# BigSecret: A Secure Data Management Framework for Key-Value Stores

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# Motivation

- Increased network traffic, and number of users in the last decade
  – Simultaneously millions of users want to surf on popular web sites, e.g. Facebook, Twitter, Amazon
- Traditional databases may cause bottlenecks
  – ACID properties may not be needed
  – Some applications may tolerate inconsistencies in the data
  – A user wouldn’t wait too much for a web page to open
- Retrieving data should be fast!

# Motivation

- Many companies have started adopting and providing Key-Value store solutions, e.g. Amazon's SimpleDB, Google's AppEngine
  - Very fast data retrieval and sending
  - Scalable
  - Allows dynamic data structure
- In a Key-Value store, data consists of a Key and Value pairing
  - Both are uninterpreted array of bytes
  - Stored based on some rules
    - Some may store in sorted order
    - Some may store using hash functions

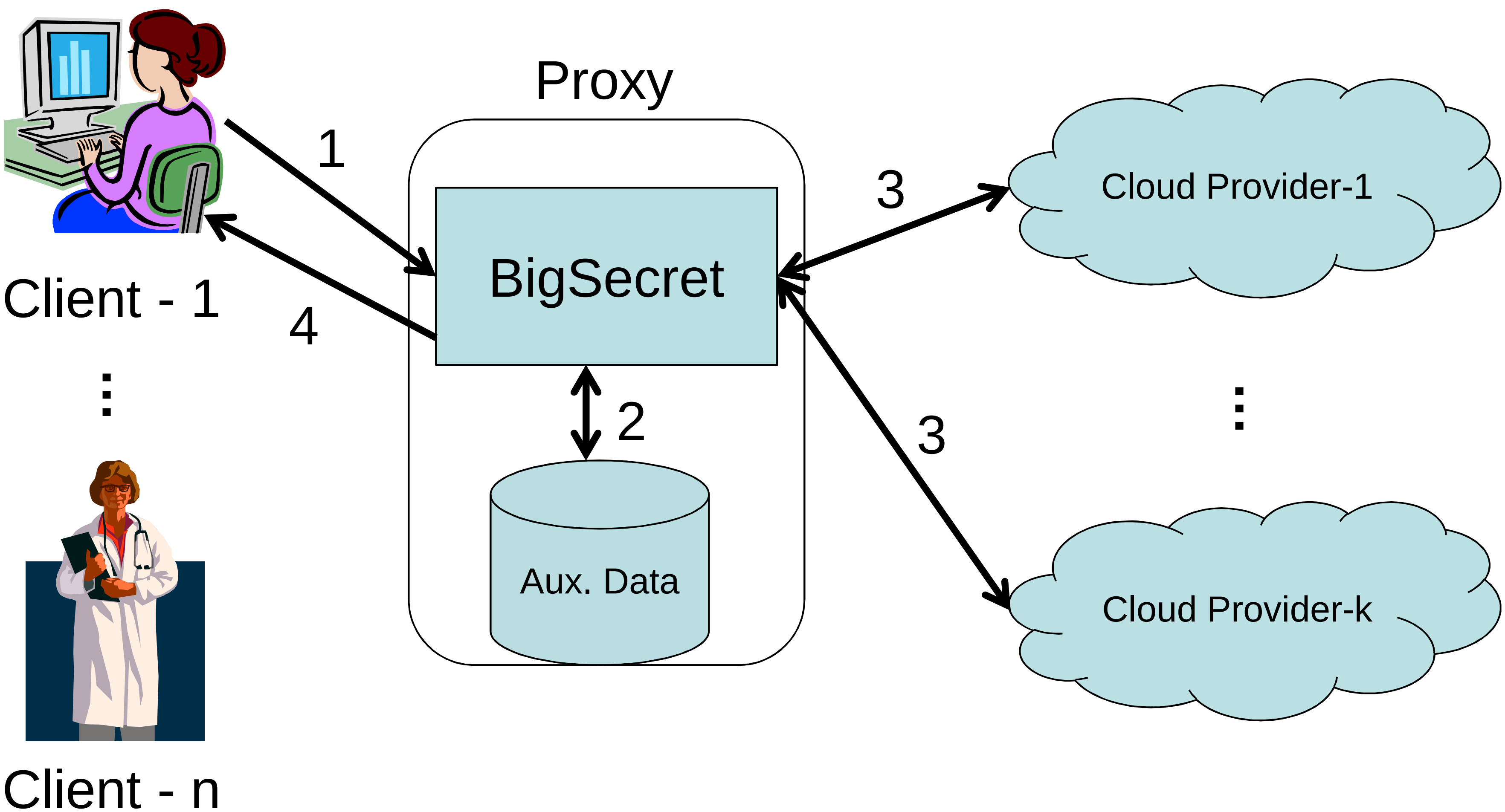
# Motivation

- A Data Owner can outsource data to any number of public cloud providers
  - May also use its own cloud infrastructure, i.e. private cloud
- When public, sensitive information needs to be protected
- Securing data and providing efficient querying mechanisms is though

# Aim

- Provide scalable, efficient and secure solutions to outsource Key-Value data
- Utilize any existing cloud infrastructures to
  - Improve performance
  - Reduce the overall monetary cost
  - Reduce the overall sensitive data disclosure

# Overview of the Solution: BigSecret



# Outline

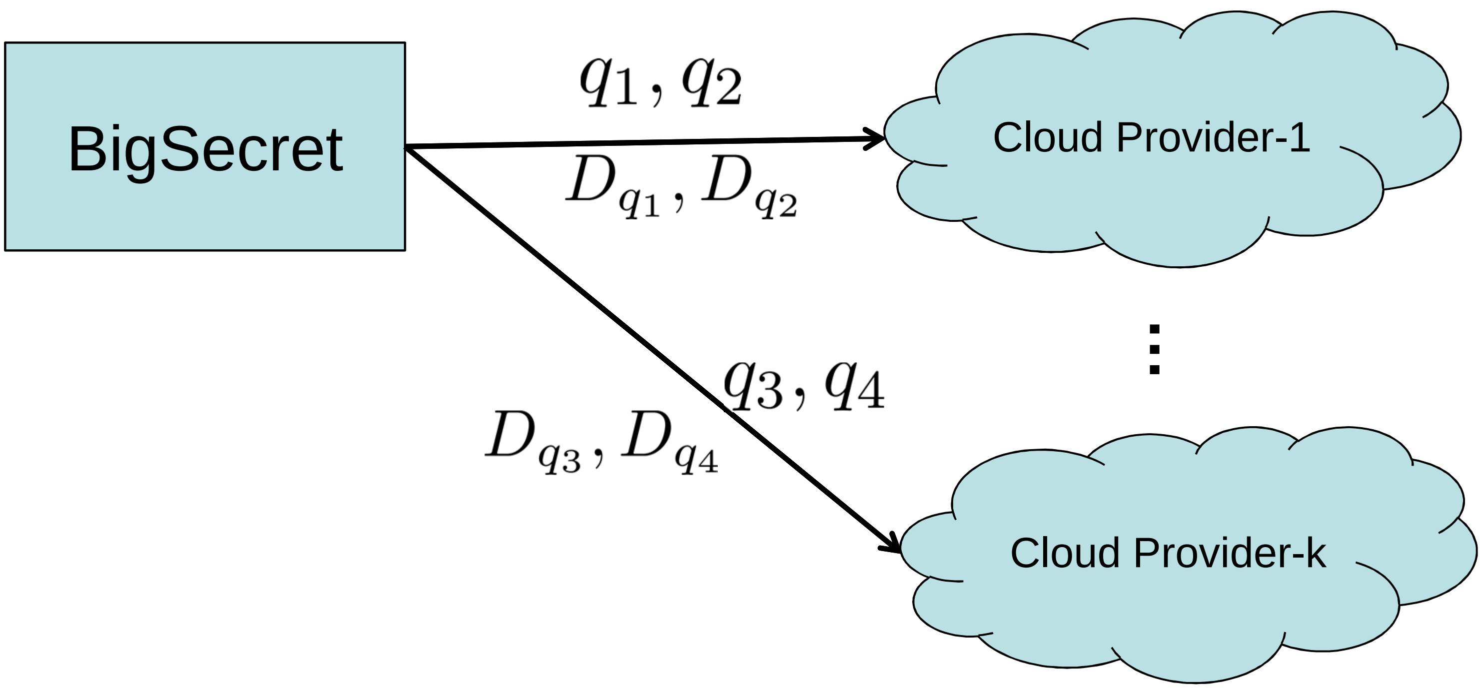
- How do we share data and workload on all providers?
  - Monetary metrics
  - Security metrics
  - Performance metrics
  - Heuristic solution
- How do we store data in encrypted form?
  - Transformation of data
  - Transformation of queries
- Experiments

