Distributed Oblivious RAM for Secure Two-Party Computation

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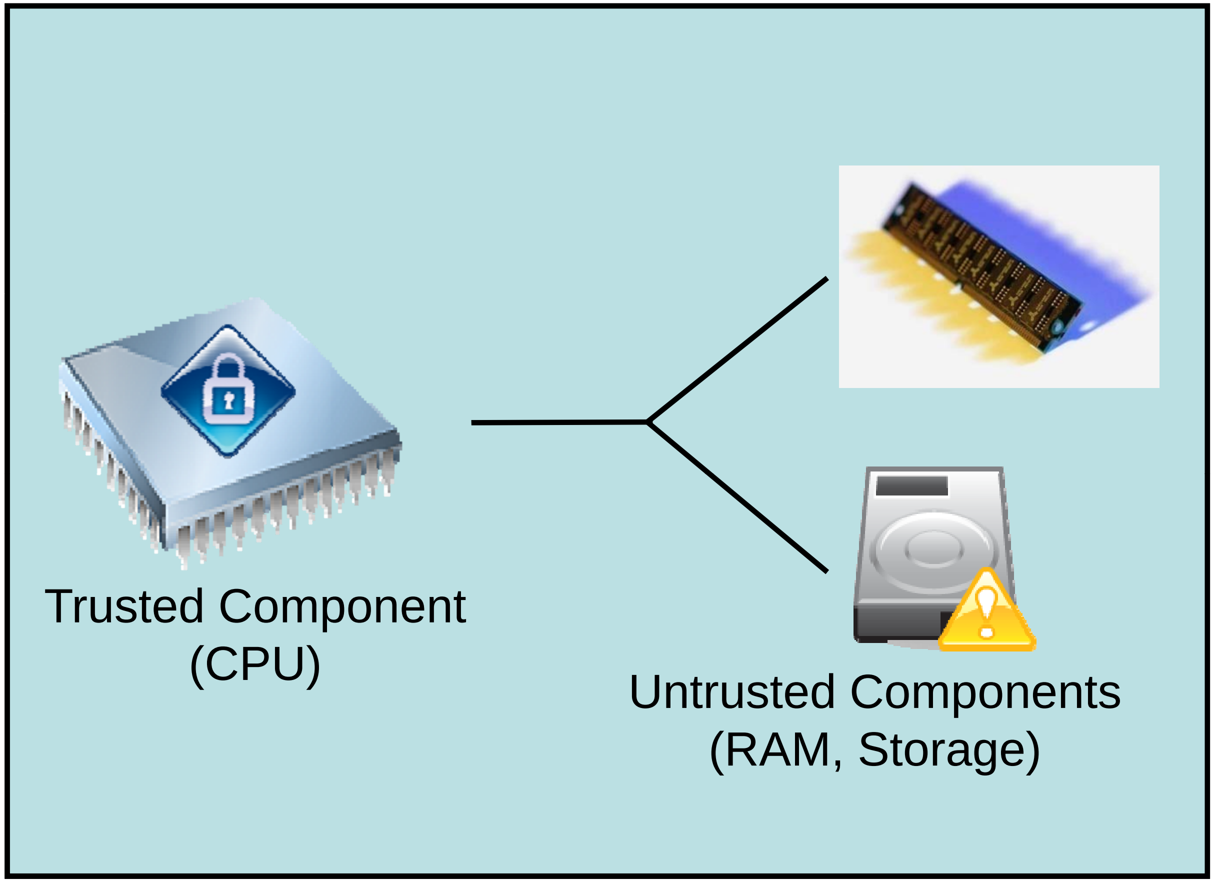
Overview

