Practical, Secure Computing through Fully Homomorphic Encryption

Kurt Rohloff
krohloff@duality.cloud

Redhat 2019

A Fear and a Vision

"Your previous provider refused to share your electronic medical records, but not to worry —I was able to obtain all of your information online."

Encryption?

A method to “hide” information.

Use cases:

Symmetric Encryption

- – Hide information so it can be used later only by you.
  - Ex: protecting your legal files.

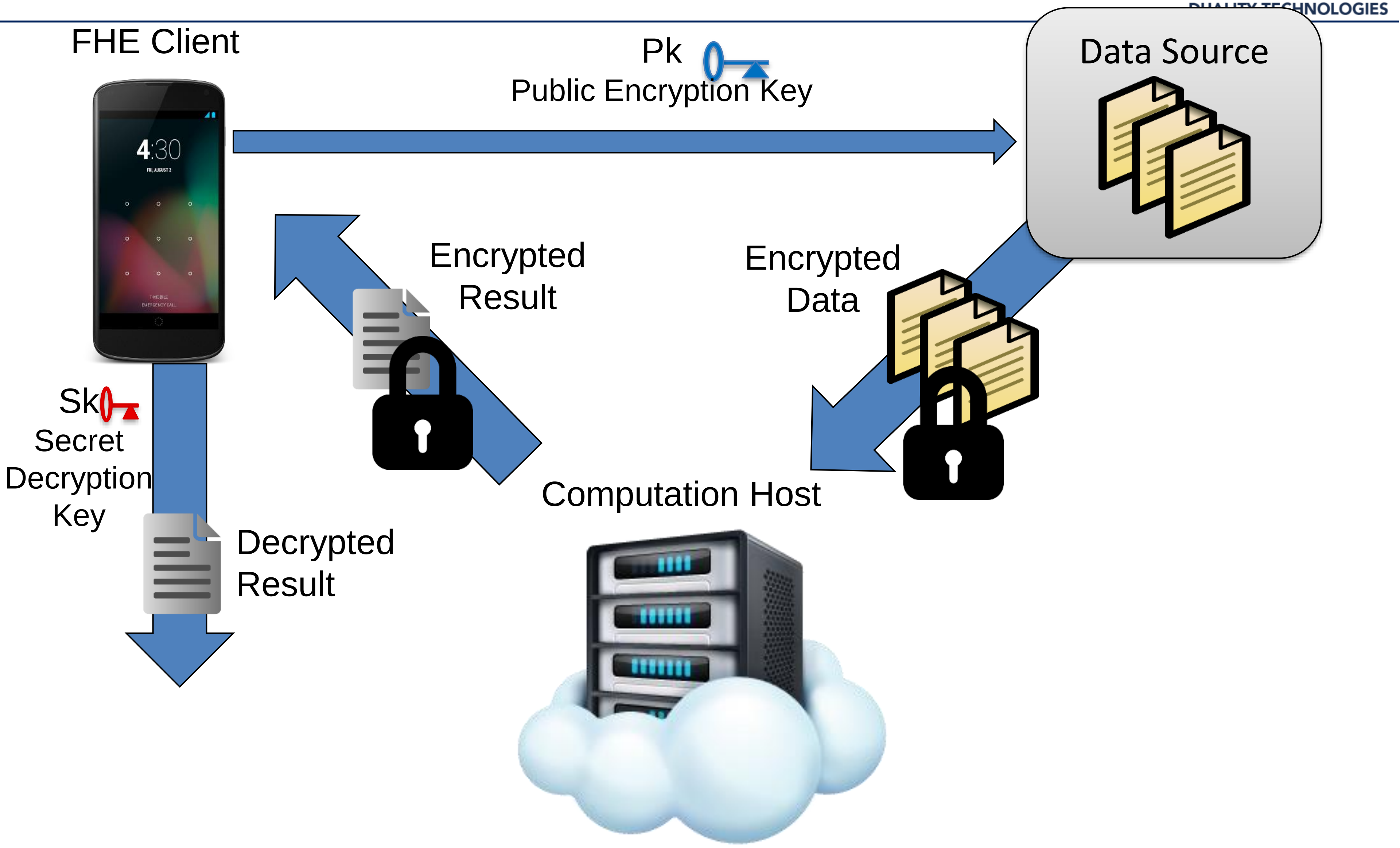
Public-Key Encryption

- – Hide information except for an intended recipient.
  - Ex: send financial transaction requests to ONLY your broker.

