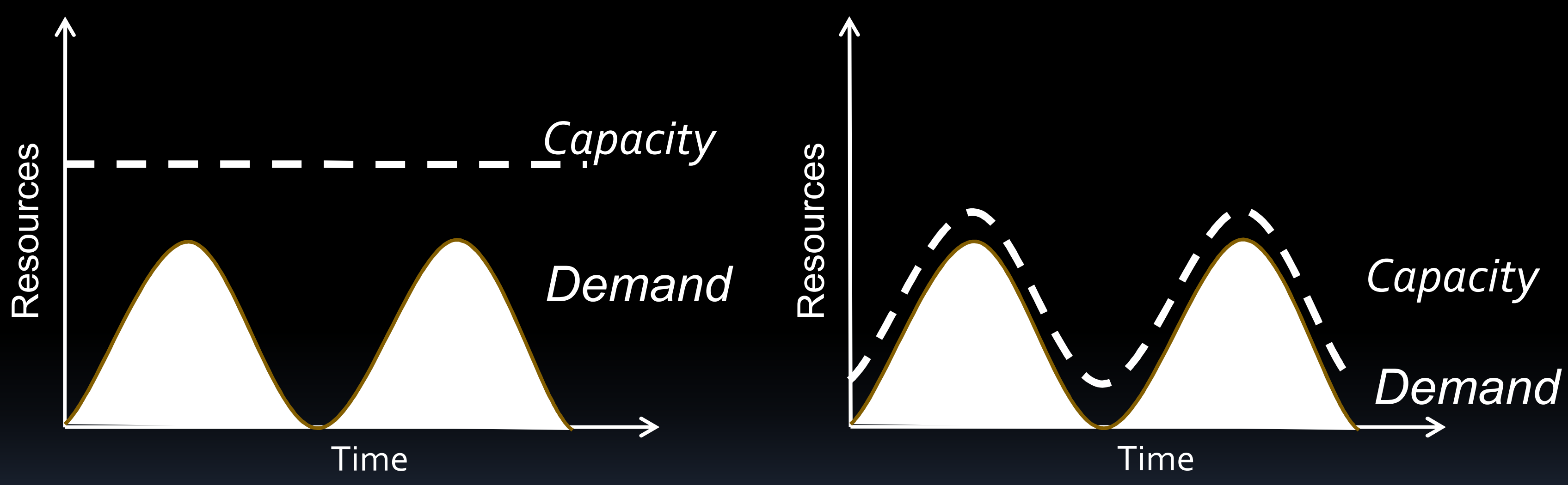
Economics of Internet Users

- Heavy penalty for under-provisioning



Economics of Cloud Computing

- Pay by use instead of provisioning for peak

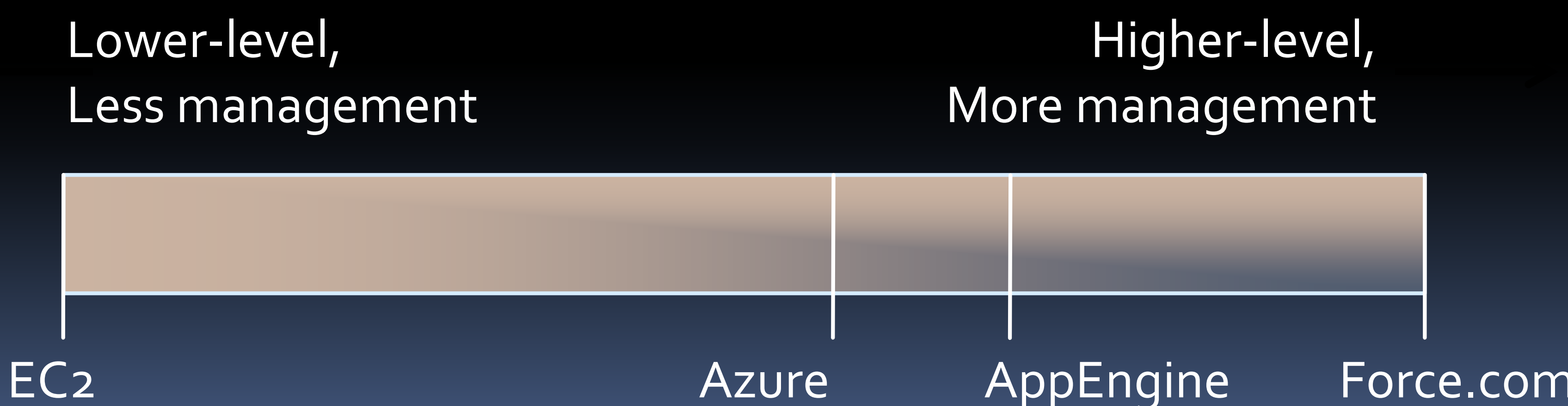


Static data center

Data center in the cloud

Cloud Computing Spectrum

- Infrastructure-as-a-Service (IaaS)
- Platform-as-a-Service (PaaS)
- Software-as-a-Service (SaaS)



The Big Picture

- Unlike the earlier attempts:
  - Distributed Computing, Distributed Databases, Grid Computing
- Cloud Computing is REAL:
  - Organic growth: Google, Yahoo, Microsoft, and Amazon
  - IT Infrastructure Automation
  - Economies-of-scale
  - Fault-tolerance: automatically deal with failures
  - Time-to-market: no upfront invesment

Cloud Reality

- Facebook Generation of Application Developers
- Animoto.com:
  - Started with 50 servers on Amazon EC2
  - Growth of 25,000 users/hour
  - Needed to scale to 3,500 servers in 2 days (RightScale@SantaBarbara)
- Many similar stories:
  - RightScale
  - Joyent
  - …

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- Cloudy Application Landscape
- Gen-next Data Management systems
  - Design Principles
  - Data Fusion and Fission
  - Elasticity

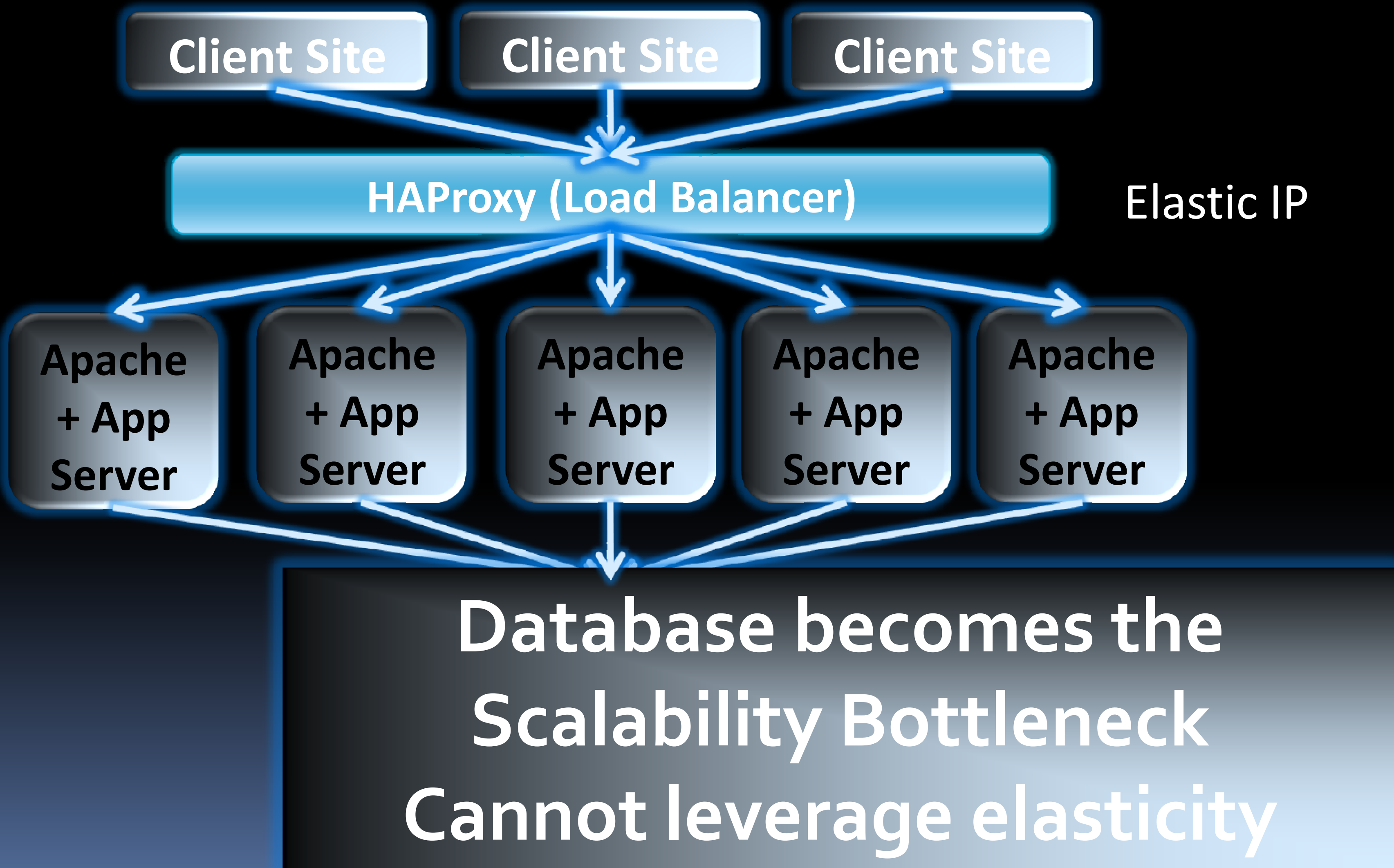
Current State

- Most enterprise solutions are based on RDBMS technology.

