ID-Based Encryption for Complex Hierarchies with Applications to Forward Security and Broadcast Encryption

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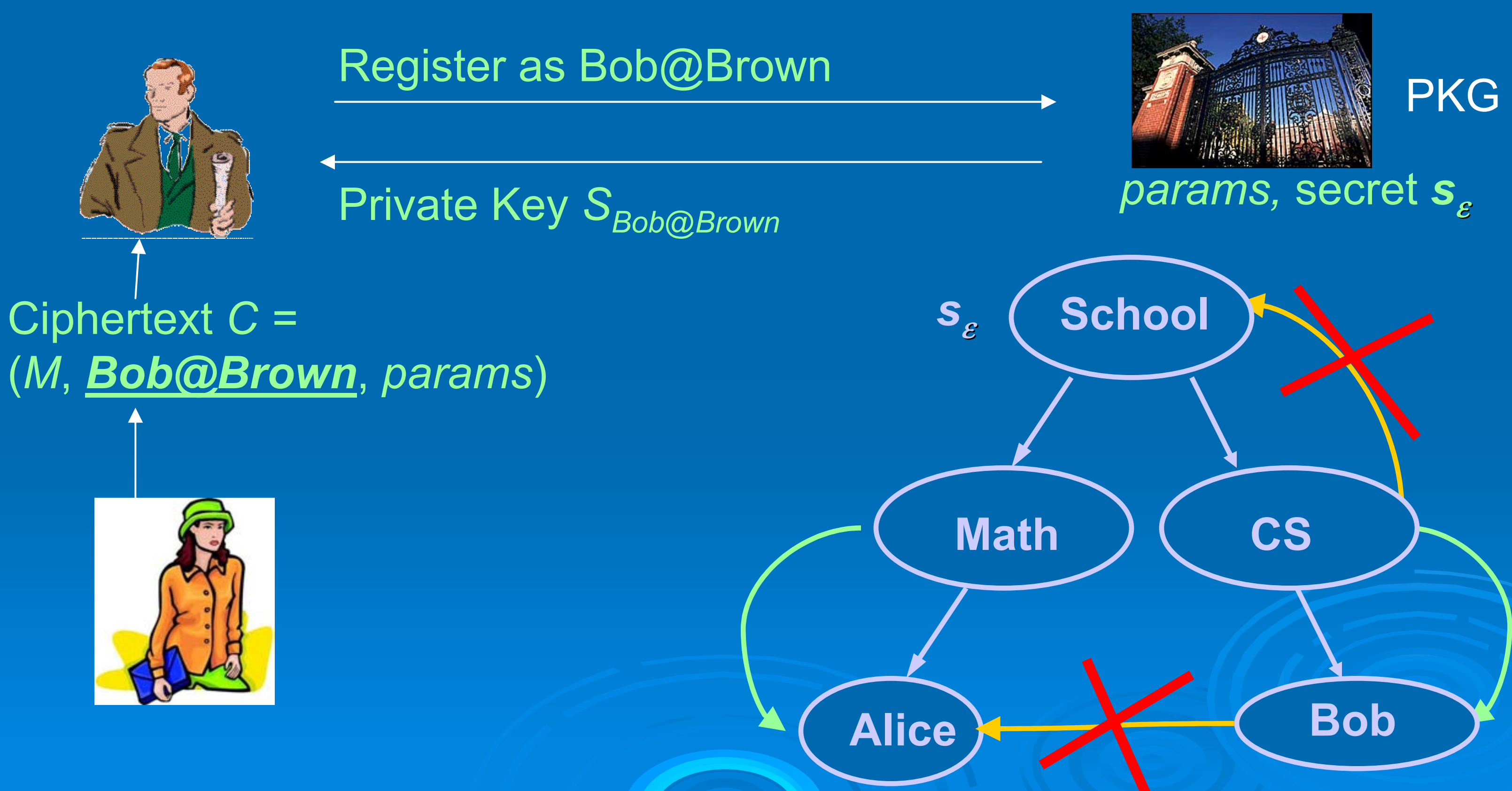
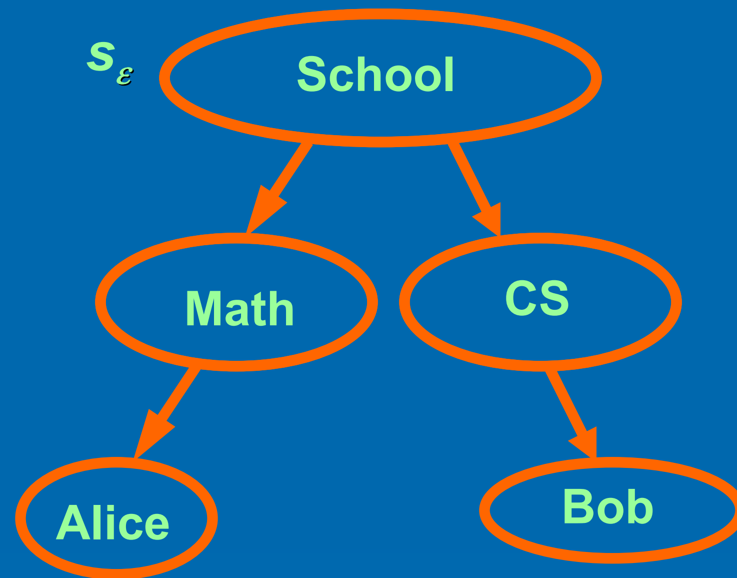
Identity-based Encryption (IBE) and Hierarchical IBE (HIBE)

