

Direct Anonymous Attestation & TPM2.0

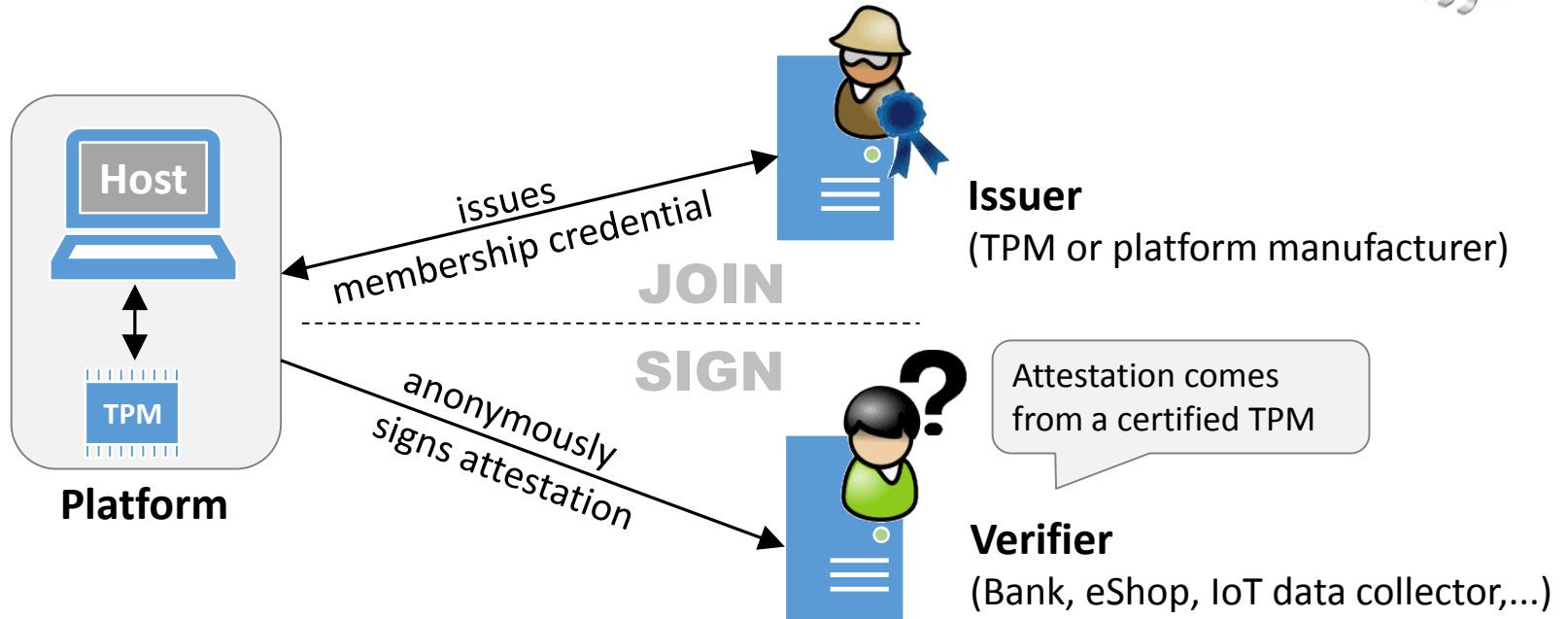
Getting Provably Secure Crypto into the Real-World

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- **Trusted Platform Module (TPM)**

- Secure crypto processor: creates, stores, uses cryptographic keys
- Makes remote attestations of host status

