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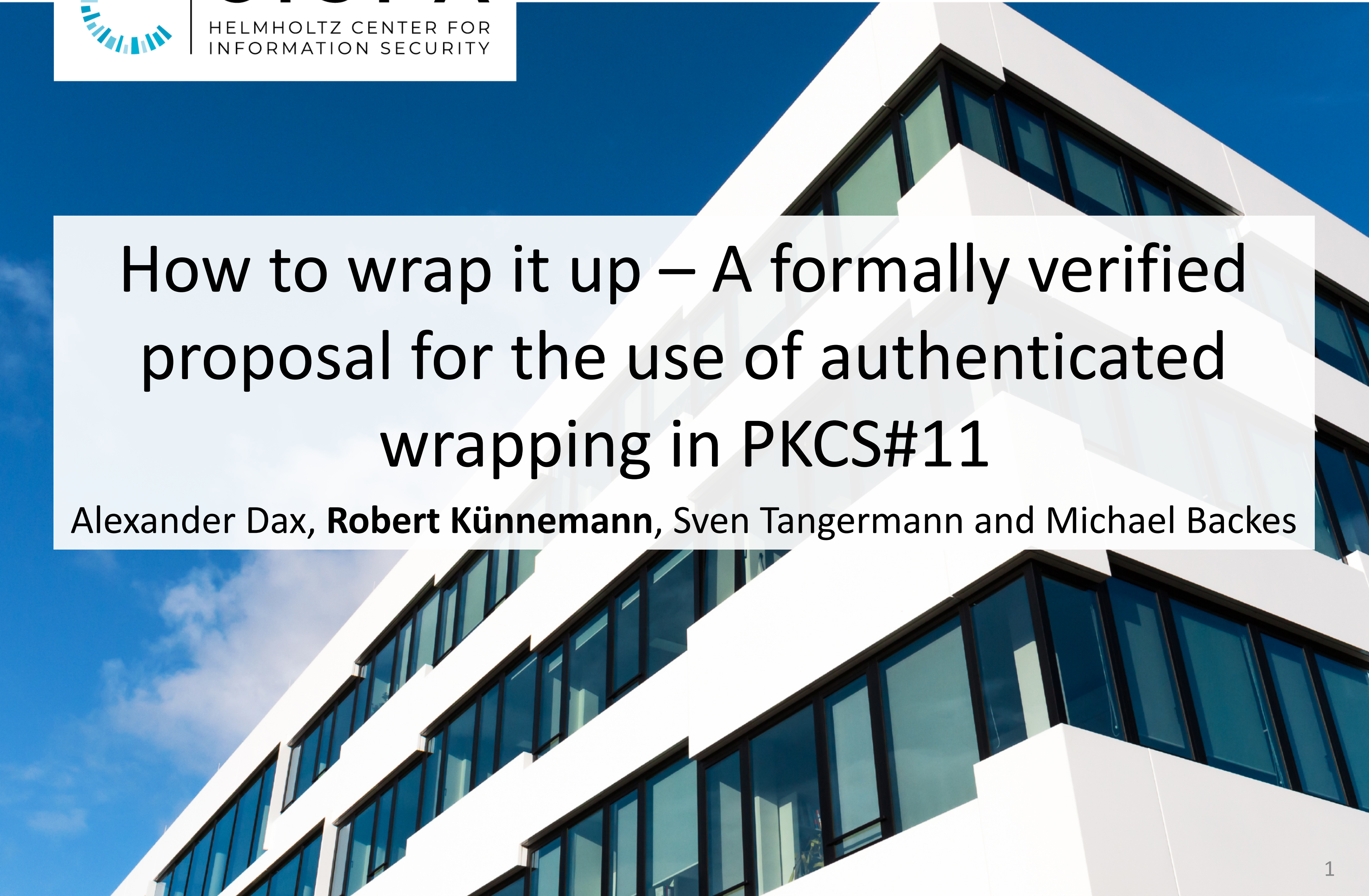
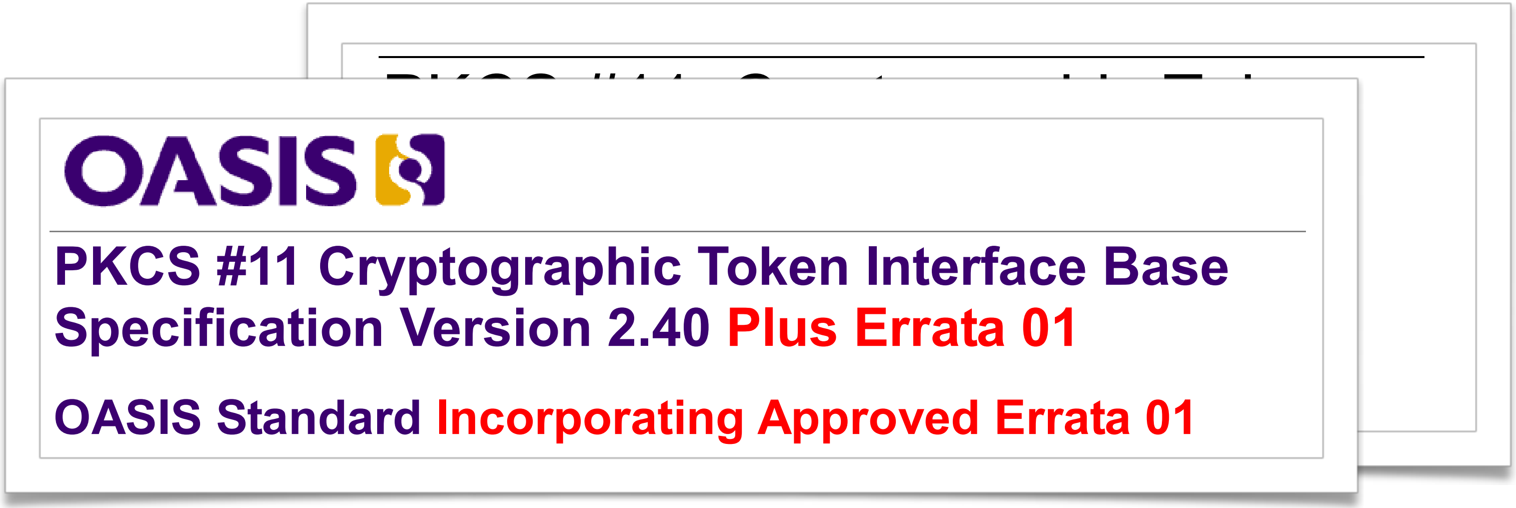


