Qualification Exam

A Domain-Specific Programming Language for Secure Multiparty Computation

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Thesis

Creating tools with strong security guaranties which exploits the benefits obtained by combining confidential information without compromising it, is feasible and useful.

Report on SMCL

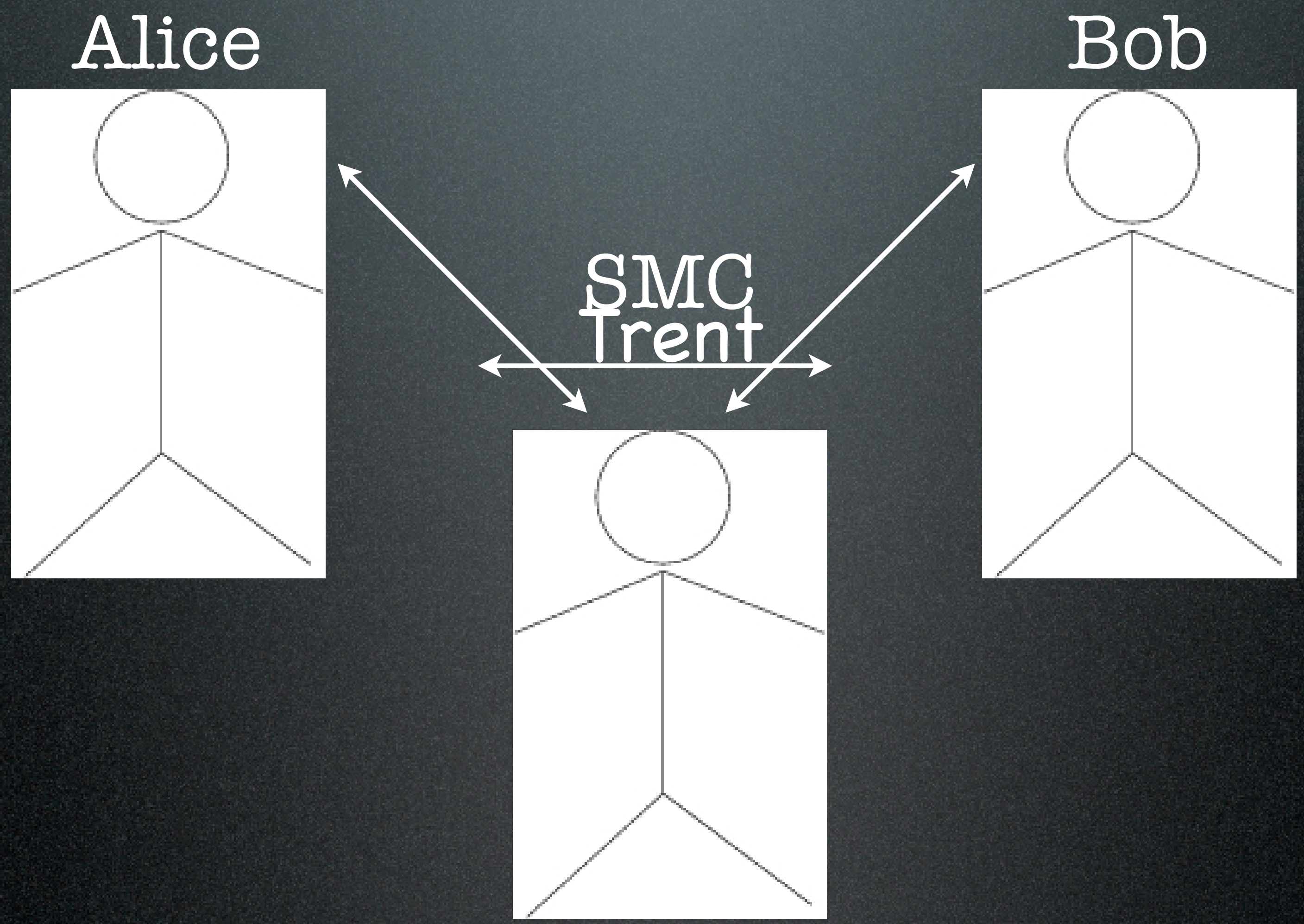
Overview

- Secure Multiparty Computation
- SMCL Concepts
- An example
- Security - what, why
- Efficiency
- Future Work
- Conclusion

