Tackling The Challenges of Big Data

Big Data Systems

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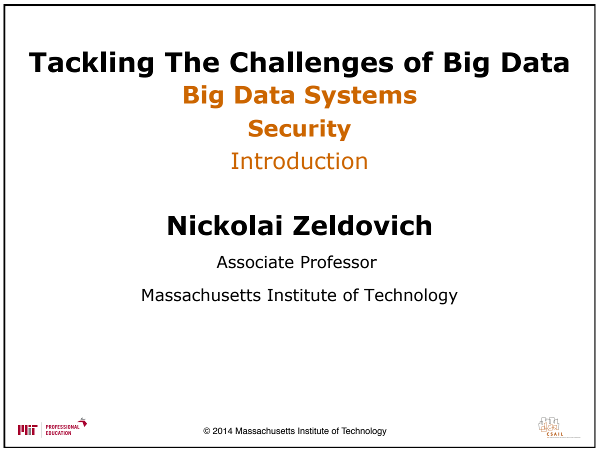

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Introduction

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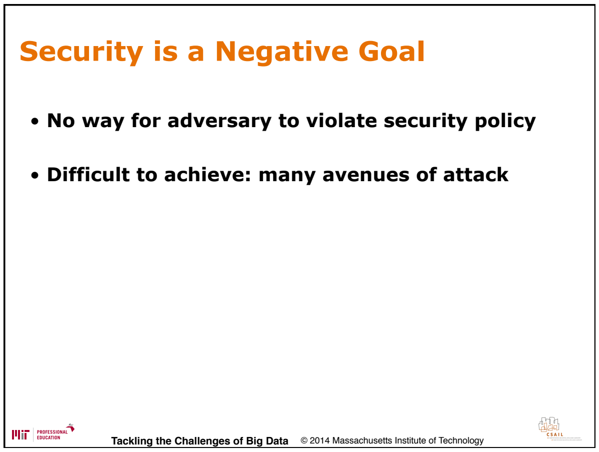
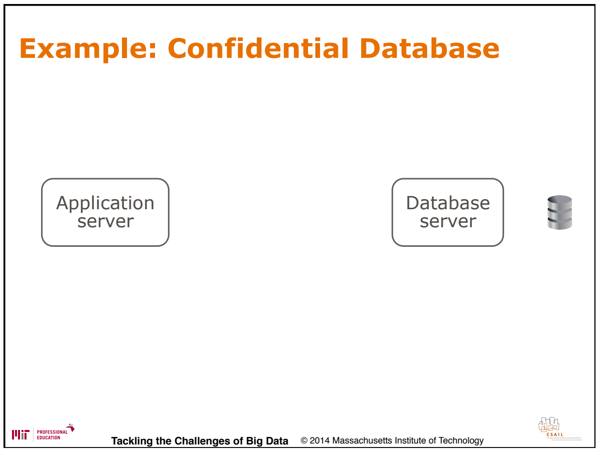


Security is a Negative Goal

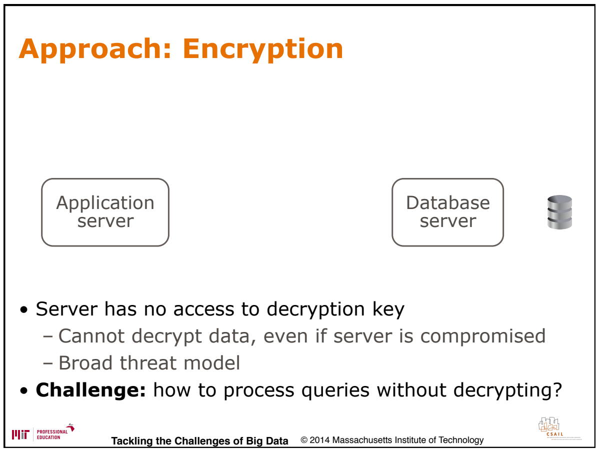
- No way for adversary to violate security policy
- Difficult to achieve: many avenues of attack



Example: Confidential Database

Application server

Database server

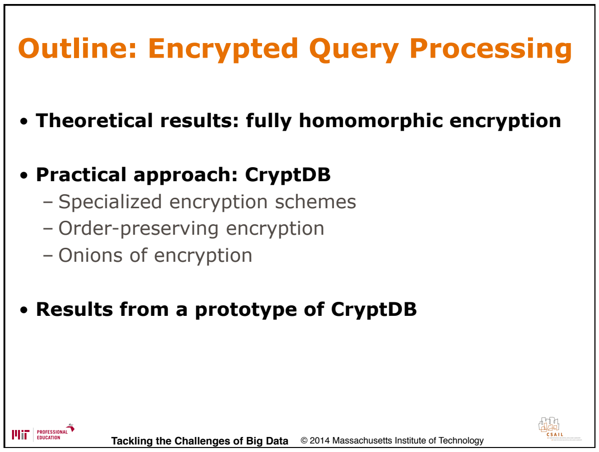


Approach: Encryption

Application server

Database server

- Server has no access to decryption key
  - Cannot decrypt data, even if server is compromised
  - Broad threat model
- **Challenge:** how to process queries without decrypting?



