PICS:
A Public IaaS Cloud Simulator

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Motivation – *how best to use cloud*

**Actual Deployment Based Evaluation**

1. **Deploying** small-scale test application to IaaS of choice.
2. **Scaling-up** the test app to meet goal/requirement of organization.
Motivation – *how best to use cloud*

- Problems:
  1. “**Time Consuming**” (including learning curve for cloud APIs).
  2. Evaluation tends to be “**Specific to One Cloud**”. (no generalizability)
  3. “**Scale-up**” approach typically requires significant changes to its architecture.
Cloud Simulator: Possible Alternatives

• **General Purpose Cloud Simulator**
  - *CloudSim* [11], *iCanCloud* [18], *GreenCloud* [15], etc.
  - More focus on “data center management” rather than
    - Public IaaS Evaluation.
    - Cloud Application Evaluation

• **Vendor and 3rd Party Tools**
  - *RightScale*, *SCALR*, *AzurePricingCalculator*…
  - Provides only short/long-term *cost* based on resource utilization.
Cloud Users’ Concerns

• What is *average/worst response time* for my cloud app under a particular workload pattern?

• *Which public IaaS clouds* provides the best (cost/performance) benefits to my cloud app?

• Which *resource management and job scheduling policy* maximize the cost efficiency/performance of my cloud app?

• Above all, if a simulator can answer above questions, but *how reliable* are the simulation results?

→ **PICS (Public IaaS Cloud Simulator)**
PICS Design: Goal

• Design Goal
  • Correct Simulation of public IaaS clouds/Cloud App.

• 3 Design Challenges:

- Behavior of Public IaaS Clouds
  - Various/Convenient Input Configuration

- Behavior of Cloud Application (e.g. perf. uncertainty)
  - Collecting and Profiling Data from Real Cloud

- Resource Management Policy
  - Various Config. Options for Resource Management
PICS Design: Input and Output

- VM Configurations (Cost/Performance)
- Storage/Network Configurations (Size/Bandwidth)
- Workload Patterns (Job Arr./Duration)
- Job Scheduling (e.g. EDF/RR)
- Resource Management Policy (Max #VM, Scaling)

Output:
- Cost (Overall/Trace)
- Resource Usage (#VM/Storage/Trace)
- Job Processing Results (Overall Result/Trace)
Design Overview of PICS

Simulation User

Simulation Configuration Layer
- Workload List/Generation Clock
  - Workload
  - Job Scheduling
  - Resource Mgmt.
  - VM Config.
  - Storage Config.
  - Network Config.

Simulation Entity Layer
- Workload Gen. Entity
  - Generate Workload based on the configuration
- Job Scheduling/Resource Mgmt. Policy
  - Job Management
  - Resource Mgmt.
  - Workload Monitor
- VM Res. Config/Storage&Net Config
  - VM Request/Result

Simulation Core Layer
- Sim. Wall Clock
- Sim. Event Processor
- Sim. Report Generator

INPUT
OUTPUT
- Cost
- Resource Usage
- Job Proc. Info

PICS
PICS Validation

• Methodology
  • Design and deploy a RM/Actual App. (MapReduce) on both real cloud infrastructure (AWS) and PICS.
  • Compare both results.

MR Jobs
1. WordCount
2. PI Calculation
3. Tera Sort
PICS Validation – Experiment Setup

