Strong Accumulators from Collision-Resistant Hashing

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Outline

- Notion of accumulator
- Motivation
  - e-Invoice Factoring
- Our construction
- Conclusion

Notion of accumulator

- Problem
  - A set X.
  - Given an element x we wish to prove that this element belongs or not to X.
- Let $X=\{x_1,x_2,...,x_n\}$:
  - X will be represented by a short value Acc.
  - $Belongs(Acc,x,w) = True \Leftrightarrow x$ belongs to X.

↑

Witness

Notion of accumulator

- Accumulator Manager
  - Computes setup values.
  - Computes the accumulated value Acc.
  - Computes the witness w_x for a given x.
- Accumulator Users
  - Check that an element belongs or not to the set, using Acc, w_x and x.

Applications

- Time-stamping [BeMa94]
- Certificate Revocation List [LLX07]
- Anonymous credentials [CamLys02]
- E-Cash [AWSM07]
- Broadcast Encryption [GeRa04]
- …

Nothing to see with Number Theory!

Factoring Industry in Chile

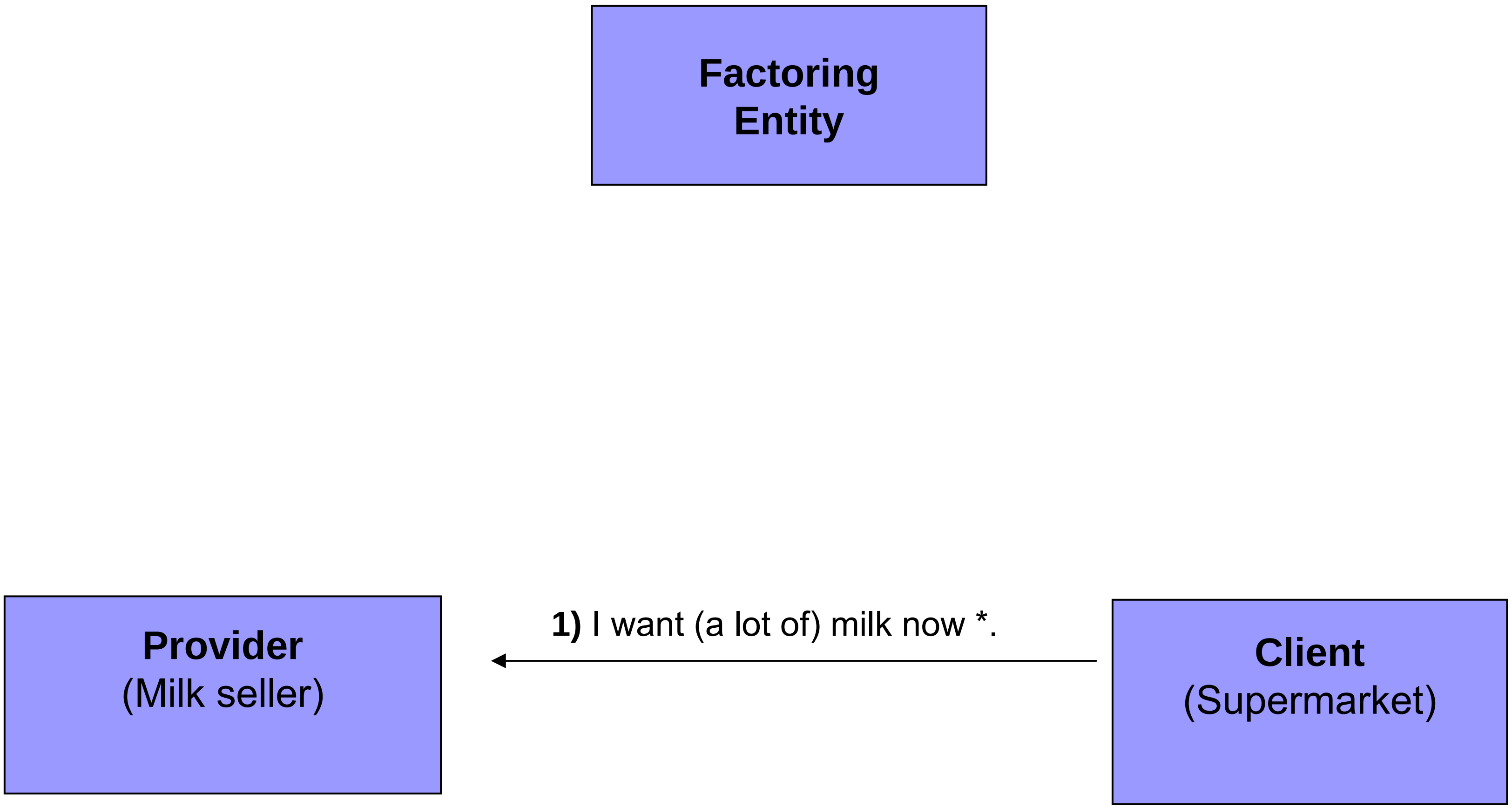
Factoring Entity

Provider
(Milk seller)

Client
(Supermarket)

Nothing to see with Number Theory!

Factoring Industry in Chile



(*) but I do not want to pay yet.

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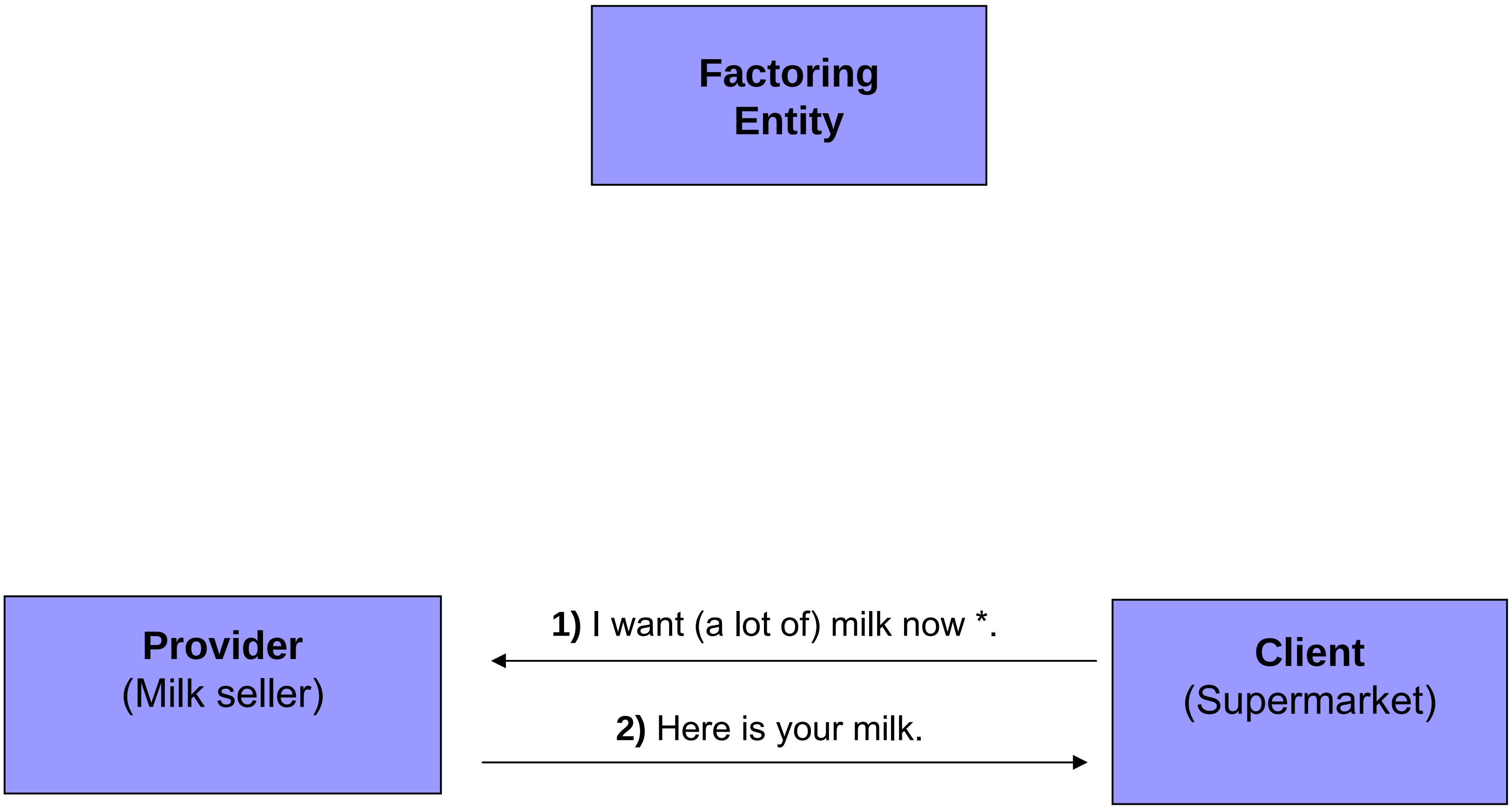

