Efficient Server-Aided Secure Two-Party Function Evaluation with Applications to Genomic Computation

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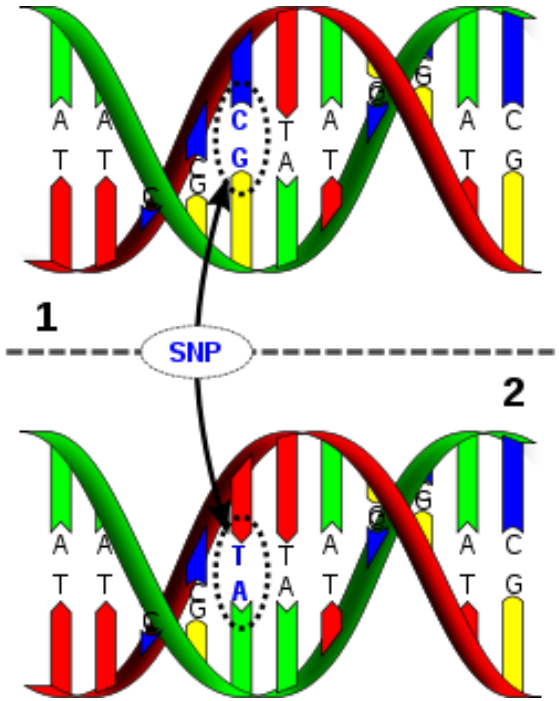
Motivation

- We treat the problem of securing computation associated with genomic tests used for voluntarily non-medical purposes
  - ✓ ancestry test
  - ✓ paternity test
  - ✓ genomic compatibility test
- There is a desire to protect highly sensitive DNA data of users participating in these tests
- Such computation often takes place between two users communicating via a server
  - ✓ this prompts the use of the server-aided secure two-party computation setting
  - ✓ participation of the server can significantly improve the participants' cost

Genomic Backgrounds

- Information extracted from one's genome is often represented in the form of SNPs or STRs
- Each SNP is referenced by a specific index and its value is 0, 1, or 2
- Each STR consists of a fixed number of pairs taking integer values



Genomic Tests

- **Ancestry test**
  - ✓ compares two SNP sequences belonging to two individuals
  - ✓ determines the number of SNPs they have in common
- **Paternity test with a single parent**
  - ✓ uses STR profiles S (the child) and S' (the contested father)
  - ✓ computes whether all elements of S and S' have at least one common component
- **Genetic compatibility test**
  - ✓ compares markers of potential partners
  - ✓ evaluates the possibility of their children inheriting genetic diseases

Security Model

- The computation takes the form of secure function evaluation with participating users A and B and server S
- We start by assuming that the server behaves **semi-honestly** and contributes **no input**
- Assumptions placed on the users vary
  - ✓ **semi-honest** users (ancestry test)
  - ✓ **malicious** users (paternity test)
  - ✓ **malicious** users **tampering with input** (genomic compatibility test)

Underlying Techniques

- We build solutions based on **garbled circuit evaluation** with different security guarantees
- Garbled circuits allows two parties P_1 and P_2 to securely evaluate a Boolean circuit of their choice
- A desired function should be converted to a Boolean circuit and then
  - ✓ one party acts as a **circuit generator**
  - ✓ the other party acts as a **circuit evaluator**
- The circuit generator creates two random labels for each (binary) wire of the circuit during garbling
- The evaluator sees only one label during evaluation and doesn't know its meaning