- Motivation
- Problem Statement
- Review
- New Results
- Conclusion

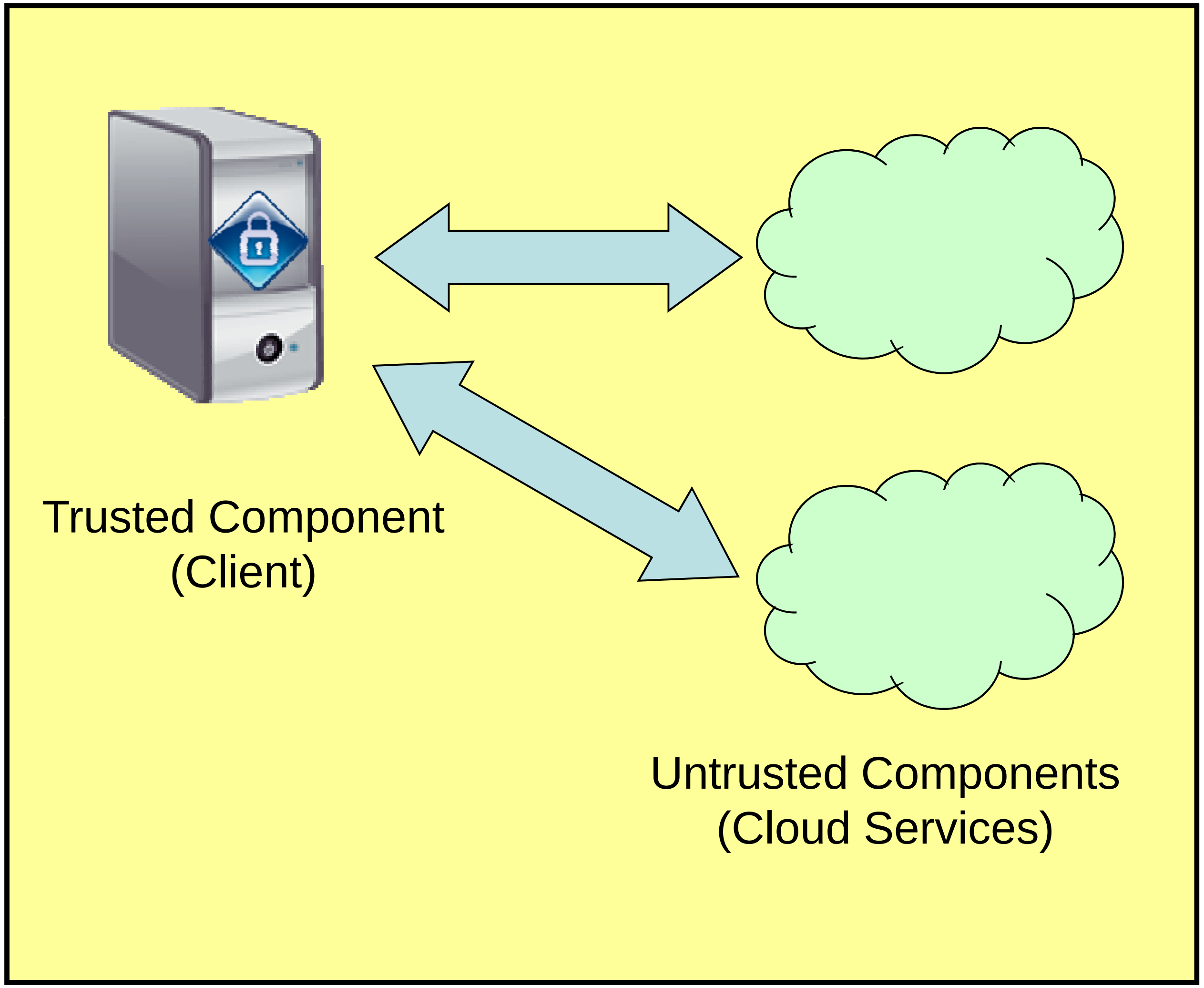
Background – Oblivious RAM (Goldreich'87)

- RAM Model
  - Small trusted component (CPU, client)
  - Large untrusted component (RAM, server)
- Obliviousness
  - Hide the contents and so-called "access-pattern"
    - A program Π is oblivious if one can simulate the (randomized) sequence of accesses to RAM given only the number of accesses

Original Motivation of ORAM: Bootstrapping Secure Hardware



Private Cloud Services



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Oblivious RAM Solutions

- Goal: Given a T-time S-space program Π, compile it into a T'-time S'-space oblivious program Π'

- "Square-root" solution (Goldreich [G87,GO96])
  - $O(n^{1/2} \log n)$ (amortized) Client time overhead
- "Hierarchical" solution (Ostrovsky [O90,GO96])
  - $O(\log^3 n)$ (amortized) Client time overhead
- Constant (in security param.)Client space in both

Many Subsequent Works

- Constant Client Space
  - Pinkas-Reinman [PR10], Goodrich-Mitzenmacher [GM11], Kushilevitz-L-Ostrovsky [KLO12],…
- Larger Client Space
  - Williams-Sion [WS08], Williams-Sion-Carbunar [WSC08], Goodrich-Mitzenmacher [GM11], Boneh-Mazieres-Popa [BMP11], Goodrich-Mitzenmacher-Ohrimenko-Tamassia [GMOT12], Stefanov-Shi-Song [SSS11],…
- Information-Theoretic
  - Ajtai [A10], Damgård-Meldgaard-Nielsen [DMN11],…
- Worst-Case Client Time per query
  - Ostrovsky-Shoup [OS97], Stefanov-Shi-Song [SSS11], Goodrich-Mitzenmacher-Ohrimenko-Tamassia [GMOT11], Shi-Chan-Stefanov-Li [SCSL11],…
- ...

