

Brokering Techniques for Managing Three-Tier Applications in Distributed Cloud Computing Environments

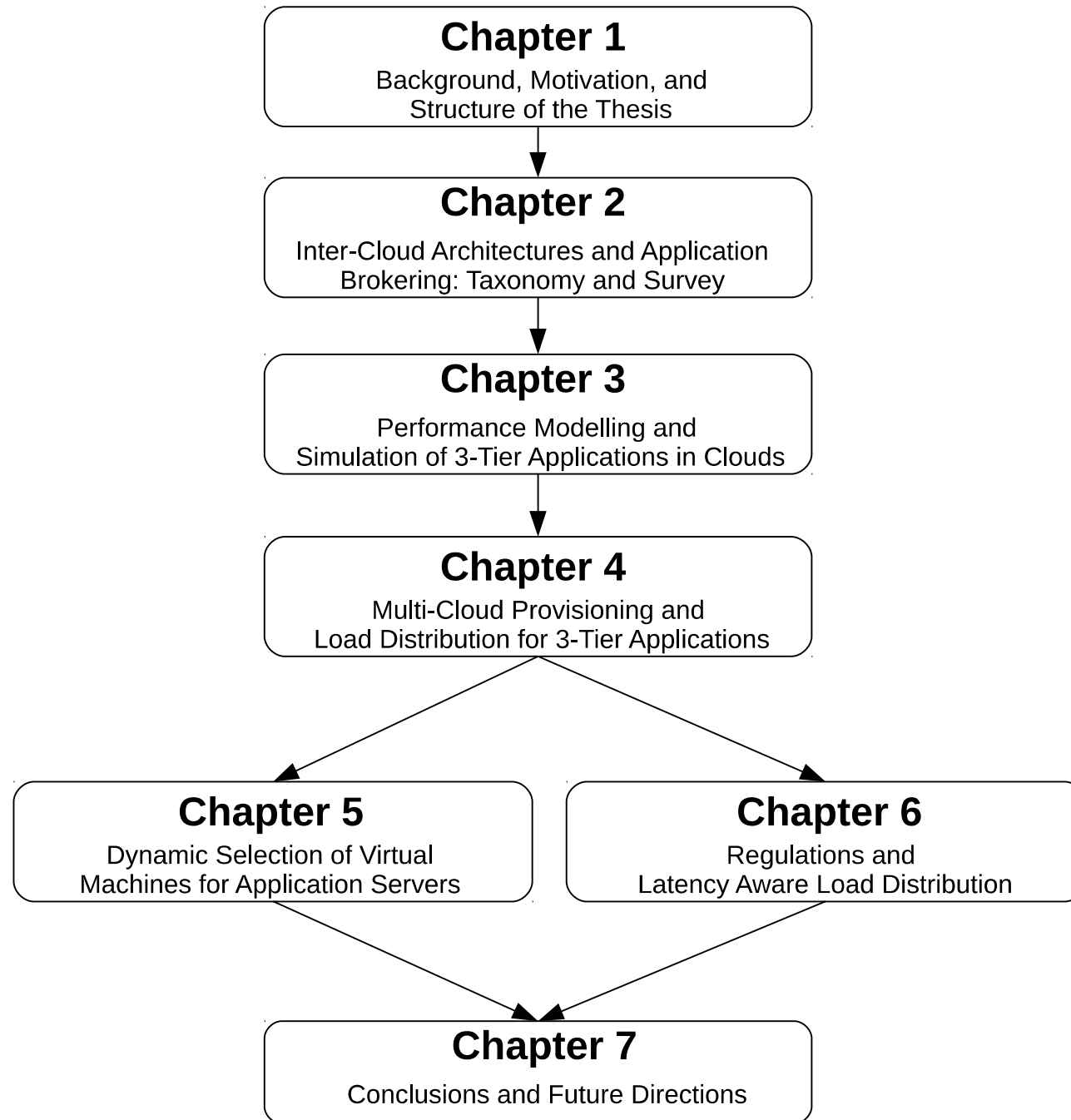


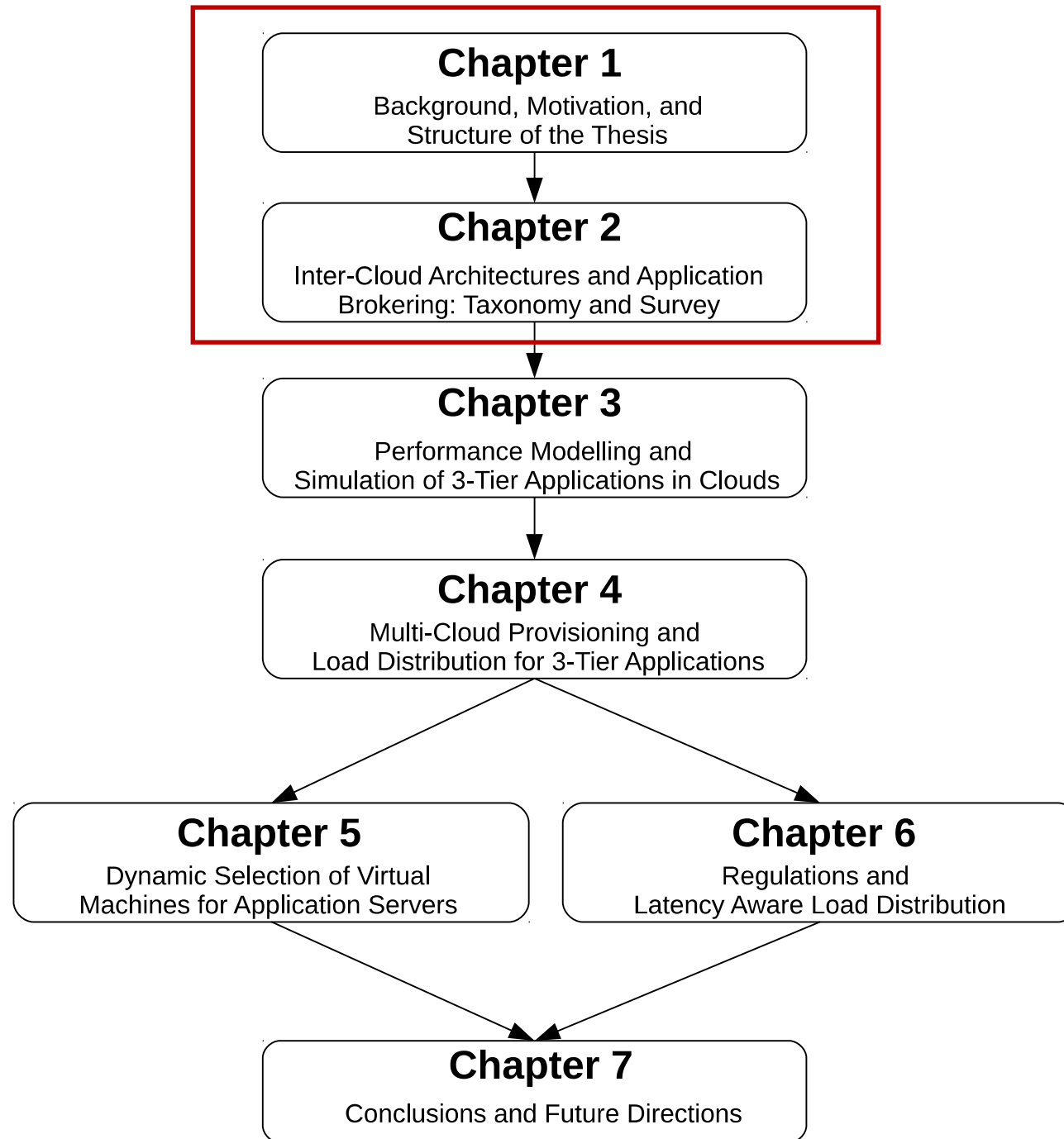
Nikolay Grozev

Supervisor: Prof. Rajkumar Buyya

7th October 2015

PhD Completion Seminar





Cloud Computing

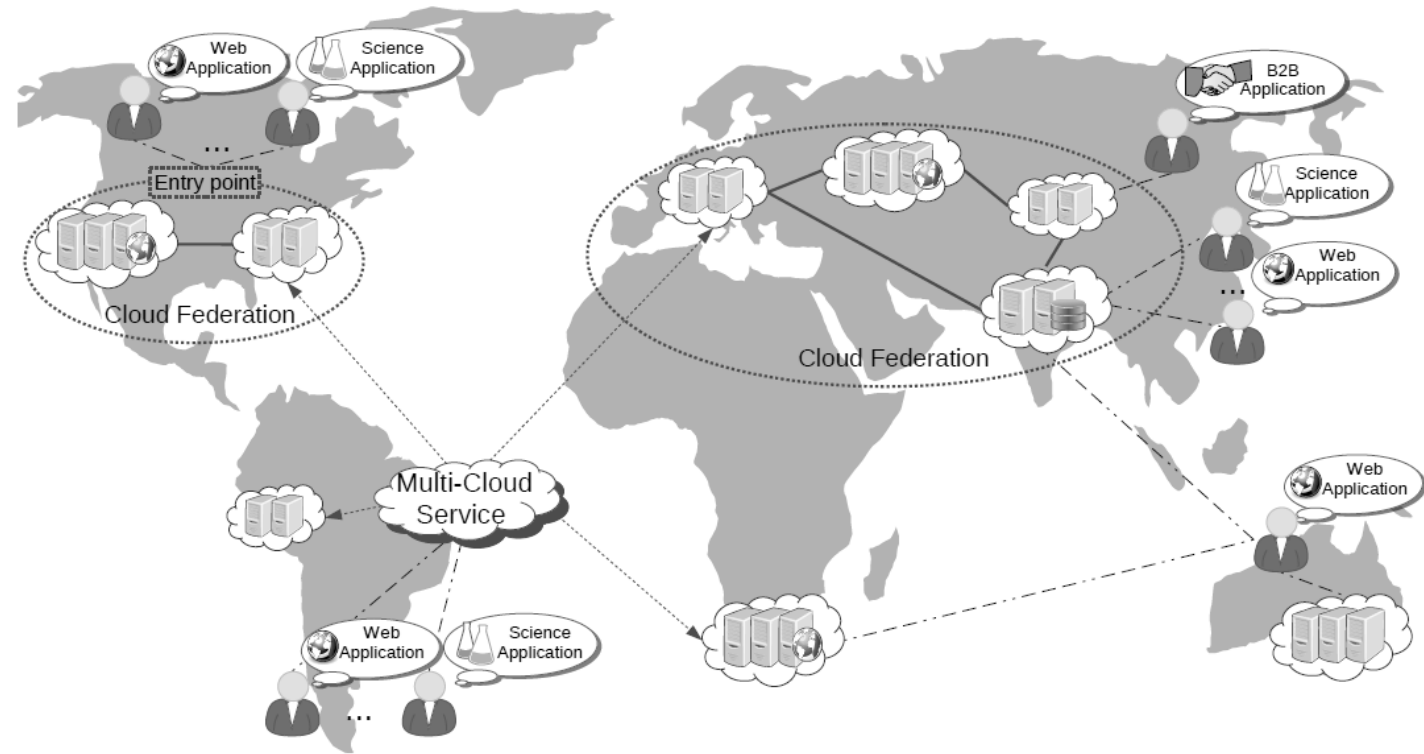
- Cloud computing ...
 - is a model for delivering virtualized computing resources over the Internet;
 - is supported by large scale data centres aggregating commodity hardware;
 - is subscription based (pay-as-you-go);
- Challenges - outages, security, etc.



www.google.com/datacenters/

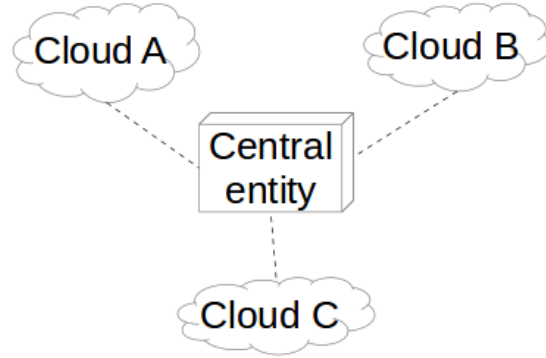
Inter-Cloud Computing

- Motivation:
 - Mitigate effects of cloud outage;
 - Diversify geographical locations;
 - Avoid vendor lock-in;
 - Latency.
- Solution - use multiple clouds

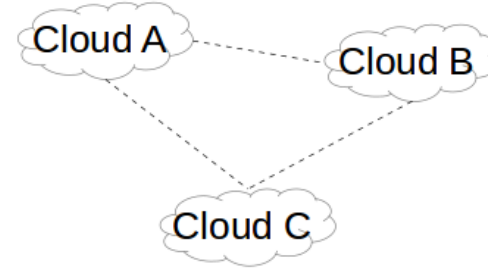


Inter-Cloud Computing: Architectures

Federations

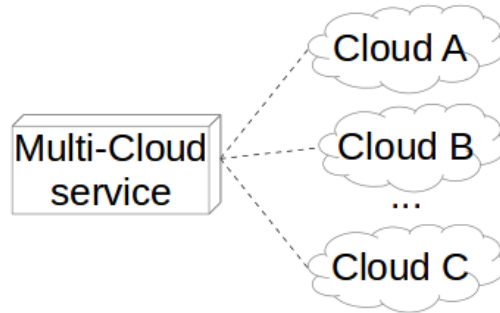


a) Centralised Inter-Cloud Federation. Clouds use a central entity to facilitate resource sharing.

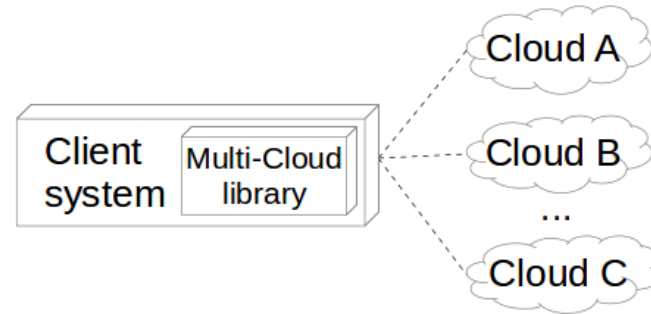


b) Peer-to-Peer Inter-Cloud Federation. Clouds collaborate directly with each other.

Multi-Clouds



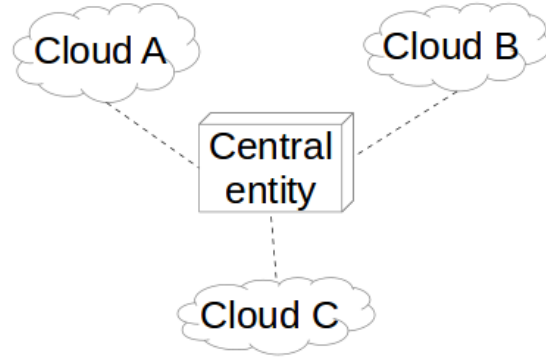
c) Multi-Cloud Service. Clients access multiple clouds through a service.



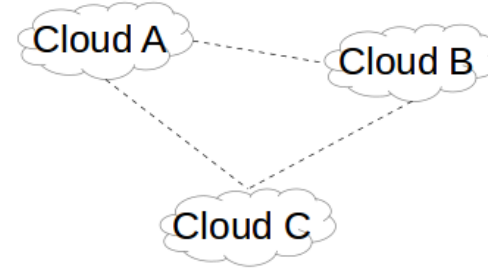
d) Multi-Cloud Library. Clients develop their own brokers by using a unified cloud API in the form of a library.

Inter-Cloud Computing: Architectures

Federations

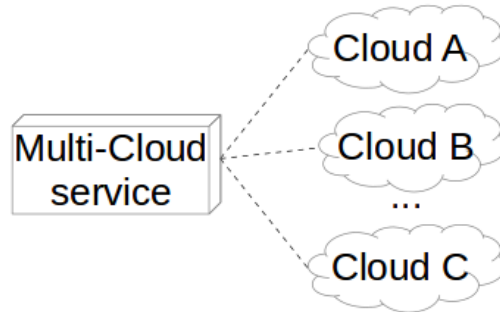


a) Centralised Inter-Cloud Federation. Clouds use a central entity to facilitate resource sharing.

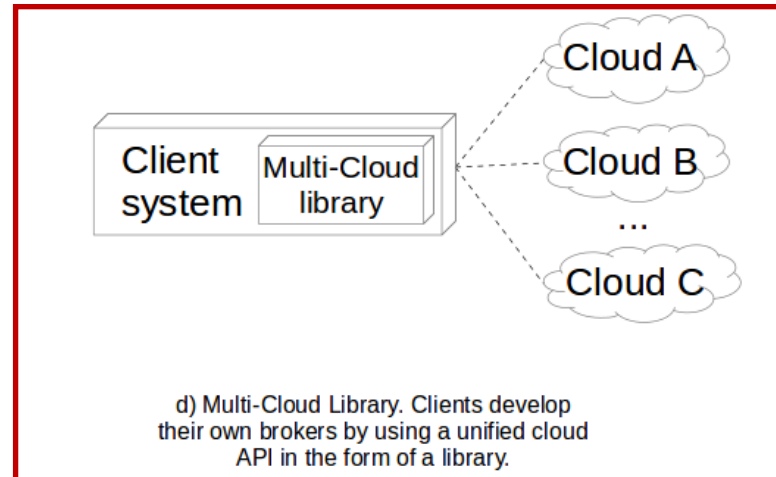


b) Peer-to-Peer Inter-Cloud Federation. Clouds collaborate directly with each other.