Secure Multiparty Computation

- n parties P1,...,Pn wish to jointly compute the computable function: f(x1,...,xn)
- Party Pi only knows the input value xi which must be kept secret from the other parties.
- Even if some adversary has power to corrupt some subset of the parties

The Millionaire's Example



SMC Solves Problems

- Auctions
- Distributed Voting
- Matchmaking
- Benchmarking

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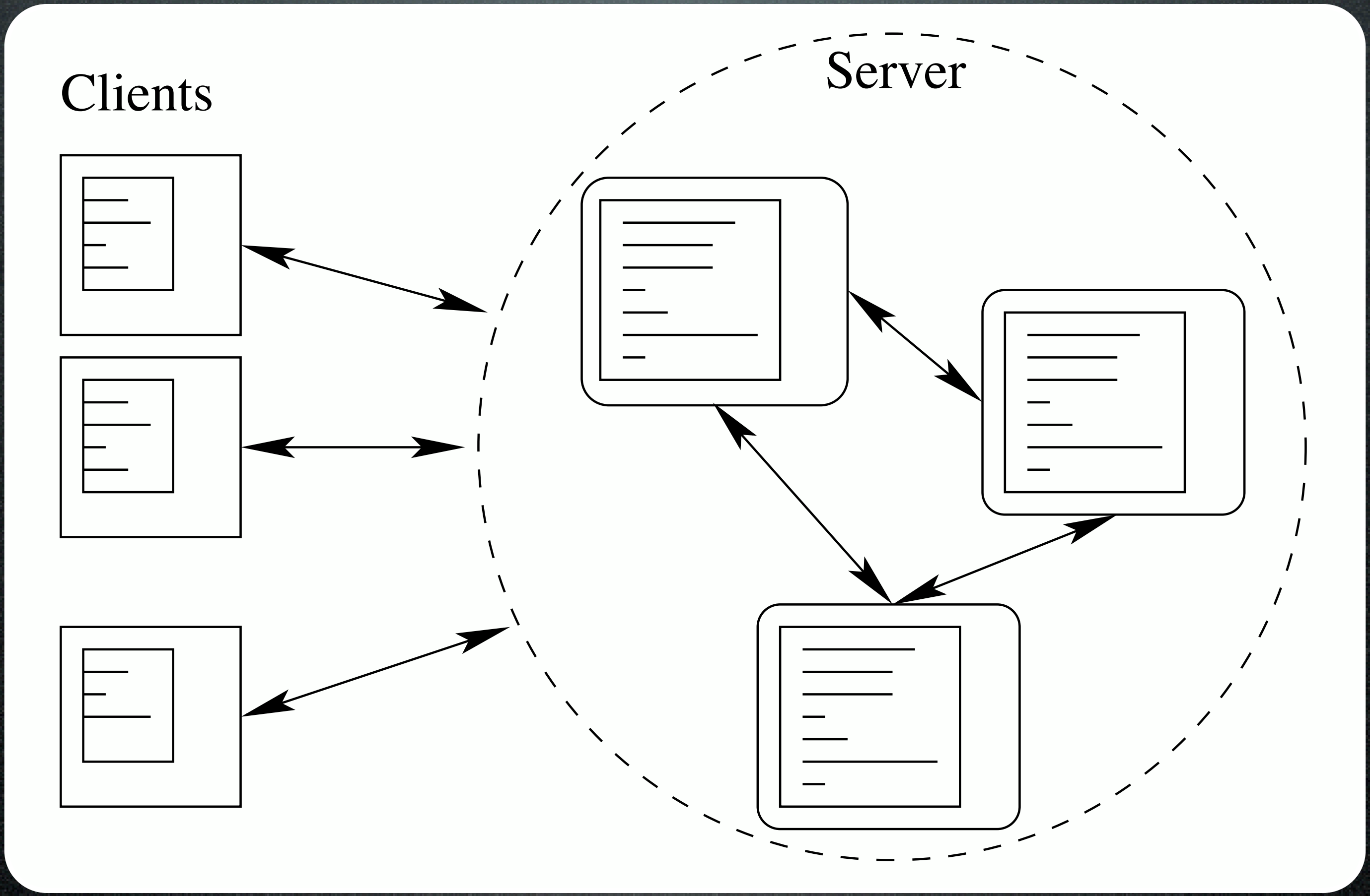
Conceptual Model



