Strong Accumulators from Collision-Resistant Hashing

ISC 2008
Taipei - Taiwan

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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 $X=\{x_1,x_2,\ldots,x_n\}$:
  - X will be represented by a short value Acc.
  - $\mathrm{Belongs}(Acc,x,\underset{\text{Witness}}{w}) = \mathrm{True} \Leftrightarrow x$ belongs to X.

Notion of accumulator

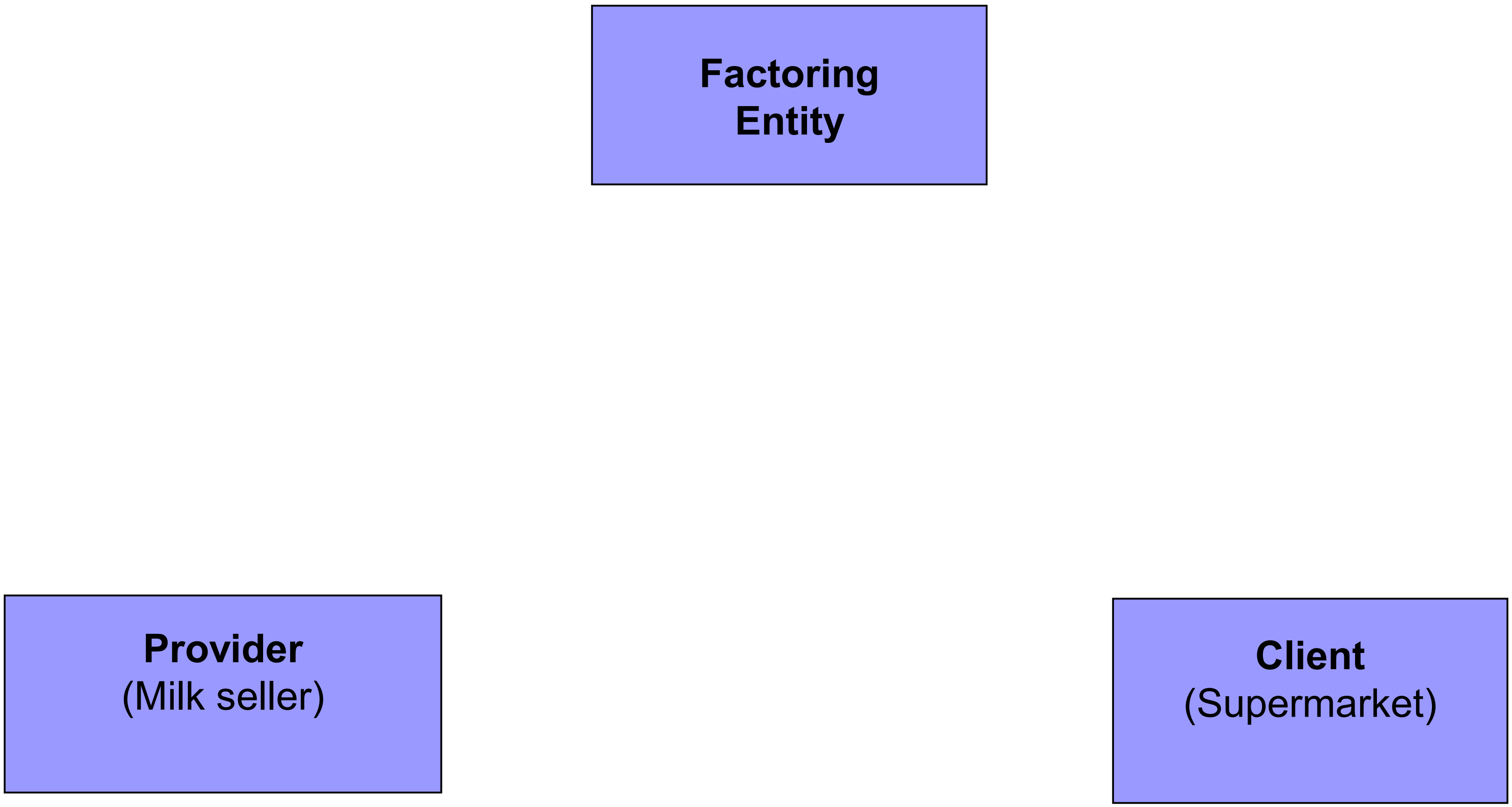
- Accumulator Manager
  - Computes setup values.
  - Computes the accumulated value Acc.
  - Computes the witness w_x for a given x.
- Accumulator Users
  - Check that an element belongs or not to the set, using Acc, w_x and x.

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



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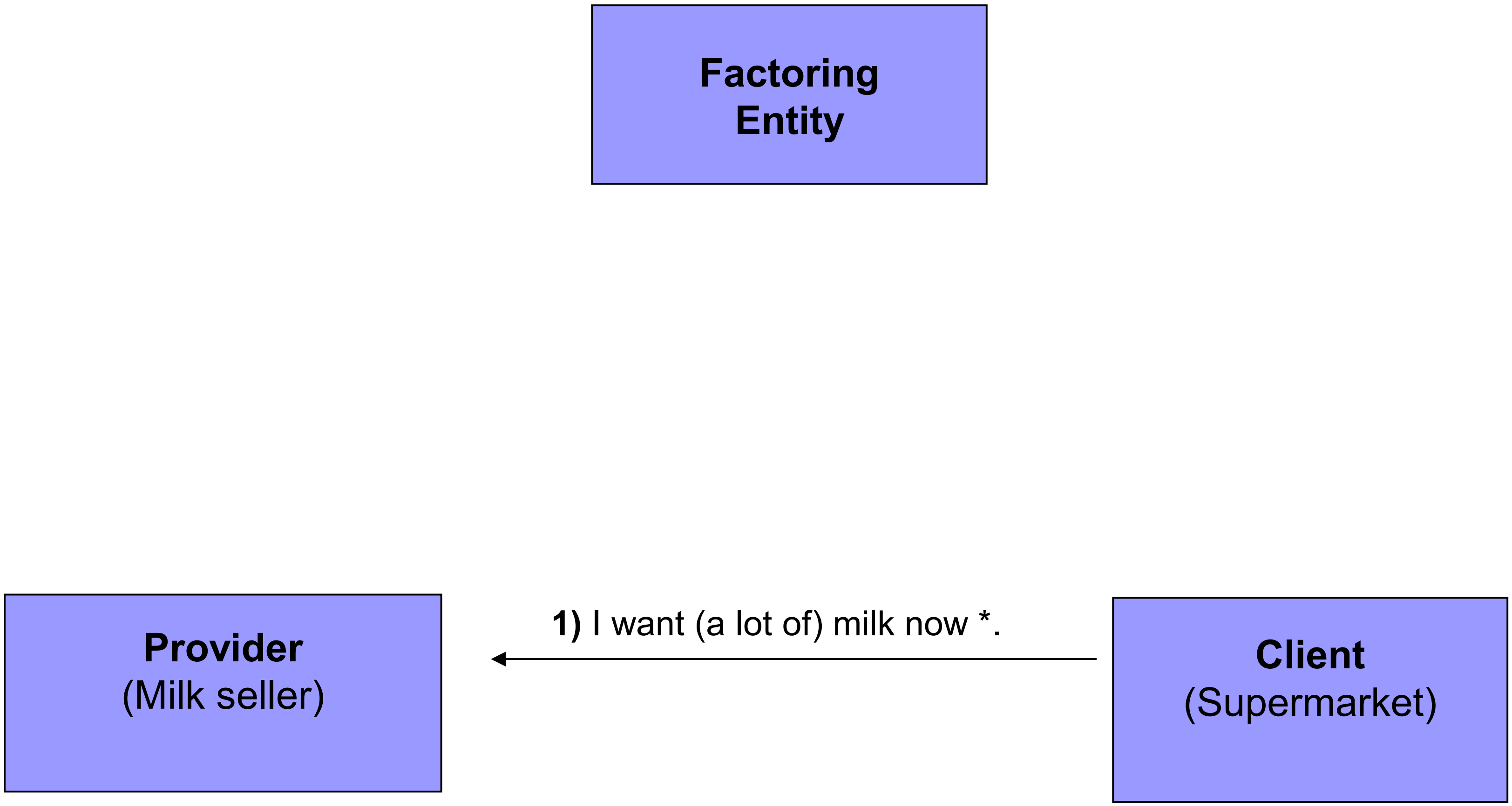

(*) but I do not want to pay yet.

