HOFSTRA UNIVERSITY

ZeroAUDIT

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PONZI
SCHEME
How did you make the money?
Commercial Secret!

Research Question

Transactions	Portfolio			Public Info.		
	Cash	Stock1	Stock2	Units	Total	NAV
[redacted]				0	$0	$50
				10	$500	$50
				30	$1500	$50
				45	$2250	$50
				45	$2250	$50
				45	$2700	$60
				35	$2100	$60

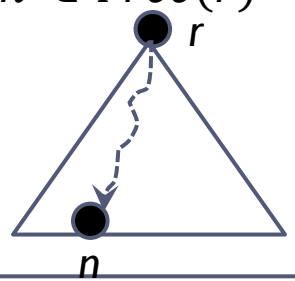
Audit Transactions But Knowing

Nothing?

Our Contributions

Zk-Membership Proof for Merkle Tree

Given C(r) and C(n):
Prove $n \in Tree(r)$



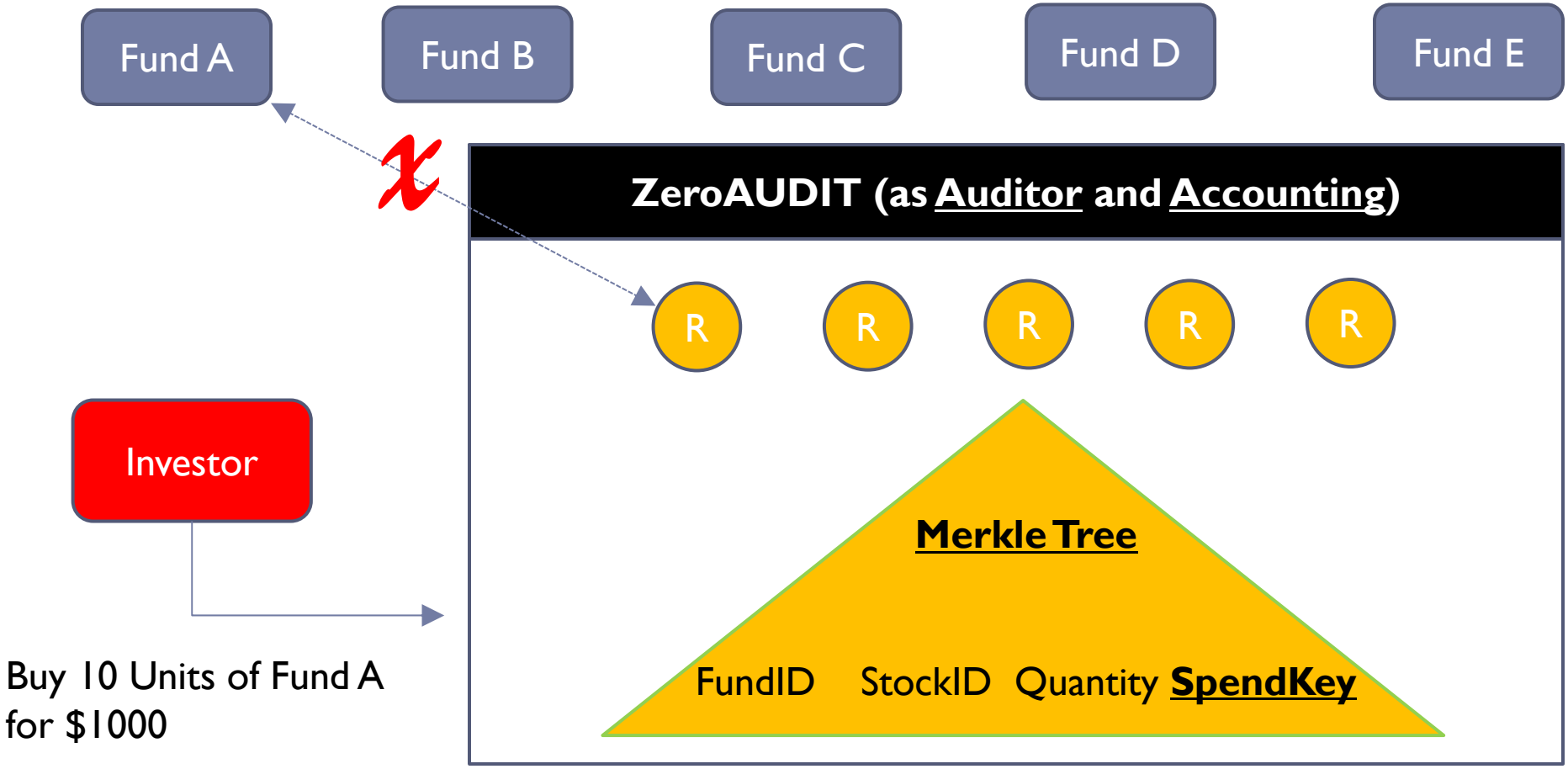
Implementation & Optimization

- 25K GO on **Fabric**
- Small Test Exponent Test
- Chained Schnorr Groups
- Pippenger's Multi-Exponent.
- Bullet Range Proof
- …

