Verifying the SET Protocol

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Inductive Protocol Verification

- Define system’s operational semantics
- Include honest parties and an attacker
- Model each protocol step in an inductive definition
- Prove security properties by induction
- Mechanize using Isabelle/HOL

Can Big Protocols Be Verified?

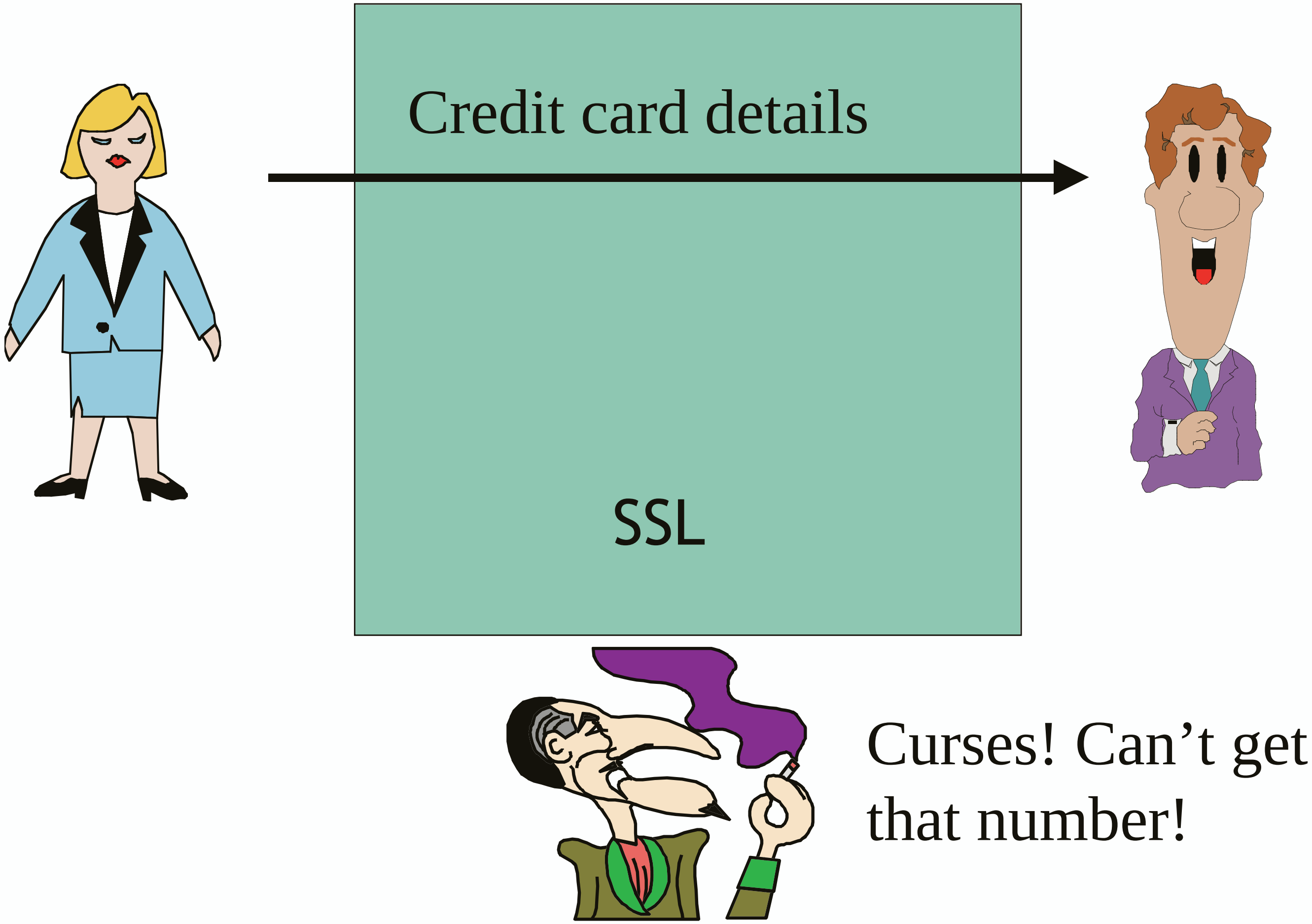
- Can verify some real protocols:
  - Kerberos IV
  - TLS (the new version of SSL)
  - APM's recursive protocol
- Other verification methods available:
  - Model-checking (Lowe)
  - NRL Protocol Analyzer (Meadows)