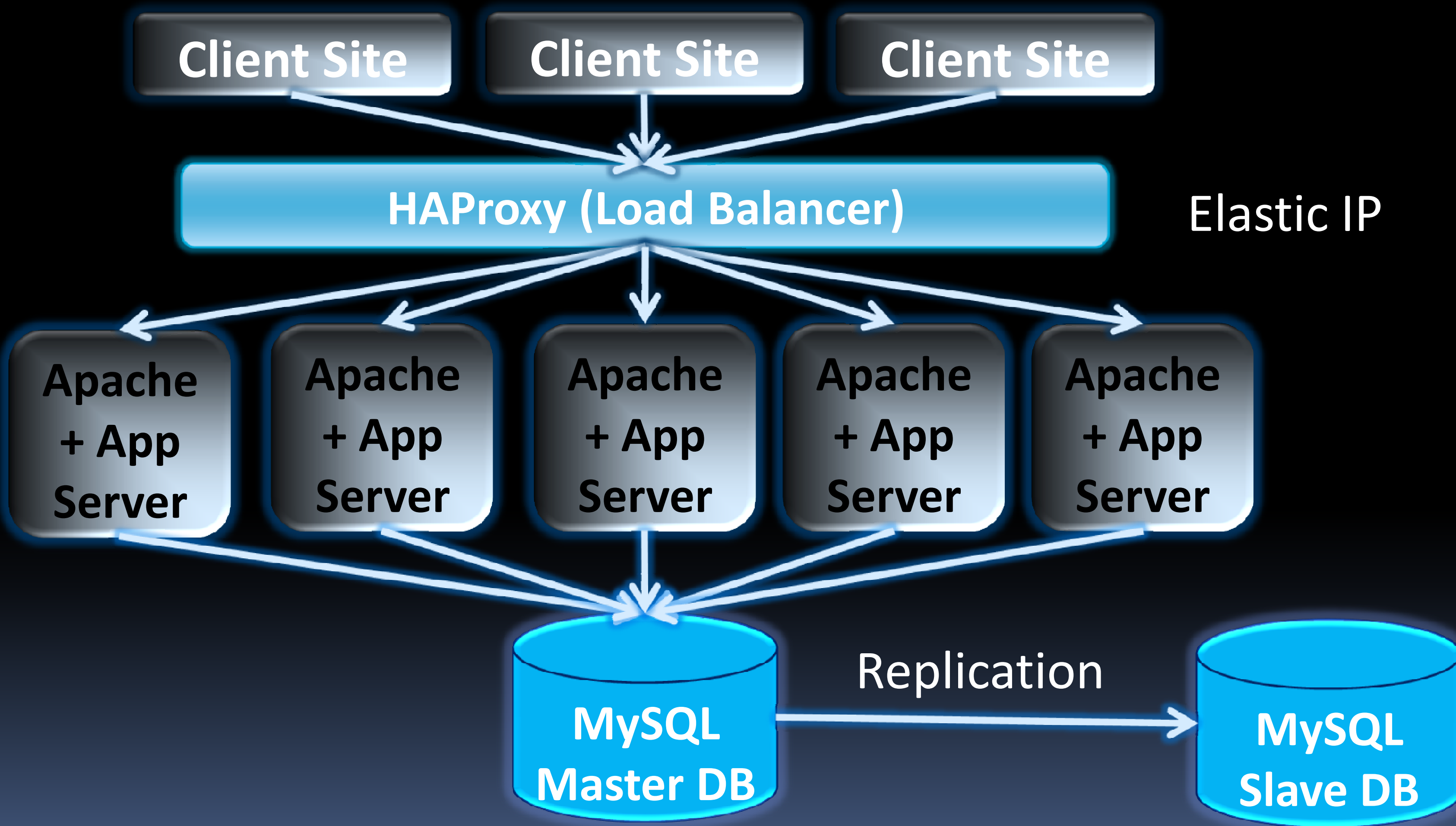
- Significant Operational Challenges:
  - Provisioning for Peak Demand
  - Resource under-utilization
  - Capacity planning: too many variables
  - Storage management: a massive challenge
  - System upgrades: extremely time-consuming
  - Complex mine-field of software and hardware licensing

➔ Unproductive use of people-resources from a company's perspective

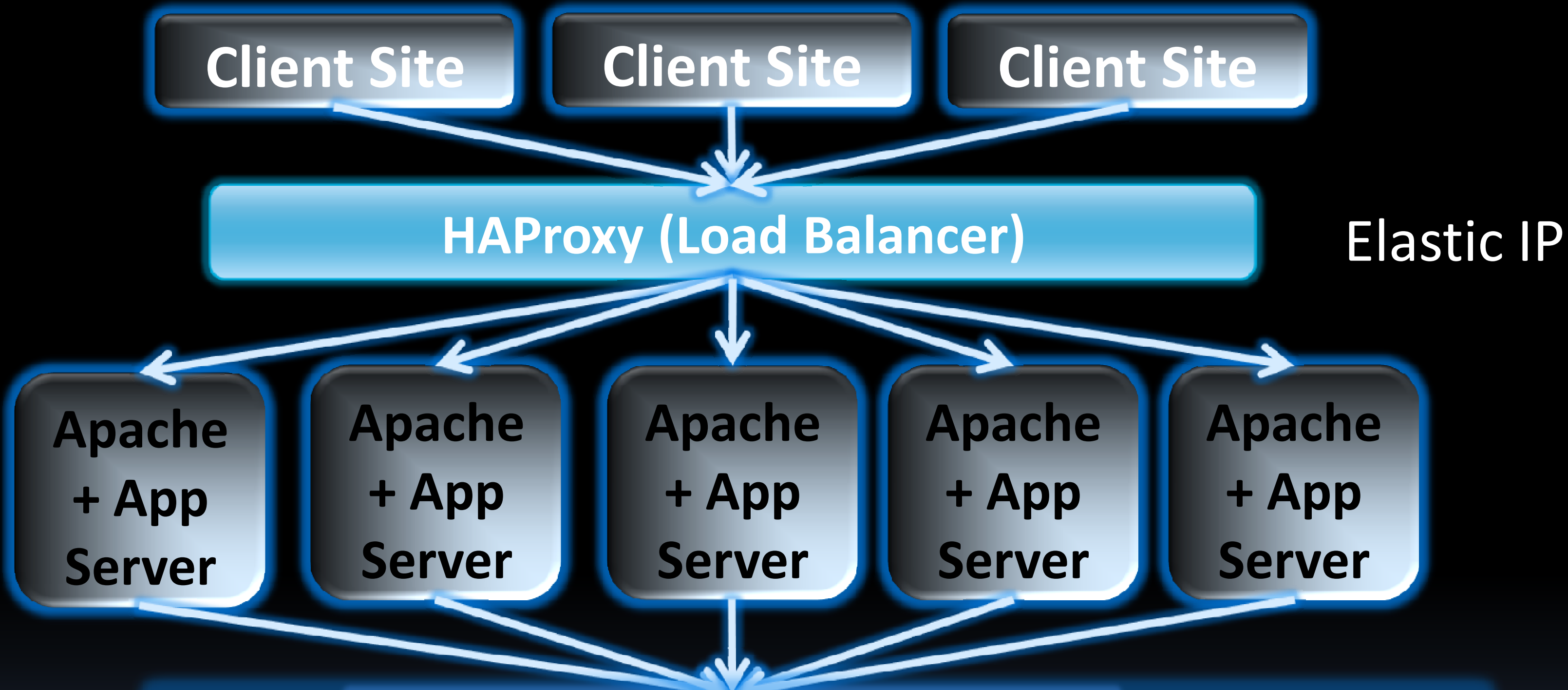
Scaling in the Cloud



Scaling in the Cloud



Scaling in the Cloud



Scalable and Elastic
But limited consistency and operational flexibility

Cloud Computing Desiderata

- Scalability
- Elasticity
- Fault tolerance
- Self Manageability
- Sacrifice consistency?
  - Foregone Conclusion!!!

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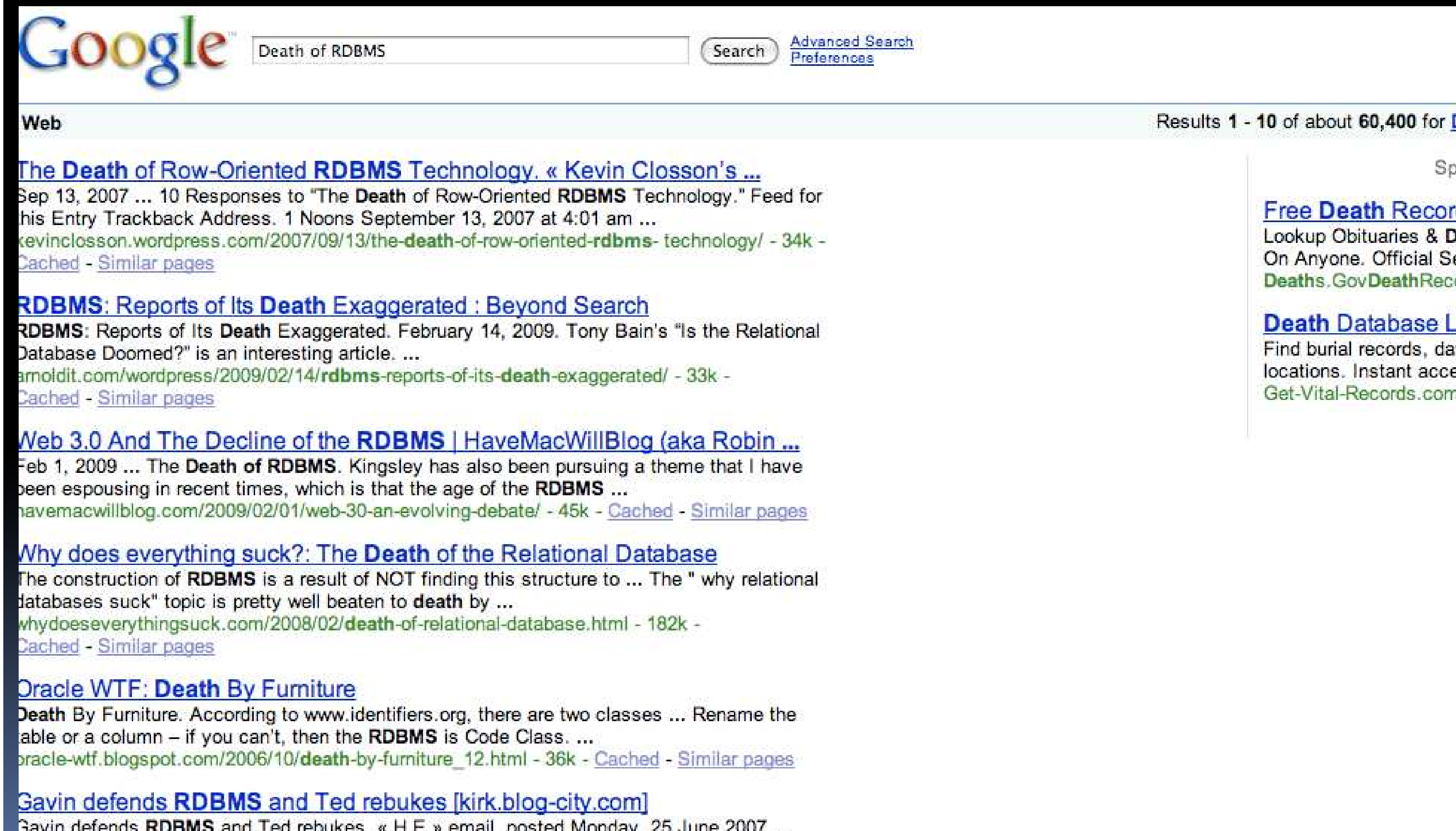
Internet Chatter