How to wrap it up – A formally verified proposal for the use of authenticated wrapping in PKCS#11

Alexander Dax, **Robert Künnemann**, Sven Tangermann and Michael Backes

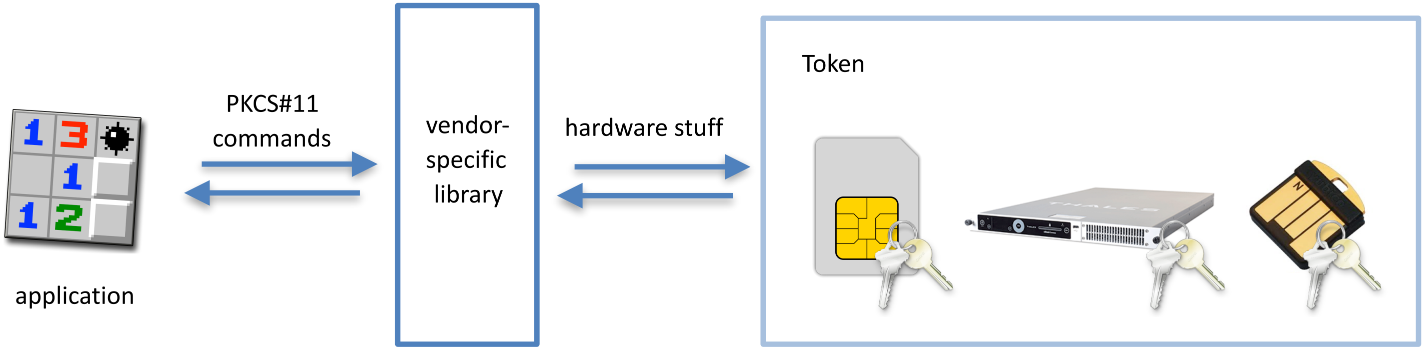
PKCS#11



OASIS

PKCS #11 Cryptographic Token Interface Base Specification Version 2.40 Plus Errata 01