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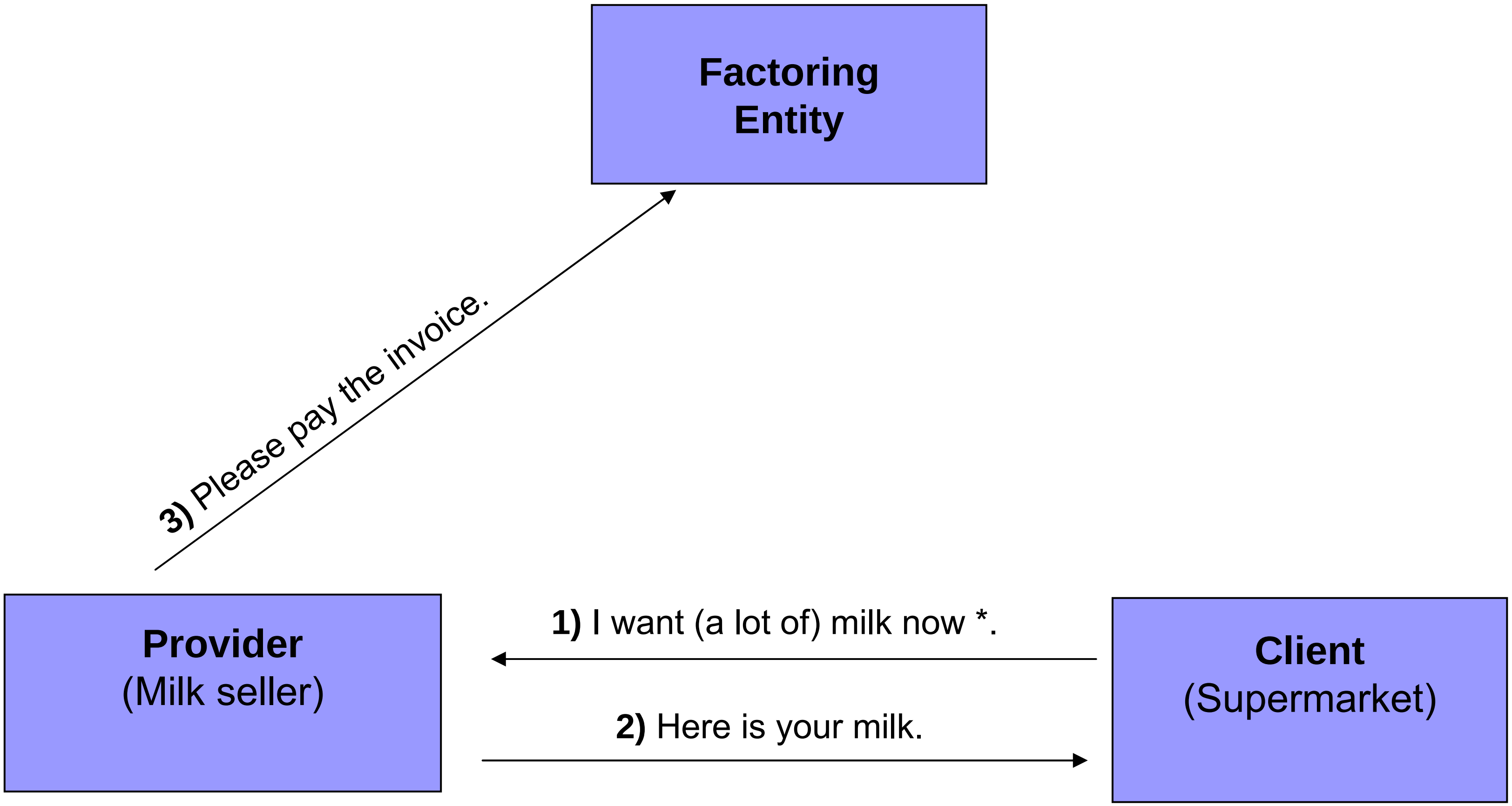

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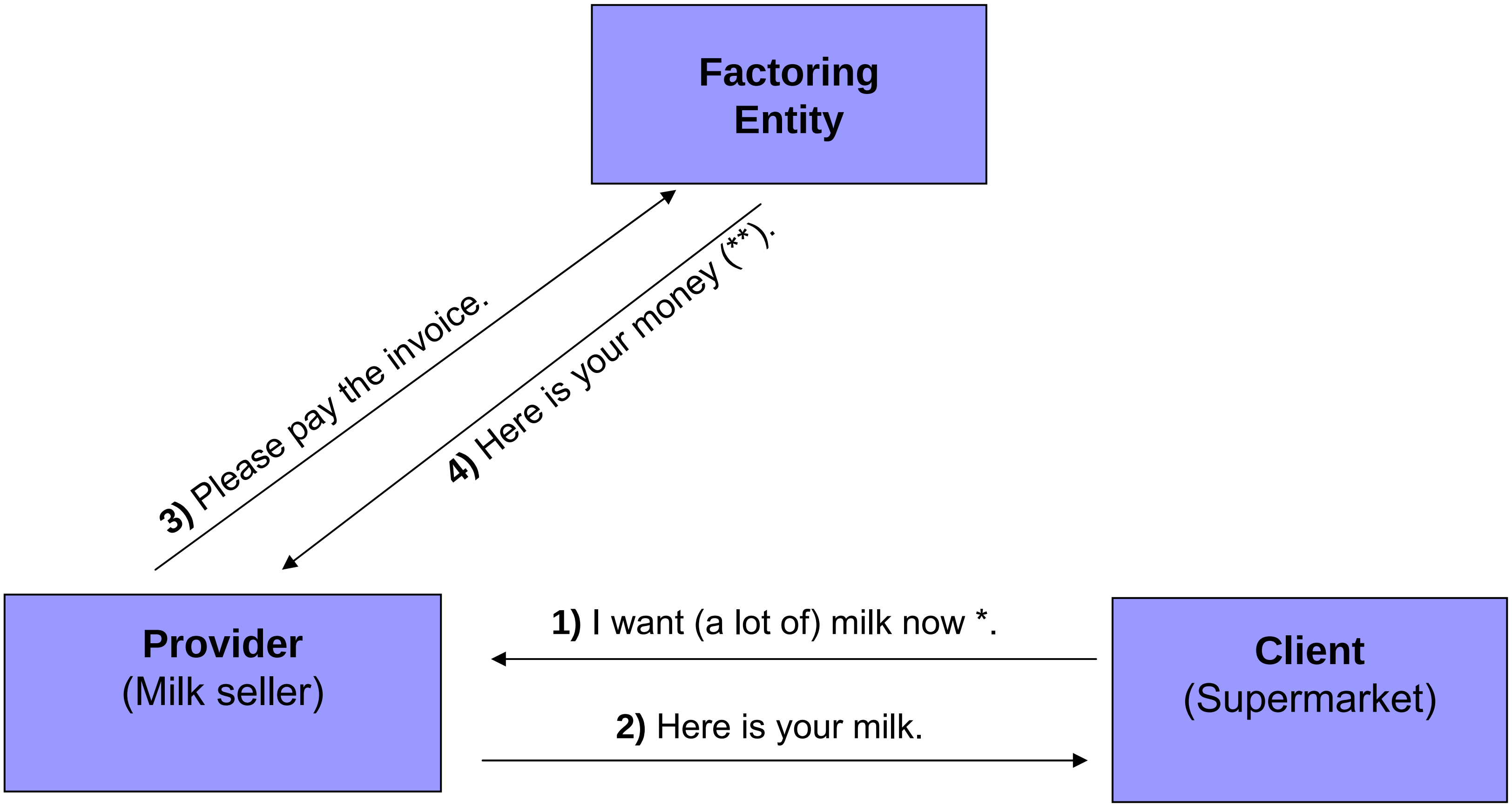

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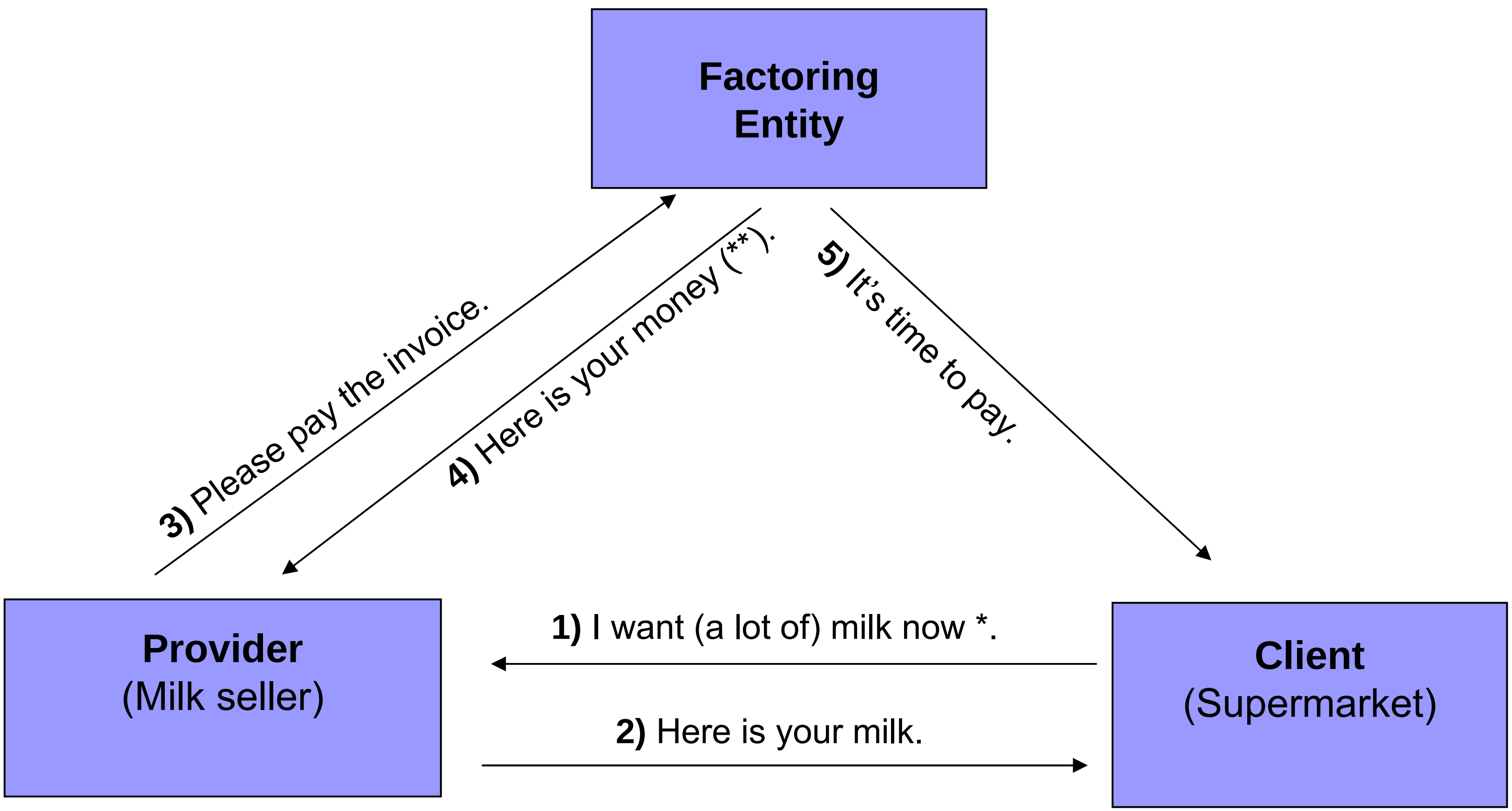