Outline: Encrypted Query Processing

- **Theoretical results: fully homomorphic encryption**
- **Practical approach: CryptDB**
  - Specialized encryption schemes
  - Order-preserving encryption
  - Onions of encryption
- **Results from a prototype of CryptDB**

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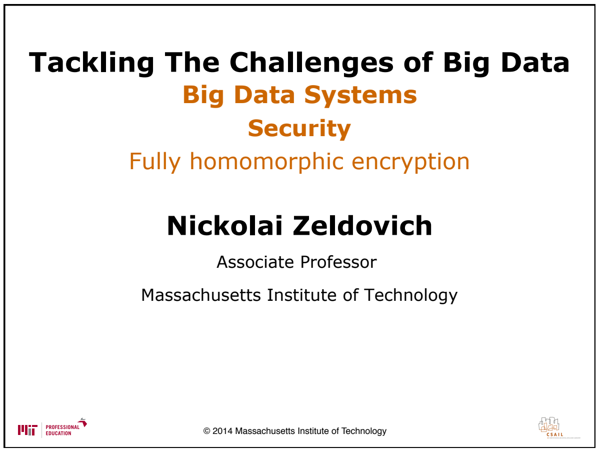

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Fully homomorphic encryption

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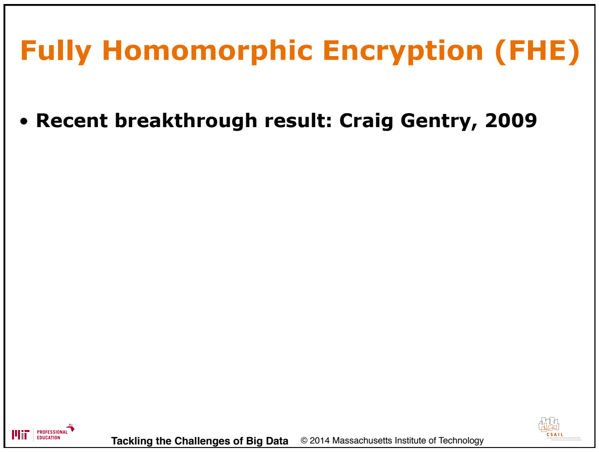
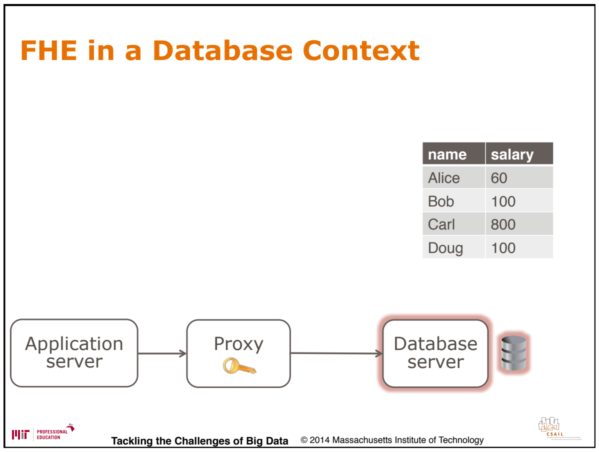


Fully Homomorphic Encryption (FHE)

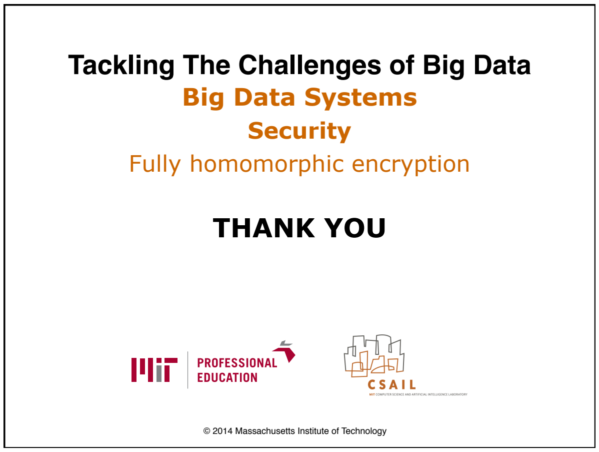
- **Recent breakthrough result: Craig Gentry, 2009**