BLOG Wisdom

- "If you want vast, on-demand scalability, you need a non-relational database." Since scalability requirements:
  - Can change very quickly and,
  - Can grow very rapidly.
- Difficult to manage with a single in-house RDBMS server.
- Although RDBMS scale well:
  - When limited to a single node (scale-up NOT scale-out).
  - Overwhelming complexity to scale on multiple servers.

Application Complexity

```
public void confirm_friend_request(user1, user2)
{
begin_transaction();
        update_friend_list(user1, user2, status.confirmed);
        //user1@Palo Alto Data Center
        update_friend_list(user2, user1, status.confirmed);
        //user2 @London Data Center
end_transaction();
}
```

public void confirm_friend_request_A(user1, user2){
 try{ update_friend_list(user1, user2, status.confirmed); //palo alto }
catch(exceptione){ report_error(e); **return;** }
 try{ update_friend_list(user2, user1, status.confirmed); //london
 }
catch(exceptione) { **revert_friend_list**(user1, user2);
 report_error(e); return; }
}

public void confirm_friend_request_B(user1, user2){
try{ update_friend_list(user1, user2, status.confirmed); //palo alto }catch(exceptione){ report_error(e); **add_to_retry_queue**(operation.updatefriendlist, user1, user2, current_time()); }
try{ update_friend_list(user2, user1, status.confirmed); //london }catch(exceptione)
{ report_error(e); **add_to_retry_queue**(operation.updatefriendlist, user2, user1, current_time()); } }

/* get_friends() method has to reconcile results returned by get_friends() because there may be data inconsistency due to a conflict because a change that was applied from the message queue is contradictory to a subsequent change by the user. In this case, status is a bitflag where all conflicts are merged and it is up to app developer to figure out what to do. */
public list get_friends(user1){   list actual_friends = new list();   list friends = get_friends();   foreach (friend in friends){   if(friend.status == friendstatus.confirmed){ //no conflict   actual_friends.add(friend);   }else if((friend.status&= friendstatus.confirmed)   and !(friend.status&= friendstatus.deleted)){   // assume friend is confirmed as long as it wasn't also deleted   friend.status = friendstatus.confirmed;   actual_friends.add(friend);   update_friends_list(user1, friend, status.confirmed);   }else{ //assume deleted if there is a conflict with a delete   update_friends_list(user1, friend, status.deleted)   }   }//foreach   return actual_friends;   }

Perspectives

James Hamilton

I love **eventual consistency** but there are some applications that are much easier to implement with strong consistency. Many like eventual consistency because it allows us to scale-out nearly without bound ***but it does come with a cost in programming model complexity.***

February 24, 2010

Recent work

- Building a database on Amazon S3 [Brantner 2008]
- Consistency Rationing in a Cloud Database [Kraska 2009]
- Unbundling Transactions in the Cloud [Lomet 2009a, 2009b]
- Supporting large number of small applications [Yang 2009]
- ePIC project at NUS [VLDB'2010 papers]

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  - **Design Principles**
  - **Data Fusion and Fission**
  - **Elasticity**

Design Principles

- **Separate System and Application State**
  - System metadata is critical but small
  - Application data has varying needs
  - Separation allows use of different class of protocols

- **Limit Application interactions to a single node**
  - Allows systems to scale horizontally
  - Graceful degradation during failures
  - Obviate the need for distributed synchronization

Design Principles (contd.)

- **Decouple Ownership from Data Storage**
  - Ownership refers to exclusive read/write access to data
  - Partition ownership – effectively partitions data
  - Decoupling allows light weight ownership transfer
- **Limited distributed synchronization is practical**
  - Maintenance of metadata
  - Provide strong guarantees only for data that needs it

Scalability & Elasticity in the Cloud

- **Data Fusion**
  - Enrich Key Value stores
  - GStore: Efficient Transactional Multi-key access [ACM SOCC'2010]
- **Data Fission**
  - Cloud enabled relational databases
  - ElasTraS: Elastic TranSactional Database [HotClouds2009;Tech. Report'2010]
- Elasticity of Data Services

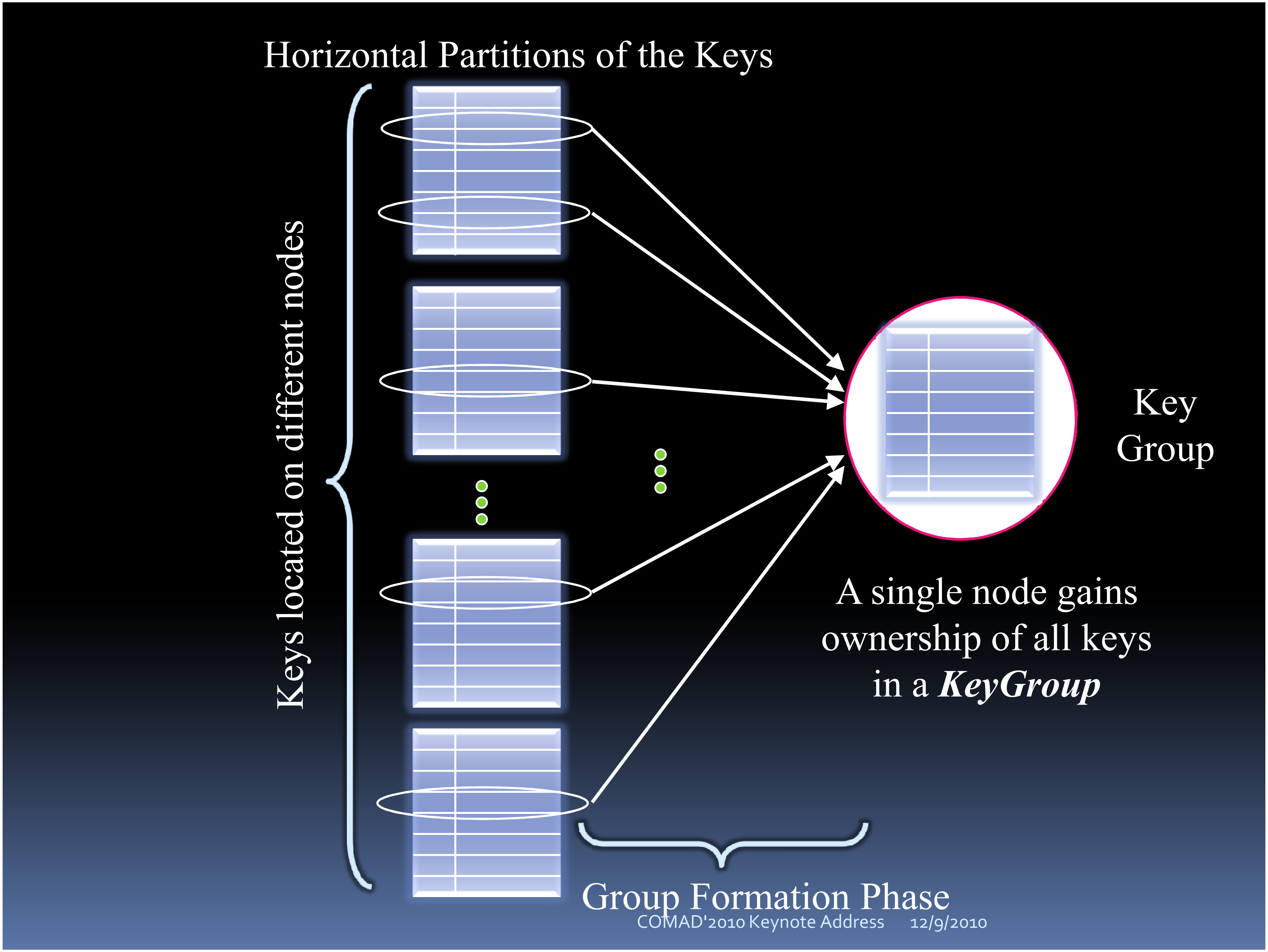
Data Fusion: GStore

Atomic Multi-key Access

- Key value stores:
  - Atomicity guarantees on single keys
  - Suitable for majority of current web applications
- Many other applications warrant multi-key accesses:
  - Online multi-player games
  - Collaborative applications
- Enrich functionality of the Key value stores [Google AppEngine&MegaStore]