- IBE [Shamir 84] [Boneh Frankline 01] [Cocks 01] [Canetti Halevi Katz 03] [Boneh Boyen 04] [Waters 04]
- HIBE [Horwitz Lynn 02] [Gentry Silverberg 02] [Boneh Boyen 04]



Why need forward-secure HIBE?

- In HIBE, exposure of parent private keys compromises children's keys
- Forward security
  - [Gunther 89] [Diffie Oorschot Wiener 92] [Anderson 97] [Bellare Miner 99] [Malkin Micciancio Miner 02] [Canetti Halevi Katz 03]
  - Secret keys are evolved with time
  - Compromising current key does NOT compromise past communications
- Forward-secure HIBE mitigates key exposure

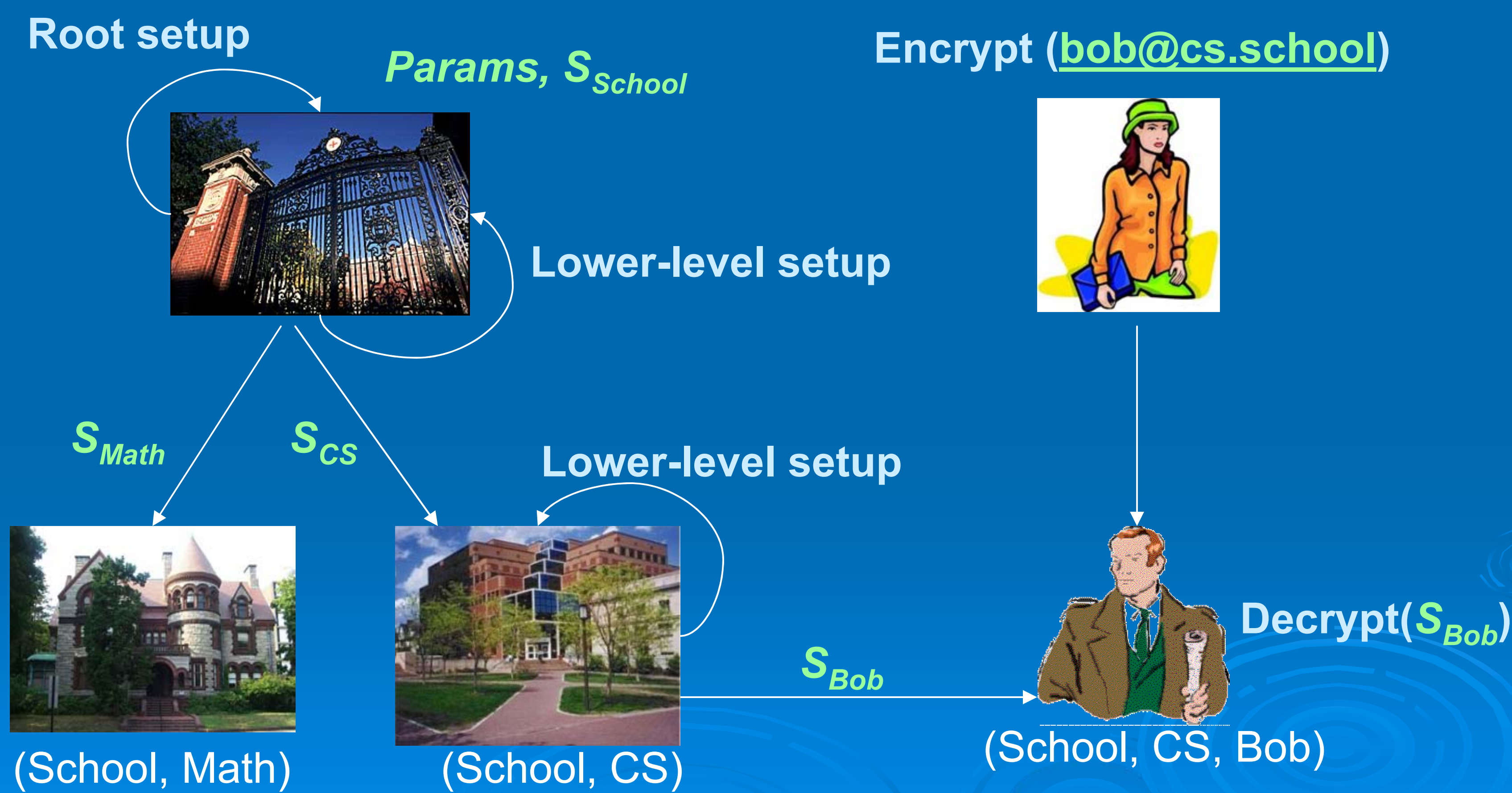


Applications of fs-HIBE

- Forward-secure public-key broadcast encryption (fs-BE)