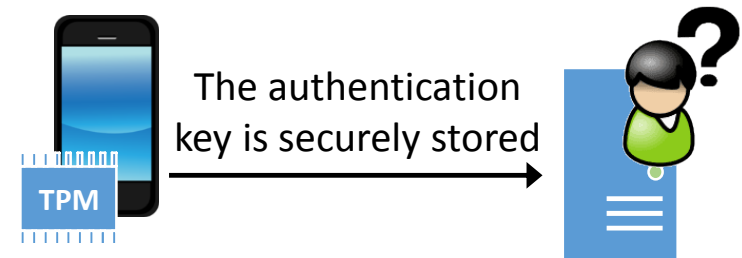
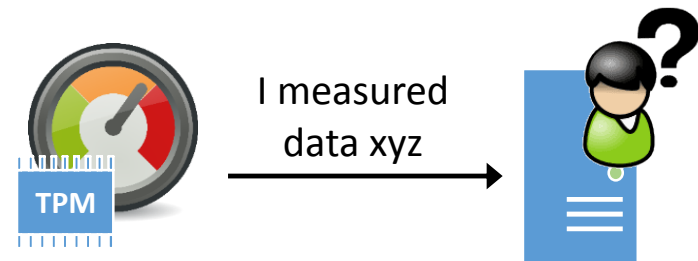




- Standard certificates would make all attestations linkable and reveal TPM's ID

- **Direct Anonymous Attestation (DAA)**

- Security properties: unforgeability, anonymity & unlinkability, non-frameability

- First DAA protocol by Brickell, Camenisch, Chen [BCC04]
 - RSA-based
 - Standardized in TPM1.2 (2004) & ISO/IEC 20008-2
- Revised TPM2.0 (2014)
 - Elliptic curve & pairing based
 - Flexible API to support different protocols
 - TPM part & protocols ISO standardized
 - ISO/IEC 20008-2
 - ISO/IEC 11889
- Over 500 million TPMs sold
- Today: Interest in TPM revived
 - Security of mobile and IoT devices
 - FIDO authentication
 - SGX & EPID



- What is needed to make DAA a provably secure real-world protocol?
 1. Security Model

 2. Provably Secure Cryptographic Protocol (secure according to 1.)

 3. Secure Implementation (of 2.)

...lets see where we are now, 12 years after DAA was invented

Simulation-based Definitions

- Brickell, Camenisch, Chen [BCC04]
 - Does not output signatures
 - Prohibits working with signatures in practice
- Chen, Morissey, Shi [CMS10]
 - Output signatures = random values
 - Not realizable by *any* construction
- Camenisch, Drijvers, Lehmann [CDL16a]
 - Security model in UC Framework
 - TPM and host separate parties
 - Signatures modeled as concrete values – for random TPM keys

Game-based Definitions

- Brickell, Chen, Li [BCL09]
 - Trivially forgeable scheme can be proven secure
 - No property for non-frameability
- Camenisch, Drijvers, Lehmann [CDL16a]
 - Same unforgeability flaw as [BCL09]
- Bernhard et al. [BFG+13]
 - Discuss flaws in all previous models
 - Extensive set of definitions for all expected properties
 - But for “pre-DAA”, where TPM + host are one party → does not cover honest TPM in corrupt host

All existing security definitions had issues, some of them severe, allowing for insecure schemes!

- What is needed to make DAA a provably secure real-world protocol?