OASIS Standard Incorporating Approved Errata 01



application

PKCS#11 commands

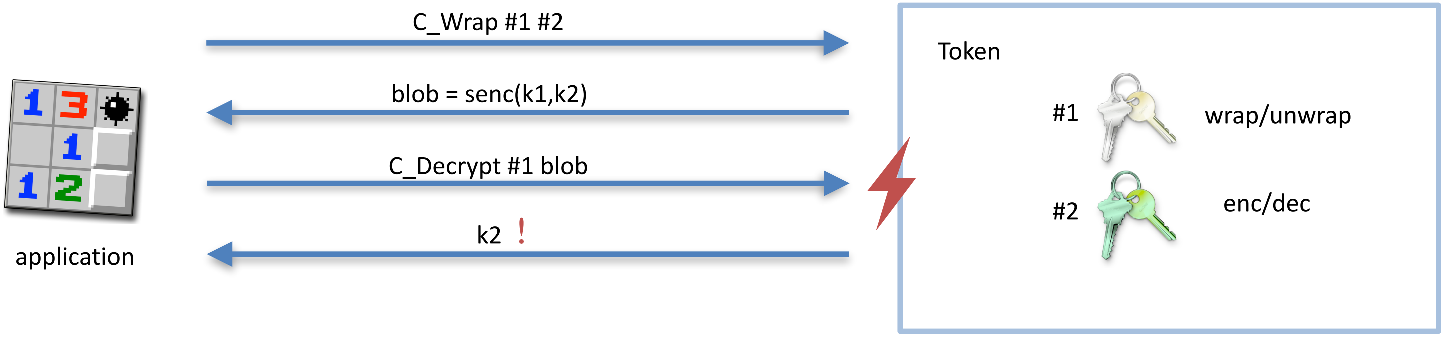
vendor-specific library

hardware stuff

Token

Pictures: Evgeny Karavashkin, Thalyss security and Yubico

PKCS#11 - logical attacks



C_Wrap #1 #2

blob = senc(k1,k2)

C_Decrypt #1 blob

k2 !

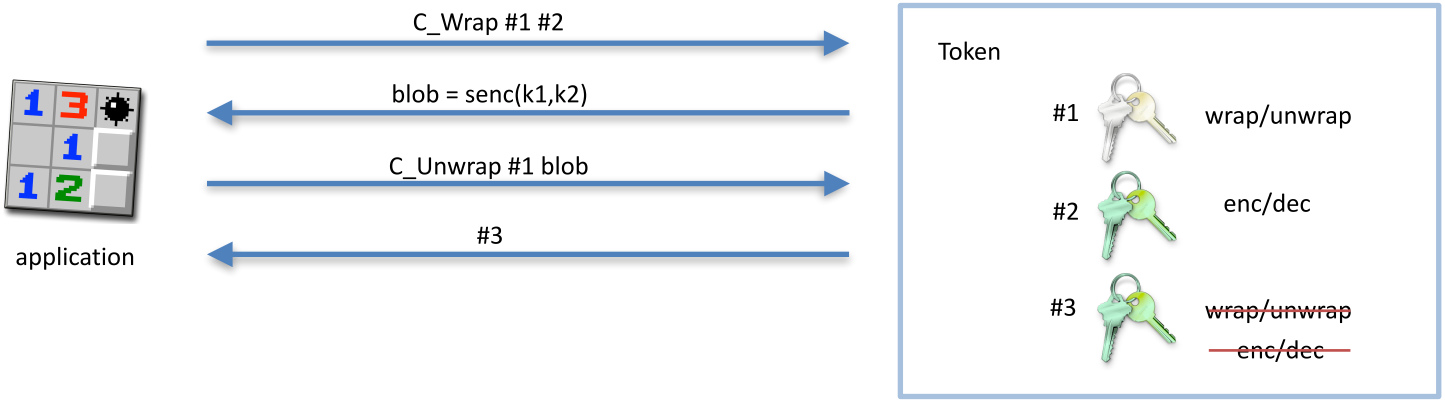
application

Token

#1 wrap/unwrap

#2 enc/dec

PKCS#11 - logical attacks



C_Wrap #1 #2

blob = senc(k1,k2)

