Panel: perspectives and experiences applying EasyCrypt 'outside' the laboratory

First EasyCrypt Workshop

19 July 2013

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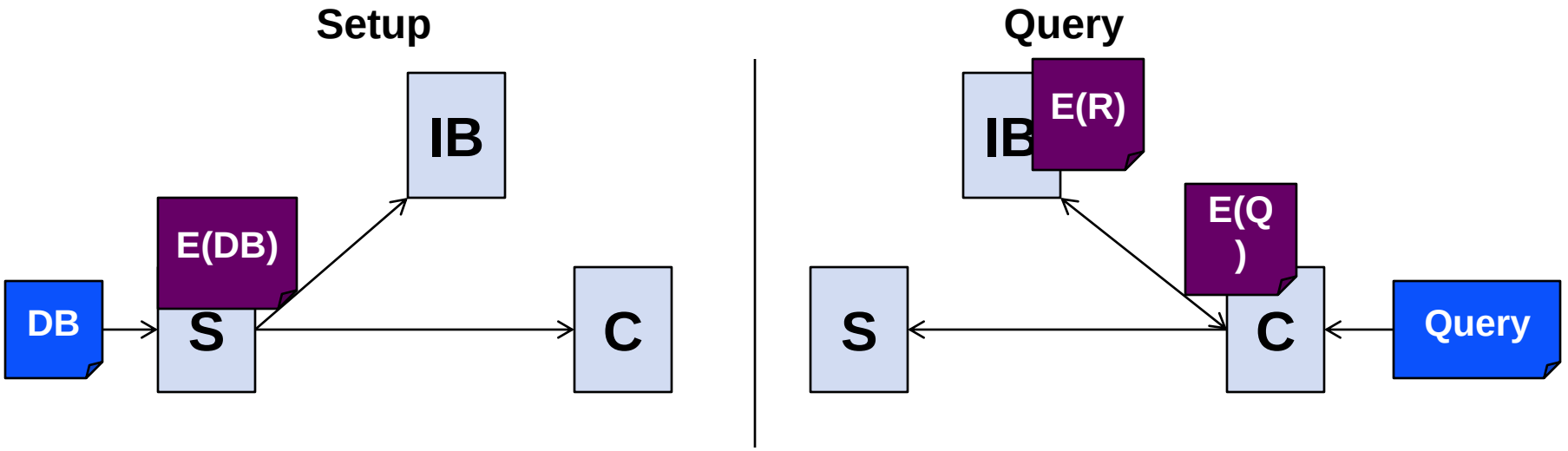
Overview