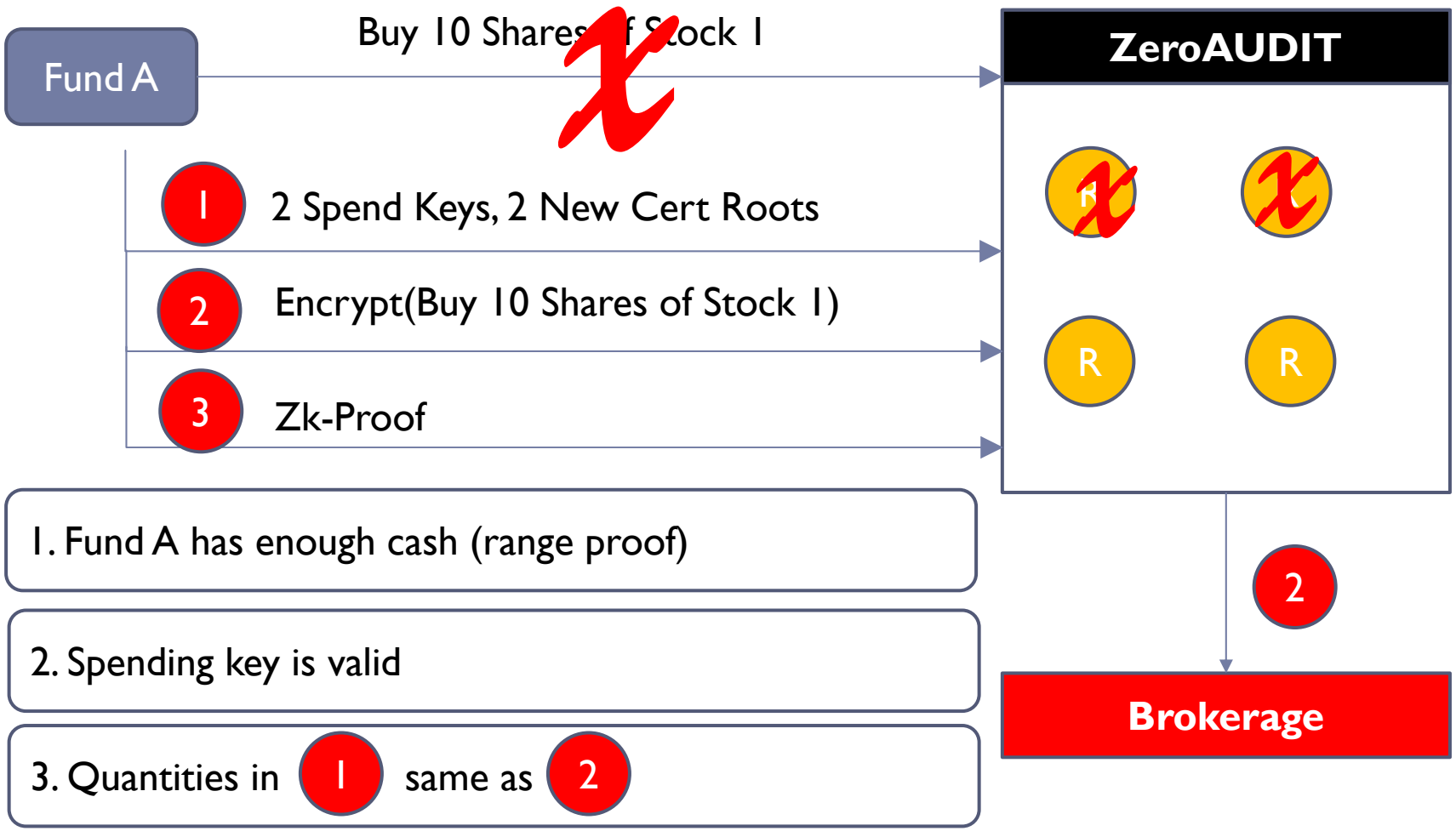
ZeroAudit Protocol

- Auditor Maintain Fund Portfolio – Work on **Commitments**
- Inspect Each Transaction at **Fair Market Price**
- Certify Net Asset Value Any Time
- **No Trusted Setup**!
  - Eq. Proof of Commits. over 2 Groups of **Different Prime Orders**
  - Using **Range Proof**

ZeroAUDIT Architecture

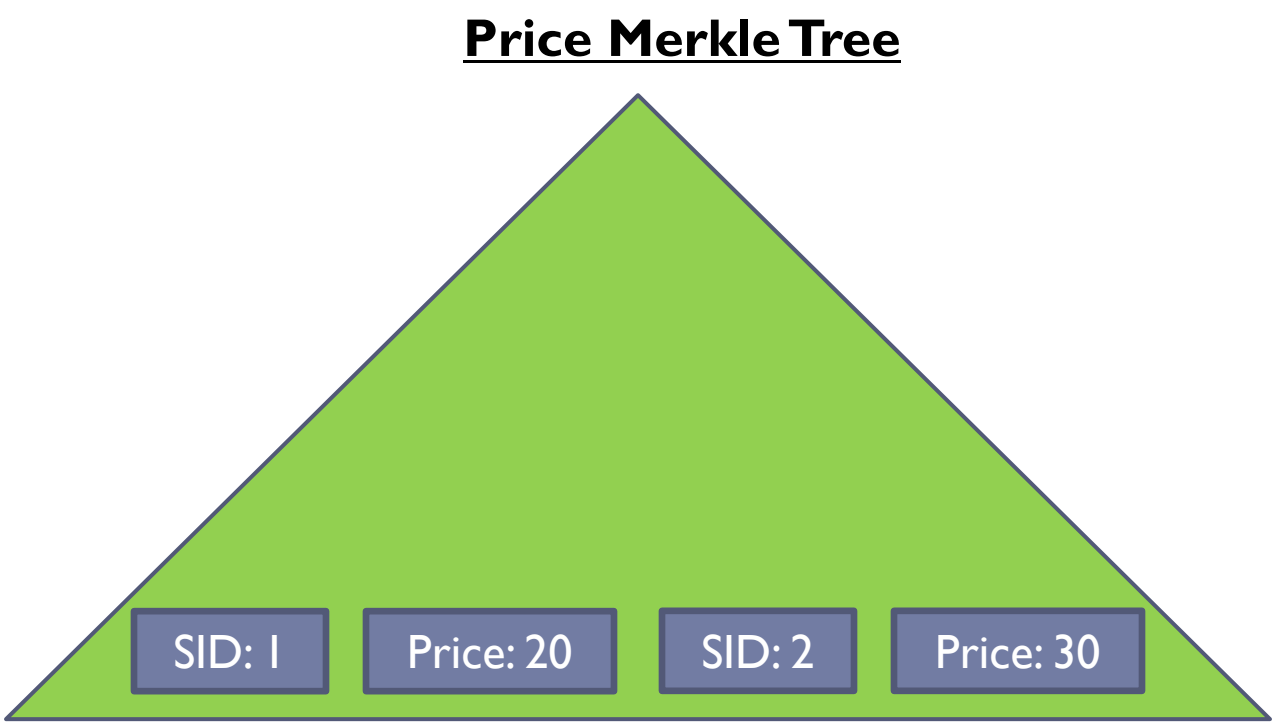


Trading Operation



Verify Fair Market Price

- Given $Commit(SID)$ and $Commit(price)$
- Prove: $(SID, price) \in Tree$

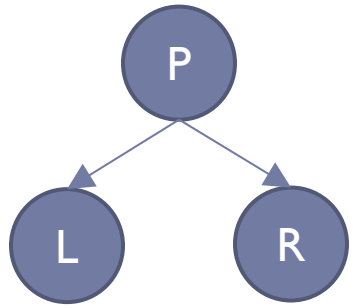


Chained Schnorr Groups

$Commit_p(P) \quad \in G_p$

$Commit_q(L) \quad \in G_q$

$Commit_q(R) \quad \in G_q$



$g_{q1}^{L} g_{q3}^{r} \; mod \; p$ $\qquad$ $g_{q2}^{L} g_{q3}^{r'} \; mod \; p$