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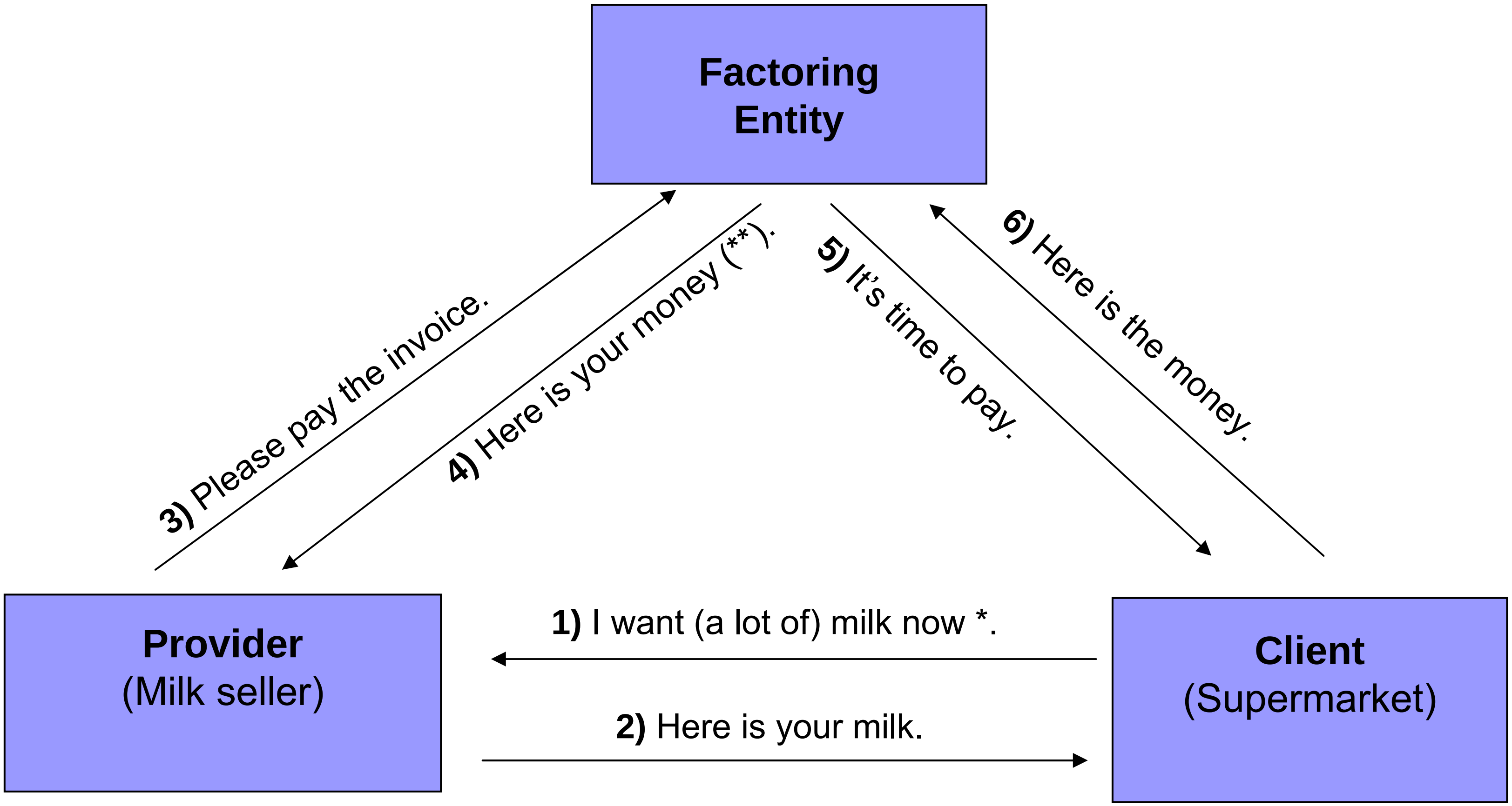

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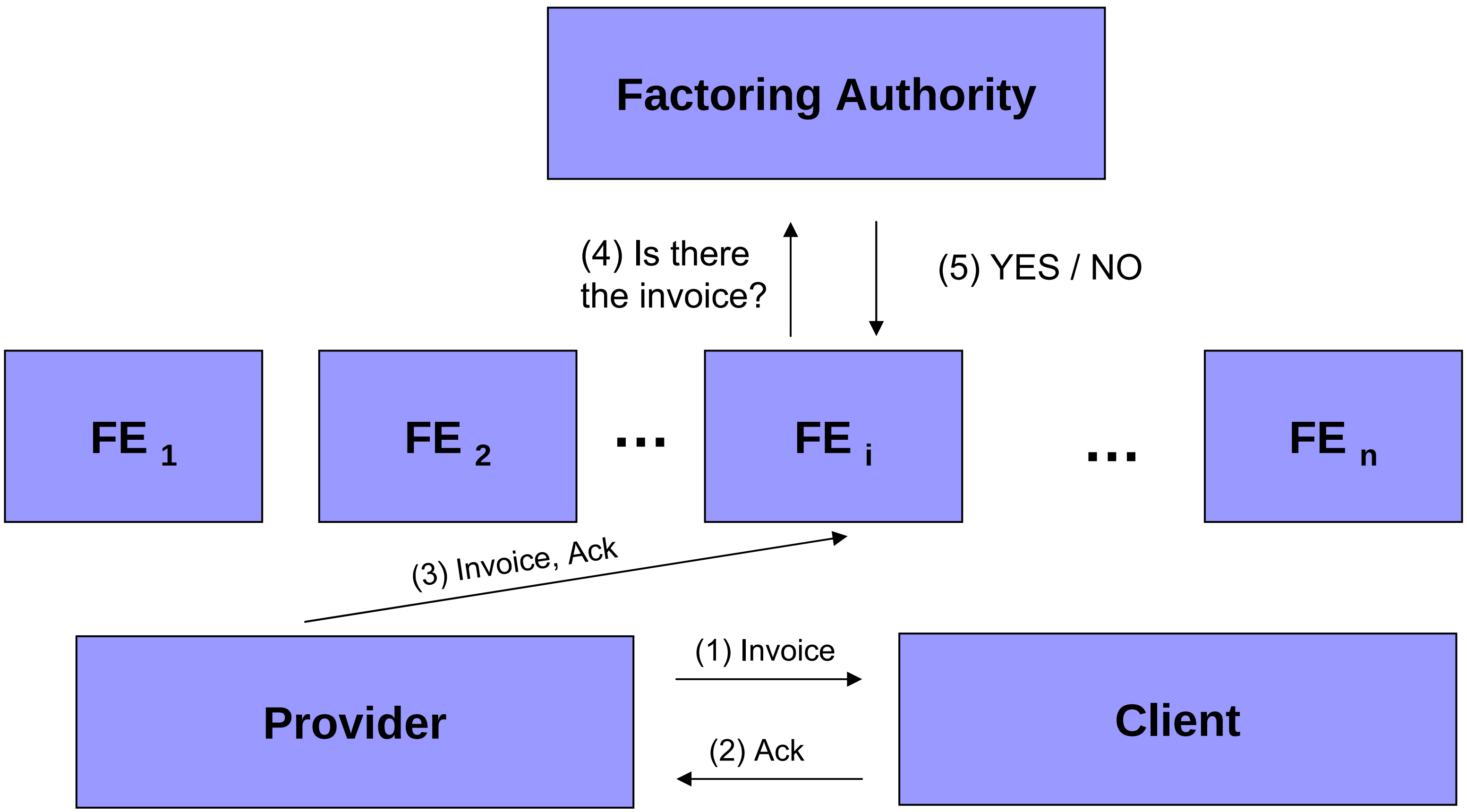
The Problem

- A malicious provider could send the same invoice to various Factoring Entities.
- Then he leaves to a far away country with all the money.
- Later, several Factoring Entities will try to charge the invoice to the same client. Losts must be shared…

Solution with Factoring Authority



Caveat

- This solution is quite simple.
- **However**
  - Trusted Factoring Authority is needed.
- Can we remove this requirement?

Properties

- Dynamic
  - Allows insertion/deletion of elements.
- Universal
  - Allows proofs of membership and nonmembership.
- Strong
  - No need to trust in the Accumulator Manager.