# Data and Workload Partitioning Problem

- Given:
  - A dataset of Key-Value pairs, $\mathcal{D}$
  - A workload on the dataset, $\mathcal{Q}$
  - A set of providers, $\mathcal{P}$
- First, partition workload over the providers such that
  - The total execution time of the workload is minimized
  - The total amount of monetary cost from cloud usage is below a limit
  - Expected amount of sensitive data disclosure is below a limit

# Data and Workload Partitioning Problem

- Second, partition data based on queries
  - All Key-Value pairs needed to answer a query is given to that provider

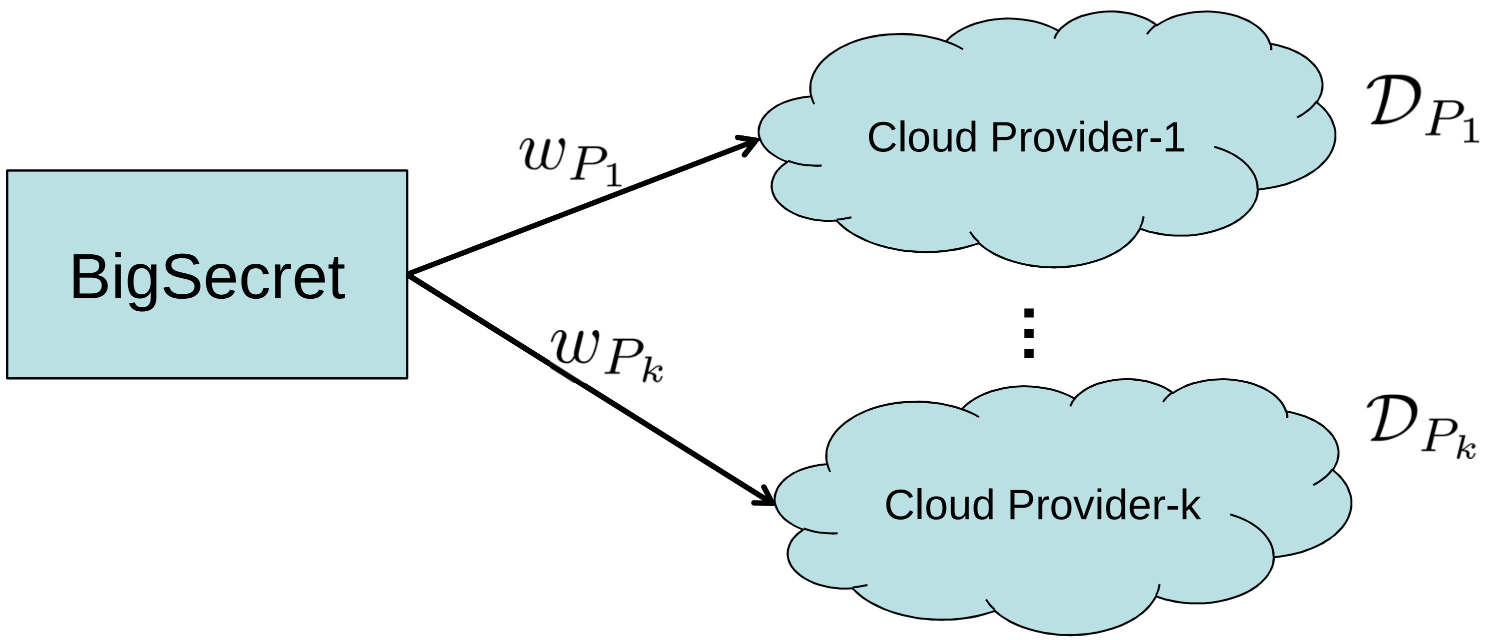


# Data and Workload Partitioning Problem

- Each provider $P_i$ is given:
  - Partitioned workload $\mathcal{Q}_{P_i}$
  - Partitioned dataset $\mathcal{D}_{P_i}$
- Total monetary cost of a workload $\mathcal{Q}_{P_i}$ on the provider $P_i$ is:
  - $t(\mathcal{Q}_{P_i}, P_i) := s(\mathcal{D}_{P_i}, P_i) + \sum_{q \in \mathcal{Q}_{P_i}} f(q) \times c(q, P_i)$
- Total monetary cost of the partitioned workload $\mathcal{Q}_{P_1}, \ldots, \mathcal{Q}_{P_k}$:
  - $\sum t(\mathcal{Q}_{P_i}, P_i) \leq C_{cost}$

# Data and Workload Partitioning Problem

- Expected number of sensitive Key-Value entries in $\mathcal{D}_{P_i}$ is represented as $sens(\mathcal{D}_{P_i})$
- Total expected disclosure:
  - $\sum w_{P_i} \times sens(\mathcal{D}_{P_i}) \leq C_{risk}$



## Data and Workload Partitioning Problem

- Expected execution time of a workload $\mathcal{Q}_{P_i}$ on $P_i$
  - $r(\mathcal{Q}_{P_i}, P_i) := \sum_{q \in \mathcal{Q}_{P_i}} f(q) \times r(q, P_i)$
