Advanced Cryptorgaphy: Promise and Challenges

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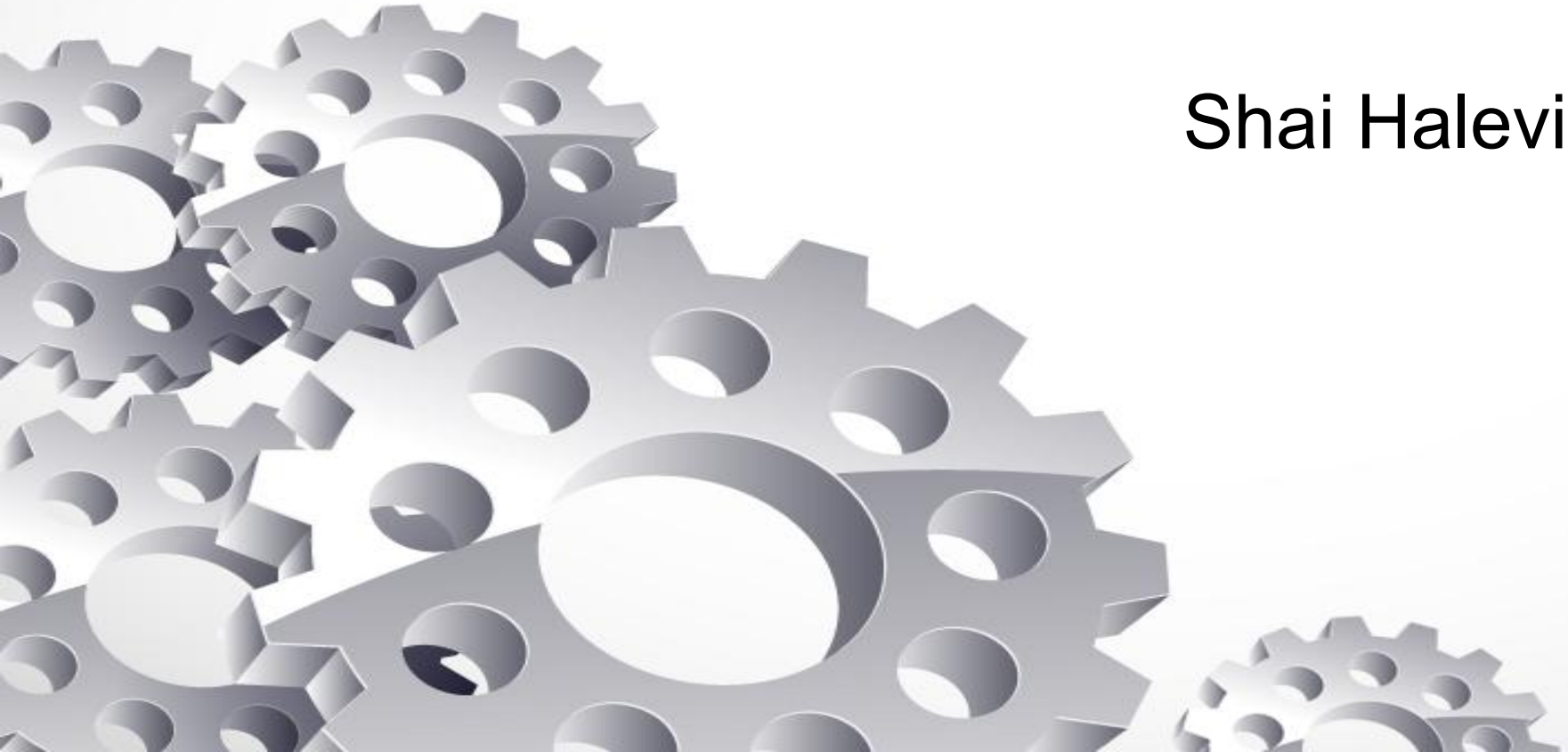
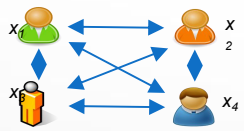


What's "Advanced Cryptography"?

