Making Secure Multi-Party Computation Scaleable

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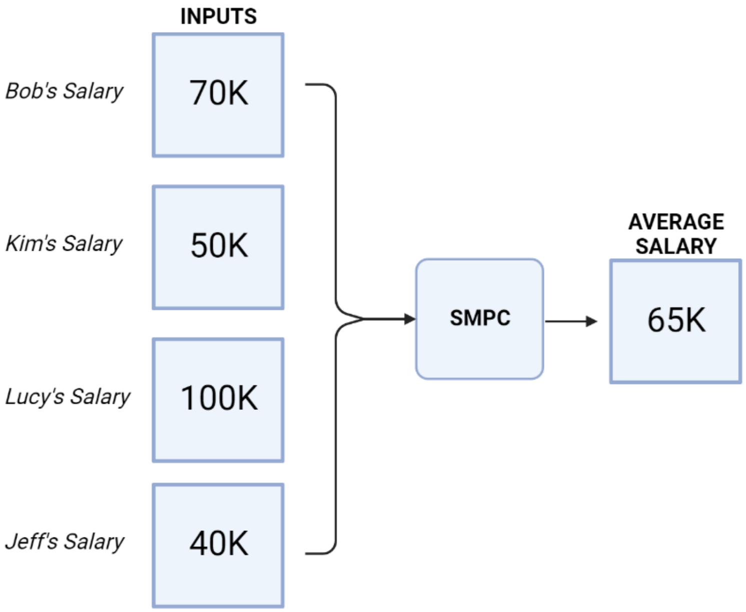
Introduction: The Salary Problem

The Salary Problem:

- We need to compute the average salary of people in a room
- We need each participant's salary to be private
- We can't use any shared trusted entity
- The solution: Secure Multi-Party Computation (SMPC)



Talk Outline

1. *INTRODUCTION*
    a. *What is SMPC?*
    b. *Implementations of SMPC*
    c. *GCE, nanoPI, and Conclave*
2. BACKGROUND
    a. Security Classifications of SMPC
3. SMPC PROTOCOLS
    a. Garbled Circuit Evaluation
4. SMPC SCALING
    a. Scaling Issues
    b. nanoPI
    c. Conclave
5. CONCLUSION

Introduction: What is SMPC?

Secure Multi-Party Computation (SMPC):

- Computation performed by multiple parties while keeping inputs private
- Arbitrary number of participants
- Arbitrary type of computation
- Privacy preservation dependent on threshold for given SMPC protocol
- Net based local decentralized process

Introduction: Implementations of SMPC

All participants see result:

- Auctions
- Privacy-preserving Machine Learning
- Poker without a trusted third party

Some participants see result:

- Financial data analysis
- Privacy-preservation in medical research

https://uxwing.com/auction-icon/

https://www.dreamstime.com/machine-learning-icon

https://stock.adobe.com/search?k=playing%20card%20symbols%20vector

Introduction: GCE, nanoPI, and Conclave

Garbled Circuit Evaluation (GCE):

- Popular implementation of SMPC
- Secure two-party computation
- Computes boolean circuits
- Configurable reception of results
- Different security level configurations

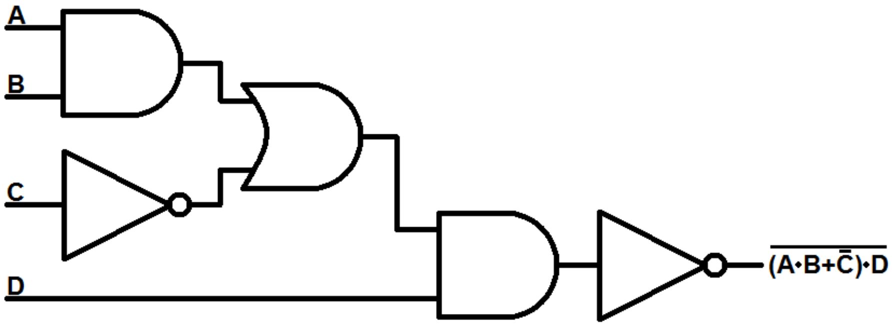


Figure: Example of a boolean circuit

Introduction: GCE, nanoPI, and Conclave

nanoPI:

- Based off state of the art SMPC protocols
- Attempts to fix scaling issues within SMPC
- Is a highly secure SMPC protocol

Introduction: GCE, nanoPI, and Conclave

Conclave:

- Query Compiler used to speed up existing SMPC implementations
- Allows for parallel processing of steps to improve efficiency
- Mid-level security

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Background: Security Classifications within SMPC

- Defends against “Semi-Honest Adversaries”
    - Passive Security
- Defends against “Malicious Adversaries”
    - Covert Security
    - Active Security

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SMPC Protocols: Garbled Circuit Evaluation