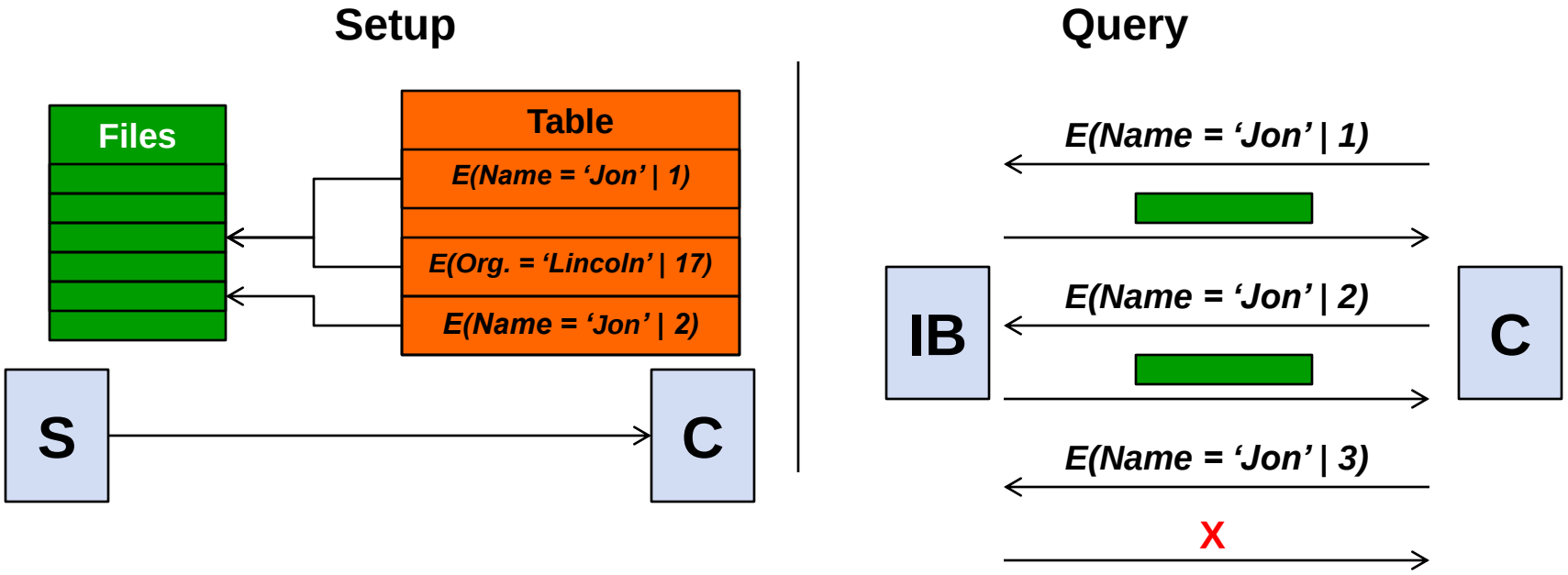
- **Basis for this panel: applying EC to a large protocol**
  - **Large team of cryptographers, formal-methods experts**
    - **No EC developers**
  - **Effort duration of 12 – 18 months**
  - **Attempt to verify 3 security properties from 8-page proof**
- **Successes, new techniques already described in prior (summer school) lecture**
- **This panel: challenges and suggested future directions**
  - **‘Impedance mismatch’ between EC and crypto research**
  - **Understanding provability and truth in EasyCrypt**
  - **The need to tame complexity**
  - **The limits of verification**
- **First, some background**

Privacy-Preserving Information Retrieval



- **Goal: Allow client to query server's database, privately**
  - **Server should not learn query**
  - **Client should not learn database (other than answer to query)**
- **Usually implemented with 'isolated box' (third party)**
  - **Setup: Server sends encrypted DB to IB (plus other communication)**
  - **Client sends encrypted query to IB (plus other communication)**
  - **IB responds with encrypted matching records**

The ‘UC Irvine’ protocol*



- Two *encrypted* data structures
  - Files: encrypted records
  - Table: masked pointers into Files for each valid query
    - To avoid correlations between entries, Table rows given unique ‘counters’
- Protocol: Client makes successive masks for given query
  - Continues sending masks, getting records, until failure

* Privacy-Protecting Information Retrieval, University of Irvine Team: Protocol and Proofs.
Included in Appendix E of Security and Privacy Assurance Research (SPAR) Program Broad Agency Announcement
https://www.fbo.gov/utils/view?id=32750071e5cf4afc3b7e973d608e657e

Notable characteristics and security properties

- **Security properties: the view of each participant should be simulatable given only limited information**
  - **Server's view simulatable from database and the number of queries**
  - **Client's, IB's views similarly simulatable**
- **All proofs: 'real' game indistinguishable from simulated game**
- **Technical ingredients:**
  - **Random oracles, hash functions, and symmetric encryption**
  - **Compound data-structures: databases, queries**
  - **'For' loops over lists (database, Files, Table, etc.)**
  - **'While' loops (client-IB interaction during query)**
  - **Random permutations on lists**
- **Protocols and proofs complex, but not unusually so**

Analysis efforts

- **UC Irvine protocol developed as part of U.S. Gov't project**
  - **Manually reviewed by academic cryptographers**
- **Follow-on project (SPAR) also included new crypto & review**
- **Also included 6-person formal-methods team**
  - **MIT Lincoln Laboratory and Naval Research Laboratory**
  - **Variety of backgrounds: computation crypto, formal methods/PL, CryptoVerif, Dolev-Yao model…**
- **Attempted to verify UC Irvine protocol in EC**

Results (1/2)

- ‘Mini UC Irvine’ (simplified version): 100% complete
- Actual server: 13 games, 4K lines of code, 80% finished
  - 1 prior sequence of games completed, scrapped
- Actual IB: 10+ games, 7.5K lines of code, 66% (?) finished
  - 1 prior sequence of games scrapped after 4 months
  - Unclear how to finish current sequence of games
    - Upcoming transition depends on high-level fact about sets (P-I-E)
- Client: 10 games, ~6K lines of code, 80% finished
  - 500 LOC per completed transition
  - 2 prior proof-sequences scrapped after 4-6 months
  - Will probably need to scrap current game-sequence, too
    - Last transition sound, but no clear way to prove in EasyCrypt

