Distributed Certificate-Chain Discovery

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Authorization Problem

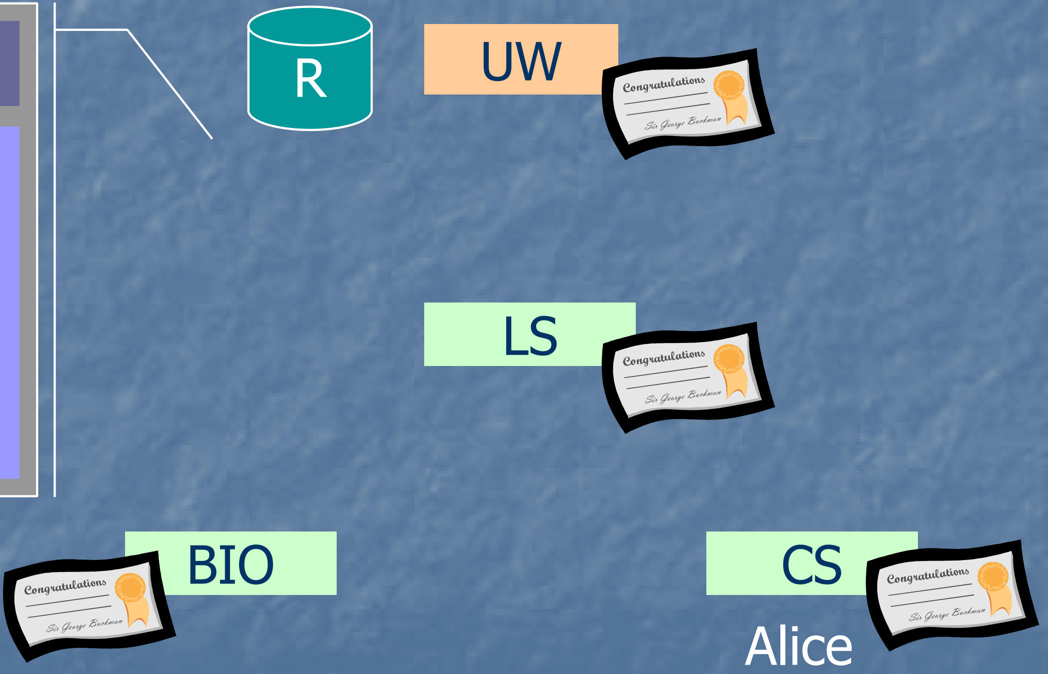
- For a given security policy *P* with respect to a resource *R*, can principal *A* access *R* ?
    - Straightforward in a centralized environment
    - But real-world is not centralized
        - Resources/services are located in different administrative domains
        - No centralized authority—policies cross domains!
        - Privacy concerns—users may not want to reveal too much information

Cross-Domain Authorization

Q1: Should Alice be allowed to access R in domain UW?
Q2: If so, prove it!

Centralized Solution

- Assume a centralized authority
- Does not deal with privacy concerns



Certificate

Solution: Distributed Certificate-Chain Discovery

- Based on two technologies
  - SPKI/SDSI—a trust-management language
  - WPDS—Weighted Pushdown Systems
- Employs a distributed algorithm to find certificate chains
  - Previous approaches use centralized algorithms
    - SPKI/SDSI, RT_0, etc.
- Addresses privacy issue—does not reveal sensitive information
- Scalable
  - Tested in a simulated environment with up to 1,600 certificates

Why Use Weighted Pushdown Systems?

- WPDS technology enables a distributed solution for the authorization problem
  - WPDS reachability algorithm uses an automaton to summarize knowledge ⇒ synopsis of SPKI/SDSI proof
  - To send a relevant proof fragment, ship an automaton fragment
- Addresses shortcomings of previous SPKI/SDSI work
  - A proof may consist of multiple certificate chains
  - Original approach of Rivest et al. only capable of finding single-chain proofs
  - Addresses privacy concerns

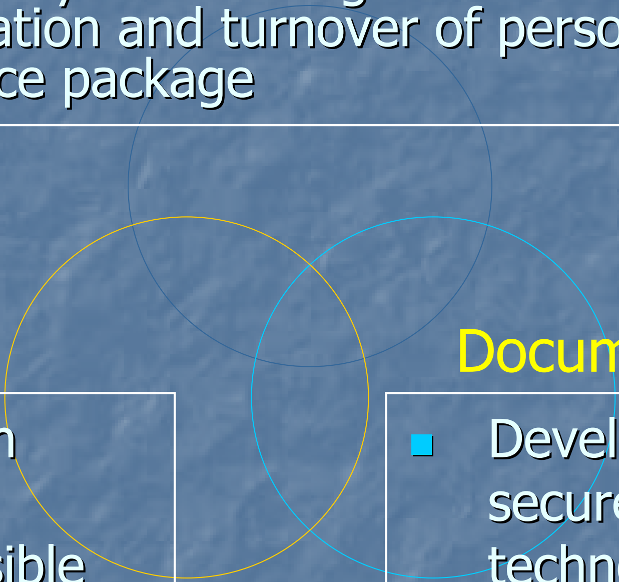
Status

- A prototype has been built and tested
  - Uses a SPKI/SDSI library to manage certificates
  - Uses the WPDS Library to perform proof search
  - Distributed algorithm coordinates interactions between multiple domains

DoD Interests

SBIR: AF03-095:
Cross-domain user identity and credential management

- Maintain organizational namespace consistency
- Enable information-system managers to effectively deal with the rapid consolidation and turnover of personnel within mission critical force package



SBIR: AF04-094:
XML Guard

- Investigate cross-domain guarding advancement opportunities made possible by the rapid growth of XML technologies

SBIR: N05-085:
Cross-Domain
Document-Based Collaboration

- Develop technologies that enable secure cross-domain collaboration technologies
  - Secure and certifiable sharing and editing of composite documents containing sensitive information
  - Span multiple security levels

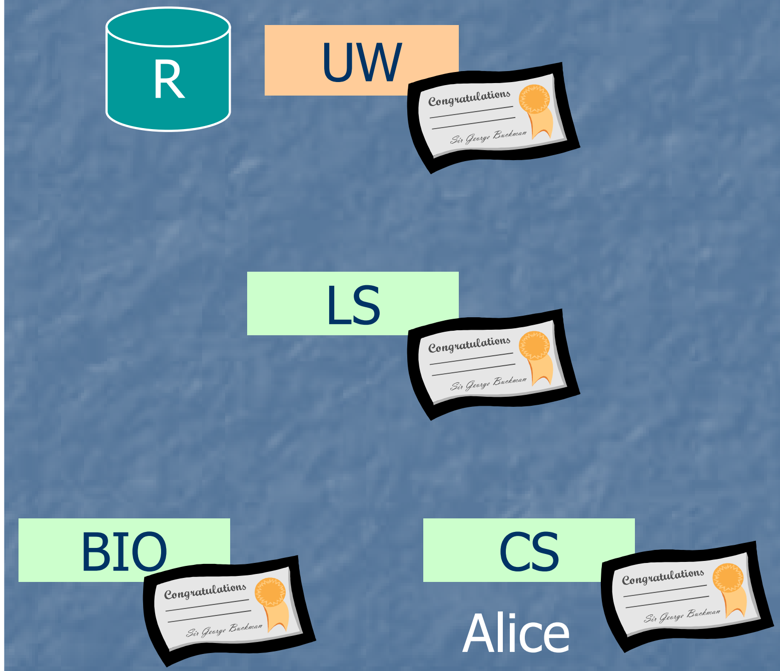
Outline

- Introduction
- SPKI/SDSI Background
- Distributed Certificate-Chain Discovery Using WPDS