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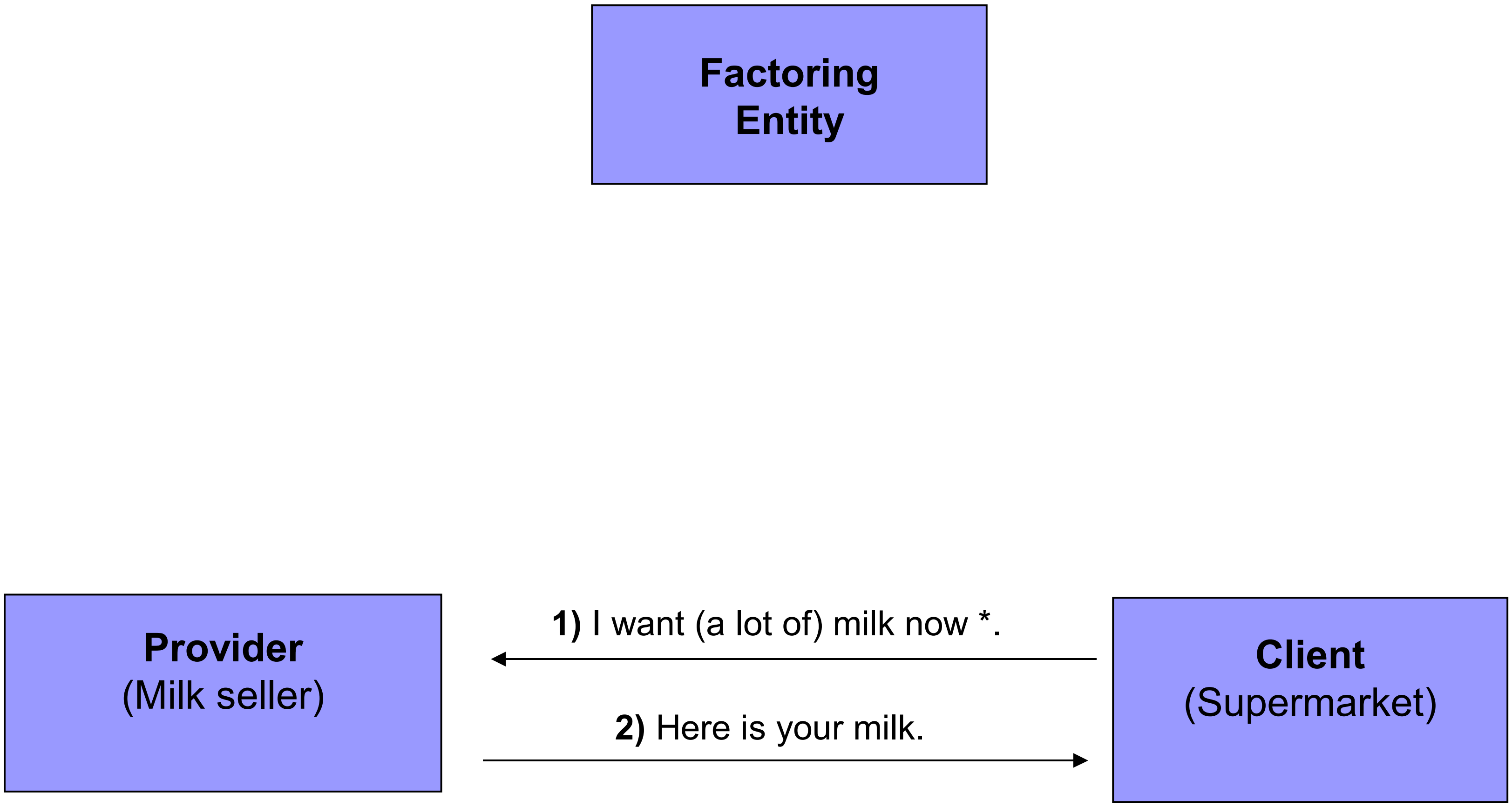

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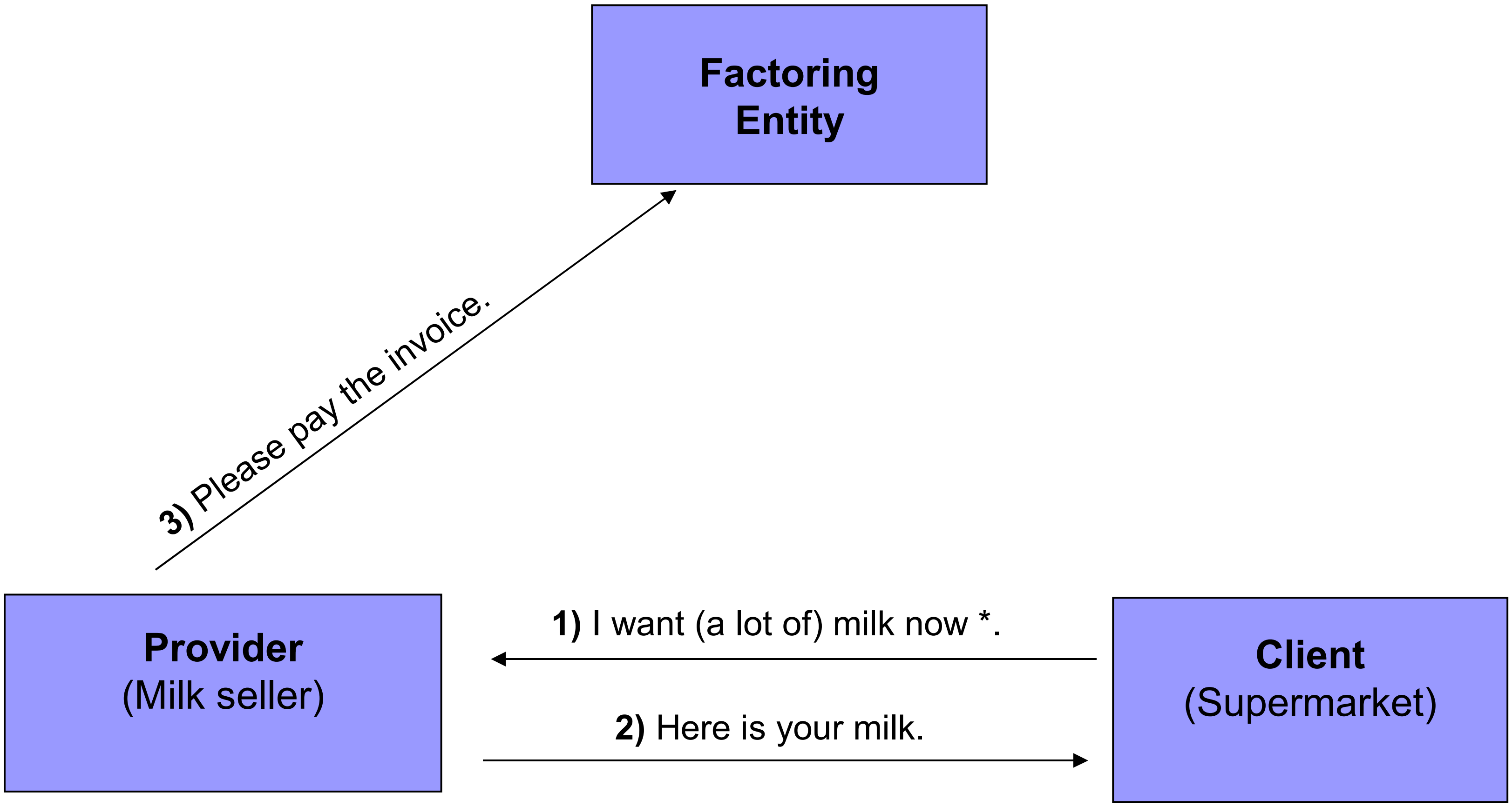

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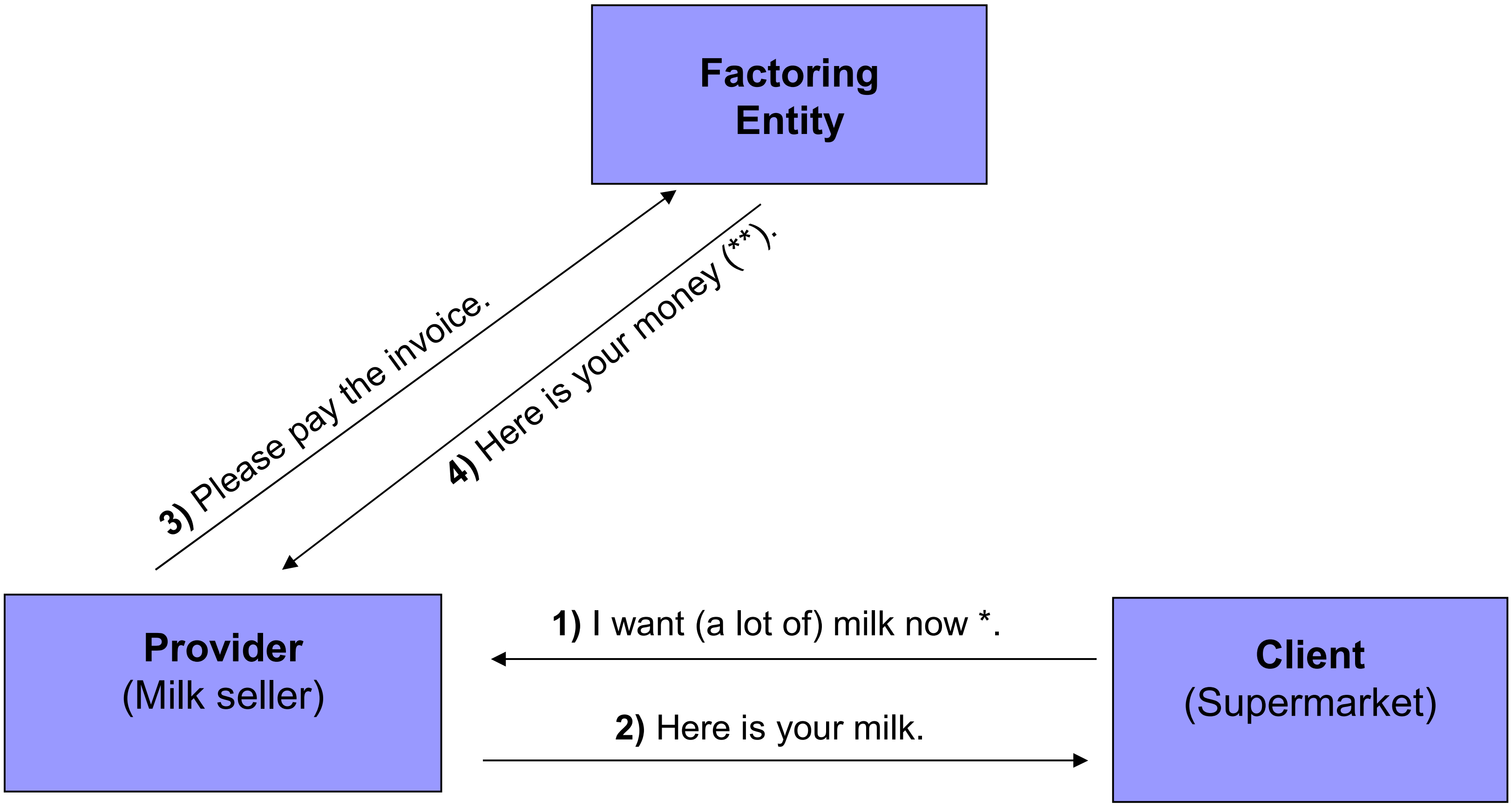