  - BE schemes: [Fiat Naor 93] [Luby Staddon 98] [Garay Staddon Wool 00] [Naor Naor Lotspiech 01] [Halevy Shamir 02] [Kim Hwang Lee 03] [Goodrich Sun Tamassia 04] [Gentry Ramzan 04]
  - HIBE is used in public-key broadcast encryption [Dodis Fazio 02]
  - Forward security is especially important in BE
- Multiple HIBE: Encryption scheme for users with multiple roles

Hierarchical IBE

- HIBE [Horwitz Lynn 02] [Gentry Silverberg 02] [Boneh Boyen 04]

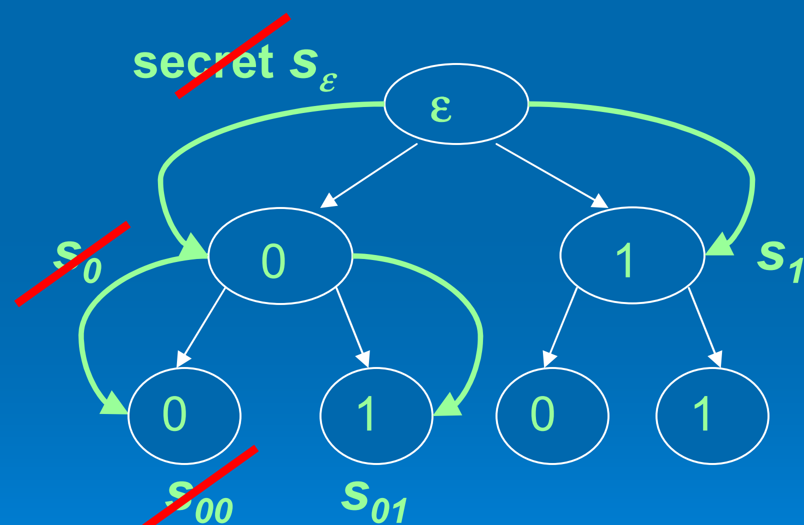


Forward-secure Public-Key Encryption

- fs-PKE (Canetti, Halevi, and Katz 2003)
  - Used to protect the private key of one user
  - Based on Gentry-Silverberg HIBE
  - A time period is a binary string
  - Private key contains decryption key and future secrets
  - Erase past secrets in algorithm **Update**