Growth in Protocol Complexity

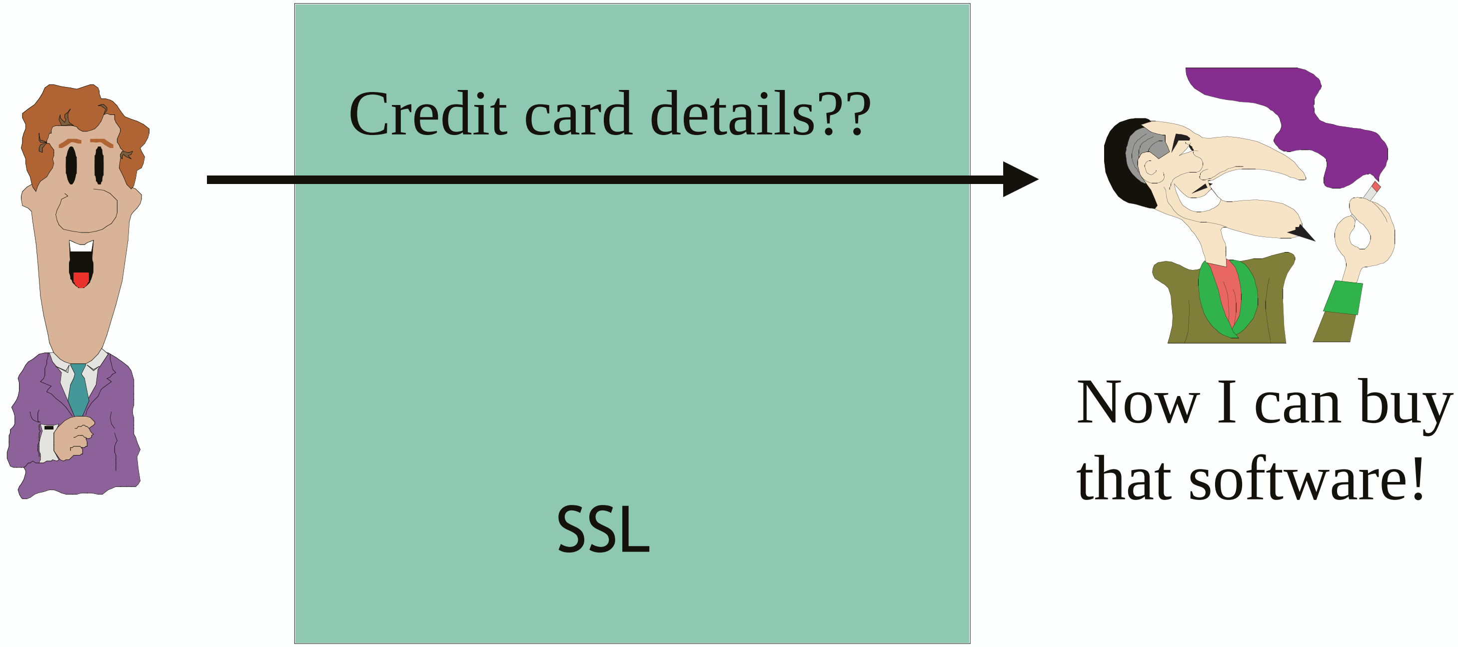
- Needham-Schroeder (1978): 6 pages
- TLS: 80 pages
- SET: 5 main sub-protocols,
  3 manuals, nearly 1000 pages

Why so big?