C_Unwrap #1 blob

#3

application

Token

#1 wrap/unwrap

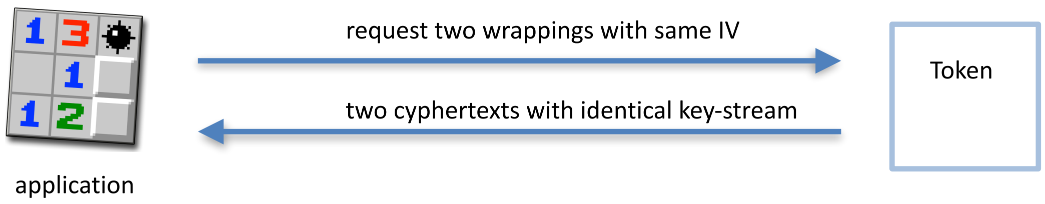
#2 enc/dec

#3 ~~wrap/unwrap~~ ~~enc/dec~~

⇒ need to authenticate attributes!

PKCS#11 - state of key-wrapping

- PKCS#11v2.40 introduces GCM and CCM. The end..?
- .. no, two-pad attack:



request two wrappings with same IV

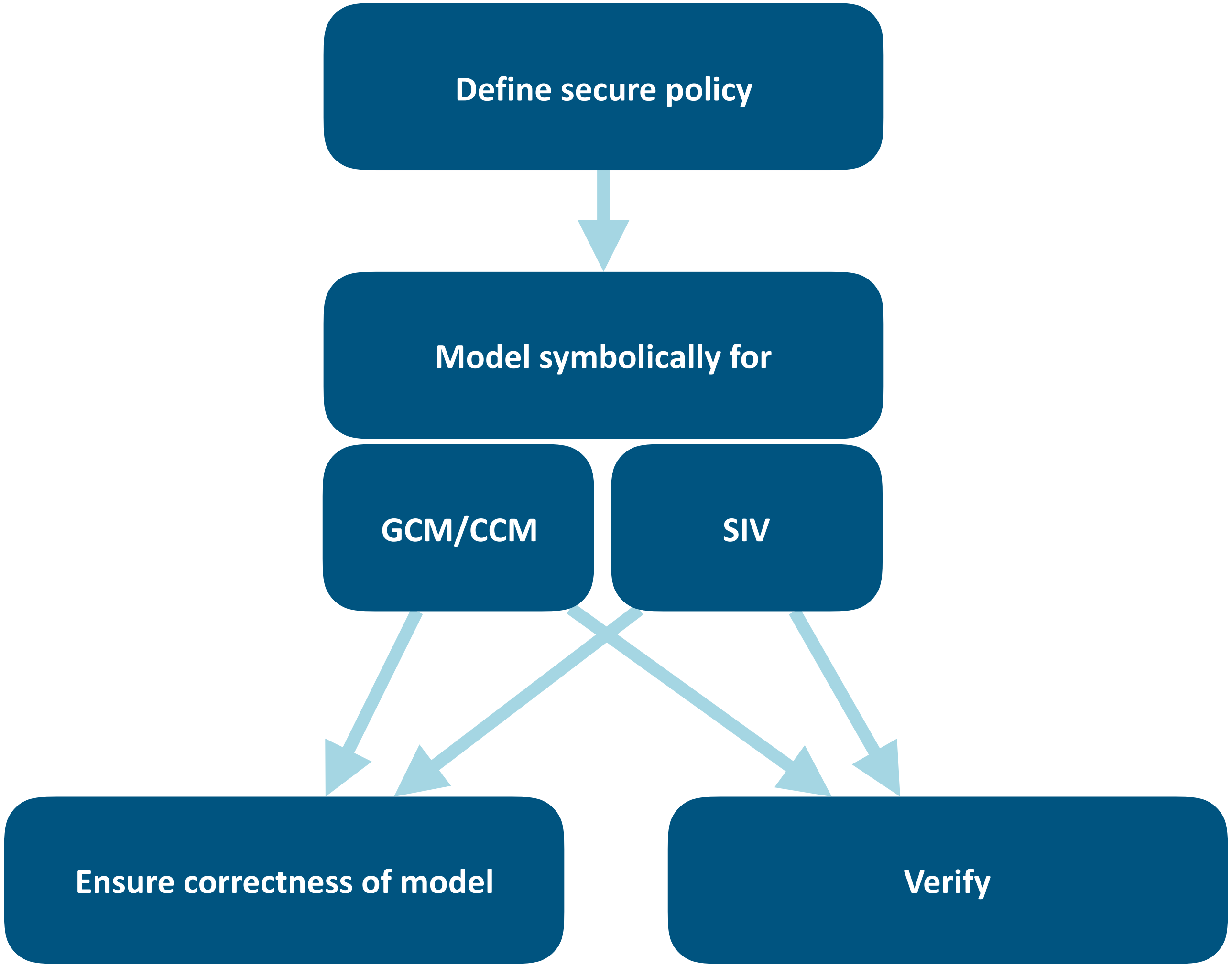
two cyphertexts with identical key-stream