Cross-Domain Authorization

Issues	Existing Approaches: *SPKI/SDSI, RT$_0$*
Policy Management How to manage certificates when there are multiple administrative domains?	√
Policy Enforcement How to prove that one is allowed to access a resource?	X

Requires all certificates to be sent to a single site



Our Focus: SPKI/SDSI

- Simple Public Key Infrastructure (SPKI)/
  Simple Distributed Security Infrastructure (SDSI)
  - A trust-management system that addresses cross-domain authorization
- Two components:
  - Principals
    - Resource owners, users, databases, etc.
    - Represented by their public keys, e.g. K_{NSF}, K_{ONR}, K_{CS}
  - Certificates
    - Security policy = set of certificates
    - No need for a centralized authority!
      - Any principal can issue a certificate
      - Each certificate specified and signed by the *issuing* principal

SPKI/SDSI Name Certificates

- Format: (Key, Name, Subject, Validity)
  - Meaning: Subject is a member of the group known (to Key) as "Name"
  - For convenience: Key Name → Subject
- Map public keys to meaningful (local) names
  - Alice is a faculty member in CS: K_{CS} faculty → K_{Alice}
  - Bob is *one* of Alice's students: K_{Alice} student → K_{Bob}
- Declares membership relation across domains
  - K_{Alice} friend → $K_{Charlie}$ enemy
  - K_{UW} faculty → K_{CS} faculty

SPKI/SDSI Authorization Certificates

- Format: (Key, Subject, Delegation, Tag, Validity)
  - Meaning: Key grants right "Tag" to Subject
  - For convenience: Key □ $\xrightarrow{R}$ Subject Delegation

- Grants access permission to other principals
  - e.g. Bob can read Prof. Alice's homework directory:
    - Directly: K_{Alice} □ $\xrightarrow{HW}$ K_{Bob} ■
    - Indirectly — via 1 or more name certificates:

K_{Alice} students → K_{Bob}

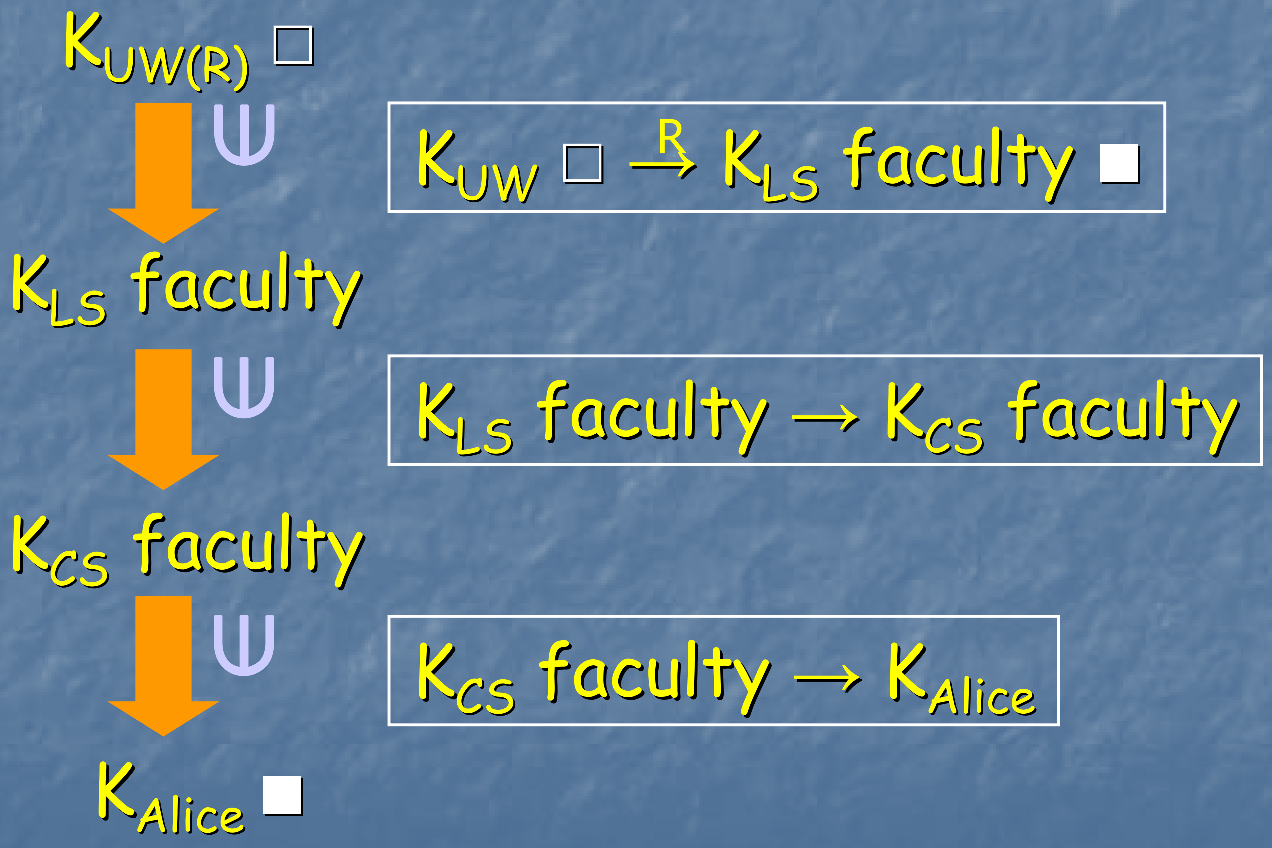
K_{Alice} □ $\xrightarrow{HW}$ K_{Alice} students ■

- May delegate rights to other principals

K_{NSF} □ $\xrightarrow{R}$ K_{EDU} programs ■

Certificate-Chain

- An authorization proof is a chain of certificates



$K_{UW(R)}$ □

$\Cup$

$\boxed{K_{UW} \; \square \xrightarrow{R} K_{LS} \text{ faculty } \blacksquare}$

K_{LS} faculty

$\Cup$

$\boxed{K_{LS} \text{ faculty} \rightarrow K_{CS} \text{ faculty}}$

K_{CS} faculty

$\Cup$

$\boxed{K_{CS} \text{ faculty} \rightarrow K_{Alice}}$

K_{Alice} ■

Algorithms for Certificate-Chain Discovery

- Previous certificate-chain-discovery algorithms require all certificates to be sent to a single site
  - Defeats the purpose of having cross-domain security policies
  - No privacy! Each site must reveal its certificates
- This work
  - Distributed algorithm for certificate-chain discovery