Prior work

	Dynamic	Strong	Universal	Security	Efficiency (witness size)	Note
[BeMa94]	✗	✓	✗	RSA + RO	O(1)	First definition
[BarPfi97]	✗	✓	✗	Strong RSA	O(1)	-
[CamLys02]	✓	✗	✗	Strong RSA	O(1)	First dynamic accumulator
[LLX07]	✓	✗	✓	Strong RSA	O(1)	First universal accumultor
[AWSM07]	✓	✗	✗	Pairings	O(1)	E-cash
[WWP08]	✓	✗	✗	eStrong RSA Paillier	O(1)	Batch Update

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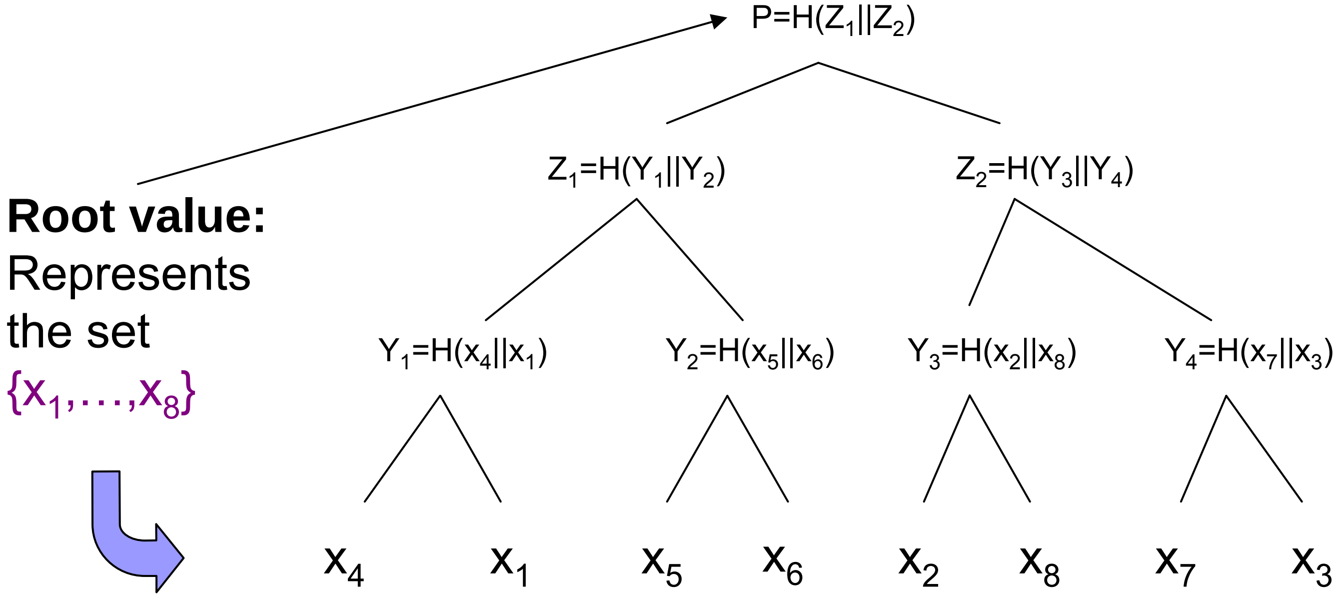
[WWP08]	✓	✗	✗	eStrong RSA Paillier	O(1)	Batch Update
[CHKO08]	✓	✓	✓	Collision-Resistant Hashing	O(ln(n))	Our work

Notation

- $H: \{0,1\}^* \rightarrow \{0,1\}^k$
  - randomly chosen function from a family of collision-resistant hash functions.
- $x_1, x_2, x_3, \ldots \in \{0,1\}^k$
  - $x_1 < x_2 < x_3 < \ldots$ where $<$ is the lexicographic order on binary strings.
- $-\infty, \infty$
  - Special values such that
    - For all $x \in \{0,1\}^k$: $-\infty < x < \infty$
- $||$ denotes the concatenation operator.

Ideas

- Merkle-trees



Ideas

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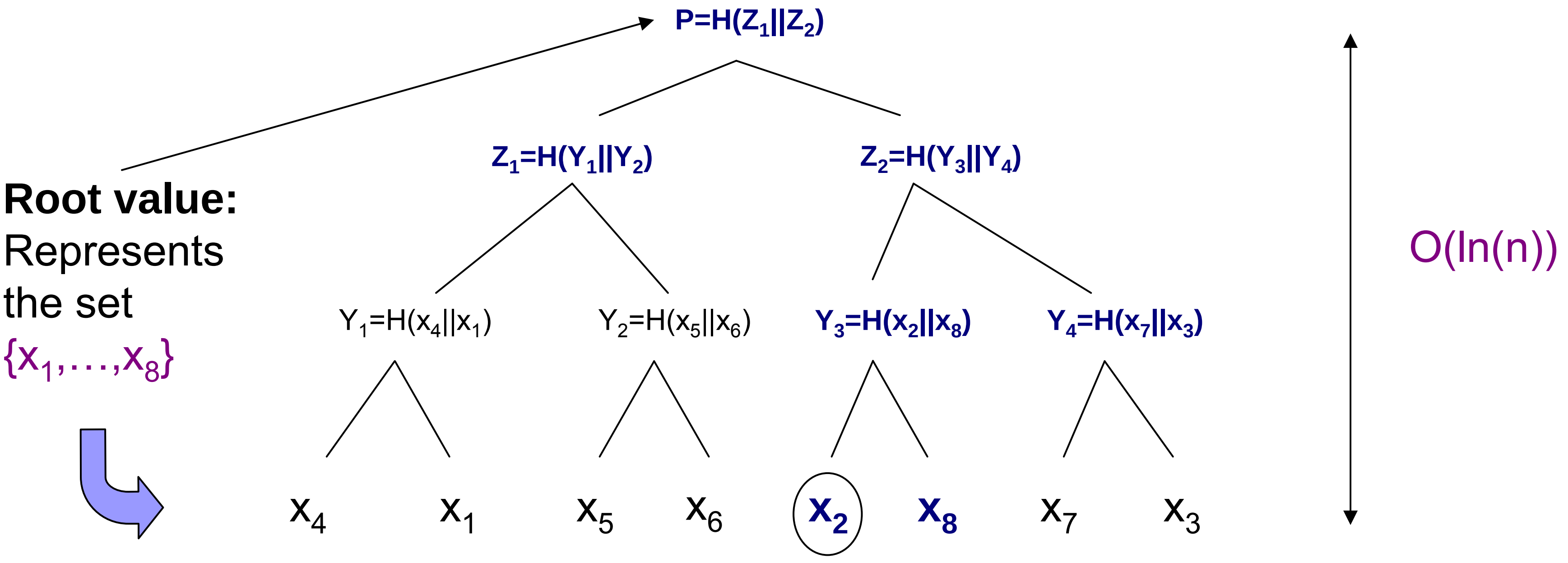


Ideas

- How to prove non-membership?
  - Kocher's trick [Koch98]: store pair of consecutive values
    - $X=\{1,3,5,6,11\}$
    - $X'=\{(-\infty,1),(1,3),(3,5),(5,6),(6,11),(11,\infty)\}$
    - $y=3$ belongs to $X \Leftrightarrow (1,3)$ or $(-\infty,1)$ belongs to X'.
    - $y=2$ does not belong to $X \Leftrightarrow (1,3)$ belongs to X'.

Public Data Structure

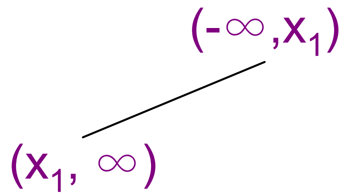
- Called “Memory”.
- Compute efficiently the accumulated value and the witnesses.
- In our construction the Memory will be a binary tree.

How to insert elements?

$(-\infty,\infty)$

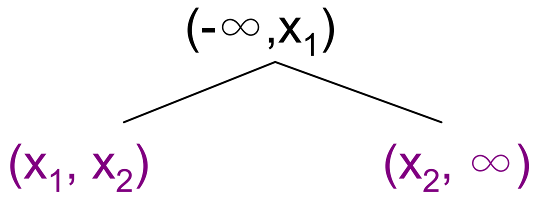
X=Ø, next: x_1

How to insert elements?



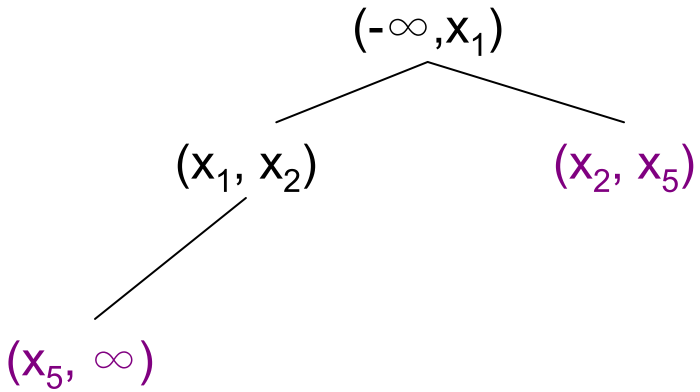
$X=\{x_1\}$, next: x_2

How to insert elements?



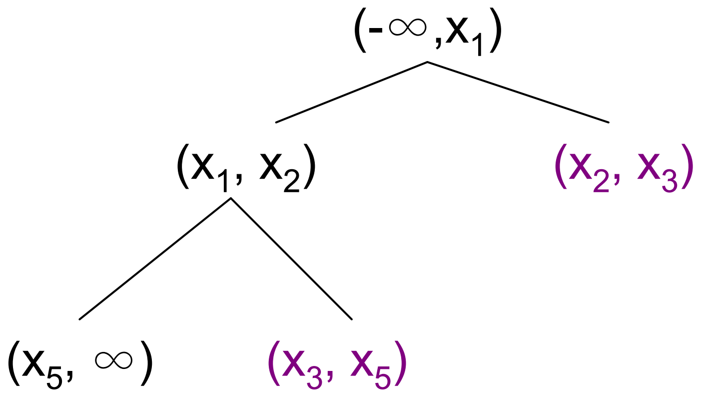
$X=\{x_1,x_2\}$, next: x_5

How to insert elements?