Total time periods: 4

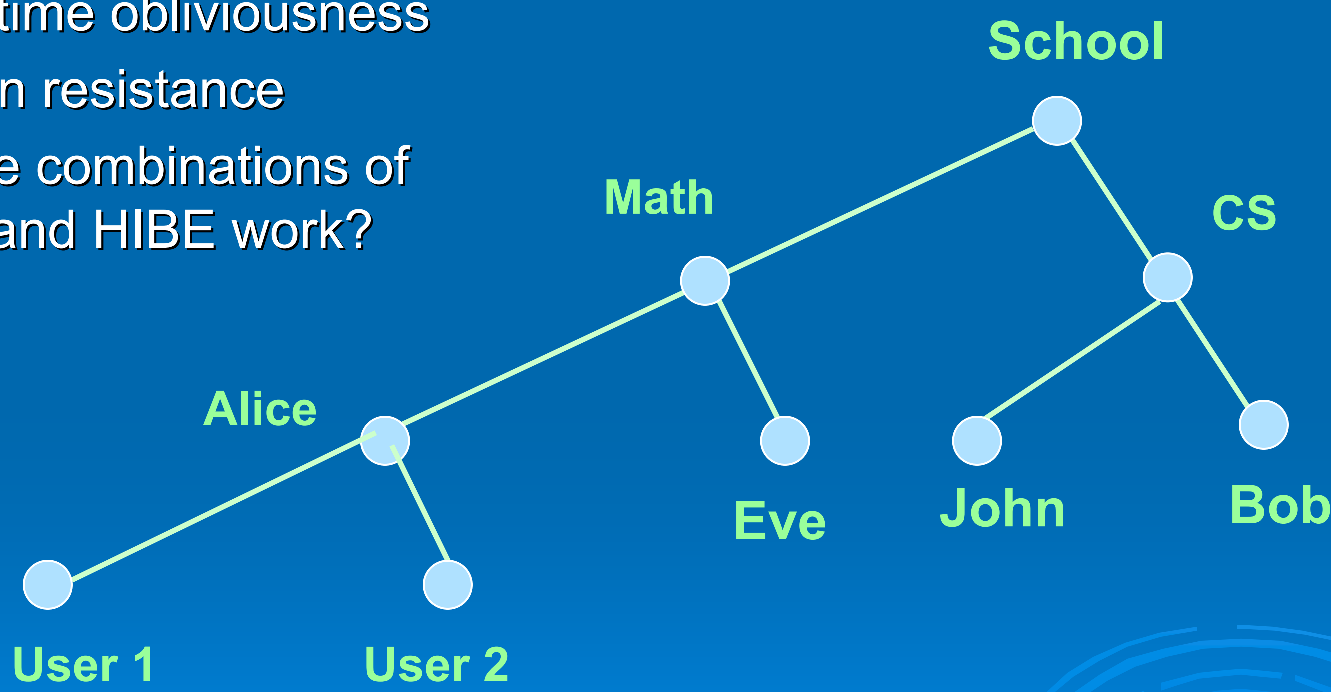
Period 1: (0 0)
Period 2: (0 1)
Period 3: (1 0)
Period 4: (1 1)



Encrypt(*params*, 0 0)