- Cryptography beyond encryption, signatures
  - Protecting computation, not just data

I'll mention three technologies:

- Zero-Knowledge Proofs (ZKP)
- Secure Multi-Party Computation (MPC)
- Homomorphic Encryption (FHE)



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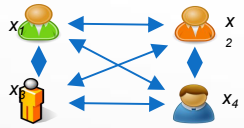

Not in this talk:

- Oblivious RAM (ORAM)
- Attribute-Based Encryption (ABE)
- ...

Advanced Cryptography is Needed

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Needed

Fast enough to be useful

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Not "generally usable" yet

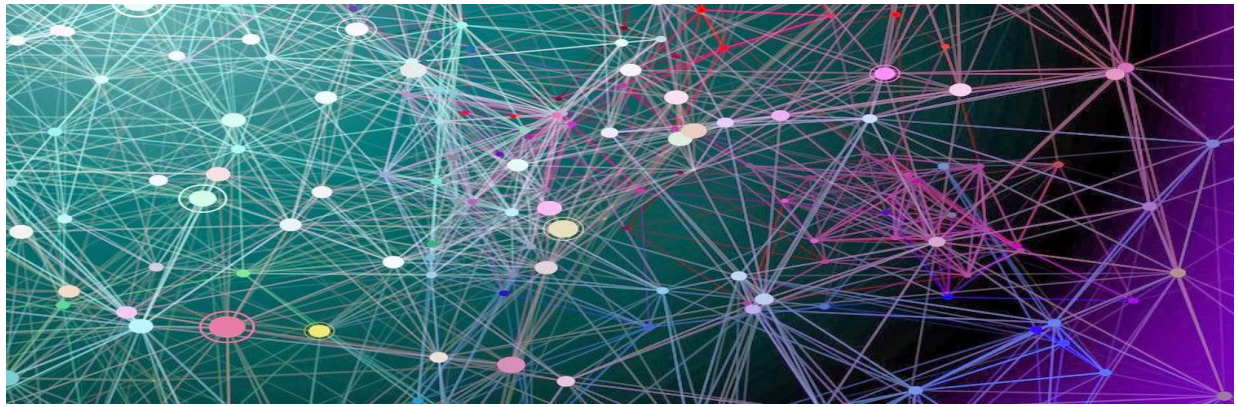
The Need for Advanced Cryptography

Your Privacy for Sale

- We give up privacy in return for services
  - location for directions, restaurant recommendation
  - health data for "personalized medicine"
  - financials for tax, investment services
  - purchace history for better ads, coupons
  - ...
- Personalized services **require** personal information
  - or so we are told

Data Abuse in the New Normal

- The entire IT industry is busy making it easier
  - Larger collections, better ways to process them



- Make no mistake: it will only get worse
  - We cannot provide the opportunity for easy abuse, and seriously expect it not to happen

The Promise of Advanced Cryptography

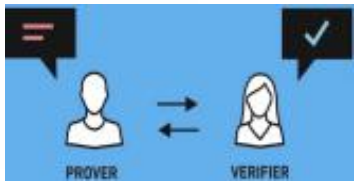
Blindfold Computation

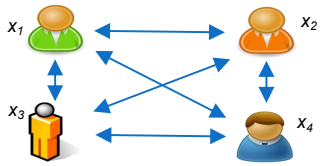
- The ability to process data without ever seeing it
  - Personalized services without access to private information

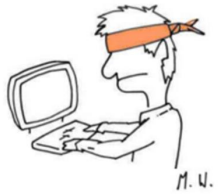
The Promise of Advanced Cryptography

Blindfold Computation

- Also useful for more traditional security issues
  - E.g., key and credential management, many more ...
  - Not the focus of this talk, though