Outline

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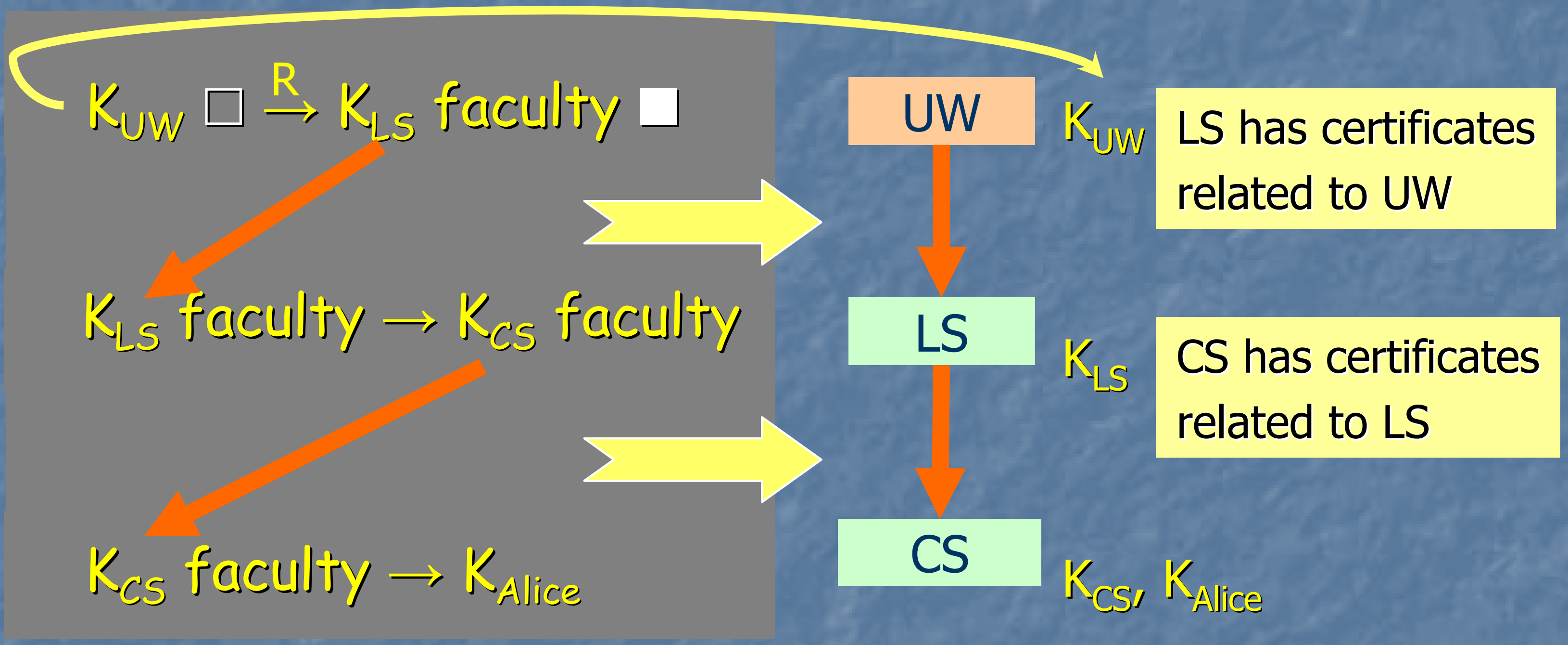
- Distributed Certificate-Chain Discovery Using WPDS

Distributed Certificate-Chain Discovery—How?

- Exploit relationships among certificates
  - Who has related certificates?

- Map SPKI/SDSI certificate-chain problem to Weighted Pushdown System (WPDS) domain
  - Ship automaton fragments to different sites
  - Different sites collaborate on proof

Exploit Certificate Relationships



$K_{UW}\ \square \xrightarrow{R} K_{LS}\ \text{faculty}\ \blacksquare$

$K_{LS}\ \text{faculty} \rightarrow K_{CS}\ \text{faculty}$

$K_{CS}\ \text{faculty} \rightarrow K_{Alice}$

LS has certificates related to UW

CS has certificates related to LS

Cross-site certificates

Weighted Pushdown System (WPDS)

- Pushdown System (PDS), plus
  - Weights on transition rules
- Three components
  - States: $\{\sigma_1, \sigma_2, \sigma_3\}$
  - Stack symbols: $\{A, B, C, D\}$
  - Transition rules with weights:

$$\langle\sigma_1, A\rangle \xrightarrow{w_1} \langle\sigma_2, \varepsilon\rangle$$

$$\langle\sigma_1, A\rangle \xrightarrow{w_2} \langle\sigma_2, B\rangle$$

Map SPKI/SDSI to WPDS

SPKI/SDSI Certificates ⟷ WPDS Transition Rules

$K_{UW}\ \square \xrightarrow{R} K_{LS}\ faculty\ \blacksquare$

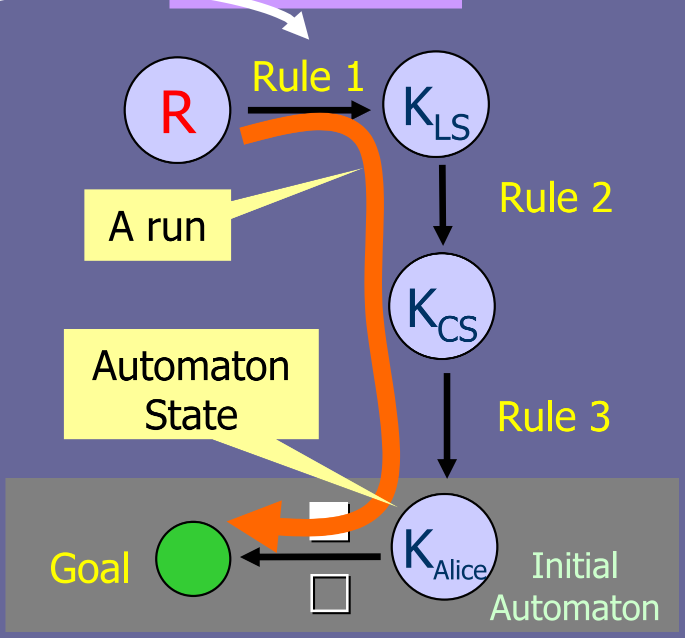
$\langle K_{UW}, \square \rangle \xrightarrow{R} \langle K_{LS}, faculty, \blacksquare \rangle$

SPKI/SDSI Certificate Chain ⟷ WPDS Run

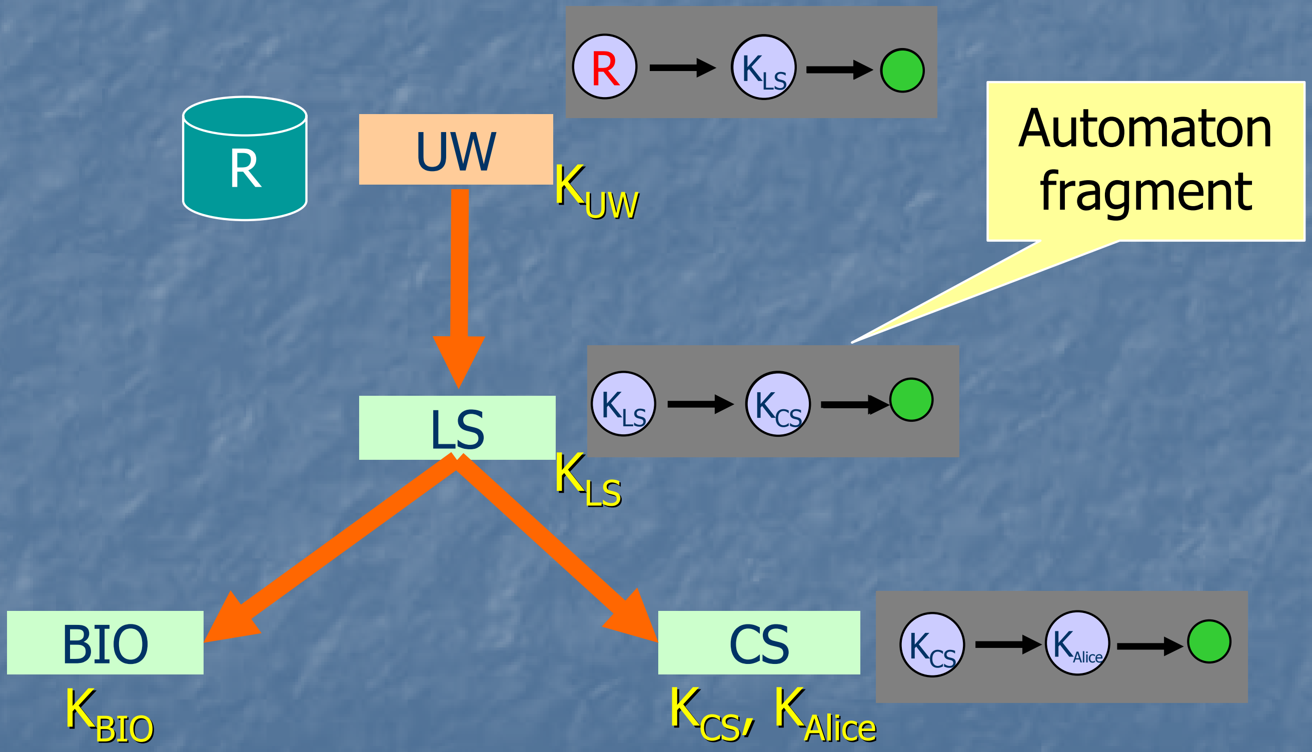
$K_{UW}\ \square \xrightarrow{R} K_{LS}\ faculty\ \blacksquare$