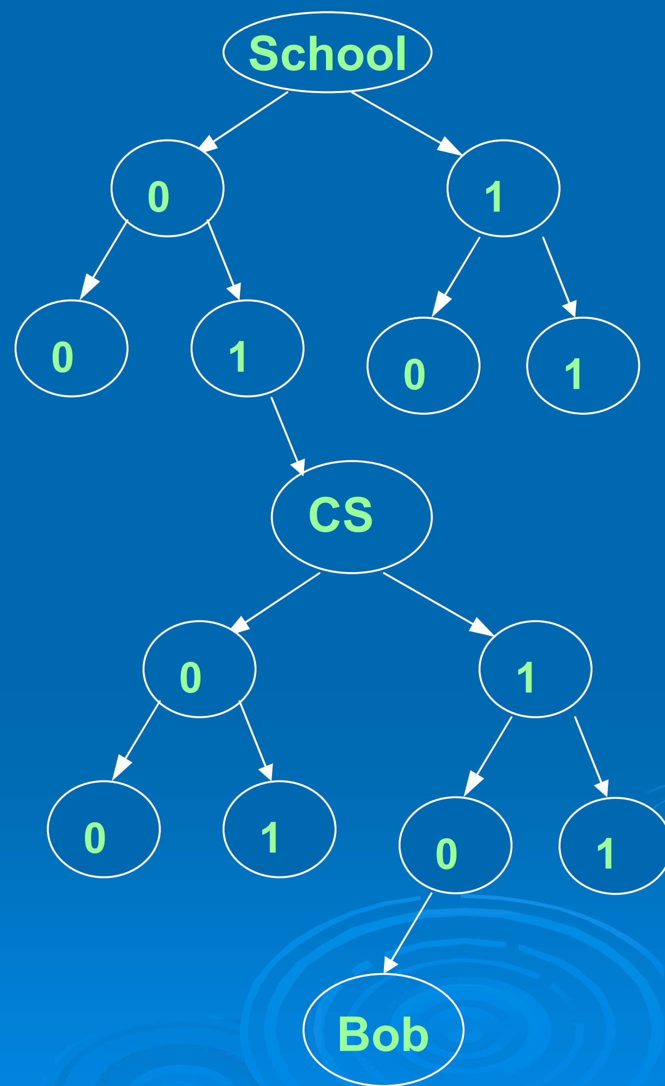
fs-HIBE requirements

- Dynamic joins
  - Users can join at any time
- Joining-time obliviousness
- Collusion resistance
- Do naïve combinations of fs-PKE and HIBE work?



An fs-HIBE attempt

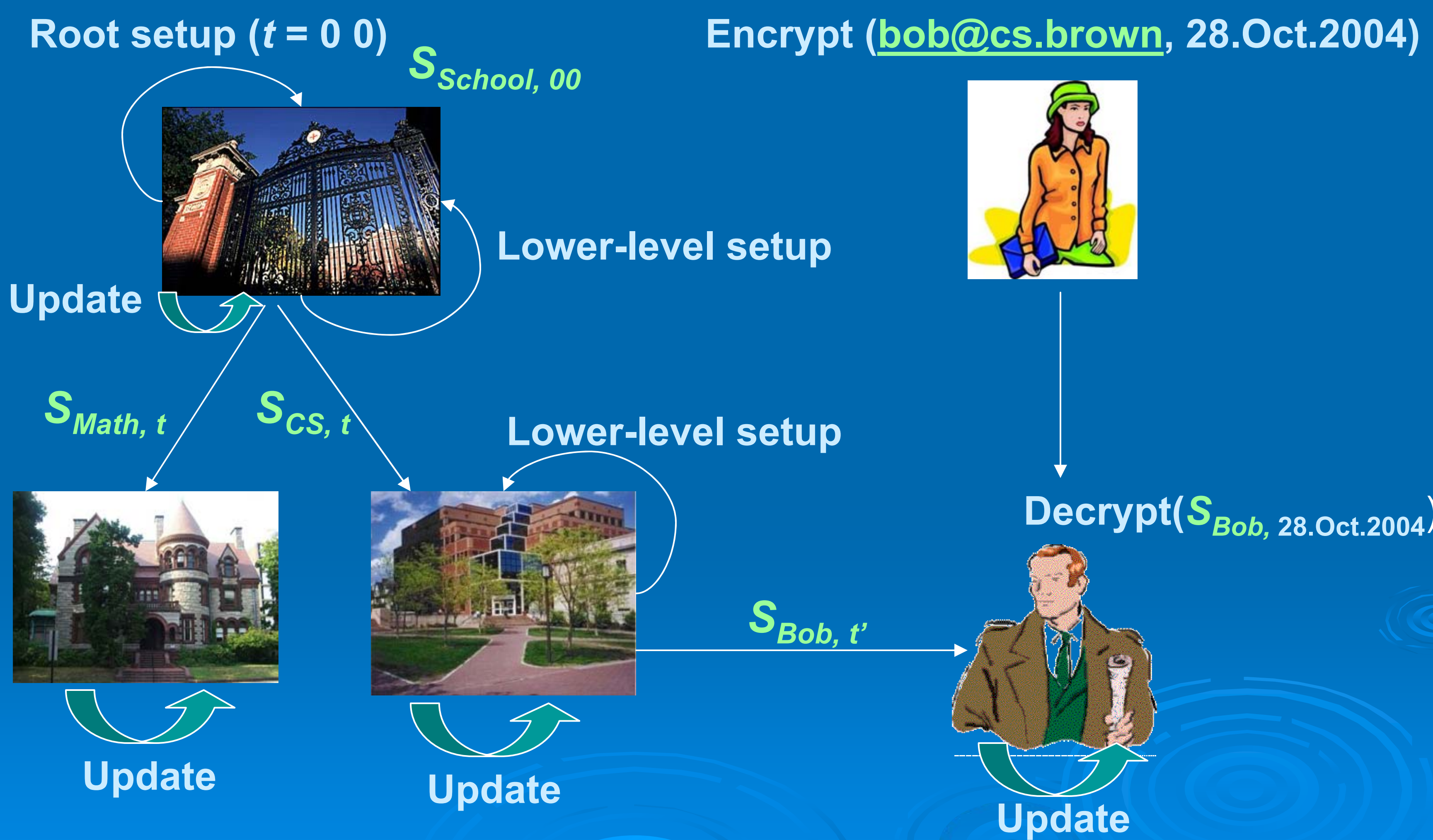
- Each entity node maintains one tree
  - For computing children's private keys
  - For the forward security of itself
- Not joining-time-oblivious
  - CS joins at (0 1) with public key (*School, 0, 1, CS*)
  - Bob joins at (1 0) with public key (*School, 0, 1, CS, 1, 0, Bob*)
  - Sender needs to know when CS and Bob joined