Multi-Clouds

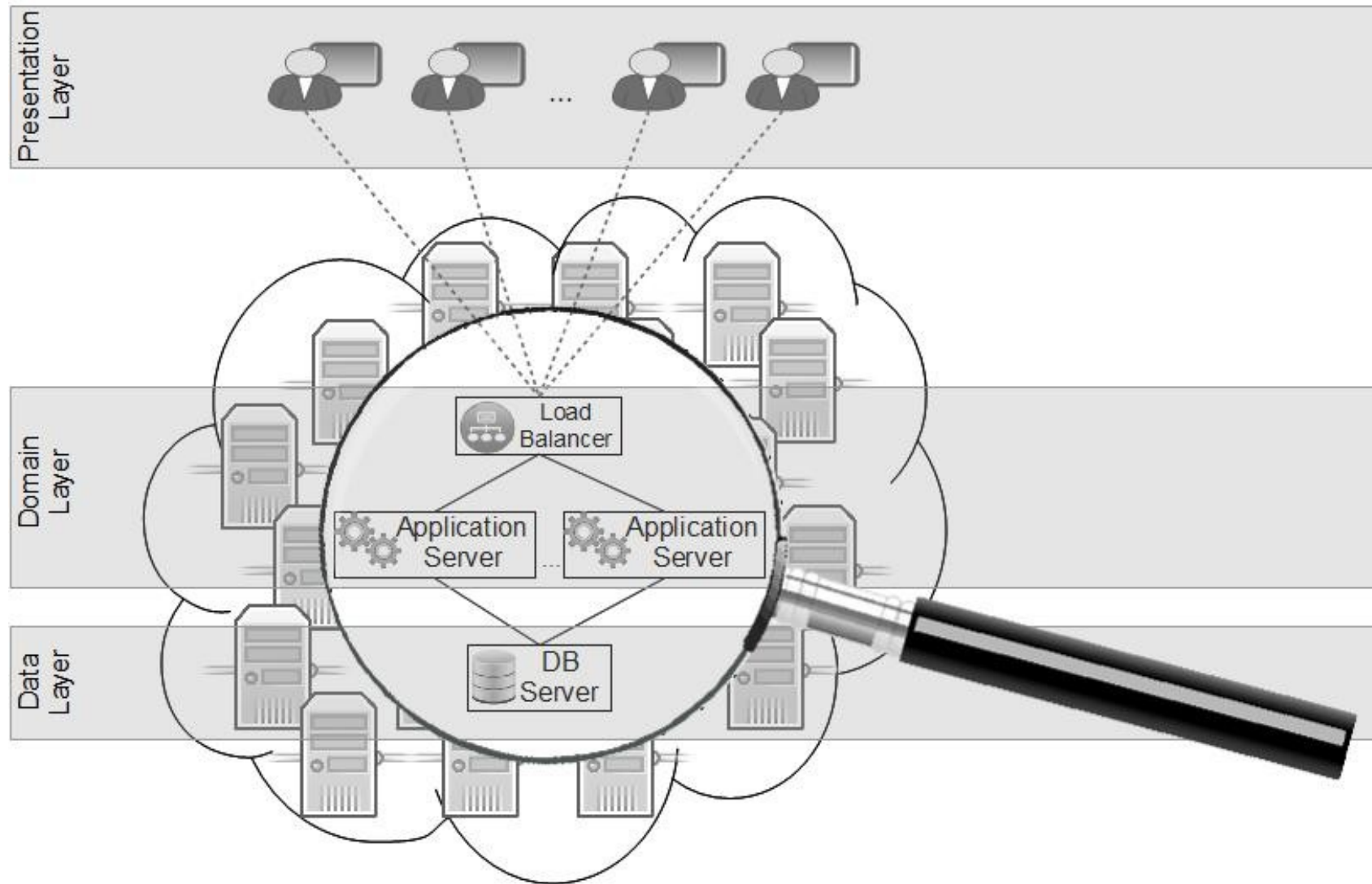


c) Multi-Cloud Service. Clients access multiple clouds through a service.

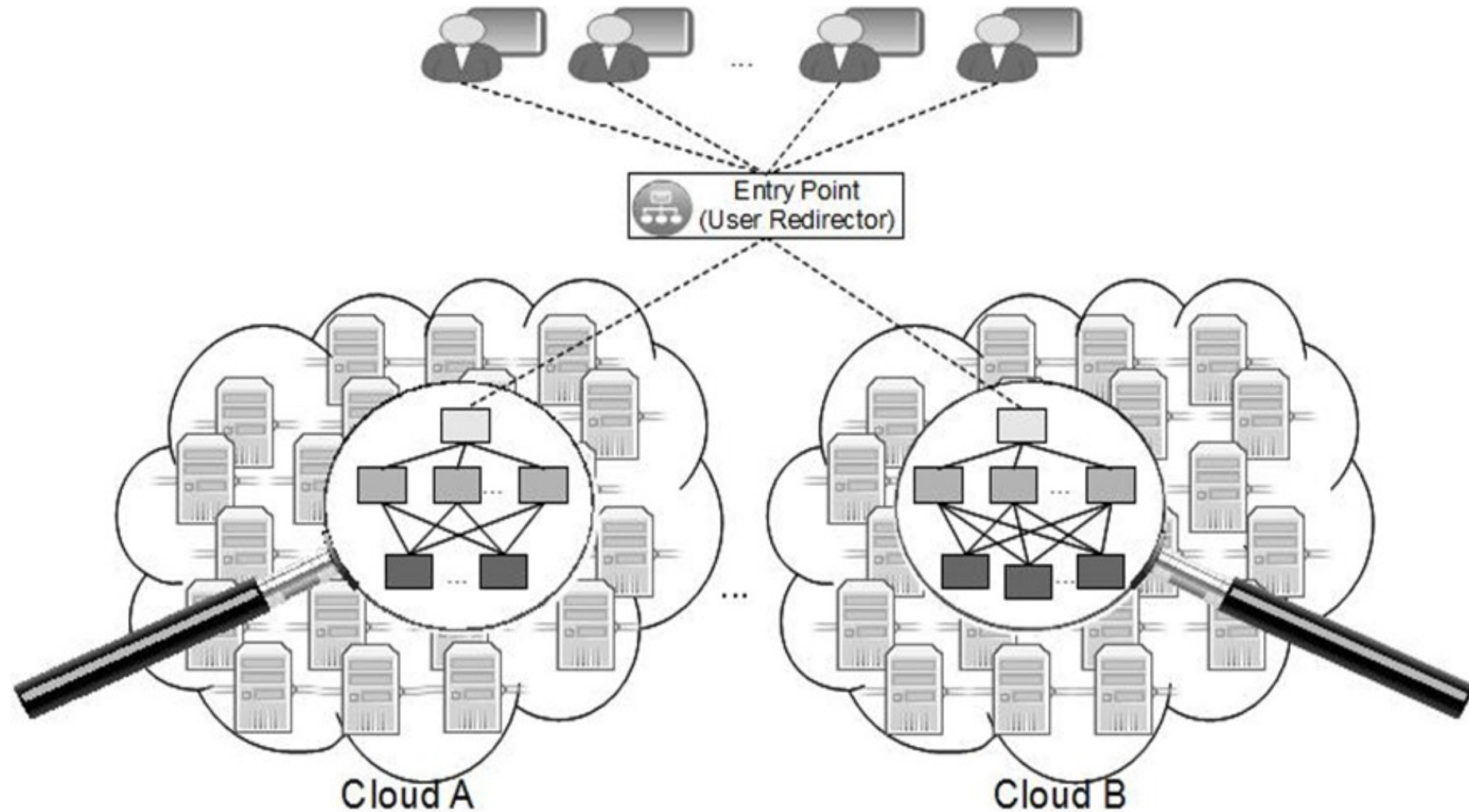


d) Multi-Cloud Library. Clients develop their own brokers by using a unified cloud API in the form of a library.

3-Tier applications in cloud



3-Tier applications in a Multi-Cloud

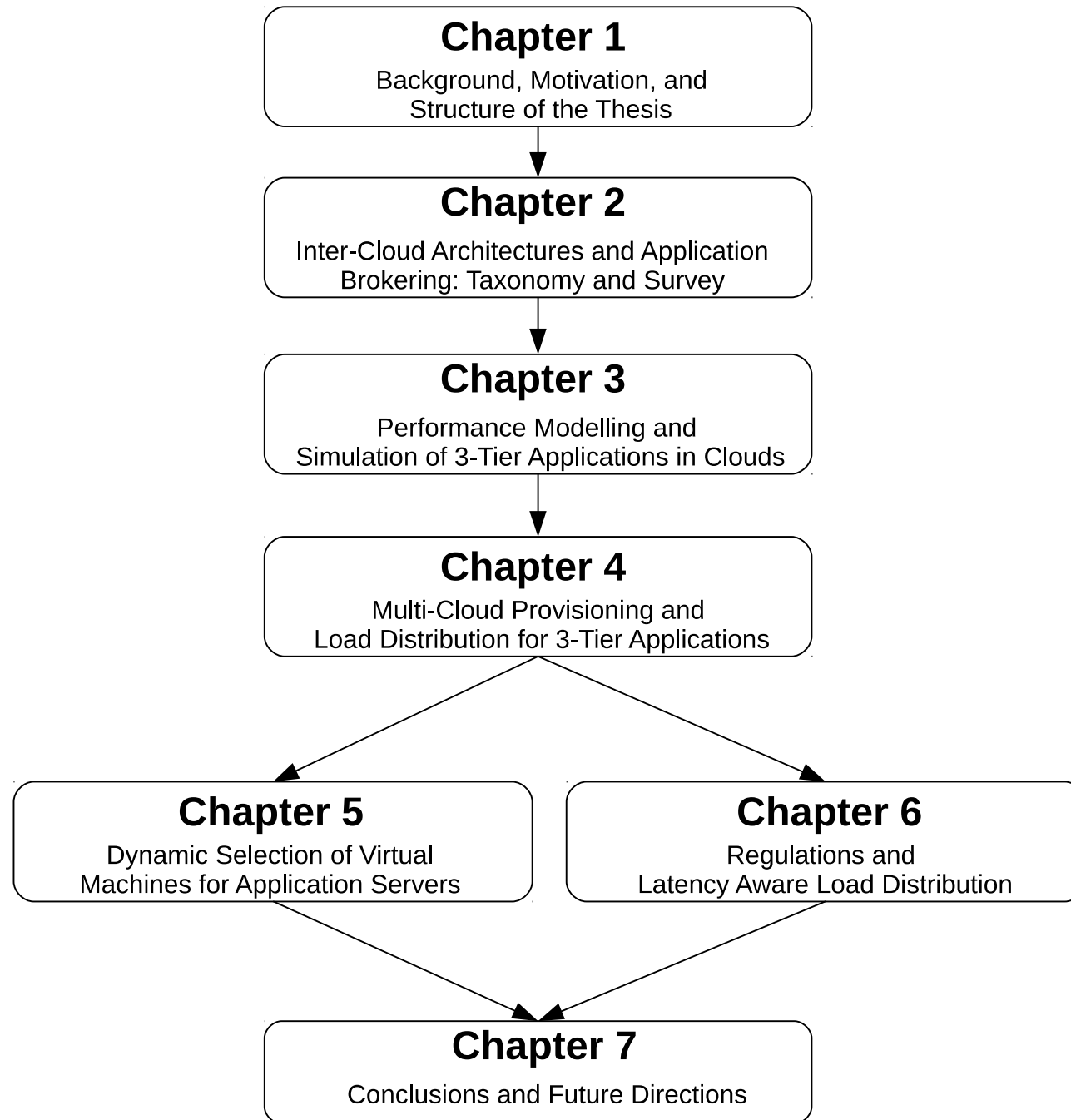


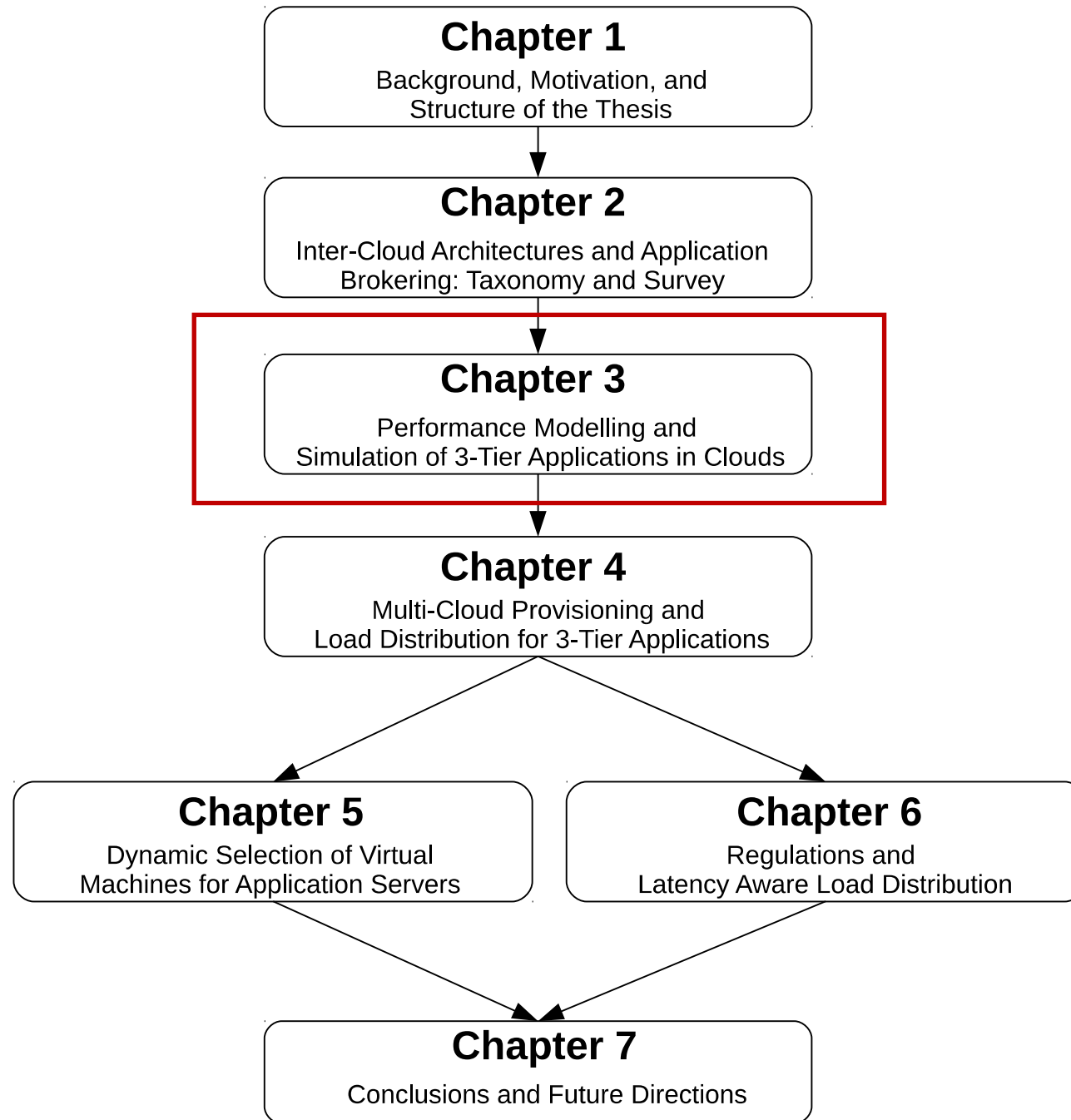
Research Question

- How to broker 3-Tier applications in a Multi-Cloud environment, considering Quality of Service (QoS) requirements in terms of:
 - **Network Latency Awareness** — end users should be served near their geographical location to experience better responsiveness;
 - **Pricing Awareness**— the overall costs for hosting should be minimized;
 - **Legislation/Policy Awareness** — legal and political considerations about where individual users are served should be honoured;
 - **Code Re-usability** — few changes to existing 3-Tier applications should be made. The technical overhead of moving an existing 3-Tier system to a Multi-Cloud should be minimal.

Research Question

- How to **broker** 3-Tier applications in a Multi-Cloud environment, considering Quality of Service (QoS) requirements in terms of:
 - **Network Latency Awareness** — end users should be served near their geographical location to experience better responsiveness;
 - **Pricing Awareness** — the overall costs for hosting should be minimized;
 - **Legislation/Policy Awareness** — legal and political considerations about where individual users are served should be honoured;
 - **Code Re-usability** — few changes to existing 3-Tier applications should be made. The technical overhead of moving an existing 3-Tier system to a Multi-Cloud should be minimal.