  - $r(q, P_i) := \frac{io(q)}{pow(P_i)}$
- Minimize the total execution time:
  - $OptRun(\mathcal{Q}_{P_1}, \ldots, \mathcal{Q}_{P_k}) := \sum_{P_i \in \mathcal{P}} r(\mathcal{Q}_{P_i}, P_i)$
- We call this particular partitioning problem over a set of providers as Multi-Cloud Partitioning Problem (MCPP), which is proven to be NP-Hard

# Heuristic Solution to MCPP

- We approach the problem using Hill-Climbing technique
- First assign each query to a provider so that the initial constraints are met
- Then, iterate over each query and check
  - Better performance can be achieved
  - Constraints are still met
- Finish when no further improvements can be made

# Background - HBase

- Apache's open source Key-Value store implementation, designed after Google's BigTable
- Key consists of four parts:
  - row-key (row)
  - family (fam)
  - qualifier (qua)
  - timestamp (ts)
- Provides 4 operations:
  - Put, Get, Delete, and Scan

# Data Transformation

- Data is transformed into encrypted form using "Encryption Models"

| | **Model-1** | **Model-2** | **Model-3** |
|---|---|---|---|
| **row** | $Map(row)$ | $H(row)$ | $H(row)$ |
| **fam** | $Map(fam)$ | $H(fam)$ | $0$ |
| **qua** | $Map(qua)\|E(KEY)$ | $H(qua)\|E(KEY)$ | $E(KEY)$ |
| **ts** | $Map(ts)$ | $H(ts)$ | $1$ |
| **val** | $E(val)$ | $E(val)$ | $E(val)$ |

# Query Translation

- Given a Put query, translation for Model-2:
  - put("Jake", "personal", "height", "170cm", 1)
  - put(H("Jake"), H("personal"), H("height")||E(KEY), E("170cm"), H(1))
  - KEY = "Jakepersonalheight1"