Overview of our fs-HIBE scheme

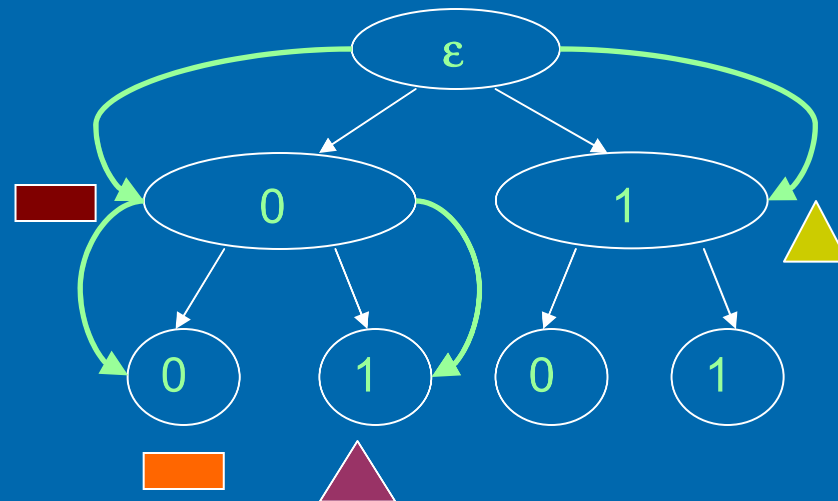
- Based on HIBE [Gentry Silverberg 02] and fs-PKE (Canetti Halevi Katz 03] schemes
- Scalable, efficient, and provable secure
  - Forward security
  - Dynamic joins
  - Joining-time obliviousness
  - Collusion resistance
- Security based on Bilinear Diffie-Hellman assumption [BF 01] and random oracle model [Bellare Rogaway 93]
  - Chosen-ciphertext secure against adaptive-chosen-(ID-tuple, time) adversary

fs-HIBE algorithm definitions



fs-HIBE Root setup

- Similar to key derivation of fs-PKE
- Private key for time (0 0) contains decryption key for (0 0), and future secrets
- Generates *params*, decryption key, and future secrets
  -  = $s_\varepsilon \times H(0 \,||\, \text{School})$
  -  = $s_\varepsilon \times H(1 \,||\, \text{School})$
  -  =  $+\ s' \times H(0\ 0 \,||\, \text{School})$
  -  =  $+\ s' \times H(0\ 1 \,||\, \text{School})$
  - Erase , s_ε and s'