Motivating Problem

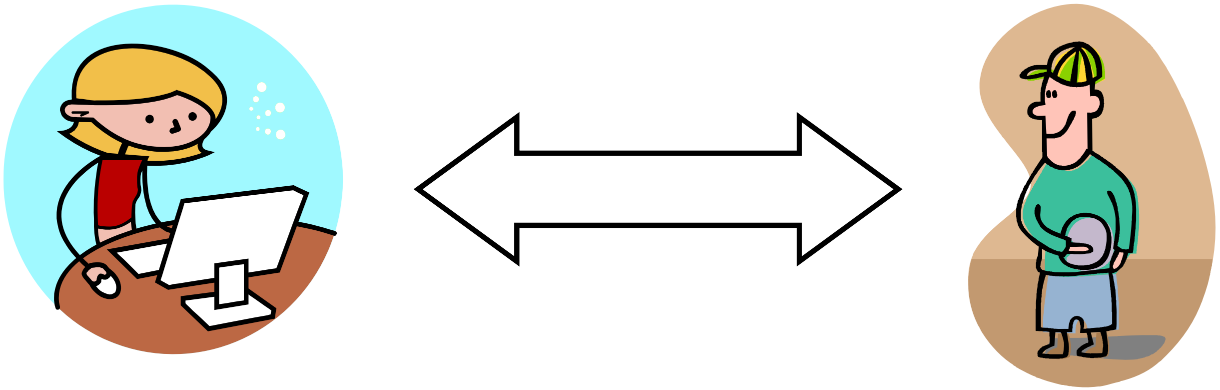
- For solutions with constant client memory
  - Lowest overhead $O(\log^2 n/\log\log n)$ Kushilevitz-L-Ostrovsky [KLO12]

- <u>Problem #1:</u> Can we improve the overhead?

More Motivation

- Most existing secure computation protocols operate on circuits
  - Circuit needs to be as large as the longest execution path
  - Circuit needs to be as large as the inputs
  - Most algorithms are not considered in terms of circuits
- Modular approach
  - Build efficient secure computation for a small class of circuits
  - Extend to arbitrary programs
- Problem #2: Can we come up with efficient candidates for secure RAM computation?

Secure Computation of RAM Programs



Input A

Input B

Wish to securely compute some
program Π (A,B)

Can we bootstrap existing secure circuit computation solutions?
(Rather than converting the programs into circuits)

Our Contribution

- We show how to get ORAM client overhead down to O(logn)
  - In a modified model
  - Constant client memory
  - From OWF

- There are alternative approaches that achieve this by increasing client memory [GM11,SSS11,…]
  - These are efficient stand-alone solutions for ORAM, but doesn't mesh well with our next step...

Our Contribution (Cont.)

- We show how this leads to an efficient 2-party protocol for secure computation *of RAM programs*

Ostrovsky-Shoup compiler [OS97]

Secure circuit computation with constant overhead (e.g. Ishai et al. [IKOS08, IPS08])