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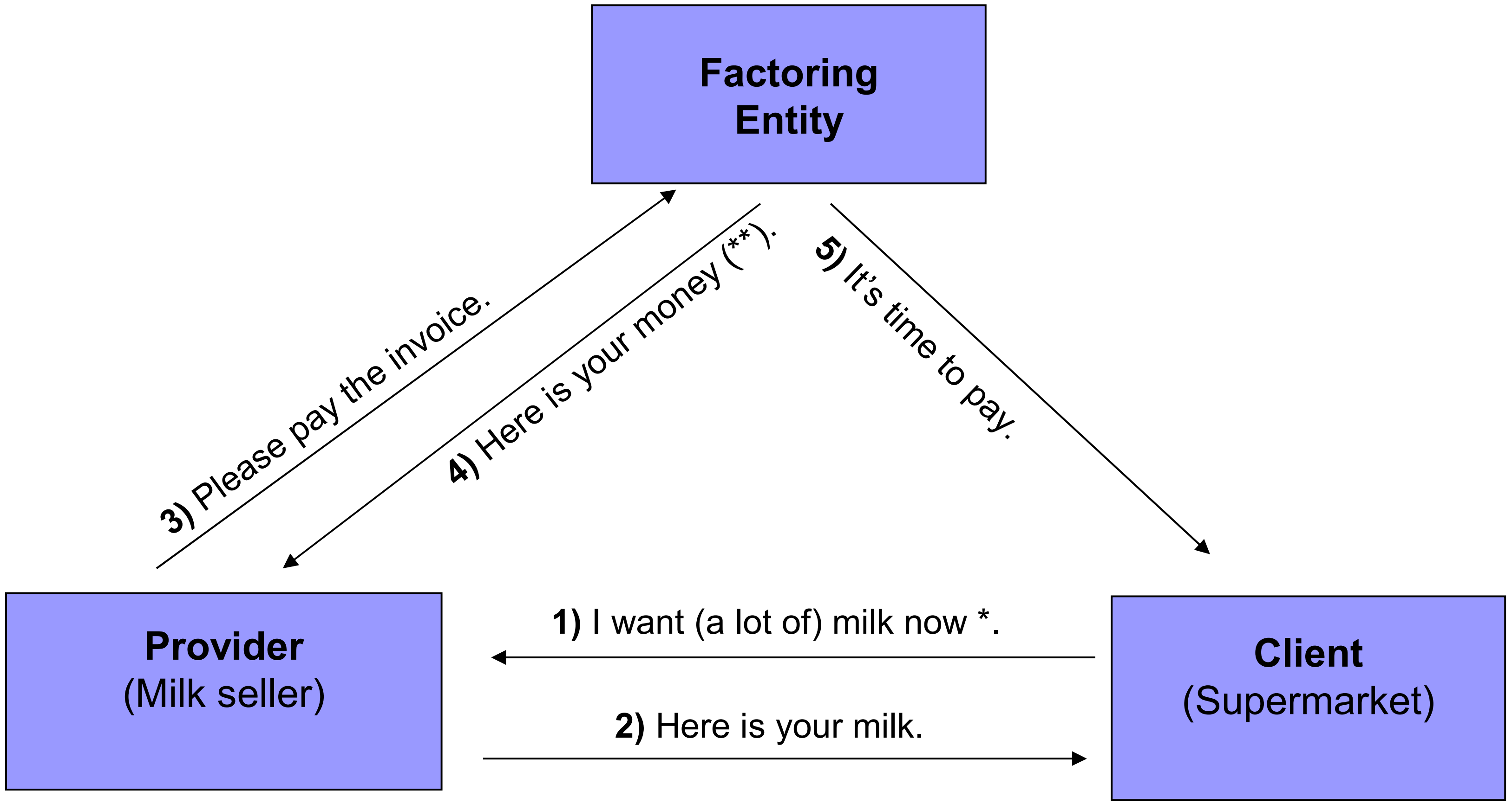

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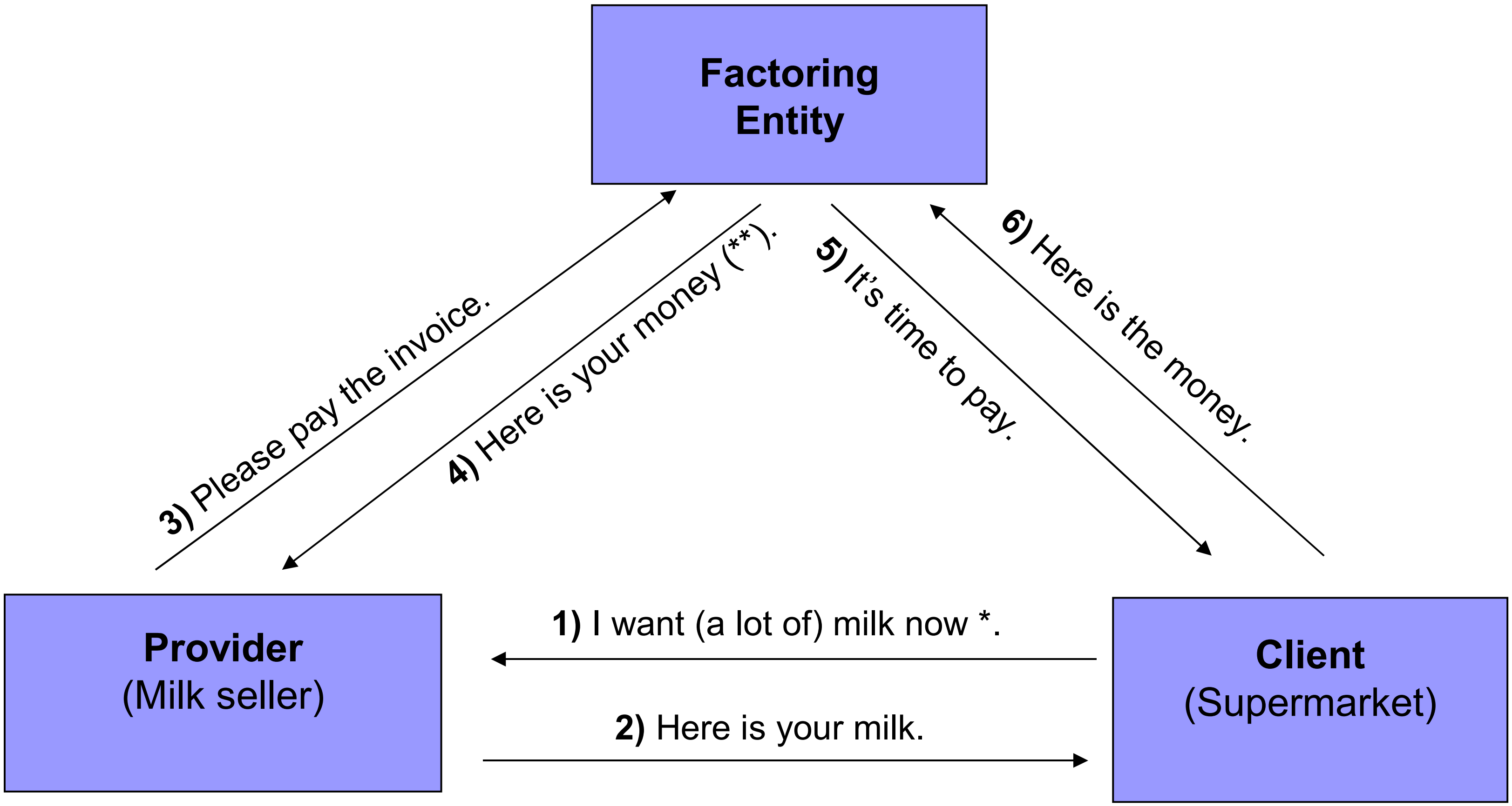