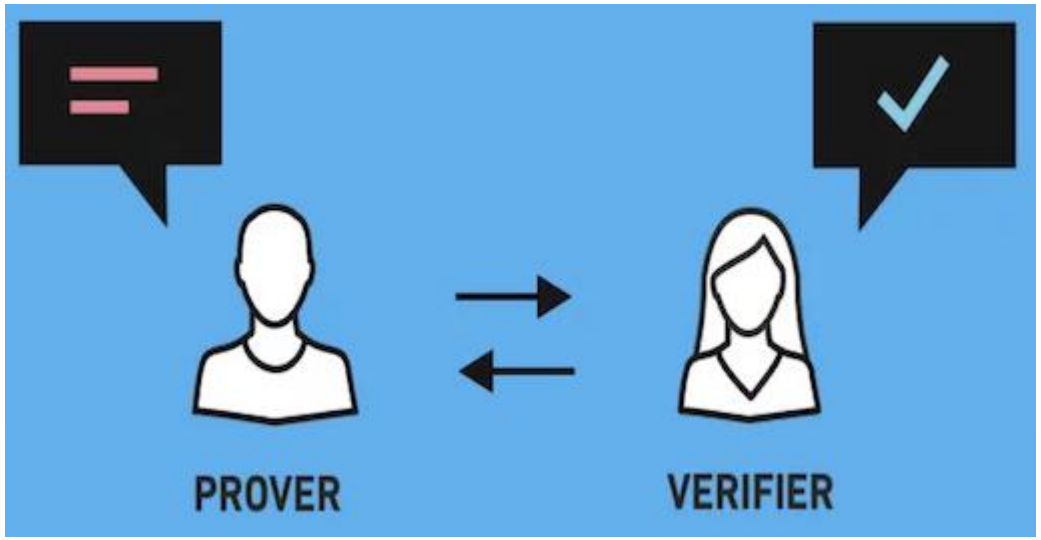




Types of Advanced Cryptography

Zero Knowledge Proofs

- I have a secret
  - I can convince you of some properties of my secret
  - Without revealing it



- Available (in principle) since the 80's [GMR'85]

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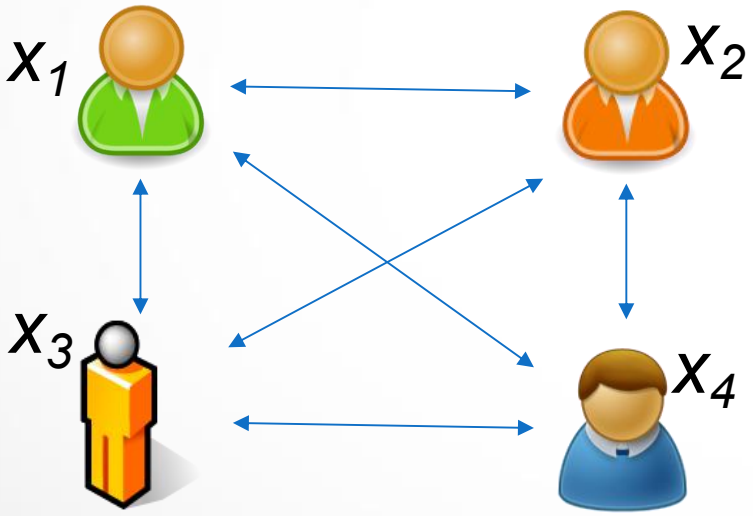
- Example: my secret is my purchase history

Zero Knowledge Proofs

- I have a secret
  - I can convince you of some properties of my secret
  - Without revealing it
- Example: my secret is my purchase history
  - I can prove that I bought 10 gallons of milk this month
    - so I can get a coupon
  - Without revealing anything else

Secure Multi-Party Computation

- We all have our individual secrets
  - We can compute a function of these secrets
  - Without revaling them to each other (or anyone else)



Goal:
Correctness: Everyone computes $y=f(x_1,\ldots,x_n)$
Privacy: Nothing but the output is revealed

- Available (in principle) since the 80's [Yao'86, GMW'86]