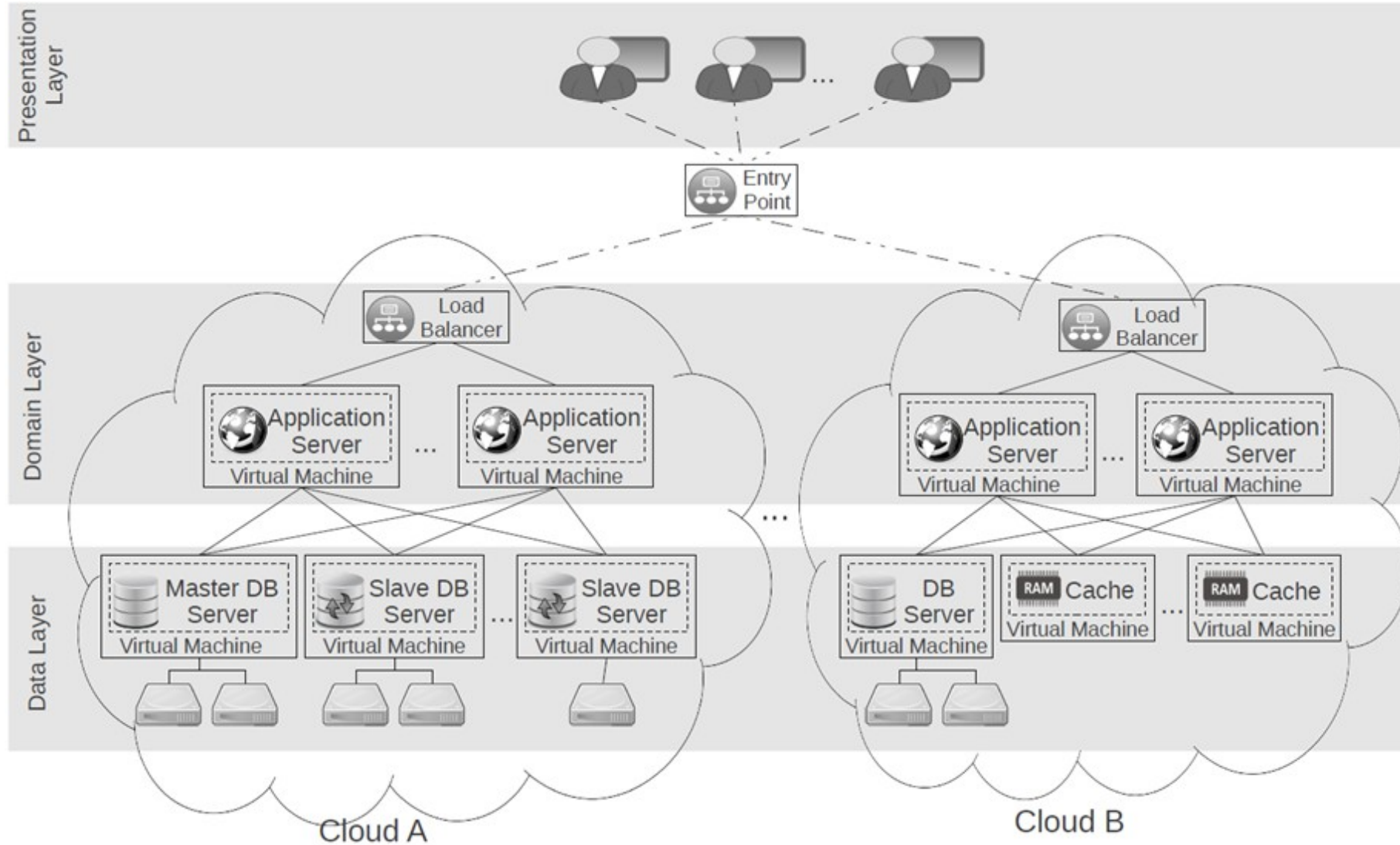




Background and Objectives

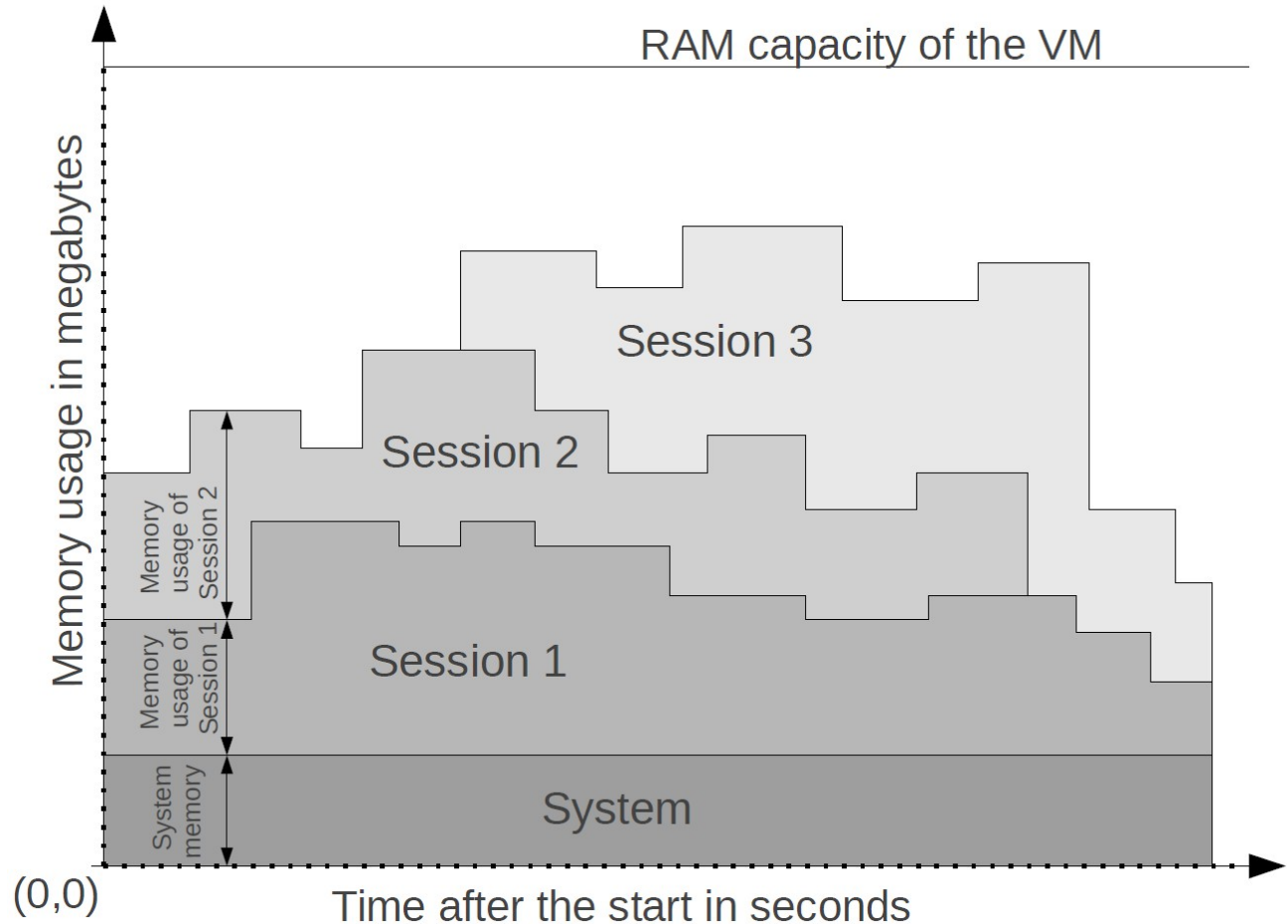
- Distributed systems simulation has already fostered the research efforts;
- Existing simulators can be used to simulate batch processing and infrastructure utilisation workloads only;
- Previous works on multi-tier application modelling have series of shortcomings;
- **Goal** – define a flexible and coarse grained model and simulator for 3-Tier applications in one and multiple clouds.

Target Scenario

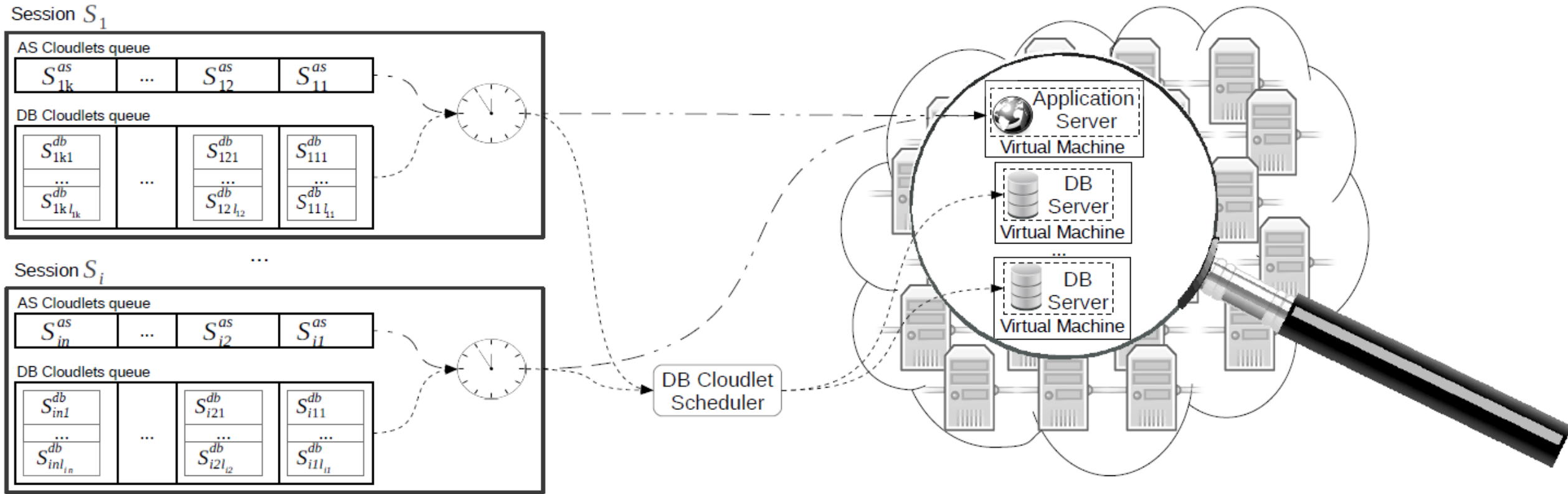


Session Performance Model

- *AS Memory Load* - $\phi_{as}(t)$
- *AS CPU Load* - $\nu_{as}(t)$
- *DB Memory Load* - $\phi_{db}(t, d_i)$
- *DB CPU Load* - $\nu_{db}(t, d_i)$
- *DB Disk I/O Load* - $\sigma_{db}(t, d_i)$
- *Step Size* - δ
- *Session arrival model:*
 - *Model each session type separately*
 - *Poisson distribution of a frequency function* - $Po(\lambda(t))$



Simulator Implementation



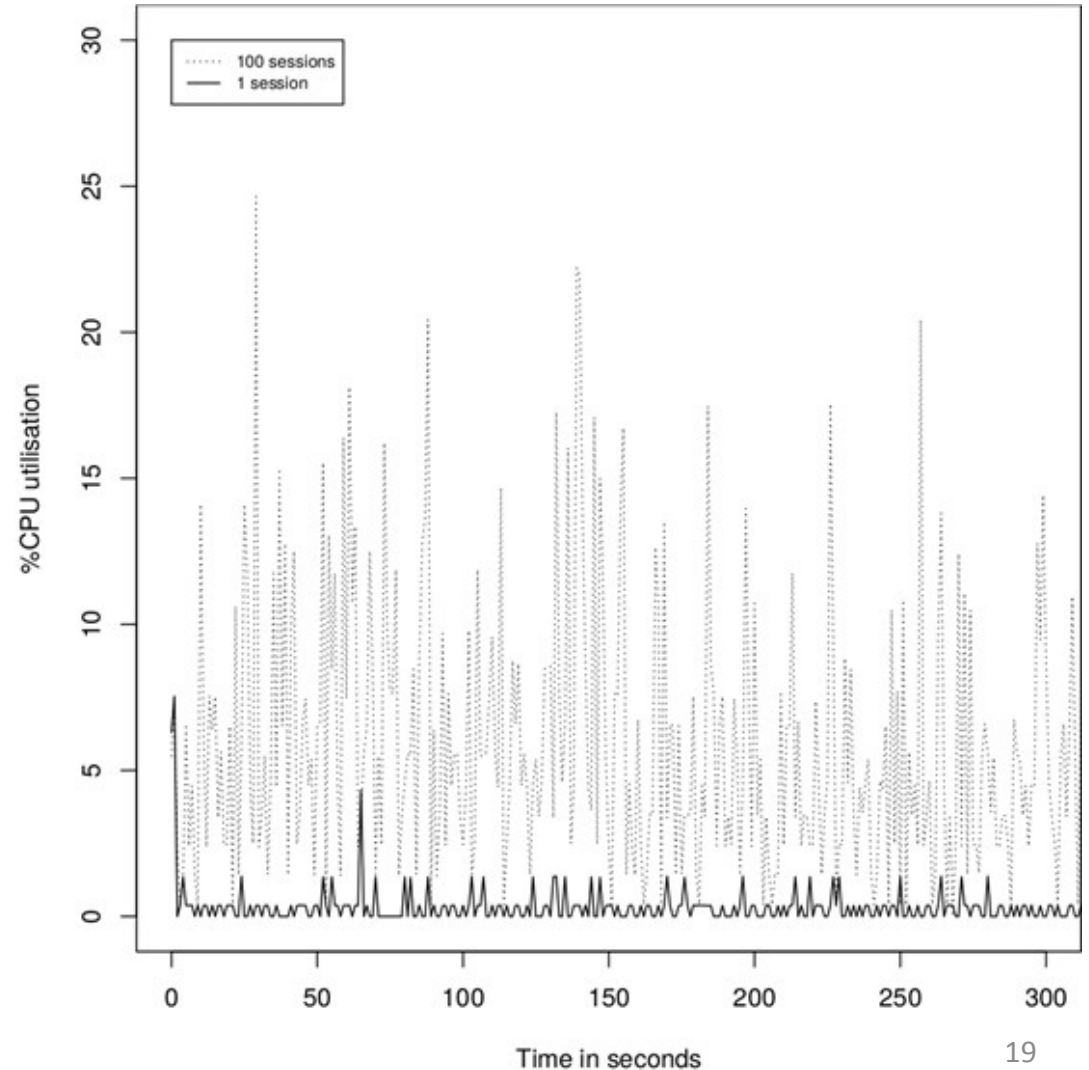
Validation Environment

- *3-Tier app. designed after ebay;*
- *Client application, generating requests;*
- *Transition table;*
- *"Think times";*
- *Experiments;*
 - *Benchmarking;*
 - *Experiment 1 - static workload on local infrastructure;*
 - *Experiment 2 - dynamic workload on local infrastructure (DC1) and EC2(DC2);*

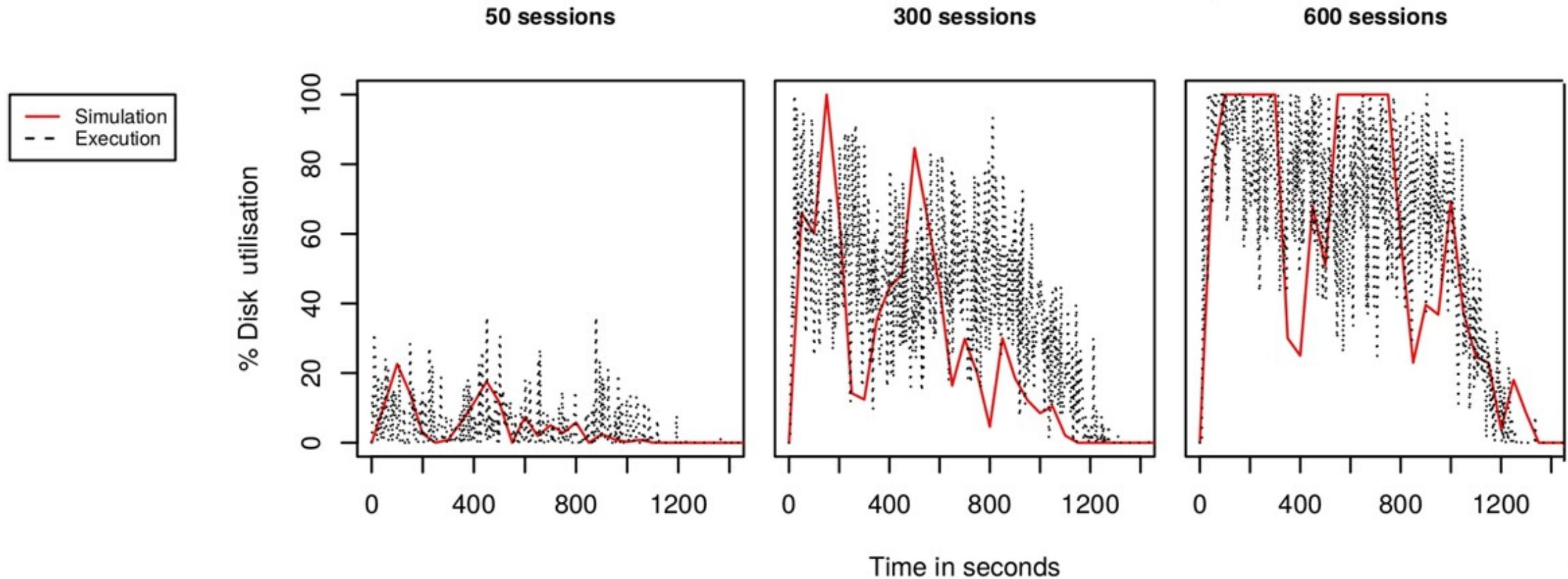


Model Extraction - Example

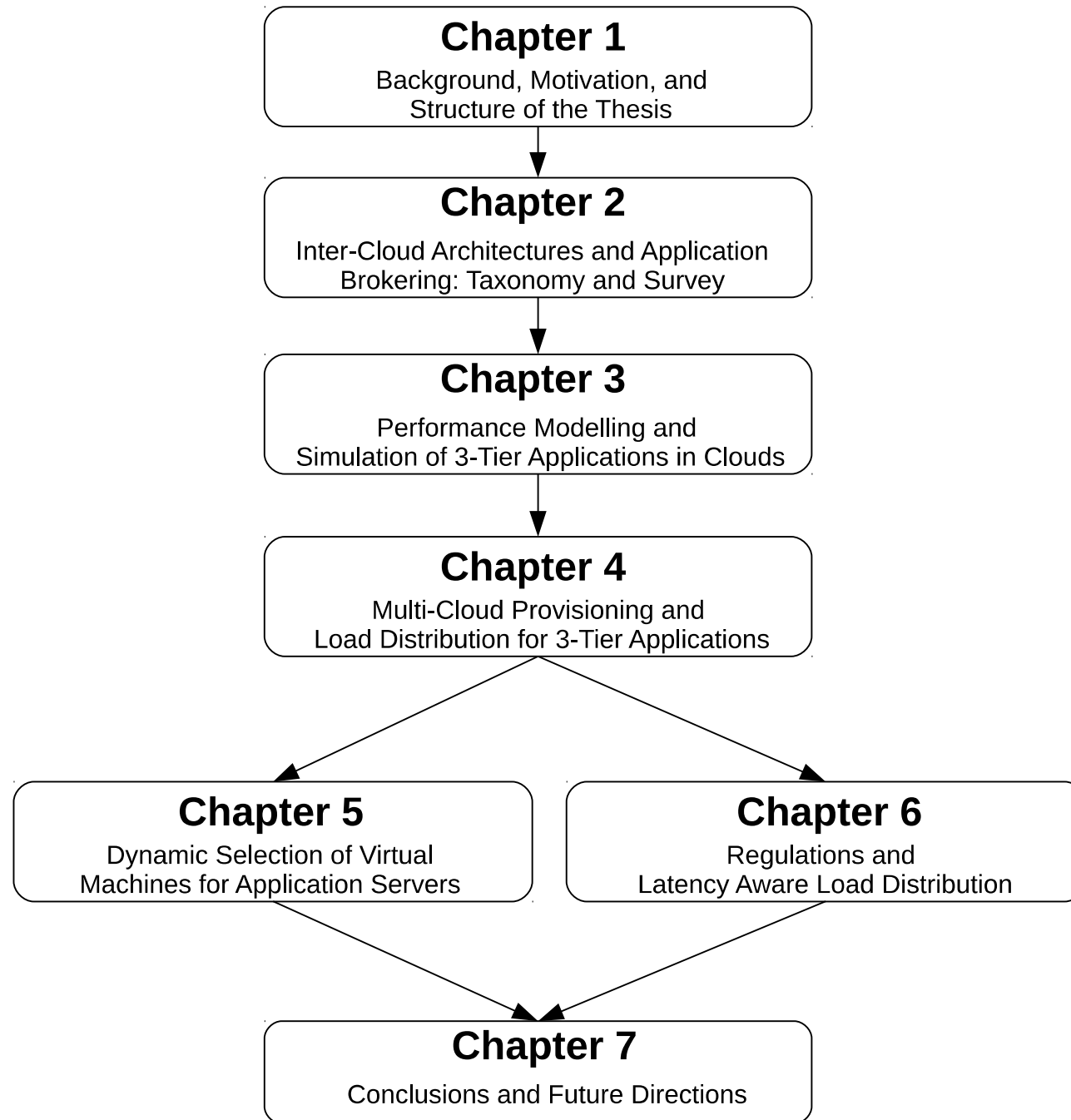
- Execute 2 Experiments:
 - With 1 user;
 - With 100 users;
- Compute the “average” session behavior;
- Standard Linux utilisation measurement tools.