Key Group Abstraction

- Define a granule of on-demand transactional access
- Applications select any set of keys
- Data store provides transactional access to the group
- Non-overlapping groups

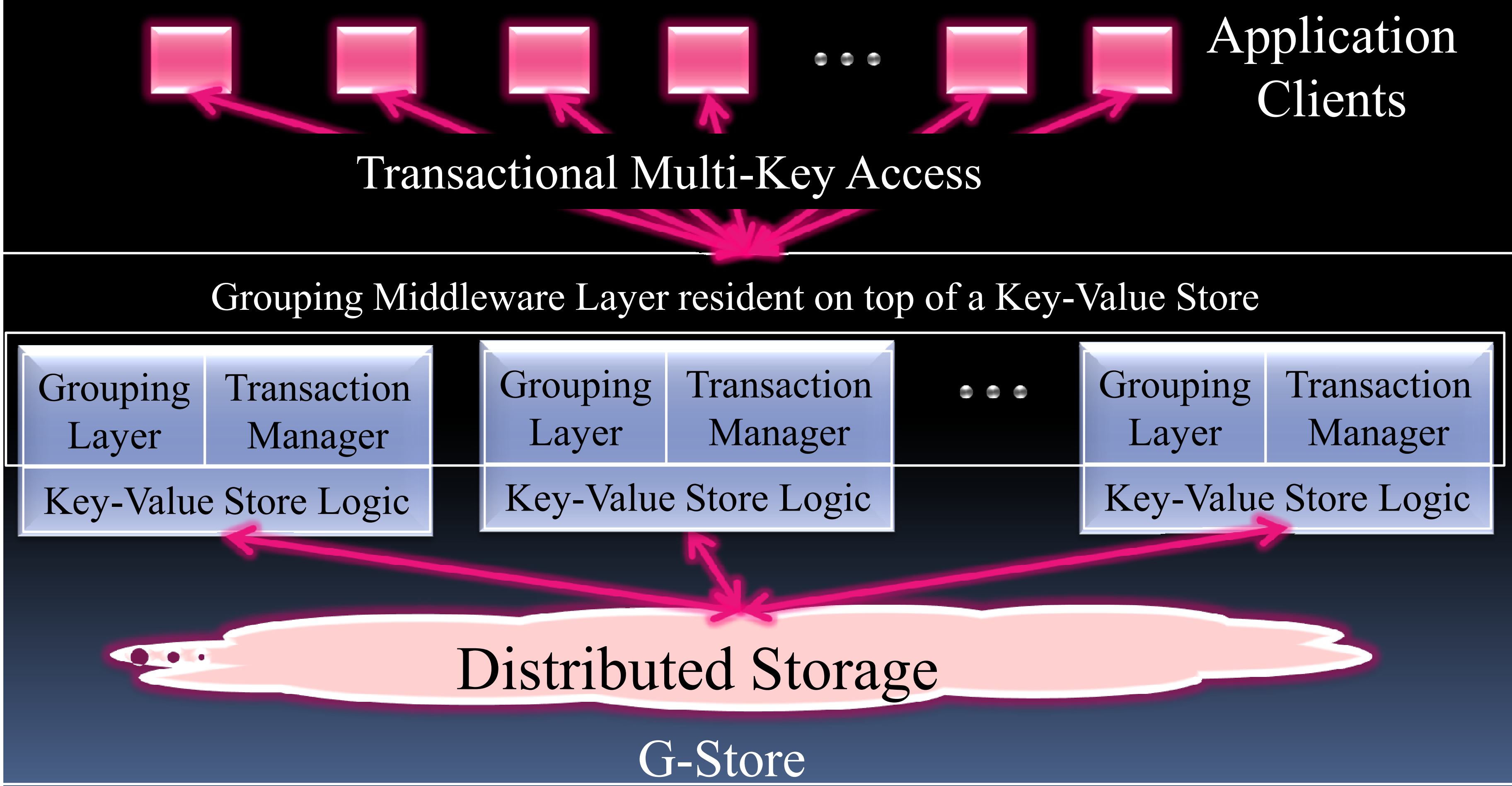


Horizontal Partitions of the Keys
Keys located on different nodes
Key Group
A single node gains ownership of all keys in a ***KeyGroup***
Group Formation Phase

Key Grouping Protocol

- Conceptually akin to “locking”
- Allows collocation of ownership
- Transfer key ownership from “followers” to “leader”
- Guarantee “safe transfer” in the presence of system dynamics:
  - Dynamic migration of data and its control
  - Failures