Token

application

- PKCS#11v3.00 in drafting stage:
  - Can we fix this for GCM and CCM?
  - Is SIV (synthetic IV) an alternative?
  - Is authenticated key-wrapping an improvement?

Research goals



Define secure policy

Model symbolically for

GCM/CCM

SIV

Ensure correctness of model

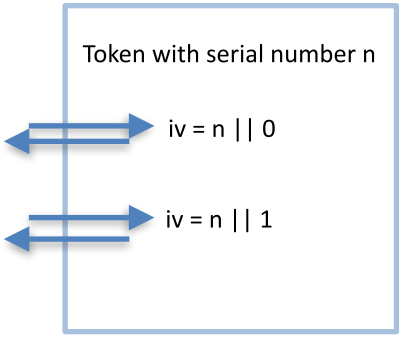
Verify

Policy - key ideas

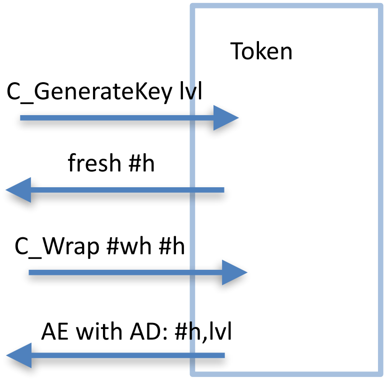
key hierarchy

lvl	type	permitted operations
≥3		management: wrap/unwrap
2		usage: enc/dec,MAC,sig
1	0101 0110 1000 1000	payload

globally unique counters



authenticated handles



- **provably secure:** key-secrecy and handle-integrity
- **more functionality** than other provable secure policies, where either
  - one cannot backup wrapping keys
  - keys have less attributes after unwrapping, they "degrade"
- **downside:** static hierarchy

Policy - relation to PKCS#11 v3.00

- PKCS#11v2.40 added GCM,CCM, but insecurely
- v3.00 in draft:
  - C_Encrypt and C_Wrap key cannot output IV (historically user supplied)
  - new interface C_EncryptMessage specifically for AEAD
    - keep cryptographic state for multiple messages with possibly different IVs, additional data
    - application can request internal IV generation, pointer to IV is thus either input or out parameter
  - need same convention for wrap (not even a new interface!)
  - FIPS basically requires internal IV-generation for GCM

Symbolic modelling

(see paper)