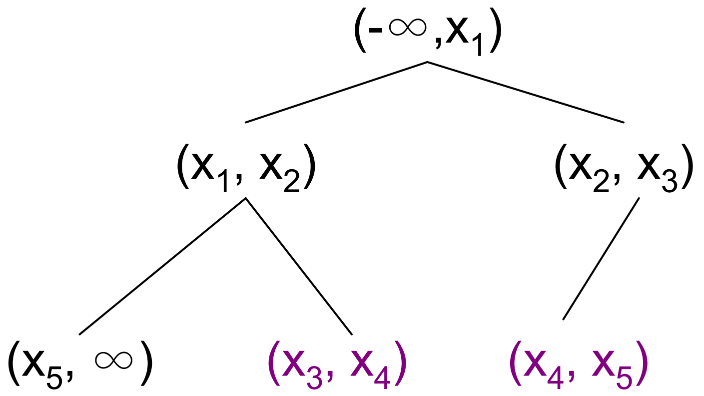
$X=\{x_1,x_2,x_5\}$, next: x_3

How to insert elements?



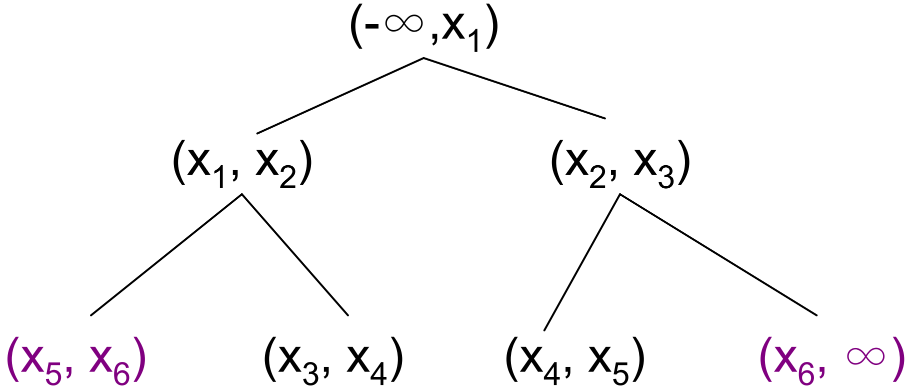
$X=\{x_1,x_2,x_3,x_5\}$, next: x_4

How to insert elements?



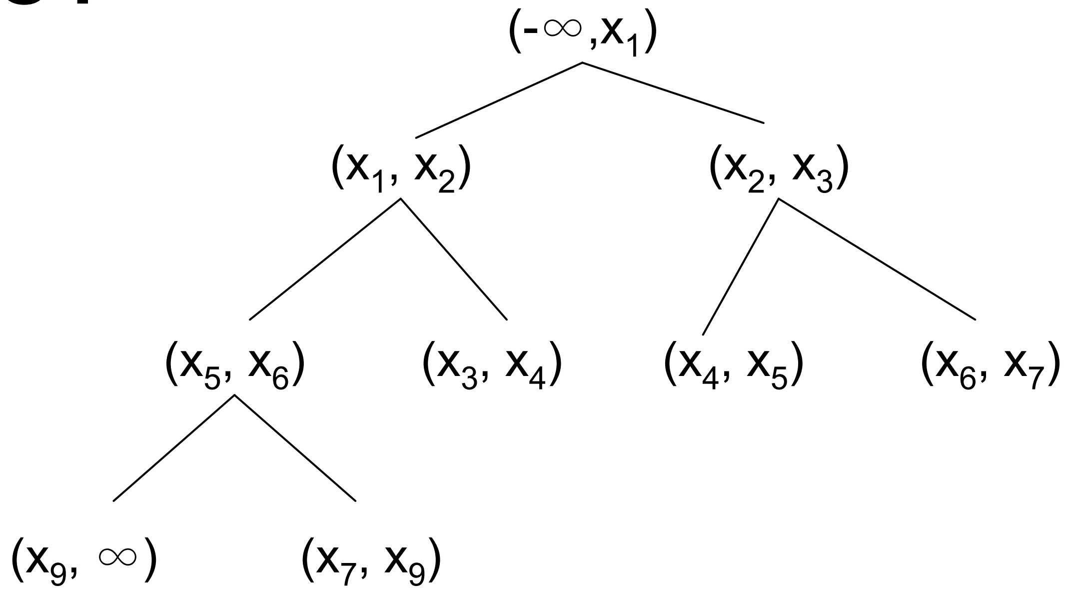
$X=\{x_1,x_2,x_3,x_4,x_5\}$, next: x_6

How to insert elements?



$X=\{x_1,x_2,x_3,x_4,x_5,x_6\}$

How to compute the accumulated value?



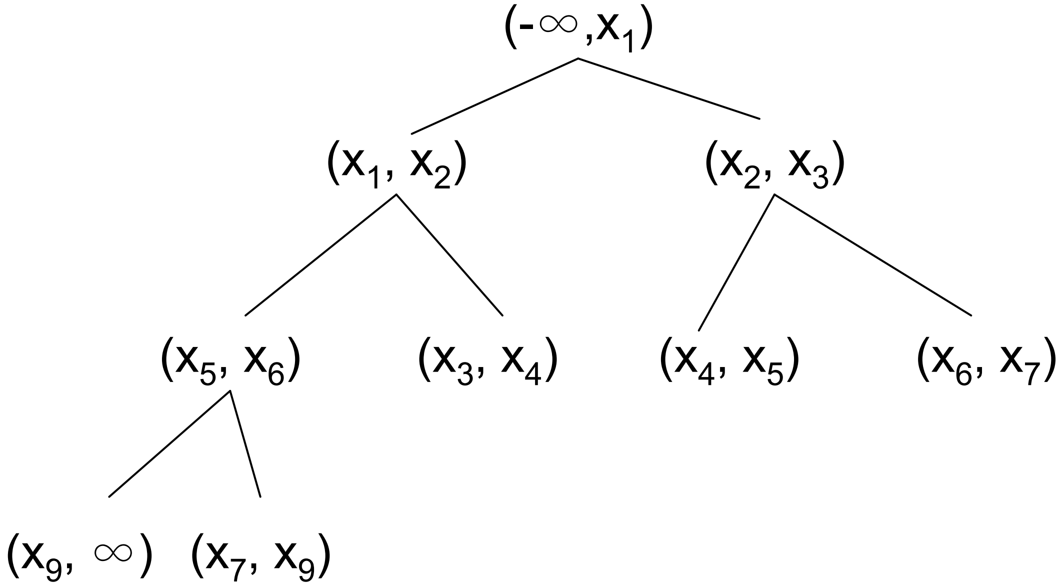
$Proof_N = H(Proof_{left} || Proof_{right} || value)$

$Proof_{Nil} =$ “”

$Acc = Proof_{Root}$

A pair (x_i, x_j)

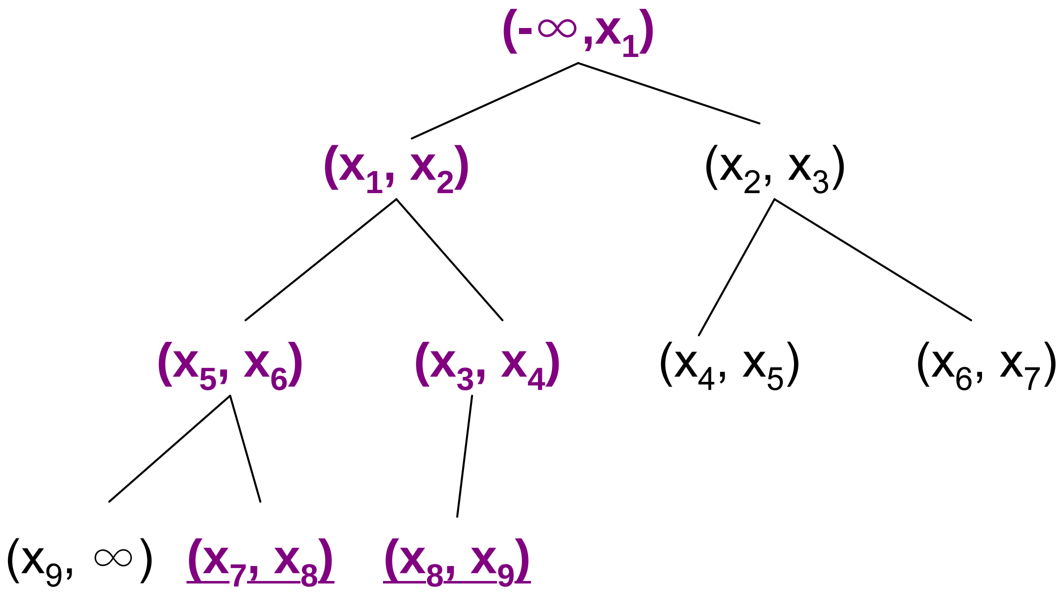
How to update the accumulated value? (Insertion)



Next element to be inserted: x_8

We will need to recompute proof node values.

How to update the accumulated value? (Insertion)



New element: x_8.

Proof_N stored in each node.

Dark nodes do not require recomputing Proof_N.

Only a logarithmic number of values needs recomputation.