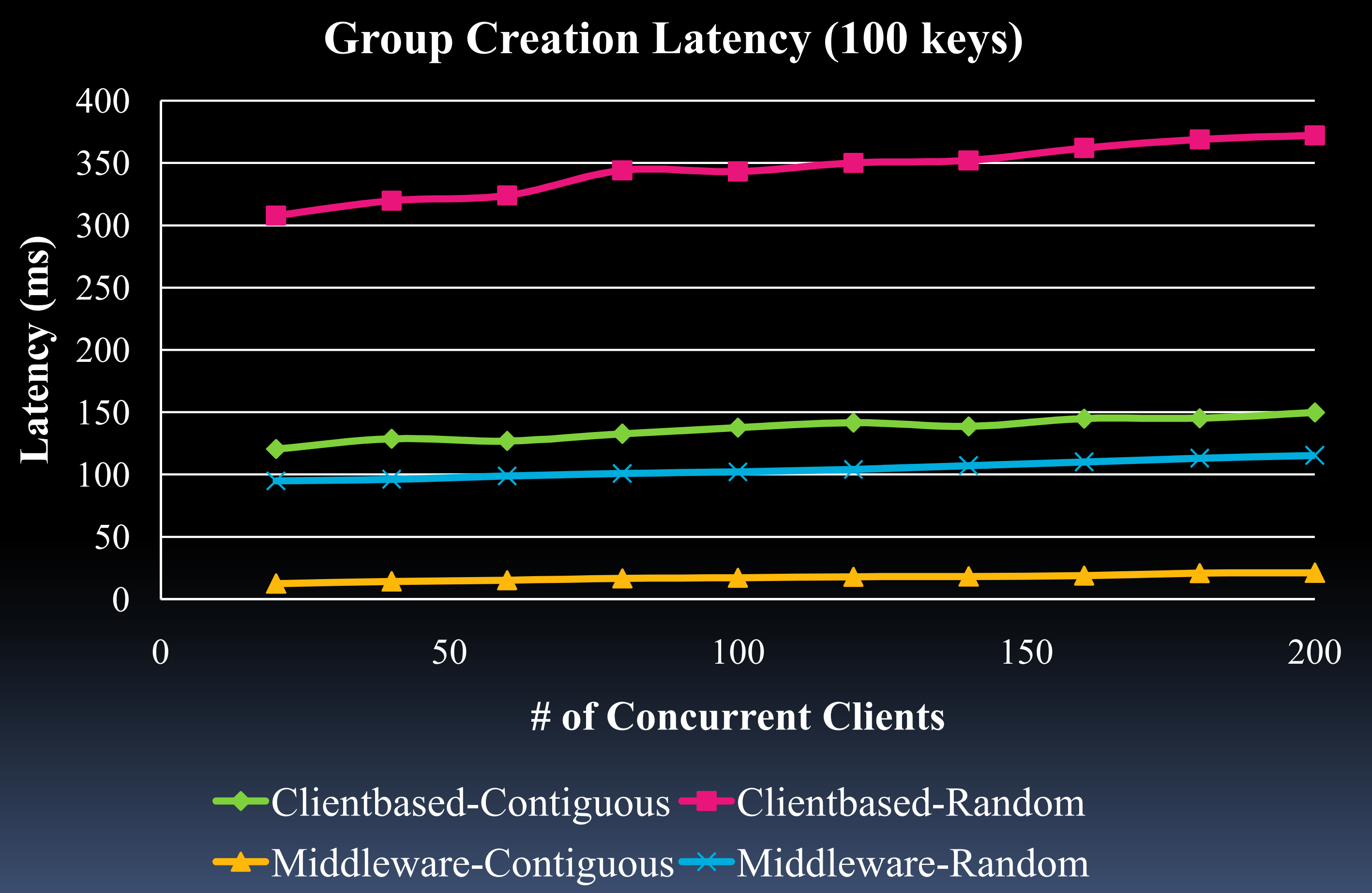
Implementing GStore



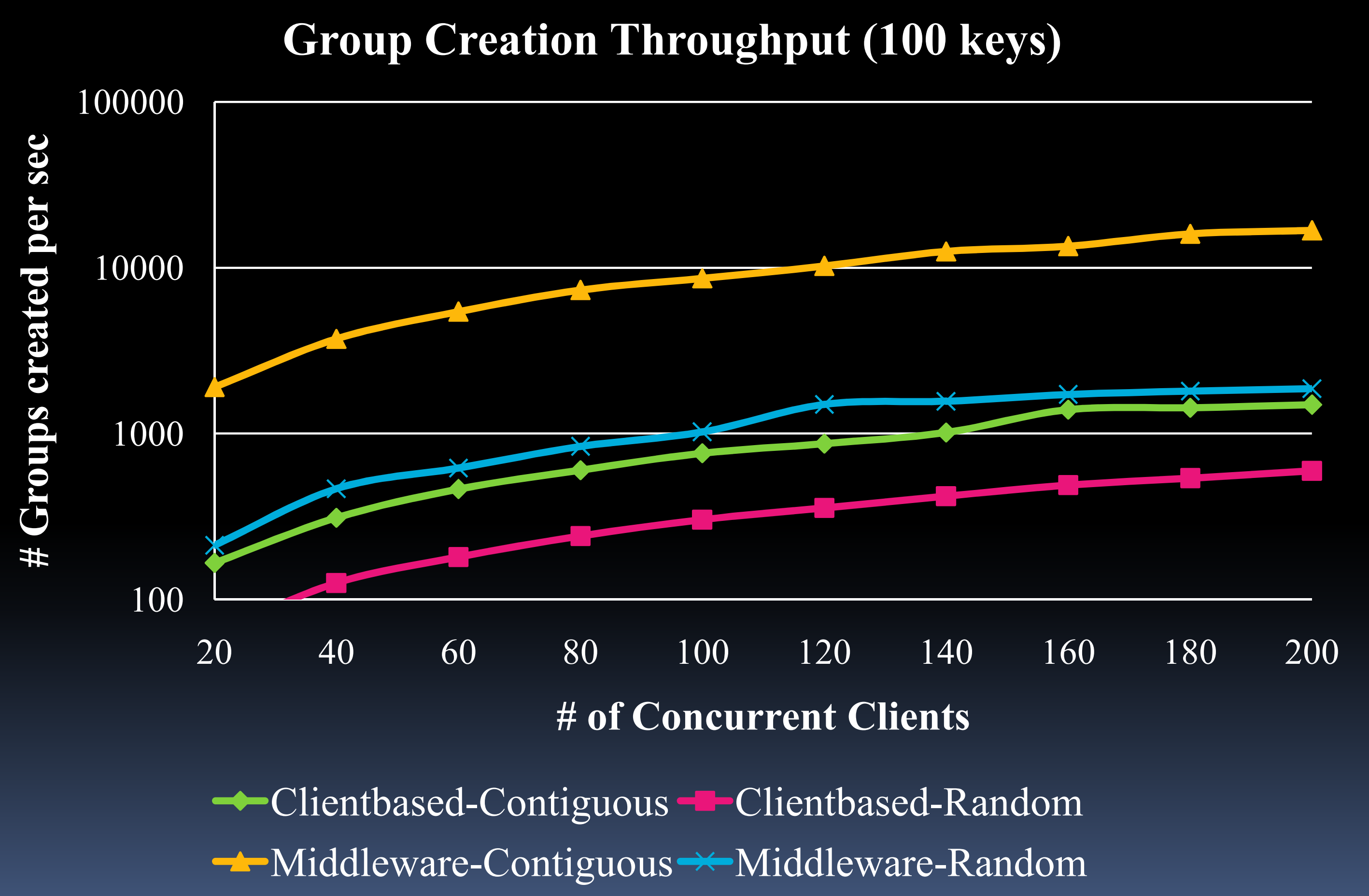
G-Store Experimental Setup

- Performed in Amazon EC2
- Application benchmark simulating an Online multi-player game
- Cluster size: 10 nodes
- Number of concurrent clients: 20 to 200
- Number of keys in a group: 10 to 100
- Data size: ~1T
- Each node in the cluster: 8 cores, 7G RAM, 1.7T disk

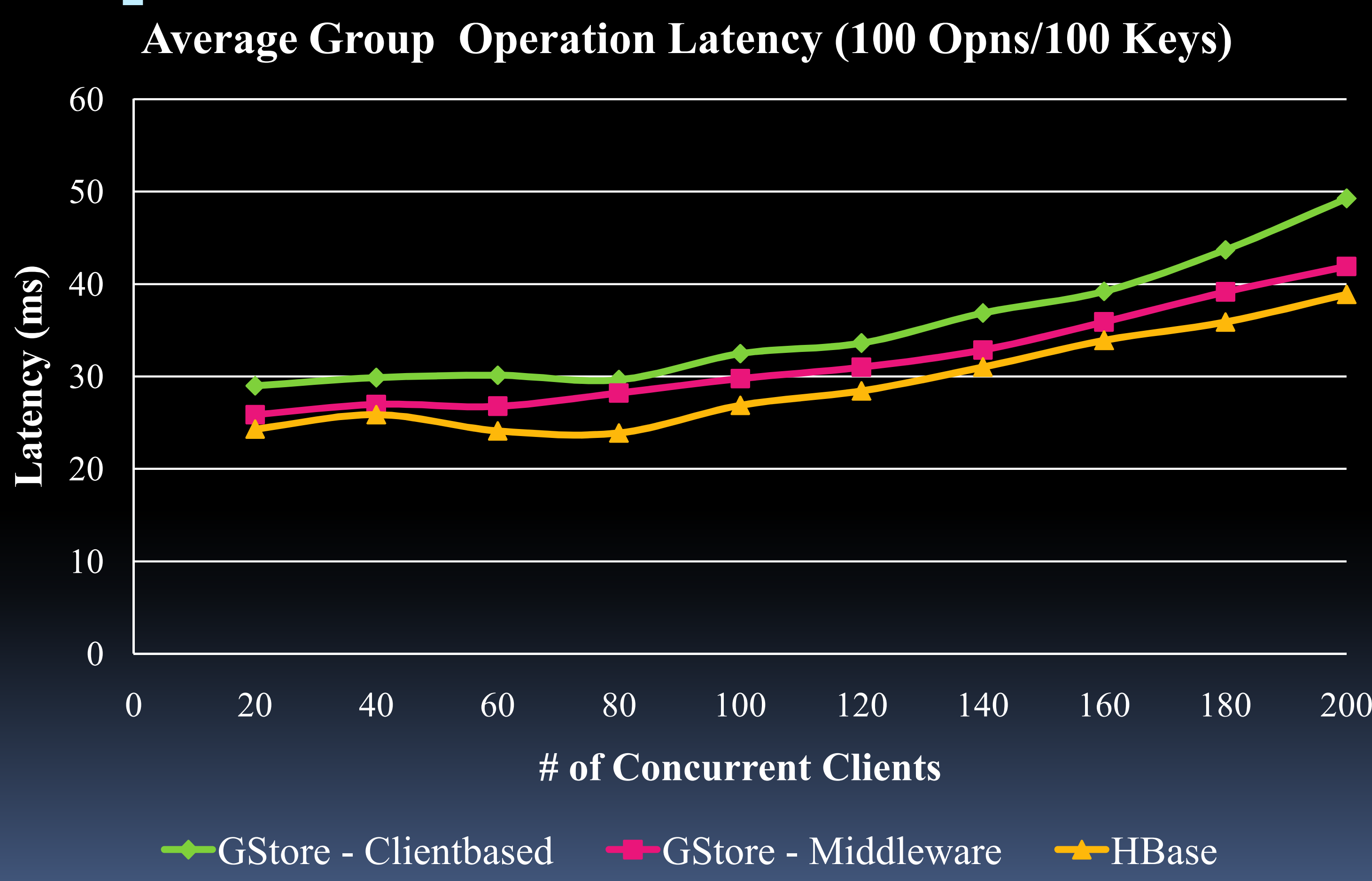
Group Creation Latency



Group Creation Throughput



Latency for Group Operations



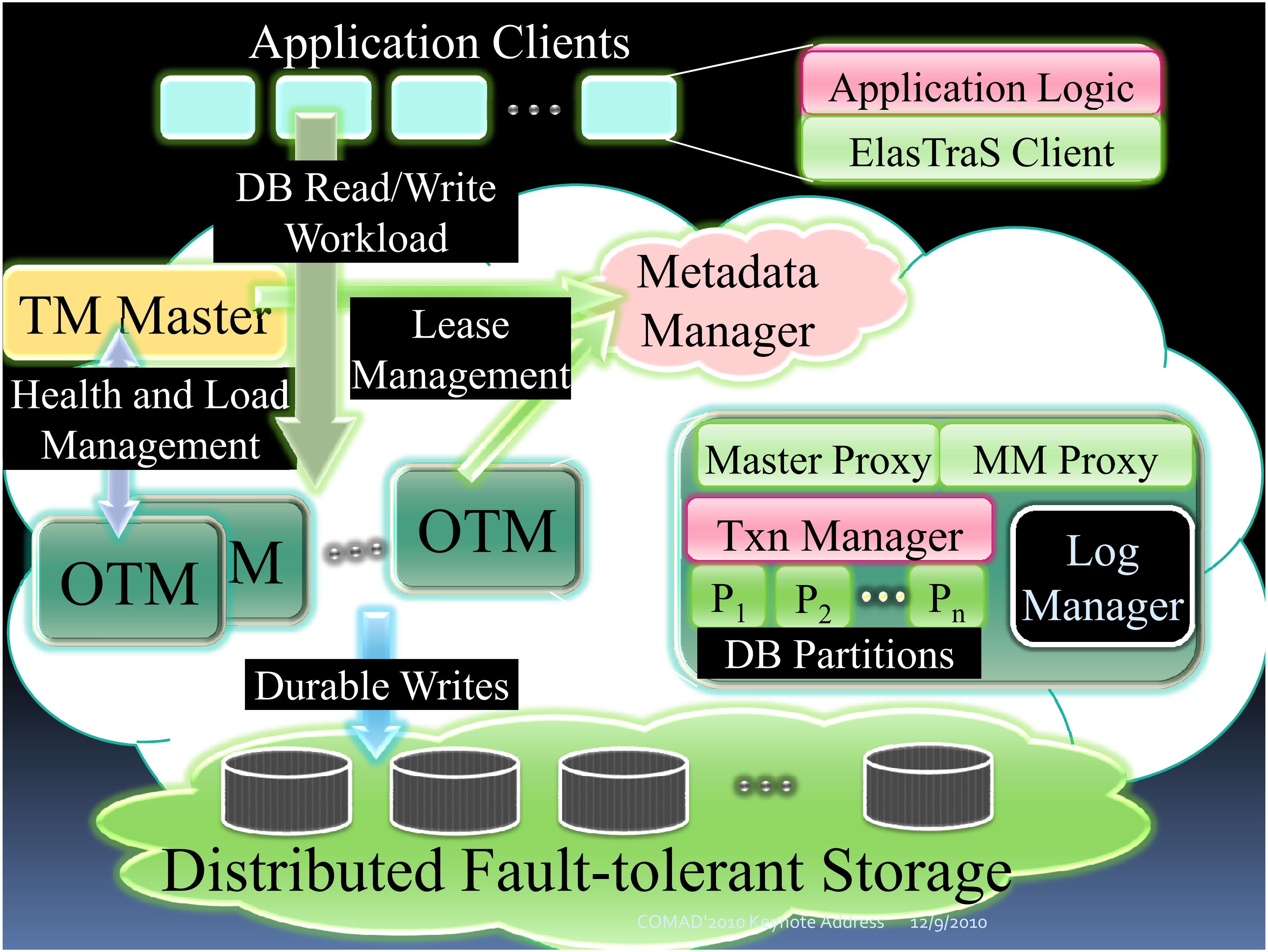
Data Fission: ElasTraS

Elastic Transaction Management

- Designed to make RDBMS cloud-friendly
- Database viewed as a collection of partitions
- Suitable for:
  - Large single tenant database instance
    - Database partitioned at the schema level
  - Multi-tenant database with large number of small databases
    - Each partition is a self contained database

