Faster Secure Two-Party Computation Using Garbled Circuits

Yan Huang
David Evans

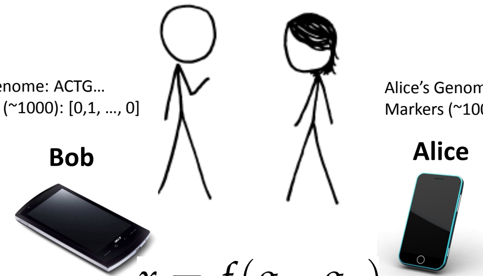
Jonathan Katz
Lior Malka

www.MightBeEvil.com

Secure Two-Party Computation

Bob's Genome: ACTG…
Markers (~1000): [0,1, …, 0]

Bob



Alice's Genome: ACTG…
Markers (~1000): [0, 0, …, 1]

Alice

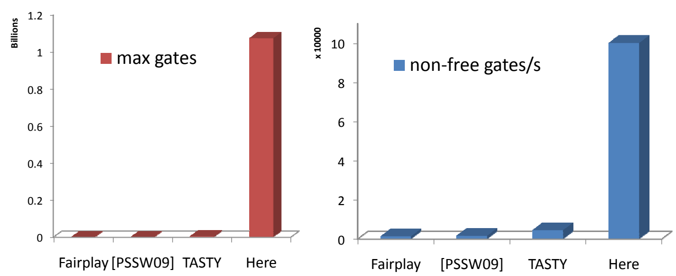
$$x = f(g_A, g_B)$$

Can Alice and Bob compute a function of their private data, without exposing anything about their data besides the result?

Overview

- Describe a system for secure 2-party computation using garbled circuits that is much more *scalable* and significantly ***faster*** than best prior work
- Applications:
  - **Face recognition:** Hamming distance
  - **Genomics:** Edit distance, Smith-Waterman
  - **Private encryption:** Oblivious AES evaluation

Our Results



Scalability **Performance**

Secure Function Evaluation

Alice (circuit generator) Holds $a \in \{0,1\}^s$

Agree on $f(a,b) \rightarrow x$

Bob (circuit evaluator) Holds $b \in \{0,1\}^t$

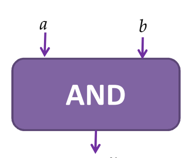
Garbled Circuit Protocol

Outputs $x = f(a,b)$ without revealing a to Bob or b to Alice.

Andrew Yao, 1986

Yao's Garbled Circuits

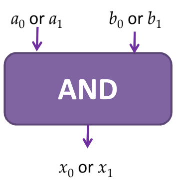
Inputs		Output
a	b	x
0	0	0
0	1	0
1	0	0
1	1	1



Computing with Meaningless Values?

Inputs		Output
a	b	x
a_0	b_0	x_0
a_0	b_1	x_0
a_1	b_0	x_0
a_1	b_1	x_1

a_i, b_i, x_i are **random** values, chosen by the **circuit generator** but **meaningless** to the **circuit evaluator**.

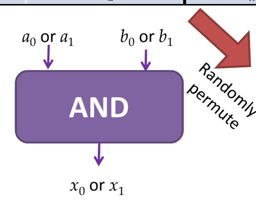


Computing with Garbled Tables

Inputs		Output
a	b	x
a_0	b_0	$Enc_{a0,b0}(x_0)$
a_0	b_1	$Enc_{a0,b1}(x_0)$
a_1	b_0	$Enc_{a1,b0}(x_0)$
a_1	b_1	$Enc_{a1,b1}(x_1)$

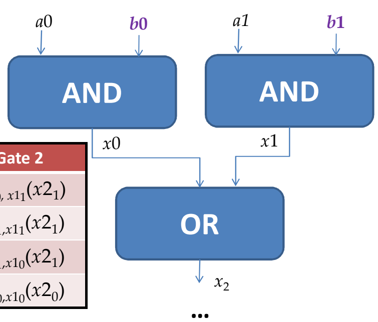
Bob can only decrypt **one** of these!

a_i, b_i, x_i are **random** values, chosen by the **circuit generator** but **meaningless** to the **circuit evaluator**.