Internet Shopping with SSL

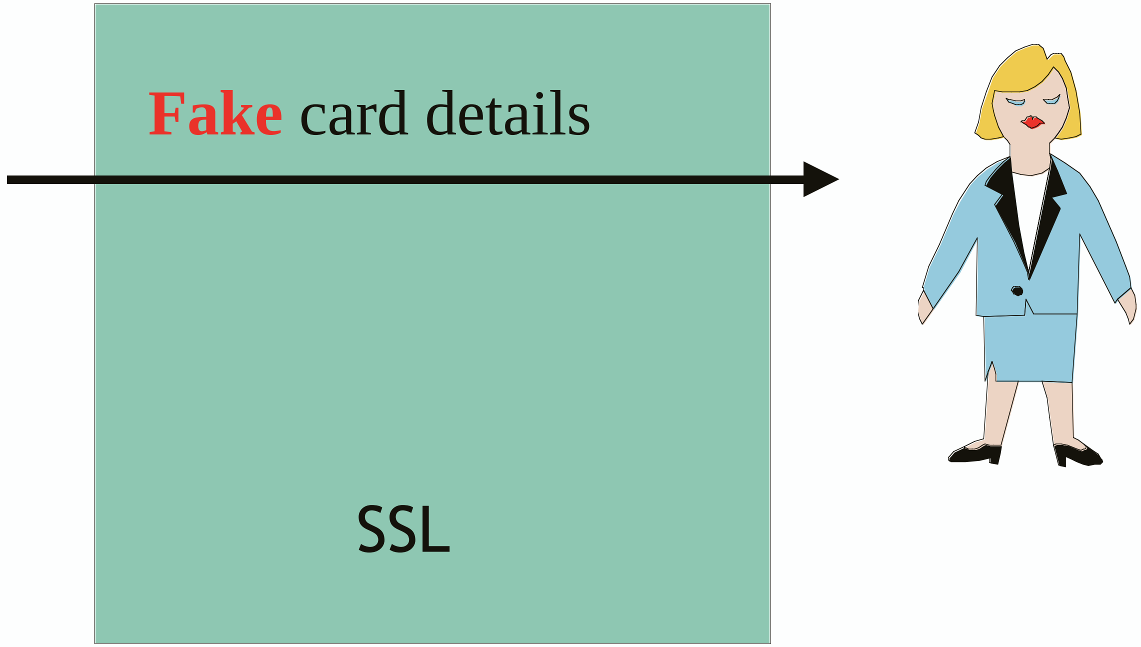


Do We Trust the Merchant?



Do We Trust the Customer?

Send MS Office, charge to my card...