Values

Clients:

Private values

- Booleans
- Integers
- Records

Server:

Public & Secret values

- Booleans
- Secret booleans
- Integers
- Secret integers
- Records
- Client identity
- Secret client identity

Communication

Clients:

Tunnels:

- Asynchronous
- put and get functions
- Primitive types only
- Data encrypted
- Secret data - shared and encrypted

Functions:

- Synchronous
- Primitive types only
- Invoked by server

Server:

Tunnels:

- Accessed via client identity
- put and get functions

Client Identity

Clients:

Server:

Groups of clients:

- A set of clients
- All of the same kind
- Iterated using a for loop
- Uniform treatment of clients
- Secrecy of client identity
- Specified externally

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SMCL

The Millionaire's Example

```
declare client Millionaires:
  tunnel of sint netWorth;

  function void main(int[] args) {
    ask();
  }

  function void ask() {
    netWorth.put(readInt());
  }

  function void tell(bool b) {
    if (b) {
      display("You are the richest!");
    } else {
      display("Make more money!");
    }
  }
```

```
declare server Max:
  group of Millionaires mills;

  function void main(int[] args) {
    sint max = 0;
    sclient rich;

    foreach (client c in mills) {
      sint netWorth = c.netWorth.take();
      if (netWorth >= max) {
        max = netWorth;
        rich = c;
      }
    }

    foreach (client c in mills) {
      c.tell(open(c==rich|rich));
    }
  }
```