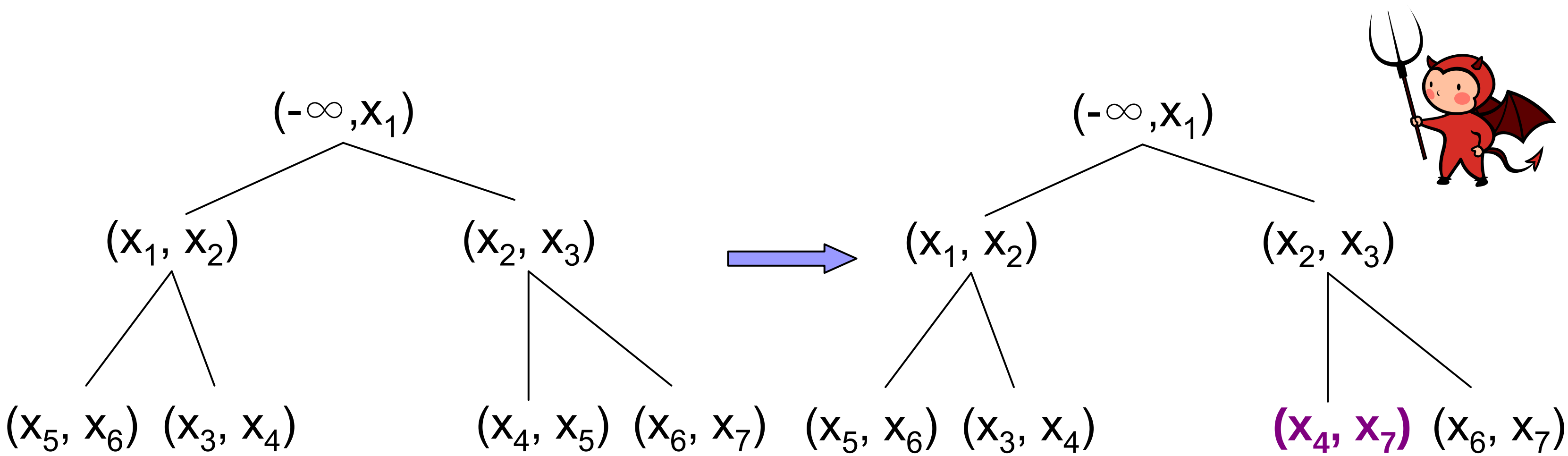
Security

- Consistency
  - Difficult to find witnesses that allow to prove inconsistent statements.
    - X={1,2}
    - Hard to compute a membership witness for 3.
    - Hard to compute a nonmembership witness for 2.
- Update
  - Guarantees that the accumulated value represents the set after insertion/deletion of x.

Security

- **Lemma:** Given a tree T with accumulated value Acc_T, finding a tree T', $T \neq T'$ such that $Acc_T = Acc_{T'}$ is difficult.

- *Proof (Sketch):* $Proof_N = H(Proof_{left}||Proof_{right}||value)$



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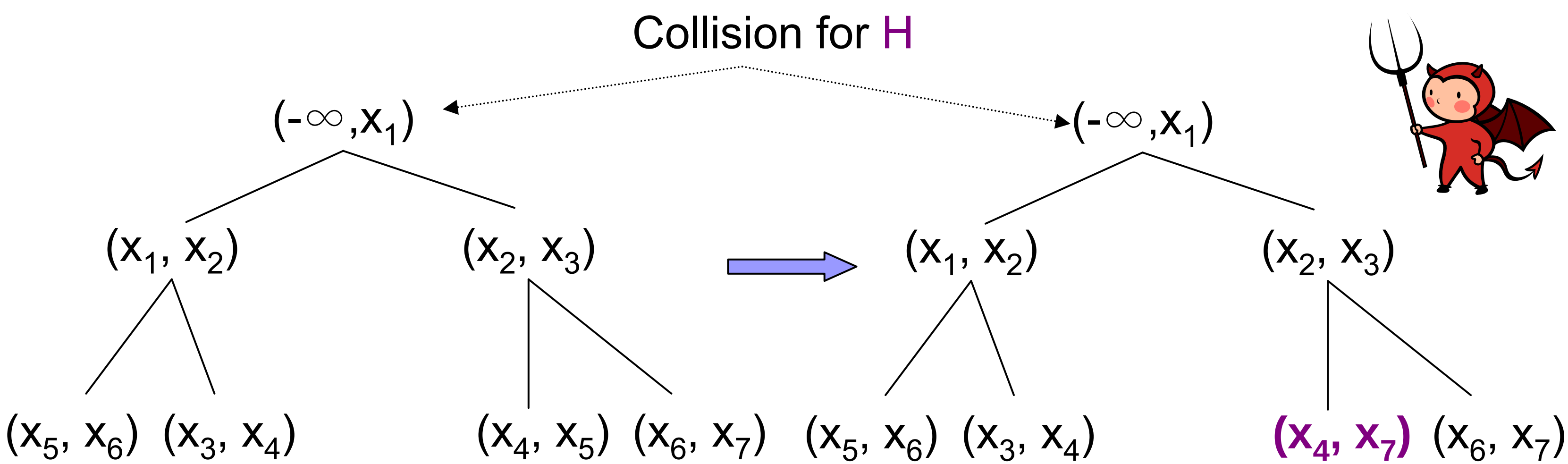

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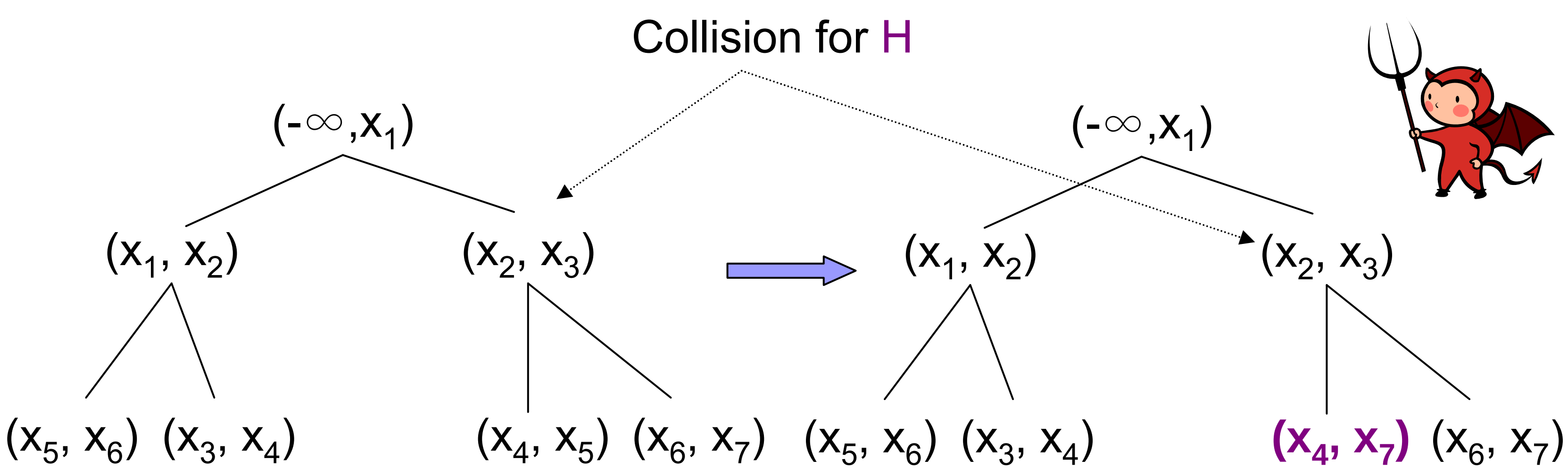

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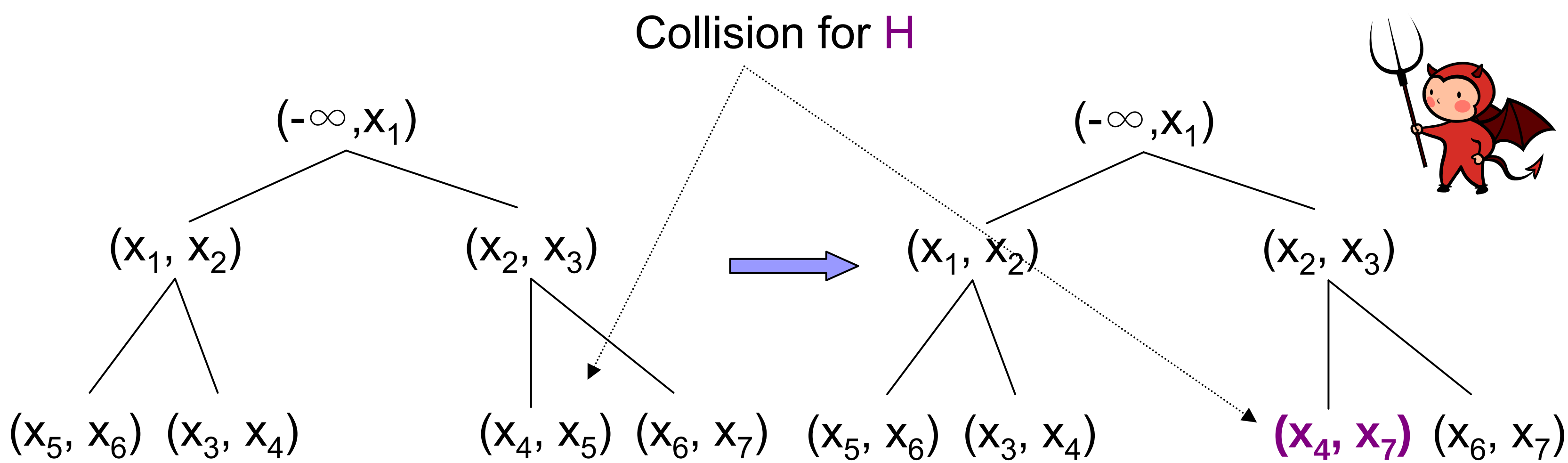
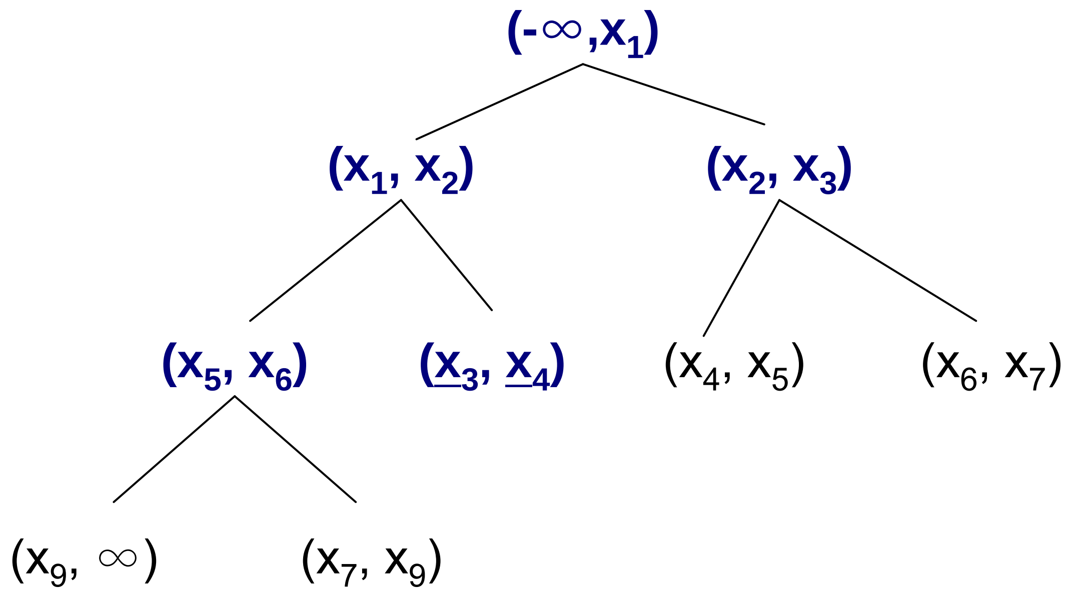