Secure Multi-Party Computation

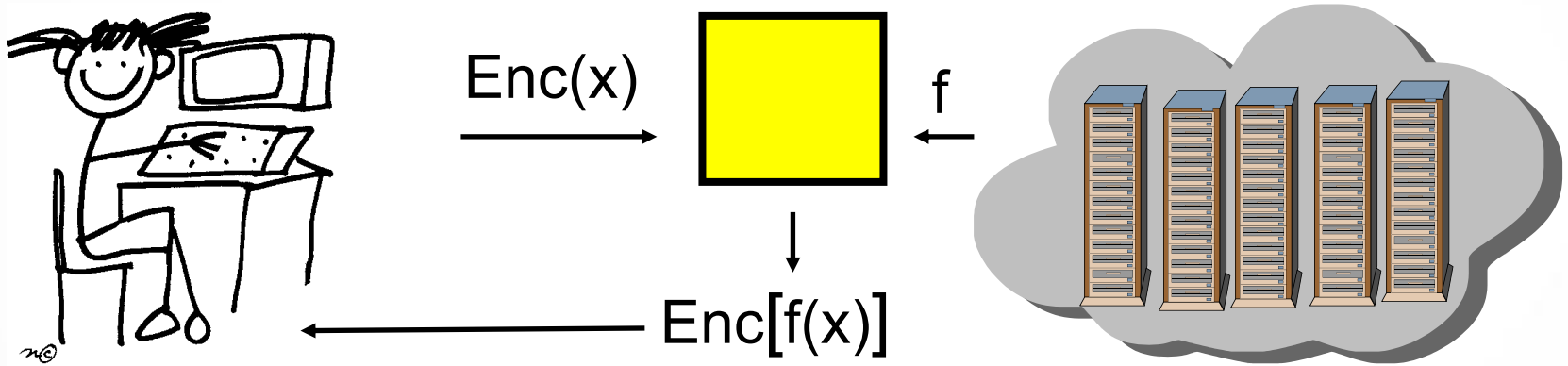
- We all have our individual secrets
  - We can compute a function of these secrets
  - Without revaling them to each other (or anyone else)

- Example: medical data
  - Evaluating the effectivness of a treatment

    ***f*(patient1Data, patient2Data, ...) = effective/not-effective**
  - Data for different patients held by different clinics
  - Can compute this with revealing any private data

Homomorphic Encryption

- Data can be processed in encrypted form
  - Result is also encrypted



- Available (in principle) for <10 years [Gen'09]

Homomorphic Encryption

- Data can be processed in encrypted form
  - Result is also encrypted

- Example: location services
  - I encrypt my location, send to yelp
  - Yelp compute an encrypted table lookup
    - T[cityBlock#] = ads for nearby coffee shops
  - I get back encrypted recommendation for coffee shops within two blocks

Fast Enough to be Useful

Performance of Advanced Cryptography

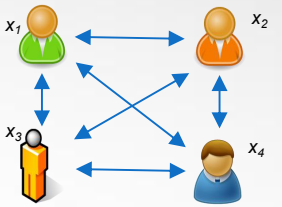
- Improving performence has been a major research topic over the last 30 years
  - Tremendous progress, many orders of magnitude

- For almost any realistic tasks, there is a cryptographic solution with adequate performance
  - Although designing it may take a team of experts

Speed Examples: Zero-Knowledge

- Digital currencies (zCoin, zCash, ...):
  - Proving that I have sufficiently many unspent coins on the ledger
  - Constructing proof in ~1min, verification in a few msec
- Anonymous credentials (idemix)
  - Proving that I possess a credential, takes 1-30 seconds
- Many other uses
  - Private payments in the Brave browser (using Anonize)
  - ...

Speed Examples: Secure MPC



- Biometric authentication in ~100ms
  - f(db, newSample) = match/noMatch
- Private set intersection in 1-30 seconds
  - Intersection of two sets with thousands of members
- Finding similar patients in a database in ~30sec
  - Best 5 (approx) matches against 4000 patients, 1000 markers
- "Generic computation": 1M gates in 1sec-5min
  - Depending on # of parties, LAN / WAN, adversary model

Speed Examples: HE

- Similarity of encrypted feature vectors
  - Computing similarity of two 1M-marker sequences in minutes
- Inference of simple NNets on encrypted data
  - Amortized 1000 perditions/minute on MNIST optical characters
- Computing a logistic-regression model on genome data
  - Under 10 minutes with 10-15 columns, ~1000 rows