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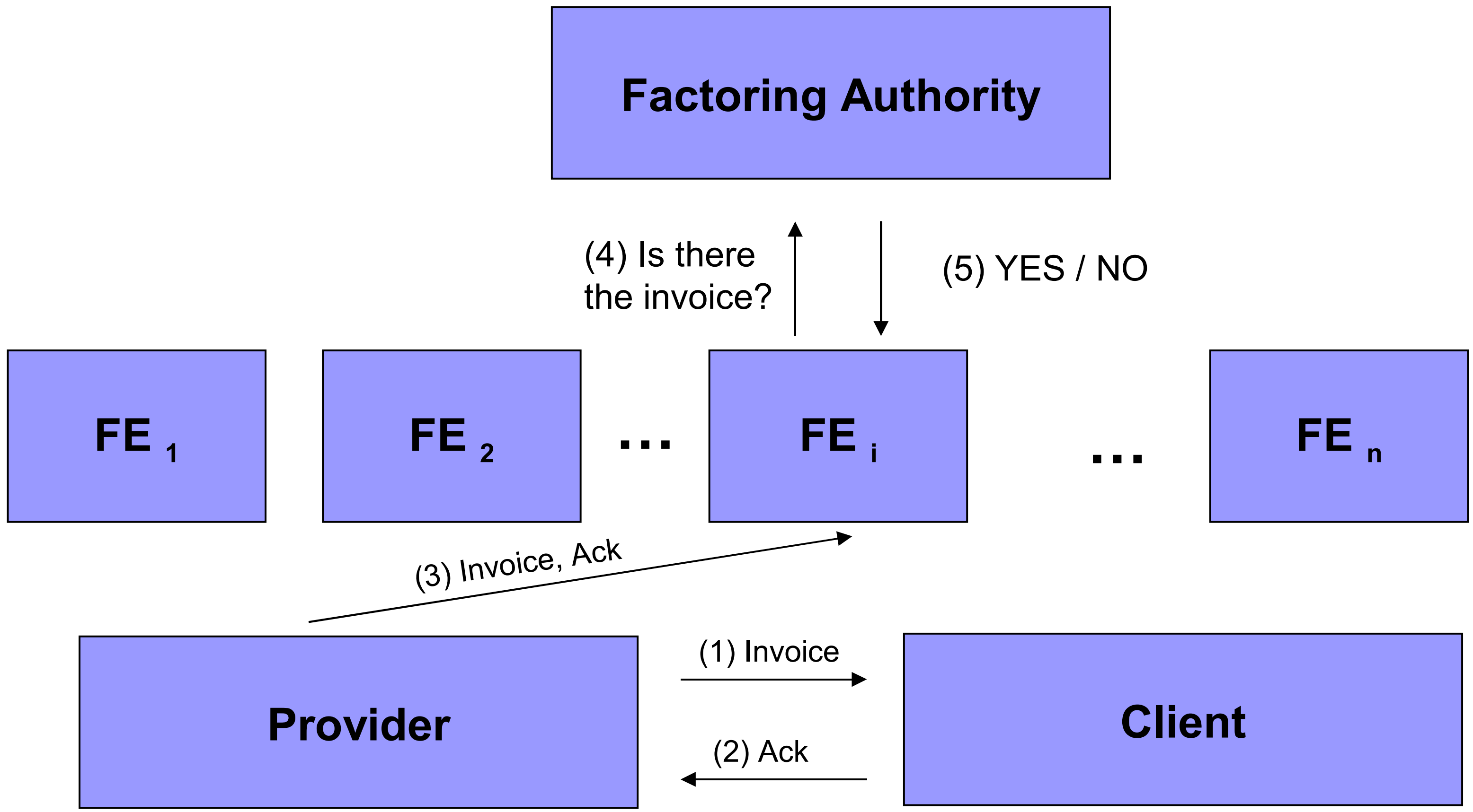
The Problem

- 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

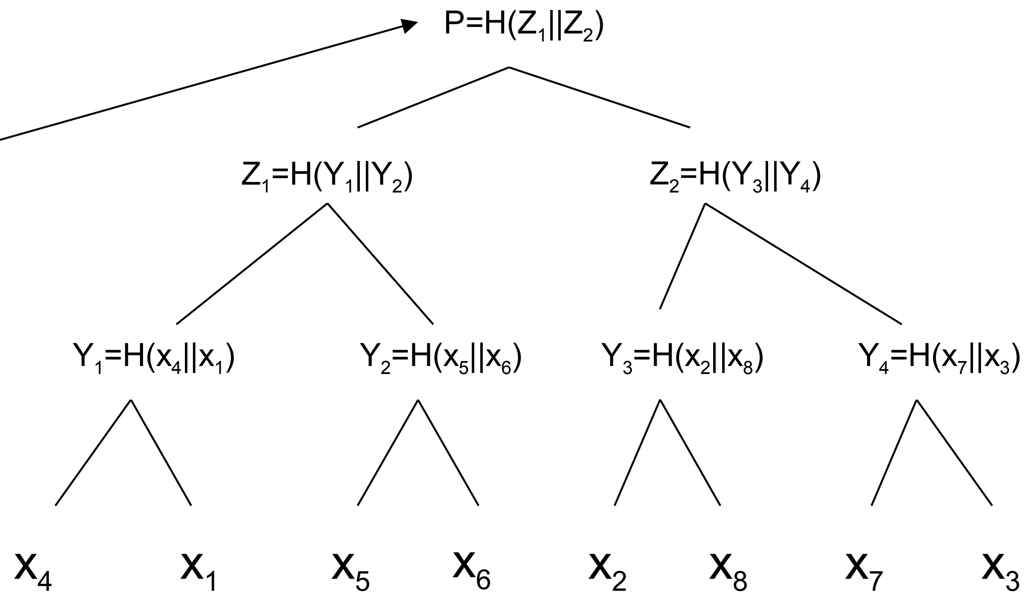
- $H: \{0,1\}^* \rightarrow \{0,1\}^k$
  - randomly chosen function from a family of collision-resistant hash functions.
- $x_1, x_2, x_3, \ldots \epsilon \{0,1\}^k$
  - $x_1 < x_2 < x_3 < \ldots$ where $<$ is the lexicographic order on binary strings.
- $-\infty, \infty$
  - Special values such that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

Ideas

- Merkle-trees

Root value:

Represents the set $\{x_1, \ldots, x_8\}$



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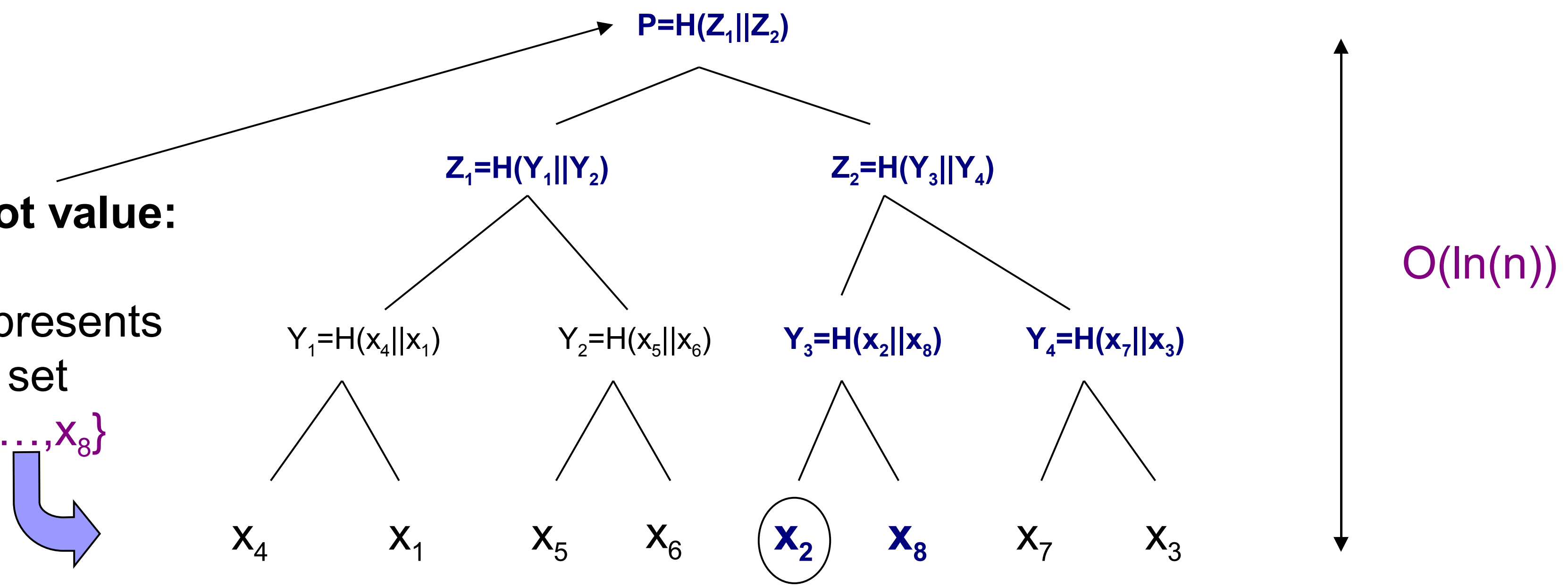


Ideas

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

$(-\infty,\infty)$

$X=\varnothing$, next: x_1

How to insert elements?

$(-\infty, x_1)$

(x_1, ∞)

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

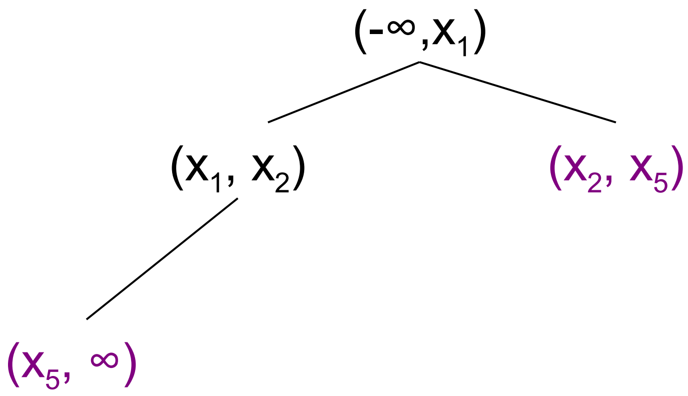
How to insert elements?

$(-\infty, x_1)$

(x_1, x_2) (x_2, ∞)

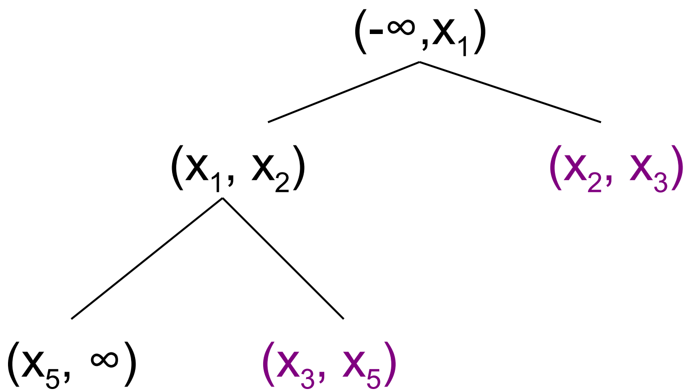
$X=\{x_1, x_2\}$, next: x_5

How to insert elements?