Model: Authenticated encryption

- IV generation is part of protocol, hence IV needs to be exposed
- equational theory:

$$\begin{aligned}
\mathsf{sdec}(k, iv, h, \mathsf{senc}(k, iv, h, m)) &= m \\
\mathsf{sdecSuc}(k, iv, h, \mathsf{senc}(k, iv, h, m)) &= \mathsf{true}() \\
\mathsf{getHeader}(\mathsf{senc}(k, iv, h, m)) &= h \\
\mathsf{getIV}(\mathsf{senc}(k, iv, h, m)) &= iv
\end{aligned}$$

- sound for GCM, CCM, SIV?
- DAE-N security: $A^{O_k^{Enc}(\cdot,\cdot,\cdot), O_k^{Dec}(\cdot,\cdot,\cdot)} \approx A^{\$(\cdot,\cdot,\cdot),\perp(\cdot,\cdot,\cdot)}$ as long as A does not reuse IVs or query previous encryptions.
- GCM and CCM are AEAD secure implies DAE-N security.

Deduction soundness

- **Intuition:** computational adversary can only deduce information if the symbolic adversary can, too.

- **Pro:** composability, thus lots of PKCS#11 functionality covered
- **Contra:** covers only secrecy, not integrity. necessary, but not sufficient

- **Approach:**
  - assume injective function mapping terms to IVs (e.g., concat)
  - as IVs have fixed length, domain needs to be finite
  - impose use of this function at IV position
  - protocol condition: uniqueness of terms given to this function

Deduction soundness - proof obligations

☑ keys only at key position or within wrapping

.. no dynamic corruption :(

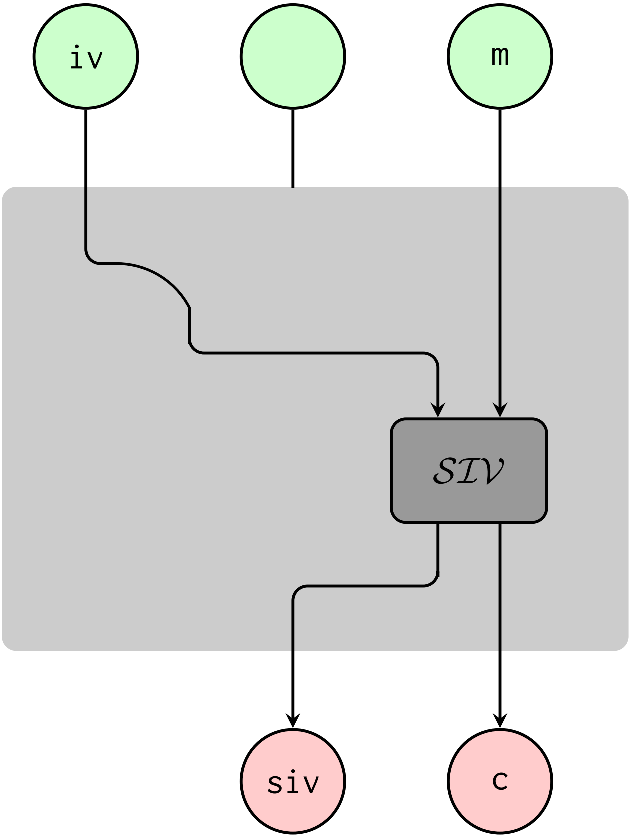
☑ no key-cycles

□ each term at IV position is unique

☛ to check

What about SIV mode?