Underlying Techniques

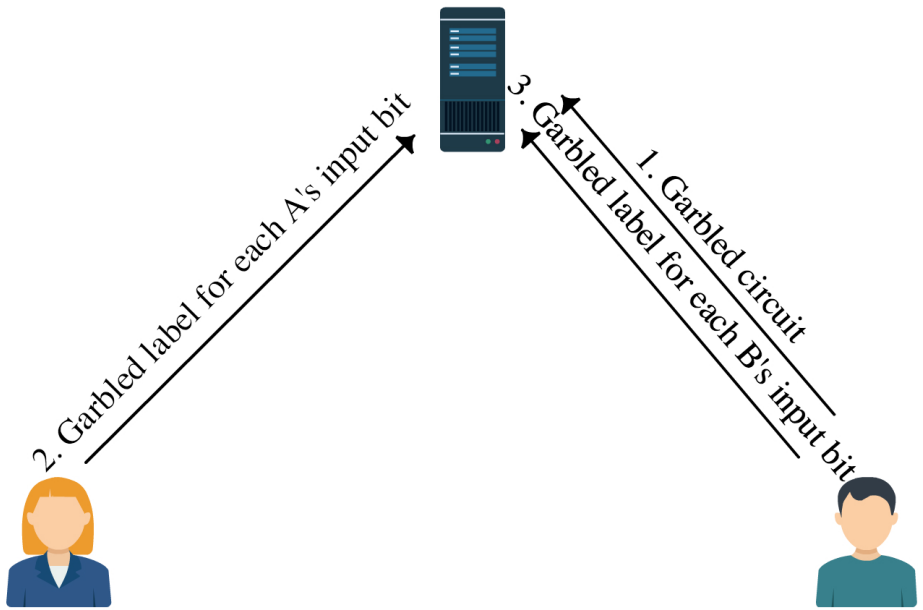
- The circuit generator directly sends to the evaluator the correct label corresponding to its input for each input wire
- The parties perform **oblivious transfer** (OT) to communicate labels corresponding to the circuit evaluator's input to the circuit evaluator
- In 1-out-of-2 oblivious transfer
  - ✓ the sender has inputs X_0 and X_1
  - ✓ the receiver obtains only X_b for its choice of bit b
  - ✓ the sender learns nothing

Scheme I: Semi-Honest Users, Malicious Server

- Our first construction
  - is cheaper than a regular garbled circuit protocol for two semi-honest parties
  - uses only garbled circuit generation and evaluation, but not OT
  - is intended for ancestry tests
  - security in the presence of a malicious server comes for free

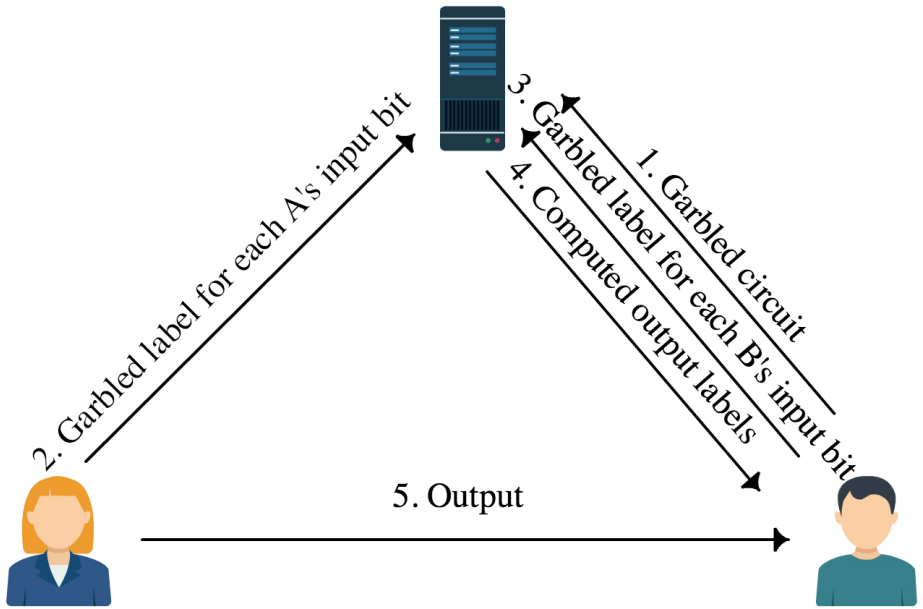
Scheme I: Semi-Honest Users, Malicious Server

- In our first construction:
  - A and B create a garbled circuit and send it to S (the task can be partitioned arbitrarily between them)
  - they also sent wire labels for their inputs to S



Scheme I: Semi-Honest Users, Malicious Server

- In our first construction:
  - S evaluates the garbled circuit and returns the output labels to A and B