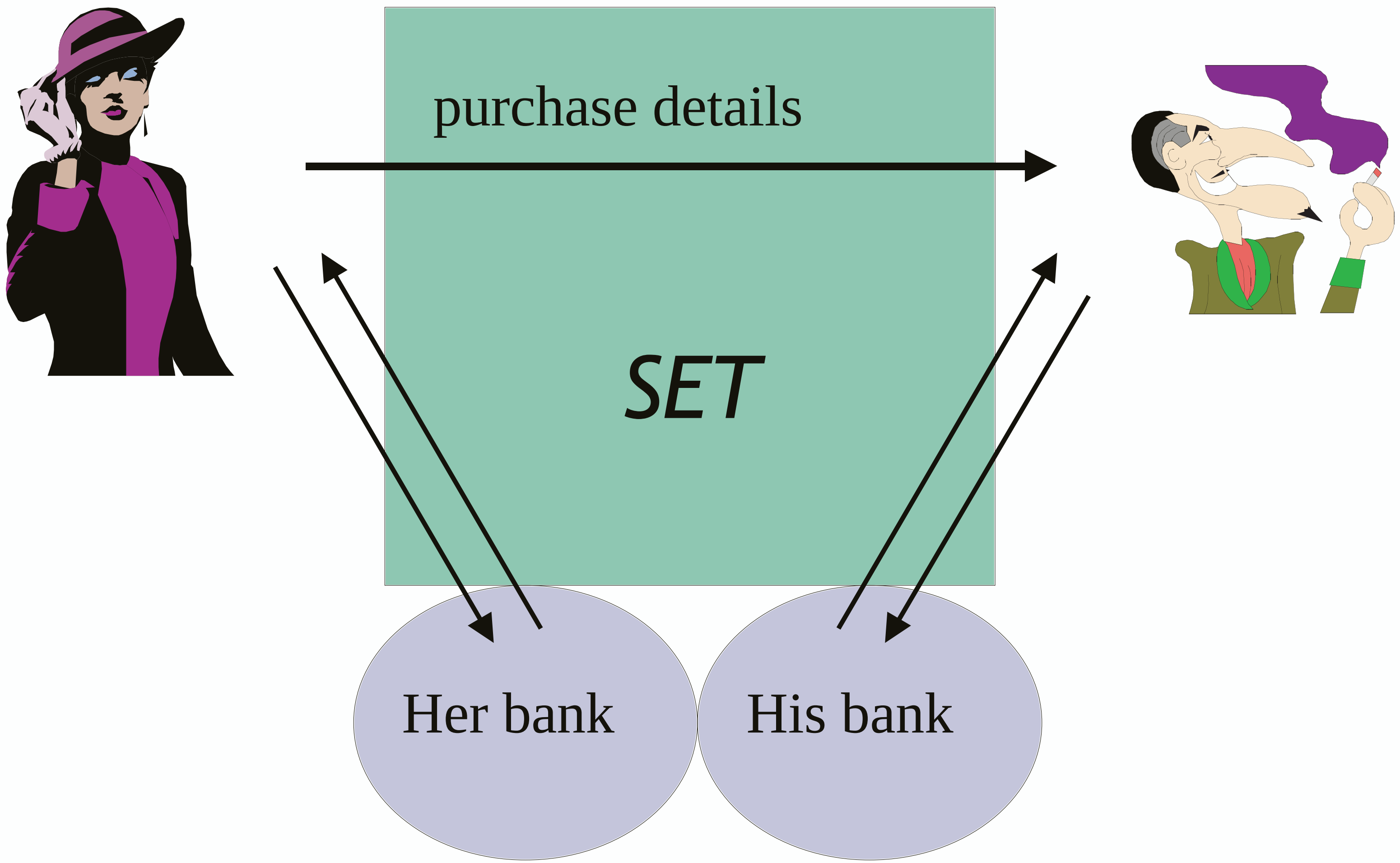
Basic Ideas of SET

- Legitimate Cardholders and Merchants receive electronic credentials
- Merchants don't see credit card numbers (usually!)
- Payment is made via the parties' banks
- Both sides are protected from fraud

SET Participants

- Issuer = cardholder's bank
- Acquirer = merchant's bank
- Payment gateway pays the merchant
- Certificate authority (CA) issues electronic credentials
- Trust hierarchy: top CAs certify others