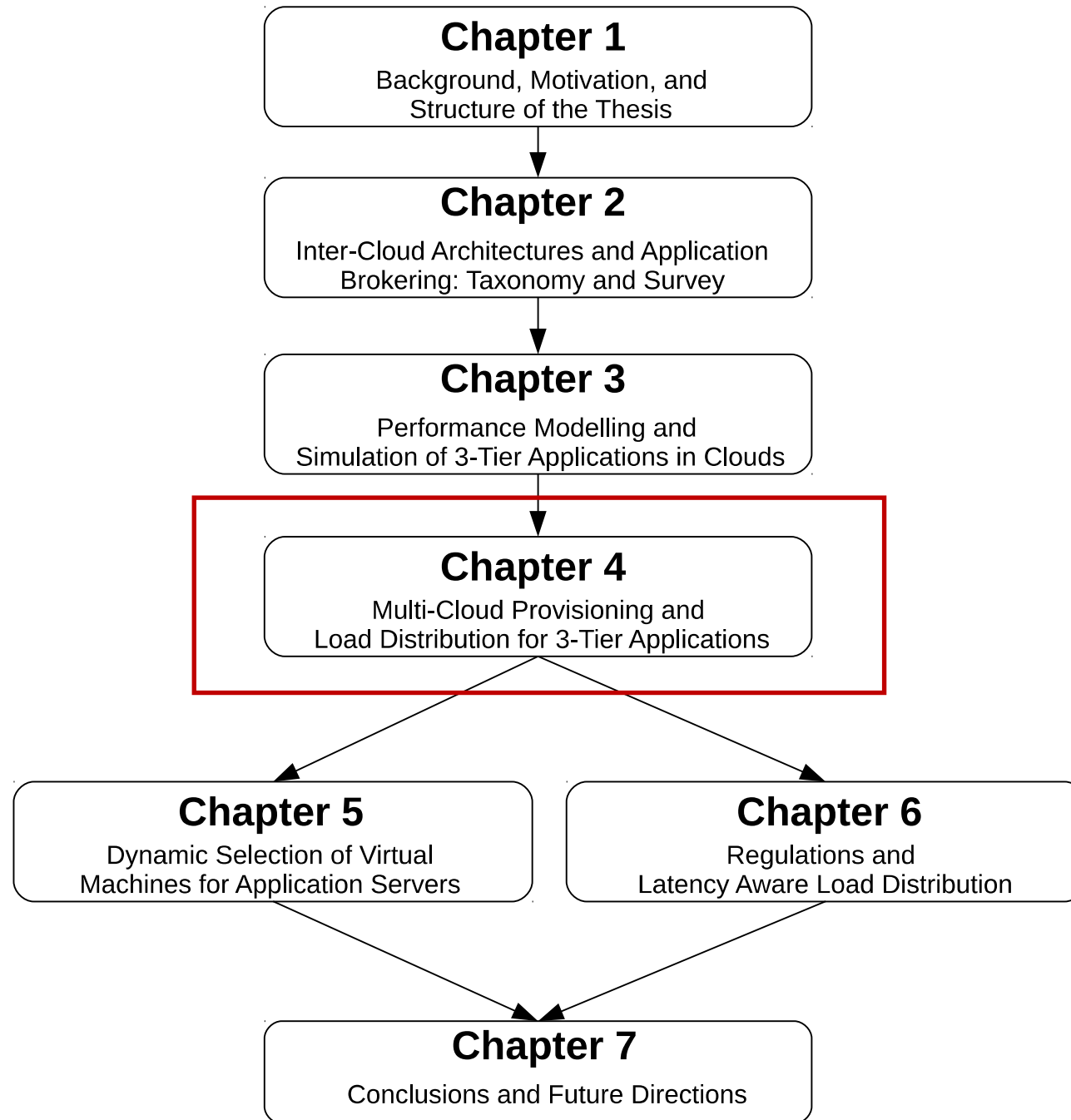


Experiment 1: Static Workload in 1 cloud



Predicted and actual disk I/O utilisation of the DB server with 50, 300, and 600 simultaneous sessions in Experiment 1.

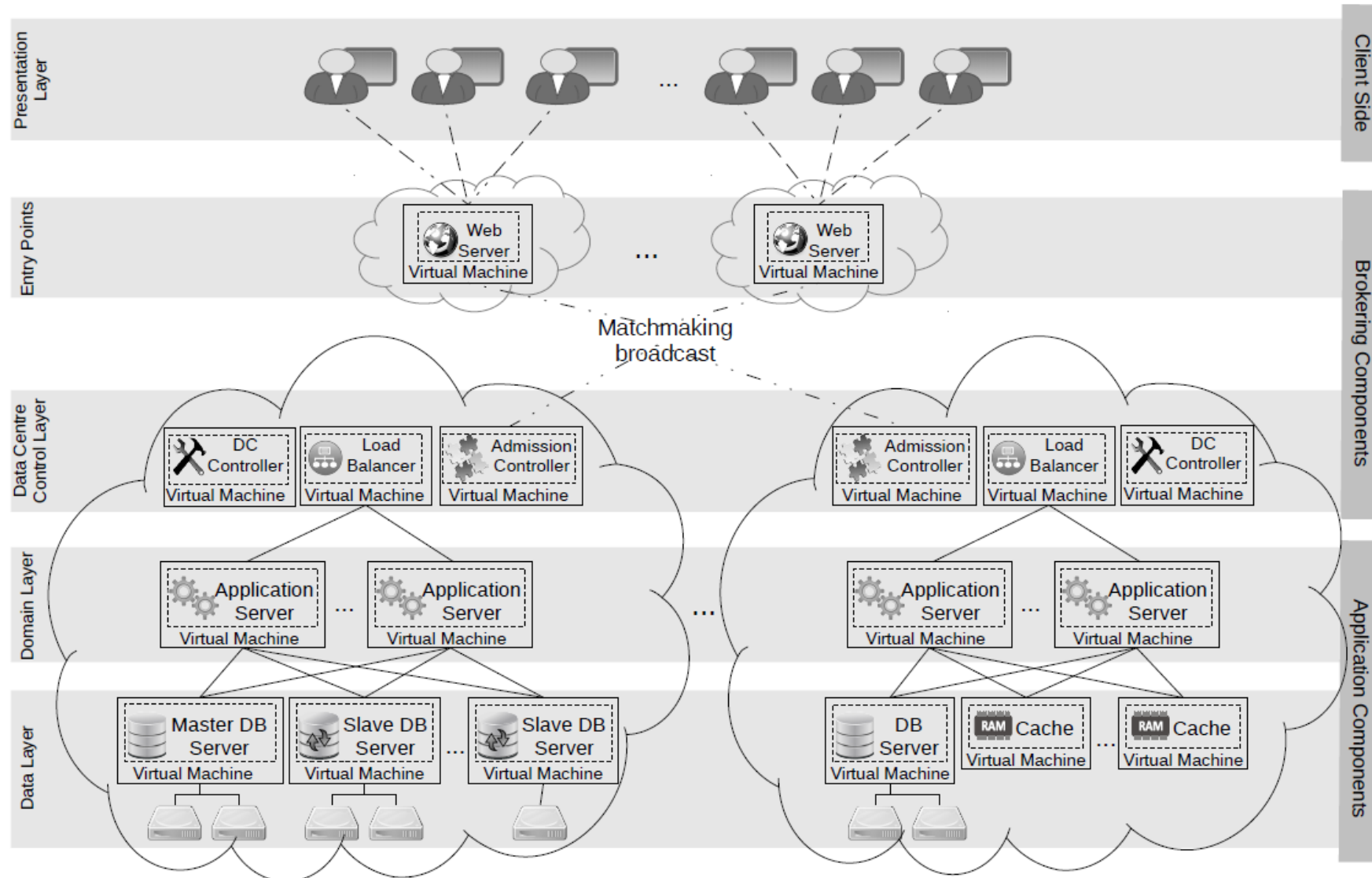




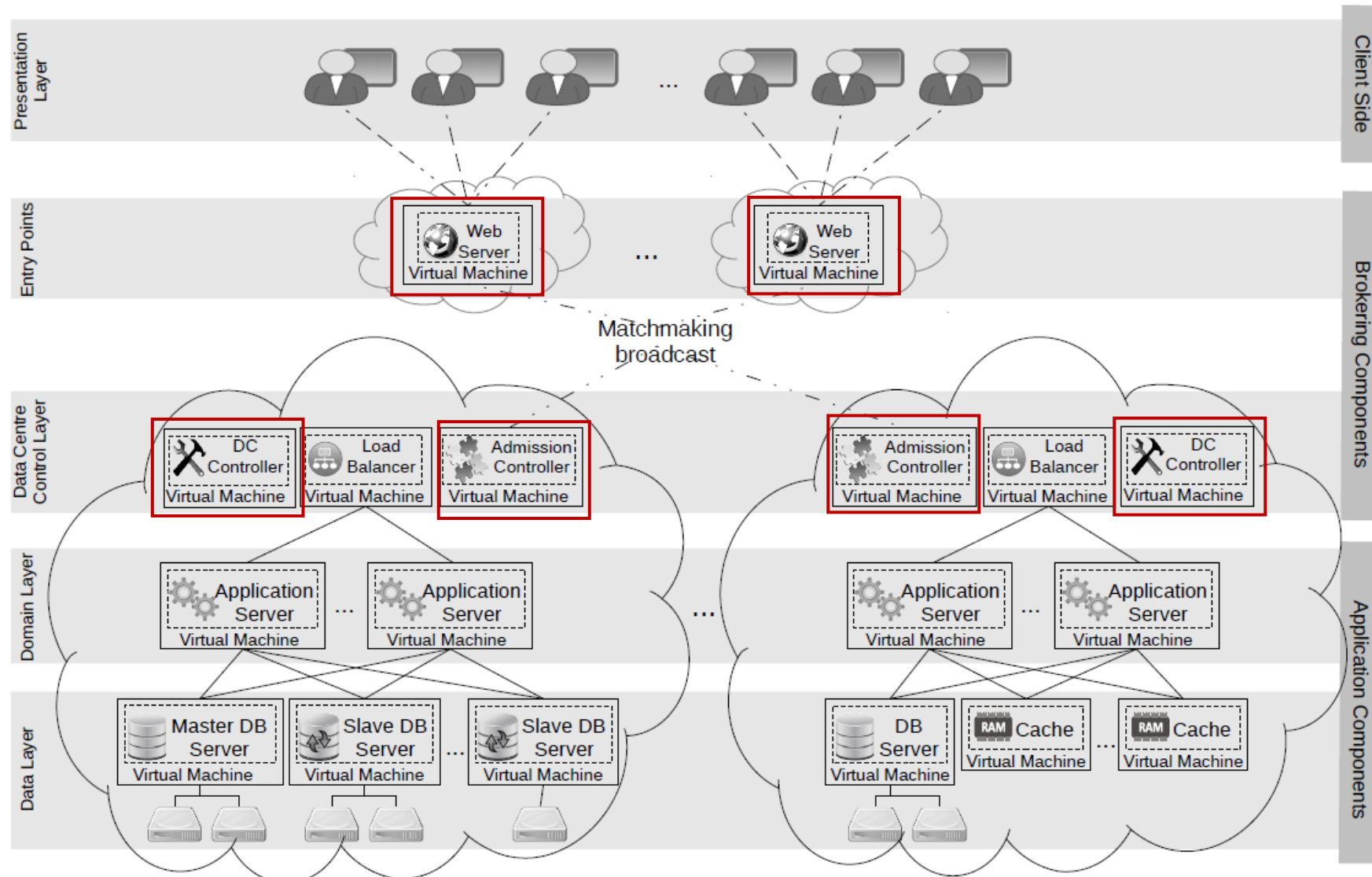
Background and Objectives

- Current Multi-Cloud 3-Tier have limitations manage resources and workload suboptimally;
- They do not consider essential regulatory requirements;
- **Goal**: propose a general and flexible architecture that honours key non-functional requirements and optimises cost and latency.

Overall Architecture



Overall Architecture



Load Balancing and Autoscaling

- Load balancing algorithm – sticky or not?
 - Monitor VM utilization;
 - Free underutilized VMs.
- Autoscaling algorithm:
 - Repeated periodically;
 - Number of pre-provisioned instances;
 - Do not terminate before billing time is over;

Load Balancing and Autoscaling

- Load balancing algorithm – sticky or not?
 - Monitor VM utilization;
 - Free underutilized VMs.
- Autoscaling algorithm:
 - Repeated periodically;
 - Number of pre-provisioned instances;
 - Do not terminate before billing time is over;

ALGORITHM 3: Load Balancing Algorithm.

input : $s_i, th_{cpu}, th_{ram}, VM_{as}$

```
1 sortDescendinglyByCPUUtilisation( $VM_{as}$ );
2  $hostVM \leftarrow$  last element of  $VM_{as}$ ;
3 for  $vm_i \in VM_{as}$  do
4    $vm_{cpu} \leftarrow$  CPU utilisation of  $vm_i$ ;
5    $vm_{ram} \leftarrow$  RAM utilisation of  $vm_i$ ;
6   if  $vm_{cpu} < th_{cpu}$  and  $vm_{ram} < th_{ram}$  and  $!networkBuffersOverloaded()$  then
7      $hostVM \leftarrow vm_i$ ;
8     break;
9   end
10 end
11 assignSessionTo( $s, hostVM$ )
```

Load Balancing and Autoscaling

- Load balancing algorithm – sticky or not?
 - Monitor VM utilization;
 - Free underutilized VMs.
- Autoscaling algorithm:
 - Repeated periodically;
 - Number of pre-provisioned instances;
 - Do not terminate before billing time is over;

Load Balancing and Autoscaling

- Load balancing algorithm – sticky or not?
 - Monitor VM utilization;
 - Free underutilized VMs.
- Autoscaling algorithm:
 - Repeated periodically;
 - Number of pre-provisioned instances;
 - Do not terminate before billing time is over;

ALGORITHM 4: Scale Up/Down Algorithm.

```
input :  $t_{cur}$ ,  $tgr_{cpu}$ ,  $tgr_{ram}$ ,  $VM_{as}$ ,  $n$ ,  $\Delta$ 
1  $nOverloaded \leftarrow 0$ ;
2  $listFreeVms \leftarrow$  empty list;
3 for  $vm \in VM_{as}$ ; // Inspect the status of all AS VMs
4 do
5    $vm_{cpu} \leftarrow$  CPU utilisation of  $vm$ ;
6    $vm_{ram} \leftarrow$  RAM utilisation of  $vm$ ;
7   if  $vm_{cpu} \geq tgr_{cpu}$  or  $vm_{ram} \geq tgr_{ram}$  or  $networkBuffersOverloaded()$  then
8      $nOverloaded \leftarrow nOverloaded + 1$ ;
9   else if  $vm_i$  serves no sessions then
10     $listFreeVms.add(vm)$ ;
11  end
12 end
13  $nFree \leftarrow$  length of  $listFreeVms$ ;
14  $nAS \leftarrow$  length of  $VM_{as}$ ;
15  $allOverloaded \leftarrow nOverloaded + nFree = nAS$  and  $nOverloaded > 0$ ;
16 if  $nFree \leq n$ ; // Provision more VMs
17 then
18    $nVmsToStart \leftarrow 0$ ;
19   if  $allOverloaded$  then
20      $nVmsToStart \leftarrow n - nFree + 1$ ;
21   else
22      $nVmsToStart \leftarrow n - nFree$ 
23   end
24   launch  $nVmsToStart$  AS VMs
25 else // Release VMs
26    $nVmsToStop \leftarrow 0$ ;
27   if  $allOverloaded$  then
28      $nVmsToStop \leftarrow nFree - n$ ;
29   else
30      $nVmsToStop \leftarrow nFree - n + 1$ 
31   end
32   sortAscendinglyByBillingTime( $listFreeVms$ );
33   for  $i = 1$  to  $nVmsToStop$  do
34      $billTime \leftarrow$  billing time of  $listFreeVms[i]$ ;
35     if  $billTime - t_{cur} < \Delta$  then
36       terminate  $listFreeVms[i]$ ;
37     else
38       break
39     end
40   end
41 end
```