Elastic Transaction Management

- Elastic to deal with workload changes
- Load balance partitions
- Recover from node failures
- Dynamic partition management
- Transactional access to database partitions

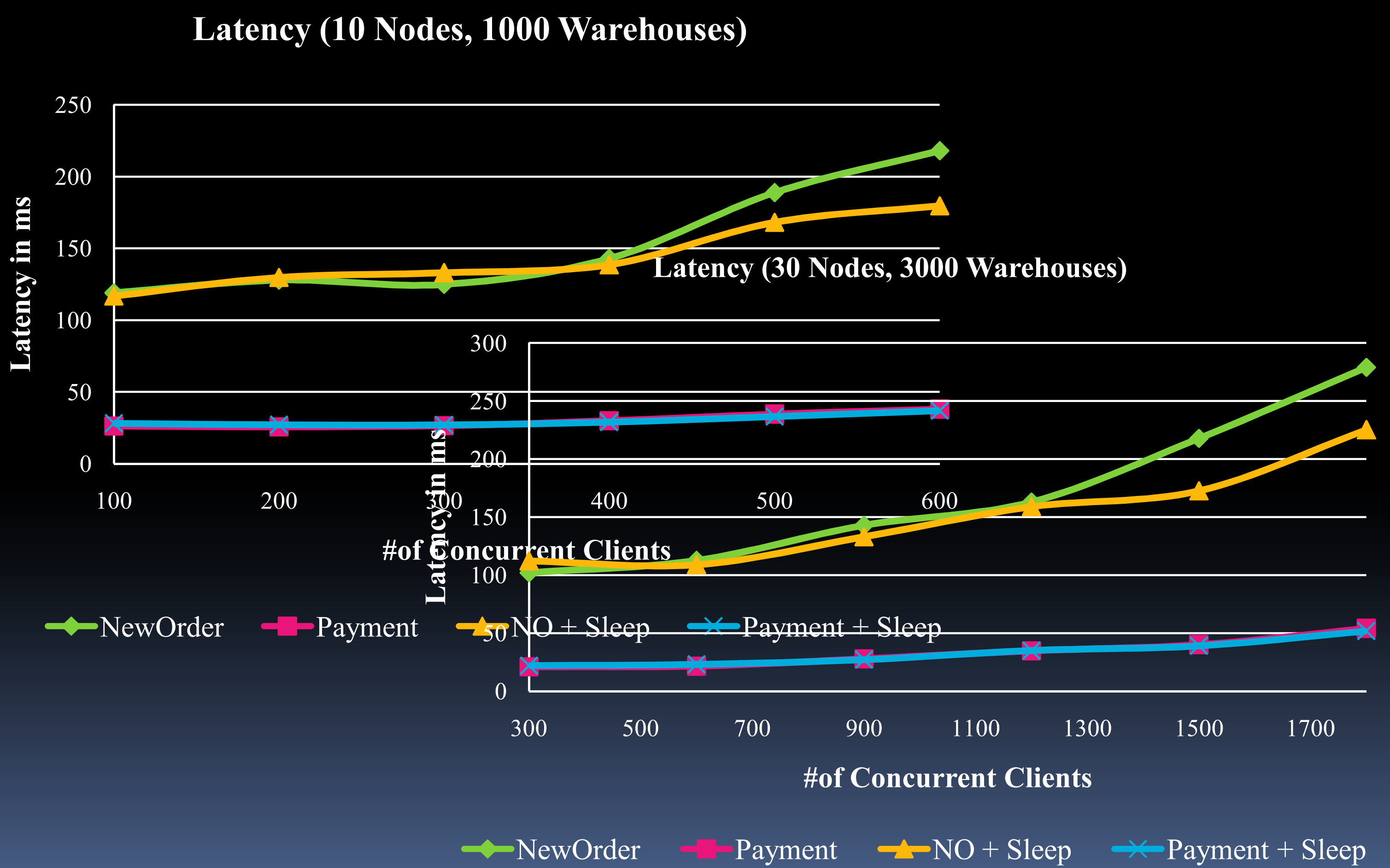


Application Clients
Application Logic
ElasTraS Client
DB Read/Write Workload
Metadata Manager
TM Master
Lease Management
Health and Load Management
OTM
M
OTM
Master Proxy
MM Proxy
Txn Manager
P_1
P_2
P_n
Log Manager
DB Partitions
Durable Writes
Distributed Fault-tolerant Storage

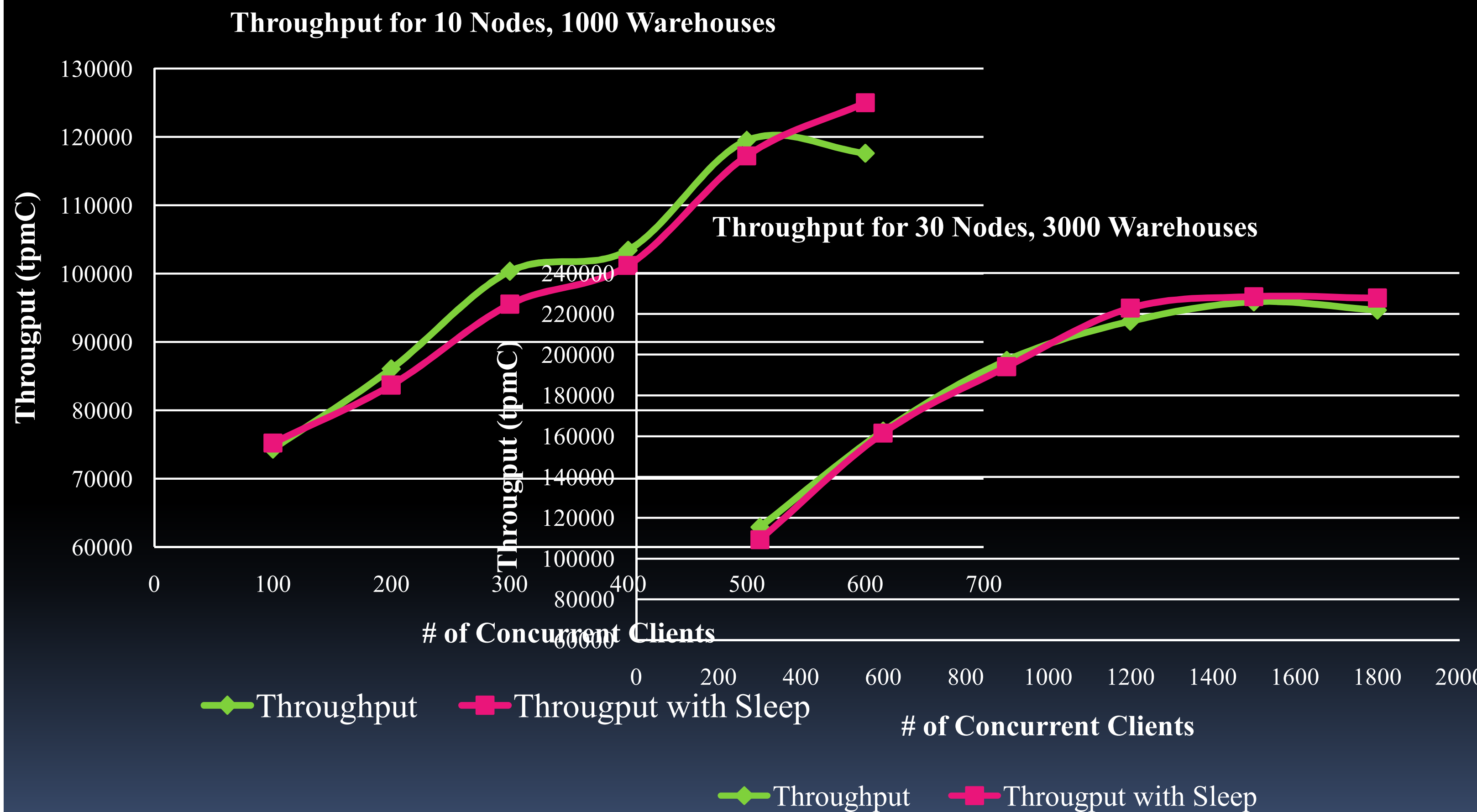
ElasTraS Experimental Setup

- Performed in Amazon EC2
- Used TPC-C for evaluation
- Cluster size: 10 to 30 nodes
- Number of concurrent clients: 100 to 1800
- Number of warehouses: 1000 to 3000
- Data size: ~1T
- Each node in the cluster: 8 cores, 7G RAM, 1.7T disk