$K_{LS}\ faculty \rightarrow K_{CS}\ faculty$

$K_{CS}\ faculty \rightarrow K_{Alice}$



Distributed Certificate-Chain Discovery Using WPDS

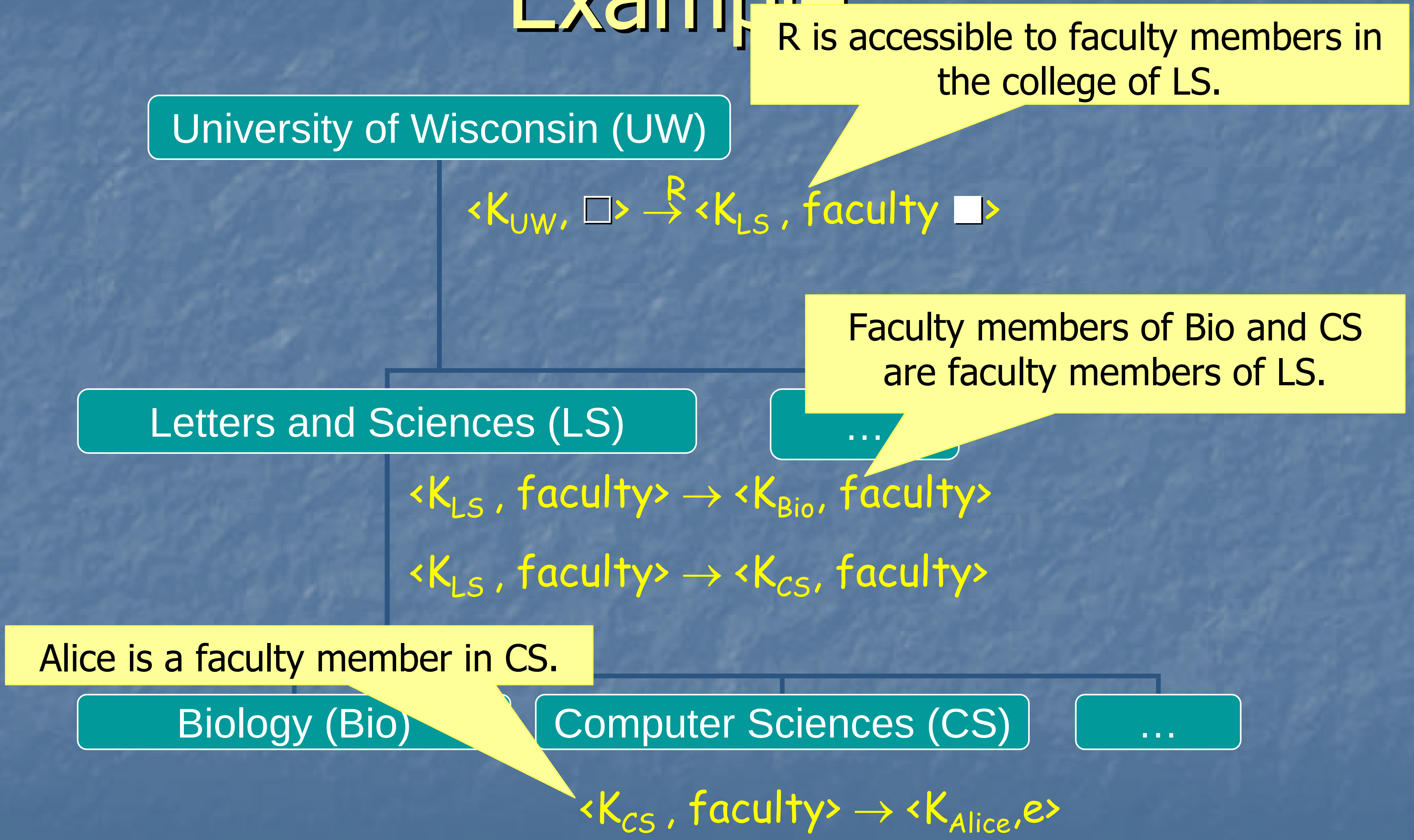


Automaton fragment

Distributed Certificate-Chain Discovery Using WPDS

- Two approaches, derived from the Generalized Pushdown Reachability (GPR) problems in WPDS:
  - Generalized Pushdown Successor (GPS)
    - Distributed Post*
  - Generalized Pushdown Predecessor (GPP)
    - Distributed Pre*

Example



R is accessible to faculty members in the college of LS.

University of Wisconsin (UW)

$\langle K_{UW}, □\rangle \xrightarrow{R} \langle K_{LS}, \text{faculty} ■\rangle$

Faculty members of Bio and CS are faculty members of LS.

Letters and Sciences (LS)

…

$\langle K_{LS}, \text{faculty}\rangle \rightarrow \langle K_{Bio}, \text{faculty}\rangle$

$\langle K_{LS}, \text{faculty}\rangle \rightarrow \langle K_{CS}, \text{faculty}\rangle$

Alice is a faculty member in CS.