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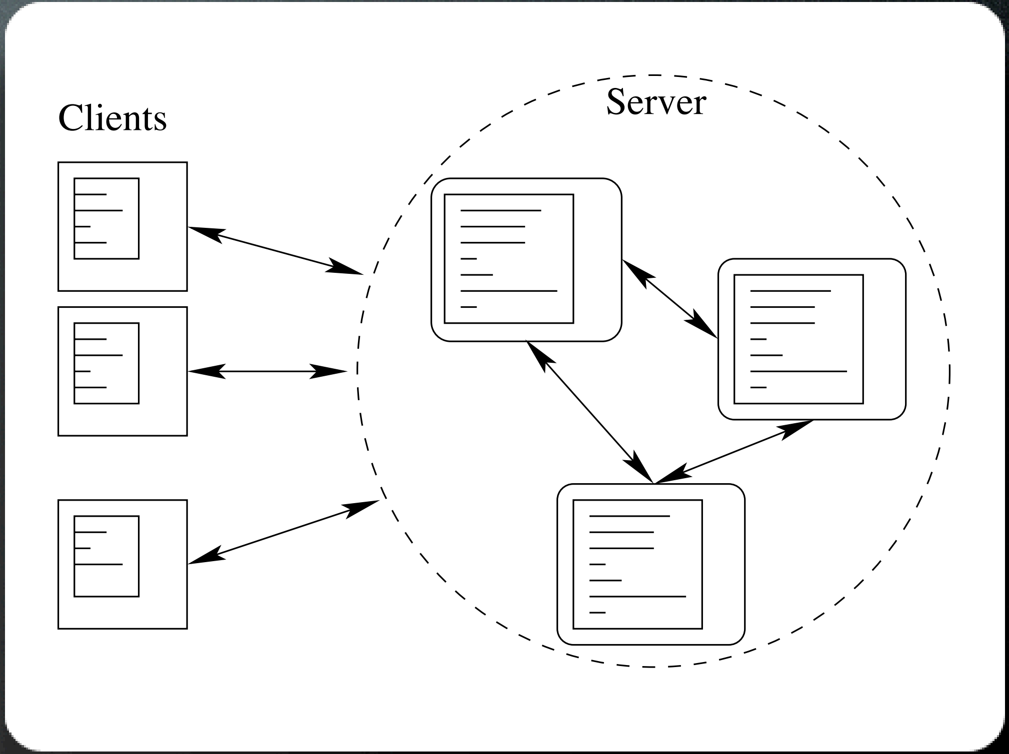
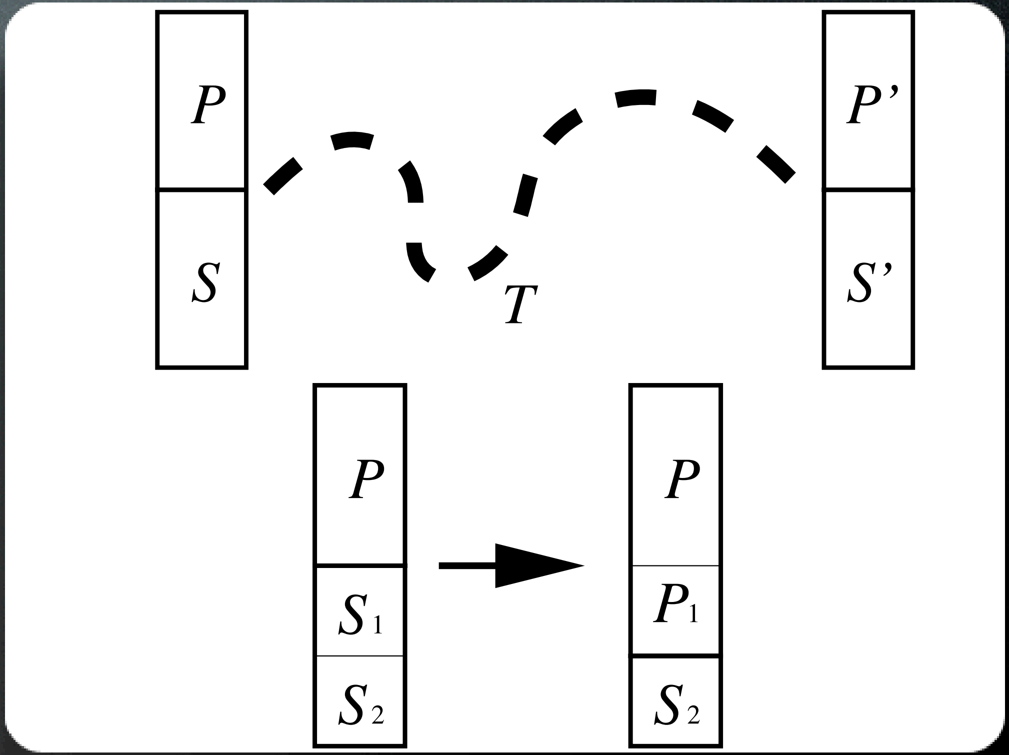
Security

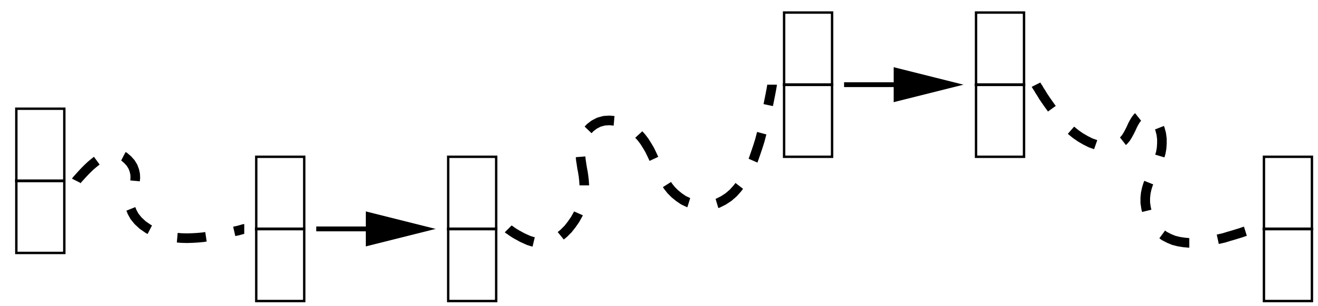
- Identity property
- Commutative property
- Adversary may:
  - Observe physical state of the server
  - Not observe private and secret values