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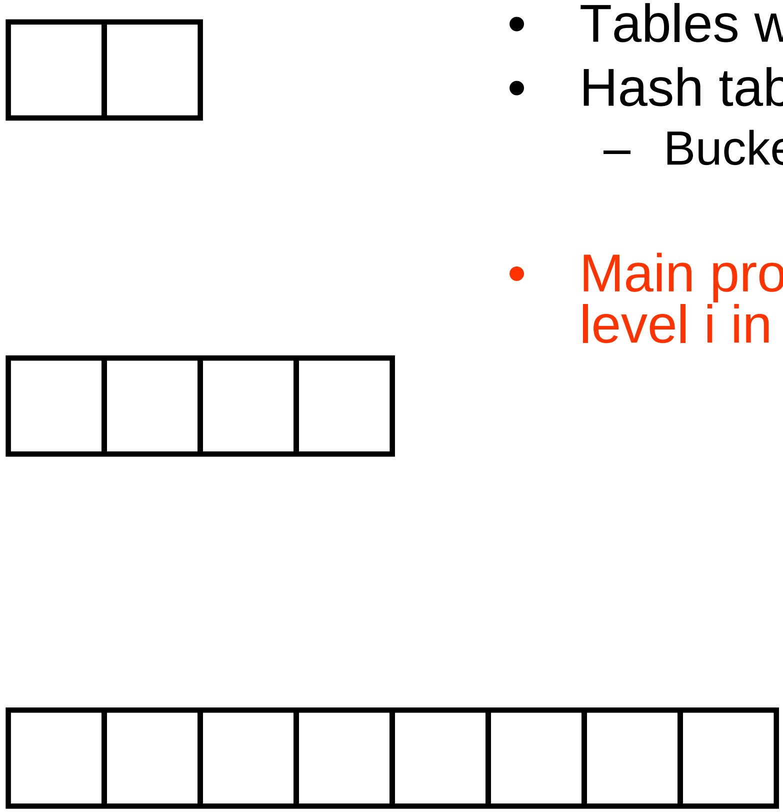
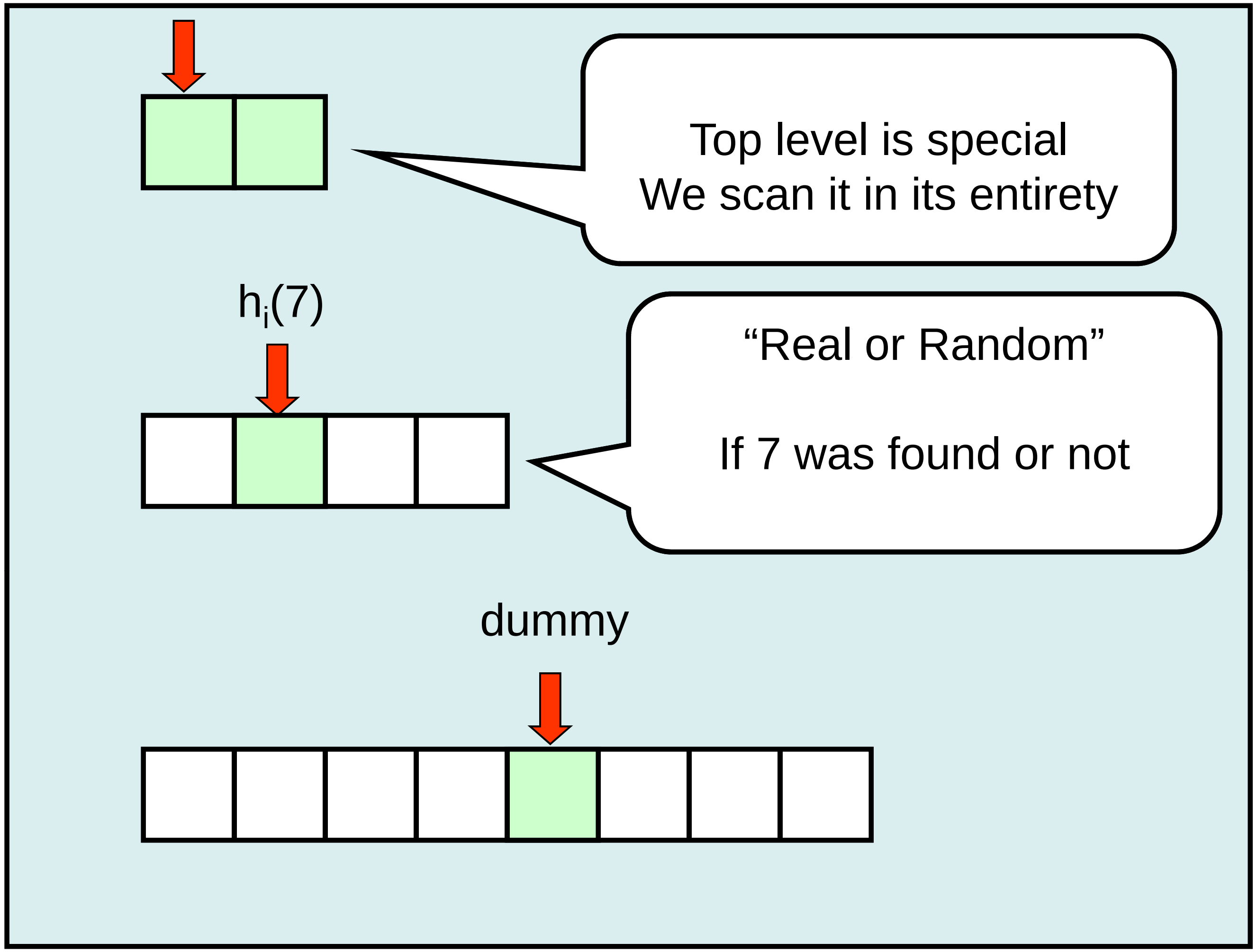
Review: Hierarchical Solution [O90,GO96]



- Set up the Server/RAM in a hierarchy of tables
- Tables with sizes in geometric progression
- Hash tables
  - Bucketed hash tables with log sized buckets

- Main property: (v,x) appears encrypted in a level i in table position $hash_i(v)$