Load Balancing and Autoscaling

- Load balancing algorithm – sticky or not?
 - Monitor VM utilization;
 - Free underutilized VMs.
- Autoscaling algorithm:
 - Repeated periodically;
 - Number of pre-provisioned instances;
 - Do not terminate before billing time is over;

Cloud Selection Algorithm

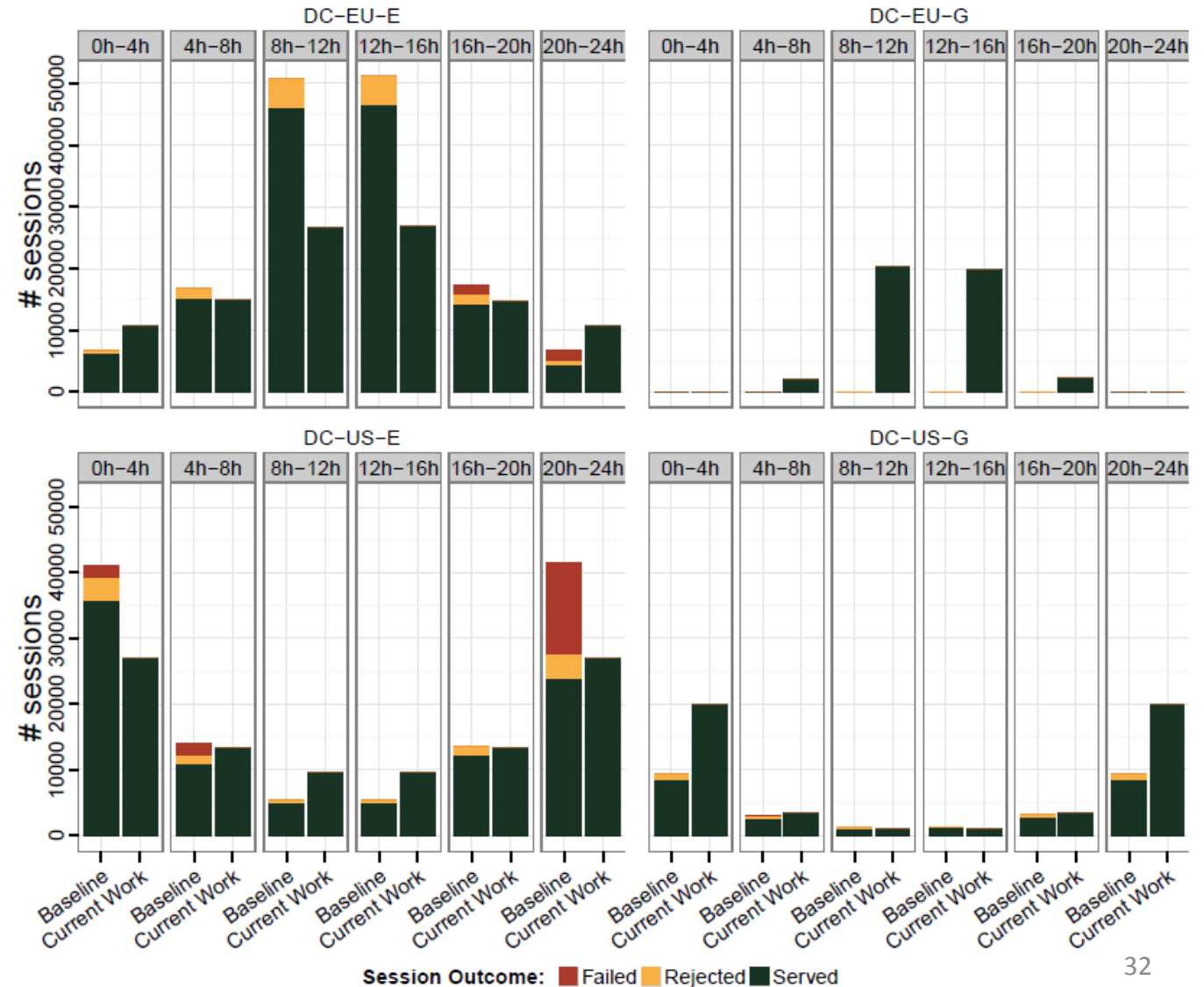
- Ensure users are served in eligible clouds;
- Timeout;
- Estimate network latency;
- Estimate potential cost;
- Overloaded infrastructure;
- Optimise latency and cost.

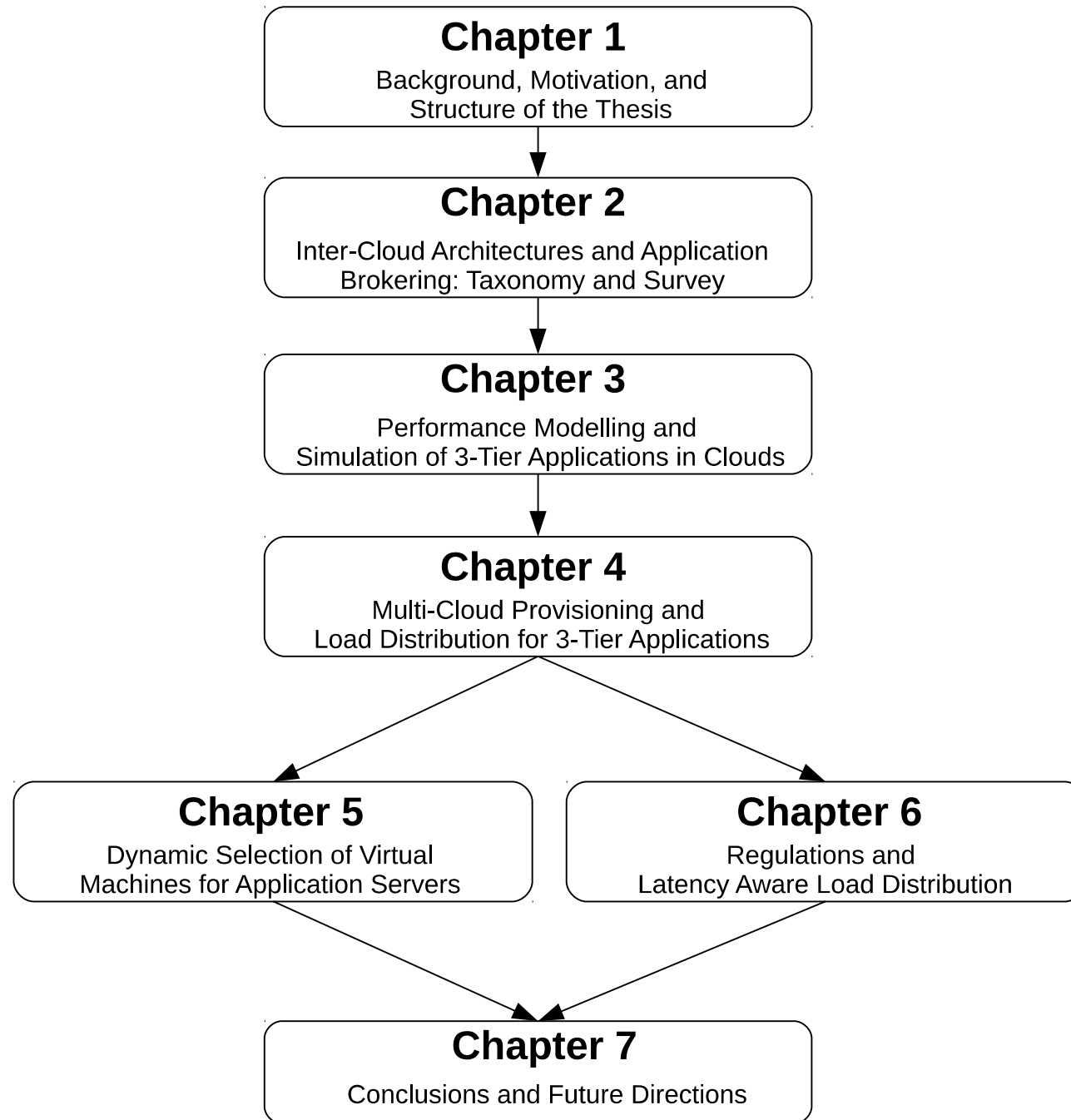
ALGORITHM 5: Cloud Site Selection Algorithm.

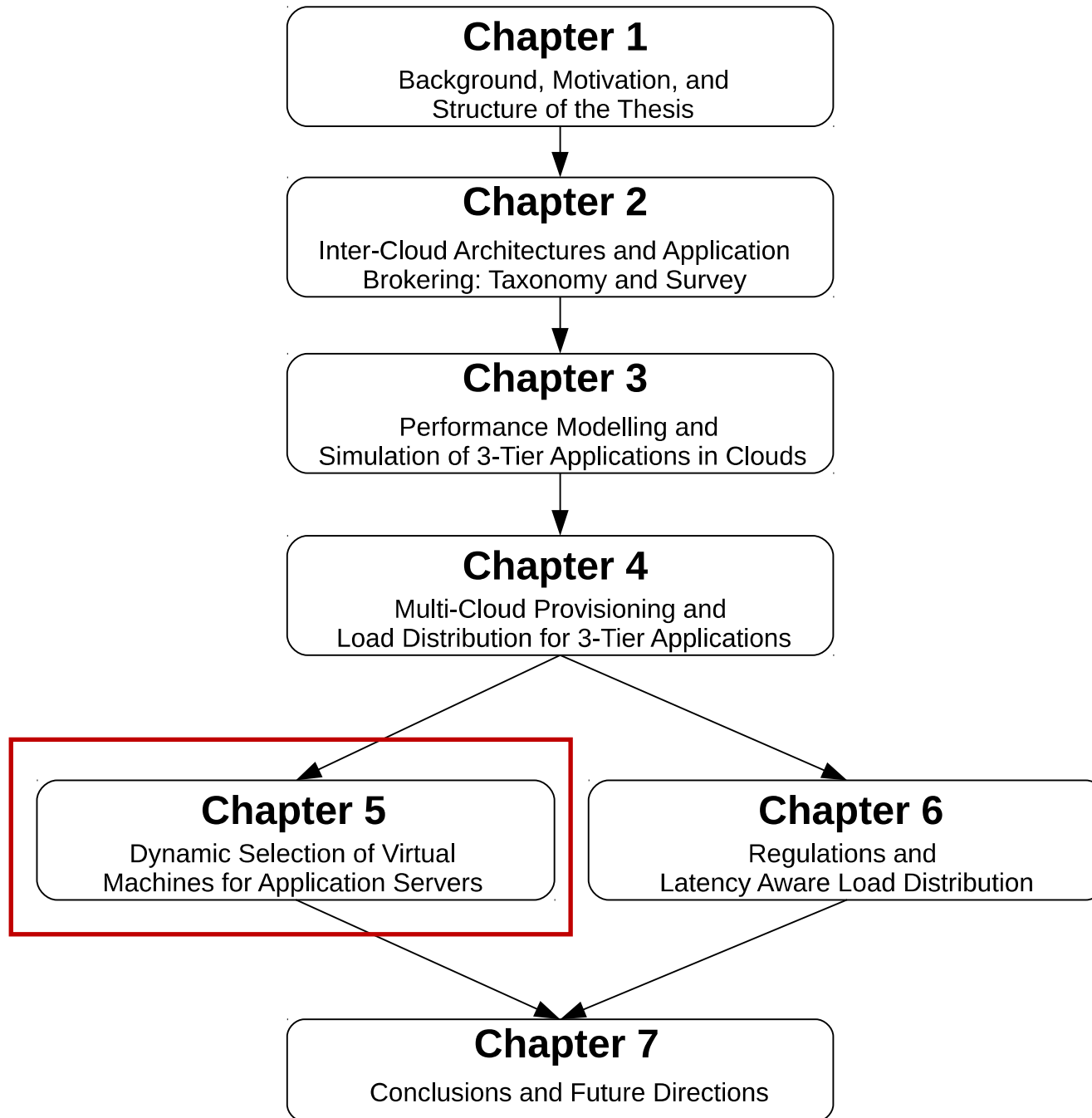
```
input : users, timeout, clouds, latencySLA
// Broadcast users' data to admission controllers
1 for  $c_i \in \text{clouds}$  do
2   |  $ac_i \leftarrow$  IP address of  $c_i$ 's admission controller;
3   | send to  $ac_i$  users' identifier;
4 end
5 wait timeout seconds or until all clouds respond;
6 for  $u_i \in \text{users}$  do
7   |  $\text{clouds}_{\text{accept}} \leftarrow$  clouds eligible to serve  $u_i$ ;
8   |  $\text{sortAscendinglyByPrice}(\text{clouds}_{\text{accept}})$ ;
9   |  $\text{selectedCloud} \leftarrow \text{null}$ ;
10  |  $\text{selectedLatency} \leftarrow +\infty$ ;
11  | for  $c_i \in \text{clouds}_{\text{accept}}$  do
12  |   |  $\text{latency} \leftarrow$  latency between  $u$  and  $c_i$ ;
13  |   | if  $\text{latency} < \text{latency}_{\text{SLA}}$  then
14  |   |   |  $\text{selectedCloud} \leftarrow c_i$ ;
15  |   |   | break;
16  |   | else if  $\text{selectedLatency} > \text{latency}$  then
17  |   |   |  $\text{selectedCloud} \leftarrow c_i$ ;
18  |   |   |  $\text{selectedLatency} \leftarrow \text{latency}$ ;
19  |   | end
20  | end
21  | if  $\text{selectedCloud} = \text{null}$  then
22  |   | Deny Service;
23  | else
24  |   |  $lb \leftarrow$  IP of load balancer in  $\text{selectedCloud}$ ;
25  |   | redirect  $u$  to  $lb$ ;
26  | end
27 end
```

Performance Evaluation

- Previous simulation env.;
- Clouds of AWS and Google in the US and Europe;
- Baseline:
 - AWS Route 53;
 - AWS Elastic LB;
 - AWS Autoscaling;

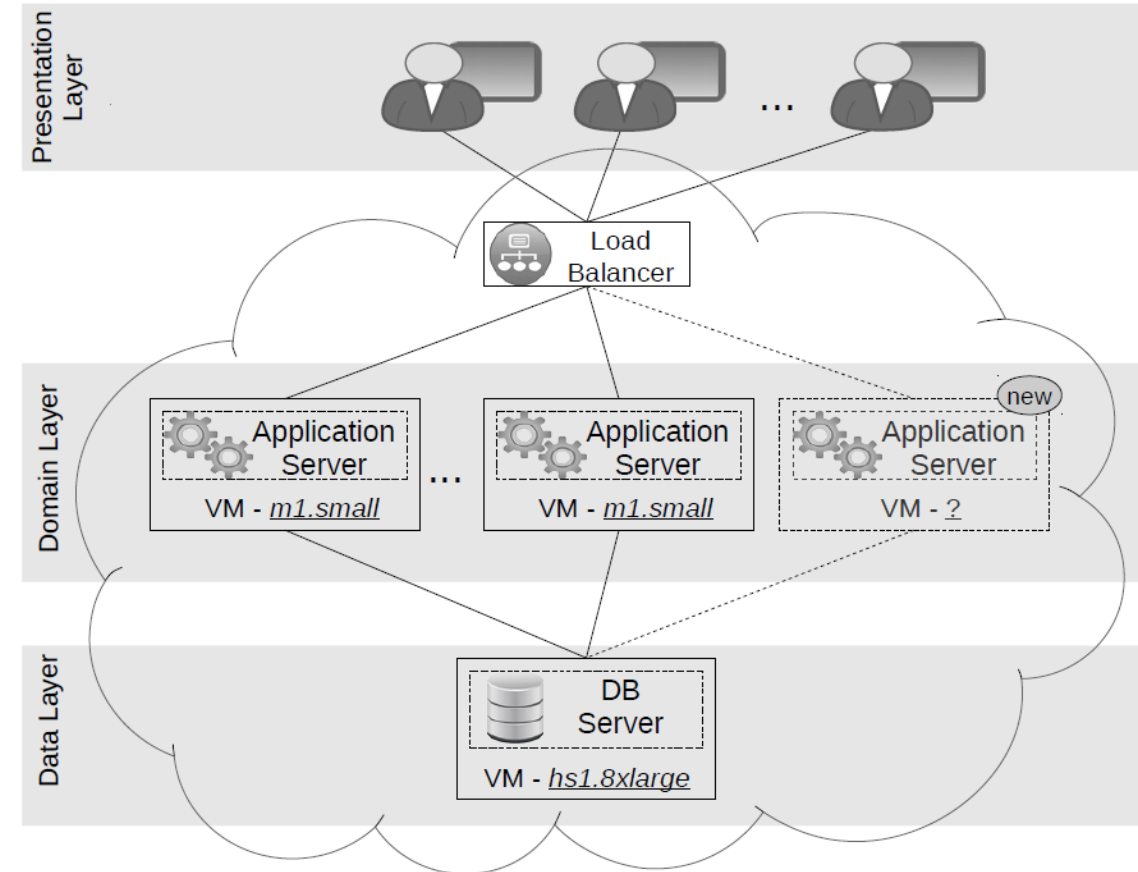






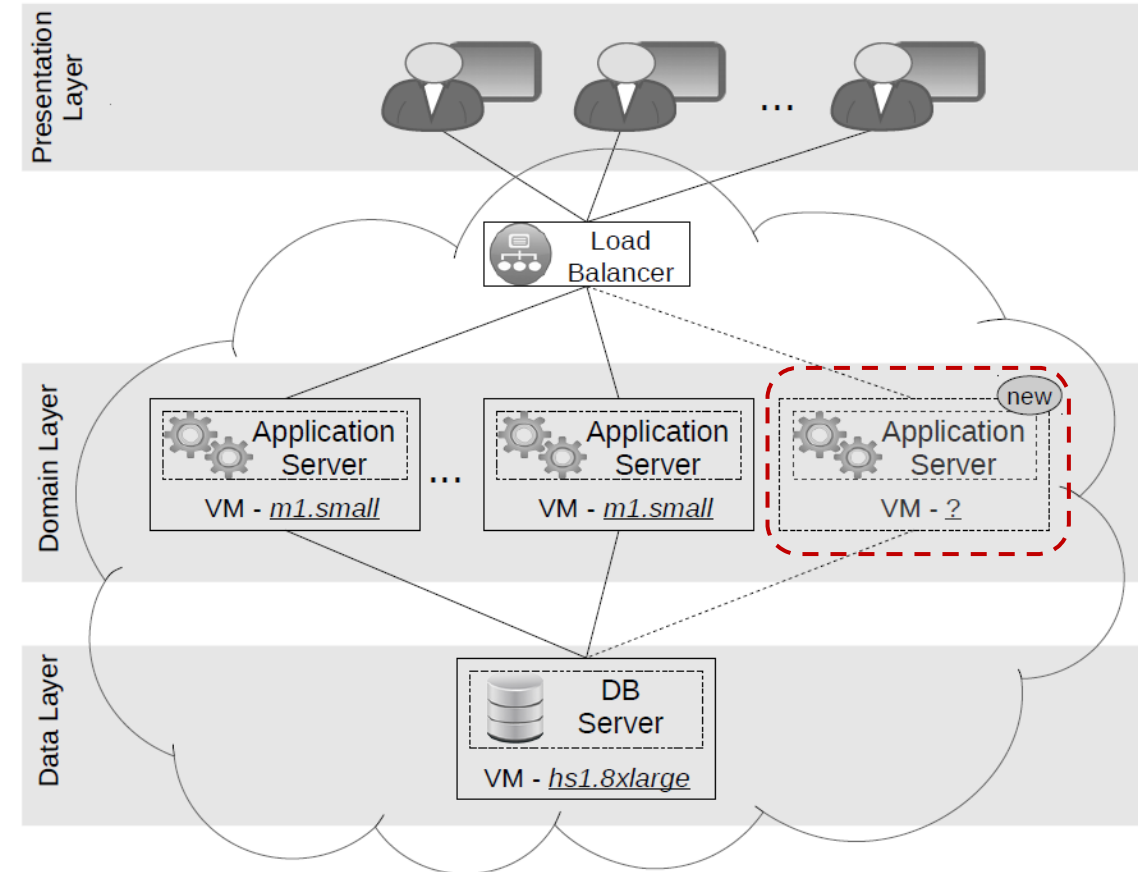
Background and Objectives

- Current autoscaling approaches select VMs statically:
 - Applications change over time;
 - Workload changes over time;
 - Infrastructure capacity changes over time.
- **Goal:** propose a flexible approach to VM selection that adapts to such changes.