Security (Consistency)



Witness: blue nodes and the (x_3,x_4) pair, size in $O(\ln(n))$

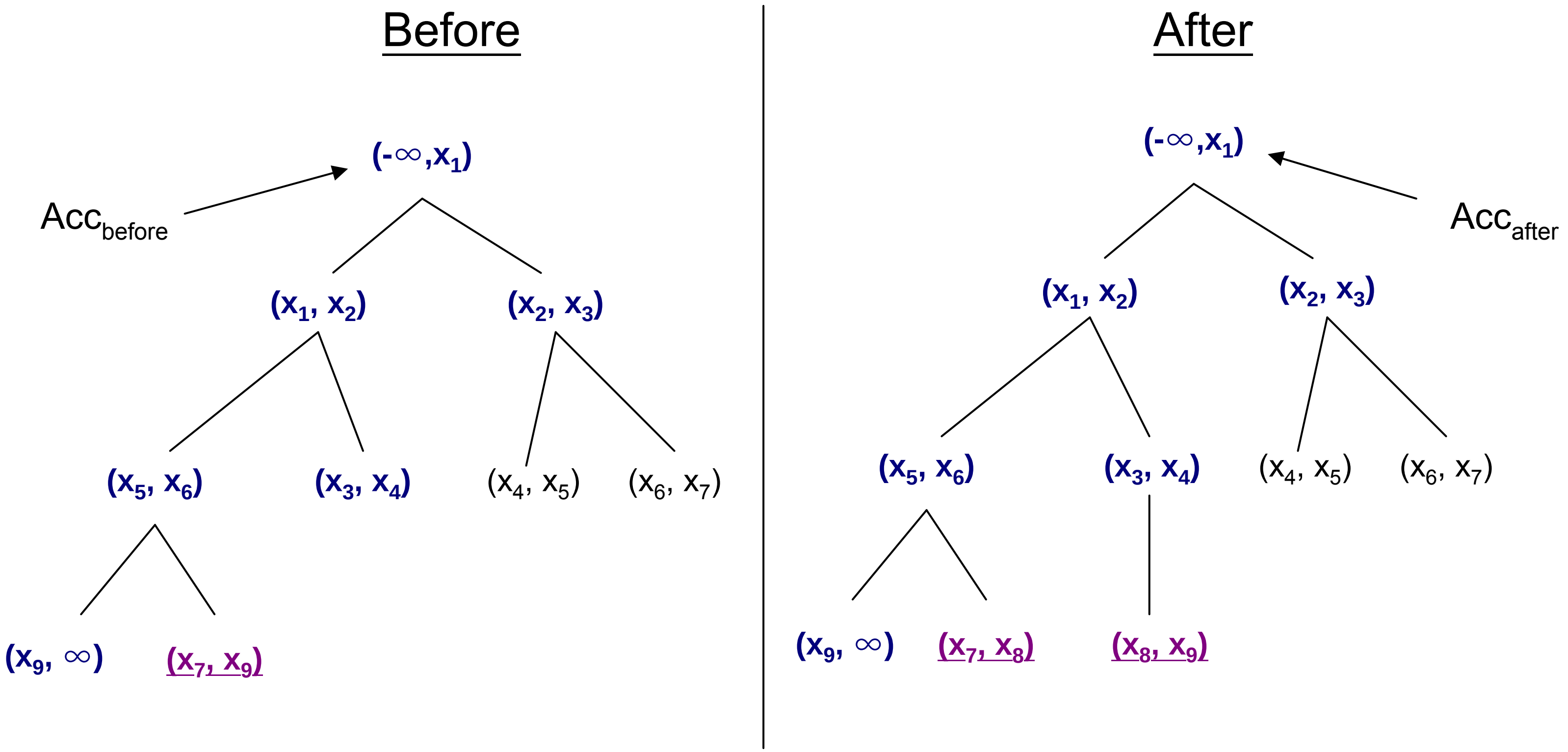
Checking that x belongs (or not) to X:

1) compute recursively the proof P and verify that P=Acc

2) check that: $x=x_3$ or $x=x_4$ (membership)

$x_3 < x < x_4$ (nonmembership)

Security (Update)



Insertion of x_8

Conclusion & Open Problem

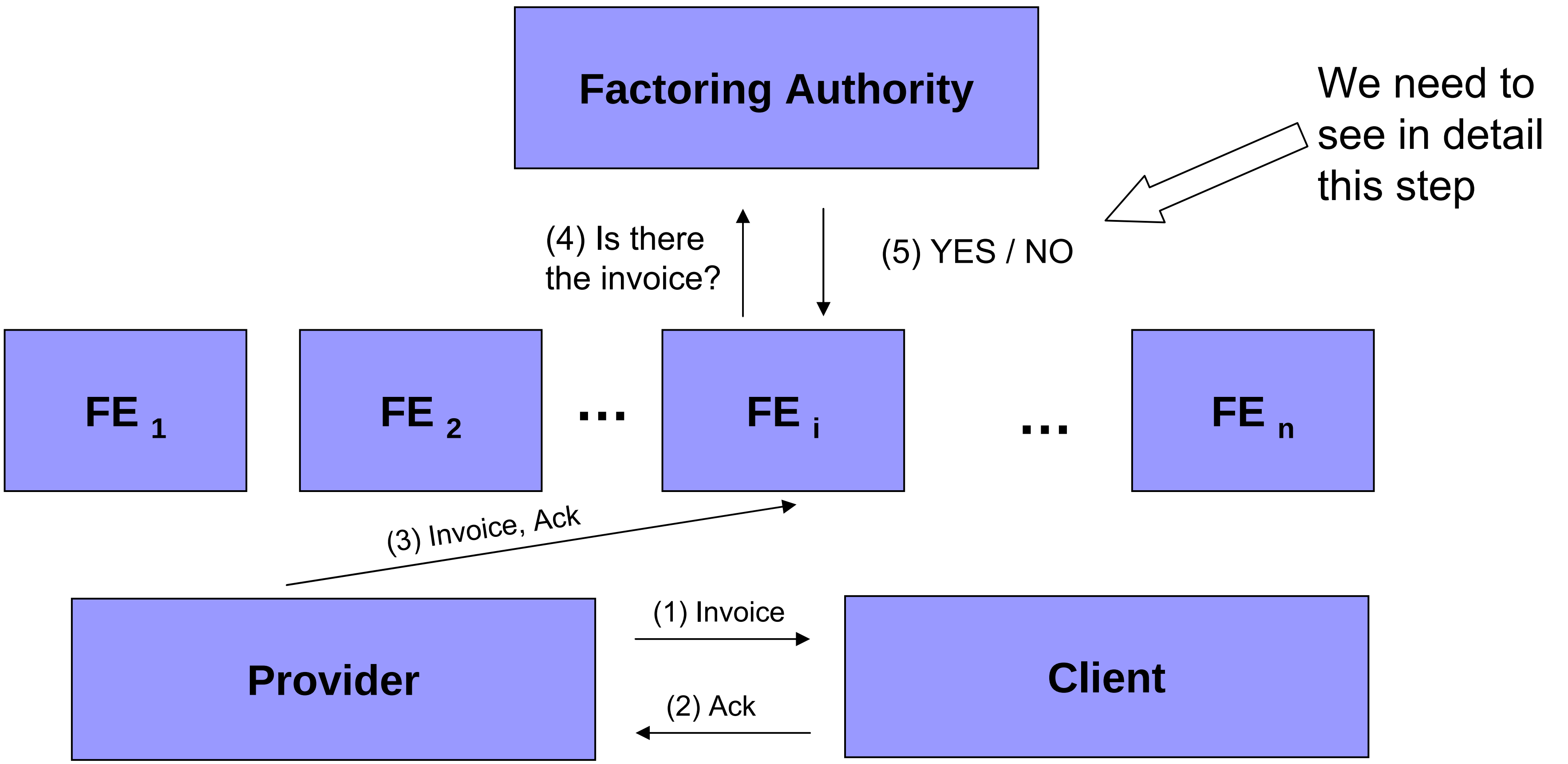
- First *dynamic, universal, strong* accumulator.
- Simple.
- Security
  - Existence of collision-resistant hash functions.
- Solves the e-Invoice Factoring Problem.
- Less efficient than other constructions
  - Size of witness in O(ln(n)).
- Open Problem
  - “Is it possible to build a *strong*,*dynamic* and *universal* accumulator with witness size lower than O(ln(n))?”