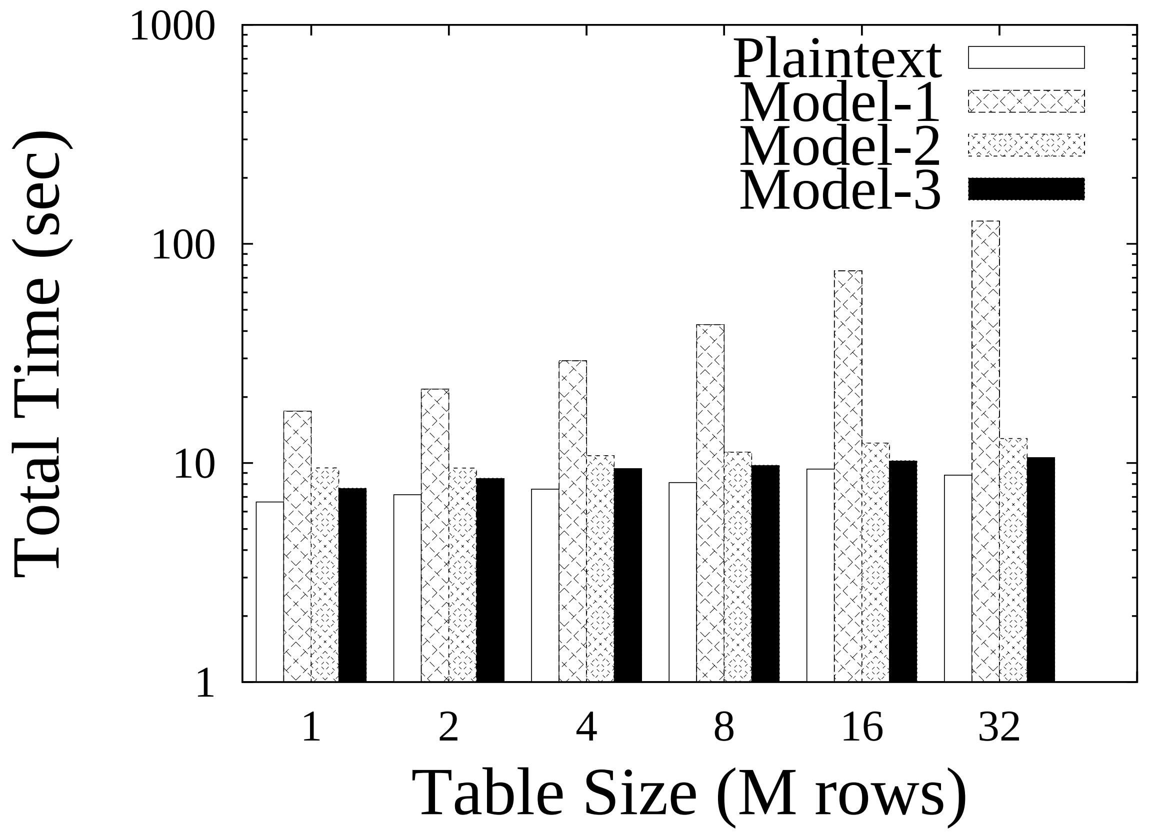
- Given a Get query, translation for Model-2:
  - get("Jake", 0, ∞, "personal")
  - get(H("Jake"), 0, ∞, H("personal"))

# Experiments

- Performed experiments using Yahoo! Cloud Serving Benchmark
- Created tables consisting of 1,2,4,8,16, and 32 Millions of rows
  - Each row has 10 Key-Value entries of 100B
- Created 3 different workloads
  - 1K queries for single-cloud experiments
  - 100K queries for multi-cloud experiments