Homomorphic Encryption

- – Hide information so you can out-source processing.
  - Cloud computing with encrypted data!!
  - Ex: spam filtering e-mail without reading e-mail.

Fully Homomorphic Encryption



FHE Client

Pk

Public Encryption Key

Data Source

Encrypted Result

Encrypted Data

Sk

Secret Decryption Key

Decrypted Result

Computation Host

Out-Sourced Computation??

- Until very recently, once data is encrypted, there was basically no way to manipulate it.
    - Minor exceptions, of course.

- Fully Homomorphic Encryption (FHE)
    - Give data to cloud provider you don’t need to trust.
    - Provider can perform arbitrary computations for you.

- Examples:
    - Send video to a contractor for facial recognition analysis, but don’t need contractor to “see” the video.
    - Securely store and query a large, sensitive DB “in the cloud.”
    - Outsourced spam filtering of encrypted e-mail.

FHE Is Now Possible

- Discovery of a possible scheme in 2009
  - Craig Gentry from Stanford/IBM
  - Most important CS breakthrough of 21st century.
  - Very different computation model.
- There have been additional theoretical improvements since then.
- Practical computation challenges…
  - Slow-down
  - Ciphertext expansion
  - Different compute model

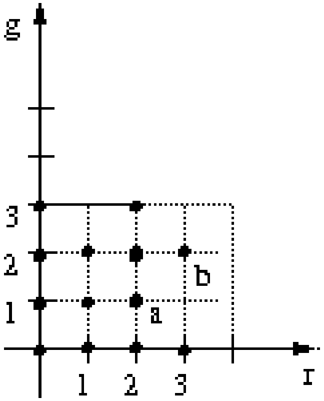
Lattice-based encryption

- FHE schemes are lattice-based encryption schemes.

- Lattice schemes form a “new” family of encryption.
  - Built on lattice mathematics.
    - Lattices are integer vectors.
  - They are resistant to quantum computing attacks.

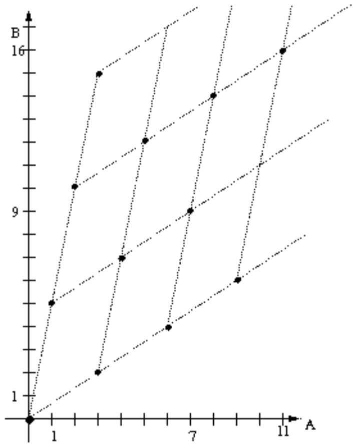
Lattice Encryption Intuition?

- Encryption, Decryption, etc… are primarily composed of linear transforms over large integer vectors.



Plaintext space

Linear transforms and add noise



Ciphertext space

- Plaintext are integer vectors, modulus small p.
- Ciphertext are integer vectors modulus very large q.

Security?