- Secure two-party computation used to construct Boolean Circuits

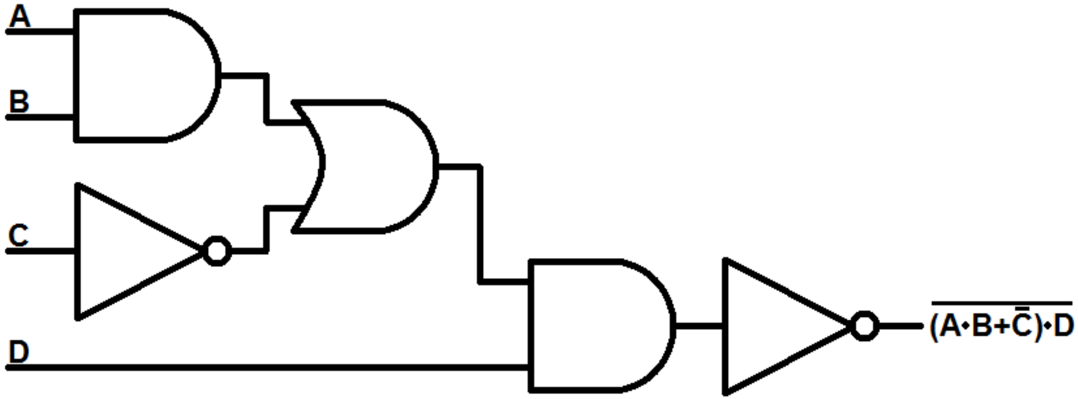

Figure: Example of a boolean circuit

SMPC Protocols: Garbled Circuit Evaluation

Garbled Circuit Evaluation Mechanics:

- Given participants Alice and Bob, their inputs $\{i_A, i_B\}$, and a function $f(\,)$
- GCE offers a way to compute $f(i_A, i_B)$ privately
- Given that Alice is the "Circuit Generator", Bob will be the "Circuit Evaluator"
- Alice creates a "Garbled Representation" of the circuit
- Bob is tasked with evaluating the inputs over this unreadable Garbled Circuit

SMPC Protocols: Garbled Circuit Evaluation

"1-out-of-2 Oblivious Transfer"

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- The Circuit Evaluator, Bob, has a bit b
- Alice $\{s_0, s_1\}$ -> Oblivious Transfer -> Bob $\{s_b\}$
- Alice doesn't know which string Bob received
- Bob has the needed string to evaluate his inputs

SMPC Protocols: Garbled Circuit Evaluation

GCE uses a randomized “Garbling Algorithm” $G(\ )$ on a function $f(\ )$ to turn it into three separate functions:

$\boldsymbol{G(f(\ ))}$ -> $\{\boldsymbol{f_e(\ ), f_g(\ ), f_d(\ )}\}$

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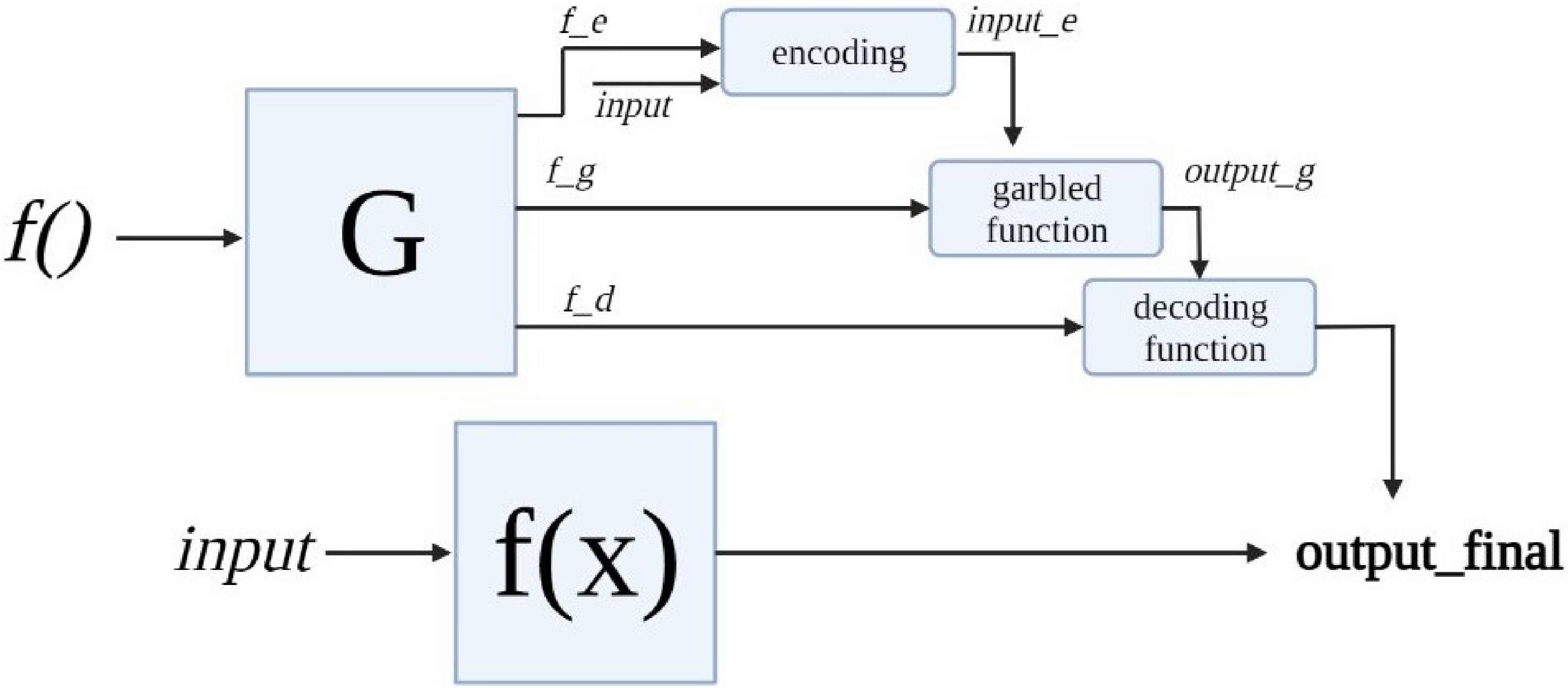
- $f_g(\ )$ is the garbled representation of the original circuit, computes the garbled output: $f_g(i_{Ae}, i_{Be}) = o_g$
- $f_d(\ )$ is a decoding function which allows us to receive the final output of the computation: $f_d(o_g) = o_{final}$
- In order to receive the correct result, it’s required that $f(\ ) = (f_e(\ ) \circ f_g(\ ) \circ f_d(\ ))$