Garbled And Gate
$Enc_{a0,\ b1}(x_0)$
$Enc_{a1,b1}(x_1)$
$Enc_{a1,b0}(x_0)$
$Enc_{a0,b0}(x_0)$

Chaining Garbled Circuits



And Gate 1
$Enc_{a10,\ b11}(x1_0)$
$Enc_{a11,b11}(x1_1)$
$Enc_{a11,b10}(x1_0)$
$Enc_{a10,b10}(x1_0)$

Or Gate 2
$Enc_{x00,\ x11}(x2_1)$
$Enc_{x01,x11}(x2_1)$
$Enc_{x01,x10}(x2_1)$
$Enc_{x00,x10}(x2_0)$

Can do ***any*** computation privately this way!

Threat Model

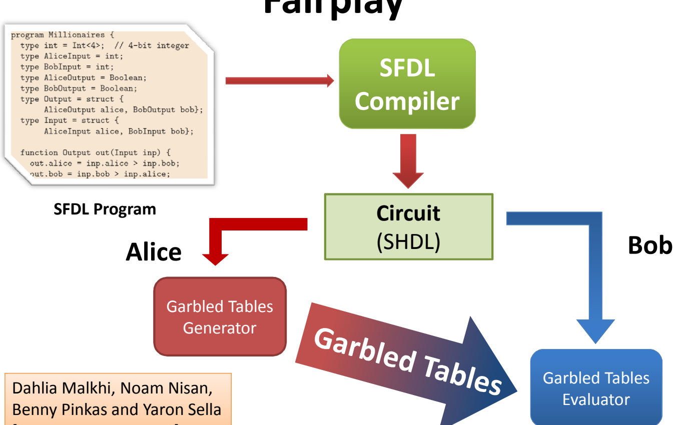
Semi-Honest (*Honest-but-Curious*) **Adversary**

Adversary follows the protocol as specified (**!**), but tries to learn more from the protocol execution transcript

May be good enough for some scenarios

We are working on efficient solutions for malicious adversaries

Fairplay



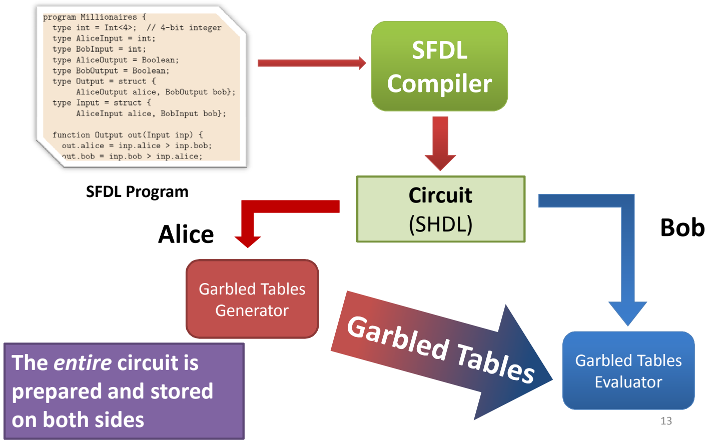
Dahlia Malkhi, Noam Nisan, Benny Pinkas and Yaron Sella [USENIX Security 2004]

Problems?

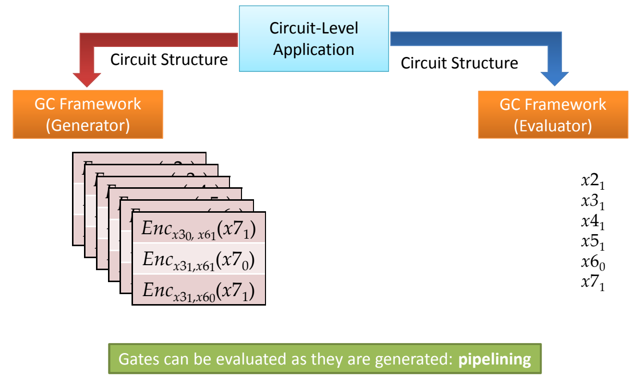
An alternative approach … would have been to apply Yao's generic secure two-party protocol…. This would have required expressing the algorithm as a circuit … and then sending and computing that circuit…. **[We] believe that the performance of our protocols is significantly better than that of applying generic protocols.**
Margarita Osadchy, Benny Pinkas, Ayman Jarrous, Boaz Moskovich. *SCiFI – A System for Secure Face Identification*. Oakland 2010.