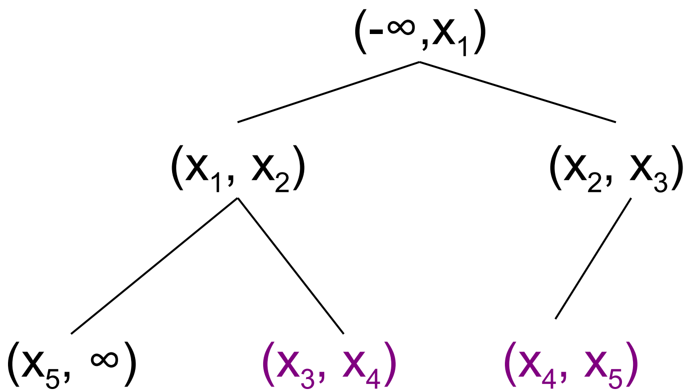
$X=\{x_1, x_2, x_5\}$, next: x_3

How to insert elements?



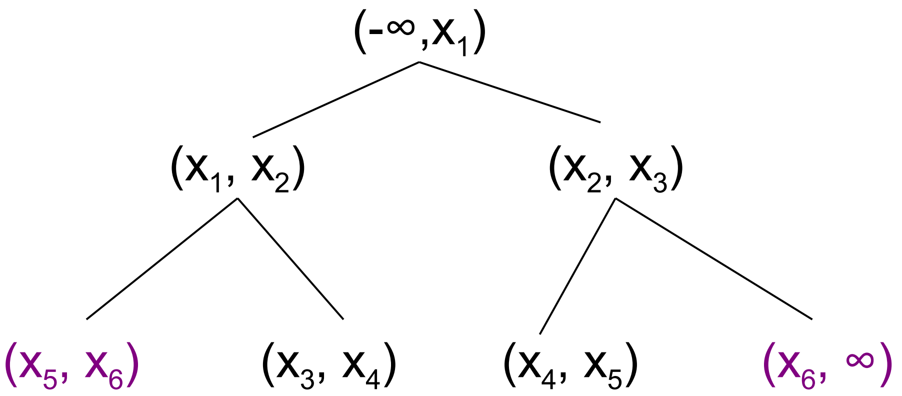
$X=\{x_1, x_2, x_3, x_5\}$, next: x_4

How to insert elements?



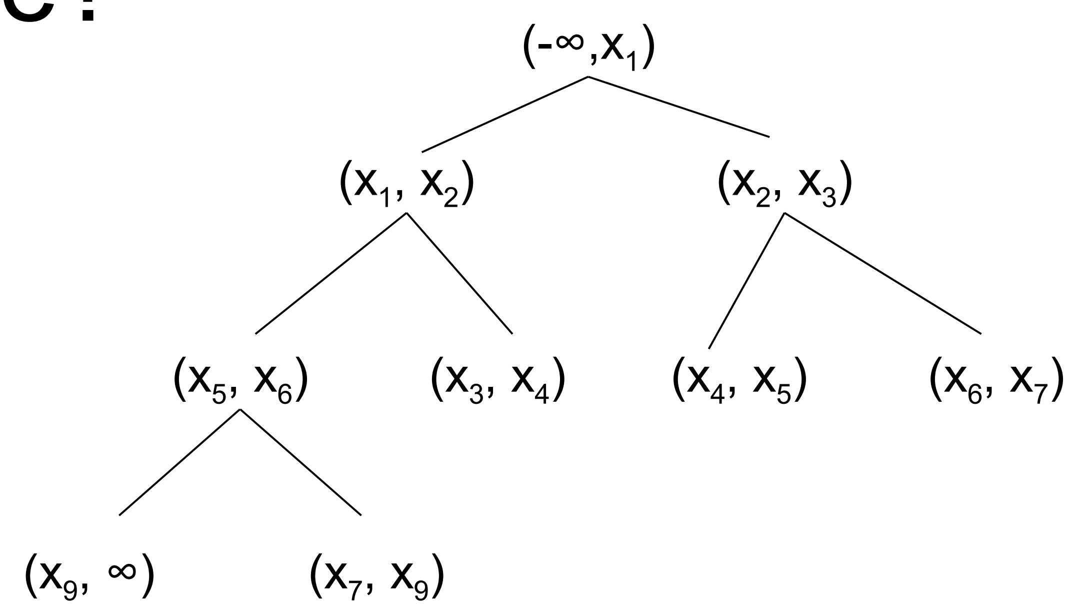
$X=\{x_1,x_2,x_3,x_4,x_5\}$, next: x_6

How to insert elements?



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

How to compute the accumulated value?



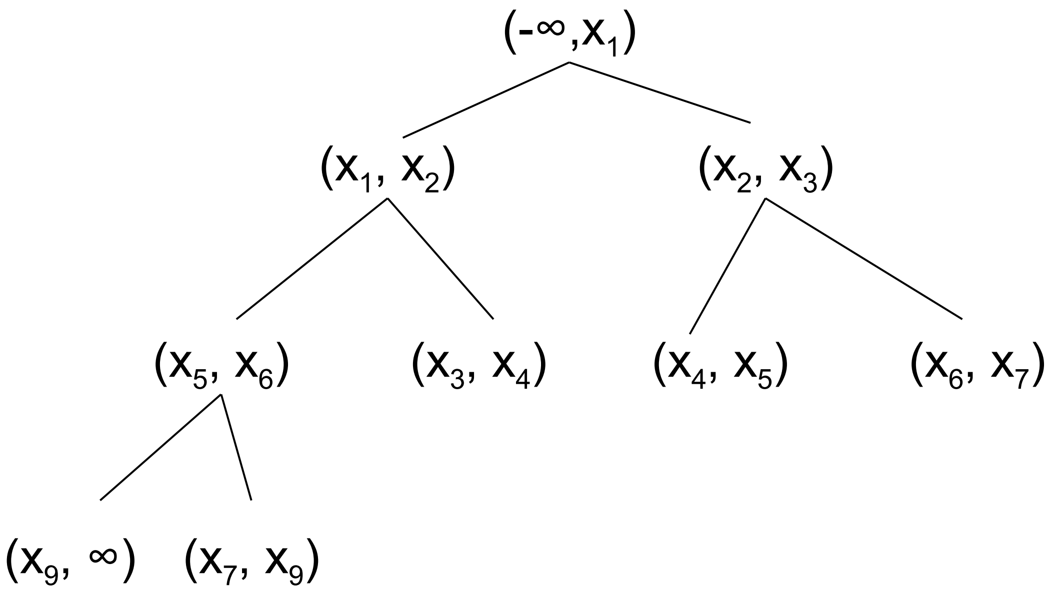
$Proof_N = H(Proof_{left} || Proof_{right} || value)$

$Proof_{Nil} =$ “”

$Acc = Proof_{Root}$

A pair (x_i, x_j)

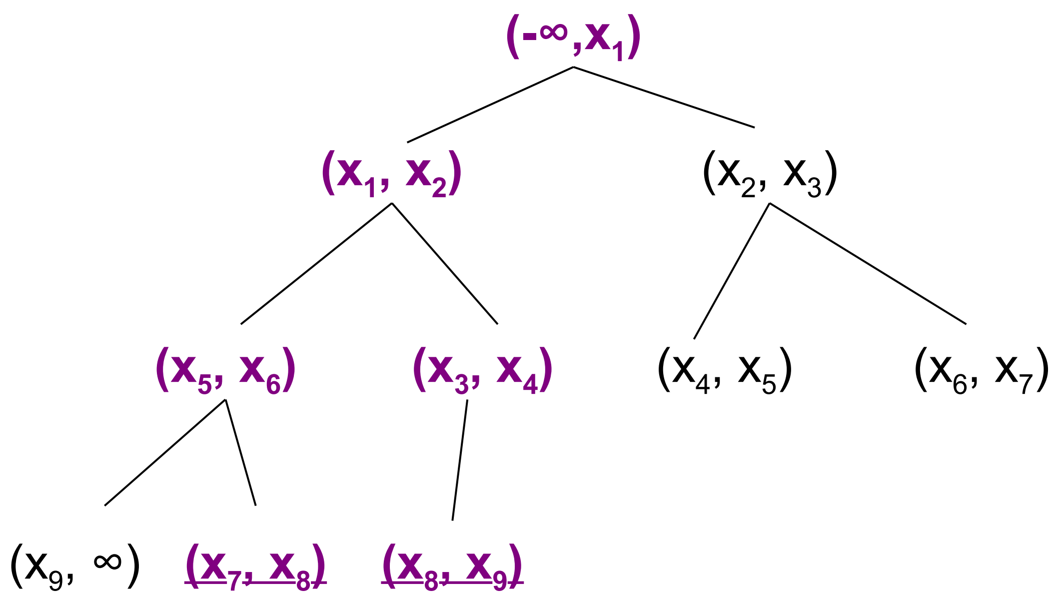
How to update the accumulated value? (Insertion)



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.