$P = hash(L, R)$

$P = \; Commit_q(L, R)$

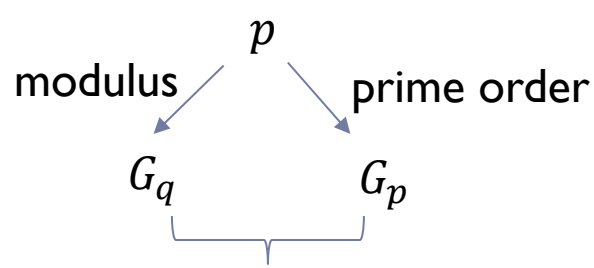
$P = g_{q1}^{L} \, g_{q2}^{R} \, g_{q3}^{r} \; mod \; p$

<u>Pedersen Commitment</u>:

2 Primes $q < p$: $G_q \; subgroup \; of \; Z_p$

2nd Larger Group

$p < r$: $G_p \; subgroup \; of \; Z_r$



<u>Chained Schnorr Groups</u>

DDLP in Child Proof

$Commit_p(P)$ $\quad P = g_{q1}^{L}\, g_{q2}^{R}\, g_{q3}^{r} \bmod p$

$Commit_q(L)$

$Commit_q(R)$ $\quad P = Commit_q(L) Commit_q(R)\, g_{q3}^{D} \bmod p$ for some D

Prover should not release D or g_{q3}^{D}

Prover can disclose $Commit_p\,(g_{q3}^{D})$

Key Observation:

$$Commit_p\,(g_{q3}^{D})^{Commit_q(L)Commit_q(R)} \triangleq Commit_p(P)$$

$$g_{p1}^{Commit_q(L)Commit_q(L)g_{q3}^{D}}\; g_{p2}^{r'}$$

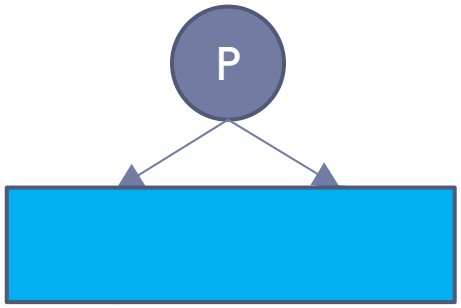
Prover knows the D
Double Discrete Logarithm Proof
(DDLP) [Stadler'97]

Complete Merkle Tree Proof

$Commit_p(P)$

$Commit_q(L)$

$Commit_q(R)$



- Disjunctive Zk-Proof
- Zk-Equality Proof Over Groups of **Different** Order
  - [Camenisch CRYPT'99] Chain Commit. on **Unknown** Order
  - Our Approach [**No Trusted Setup**]
    - **Range Proof** to Confine Values [Special Chained Schnorr Setting]
    - Challenge: Huge Range $[0, 2^{1800}]$
    - Incorporate ***Inaccurate*** Range Proof