FHE in a Database Context

name	salary
Alice	60
Bob	100
Carl	800
Doug	100

Application server → Proxy → Database server



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Fully homomorphic encryption

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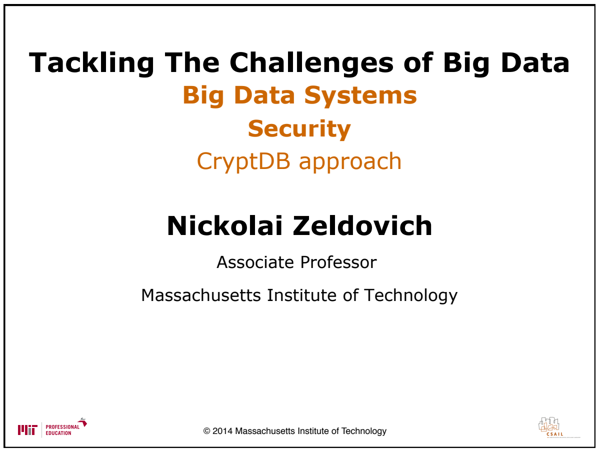

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CryptDB approach

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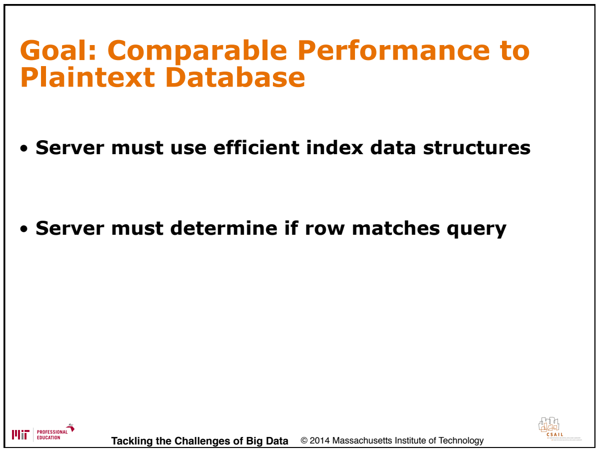
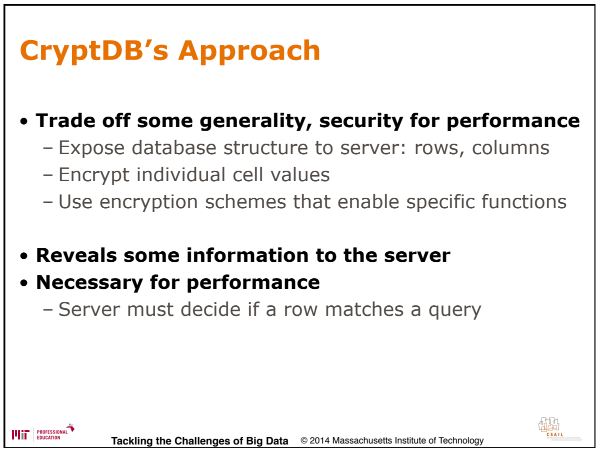


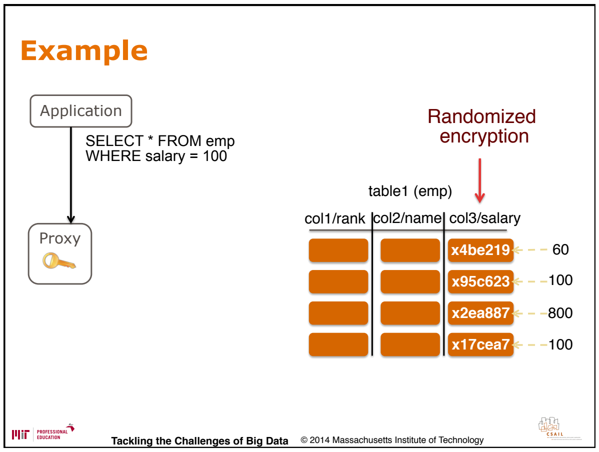
Goal: Comparable Performance to Plaintext Database

- **Server must use efficient index data structures**
- **Server must determine if row matches query**