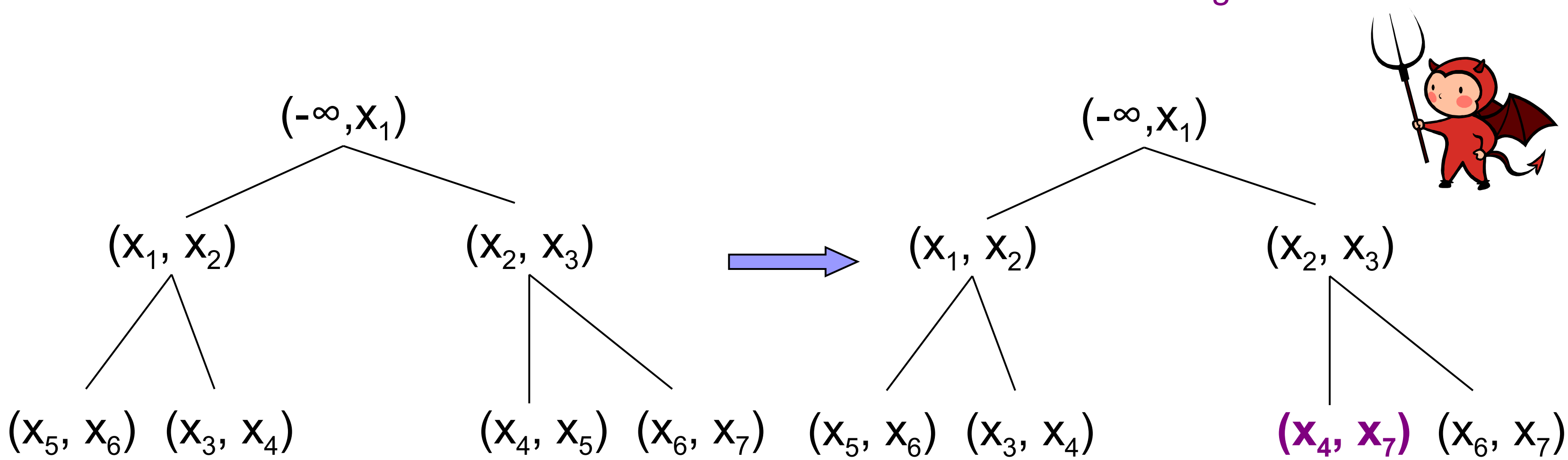
Security

- 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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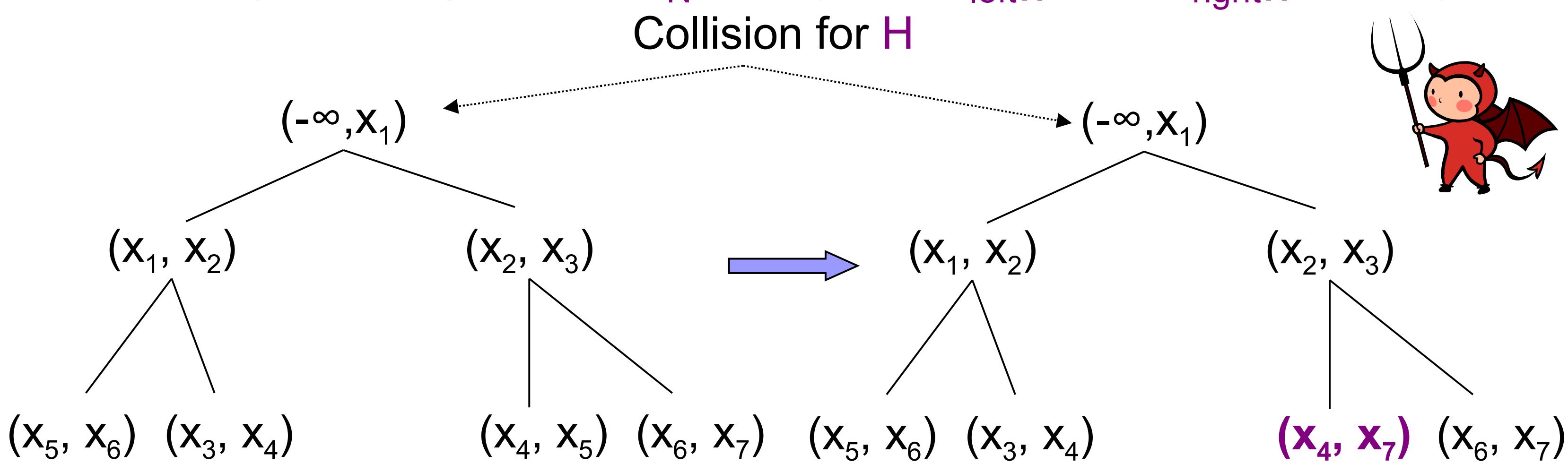

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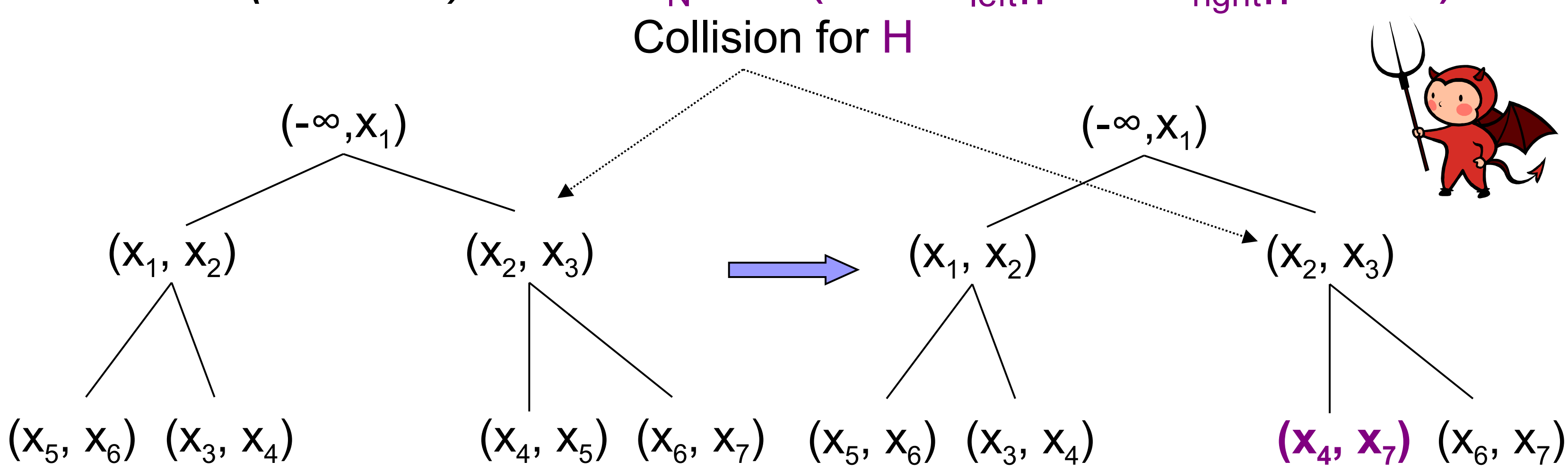

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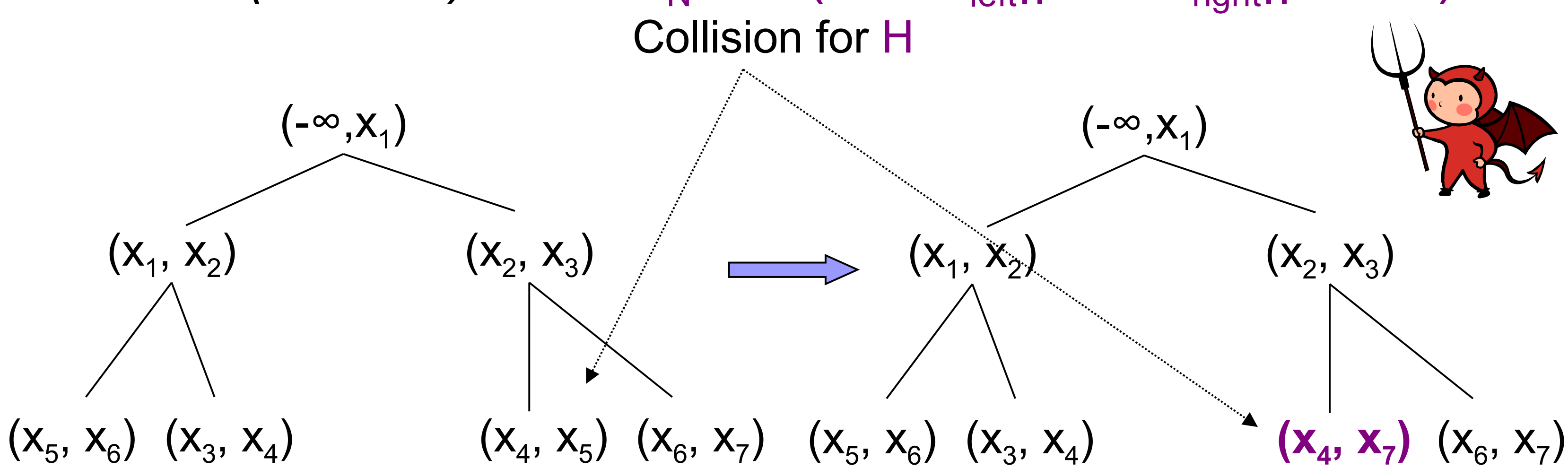
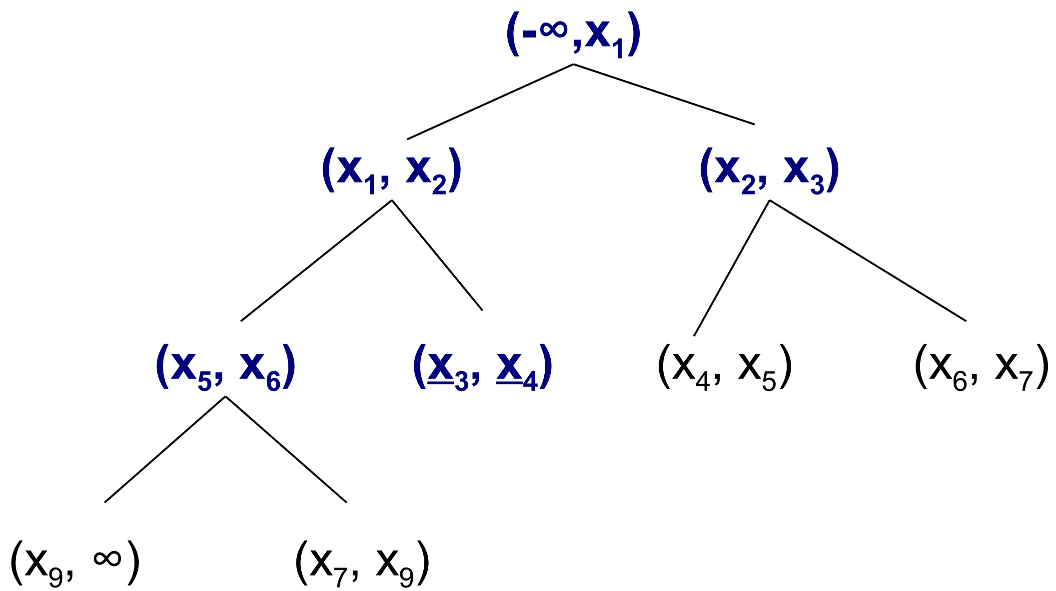