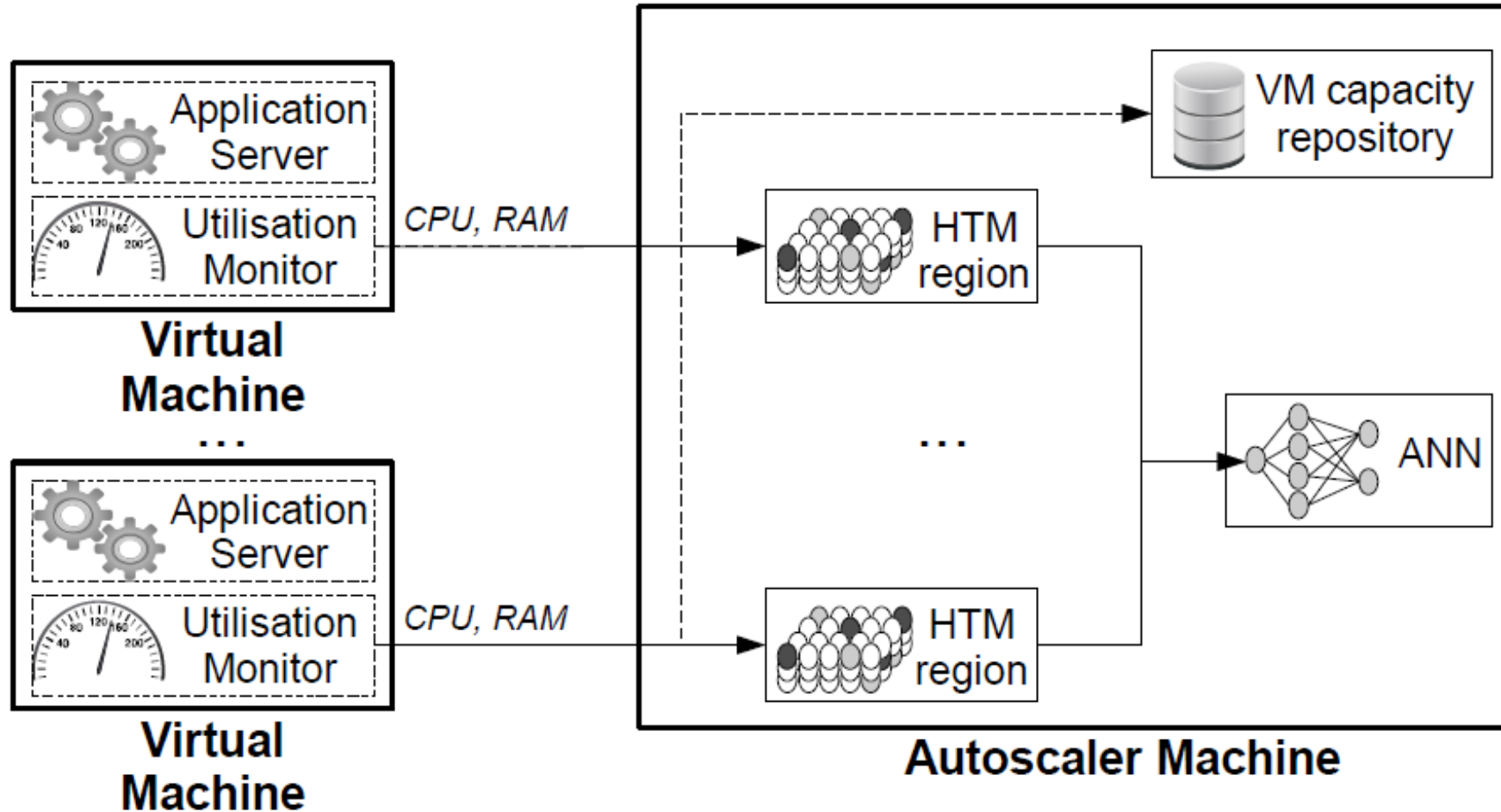


Background and Objectives

- Current autoscaling approaches select VMs statically:
 - Applications change over time;
 - Workload changes over time;
 - Infrastructure capacity changes over time.
- **Goal:** propose a flexible approach to VM selection that adapts to such changes.



Approach Overview



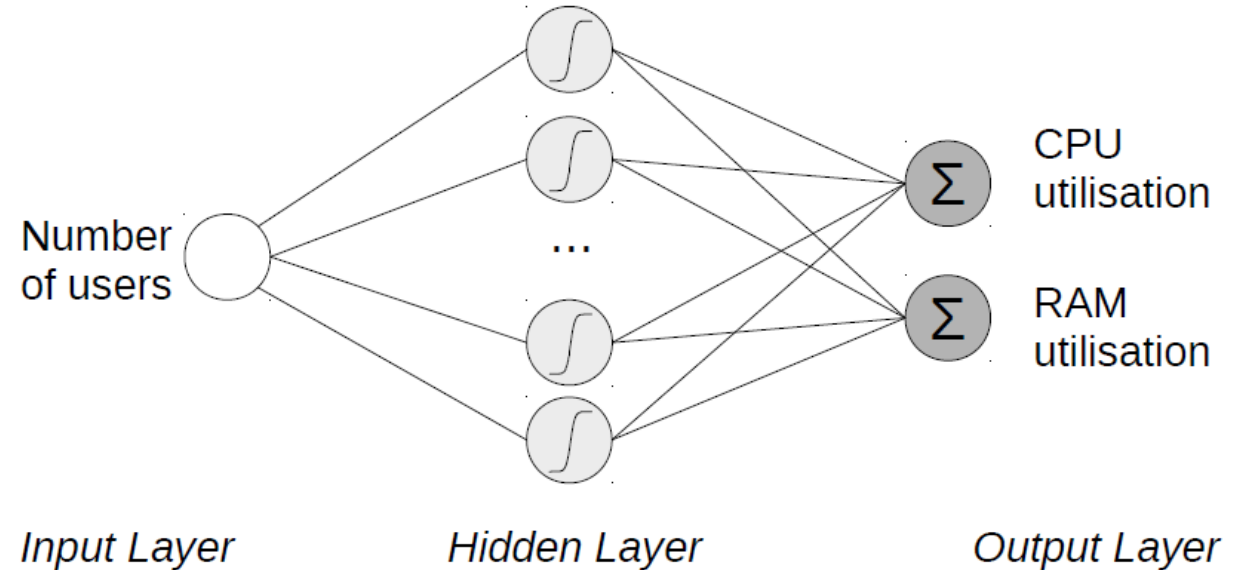
Capacity Estimation and Normalisation

- Linux kernel file: `/proc/cpuinfo`;
- Mpstat: `%steal`, `%idle`, `active_memory`;
- Frequencies: fr_1, \dots, fr_n ;
- n_{max_cores} , f_{rmax} , RAM_{max} ;

- $$cpuCapacityNorm = \frac{(100 - \%steal) \sum_{i=0}^n fr_i}{100 n_{max_cores} f_{rmax}}$$
- $$cpuLoadNorm = \frac{(100 - \%idle - \%steal) \sum_{i=0}^n fr_i}{100 n_{max_cores} f_{rmax}}$$
- $$cpuCapacity(vmt) = \frac{1}{|V|} \sum_{vmt_i \in V} \frac{cpuCapacity(vmt_i) \times cpuSpec(vmt_i)}{cpuSpec(vmt)}$$
- $$ramLoadNorm = \frac{active_memory}{RAM_{max}}$$

ANN based online regression

- Learning rate and Momentum;
 - Increase learning rate in the beginning and when anomaly is detected;
 - Increase momentum at later stages and when no anomaly is detected;
- Online training and filtering;



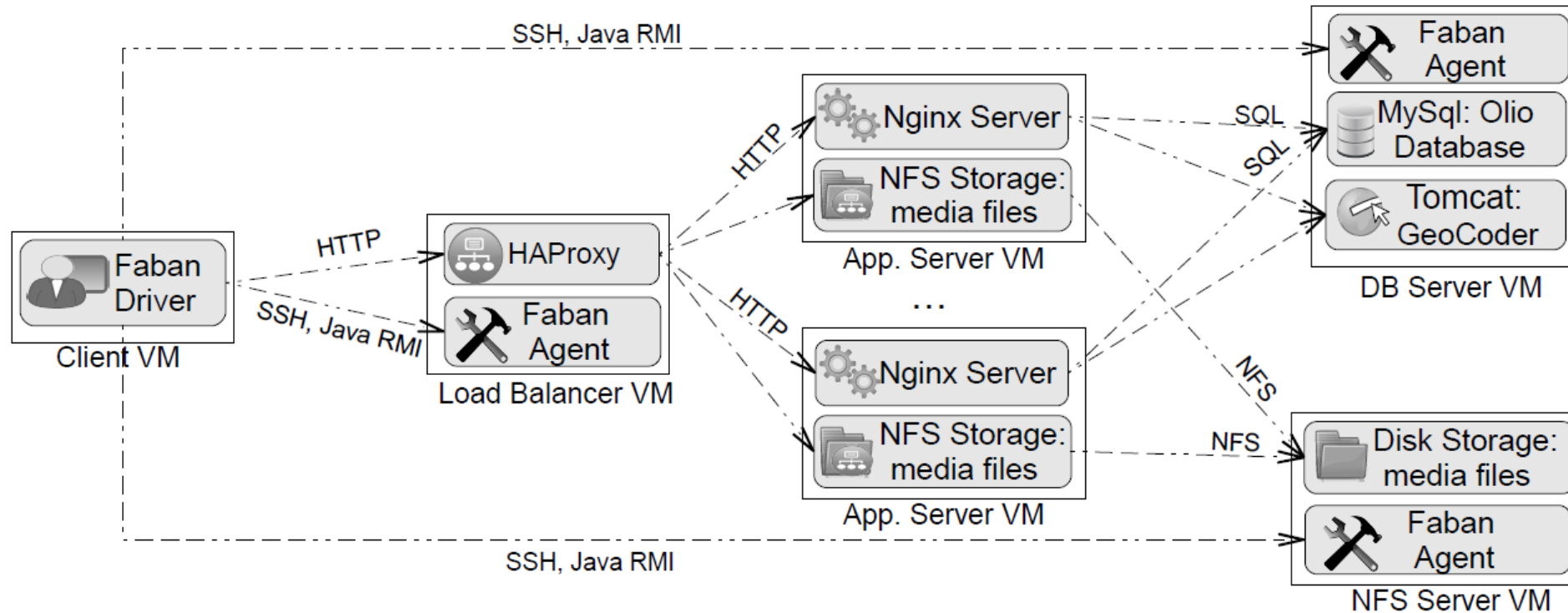
VM type selection algorithm

- For each VM type:
 - Estimate its capacity;
 - Estimate how many users it can serve;
- Choose best VM type in terms of cost per user;

ALGORITHM 6: Dynamic VM Type Selection (DVTS).

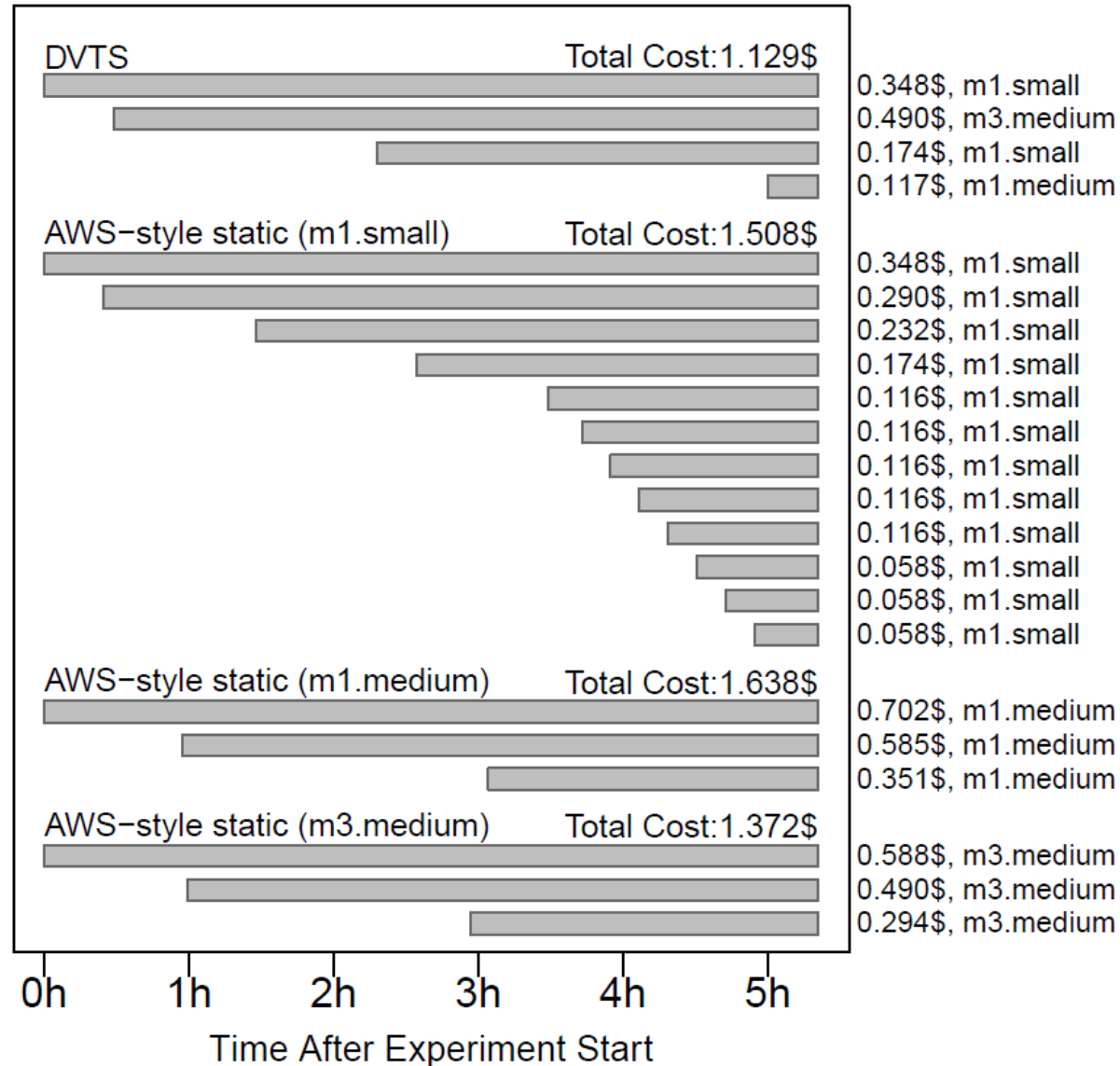
```
input :  $VT, ann, \Delta, minU, maxU$ 
1  $bestVmt \leftarrow null$ ;
2  $bestCost \leftarrow 0$ ;
3 for  $vmt \in VT$  ; // Inspect all VM types
4 do
5    $cpuCapacity \leftarrow vmt$ 's norm. CPU capacity ;
6    $ramCapacity \leftarrow vmt$ 's norm. RAM capacity;
7    $vmtCost \leftarrow vmt$ 's cost per time unit;
8    $userCapacity \leftarrow 0$ ;
9    $n \leftarrow minU$ ;
10  while True ; // Find how many users it can take
11  do
12     $cpu, ram \leftarrow predict(ann, n, minU, maxU)$ ;
13    if  $cpu < cpuCapacity$  and  $ram < ramCapacity$  then
14       $userCapacity \leftarrow n$ ;
15    else
16      break;
17    end
18     $n \leftarrow n + \Delta$ ;
19  end
20  // Approximate the cost for a user per time unit
    $userCost \leftarrow \frac{vmtCost}{userCapacity}$ ;
21  // Find the cheapest VM type
   if  $userCost < bestCost$  then
22     $bestCost \leftarrow userCost$ ;
23     $bestVmt \leftarrow vmt$ ;
24  end
25 end
26 return  $bestVmt$ ;
```