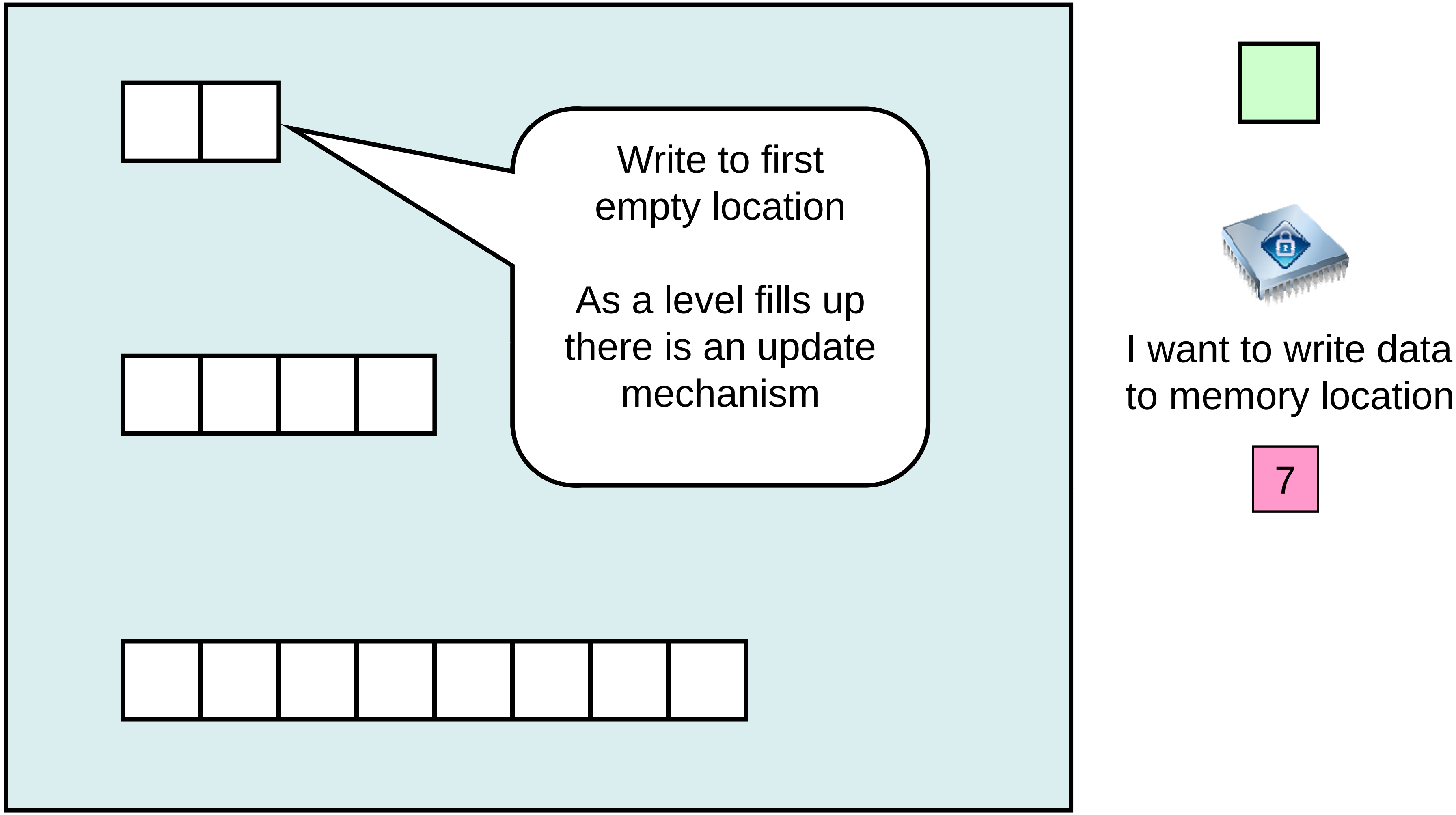
Review: Reading an element



I want to read memory location

7

Review: Writing an element

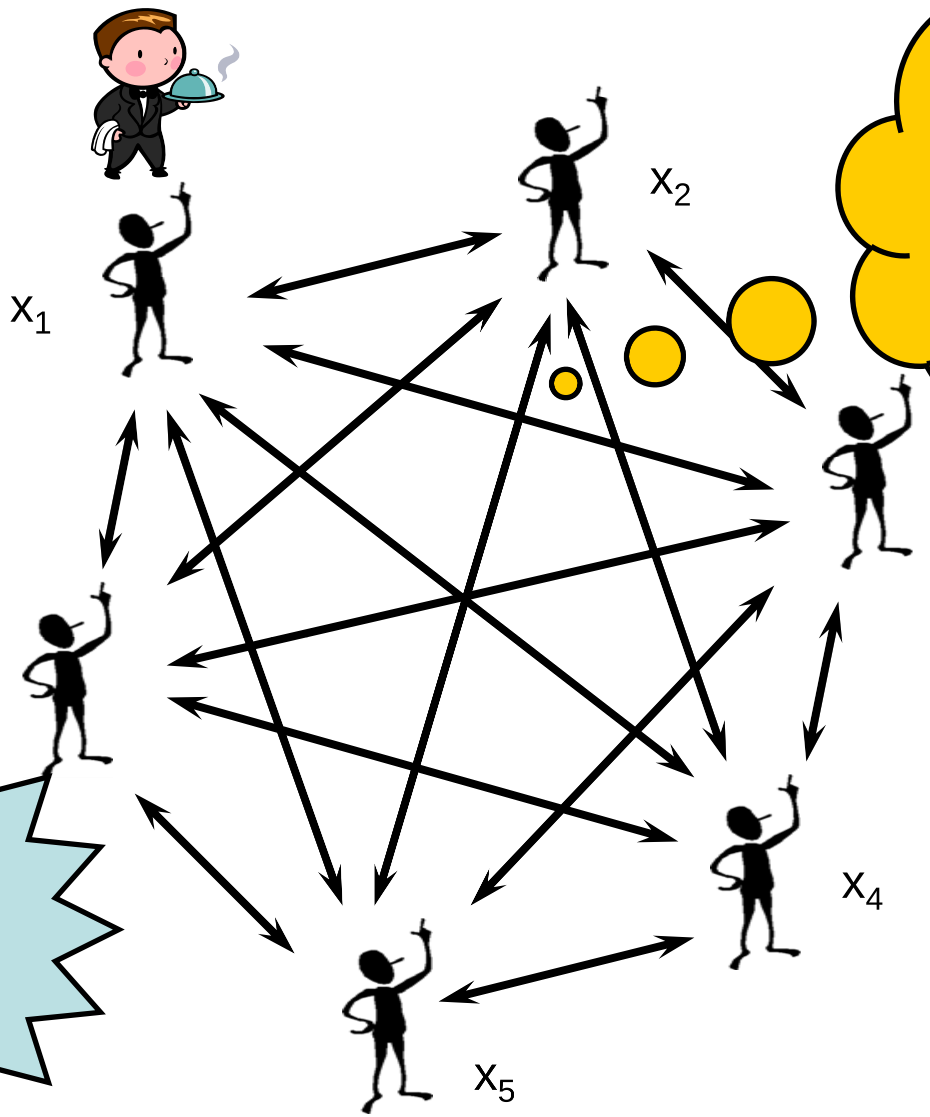


Review [GM11]: ORAM with Cuckoo Hashing

- Cuckoo hash tables [PR01]
  - O(1) worst-case lookup, O(n) space
- Given a *log-sized stash* and sufficiently large table, negl. overflow
- Use cuckoo hash for larger levels
- Oblivious shuffle into cuckoo hash table
  - Our solution bypasses this

