Computing over encrypted data: homomorphic encryption and CryptDB

Homomorphic encryption

- Encryption *Enc* is called homomorphic with respect to an operation * if
- Enc(x*y) = Enc(x)*Enc(y).
- That is given encrypted forms of x and y, in order to compute encrypted form of x*y one does not need to decrypt Enc(x) and Enc(y)
- Computations over encrypted values!

Partial vs Fully homomorphic schemes

- Partially homomorphic encryption: with respect just to one operation;
- RSA (unpadded) is homomorphic with respect to multiplication. Why?
- Fully homomorphic schemes:
  - With respect to multiplication and addition
  - Allow to perform arbitrary computations
  - Existence is by no means obvious

Breakthrough: FHE is possible!

- *Craig Gentry*: first fully homomorphic encryption scheme is announced by IBM on June 25, 2009.

- The scheme is impractical for many applications:

  ciphertext size and computation time increase sharply as one increases the security level. Key’s size is also an issue.

Recent developments

- New more efficient schemes and implementations since 2010, key size is reduced at least to 600Kb (~2016)
- *HELib* is an open source implementation (2013, new version 2018)) (C++)
- More implementations available, including in R and Python;
- New library SEAL made available by Microsoft in 2018
- Still more work is needed to make it practical;

Potential applications

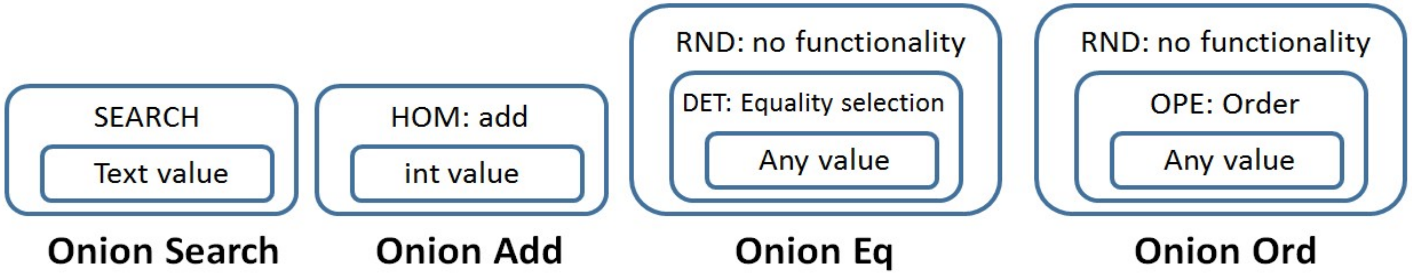
- Computations on not entirely trusted services (e.g. in the cloud) :
  - Encrypt your computational task and send it to a remote server;
  - The server computes over encrypted data and returns an encrypted result;
  - Decrypt result;
- Pipeline processing without revealing intermediate data;
- …

CryptDB

- Similar idea in data processing:

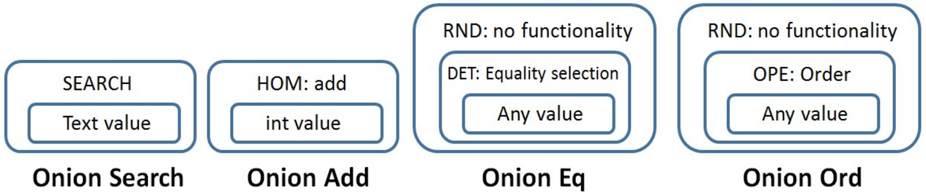
- To query encrypted SQL database without decrypting;
- Selected fields can be encrypted;
- Practical working prototype system: CryptDB,
- Raluca Ada Popa et al, MIT (2011-..): http://css.csail.mit.edu/cryptdb/
- Low overhead: reducing throughput 15-25%

Onion-layered SQL-aware encryption



- All data in CrypDB can be encrypted using several layers of encryption;
  - Each layer may “release” some information about encrypted value

Querying in CryptDB



- Before querying, depending on a query :
  - some values in the query are encrypted;
  - encryption layers in the database are adjusted (both steps are done by a proxy)
- After the query execution: encrypted results are returned
  - The proxy decrypts them and returns to the client the final result
- Examples to consider:

  SELECT * FROM Customers

  SELECT * FROM Customers WHERE Country = ‘Mexico’

(SQL tutorial at w3schools.com/sql)

Developments here in the Department

- In two PhD projects:
  - CryptDB-like approach to graph DBs (Neo4j);
  - CryptDB-like approach do document-based DBs (MongoDB).