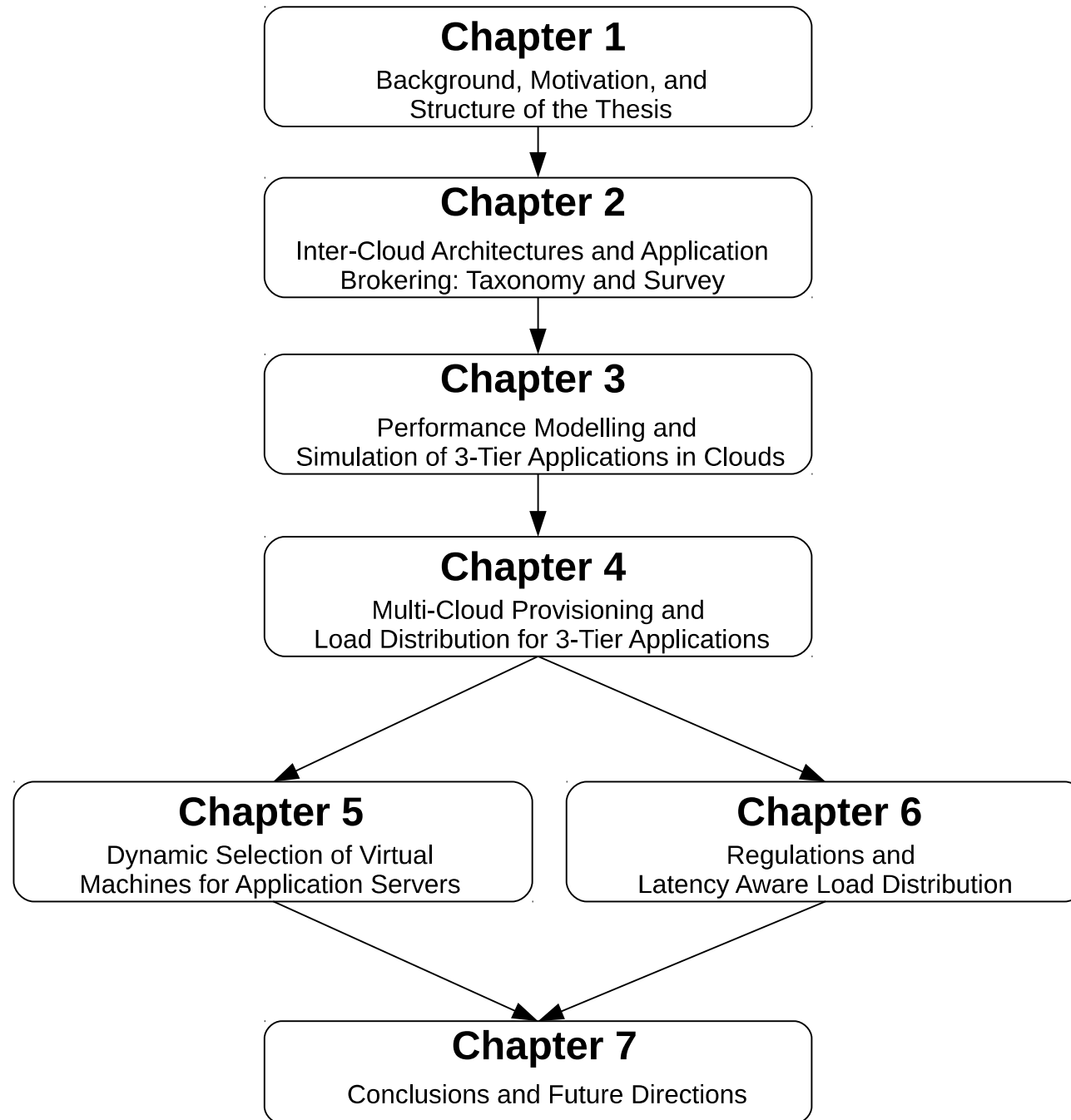
Experimental setup and workload

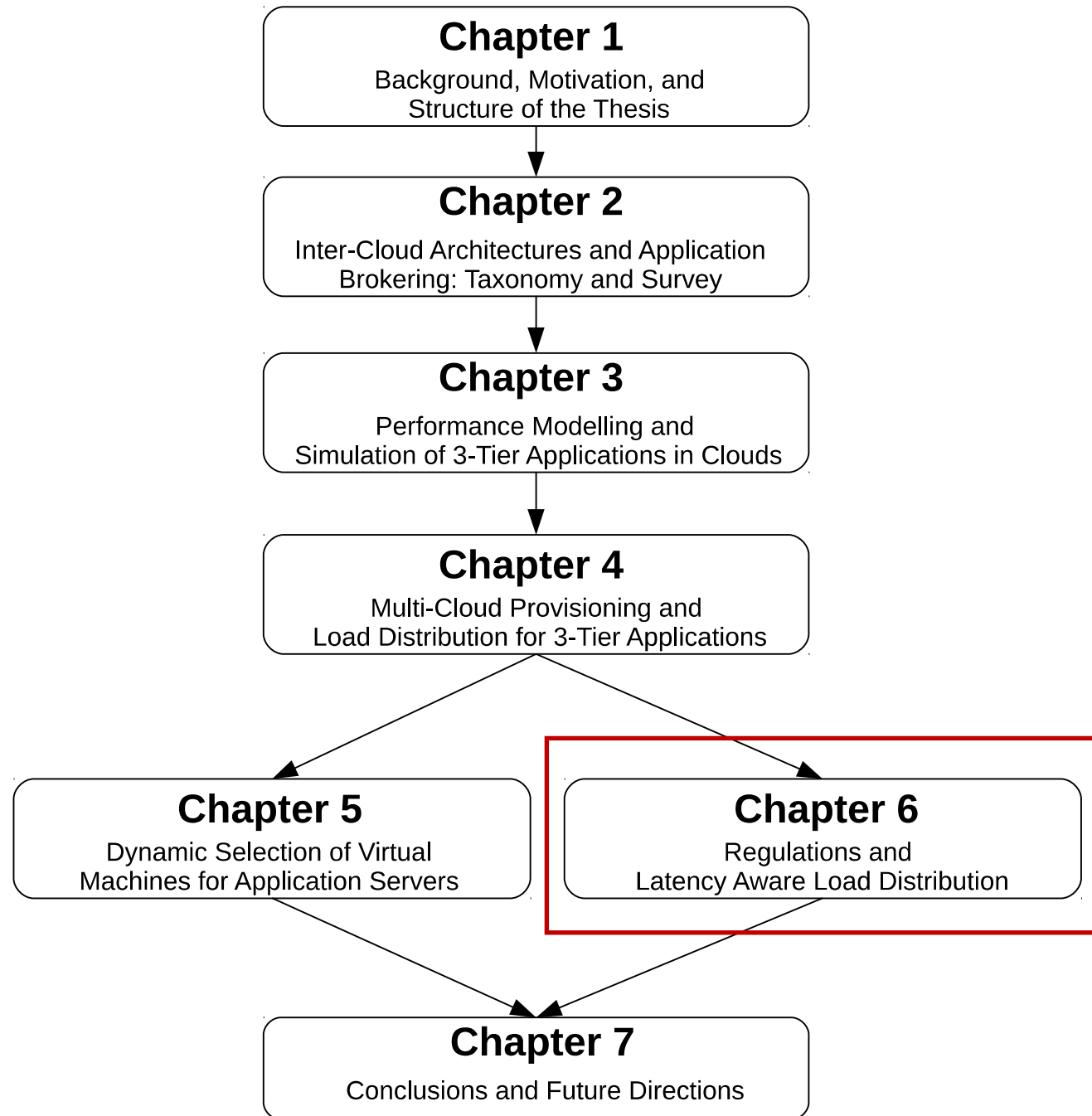


- CloudStone in AWS EC2;
- Choose best VM type in terms of cost per user;
- Increasing workload for 5 hours;
- Workload change after 3.5 hours;
- Baseline – AWS-like autoscaling;

Experimental Results



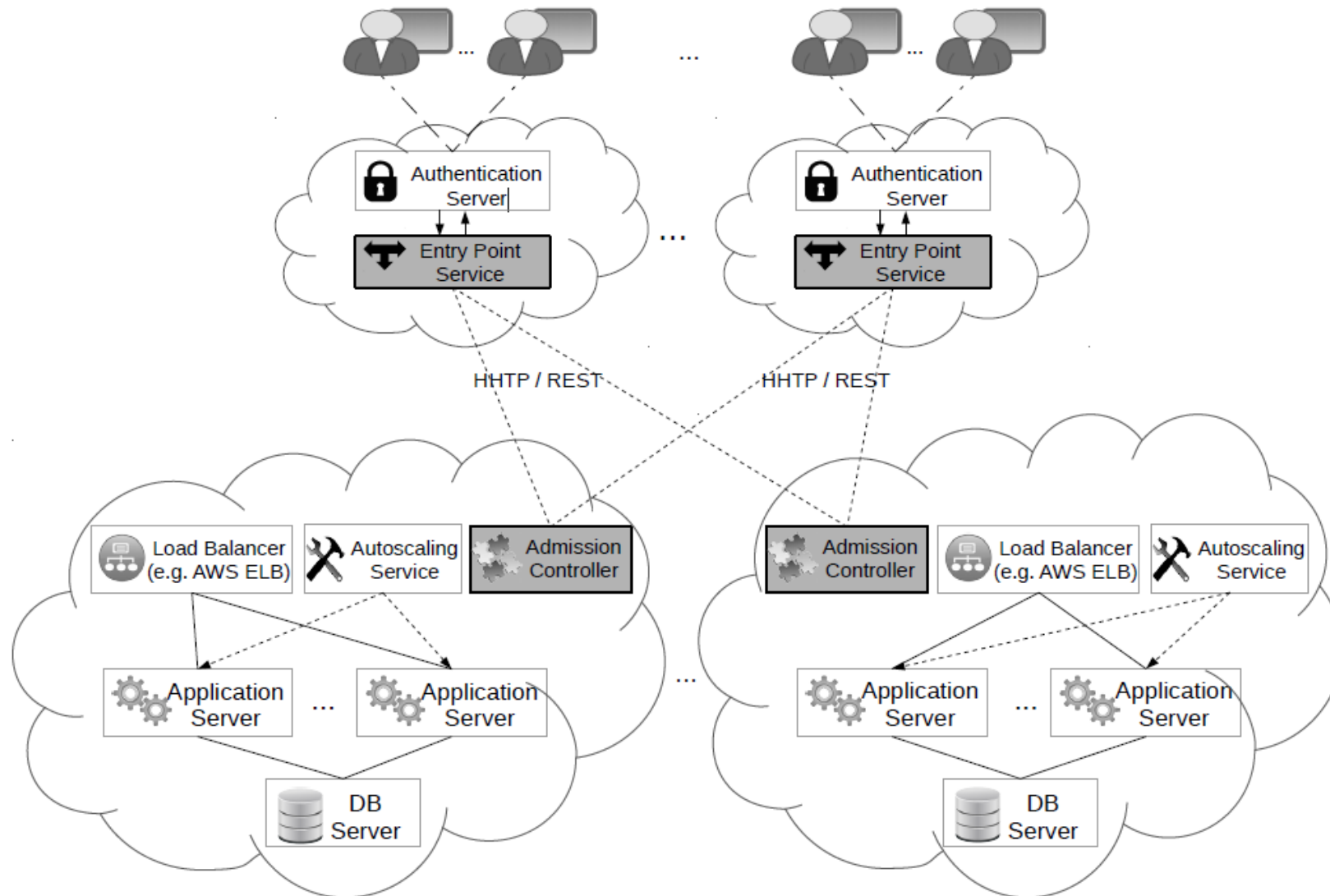




Background and Objectives

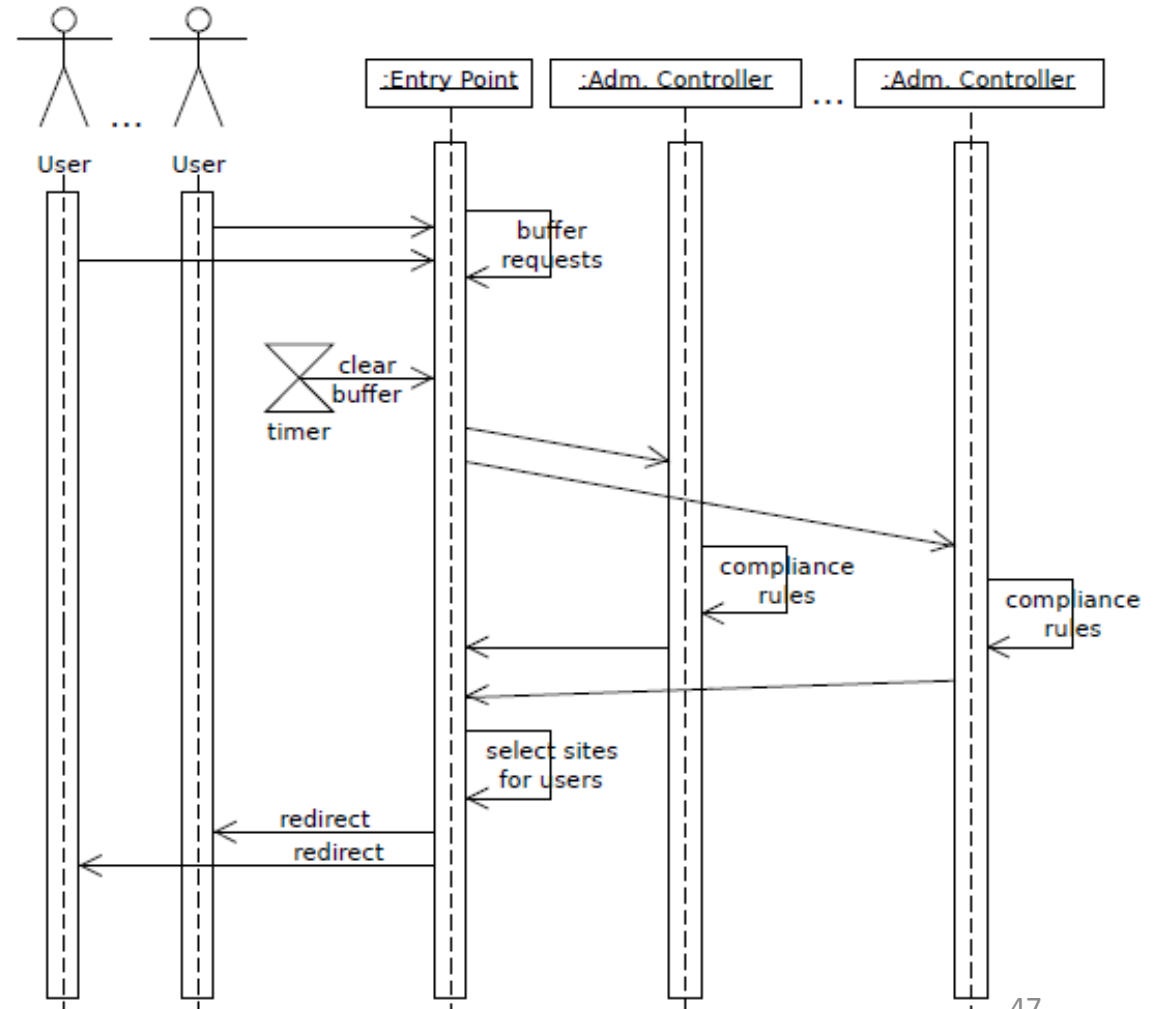
- How to implement the system from Chapter 4 with modern software technologies;
- How to easily model user redirection requirements;

Scope



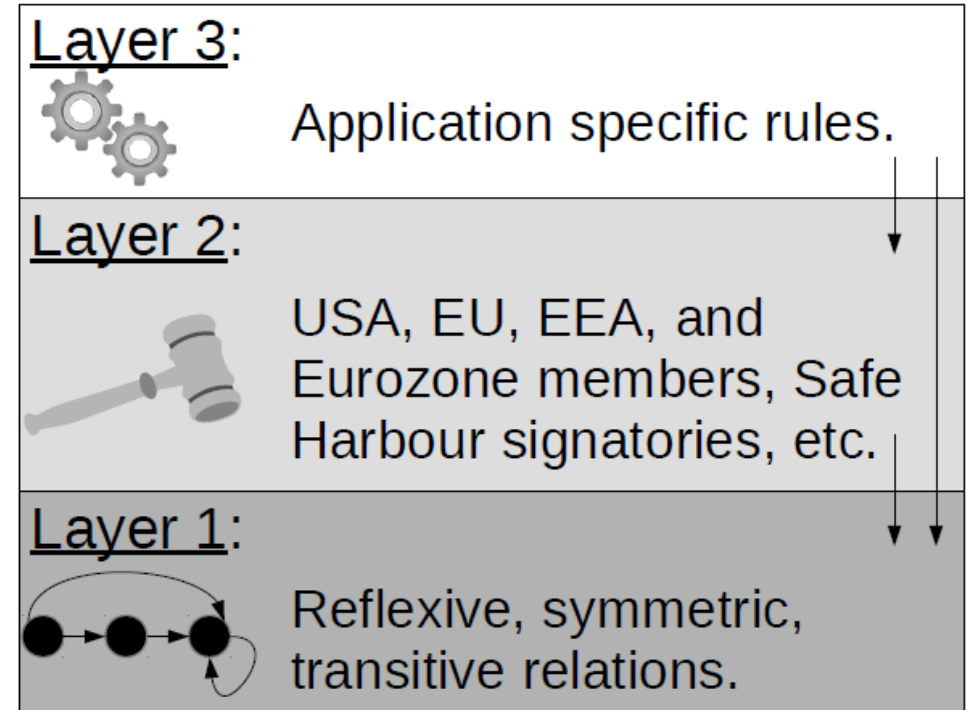
Entry Point – Admission Controller interaction

- Restful web servers;
- Entry Point buffers and sends requests in batch;
- Admission Controller uses a rule inference engine;
- Entry Point choses optimal cloud site.