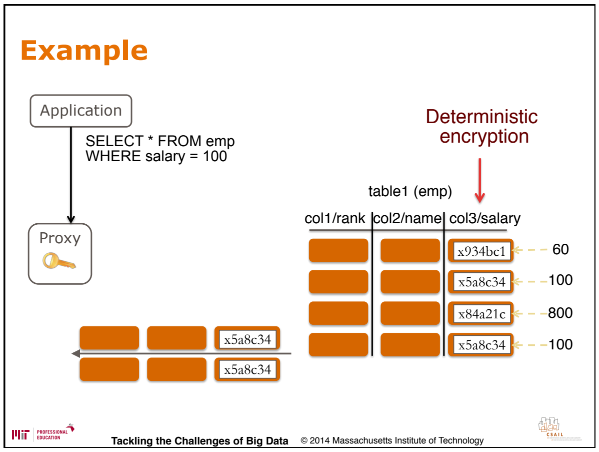


CryptDB's Approach

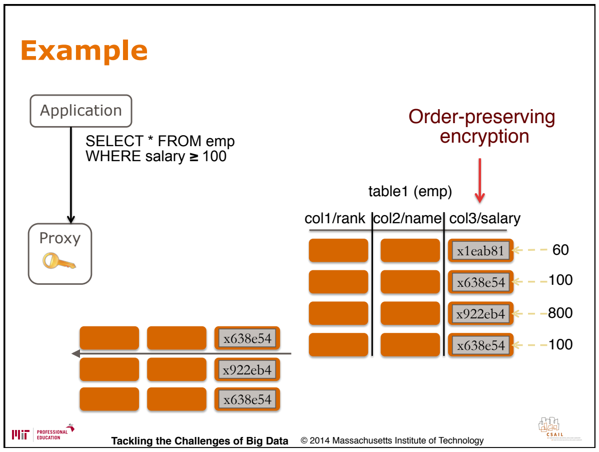
- **Trade off some generality, security for performance**
  - Expose database structure to server: rows, columns
  - Encrypt individual cell values
  - Use encryption schemes that enable specific functions
- **Reveals some information to the server**
- **Necessary for performance**
  - Server must decide if a row matches a query



Example



Example



Example

Application

SELECT * FROM emp
WHERE salary ≥ 100

Proxy

Order-preserving encryption

table1 (emp)

col1/rank	col2/name	col3/salary	
		x1eab81	60
		x638e54	100
		x922eb4	800
		x638e54	100

x638e54
x922eb4
x638e54

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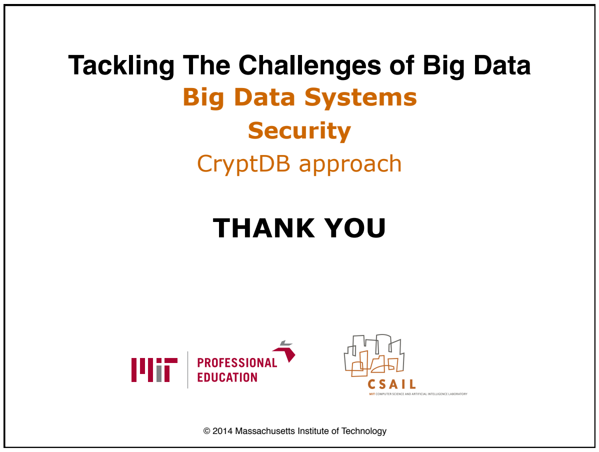

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CryptDB approach

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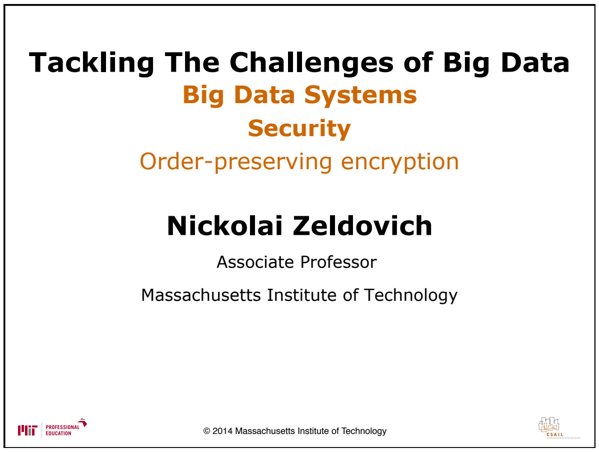