Review: Application to Secure RAM Computation (introduced in [OS97])

We want to Compute $F(x_1,\ldots,x_6)$



Main Idea:
Designate Servers,
Then jointly simulate
ORAM CPU using
secure *circuit*
computation

This means
we are able to get
secure program
computation with
overhead proportional
to that of ORAM (and
underlying secure
circuit computation)

Gordon et al.
[G+12] for
sublinear
DB queries

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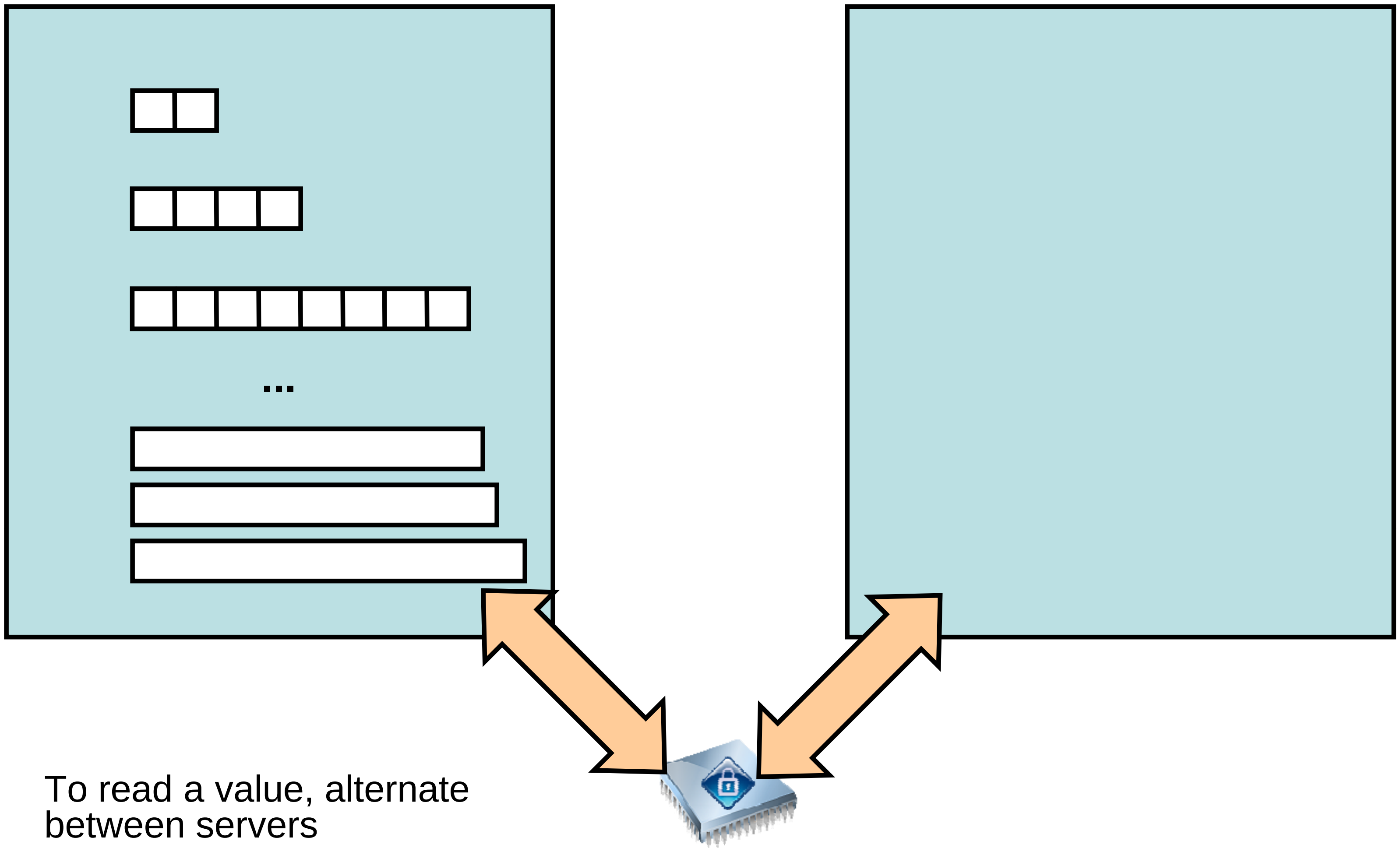
Our Results