Adversary Traces

- A sequence of states of an entire computation
- Secret values are masked out
- Private state of clients not available
- No declassification

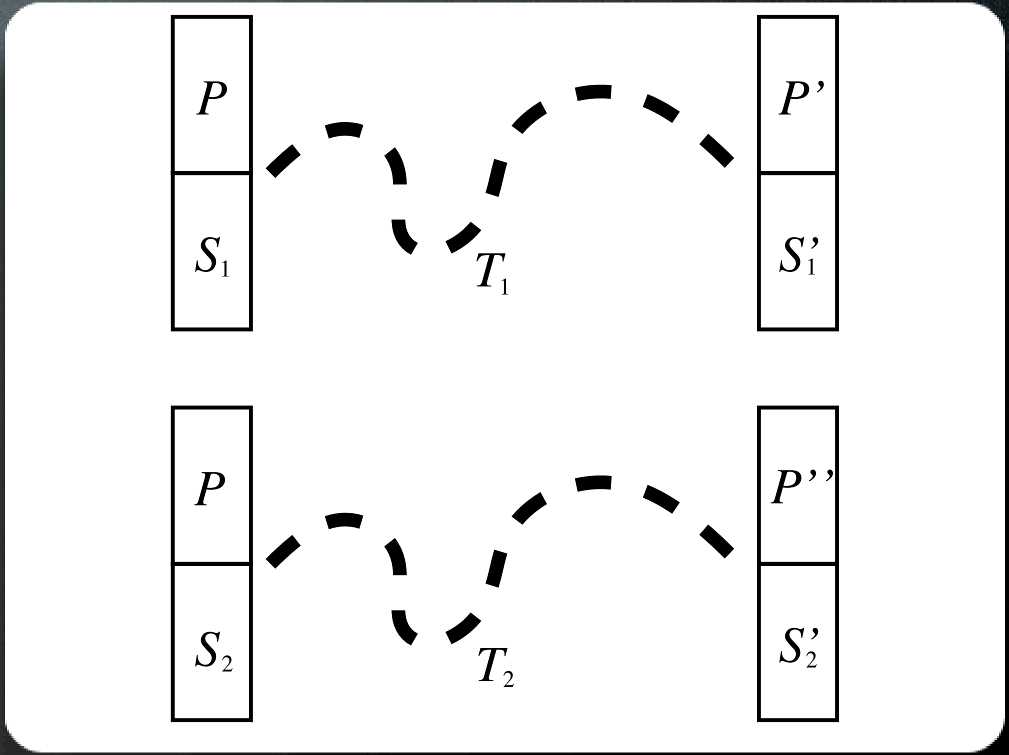




Adversary Traces (cont')