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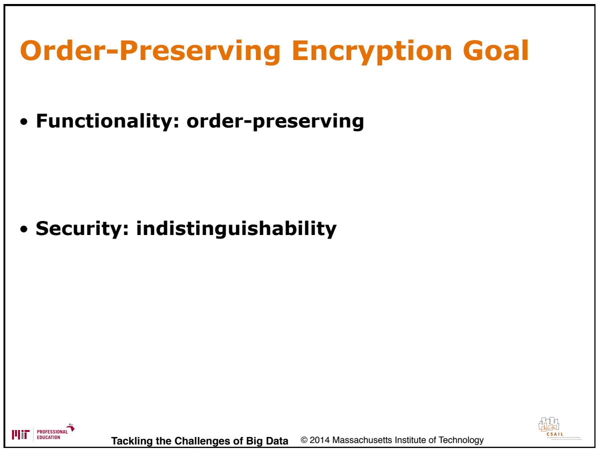
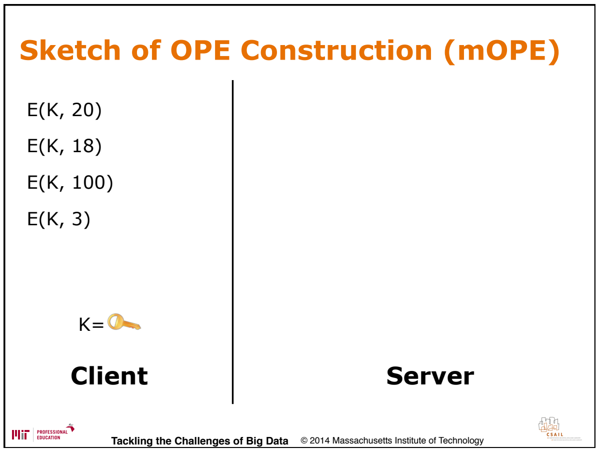


Order-Preserving Encryption Goal

- **Functionality: order-preserving**
- **Security: indistinguishability**



Sketch of OPE Construction (mOPE)

E(K, 20)

E(K, 18)

E(K, 100)

E(K, 3)

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Order-preserving encryption

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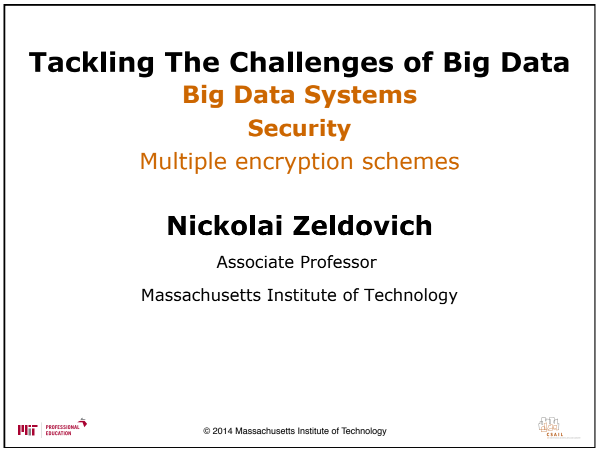

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Multiple encryption schemes

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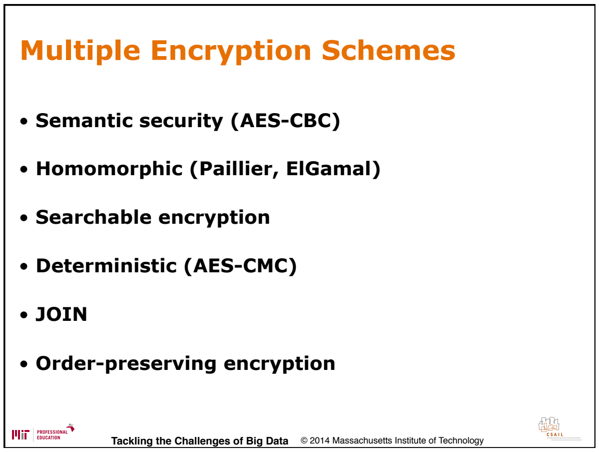
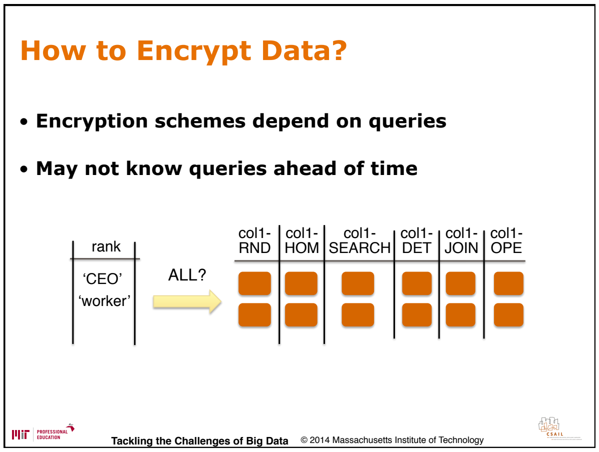