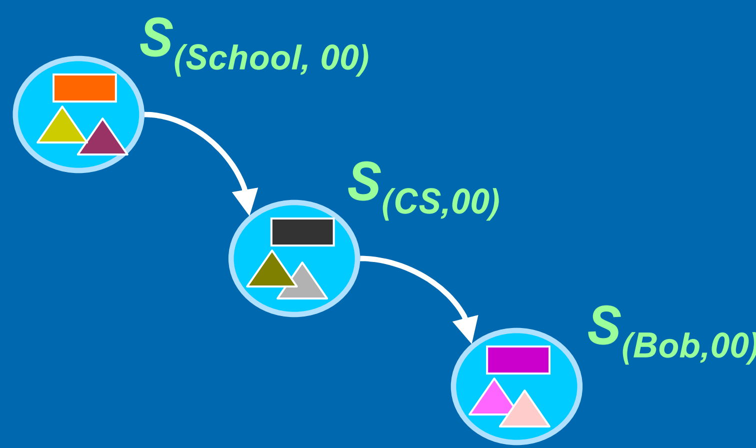


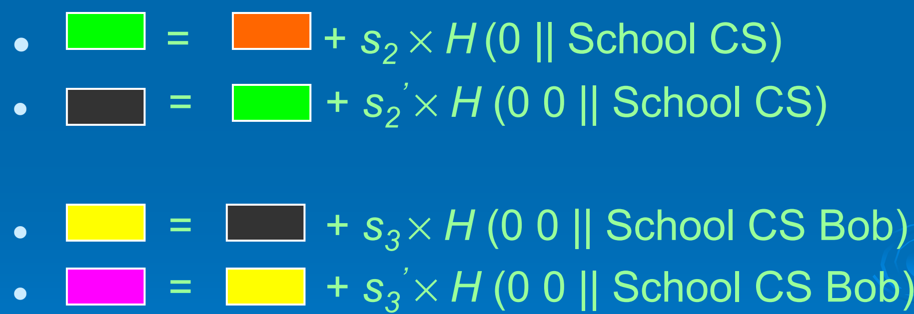
$S_{(School,00)}$

|| String concatenation
\+ Group addition operation
× Group multiplication operation

fs-HIBE algorithms cont'd

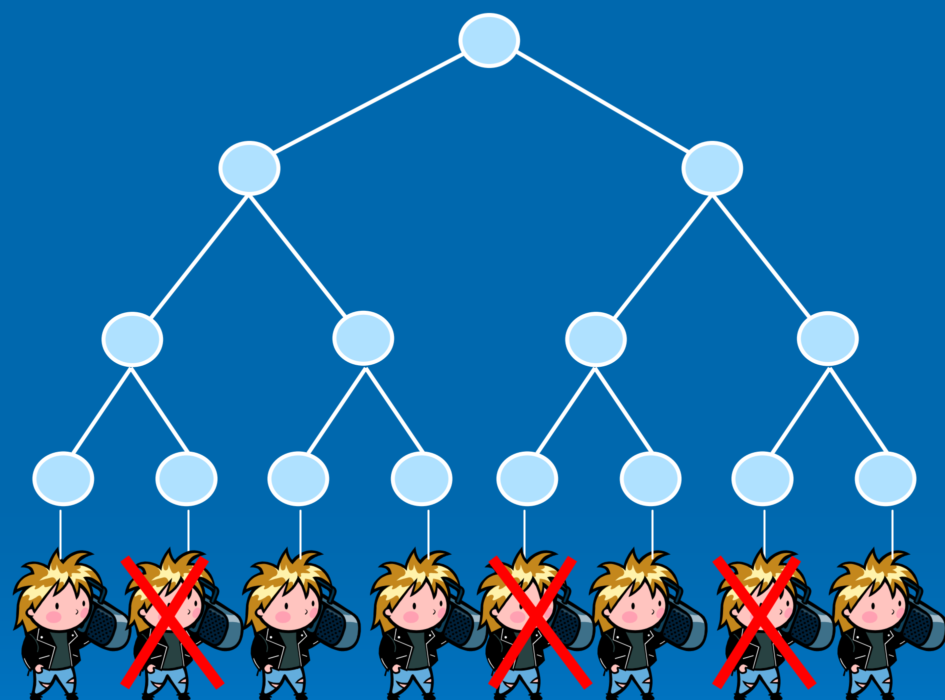
- **Lower-level setup** is used by a node at time *t* to compute keys for its children
  - Generalization of **Root setup**
  - Computes both decryption key at time *t*, and future secrets
- **Update**
  - Similar as in fs-PKE
- **Encrypt**
  - Ciphertext: $O(h \log(N))$
- **Decrypt**
  - Bob's decryption key is used