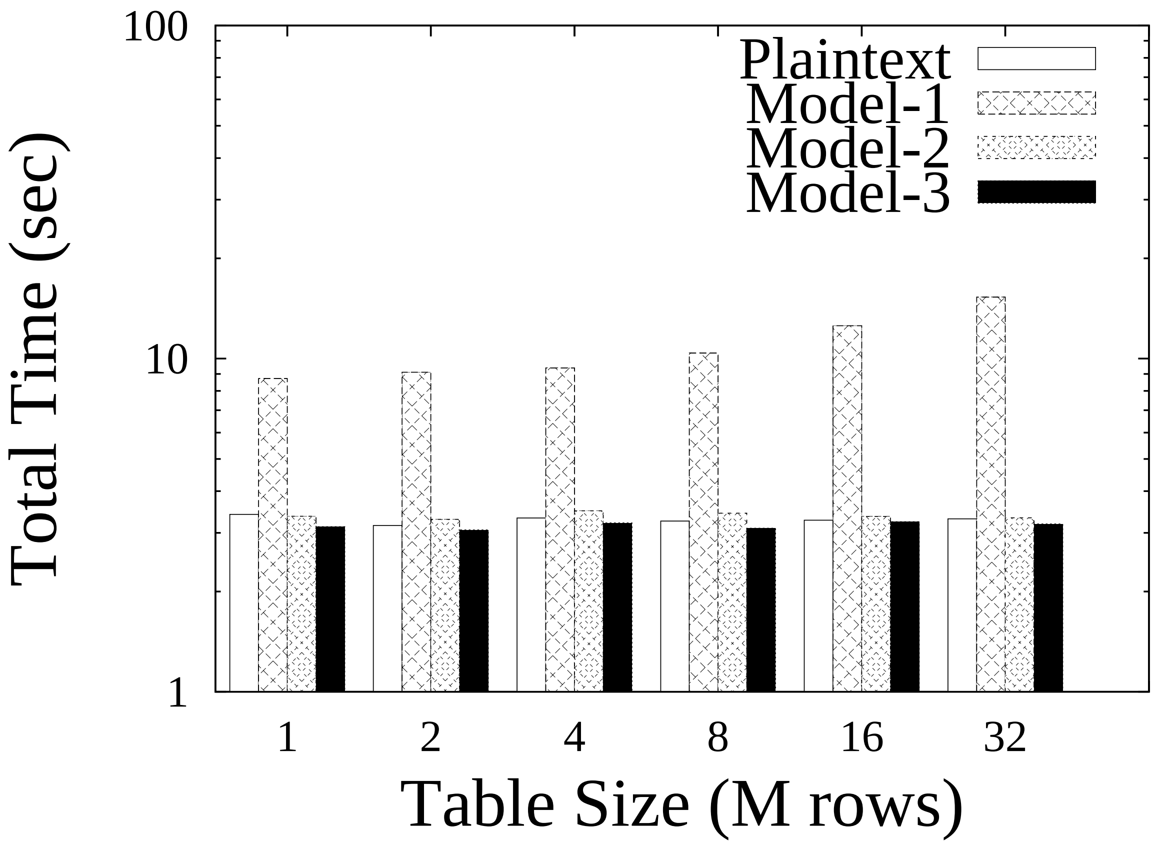
| | Workload-1 | Workload-2 | Workload-3 |
|---|---|---|---|
| Put (%) | 5 | 95 | 25 |
| Get (%) | 95 | 5 | 25 |
| Scan (%) | 0 | 0 | 50 |