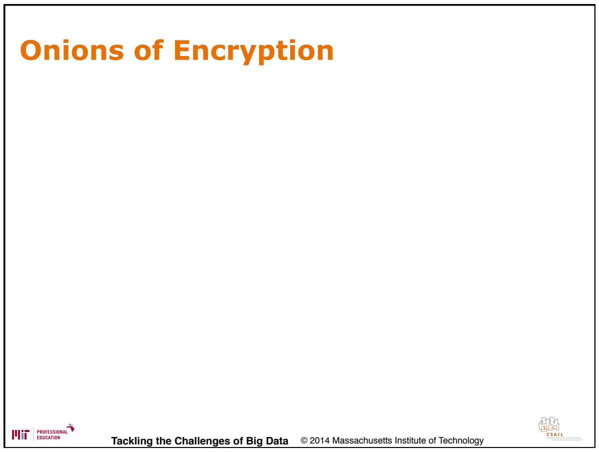
Multiple Encryption Schemes

- Semantic security (AES-CBC)
- Homomorphic (Paillier, ElGamal)
- Searchable encryption
- Deterministic (AES-CMC)
- JOIN
- Order-preserving encryption

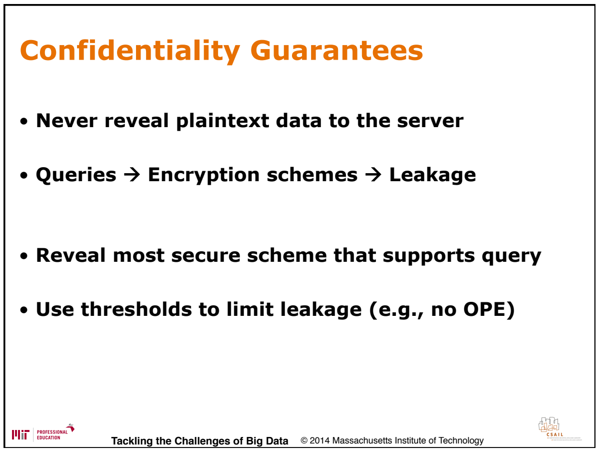


How to Encrypt Data?

- Encryption schemes depend on queries
- May not know queries ahead of time



Onions of Encryption



Confidentiality Guarantees

- Never reveal plaintext data to the server
- Queries → Encryption schemes → Leakage
- Reveal most secure scheme that supports query
- Use thresholds to limit leakage (e.g., no OPE)

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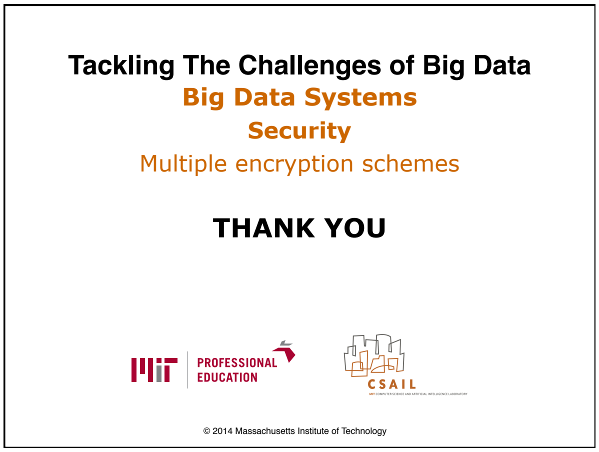

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CryptDB results

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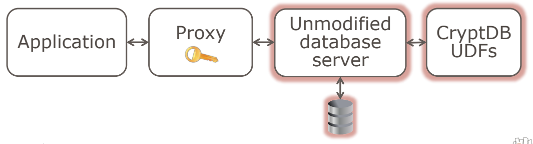
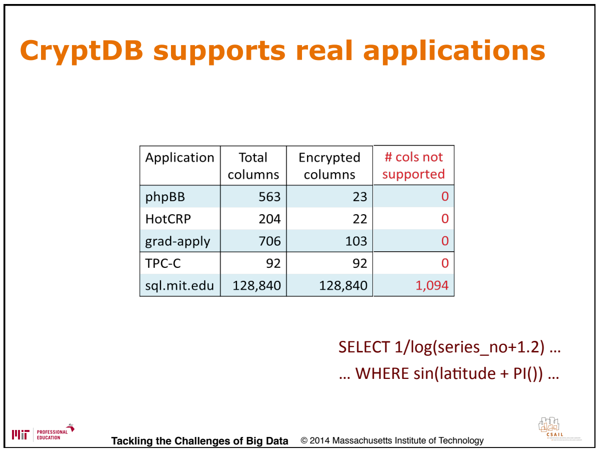
Implementation