- Erase intermediate secrets

HIBE in broadcast encryption



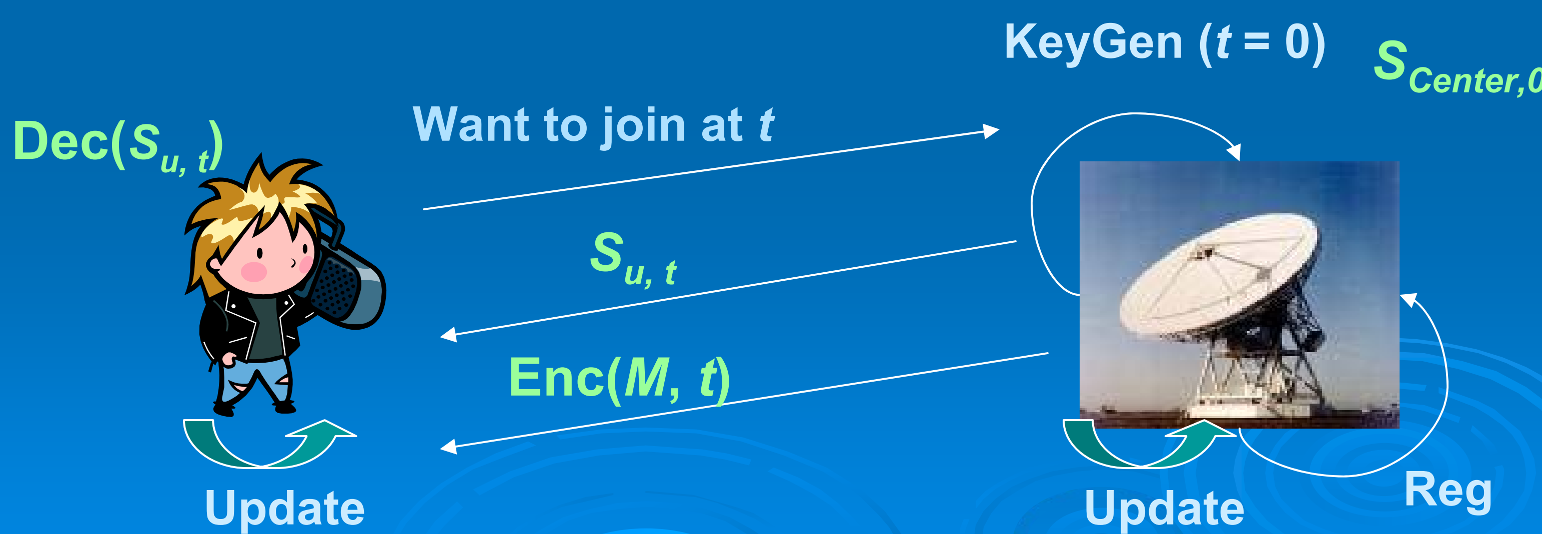
Center

Valid user

Revoked user

Forward-secure broadcast encryption

- Public-key BE by Dodis and Fazio
  - Uses HIBE to implement a subset-cover framework [Naor Naor Lotspiech 01]
- A scalable fs-BE scheme
  - Dynamic joins and joining-time obliviousness
  - Users update secret keys autonomously
- Algorithms: **KeyGen**, **Reg**, **Upd**, **Enc**, **Dec**



Security of fs-HIBE

- "Security definitions"
- Security based on hardness of BDH problem and random oracle model
- **Theorem** *Suppose there is an adaptive adversary A that has advantage ε against one-way secure fs-HIBE targeting some time and ID-tuple at level h, and that makes q_{H2} hash queries to hash function H_2 and q_E lower-level setup queries. Let N be total number of time, $l = \log_2 N$. If H_1, H_2 are random oracles, then exists an algorithm B that solves BDH problem with advantage* $\varepsilon\left(\left(\frac{h+l}{e(2lq_E+h+l)}\right)^{(h+l)/2} - \frac{1}{2^n}\right)/q_{H2}$.