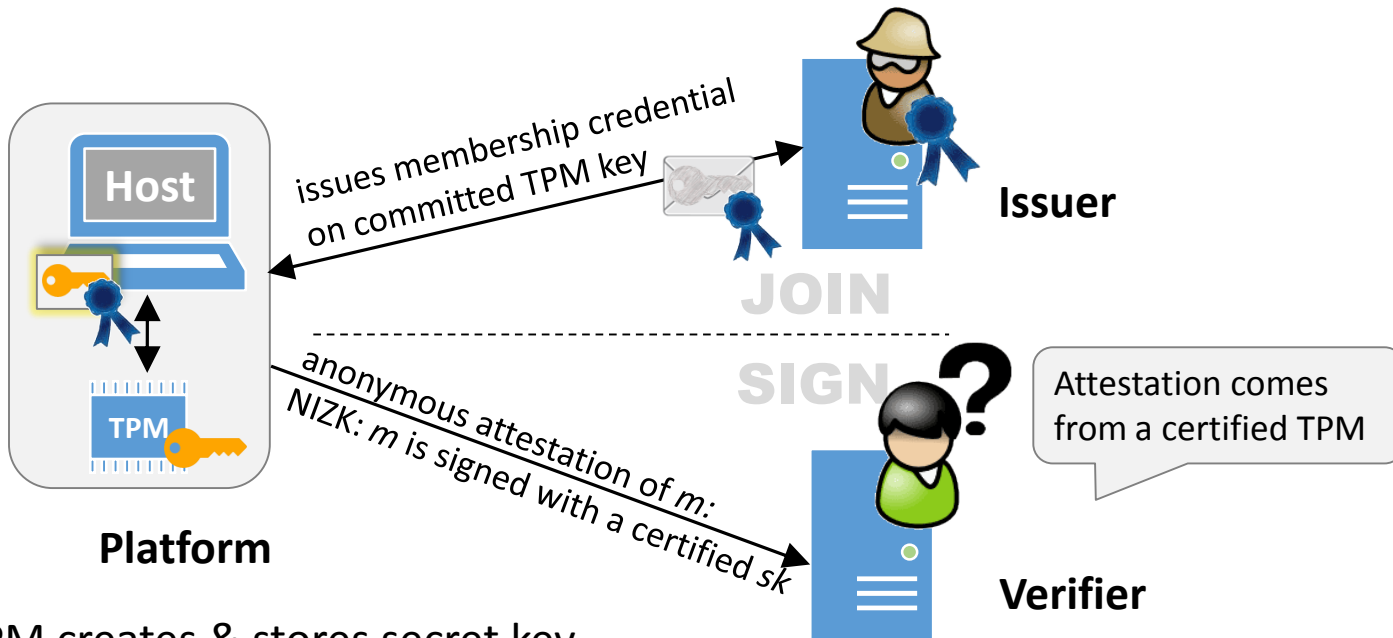
1. Security Model



2. Provably Secure Cryptographic Protocol (secure according to 1.)



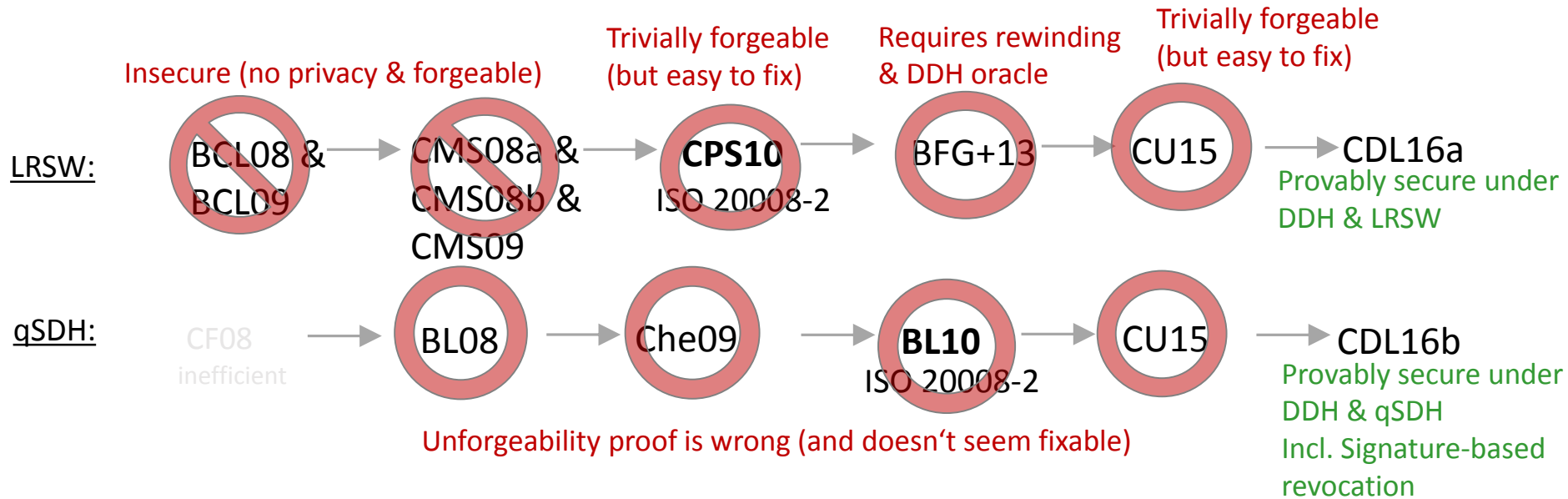
3. Secure Implementation (of 2.)