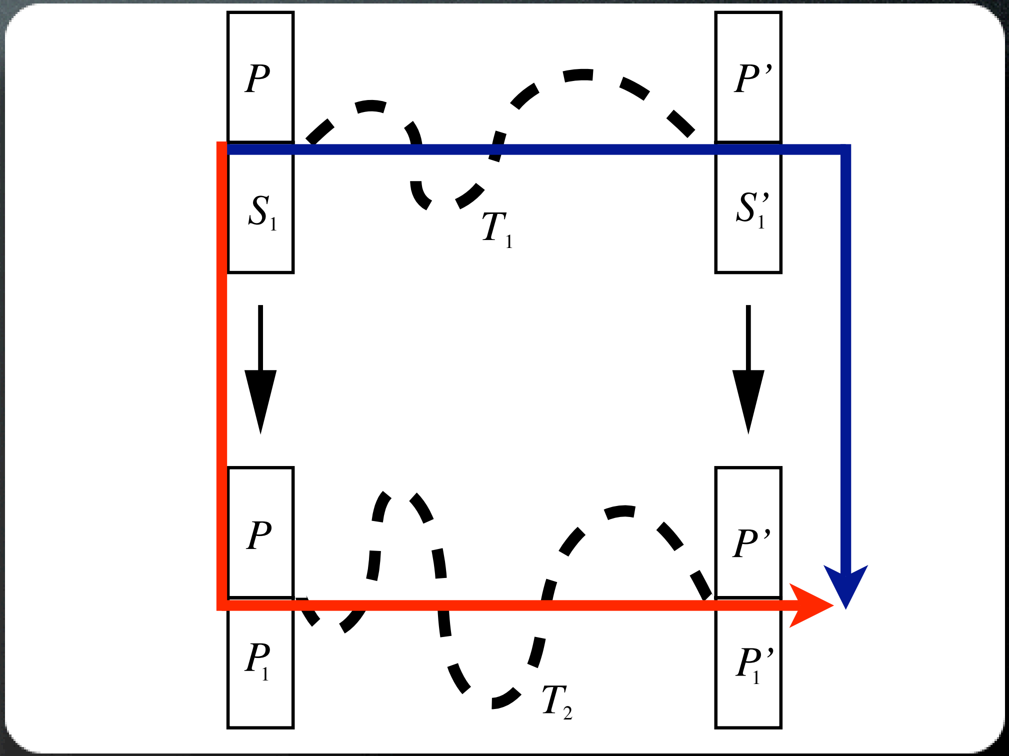
Identity Property

- p’ = p’’ - Low equiv.
- Traces must be identical
- Prevents attacks which are a function of the trace (e.g. timing)
- Requires basic operations independent of arguments



Commutative Property

- Soundness of secret representation



Ensuring Security

- Carefully crafted semantics
- Static analysis of well-typed SMCL programs

Semantics

- Conditionals are a source of differences in trace
  - Execute both branches
  - Termination

```
if (b) {
  x = y;
}
else {
  x = z;
}
```

x = b*y + (1-b)*z

$$\frac{G \vdash \langle C_2, S\rangle \ \rightarrow_{COM_{sv}} \ \langle C_2', S'\rangle}{G \vdash \langle \textbf{if}(\boxed{v})\ \{\}\ \textbf{else}\ \{C_2\}, U_{then}, S\rangle \ \rightarrow_{COM_{sv}} \ \langle \textbf{if}(\boxed{v})\ \{\}\ \textbf{else}\ \{C_2'\}, S', U_{then}, S\rangle}$$

(IF-SBOOL-ELSE)

$$\frac{\begin{array}{c}\sigma.S' = S[x \mapsto \boxed{v} * U_{then}(x) + (1 - \boxed{v}) * U_{else}(x)] \\ \forall x \in S | U_{then}(x) = v \ = U_{else}(x) \vee U_{then}(x) = \boxed{v'} \ \wedge \ U_{else}(x) = \boxed{v''}\end{array}}{G \vdash \langle \textbf{if}(\boxed{v})\ \{\}\ \textbf{else}\ \{\}, U_{else}, U_{then}, S\rangle \ \rightarrow_{COM_{sv}} \ \langle \sigma.S'\rangle}$$

(IF-SBOOL-PHI)

Hoistability

- Branches must agree on public side-effects
  - Assignment to public variables
  - Communication
  - Function calls
- While loops and recursion with secret condition - not allowed

$$\frac{\Gamma_t \vdash e : (\text{bool}, \mathsf{S}, \nu, \iota o)\text{-exp} \qquad \Gamma_t \vdash C_1 : (\mathsf{PL}, \mathsf{NIO})\text{-cmd} \qquad \Gamma_t \vdash C_2 : (\mathsf{PL}, \mathsf{NIO})\text{-cmd}}{\Gamma_t \vdash \textbf{if}\ (e)\ \{C_1\}\ \textbf{else}\ \{C_2\} : (\mathsf{PL} \mathbin{\bar{\wedge}} \nu, \iota o)\text{-cmd}}$$