- We make two changes to the model:
  - Multiple non-colluding servers
    - Useful theoretical tool
      - Interactive Proofs → multiple provers
      - Private Information Retrieval → multiple servers
      - …
    - e.g. two different cloud services
  - Server can now perform simple computations

Our Results

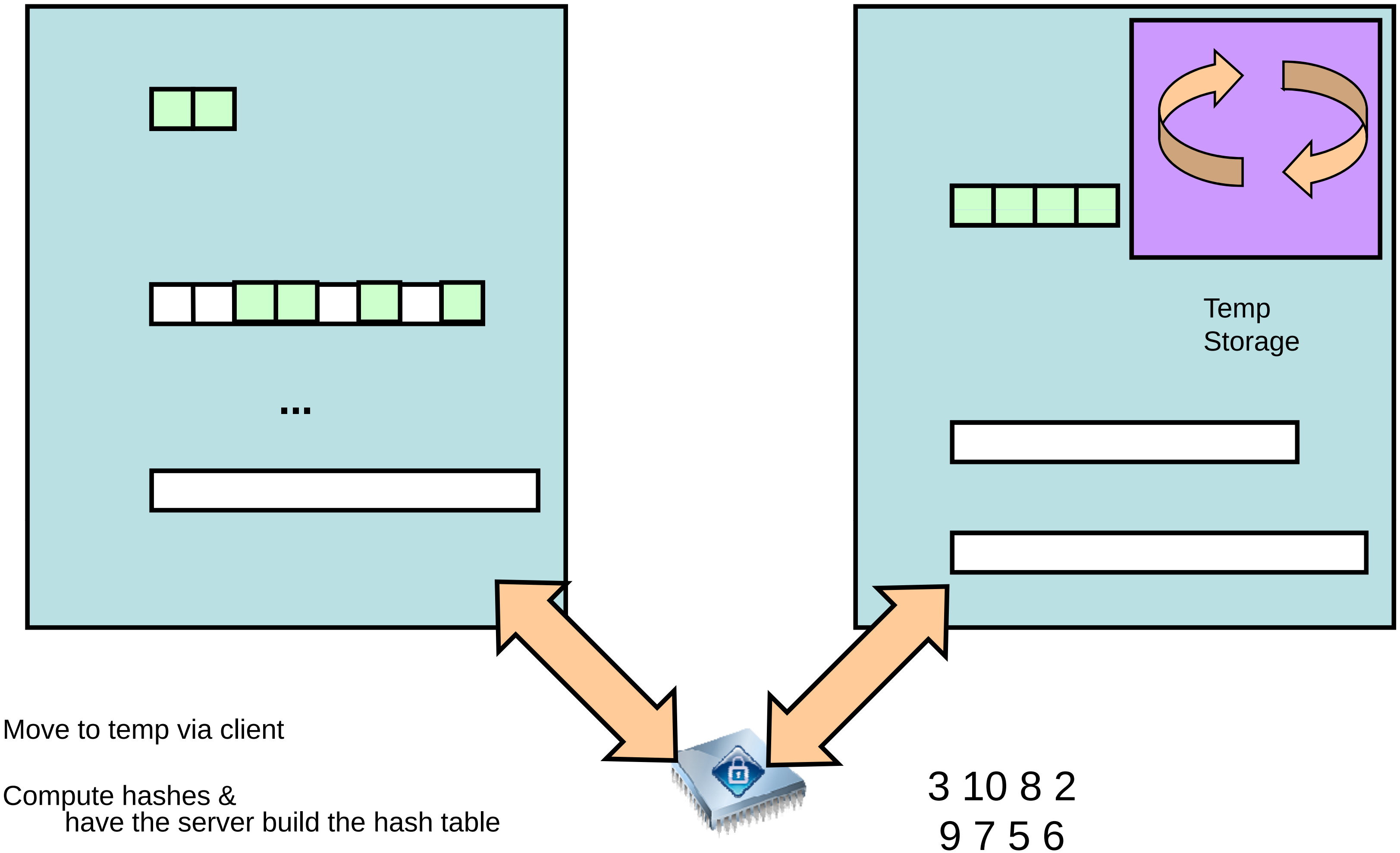
- In this model:
  - O(log n) access overhead with constant client memory
    - Matches lower bound in the *original* setting [GO96]
  - Bypass the expensive “oblivious sort” during updates