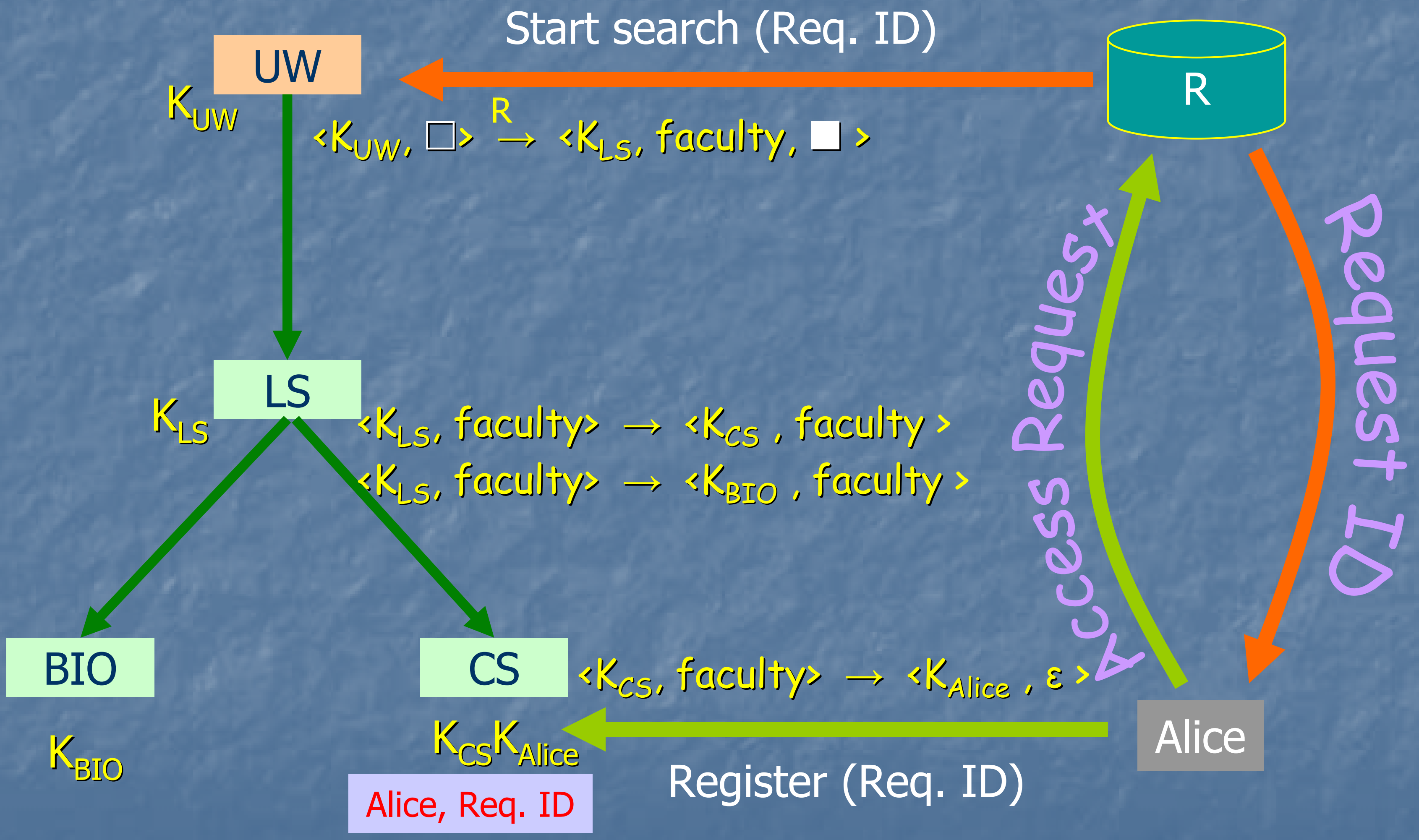
Biology (Bio)

Computer Sciences (CS)

…

$\langle K_{CS}, \text{faculty}\rangle \rightarrow \langle K_{Alice}, e\rangle$

Distributed Post*



Start search (Req. ID)

UW

K_{UW}

$\langle K_{UW}, \Box \rangle \xrightarrow{R} \langle K_{LS}, \text{faculty}, \blacksquare \rangle$

R

LS

K_{LS}

$\langle K_{LS}, \text{faculty} \rangle \rightarrow \langle K_{CS}, \text{faculty} \rangle$

$\langle K_{LS}, \text{faculty} \rangle \rightarrow \langle K_{BIO}, \text{faculty} \rangle$

Access Request

Request ID

BIO

CS

$\langle K_{CS}, \text{faculty} \rangle \rightarrow \langle K_{Alice}, \varepsilon \rangle$