System Implementation

- 25K Golang
- Over Hyperledger Fabric

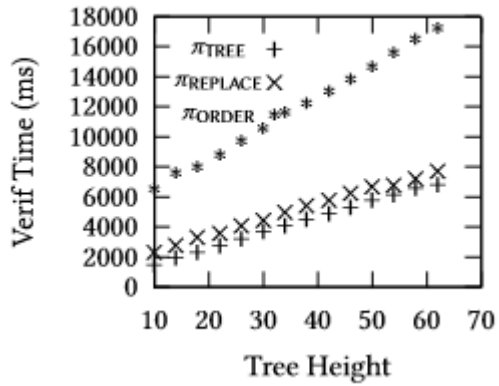
Proof	Reps	Build	Verif	Size	SmallExp	LargeExp
π_{DLP}	200	1.08	0.78	0.29	2	0
π_{DDLP}	200	561.98	48.23	76.22	189	1
π_{SAME}	200	57.43	5.75	2.08	4	1
π_{OR}	100	3614.53	59.13	494.67	91	2
π_{EDGE}	100	4241.48	111.20	557.44	259	4
π_{TREE}	1	42778.61	1597.28	5732.72	3437	87
π_{RANGE}	100	7995.79	69.65	6.24	21	18
$\pi_{REPLACE}$	1	75163.24	2640.24	10324.36	6370	111
π_{ORDER}	1	216961.74	8382.76	28726.65	18722	238
$\pi_{HOLDING}$	1	116534.11	3811.67	16091.07	8342	151

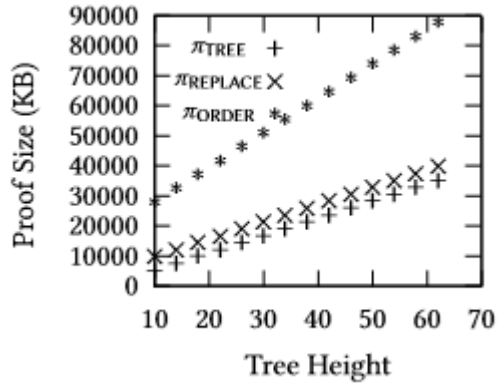
Build & Verif: Proof construction and verification time in milliseconds. SmallExp: number of small exponentiation (exp < 2ℓ). LargeExp: large exponentiation. Size: proof size in KB. Tree height settings for $\pi_{REPLACE}$, π_{ORDER}, and $\pi_{HOLDING}$: T_{RR} (11) and T^{PRICE} (16).

Table 3: Zero Knowledge Proof Cost

Operation	Verif Time (ms)	Chaincode Request (KB)
NewFund (per cert)	571	3648
Order	15443	36742
Invest	7062	16051
SetNAV (per cert)	8076	20425

Table 4: Hyperledger Fabric Client Operation Cost





Performance Data

	Trusted Setup	Assumptions	Approach	Security Strength	Anonymity Set Size	Proof Size	Proof Time (ms)	Verify Time (ms)	Verify Complexity
ZeroCoin [33]	Yes	SRSA	SRSA Accumulator[13]	128/80-bit	2^{160} [a]	45KB	–	420 [b]	$O(1)$
ZeroCash [21]	Yes	DH, KEP	zkSnark	128-bit	2^{64}	0.28KB	175000	8.5 [c]	$O(1)$
zkLedger [35]	No	DH	Columnar Update	128-bit	20	96KB	160	140 [d]	$O(n^2)$
Monero [53]	No	DLP, DH	Ring Signature LogSize Set Member. Prf	128-bit	2^{10}	1.3KB	5000	3000 [e]	$O(n)$
ZeroAUDIT	No	DLP, RO	Anony. Merkle Tree Member. Prf	112-bit	2^{15}	28MB	216961	8382 [f]	$O(\log_2 n)$

Assumptions. DLP: Discrete Logarithm; DH: Diffie-Hellman Variants; KEH: Knowledge of Exponent; RO: Random Oracle; SRSA: Strong RSA. **Verify Complexity.** the verification run-time on the anonymity set size n. –: not reported. [a] Estimate is based on 160-bit serial numbers. [b] Data is from Figure 3 (a),(b). [c] Data is from Figure 3. [d] Data is estimated from Table 1. Using k=20. [e] Data is estimated from Figure 2(a)(b) with input size 2. [f] Data is from the cost of π_{ORDER} in Table 3.

Table 5: Performance Comparison

- Extra Cost Paid for No Trusted Setup
- Proof Size Huge (Needs Improvement)

Conclusion

- ZeroAUDIT
  - Inspect Trading Transactions Without Knowing Details
- Anonymous Merkle Tree Membership Zk-Proof
  - No Trusted Setup
  - Simple Assumptions: DLP + Random Oracle
  - Log(n) Proof Size and Verification Time (n: anonymity set size)
  - Equality Proof (on Different Order Groups) Using Range Proof
- Varieties of Optimization Techniques

Questions