Admission rules

- Drools rule inference engine;
- 3 layers of rules;
- Polymorphism and rules;
- Admission through contradiction.

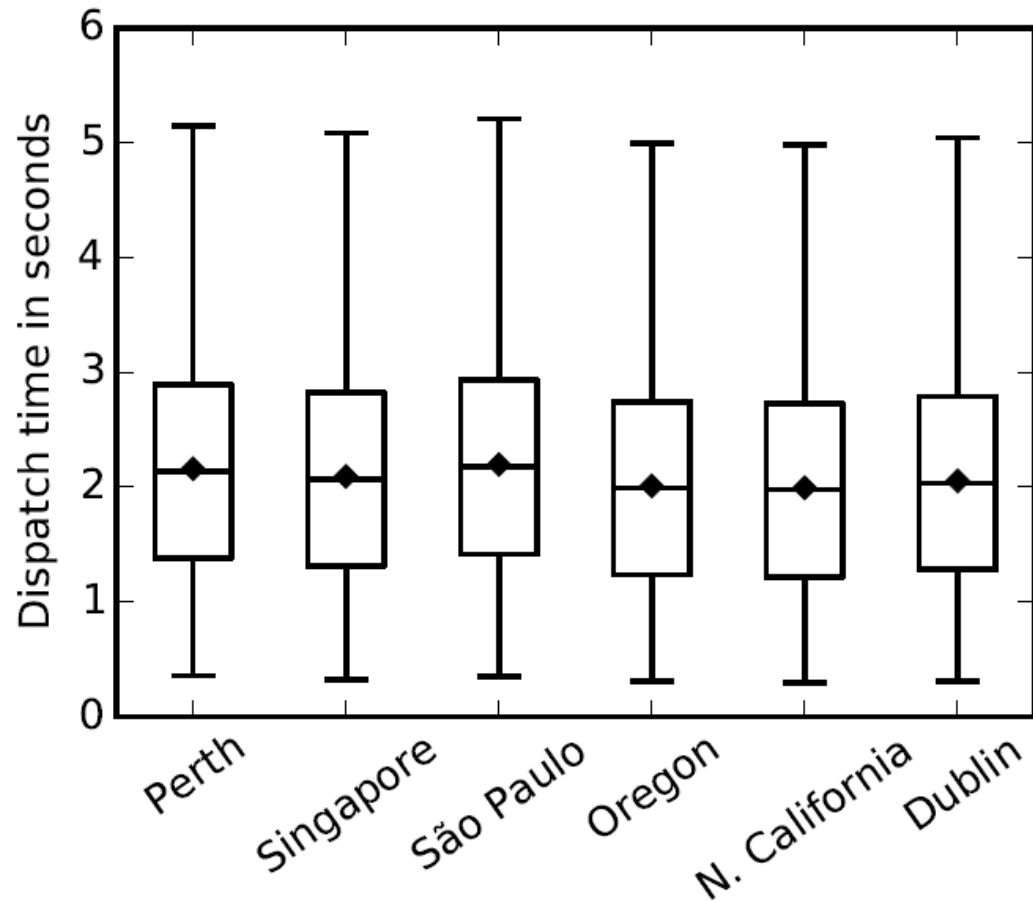


Experimental setup and workload



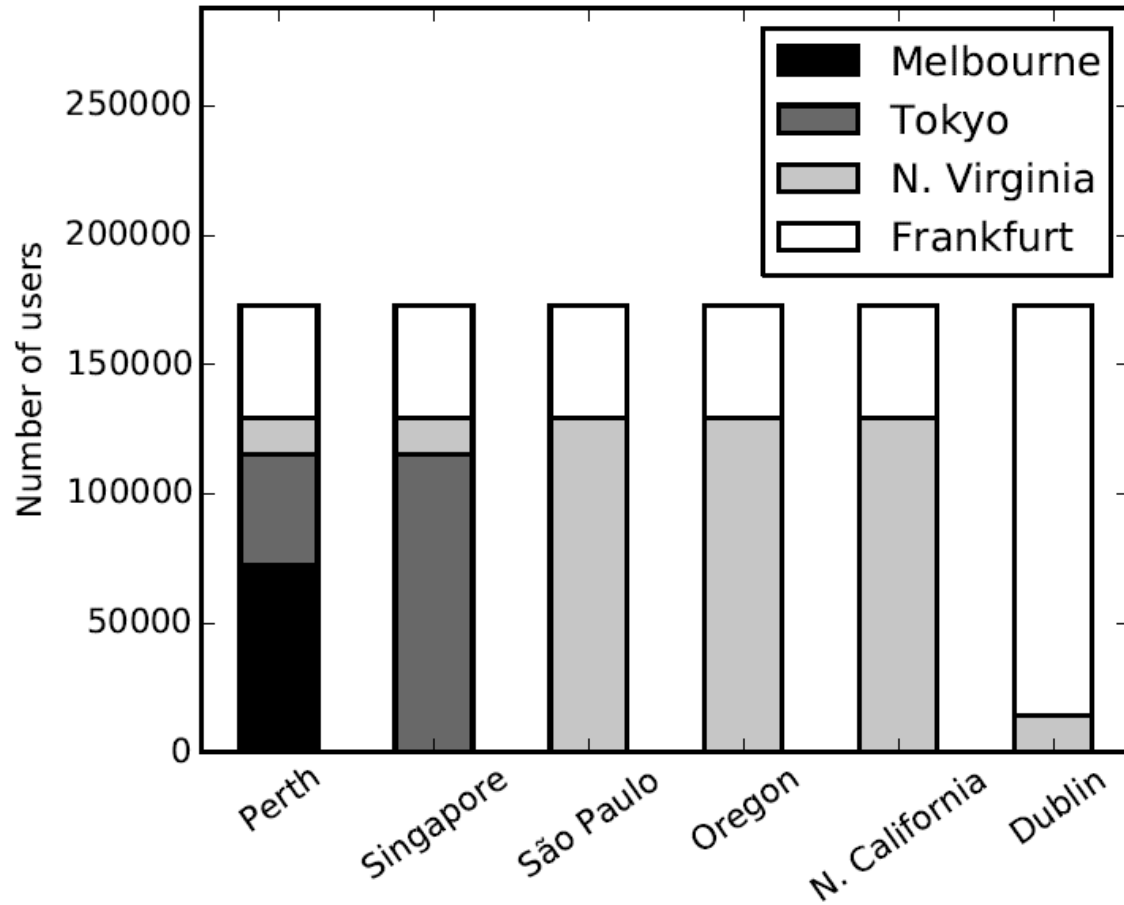
- 24 hours, 2 users per second;
- 50% of users require PCI-DSS compliant clouds;
- Random citizenship: Germany, USA, Australia, or Canada;
- 50% of US citizens are government officials.

Results: dispatch times and destinations

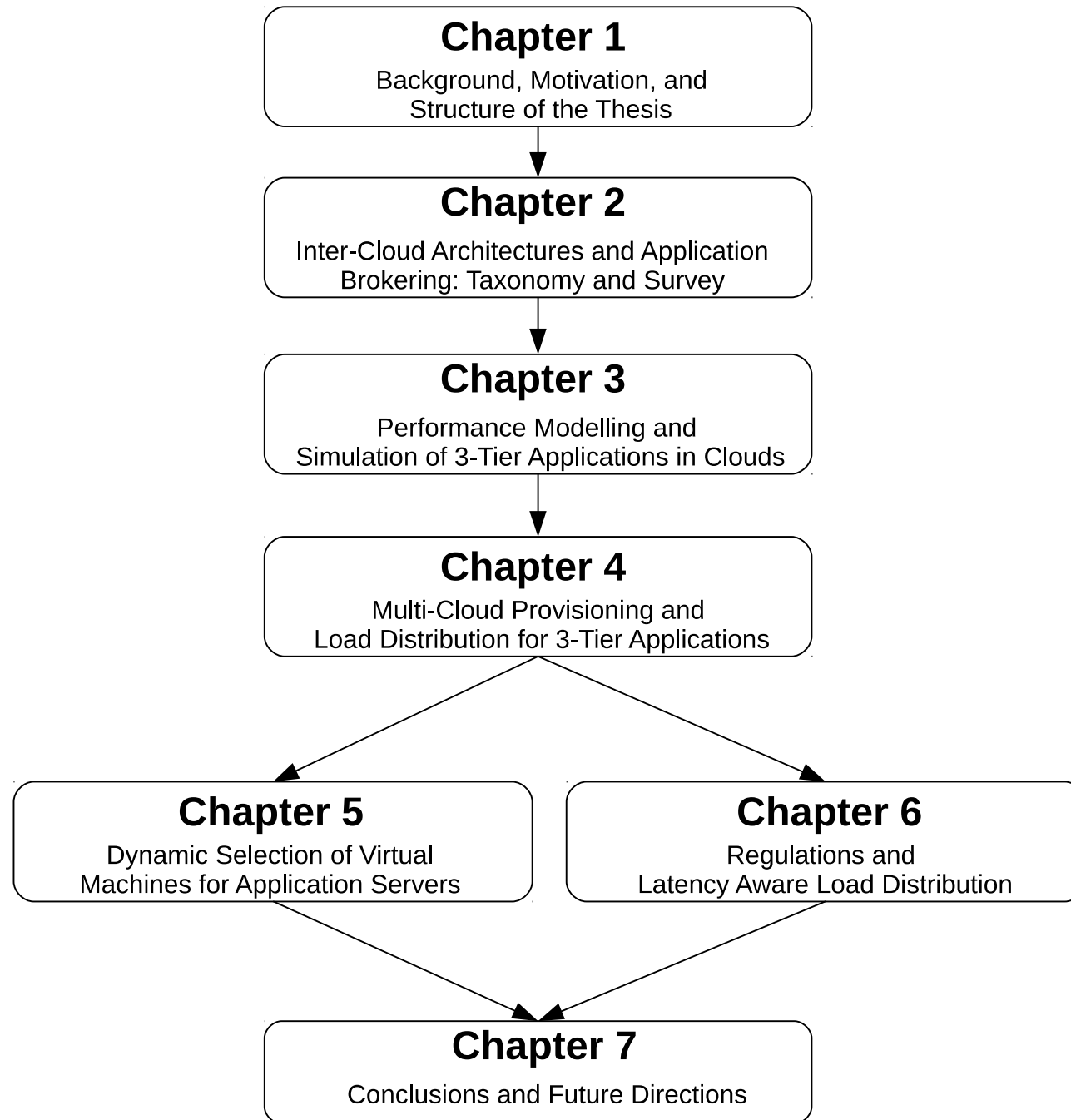


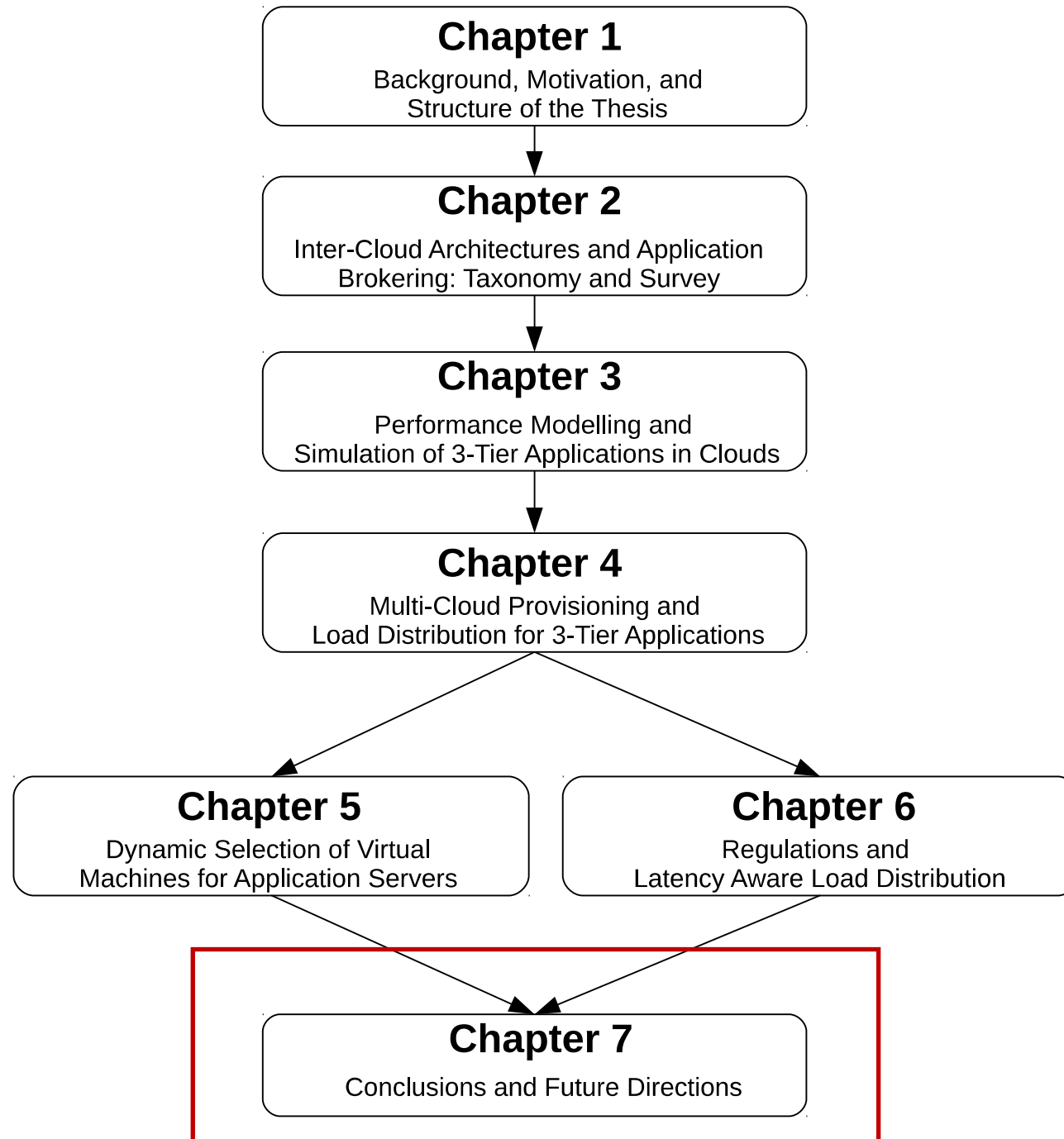
	N. Virginia	Frankfurt	Melbourne	Tokyo
Perth	137.0	180.0	20.0	124.0
Singapore	121.0	131.0	69.0	44.0
São Paulo	61.0	106.0	224.0	140.0
Oregon	38.0	73.0	88.0	45.0
N. Cal.	41.0	84.0	84.0	52.0
Dublin	39.0	11.0	159.0	108.0

Results: dispatch times and destinations



	N. Virginia	Frankfurt	Melbourne	Tokyo
Perth	137.0	180.0	20.0	124.0
Singapore	121.0	131.0	69.0	44.0
São Paulo	61.0	106.0	224.0	140.0
Oregon	38.0	73.0	88.0	45.0
N. Cal.	41.0	84.0	84.0	52.0
Dublin	39.0	11.0	159.0	108.0





Summary

- Proposed a performance model and a simulator for 3-Tier apps in clouds;
- Defined a generic architecture for such applications that honors the key functional and non-functional requirements;
- Proposed a method for VM type selection during autoscaling;
- Proposed and implemented a user redirection approach in Multi-Clouds.

Future Directions

- Provisioning Techniques Using A Mixture of VM Pricing Models;
- Dynamic Replacement of Application Server VMs;
- VM Type Selection In Private Clouds;
- Regulatory Requirements Specification Using Industry Standards;
- Generalisation to Multi-Tier Applications.

List of publications

- **Nikolay Grozev** and Rajkumar Buyya, “Inter-cloud Architectures and Application Brokering: Taxonomy and Survey”, *Software: Practice and Experience*, John Wiley & Sons, Ltd, vol. 44, no. 3, pp. 369–390, 2014;
- **Nikolay Grozev** and Rajkumar Buyya, “Performance Modelling and Simulation of Three-Tier Applications in Cloud and Multi-Cloud Environments”, *The Computer Journal*, Oxford University Press, vol. 58, no. 1, pp. 1–22, 2015;
 - Nitisha Jain, **Nikolay Grozev**, J. Lakshmi, Rajkumar Buyya , “*PriDynSim: A Simulator for Dynamic Priority Based I/O Scheduling for Cloud Applications*”, Proceedings of the IEEE International Conference on Cloud Computing for Emerging Markets, 2015 (In Press);
- **Nikolay Grozev** and Rajkumar Buyya, “Multi-Cloud Provisioning and Load Distribution for Three-tier Applications”, *ACM Transactions on Autonomous and Adaptive Systems*, vol. 9, no. 3, pp. 13:1–13:21, 2014;
- **Nikolay Grozev** and Rajkumar Buyya, “Dynamic Selection of Virtual Machines for Application Servers in Cloud Environments”, *Technical Report, CLOUDS Laboratory, The University of Melbourne*, CLOUDS-TR-2016-1
- **Nikolay Grozev** and Rajkumar Buyya, “Regulations and Latency Aware Load Distribution of Web Applications in Multi-Clouds”, *Journal of Supercomputing* (Under Review), 2015;

Acknowledgements

- **Supervisor:** Professor Rajkumar Buyya;
- **Committee:** Professor James Bailey, Dr. Rodrigo Calheiros;
- Dr. Amir Vahid and Dr. Anton Beloglazov;
- Past and Present CLOUDS Lab members and CIS Department;
- Microsoft;
- Amazon Inc;
- Family and Friends.

Q&A



Thank you!