• Validation Workloads

<table>
<thead>
<tr>
<th>Workloads</th>
<th>Scaling</th>
<th>Job Arr. Pattern</th>
<th>Job Type</th>
<th># of Concurr. VMs</th>
<th>Used VM Types</th>
<th># of Jobs</th>
<th>Avg. Job DL.</th>
<th>Std. Dev</th>
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<tbody>
<tr>
<td>WL #1</td>
<td>Horizontal Scaling</td>
<td>Poisson</td>
<td>WC</td>
<td>Unlimited</td>
<td>m3.medium</td>
<td>200</td>
<td>272s</td>
<td>129.55</td>
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<tr>
<td>WL #2</td>
<td></td>
<td></td>
<td>PI</td>
<td></td>
<td>All Types m3.large All Types m3.xlarge</td>
<td>538s</td>
<td>266.10</td>
<td></td>
</tr>
<tr>
<td>WL #3</td>
<td></td>
<td></td>
<td>TS</td>
<td></td>
<td>All Types m3.medium</td>
<td>1065s</td>
<td>531.09</td>
<td></td>
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<tr>
<td>WL #4</td>
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<td></td>
<td>WC</td>
<td>Unlimited</td>
<td>All Types m3.large All Types m3.xlarge</td>
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<td>127.60</td>
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<tr>
<td>WL #5</td>
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<td></td>
<td>PI</td>
<td></td>
<td>All Types</td>
<td>515s</td>
<td>263.50</td>
<td></td>
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<tr>
<td>WL #6</td>
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<td></td>
<td>TS</td>
<td></td>
<td>All Types</td>
<td>1102s</td>
<td>559.75</td>
<td></td>
</tr>
<tr>
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<td></td>
<td>WC</td>
<td></td>
<td>All Types m3.large All Types m3.xlarge</td>
<td>510s</td>
<td>265.03</td>
<td></td>
</tr>
<tr>
<td>WL #8</td>
<td></td>
<td></td>
<td>PI</td>
<td></td>
<td>All Types</td>
<td>1029s</td>
<td>556.50</td>
<td></td>
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<tr>
<td>WL #9</td>
<td></td>
<td></td>
<td>TS</td>
<td></td>
<td>All Types</td>
<td>523s</td>
<td>279.38</td>
<td></td>
</tr>
<tr>
<td>WL #10</td>
<td></td>
<td></td>
<td>WC</td>
<td></td>
<td>All Types</td>
<td>1045s</td>
<td>563.15</td>
<td></td>
</tr>
<tr>
<td>WL #11</td>
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<td></td>
<td>PI</td>
<td></td>
<td>All Types</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>WL #12</td>
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<td></td>
<td>TS</td>
<td></td>
<td>All Types</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WL #13</td>
<td>Vertical Scaling</td>
<td>Poisson</td>
<td>WC</td>
<td>3</td>
<td>All Types</td>
<td>510s</td>
<td>265.03</td>
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<td></td>
<td>PI</td>
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<td>1029s</td>
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<tr>
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<td>WC</td>
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<td>All Types</td>
<td>523s</td>
<td>279.38</td>
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<tr>
<td>WL #16</td>
<td></td>
<td></td>
<td>PI</td>
<td>10</td>
<td>All Types</td>
<td>1045s</td>
<td>563.15</td>
<td></td>
</tr>
</tbody>
</table>

• Validation Metrics

\[
\text{Cost} = \sum_{i=1}^{n} \text{cost}_{VM_i}
\]

\[
\text{VM Utilization} = \frac{\sum_{i=1}^{n} \text{Time}_{JobExec.\cdot VM_i}}{\sum_{i=1}^{n} \text{Time}_{Total\cdot Run.\cdot VM_i}}
\]

\[
\text{Job DL Satisfaction Rate} = \frac{N_{Deadline\cdot Satisfied\cdot Jobs}}{N_{All\cdot Jobs}}
\]

\[
\text{Simulation Error} = \left| \frac{\text{Actual} - \text{Simulation}}{\text{Actual}} \right| \times 100\%
\]
PICS Validation – Horizontal Scaling