# Single-Cloud Experiments



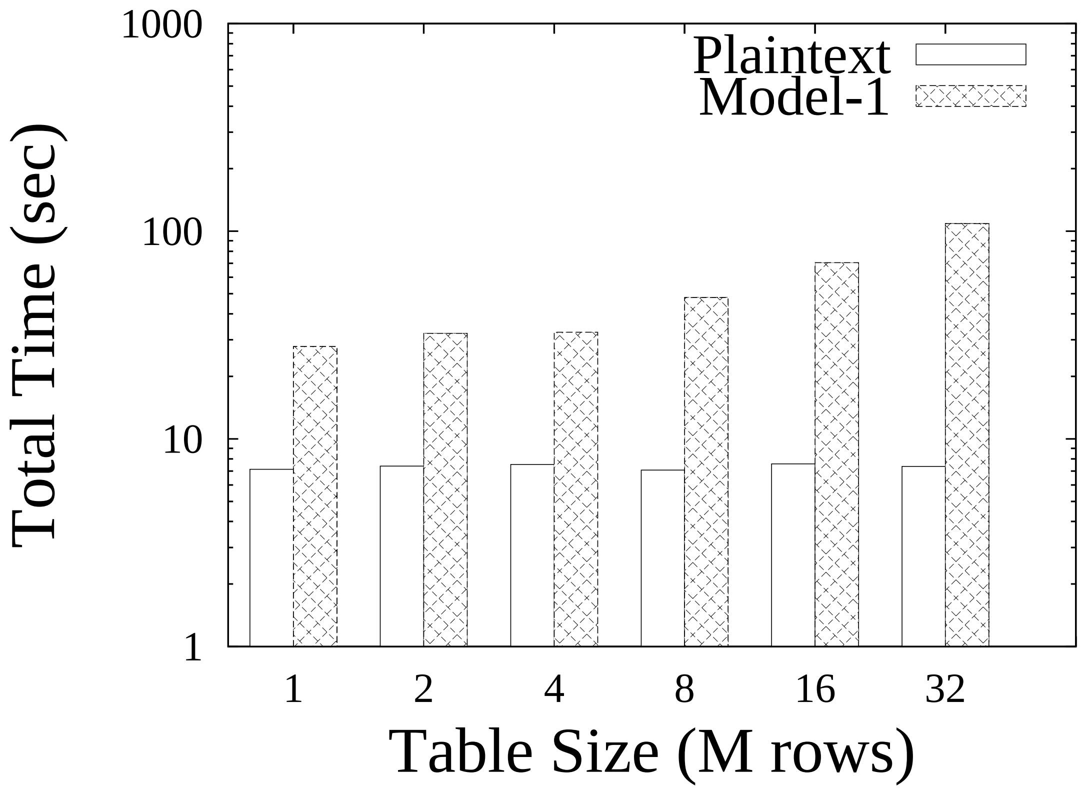

Workload - 1

# Single-Cloud Experiments




Workload - 2

# Single-Cloud Experiments

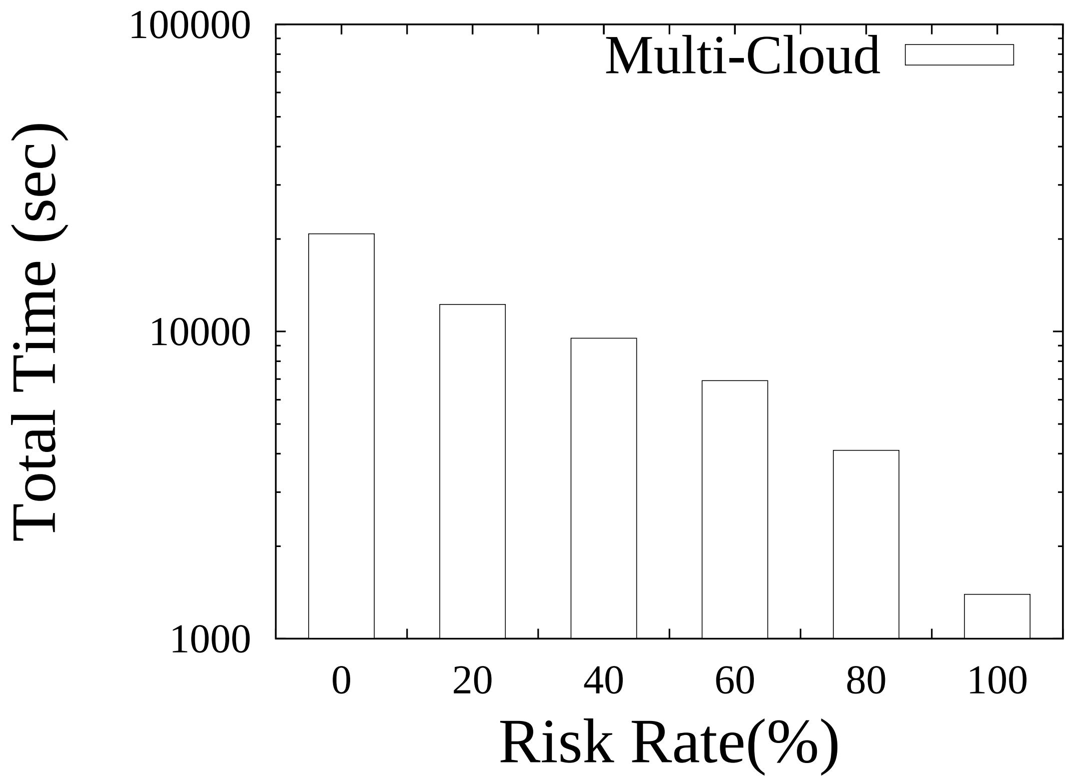



Workload - 3

# Multi-Cloud Experiments

- Same cluster is used with two different settings:
  - Provider-1: Plaintext storage, $w_{P_1}$ is 1
  - Provider-2: Uses Model-2, $w_{P_2}$ is 0.7
- Both have the same pricing policies
  - Amazon S3, EC2, and EMR pricing
- Monetary cost constraint varies between \$700 and \$3700
- All data is assumed to be sensitive

# Multi-Cloud Experiments




Workload - 3

# Conclusion

- We proposed efficient and secure storage techniques, specially designed for Key-Value stores
- We formalized how to partition data and workload on a multi-cloud setup with monetary, sensitivity disclosure, and performance constraints
- We implemented BigSecret on Hbase, and evaluated the performance

# Conclusion

- We plan to add support for other Key-Value stores
- BigSecret will be open-source

# Q&A

Thank You