- **Proxy rewrites query to run over encrypted data**
  - User-defined functions for crypto (onion adjustment, …)
- **Prototype: 26,000 lines of C++ code**



Evaluation Questions

- **Can CryptDB support real queries and applications?**
- **What is the resulting level of confidentiality?**
- **What is the performance overhead of CryptDB?**

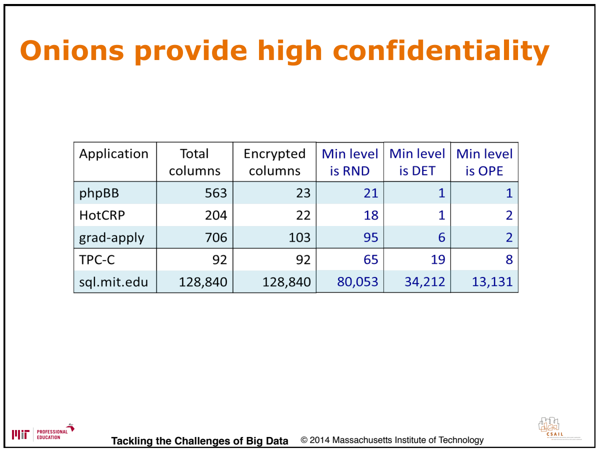


CryptDB supports real applications

Application	Total columns	Encrypted columns	# cols not supported
phpBB	563	23	0
HotCRP	204	22	0
grad-apply	706	103	0
TPC-C	92	92	0
sql.mit.edu	128,840	128,840	1,094

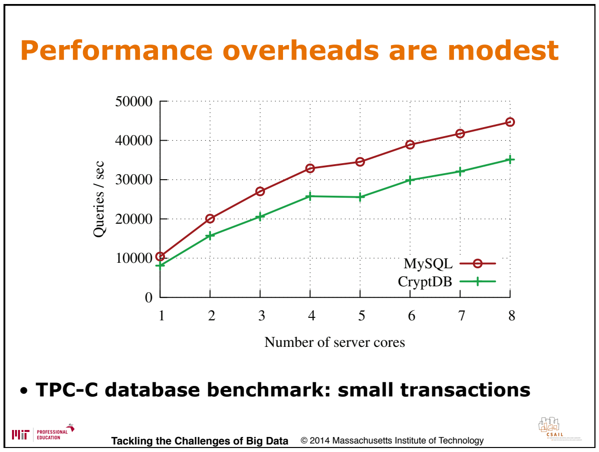
SELECT 1/log(series_no+1.2) …

… WHERE sin(latitude + PI()) …



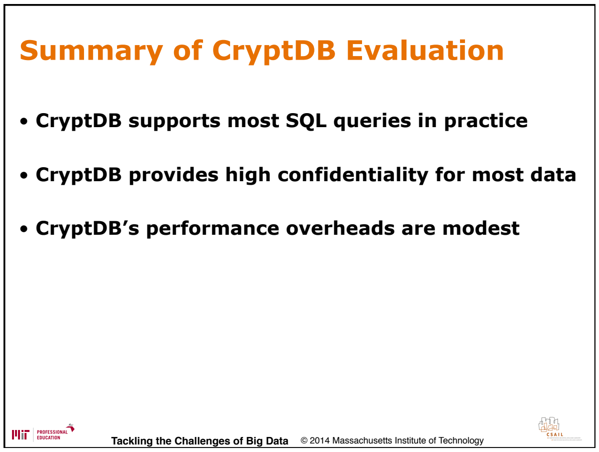
Onions provide high confidentiality

Application	Total columns	Encrypted columns	Min level is RND	Min level is DET	Min level is OPE
phpBB	563	23	21	1	1
HotCRP	204	22	18	1	2
grad-apply	706	103	95	6	2
TPC-C	92	92	65	19	8
sql.mit.edu	128,840	128,840	80,053	34,212	13,131



Performance overheads are modest

- **TPC-C database benchmark: small transactions**



Summary of CryptDB Evaluation

- CryptDB supports most SQL queries in practice
- CryptDB provides high confidentiality for most data
- CryptDB's performance overheads are modest

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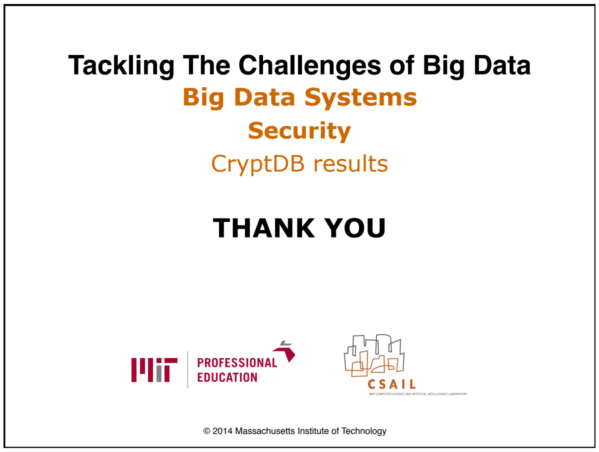