Thank you!

Invoice Factoring using accumulator

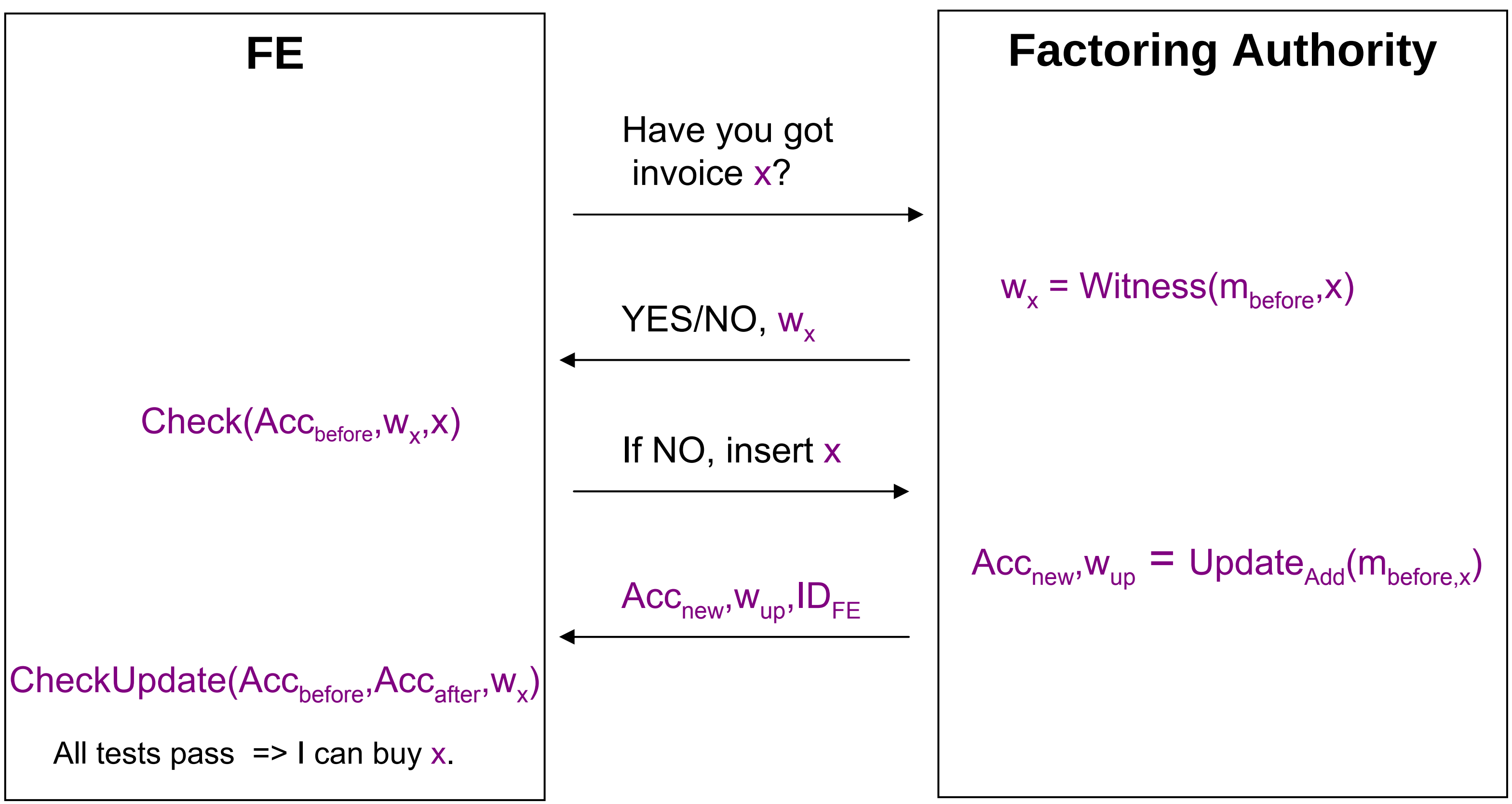
- We need a secure broadcast channel
  - If a message m is published, every participant sees the same m.
- Depending on the security level required
  - Trusted http of ftp server
  - Bulletin Board [CGS97]

Invoice Factoring using accumulator



Invoice Factoring using accumulator

- Step 5 (Details)



Distributed solutions?

- Complex to implement
- Hard to make them robust
- High bandwith communication
- Need to be online – synchronization problems
- **That’s why we focus on a centralized solution.**

Checking for (non-)membership

User

Accumulator Manager

Does x belong to X?

Memory

$w_x = \text{Witness}(m,x)$

w_x

$\text{Belongs}(\text{Acc},w_x) = \text{True} \Leftrightarrow x \in X$

If w_x is not valid Belongs returns $\perp$.

Update of the accumulated value

User

$CheckUpdate(Acc_{before}, Acc_{after}, w_{up})$

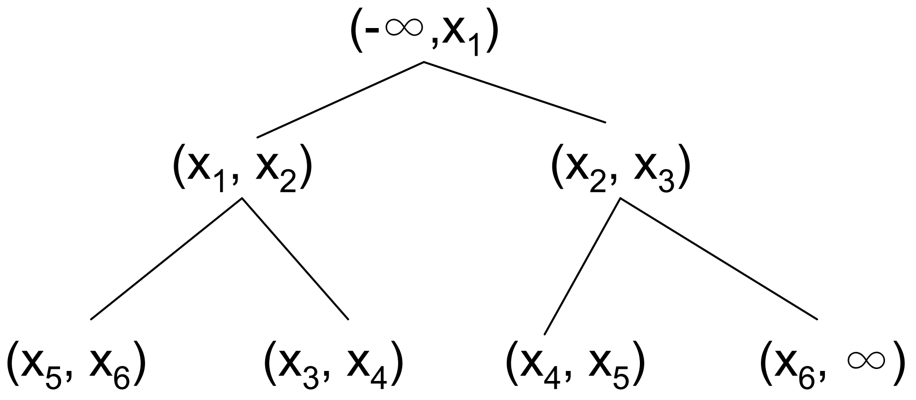
Insert or Delete x →

← Acc_{after}, w_{up}

Accumulator Manager

$m_{after}, Acc_{after}, w_{up} = Update_{Add/Del}(m_{before}, x)$

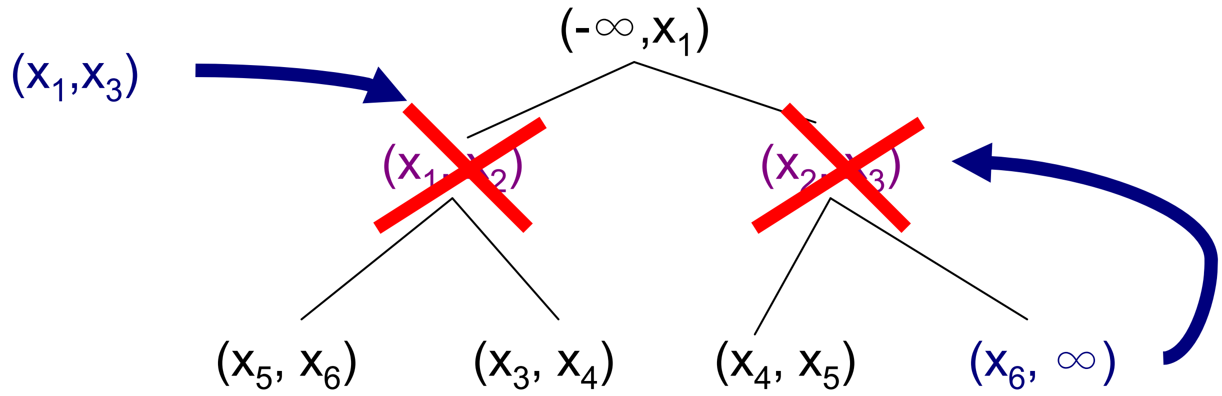
How to delete elements?



$X=\{x_1,x_2,x_3,x_4,x_5,x_6\}$

element to be deleted: x_2

How to delete elements?



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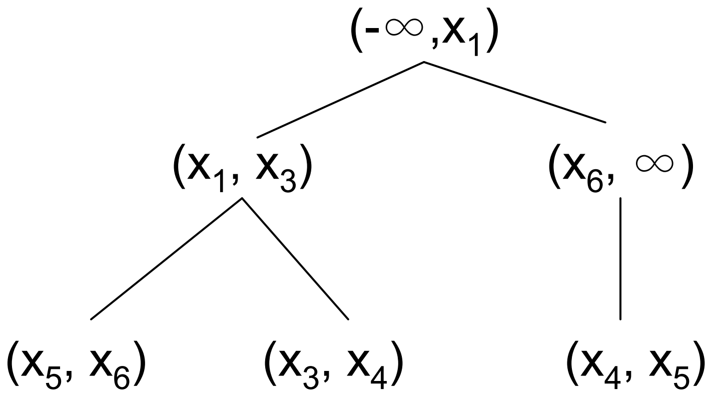

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