K_{BIO}

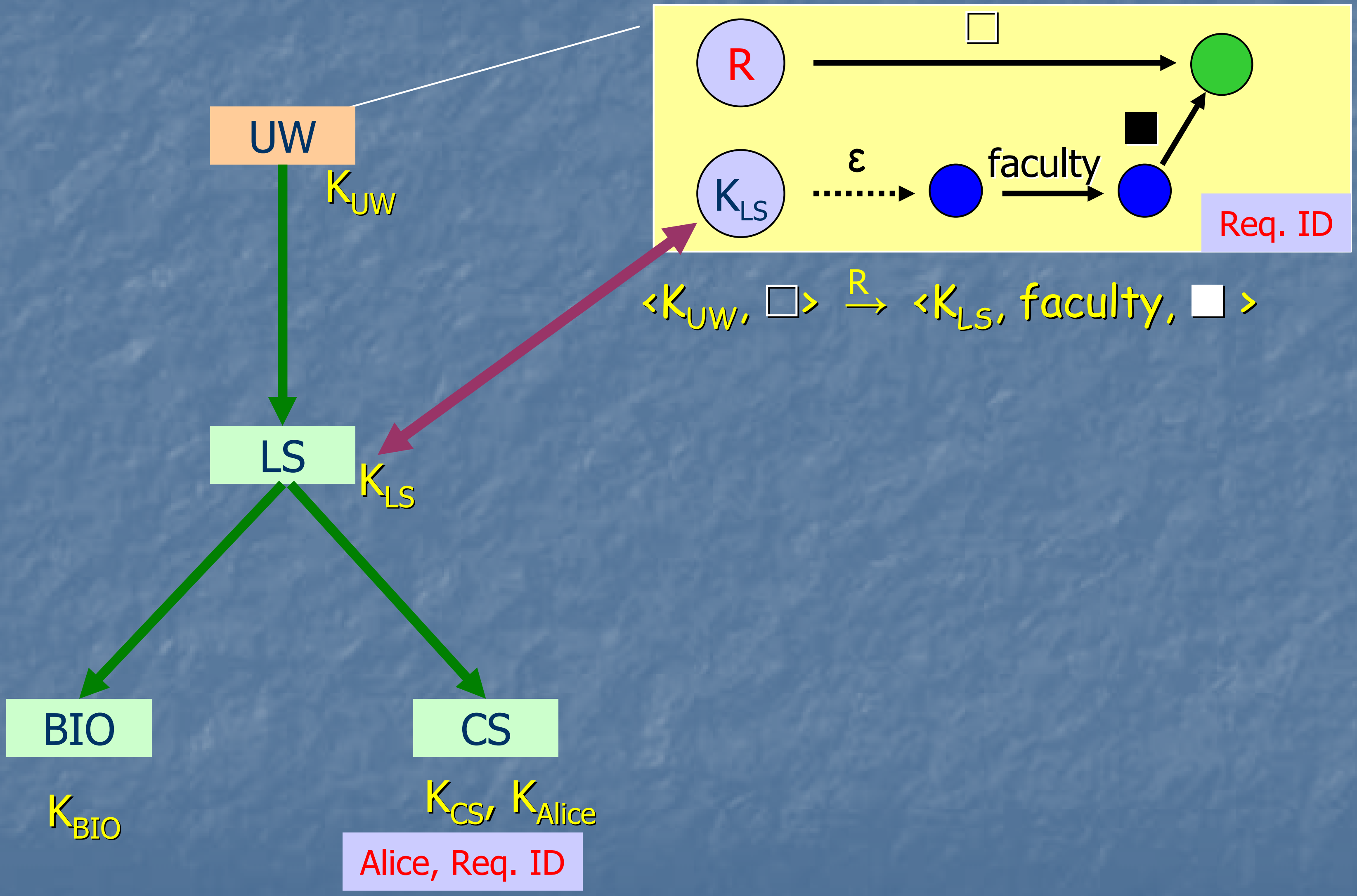
$K_{CS} K_{Alice}$

Alice, Req. ID

Alice

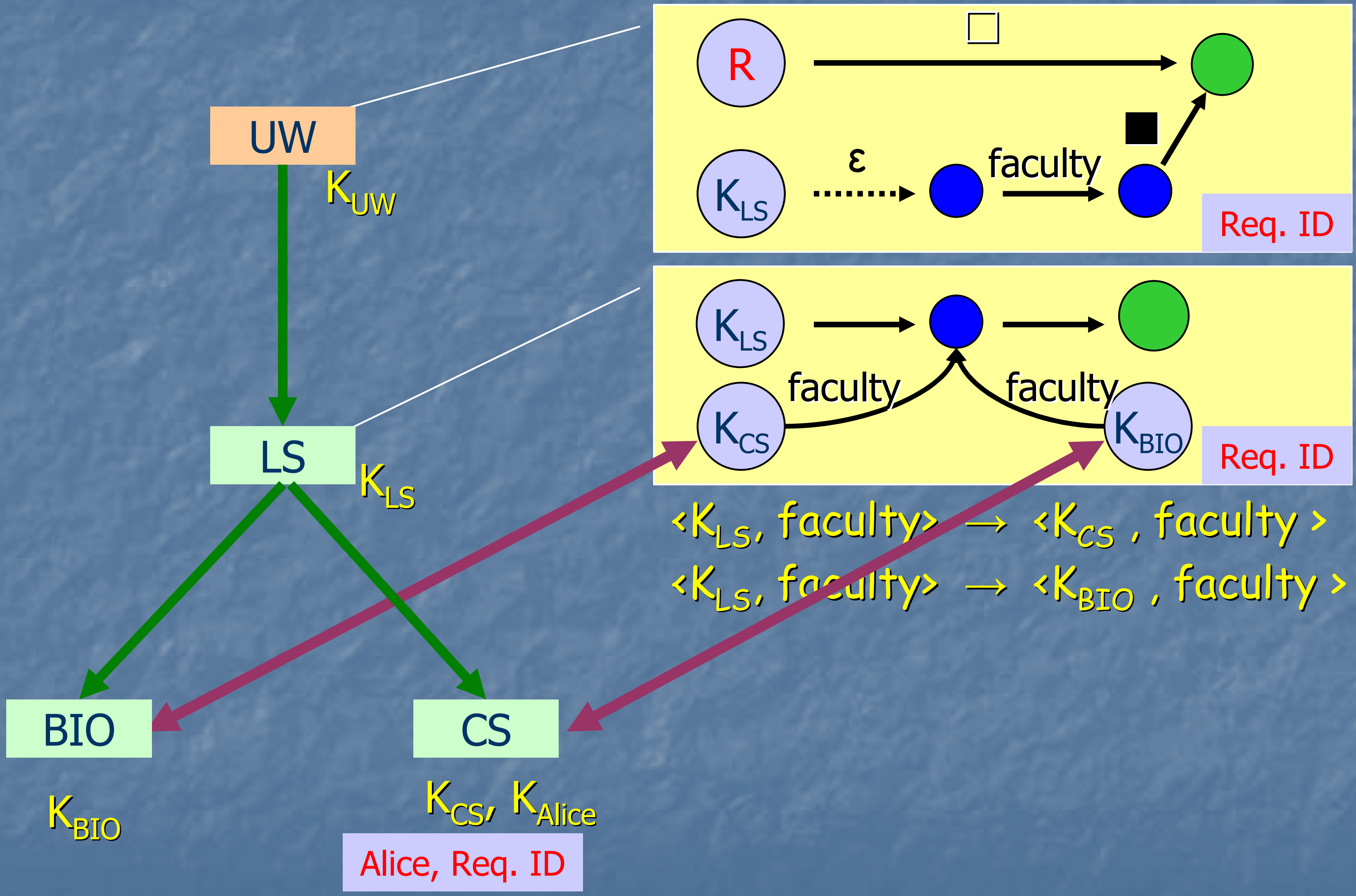
Register (Req. ID)

Distributed Post*



$\langle K_{UW}, \square \rangle \xrightarrow{R} \langle K_{LS}, \text{faculty}, \blacksquare \rangle$