SMPC Protocols: Garbled Circuit Evaluation



SMPC Protocols: Garbled Circuit Evaluation

- $G(\ )$ must be randomized
- Both participants Alice and Bob receive $f_e(\ )$ right away
- $f_g(\ )$ returns the encoded result of the boolean circuit
- This allows for control over who receives the result of the computation

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SMPC Scaling: Scaling Issues

- SMPC is used on massive amounts of data
    - Medical Data, Financial Data
- Boolean circuits are large scale representations of functions
- SMPC protocols will often generate circuits with billions of gates
- Actively secure SMPC protocols require either linear space or linear rounds of computations
- Modern Actively Secure GCE protocols compute hundreds of thousands of gates per second
- Even powerful GCE protocols requires linear space, scaling poorly with size

SMPC Scaling: Scaling Issues

- Many possible applications of SMPC on resource constrained devices
  - Smart Watches
  - IoT Devices
- Majority of SMPC scaling advancements only made on passively secure protocols
- Actively secure SMPC protocols achieve constant-round time efficiency by trading:
  - |*Circuit*| space

SMPC Scaling: nanoPI

nanoPI

- Based on SMPC protocol WRK
    - Incredibly Efficient
    - Actively secure against n-1 active adversaries
- Developed by fixing space inefficiencies within WRK
- Modifies sub-protocols of WRK to batch operations

SMPC Scaling: nanoPI

- Authenticated Bit Changes:
  - Changes made to batch repeated computations of the Authenticated bit protocol in order to save space
- Authenticated AND Changes:
  - Takes advantage of a predictable pool based cut-and-choose system, freeing up space that would otherwise be needed for some Authenticated AND computations

SMPC Scaling: nanoPI

Memory Budget		20 MB		200 MB		2 GB	
Protocol		nanoPI	WRK	nanoPI	WRK	nanoPI	WRK
Speed (AND/s)	20 Mbps 40 ms	795.03	1.73K	2.73K	2.75K	3.12K	3.23K
	200 Mbps 40ms	825.18	2.76K	6.94K	12.94K	20.94K	22.38K
	2 Gbps <1 ms	20.27K	20.53K	46.66K	46.84K	49.34K	50.64K
Bandwidth (Byte/AND)		505	504	380	504	379	378

SMPC Scaling: Conclave

Conclave

- Query compiler built to efficiently perform SMPC
- Parts of relational analytics queries can be performed insecurely
- Hybrid Datasets
- Conclave computes SMPC steps & unprotected data in parallel with SMPC processes
- Can be done locally in cleartext due to the nature of these operations

SMPC Scaling: Conclave

Mechanics:

- A data analyst writes relational queries for the data as if they had access to all inputs
- Conclave transforms them into a set of local processing steps and modified SMPC steps
- Conclave runs private SMPC steps and local processing steps in parallel
- Conclave is often able to return the results of an SMPC protocol within minutes, even on large scale inputs

SMPC Scaling: Conclave

- Conclave can generate code for GCE and Secret Sharing SMPC protocols
- Conclave is only passively secure
- In testing: Conclave sped up operators such as "join" and "aggregate" to 7 plus times faster when compared to Sharemind, a commercial framework used in applications of SMPC
- These tests were done on hybrid data sets
- Conclave is best suited for SMPC applications relating to research

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Conclusion: Partial Solutions

- nanoPI and Conclave are partial solutions
- nanoPI:
  - Kept up with WRK, however still slower in all tests
  - Has the unique ability to run arbitrarily large circuits
- Conclave:
  - 7+ times faster use of important operators in testing
  - Only passively secure, and requires a hybrid data-set to tap into most of its efficiency
  - Perfect for data analytics such as Medical Research

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Questions?