Results (2/2)

- **Main successes (new techniques, 'mini UCI' analysis) already presented in summer-school lecture**
- **Other successes:**
  - **EC helped us find bugs that crept past manual review**
    - **Simulator shuffles DB, real server does not**
    - **Proof written in concrete model, but uses deterministic hash functions**

    Both flaws easily patched, but found due to EC's formalism
  - **Feedback to EasyCrypt developers (modules, instantiation)**
  - **Larger protocols, proofs than previously attempted in EasyCrypt**

- **This panel: constructive look at the negatives**
  - **What were the technical obstacles to our analysis?**
  - **How can these be mitigated?**
  - **Where should EC development go?**

This panel: perspectives and experiences

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(MIT Lincoln Laboratory)

Cathy Meadows
(Naval Research Laboratory)

Aaron Jaggard
(Naval Research Laboratory)

Jon Katz
(University of Maryland)

Jon Herzog
(MIT Lincoln Laboratory)

Adam Petcher
(MIT Lincoln Laboratory)

Note: panelists will present their own opinions

Individual position slides: Jonathan Herzog

Obstacles to success

- **Disclaimer: analysis hindered due to late-in-game ‘course correction’**
  - **Hashing changed from deterministic function to random oracles**
  - **Some prior progress lost, some game-sequences scrapped**
- **But other problems more general, more relevant, and ultimately more important***
- **Chose two to discuss here:**
  - **Specific technical obstacles**
  - **‘Impedance mismatch’ between EC and actual practice of cryptographic proofs**

*** My opinion**

Technical problems

- No way to invoke the generic definition of lower-level primitive
  - 'This transition is a special case of semantic security'
  - Soon moot: 'instantiation' to be provided in future version of tool
- Tracking probability-distributions: how to show these to be equivalent?

```
for (i = 0 to n) {
        key[i] = generate_key();
        ct[i] = enc(key[i],
msg[i]);
        }
```

```
for (i = 0 to n) {
        key[i] = generate_key();
        }
for (i = 0 to n) {
        ct[i] = enc(key[i],
msg[i]);
        }
```

- The 'permutation problem: how to show these are the same?

```
for (i = 0 to n){
        key[i] = generate_key();
        }
```

```
perm = random_permutation(n)
for (i = 0 to n){
        j = perm(i);
        key[j] = generate_key();
        }
```

‘Impedance mismatch’

- **(My) primary problem actually not technical:**
  - **Huge disconnect between EC ‘mindset’ and my actual background**
- **Computational cryptography an incomplete preparation**
  - **Good for devising reasonable-seeming sequence of informal, human-readable games**
  - ***Not at all* good for proving sequence of games in EC**

Typical problem

```
Current goal
Pending subgoals: 1
pre   = true
stmt1 =   1 : (i, l) = A ();
stmt2 =   1 : (i, l) = A ();
          2 : perm = randomPermutation (length (l));
          3 : l = permute (l,perm);
post  = mem (i{1},l{1}) = mem (i{2},l{2})
```

- `auto` **doesn't work.**
- **…Now what?**
  - **Is goal true? Is there a way to prove it from existing lemmas? Do I need to let the SMT solvers run longer? Do I need to add more lemmas? Do I need to add an axiom? How will I be sure it is consistent? Etc. etc. etc.**

Big picture / takeaways

- ***Not*** **saying that EC should require no thought/expertise at all**
- ***Am*** **saying that <u>none</u> of this was covered in my PhD program**
  - **In fact, was implicitly taught to elide over this type of detail**

- ***Predict other working cryptographers will be baffled at how hard it is to prove 'obvious' (i.e., non-cryptographic) steps***
- **Problem at both tactical and strategic levels:**
  - **Unable to answer "how do I prove this specific goal?"**
  - **Also unable to answer "Is this a reasonable sequence of games?"**

- **Need better tactics or library of examples**
  - **To extent possible, allow cryptographers to use EasyCrypt without a second degree in program verification**