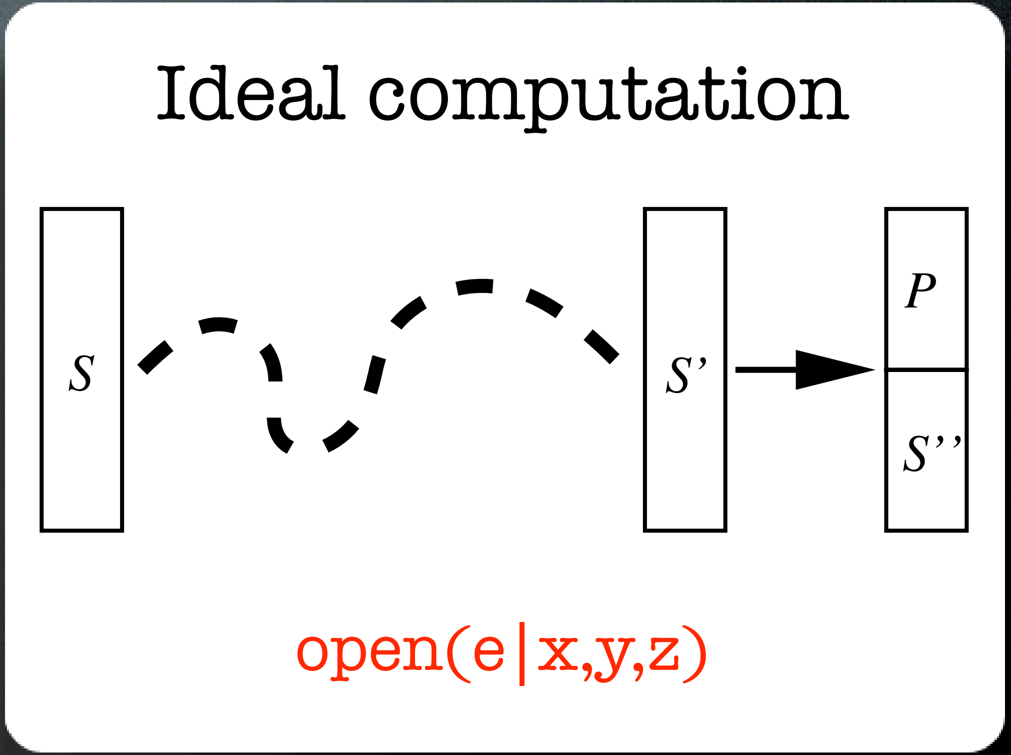
(TIf-secret)

$$\frac{\Gamma_t \vdash e : (\text{bool}, \mathsf{P}, \nu_0, \iota o_0)\text{-exp} \qquad \Gamma_t \vdash C_1 : (\nu_1, \iota o_1)\text{-cmd} \qquad \Gamma_t \vdash C_2 : (\nu_2, \iota o_2)\text{-cmd}}{\Gamma_t \vdash \textbf{if}\ (e)\ \{C_1\}\ \textbf{else}\ \{C_2\} : (\bar{\bigwedge}_{i=0}^{2} \nu_i, \underline{\bigvee}_{i=0}^{2} \iota o_i)\text{-cmd}}$$

(TIf-public)

Semantic Security

- Ideal computations are inefficient
- Prove that a pragmatic version reveals same information as the ideal version
- Assist the programmer



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Efficiency

Ideal

```
sint x = 17;
sint a = 42;
sint b = -5;
sint c = 87;
sint p = a*(x*x) + b*x +c
sint sign = 0;
int output;
if (p<0) sign = -1;
if (p>0) sign = 1;
output = open(sign|p);
```

Pragmatic

```
int x = 17;
sint a = 42;
sint b = -5;
sint c = 87;
int p = open(a*(x*x) + b*x +c|a,b,c)
int sign = 0;
int output;
if (p<0) sign = -1;
if (p>0) sign = 1;
output = sign;
```

(parties, threshold)	ideal	pragmatic	public
(3,1)	12 sec	30 ms	< 1 ms
(5,2)	17 sec	65 ms	< 1 ms
(7,3)	30 sec	132 ms	< 1 ms

Future Work

- SMCL
  - Formalize Adversary traces
  - Dynamic groups
  - Secret compound datatypes
  - More elaborate examples
- SecRas
- SVM, SPL...

Conclusion

- A DSL for SMC
  - High-level abstractions
  - Strong security guaranties
  - Useful in practice

Questions?