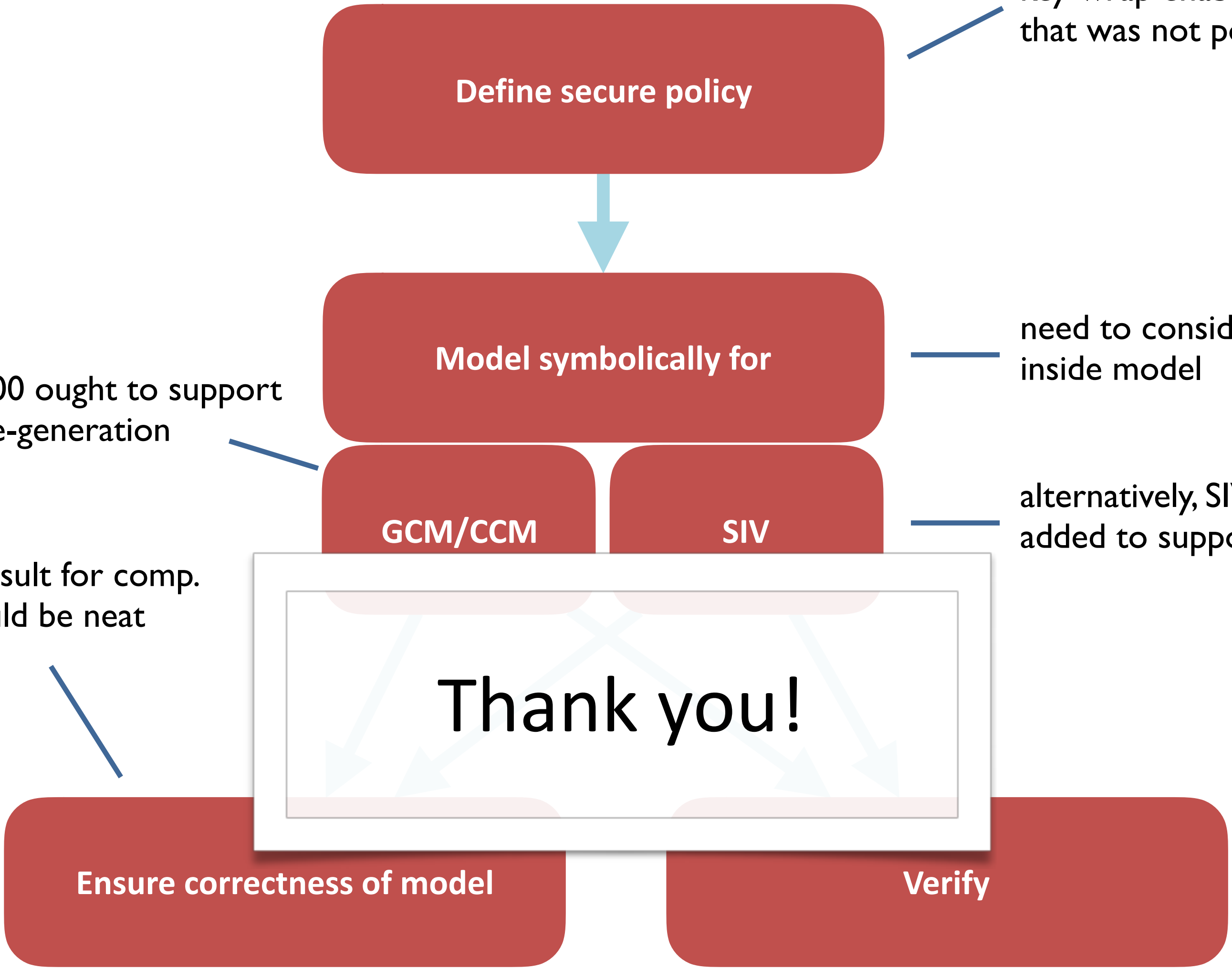
- if we prepend IV to header, SIV is DAE-N secure
- but if protocol always sets h:=ε, construction vanishes
- we obtain model for SIV mode without need for deduction soundness result by writing senc(k,<iv,h>,ε,m) in place of senc(k,iv,h,m)
- PKCS#11v3.00 draft: interface spec would be fine, but SIV not part of "current mechanisms"



Verification

- IV uniqueness
- key-integrity: all keys are created on some device
- key-secrecy: no key can ever leak
- handle-integrity: keys retain the handle (and level) they were created with
- total verification time: 3mins (GCM/CCM), 3.5 min (SIV)
- three helping lemmas

Wrap-up & Take-away



Define secure policy

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Thank you!

key-wrap enables functionality that was not possible before

need to consider IV generation inside model

alternatively, SIV mode could be added to supported mechanisms

PKCS#11 v3.00 ought to support internal nonce-generation

composition result for comp. soundness would be neat