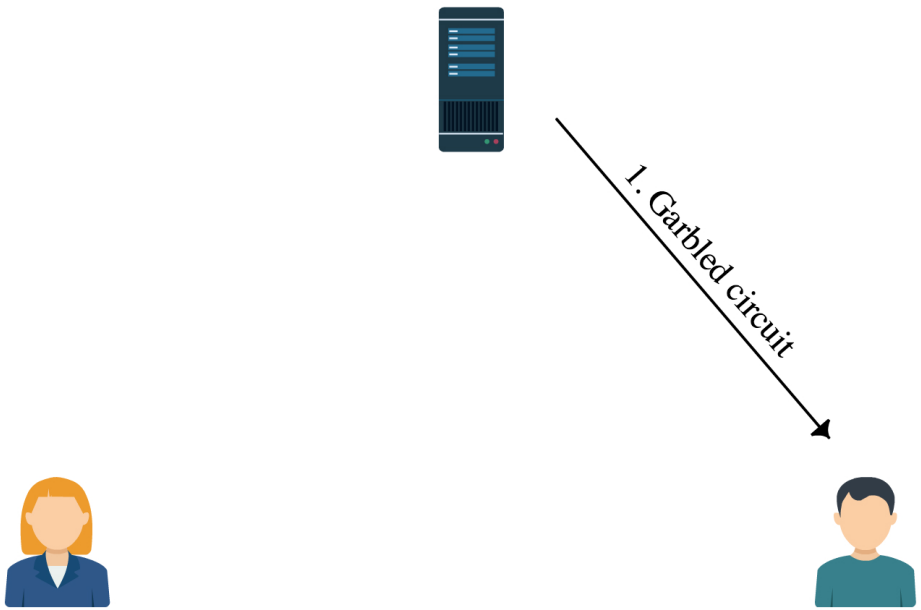


Scheme II: Malicious Users, Semi-Honest server

- Our second construction
  - has cost similar to a regular garbled circuit protocol for two semi-honest parties
  - is intended for paternity tests

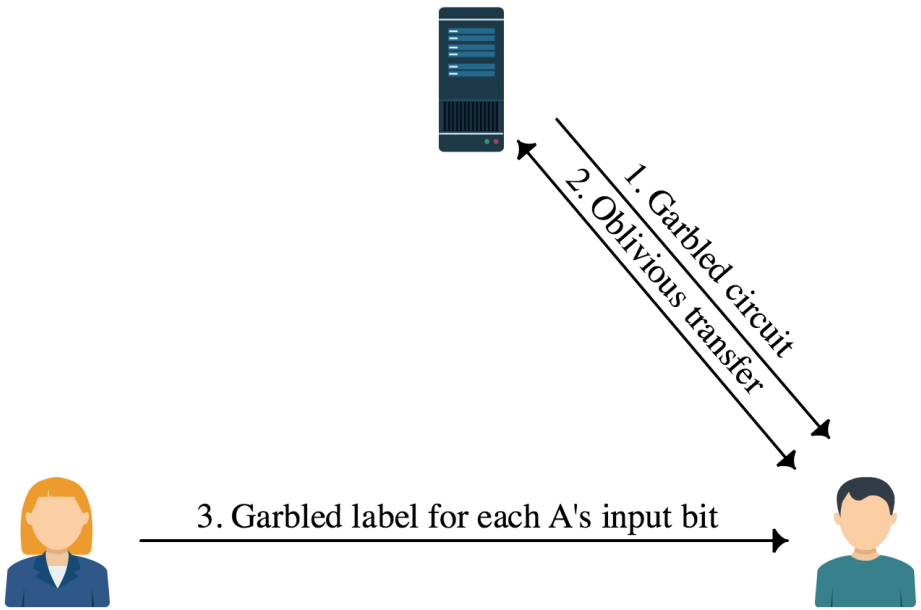
Scheme II: Malicious Users, Semi-Honest Server

- In our second construction:
  - S garbles the circuit and sends it to B
  - S communicates to A information about label pairs corresponding to A input wires