TPM creates & stores secret key
Host stores membership credential

- DAA protocols mainly differ on how the membership credential & NIZK is computed
- First protocol [BCC04] based on RSA, standardized in TPM1.2 (very slow)
- Subsequent DAA protocols & TPM2.0 based on elliptic curves and pairings

- TPM2.0 offers generic APIs to support various schemes, e.g., DAA based on LRSW (CL-signature) & qSDH (BBS+ signature)



- All existing schemes are either insecure, or cannot be proven secure
 - (1, 1, 1, 1) is a valid credential on *any* key in [CPS10] – ISO 20008 standardized!
- Revised provably secure protocols [CDL16a, CDL16b]
 - as efficient as existing schemes – mainly details had to be fixed

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1. Security Model



2. Provably Secure Cryptographic Protocol (secure according to 1.)



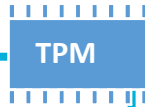
3. Secure Implementation (of 2.)

Efficient protocol, lightweight part for TPM Done!



Our real-world: TPM = lightweight device

Real real-world: TPM accessible via few, limited APIs



TPM.Create()

draw $sk \in \mathbb{Z}_q$, store sk
 output $pk \leftarrow g^{sk}$

TPM.Hash(t, m)

output $c \leftarrow H(t, m)$

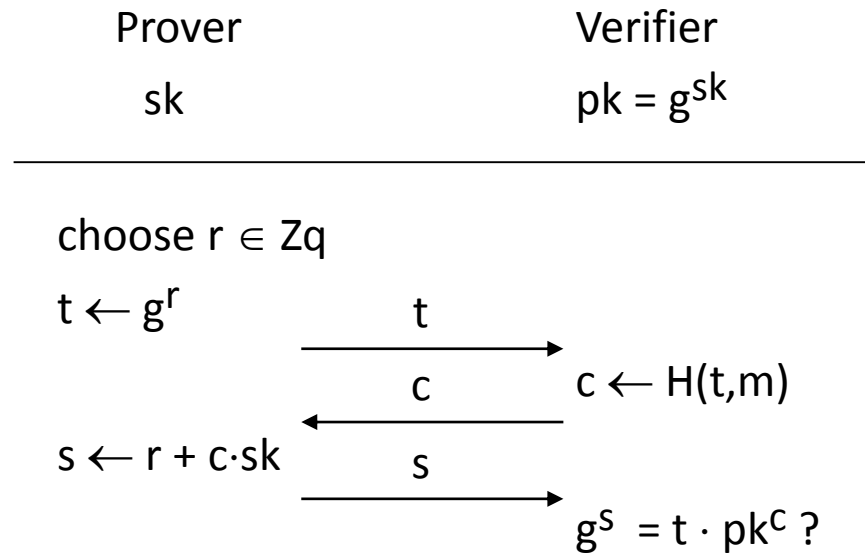
TPM.Commit(P)

choose $r \in \mathbb{Z}_q$, store (ctr, r)
 $t \leftarrow P^r$
 output (ctr, t)

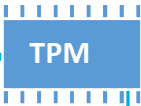
TPM.Sign(c, ctr)

get (ctr, r)
 output $s \leftarrow r + c \cdot sk$

(Signature) Proof-of-Knowledge:



- Both revised protocols are not compatible with current TPM2.0 interfaces
- Protocols designed to avoid a static Diffie-Hellman oracle – but TPM2.0 is one



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TPM2.0 interfaces provide **static Diffie-Hellman Oracle**

- DH oracle via Commit, Hash & Sign query:

$$p^{sk} \leftarrow (P^s / t)^{1/c}$$

For **arbitrary P** chosen by (corrupt) host

- Get TPM to compute $g^{sk}, g^{sk^2}, g^{sk^3} \dots g^{sk^n}$
- Static DH oracle significantly reduces security level,
e.g., 256bit BN curve: 128bit security reduced to 85bit

TPM interfaces should be revised to remove the static DH oracle!



TPM.Create()

draw $sk \in \mathbb{Z}_q$, store sk
output $pk \leftarrow g^{sk}$

TPM.Hash(t, m)

output $c \leftarrow H(t, m)$

TPM.Bind(P, K, π)

verify that π is valid
store P as „cleared point“

TPM.Commit(P)

abort if P is not a cleared
choose $r \in \mathbb{Z}_q$, store (ctr, r)
 $t \leftarrow P^r$
output (ctr, t)

TPM.Sign(c, ctr)

get (ctr, r)
output $s \leftarrow r + c \cdot sk$

Cleared Generators (Xi et al. [XYZF14])

- Generator has form $P = g^y$
- Issuer knows y ... And therefore $K = P^{sk} = pk^y$
 $\pi \leftarrow \text{SPK}\{(y): P = g^y \text{ and } K = pk^y\}$

Random (Hashed) Generators

- P is chosen at random, input to attestation
- Use $P \leftarrow H(\text{bsn})$ for random bsn

TPM.Commit2(bsn)

choose $r \in \mathbb{Z}_q$, store (ctr, r)
 $P \leftarrow H(\text{bsn})$, $t \leftarrow P^r$
output (ctr, t)

OK, but only if it can be used for qSDH & LRSW DAA!

TPM

TPM.Create()

draw $sk \in \mathbb{Z}_q$, store sk
output $pk \leftarrow g^{sk}$

TPM.Hash(t, m)

output $c \leftarrow H(t, m)$

TPM.Commit(bsn)

choose $r \in \mathbb{Z}_q$, store (ctr, r)
 $P \leftarrow H(bsn)$, $t \leftarrow P^r$
output (ctr, t)

TPM.Sign(c, ctr)

get (ctr, r)
output $s \leftarrow r + c \cdot sk$

Revised TPM2.0 interfaces w/o static DH

Re-revised provably secure LRSW/qSDH-DAA

Are we done now?

Are the TPM-based contributions unforgeable & anonymous

- Chen, Li [CL13]
 - Proof that TPM2.0 generated SPKs are unforgeable
- Xi et al. [XYZF14]
 - Proof by [CL13] is wrong
 - Unforgeability cannot be proven



TPM.Create()

draw $sk \in \mathbb{Z}_q$, store sk
output $pk \leftarrow g^{sk}$

TPM.Hash(t, m)

output $c \leftarrow H(t, m)$

TPM.Commit(bsn)

choose $r \in \mathbb{Z}_q$, store (ctr, r)
 $P \leftarrow H(bsn)$, $t \leftarrow P^r$
output (ctr, t)

TPM.Sign(c, ctr)

get (ctr, r)
random n , $c' \leftarrow H(n, c)$
output **n , $s \leftarrow r + c' \cdot sk$**

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 - Proof by [CL13] is wrong
 - Unforgeability cannot be proven
 - Simple Fix: add nonce and hash



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output $pk \leftarrow g^{sk}$

TPM.Hash(t, m)

output $c \leftarrow H(t, m)$

TPM.Commit(bsn)

choose $r \in \mathbb{Z}_q$, store (ctr, r)
 $P \leftarrow H(bsn)$, $t \leftarrow P^r$
output (ctr, t)

TPM.Sign(c, ctr)

get (ctr, r)
random n , $c' \leftarrow H(n, c)$
output **n** , $s \leftarrow r + c' \cdot sk$

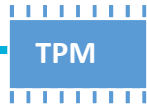
Revised TPM2.0 interfaces w/o static DH

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The TPM-based contributions are unforgeable & anonymous

- Fix by Xi et al. introduces subliminal channel!