• Overall Simulation Error

<table>
<thead>
<tr>
<th>Workloads</th>
<th>Cost</th>
<th># of VMs</th>
<th>VM Util.</th>
<th>Job DL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WL #1</td>
<td>3.1%</td>
<td>3.4%</td>
<td>1.1%</td>
<td>0.6%</td>
</tr>
<tr>
<td>WL #2</td>
<td>2.4%</td>
<td>1.8%</td>
<td>1.4%</td>
<td>1.1%</td>
</tr>
<tr>
<td>WL #3</td>
<td>1.8%</td>
<td>2.3%</td>
<td>0.7%</td>
<td>0.6%</td>
</tr>
<tr>
<td>WL #4</td>
<td>5.2%</td>
<td>4.7%</td>
<td>2.2%</td>
<td>3.2%</td>
</tr>
<tr>
<td>WL #5</td>
<td>2.2%</td>
<td>7.1%</td>
<td>1.6%</td>
<td>2.1%</td>
</tr>
<tr>
<td>WL #6</td>
<td>0.8%</td>
<td>2.4%</td>
<td>2.4%</td>
<td>2.6%</td>
</tr>
<tr>
<td>WL #7</td>
<td>2.6%</td>
<td>3.6%</td>
<td>0.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>WL #8</td>
<td>3.6%</td>
<td>0.0%</td>
<td>1.0%</td>
<td>1.1%</td>
</tr>
<tr>
<td>WL #9</td>
<td>1.5%</td>
<td>1.5%</td>
<td>0.7%</td>
<td>0.6%</td>
</tr>
<tr>
<td>WL #10</td>
<td>0.9%</td>
<td>1.5%</td>
<td>0.9%</td>
<td>3.9%</td>
</tr>
<tr>
<td>WL #11</td>
<td>1.0%</td>
<td>0%</td>
<td>2.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>WL #12</td>
<td>6.1%</td>
<td>1.4%</td>
<td>1.3%</td>
<td>3.8%</td>
</tr>
<tr>
<td>Average Error</td>
<td>2.6%</td>
<td>2.4%</td>
<td>1.3%</td>
<td>1.9%</td>
</tr>
</tbody>
</table>
PICS Validation – Horizontal Scaling

- Cost Trace

(a) Cost Trace for WL #4
(b) Cost Trace for WL #6
(c) Cost Trace for WL #8
(d) Cost Trace for WL #10
PICS Validation – Horizontal Scaling

- Horizontal VM Scaling Trace

(a) VM scaling trace for WL #4
(b) VM scaling trace for WL #8
(c) VM scaling trace for WL #10
(d) VM scaling trace for WL #12
PICS Validation – Vertical Scaling

- Overall Simulation Error

<table>
<thead>
<tr>
<th>Workloads</th>
<th>Cost</th>
<th># of VMs</th>
<th>VM Utilization</th>
<th>Job Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>WL #13</td>
<td>6.1%</td>
<td>7.1%</td>
<td>4.3%</td>
<td>0.8%</td>
</tr>
<tr>
<td>WL #14</td>
<td>3.1%</td>
<td>1.9%</td>
<td>2.4%</td>
<td>4.6%</td>
</tr>
<tr>
<td>WL #15</td>
<td>3.2%</td>
<td>3.4%</td>
<td>1.7%</td>
<td>1.9%</td>
</tr>
<tr>
<td>WL #16</td>
<td>9.7%</td>
<td>1.9%</td>
<td>3.3%</td>
<td>3.2%</td>
</tr>
<tr>
<td>Average</td>
<td>5.5%</td>
<td>3.6%</td>
<td>2.9%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

- Cost Trace

- # of Vertical Scaling Decision

Fig. 7: Cost traces for vertical scaling cases.

Fig. 10: Simulation errors for the numbers of vertical scaling decisions.
PICS – Sensitivity Test

- **PICS** is **Accurate!**, but you may claim…
  - Accuracy of PICS depends on the accuracy of user-provided parameters.
  - Job execution time may be **difficult to acquire** precisely (due to performance uncertainty [19-21]).

- We conduct **Sensitivity Test** with imprecise job execution time (±10% and ±20%)
  - Why ±10%?
    - 88% of samples have at most 10% errors.
  - Why ±20%?
    - Maximum error case → 22% difference.
PICS – Sensitivity Test

• Simulation Errors with Imprecise Job Exec Time

TABLE V: Simulation Errors when the job execution time parameter has ±10% and ±20% errors.