Distributed Oblivious RAM



- To read a value, alternate between servers
- Let’s see how update works

Distributed Oblivious RAM
Updating the levels – without sorting!



Move to temp via client

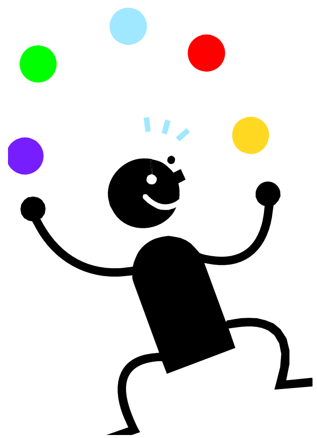
Compute hashes &
have the server build the hash table

Move back to other server via client

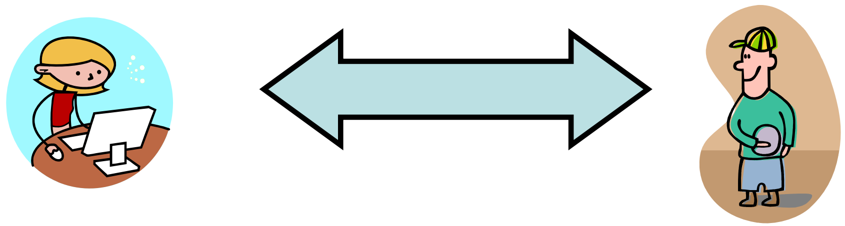
3 10 8 2
9 7 5 6
4 1

Choosing The Parameters

- Top level size
  - O(log n)
- Bucket size
  - O(log n/loglog n)
  - Stash of O(log n)
- Cuckoo Stash size
  - O(log n)
- “Cache the stash”



Application: Secure Computation on RAM Programs



Input A　　　　　　Input B

Wish to securely compute some program Π (A,B)

Exploring the idea of [OS97]:

- Alice plays the role of Server 1
- Bob plays the role of Server 2
- Design a circuit for ORAM CPU
- Use secure (constant overhead) *circuit* computation to run the CPU step
- Result of computation tells each server where to look

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Conclusion

- Described new result for $O(\log n)$ overhead ORAM in the multi-server model
- Application to secure RAM computation

Open Problems

- Improve the overhead (or show a new lower bound in this model)

- What else can we do with this model?

- Can we get non-interactive ORAM for an entire program (multiple read/write)?

  (Yes! --Come to the rump session ☺)

Thank You

Choosing The Hash Tables

- Smallest buffer
  - Just an array
  - O(log n) size turns out to be the right answer
- Standard Bucket Hashing for smaller levels:
  - Tension between bucket size and overflow probability
    - Bucket too big → Too much overhead
      - How big is too big? O(loglog n) levels, goal is O(log n) overhead, so at most O(log n/loglog n)
    - Bucket too small → Overflow probability becomes 1/poly (leads to security problems, see [KLO12])
      - O(log n/loglog n) not large enough!

Choosing The Hash Tables (cont.)

- How do we get around this?
  - Add a log n sized stash
  - Isn't this worse?
    - Additional log n elements we need to scan per level
    - Larger than a bucket!
- Observation (cf [GM11,KLO12]):
  - Only one active stash (lowest updated level)
  - This stash can be re-inserted into the hierarchy

Choosing The Hash Tables (cont.)

- Cuckoo Hash Tables
  - Larger levels all use cuckoo hash tables with stash
  - log n sized stash
    - Can be re-inserted as well

Client Overhead

- Read/Write
  - Read the entire smallest buffer O(log n)
  - Read one bucket for each bucketed hash level
    - ~7loglog n levels
    - Stash implicitly read
    - Bucket of size O(log n/loglog n)
    - Total: O(log n)
  - Read two locations for each cuckoo hash table
    - ~log n levels
    - Stash implicitly read
    - 2 locations each
    - Total: O(log n)
- Update
  - For each level, if that level is of size k, then every k steps the Client moves O(k) elements between the servers
  - O(log n) levels
  - Total: O(log n)