Internet Shopping with SET



SET Cryptographic Primitives

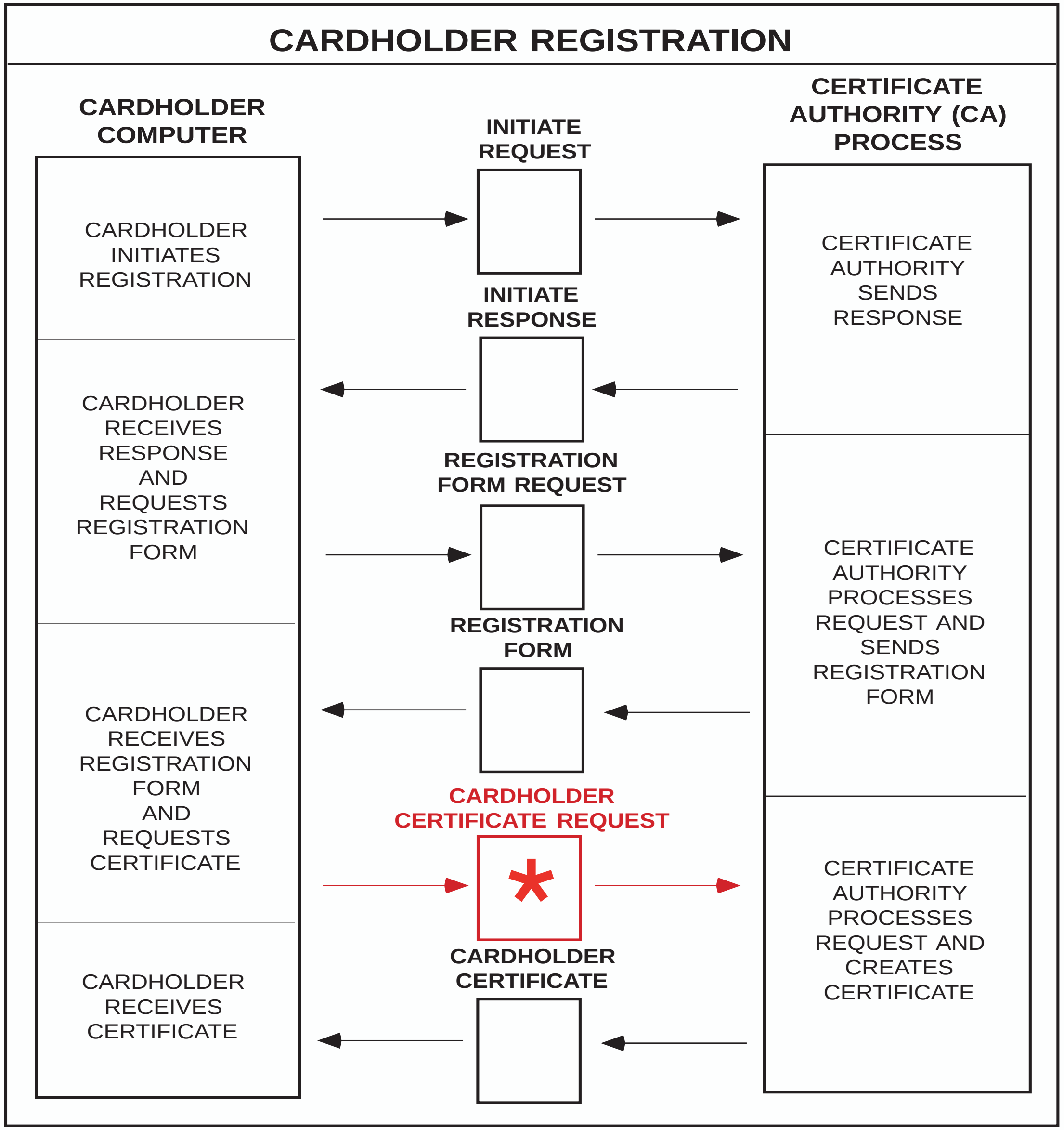
- Hashing, to make message digests
- Digital signatures
- Public-key encryption
- Symmetric-key encryption: session keys

- Digital envelopes involving all of these!
- Deep nesting of crypto functions

The 5 Sub-Protocols of SET

- Cardholder registration ✓
- Merchant registration ✓
- Purchase request
- Payment authorization
- Payment capture

✓ *verified!*



* Let’s look at this message

Message 5 in Isabelle

```
⟦evs5 ∈ set_cr;  C = Cardholder k;
 Nonce NC3 ∉ used evs5;
 Nonce CardSecret ∉ used evs5; NC3≠CardSecret;
 Key KC2 ∉ used evs5; KC2 ∈ symKeys;
 Key KC3 ∉ used evs5; KC3 ∈ symKeys; KC2≠KC3;
 Gets C ...  ∈ set evs5;  Says C (CA i) ...  ∈ set evs5⟧
⟹ Says C (CA i)
      ⦃Crypt KC3 ⦃Agent C, Nonce NC3, Key KC2, Key cardSK,
                  Crypt (invKey cardSK)
                        (Hash⦃Agent C, Nonce NC3, Key KC2,
                              Key cardSK, Pan(pan C),
                              Nonce CardSecret⦄)⦄,
        Crypt EKi ⦃Key KC3, Pan (pan C), Nonce CardSecret⦄⦄
 # evs5 ∈ set_cr
```

What Did That Mean?

- Cardholder had asked to register a PAN (primary account number)
- Cardholder has received the CA's reply
- Cardholder sends a digital envelope:
  - A public signing key, cardSK
  - A message, signed using the private key
  - *Two* session keys (one for the CA's reply)
  - A secret number, CardSecret

Secrecy of the Card Number

- Intuitively obvious: PAN is always hashed or encrypted
- Huge case-splits caused by nested encryptions
- Two lemmas:
  - Session keys never encrypt PANs
  - Session keys never encrypt private keys