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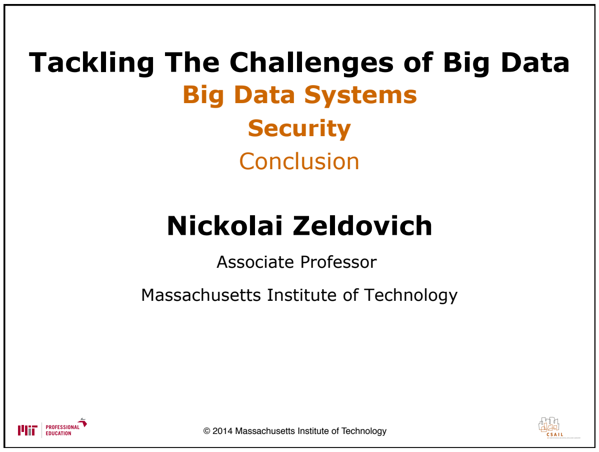

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Conclusion

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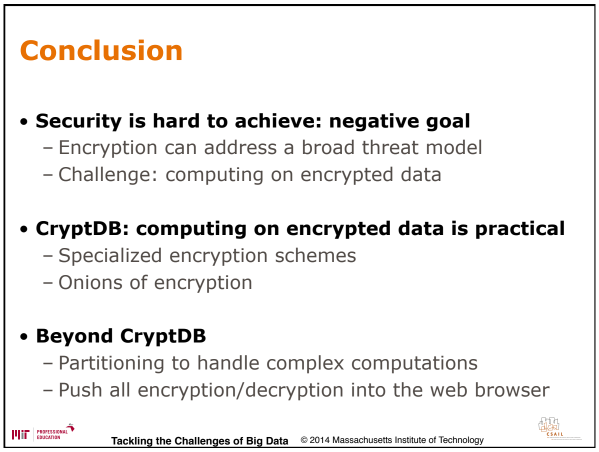
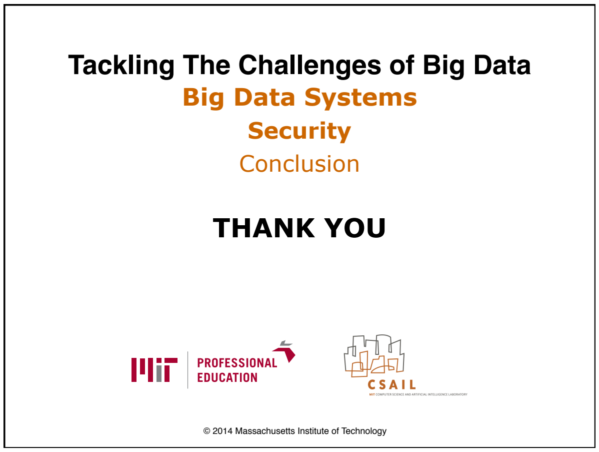


Conclusion

- **Security is hard to achieve: negative goal**
  - Encryption can address a broad threat model
  - Challenge: computing on encrypted data
- **CryptDB: computing on encrypted data is practical**
  - Specialized encryption schemes
  - Onions of encryption
- **Beyond CryptDB**
  - Partitioning to handle complex computations
  - Push all encryption/decryption into the web browser



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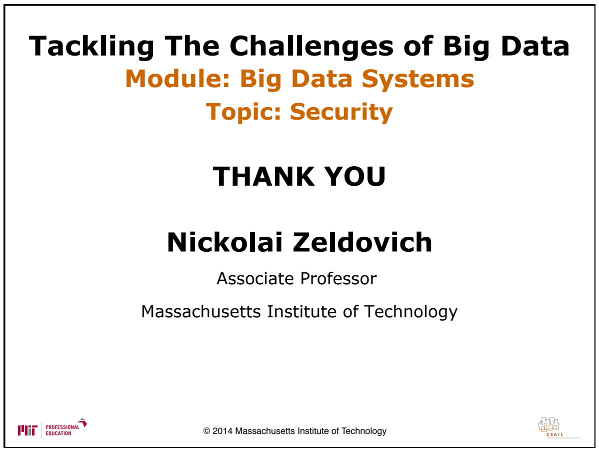

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