[Generic SFE] is very fast … but the circuit size is extremely large…. Our prototype circuit compiler can compile circuits for problems of size (200, 200) but uses almost 2 GB of memory to do so…. **larger circuits would be constrained by available memory for constructing their garbled versions.**
Somesh Jha, Louis Kruger, Vitaly Shmatikov. *Towards Practical Privacy for Genomic Computation*. Oakland 2008.

The Fallacy



Faster Garbled Circuits



Benefits of *Pipelining*

- Allows GC to scale to circuits of arbitrary size

  We ran circuits with over a billion gates, at a rate of roughly 10 µs per gate.

- Improves the time efficiency

Problems in Existing (SFDL) Compilers

Resource-demanding SFDL compilation

It takes hours on a 40GB memory server to compile a SFDL program that implements AES.

Many optimization opportunities are missed

Circuit level
Minimize bitwidth
Reduce the number of non-free gates

Program level
Treat public and secret values differently

Example: Secure Counter

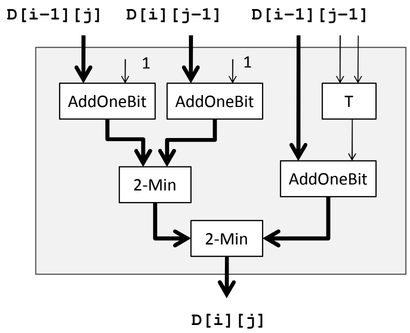
```
class Counter {
  int c = 0;
  void increment(bool b) {
    if (b) c++;
}
```

- SFDL requires pre-setting **c** to a fixed bit width
- For best performance, its bit width should be adjusted *dynamically*
- Saves n non-free gates (out of original $n \log n$)

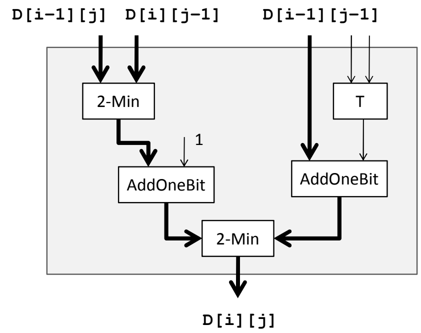
Circuit Optimization – Edit Distance

```
for (int i = 1; i < a.length; ++i)
  for (int j = 1; j < b.length; ++j) {
    T = (a[i] == b[j]) ? 0 : 1;
    D[i][j] = min(D[i-1][j]+1, D[i][j-1]+1,
                  D[i-1][j-1] + T);
  }
```

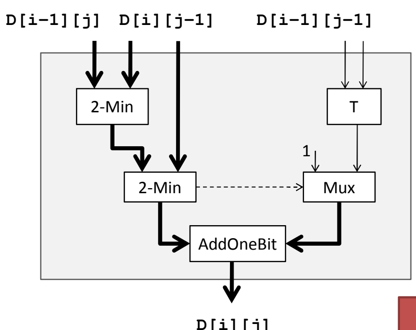
Circuit Optimization – Edit Distance



Circuit Optimization – Edit Distance

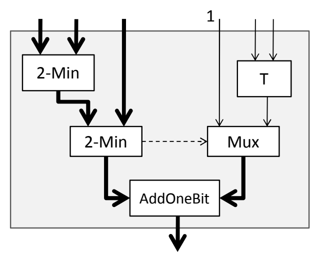


Circuit Optimization – Edit Distance



Saves about 28% of gates

Circuit Library



Through custom circuit design and the use of optimal circuit components, we strive to minimize the number of *non-free* gates