Latency of Transactions



Throughput

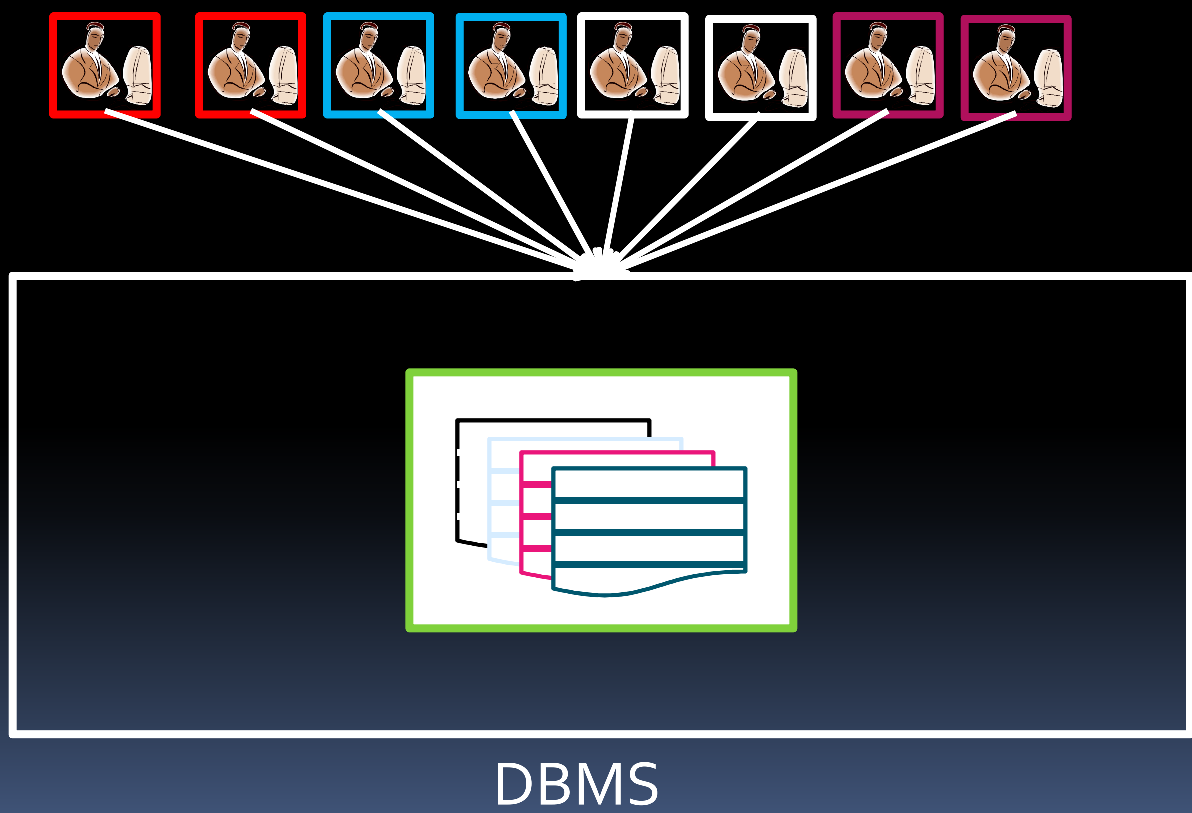

Throughput for 10 Nodes, 1000 Warehouses
Througput (tpmC)
130000
120000
110000
100000
90000
80000
70000
60000
0
100
200
300
400
500
600
700
# of Concurrent Clients
Throughput
Througput with Sleep
Throughput for 30 Nodes, 3000 Warehouses
Througput (tpmC)
240000
220000
200000
180000
160000
140000
120000
100000
80000
60000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
# of Concurrent Clients
Throughput
Througput with Sleep

Elasticity in the Cloud: Live Data Migration

Elasticity

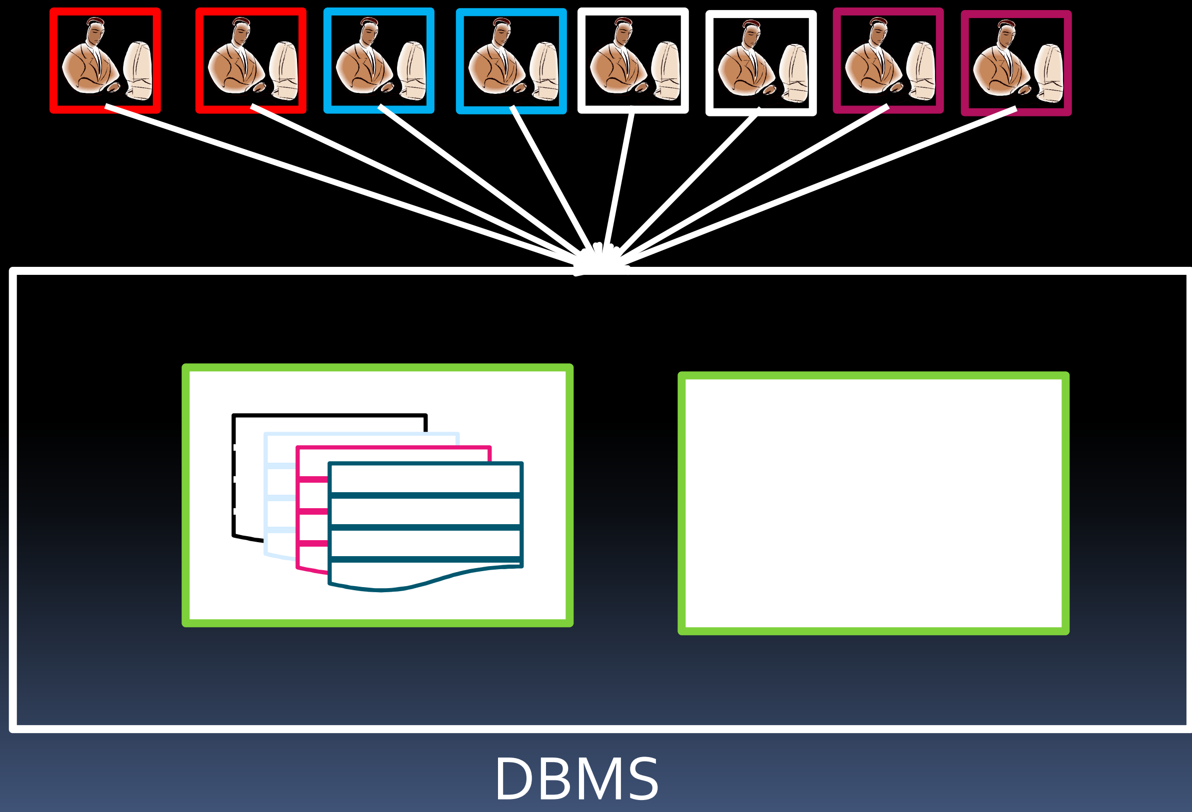
- A database system built over a pay-per-use infrastructure
  - Infrastructure as a Service for instance
- Scale up and down system size on demand
  - Utilize peaks and troughs in load
- Minimize operating cost while ensuring good performance