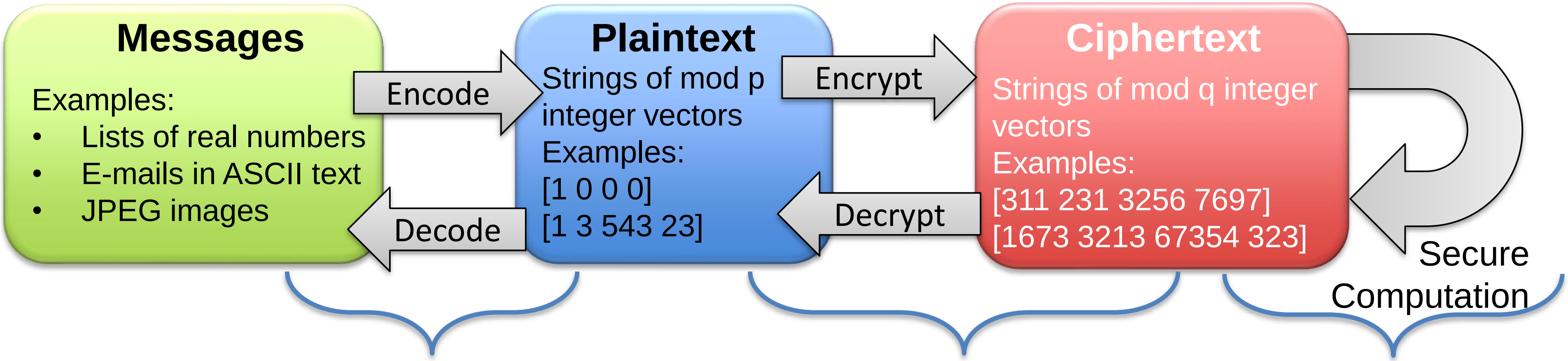
- Key length is a heuristic for security provided.
  - It is effective for RSA, AES, etc…
- “Real” security is “work factor”
  - Amount of computational effort required to “crack” a key, ciphertext, etc…

Post-Quantum

- Quantum attacks:
  - Shor showed quantum algorithms for factoring.
  - Grover showed a quadratic speedup relative to search algorithms.

- Modern lattice encryption security proofs built on hardness of Shortest Vector Problem (SVP).
  - Best known quantum result is that we can provably find a shortest vector in time 2^(C*n+o(n)).
  - Resistance to quantum attacks is still a conjecture.
    - Similar to conjecture that factoring is hard for classical computers.

Computing on Encrypted Data



Messages

Examples:

- Lists of real numbers
- E-mails in ASCII text
- JPEG images

Plaintext

Strings of mod p integer vectors

Examples:

[1 0 0 0]

[1 3 543 23]

Ciphertext

Strings of mod q integer vectors

Examples:

[311 231 3256 7697]

[1673 3213 67354 323]

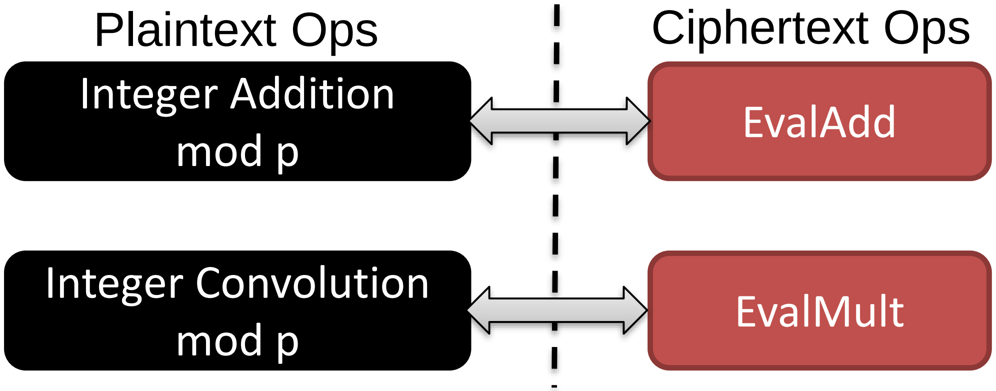
- Message-Plaintext encodings determined by translation of program into EvalAdd, EvalMult operations.
- Coding is an open research topic and drastically impacts effective runtime.

- Plaintext-Ciphertext encryption/decryption defined by FHE scheme.

- Operations on ciphertexts

Secure Programs with FHE

- Very different computation model.
- Base operations on ciphertext:



- Much of our innovations come from developing novel algorithms and data structures that are efficient for homomorphic computing model

- Conditional "if" statements on encrypted data not permitted.

Looking Forward

- Software
  - Smaller, Faster, Better!
- Hardware
  - Fit everything on board.
- Applications/Demos
  - Secure string searching (aka simple spam filtering) over encrypted ciphertext.
- Transition & Broader Adoption

A Fear and a Vision

"Your previous provider refused to share your electronic medical records, but not to worry —I was able to obtain all of your information online."

Questions?

Kurt Rohloff

krohloff@duality.cloud