Security (Consistency)



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

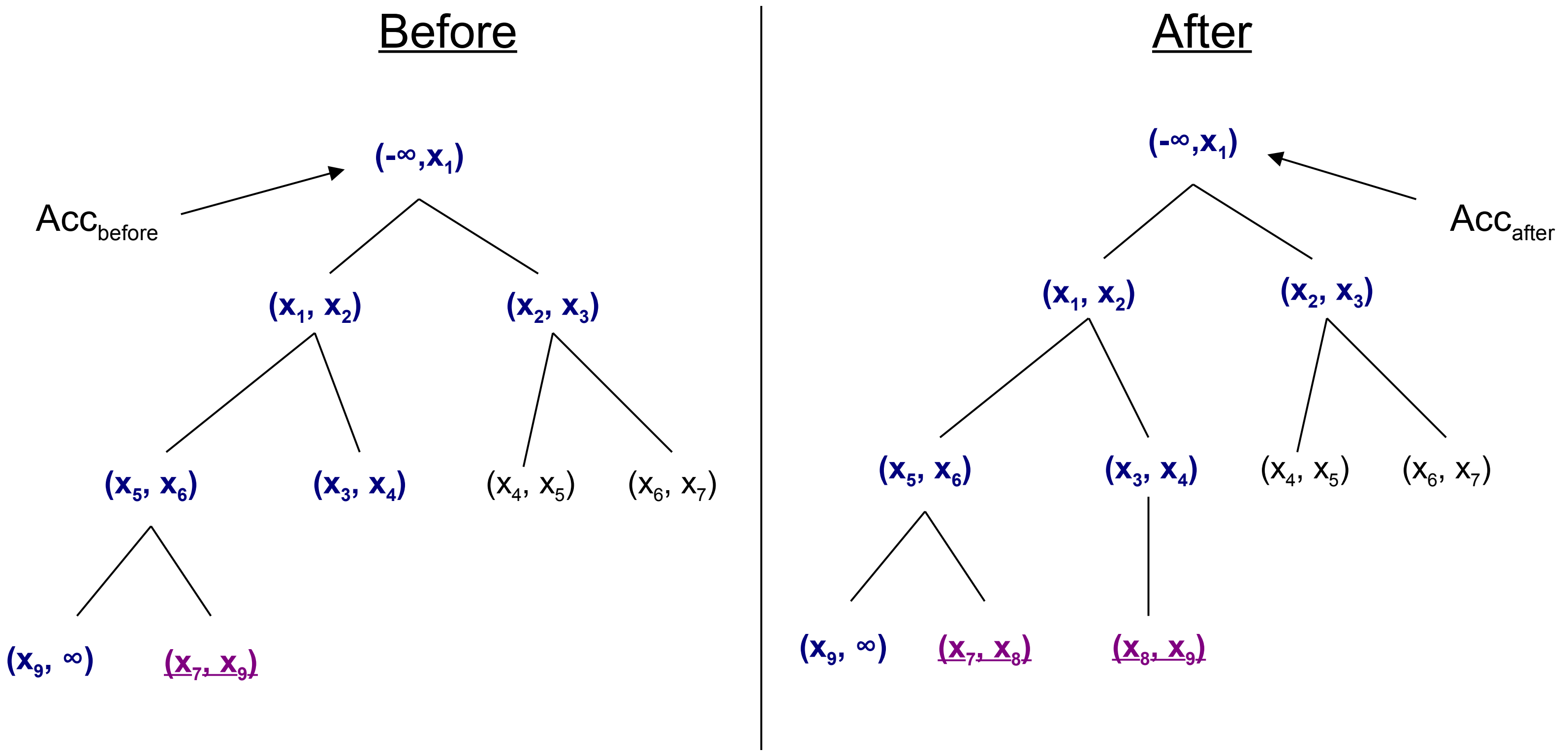
Checking that x belongs (or not) to X:

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

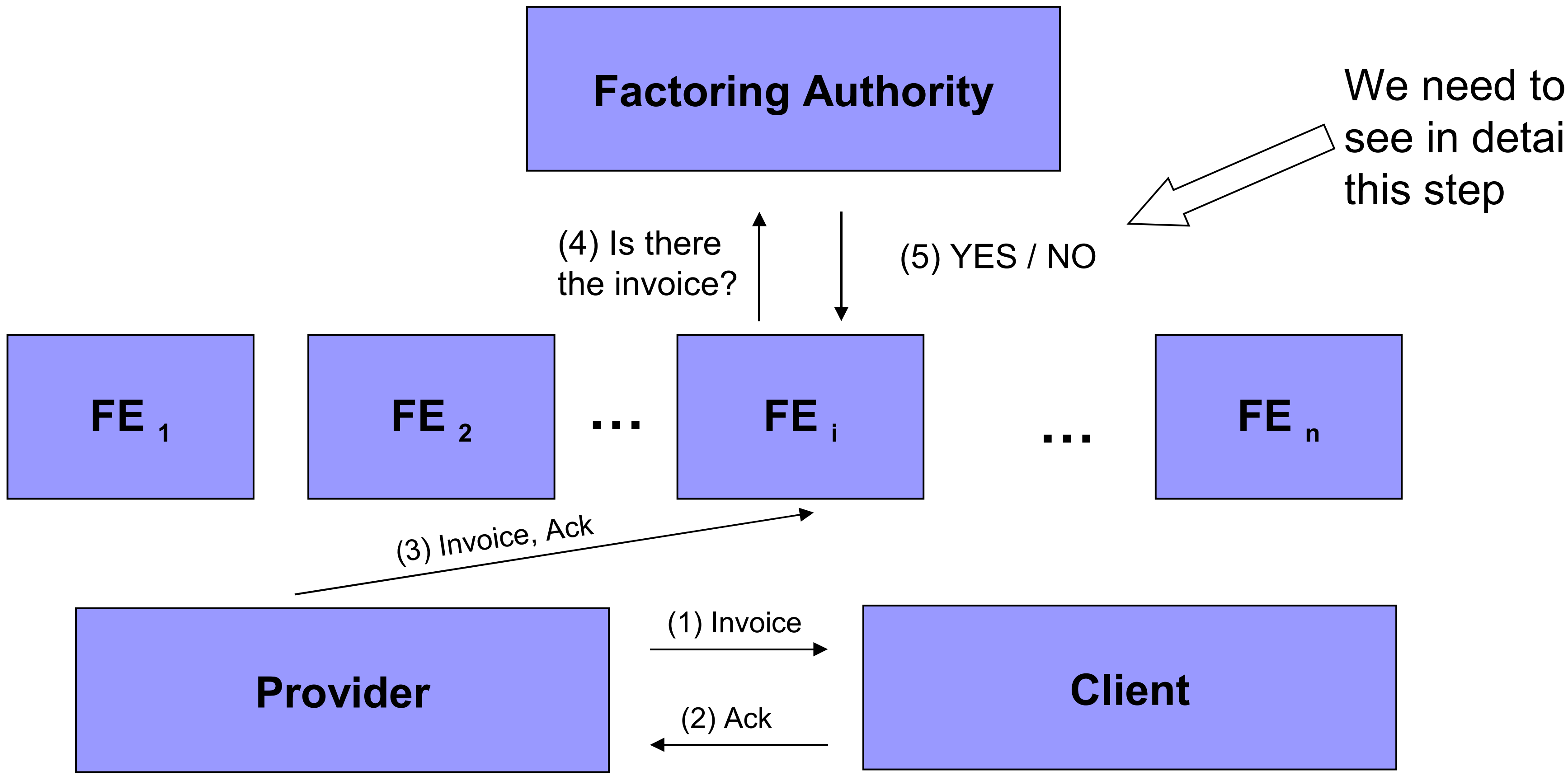
- First *dynamic, universal, strong* accumulator.
- Simple.
- Security
  - Existence of collision-resistant hash functions.
- Solves the e-Invoice Factoring Problem.
- Less efficient than other constructions
  - Size of witness in $O(\ln(n))$.
- Open Problem
  - "Is it possible to build a *strong*,*dynamic*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

Thank you!