Elasticity in the Database Layer



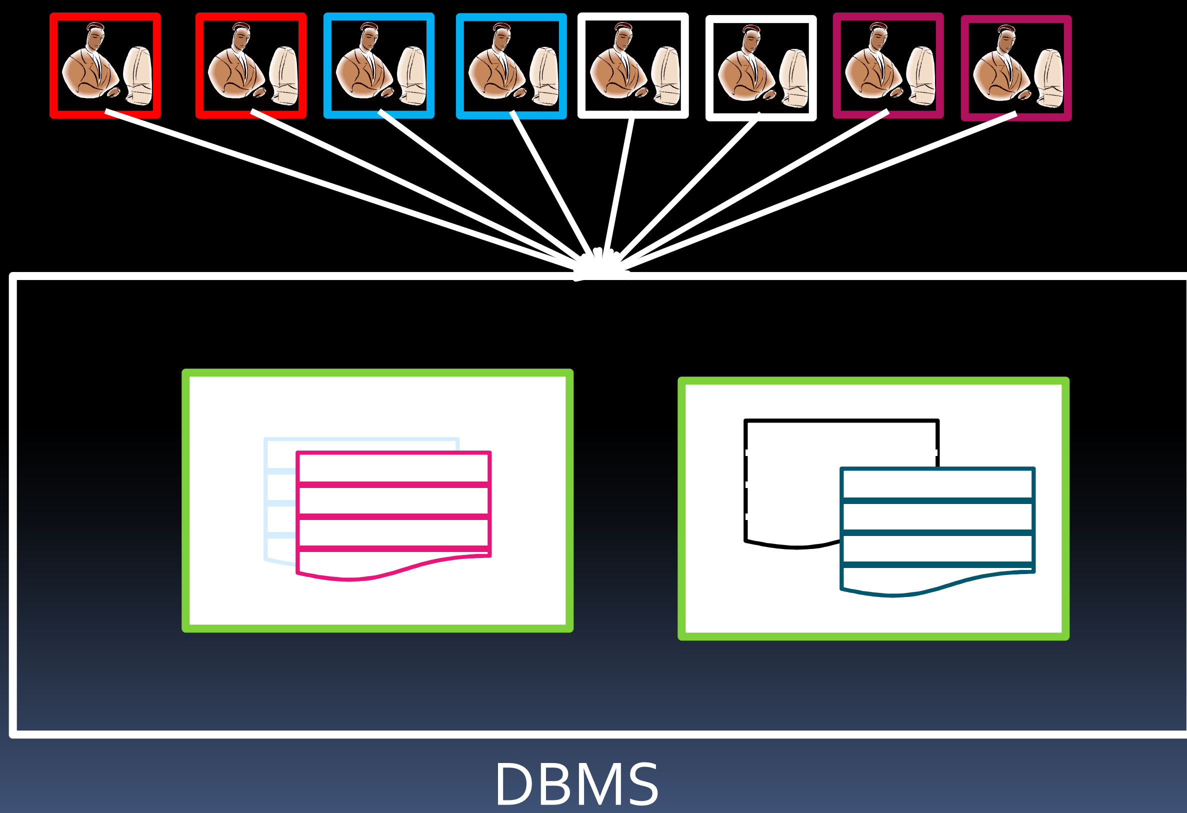
Elasticity in the Database Layer

Capacity expansion to deal with high load – Guarantee good performance



Elasticity in the Database Layer

Consolidation during periods of low load – Cost Minimization



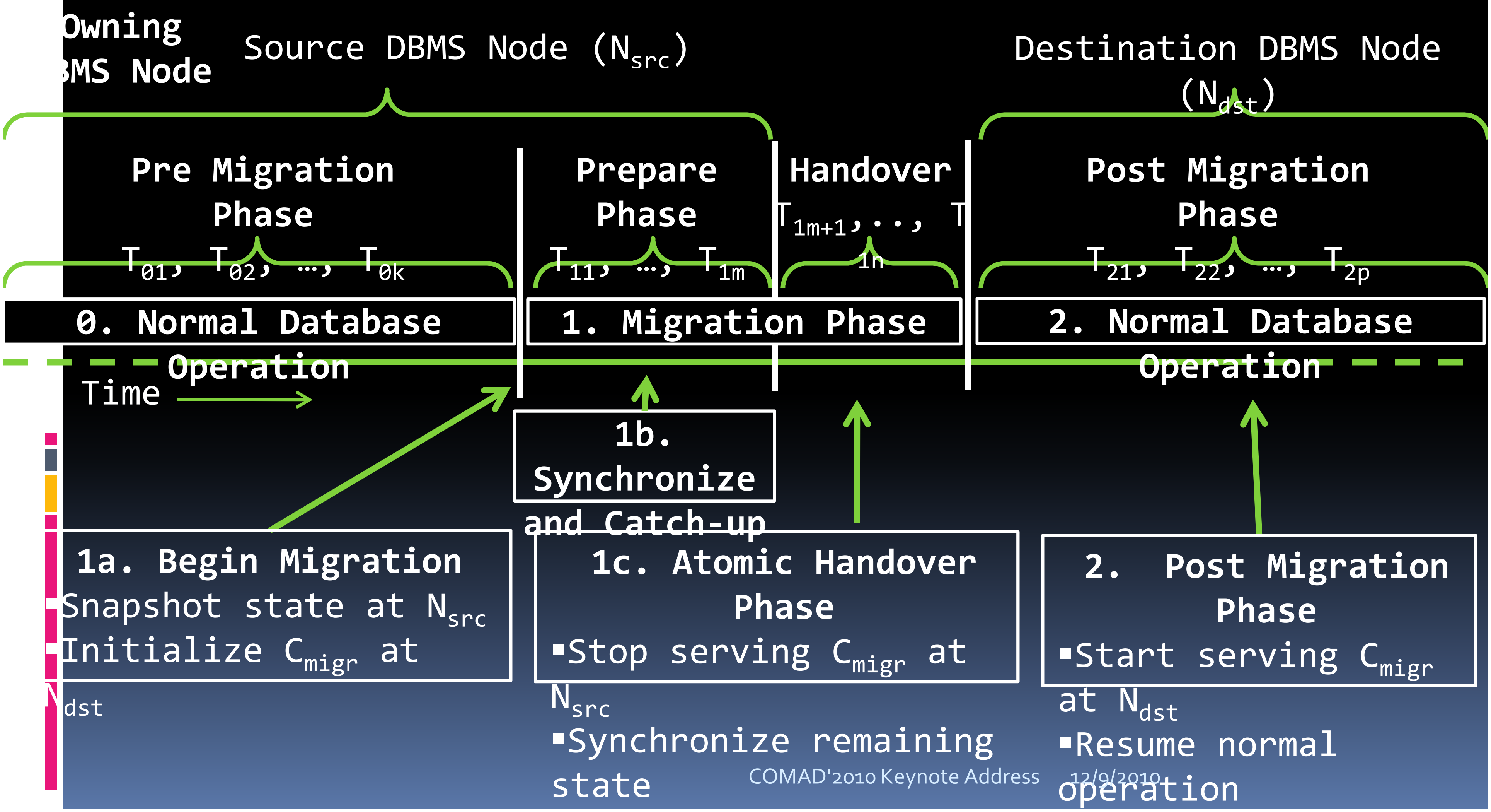
Live Database Migration

- All Elasticity induced dynamics in a Live system
- Minimal service interruption for migrating data fragments
  - Minimize operations failing
  - Minimize unavailability window, if any
- Negligible performance impact
- No overhead during normal operation
- Guaranteed safety and correctness

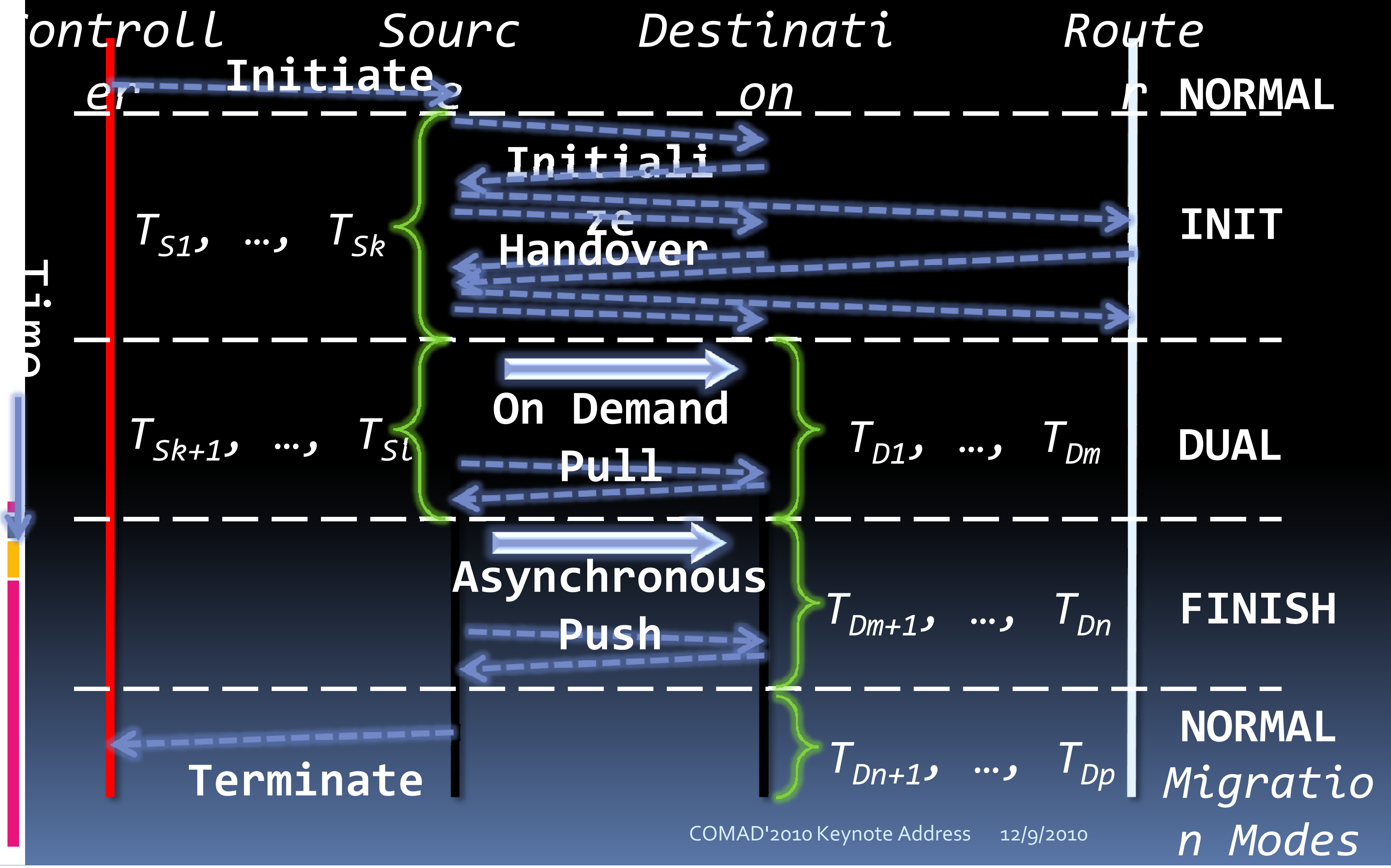
Live Database Migration
Current State – A teaser

- **Shared storage** architecture
  - **Proactive** state migration
    - No need to migrate persistent data
    - Migrate database cache and transaction state proactively
    - Ensures low performance impact
- **Shared nothing** architecture
  - **Reactive** state migration
    - Migrate minimal database state
    - Persistent image migrated asynchronously on demand
- More details to follow in the near future
  - A long presentation in its own merit

Migration in Shared Storage



Migration in Shared Nothing



Cloud Computing at UCSB & Santa Barbara

Research Activities

- Cloud Computing Infrastructures:
  - Rich Wolski, UCSB
- Cloud Programming Models, Applications and Languages:
  - ChadraKrintz, UCSB
- Data Management in Clouds:
  - Divy Agrawal &Amr El Abbadi, UCSB
- Security & Privacy Models in Clouds:
  - Giovanni Vigna& Christopher Kruegel, UCSB

Industrial Start-ups

- Cloud Computing Infrastructures:
  - Eucalyptus: Rich Wolski
- Cloud Computing Management:
  - RightScale: Thurston von Eicken
- Application Hosting in the Cloud:
  - AppFolio: Klaus Schauser

Concluding Remarks

- Data Management for Cloud Computing poses a fundamental challenges:
  - Scalability
  - Reliability
  - **Elasticity**
  - **Payment Model**
  - Data Consistency
- Cloud Computing in Emerging Markets:
  - Leveling the playing field in the context of IT
- Finally, the computing substrate will also evolve:
  - Multiple Data Centers
  - Leveraging the Network Edge (beyond content caching)

References

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An Alternative View