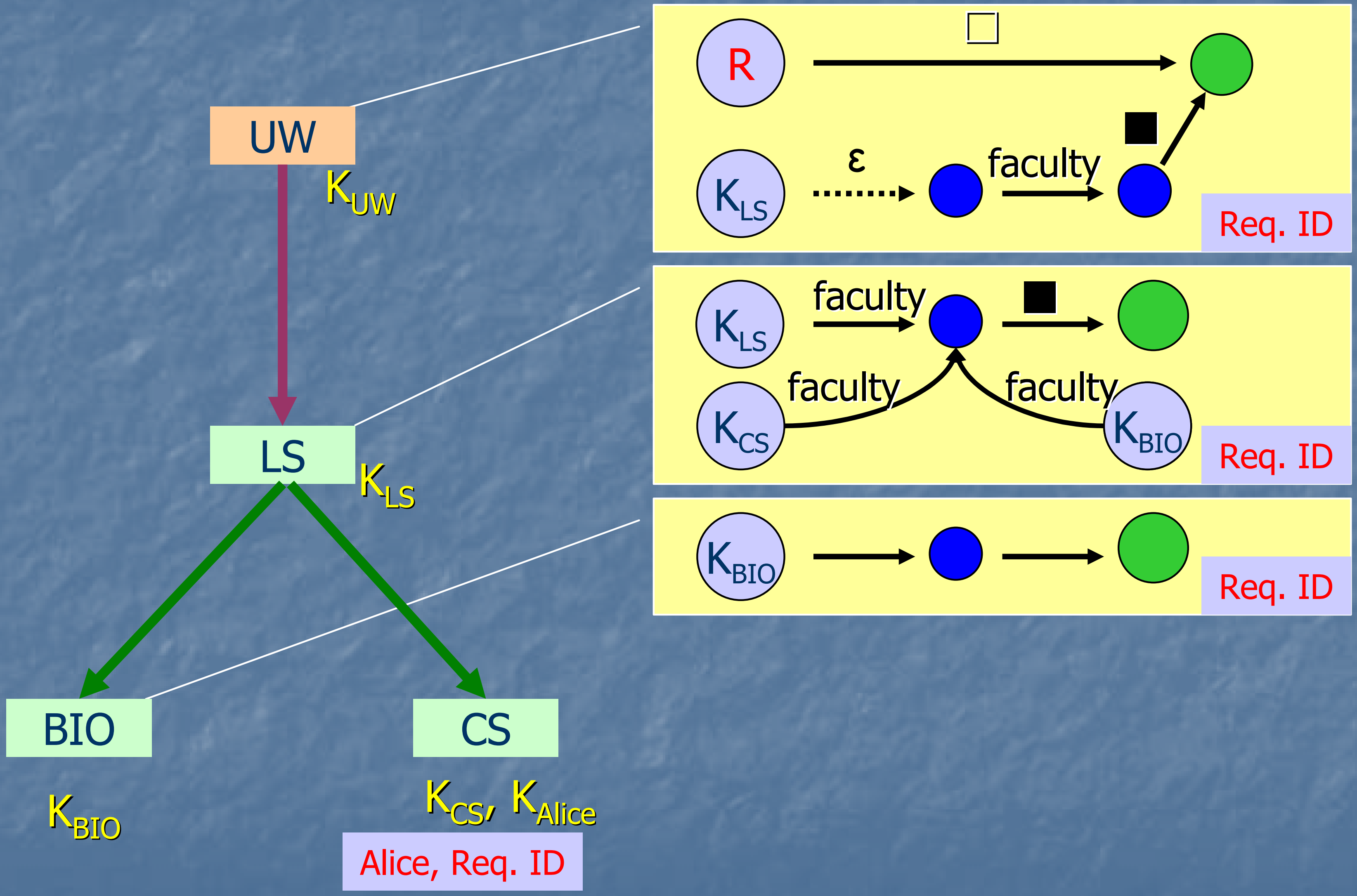
Distributed Post*



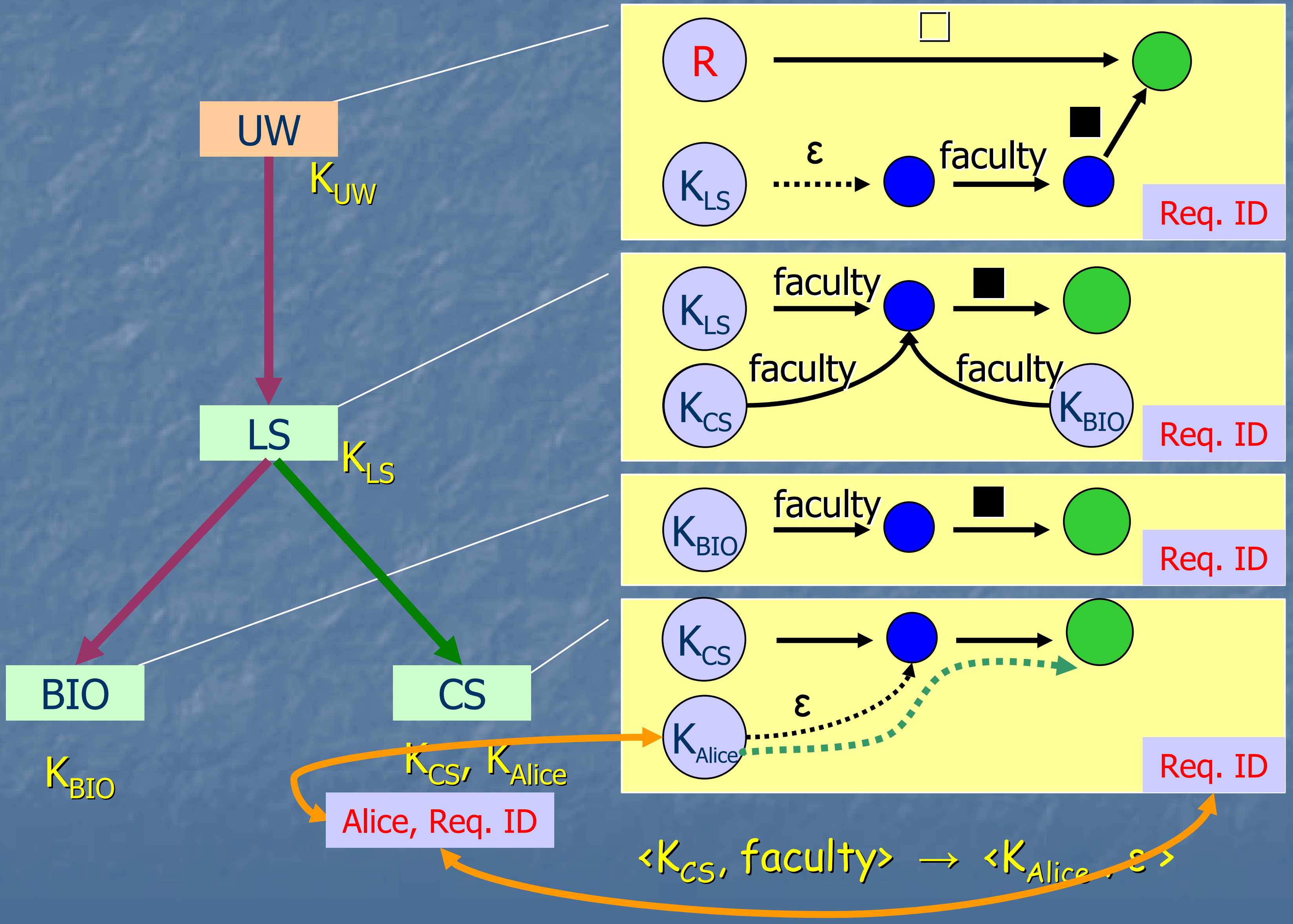
<K_{LS}, faculty> → <K_{CS} , faculty >

<K_{LS}, faculty> → <K_{BIO} , faculty >

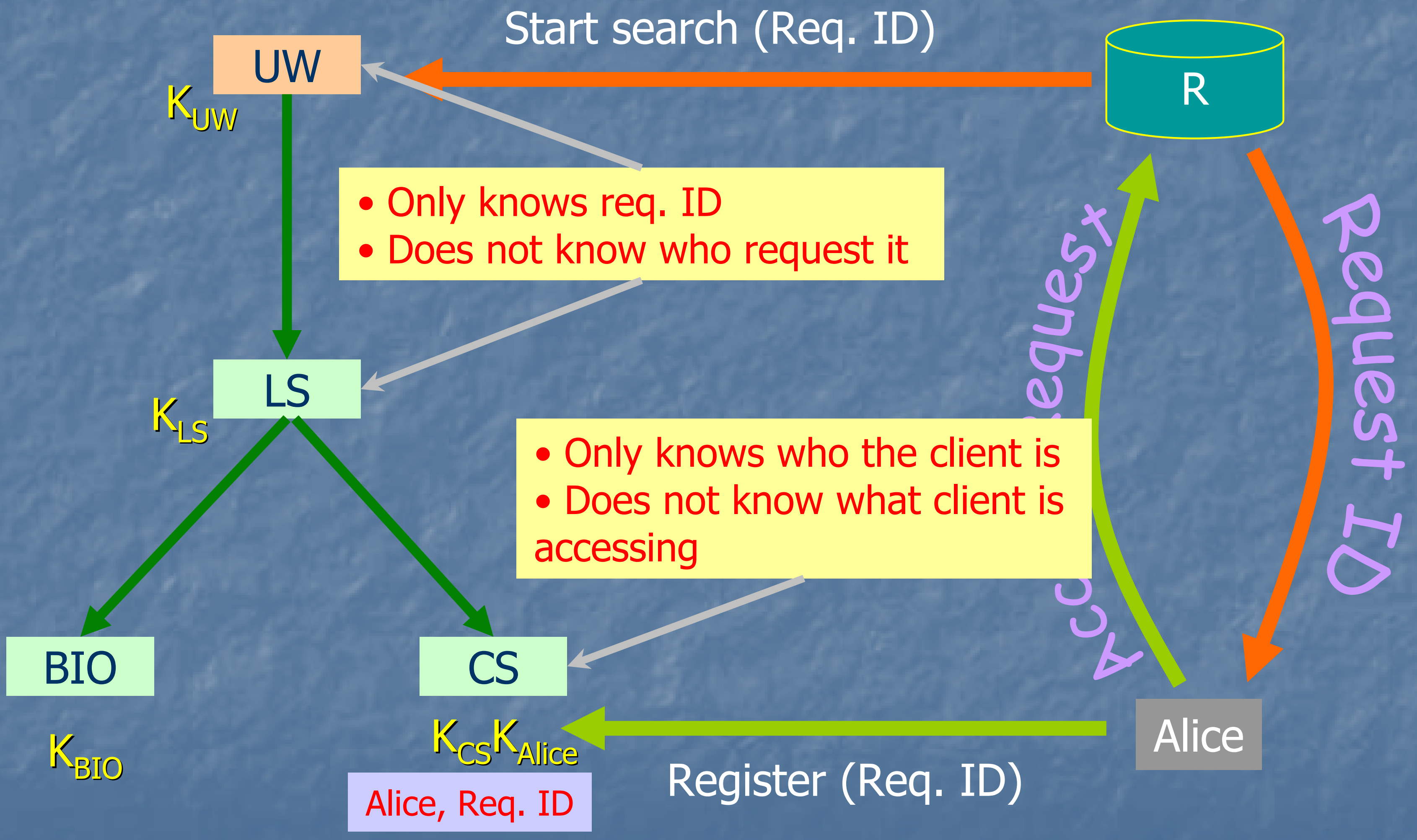
Distributed Post*



Distributed Post*



Preserving Privacy

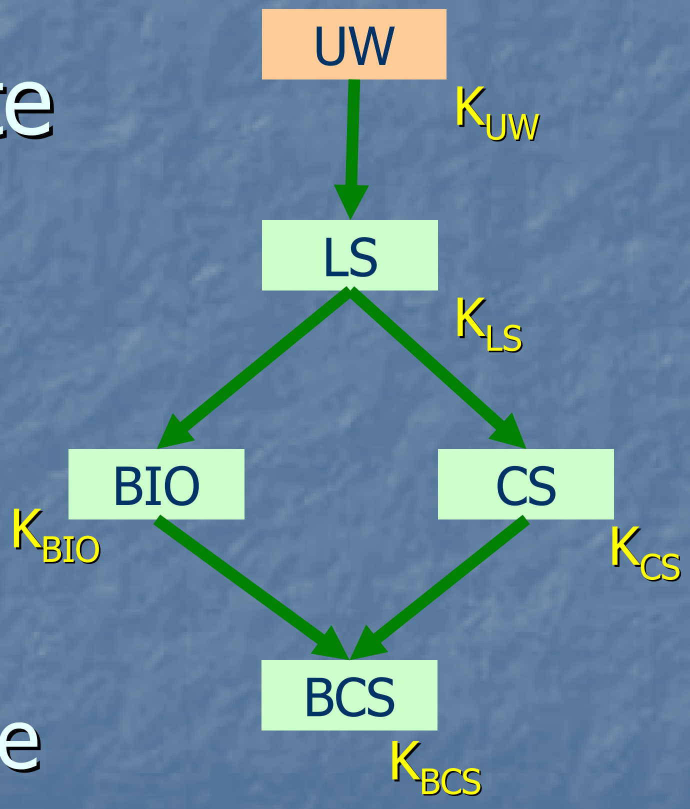


- Only knows req. ID
- Does not know who request it

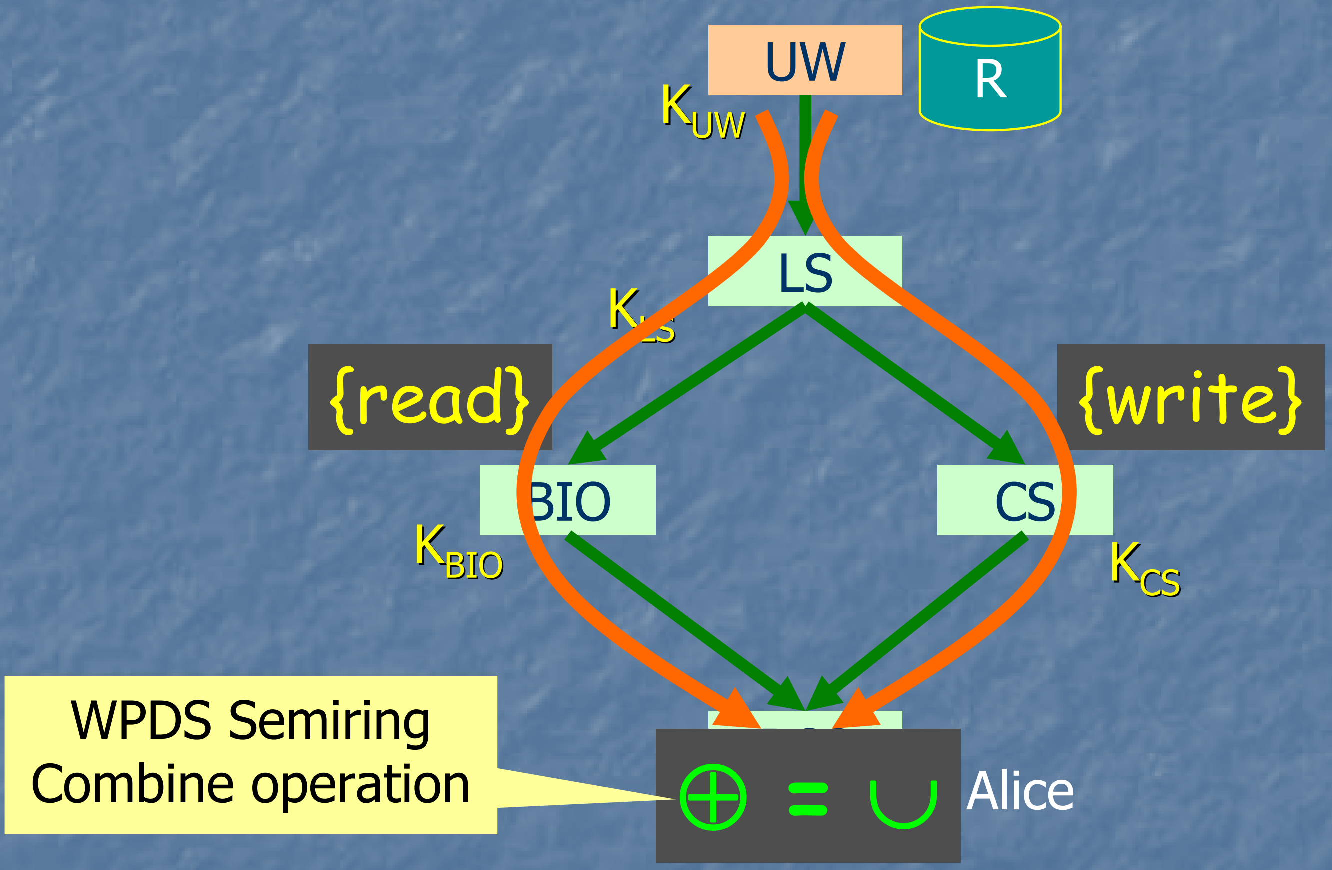
- Only knows who the client is
- Does not know what client is accessing

Multiple Certificate Chains

- In real world, a proof may consist of multiple certificate chains
  - Previous work assumes one certificate chain
- Our approach addresses this issue
  - WPDS enables us to solve the problem—using semirings



WPDS and Multiple Certificate Chains



WPDS Semiring Combine operation

Alice requests for {read, write}

Future Work

- Performance enhancement
  - Use caching to reduce response time
    - Especially for long certificate chains
  - Network optimization—piggyback messages
- Termination
  - How to determine whether all possible paths have been exploited and terminate the search early?

END

Questions and comments?