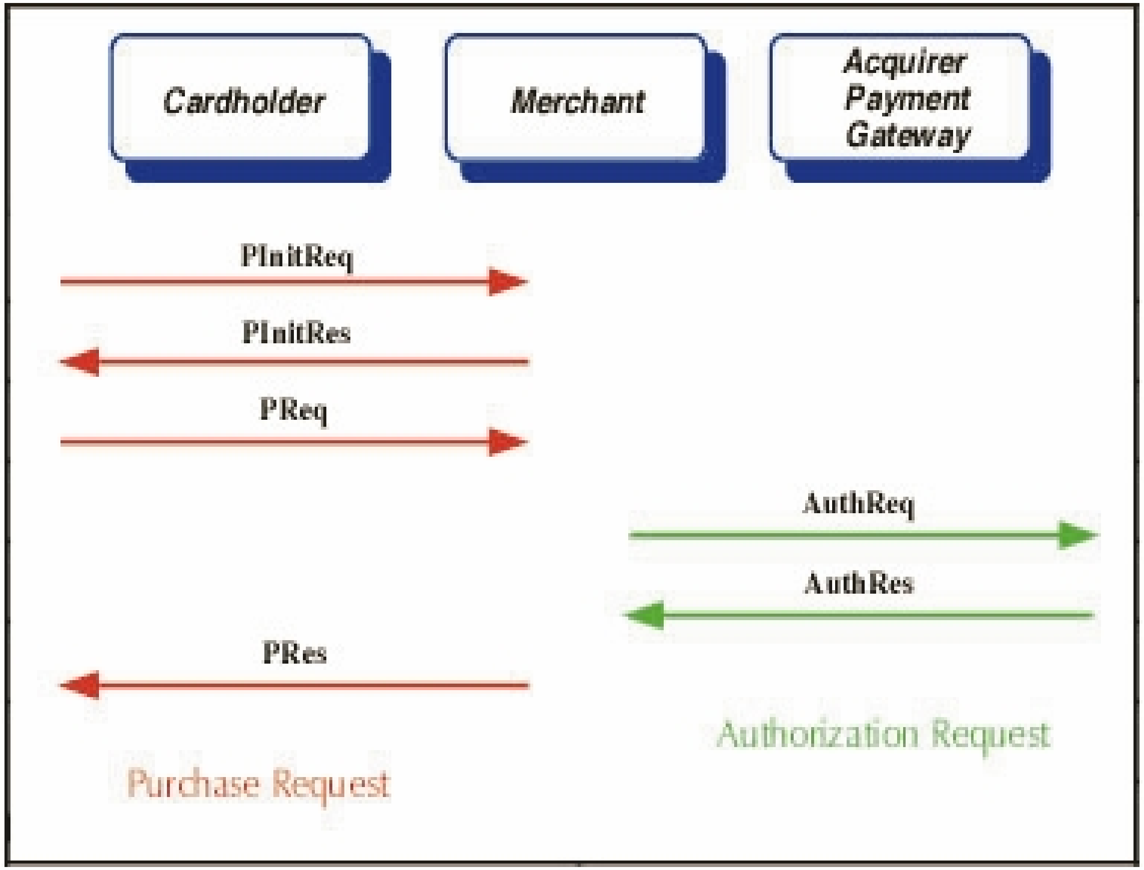
Secrecy of Session Keys

- Three keys, created for digital envelopes
- Dependency: one key protects another
- Main theorem on this dependency relation
- Generalizes an approach used for simpler protocols (Yahalom)

Secrecy of Nonces

- Secret numbers exchanged to generate Cardholder's password
- Protected using those session keys
- Similar to the proofs for keys
- Main theorem about the Key/Nonce dependency relationship

The Purchase Phase!



Novel Aspects of SET Purchase

3-way agreement: with partial knowledge!

- Cardholder shares Order Information only with Merchant
- Cardholder shares Payment Information only with Payment Gateway
- Cardholder signs hashes of OI, PI
- Non-repudiation: all parties sign messages

Complications in SET Purchase

- Massive redundancy: exponential blow-ups
- Insufficient redundancy (no explicitness), requiring toil to prove trivial facts
- Two message flows: signed and unsigned
- Many digital envelopes
- No clear goals: What should I prove??

Conclusions

- Proofs are big, but not too big!
- Can prove secrecy for several keys and nonces, with dependency chains
- Can handle digital envelopes
- Merchant registration verified similarly—Purchase & Payment phases too!