Not “Generally Usable" Yet

Advanced Crypto Implementations

- Many software libraries for ZKP / MPC / FHE
  - Most of them open-source, a few proprietary
- Very hard to compare them, decide which technology/implementation to use for what purpose
  - Different tools, data & computation models, performance profiles, security guarantees, ...
  - Hardly any accepted benchmarks
- Most libraries are written for speed, not usability

Complexity of Advanced Cryptography

- Distributed computing is already complex
- “Advanced cryptography” also needs oblivious computation
  - Usually cannot do

    ```
    if (secretCondition) then do X else do Y
    ```

  - Instead must do both `X,Y`, then `MUX(X,Y;secretCondition)`
- Good performence requires extreme optimizations
  - Straightforward implementation will be exceedingly slow
- Tension between simplicity/usability and performance

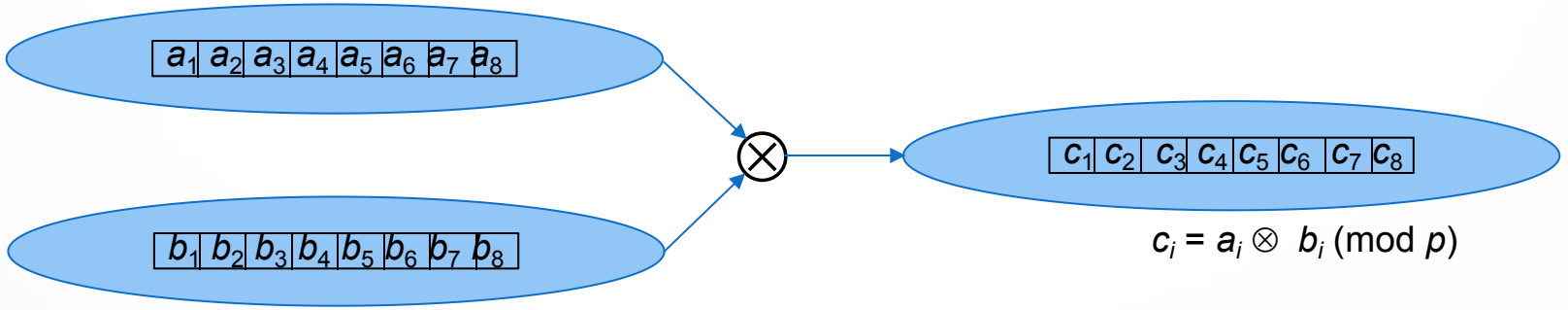
Example: Communication in Secure-MPC

- Communication between parties is a bottleneck in many protocols for secure multi-party computation
  - To optimize, many MPC libraries work with sockets
    - The library expects to be “in charge” of IP-address:port
- What if my system has its own communication layer?
  - E.g. working over https, gRPC, …
- Retrofitting existing libraries to use “abstract channels” is a lot of work, may degrade performance

Example: Data Encoding for FHE

- Ciphertext operations in contemporary FHE is slow

- "Ciphertext packing" to gain in performance
  - Each ciphertext encrypts a vector of plaintext element
  - Ciphertext operations effect element-wise operations



- Vector-size is a parameter, depends on the algebra

Example: Data Encoding for FHE (2)

- Lots of flexibility in setting the parameters
  - Determine plaintext modulus, vector-size, more
  - Choosing the right parameters is an art form
- Even with parameters set, where to put each piece of data requires a careful design
  - Could get orders-of-magnitude performance difference between different packing schemes
- No tool support for making any of these choices

Taming the Complexity

- How to make advanced cryptography usable to non-expert programmers?
- Frameworks, compiler support
  - Initial research work along these lines (Fabric, Obliv-C)
- Usable “toolboxes” for common tasks
  - Low level: arithmetic, sorting, linear algebra, …
  - Mid level: graphs algorithms, set intersection, ML tools, …
  - Domain specific tasks (medical, financial, …)
- We must shift focus from speed to usability

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Questions?

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