Invoice Factoring using accumulator

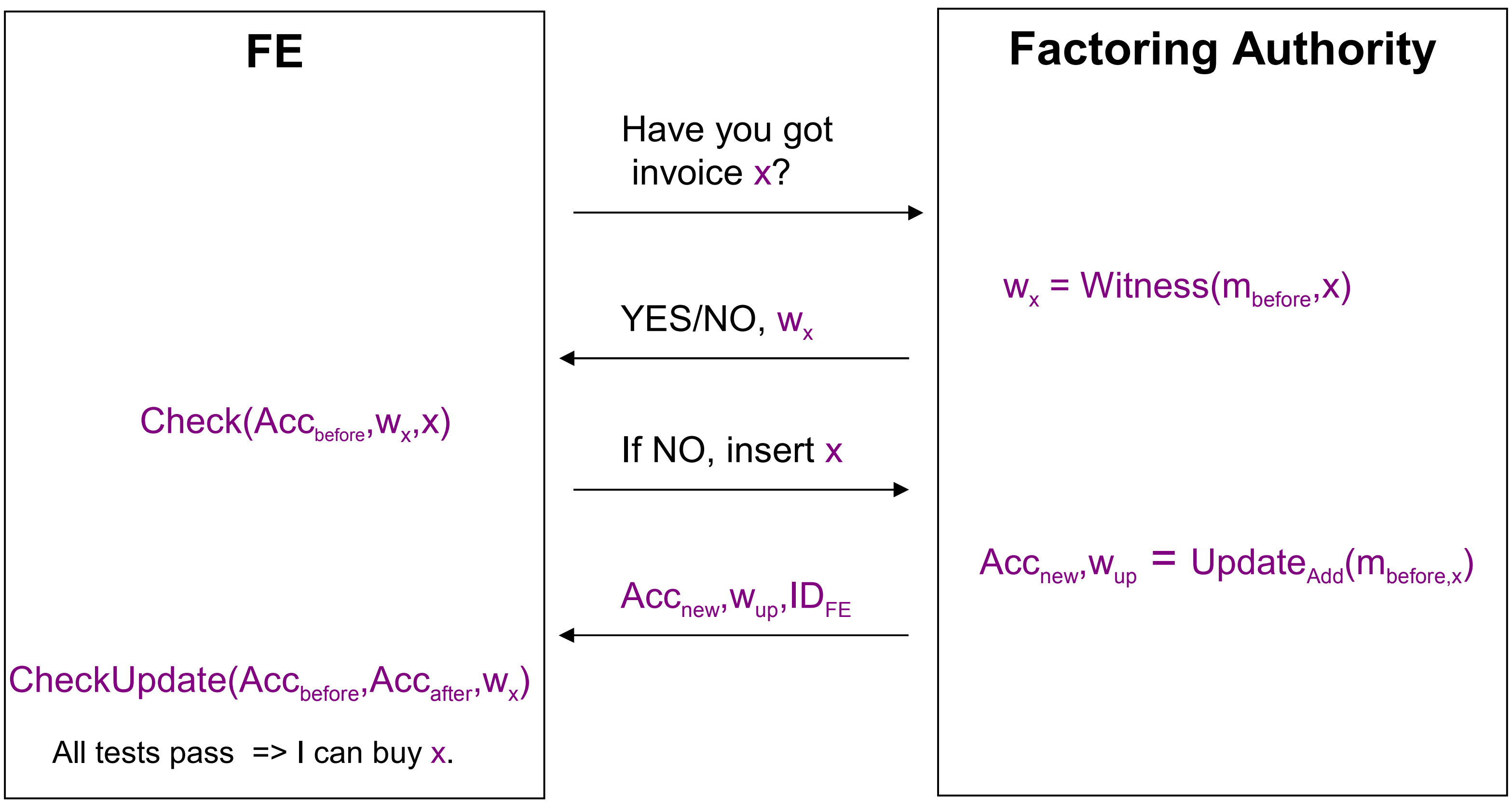
- We need a secure broadcast channel
  - If a message m is published, every participant sees the same m.
- Depending on the security level required
  - Trusted http of ftp server
  - Bulletin Board [CGS97]

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 = Witness(m,x)

w_x

Belongs(Acc,w_x) = True ⇔ x є X

If w_x is not valid Belongs returns ⊥.

Update of the accumulated value

User

Accumulator Manager

Insert or Delete x

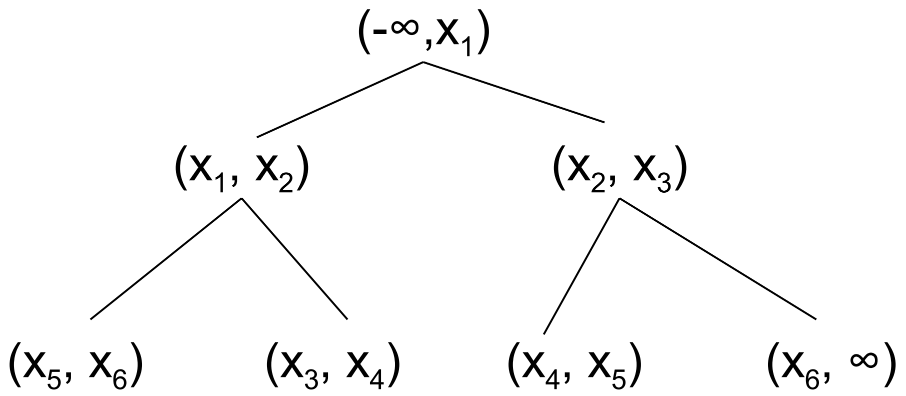
m_{after}, $Acc_{after,} w_{up}$

$= \mathrm{Update}_{Add/Del}(m_{before}, x)$

Acc_{after}, w_{up}

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

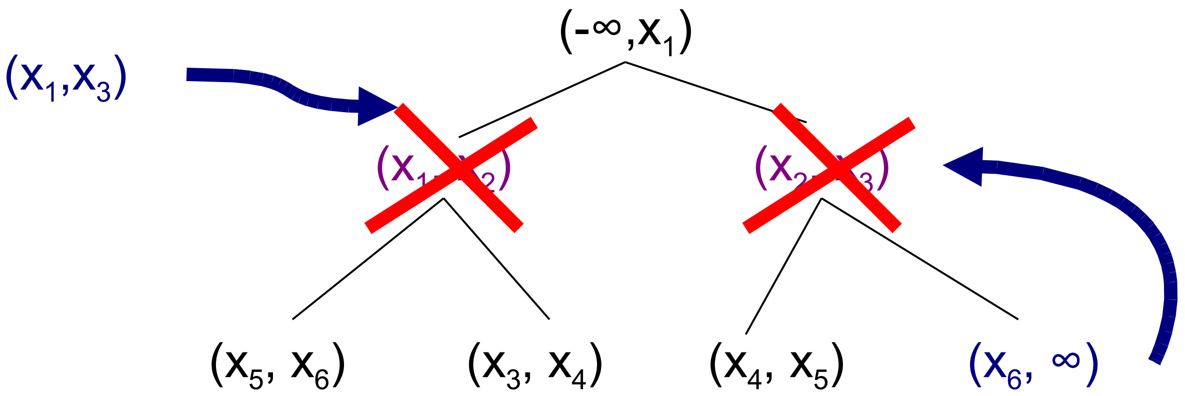
How to delete elements?



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

element to be deleted: x_2

How to delete elements?



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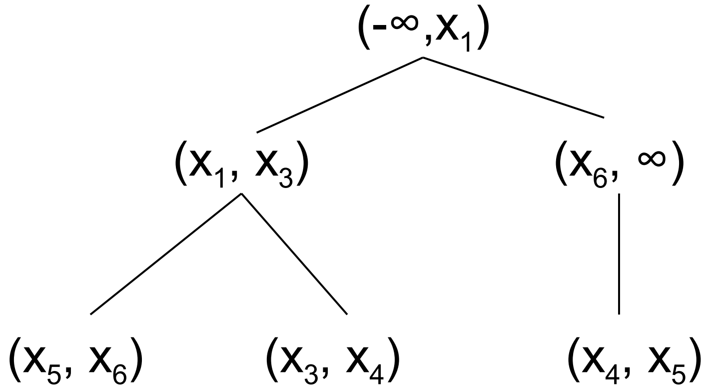

Bibliography

- **[BeMa92]** Efficient Broadcast Time-Stamping *Josh Benaloh and Michael de Mare* 1992
- **[BeMa94]** One-way Accumulators: A decentralized Alternative to Digital Signatures *Josh Benaloh and Michael de Mare* , 1994
- [**BarPfi97]** Collision-Free Accumulators and Fail-Stop Signature Schemes Without Trees *Niko Barić and Birgit Pfitzmann* 1997
- **[CGS97]** A secure and optimally efficient multi-authority election scheme *R. Cramer, R. Gennaro, and B. Schoenmakers* 1997
- **[Koch98]** On certificate revocation and validation *P.C. Kocher* 1998
- **[CGH98]** The random oracle methodoly revisited R. Canetti, O. Goldreich and S. Halevi 1998
- **[Sand99]** Efficient Accumulators Without Trapdoor *Tomas Sanders* 1999
- **[GoTa01]** An efficient and Distributed Cryptographic Accumulator *Michael T. Goodrich and Roberto Tamassia* 2001
- **[CamLys02]** Dynamic Accumulators And Application to Efficient Revocation of Anonymous Credentials *Jan Camenisch Anna Lysyanskaya* 2002
- **[GeRa04]** RSA Accumulator Based Broadcast Encryption *Craig Gentry and Zulfikar Ramzan 2004*
- **[LLX07]** Universal Accumulators with Efficient Nonmembership Proofs *Jiangtao Li, Ninghui Li and Rui Xue* 2007
- **[AWSM07]** Compact E-Cash from Bounded Accumulator *Man Ho Au, Qianhong Wu, Willy Susilo and Yi Mu* 2007
- **[WWP08]** A new Dynamic Accumulator for Batch Updates *Peishun Wang, Huaxiong Wang and Josef Pieprzyk* 2008
- **[CKHO08]** Strong Accumulators from Collision-Resistant Hashing *Philippe Camacho, Alejandro Hevia, Marcos Kiwi, and Roberto Opazo* 2008