<table>
<thead>
<tr>
<th>Err. in Params</th>
<th>Cost</th>
<th># of VMs</th>
<th>VM Util.</th>
<th>Job DL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20%</td>
<td>16.2%</td>
<td>13.5%</td>
<td>0.9%</td>
<td>5.96%</td>
</tr>
<tr>
<td>-10%</td>
<td>7.5%</td>
<td>6.3%</td>
<td>0.9%</td>
<td>4.25%</td>
</tr>
<tr>
<td>+10%</td>
<td>4.6%</td>
<td>4.7%</td>
<td>0.2%</td>
<td>3.31%</td>
</tr>
<tr>
<td>+20%</td>
<td>13.8%</td>
<td>11.7%</td>
<td>1.9%</td>
<td>2.01%</td>
</tr>
</tbody>
</table>

• Simulation Error of PICS are considerably smaller than the errors in the job execution time parameter.
• PICS retains high accuracy even when user provides imprecise job execution time parameters.
PICS – Sensitivity Test

- Cost Trace with Errors

- VM Scaling Trace with Errors

(a) WL #6 with imprecise parameter

(b) WL #10 with imprecise parameter

(a) WL #6 with imprecise parameter

(b) WL #11 with imprecise parameter
PICS – Conclusion

• We design **PICS** to answer cloud user’s question about
  • “*Evaluating the public clouds without actually deploying the cloud-application.*”

• PICS provides capabilities of simulating:
  • Cloud Cost
  • Resource *Horizontal/Vertical* Scaling
  • Resource Utilization
  • SLA satisfaction (e.g. Deadline)

• Validating PICS by comparing with actual MapReduce application on real public IaaS.
PICS – Future Works

1. **Validating PICS on Other Public IaaS Clouds:**
   - MS Azure, Google Compute Cloud, etc.

2. **Validating PICS with Other Application:**
   - n-Tier Application
   - Big Data/Scientific Application

3. **Validating PICS with Other Metrics:**
   - I/O, Network
   - Storage
Download PICS:
http://www.cs.virginia.edu/~ik2sb/PICS/

Thank You!
Support Slides
Requirements for New IaaS Simulator

- Assessing a wide range of cloud properties. (e.g. cost, response time, resource utilization)
- Simulating various RM policies. (e.g. Horizontal/Vertical auto scaling, job scheduling, job failure)
- Allowing users to specify different workloads (e.g. Varying job arrival time, SLA satisfaction)
- Evaluating performance of different IaaS configurations (e.g. variety of resource types, billing models, performance uncertainty)

+ Ease of Use
**PICS: Related Works**

- **Comparison of Simulation Capabilities**

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<th></th>
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<tbody>
<tr>
<td><strong>Datacenter Issues</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM management (allocation, provisioning, scheduling, migration)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Physical resource management and scaling</td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
<td>No</td>
</tr>
<tr>
<td>Network resource management</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Power consumption management</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Federated cloud management</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Datacenter workload management</td>
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<td>No</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td><strong>Cloud User Issues</strong></td>
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<tr>
<td>Horizontal VM auto-scaling (scale-in/out)</td>
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<td>No</td>
<td>Yes</td>
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<tr>
<td>Vertical VM auto-scaling (scale-up/down)</td>
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<td>No</td>
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<td>Storage service management</td>
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<td>Job/Application scheduling</td>
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<td>No</td>
<td>Yes</td>
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<td>Billing management (cost optimization)</td>
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<td>Yes</td>
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<tr>
<td>Application/Job failure management</td>
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<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
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<td>IaaS performance uncertainty</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Horizontal Scaling: VM Utilization and Job Deadline Match

Fig. 3: The VMs numbers per VM type, normalized over the actual measurement (M: m3.medium, L: m3.large, X: m3.xlarge, XL: m3.xlarge)

Fig. 4: The VM utilisations per VM type, normalized over the actual measurement (M: m3.medium, L: m3.large, X: m3.xlarge, XL: m3.xlarge)

Fig. 5: Job deadline satisfaction traces for horizontal scaling cases.
Vertical Scaling: VM Utilization and Job Deadline Match

Fig. 8: The VM numbers (a) and utilizations (b) per VM type, normalized over the actual measurement (M: m3.medium, L: m3.large, X: m3.xlarge, XL: m3.xlarge)

Fig. 9: Job deadline satisfaction traces for vertical scaling cases