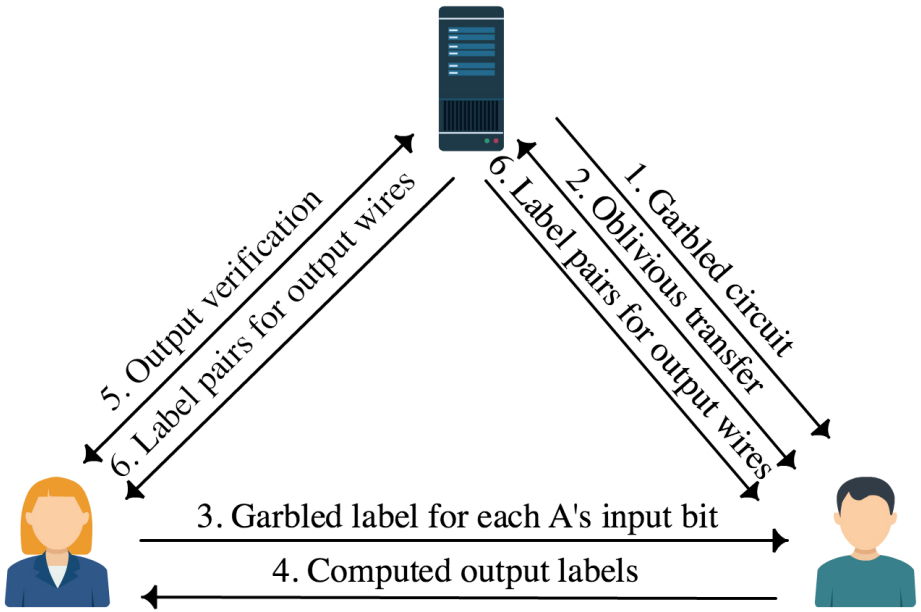
Scheme II: Malicious Users, Semi-Honest Server

- In our second construction:
  - B obtains wire labels for his input from S using OT and wire labels for A's input directly from A
  - B evaluates the circuit and sends the computed output wire labels to A



Scheme II: Malicious Users, Semi-Honest Server

- In our second construction:
  - A verifies validity of output wire labels obtained from B with the help of S
  - if A is satisfied, S opens the meaning of output wire labels to both A and B (**fairness**)



Scheme III: Malicious users, Semi-Honest Server, Input Certification

- We enhance Scheme II with input certification
  - A and B hold signatures (with special properties) on their inputs
  - A and B prove in zero knowledge possession of a signature and that the chosen input wire labels match the signed values
    - ✓ **this is the most interesting part from the technical point of view**
- The solution works for signatures on messages of any size, blocks of messages, a mix of certified and regular inputs, etc.

Performance Results

- **Ancestry testing**
  - each party inputs 2^{17} SNPs
  - the circuit used 655,304 XOR gates and 131,072 non-XOR gates
  - computation resembles the Hamming distance

	Garbled circuit		Communication	
	garble (offline)	eval (online)	sent	received
A	1.8ms	–	2MB	0MB
B	19.8ms	–	8MB	0MB
S	–	12.5ms	0MB	10MB

Performance Results

- **Paternity testing**
  - A and B input 13 pairs of STRs (x_i, y_i)
  - A is a parent of B if A's x_i or y_i appears in B's pair for each i
  - the circuit used 234 input bits from each party, had 468 XOR gates and 467 non-XOR gates

	Garbled circuit		OT		Total time		Communication	
	garble	eval	offline	online	offline	online	sent	received
A	0.003ms	–	–	–	0.003ms	–	3.7KB	0.06KB
B	–	0.01ms	515ms	202ms	515ms	202ms	31.7KB	56.9KB
S	0.03ms	–	196ms	261ms	196ms	261ms	53.3KB	31.7KB

Performance Results

- **Genetic compatibility testing**
  - A and B agree on k relevant genetic diseases and get their susceptibility to each of them tested and certified
  - the test outputs 1 if there is at least one disease to which both A and B are susceptible, and 0 otherwise
  - the circuit used $k = 10$ certified inputs for each party and had 19 non-XOR gates

	Garbled circuit		OT		Sign PK		Other PK		Total time		Comm	
	garble	eval	offline	online	offline	online	offline	online	offline	online	sent	received
A	0	–	–	–	1170	42	617	21	1790	63	34	0.06
B	–	0.001	15	15	1170	42	282	16	1470	72	36	3
S	0.003	–	29	15	0	2060	0	756	29	2830	3	71

  - computation times are in ms, communication is in KB, PK stands for proof of knowledge


Q&A