TPM.Create()

draw $sk \in \mathbb{Z}_q$, store sk
output $pk \leftarrow g^{sk}$

TPM.Hash(t, m)

output $c \leftarrow H(t, m)$

TPM.Commit(bsn)

random $nT, hT \leftarrow H(nT)$

choose $r \in \mathbb{Z}_q$, store (ctr, r, nT)

$P \leftarrow H(bsn), t \leftarrow P^r$

output (ctr, t, hT)

TPM.Sign(c, ctr, nH)

get (ctr, r, nT)

$c' \leftarrow H(nH \oplus nT, c)$

output $nT, s \leftarrow r + c' \cdot sk$

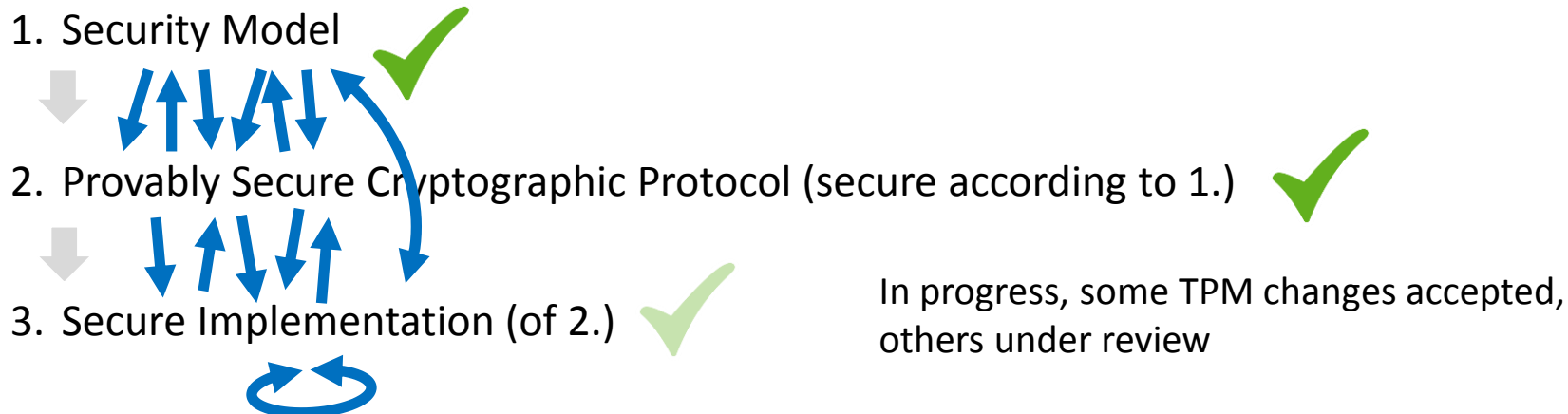
Revised TPM2.0 interfaces w/o static DH

Re-revised provably secure LRSW/qSDH-DAA

Are we done now?

The TPM-based contributions are unforgeable & anonymous

- Fix by Xi et al. introduces subliminal channel!
- New fix: use nonce jointly computed by host and TPM



Next Steps:

- Continue work with TCG on revision of TPM2.0 APIs
- Working to get flawed ISO standards fixed
- Working with Intel on revision of EPID spec
- FIDO key attestation spec using DAA

Conclusions:

- Provably secure crypto and real-world should be compatible
- Ideally, provable security from the beginning – a number of standards have issues!
- It often takes far longer than one would expect & still not done

Thanks!

Based on joint work with Jan Camenisch, Liqun Chen, Manu Drijvers, David Novick, Rainer Urian

Questions?

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ia.cr/2016/663
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