V. Kolesnikov and T. Schneider. *Improved Garbled Circuit: Free XOR Gates and Applications*. (ICALP), 2008.

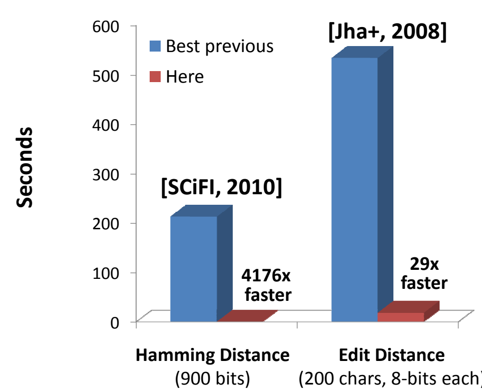
Some Results

Problem	Best Previous Result	Our Result	Speedup
Hamming Distance (Face Recognition, Genetic Dating) – two 900-bit vectors	213s [SCiFI, 2010]	**0.051s**	**4176x**
Levenshtein Distance (genome, text comparison) – two 200-character inputs	534s [Jha+, 2008]	**18.4s**	**29x**
Smith-Waterman (genome alignment) – two 60-nucleotide sequences	[Not Implementable]	**447s**	**-**
AES Encryption	3.3s [Henecka, 2010]	**0.2s**	**16.5x**

Scalable: 1 billion gates evaluated at ≈100,000 gates/second on regular PCs

Comparisons are aligned to the same security level in the semi-honest model.

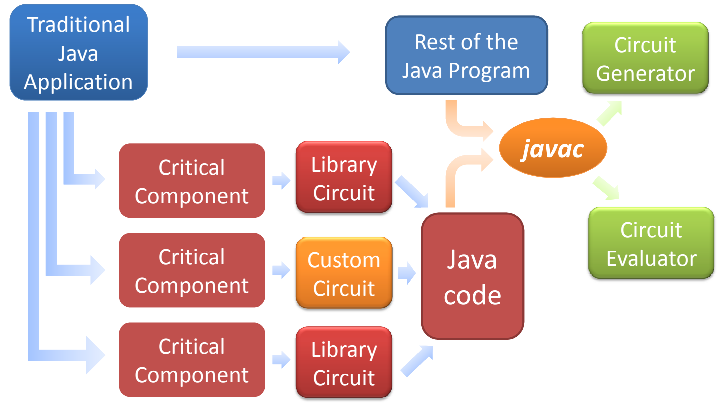
Timing Results



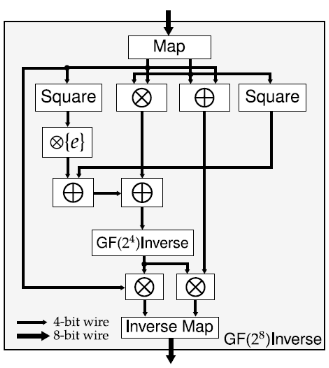
Ease of Use

- Our framework assumes no expert knowledge of cryptography
- Need basic ideas of Boolean circuits
- Circuit designs converted directly to Java programs

Use the Framework



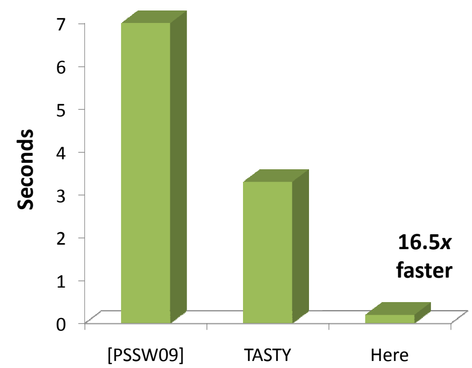
Example: AES SBox



Leveraging an existing ASIC design for AES allows us to reduce the state-of-the-art AES circuit by **30%** of non-free gates, compared to [PSSW09] and [HKSSW10]

Wolkerstorfer, et al. *An ASIC Implementation of the AES S-boxes*. RSA-CT 2002.

Time Savings: AES



[Henecka, et al. *CCS* 2010]

Conclusion

- **Pipelining** enables garbled-circuit technique to scale to large problem sizes
- **Circuit-level optimizations** can dramatically reduce performance overhead

Privacy-preserving applications can run orders of magnitude faster than previously thought.

Thanks!

Questions?

Download framework and Android demo application from **MightBeEvil.com**