Using the TPM: Machine Authentication and Attestation

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Day 2

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What We'll Cover

- Review and deep dive: PCRs and Locality
- Attestation
- Machine authentication

PCR Review

- Series of 20-byte registers (length of a SHA-1 hash)
- Most modern TPMs have 24; older ones have 16
- Addressed by number: PCR-0, PCR-1, etc.
- Used primarily to store system measurements
- Reset to known value on every boot
- Can never be freely overwritten; use special extend, reset operations
- Easy to check; computationally infeasible to forge

Digging a Little Deeper: PCR Extend

The only way to *add* data to a PCR is with `TPM_Extend`

- Current value of a PCR is X. (Say, 0x0000....0000.)
- We extend the PCR with some data Y.
  - Y must be 160 bit (20 byte) value
  - 20 bytes = SHA1 hash, allowing longer data
- TPM calculates hash(Y,X)=Z; changes value in PCR to Z.
- We can update further:
  - Extend with A: value is hash(A,Z)=hash(A, hash(Y,X))
  - Extend with B: PCR value is hash(B, hash(A,Z))
  - ...etc.
- Verifiers who know the values extended into the PCRs can easily verify
  - Perform the same hash chain themselves
- Computationally infeasible to forge (must break SHA-1)
  - Given PCR state N and desired state M, adversary would need to find X such that hash(X,N)=M; violates one-way assumption

Digging a Little Deeper: PCR Reset

Some (but not all) PCRs are *resettable*.

This means they can be reset to a known state by executing the `TPM_PCR_Reset` command.

- Whether a given PCR is resettable or not is defined in platform spec
  - All PC client TPMs have the same settings
  - Server or virtual TPMs could differ; specs do not exist yet
- Reset requires appropriate permissions
  - Usually based on *locality*, which we'll discuss next
- Sets PCR value back to default, erasing all data currently present
  - Either 0x000...000 or 0xFFF...FFF, depending on PCR & machine state

Locality

What is locality?

- Primitive caller-based access control for TPM
- Based on CPU state, flags on memory pages
  - If you're familiar with OS rings, similar concept
- PCRs provide state check; locality says "who sent this command?"
  - Even if my OS is in approved state, random apps shouldn't be able to use OS' keys
- Used to regulate access to PCRs
- Locality checked whenever PCR state checked
- Not utilized much today outside DRTM

Locality in Theory

Locality	Meaning
4	Trusted Hardware/DRTM
3	Auxiliary Components/DRTM
2	Trusted OS
1	Trusted Applications
0	Static RTM/Legacy

Locality in Practice

Locality	Meaning
4	Trusted Hardware/DRTM
3	Software launched by DRTM
2	Controlled by OS/TPM Driver
1	Controlled by OS/TPM Driver
0	SRTM; Default

PCR Usage

PCR Index	Alias	pcrReset	pcrResetLocal for Locality 4, 3, 2, 1, 0	pcrExtendLocal for Locality 4, 3 ,2, 1, 0
0 – 15	Static RTM	0	0,0,0,0,0	1,1,1,1,1
16	Debug	1	1,1,1,1,1	1,1,1,1,1
17	Locality 4	1	1,0,0,0,0	1,1,1,0,0[2]
18	Locality 3	1	1,0,0,0,0	1,1,1,0,0
19	Locality 2	1	1,0,0,0,0	0,1,1,0,0
20	Locality 1	1	1,0,1,0,0	0,1,1,1,0
21	T/OS Controlled	1	0,0,1,0,0	0,0,1,0,0
22	T/OS Controlled	1	0,0,1,0,0	0,0,1,0,0
23	Application Specific	1	1,1,1,1,1	1,1,1,1,1

PCR Usage Rules of Thumb

- Static RTM boot process: 0-7
  - Only subset contains real content today
- DRTM launch and code: 17-20
- Need a non-resettable PCR? Use 8-15
  - Set aside for OS, but rarely used
  - Linux trusted boot loader uses 8,9, 12-14
- Need a resettable PCR? Use 16 or 23

The Fragility of PCR Values

- PCR contents are all hash chains
  - Most values extended into PCRs are also hashes
- *Any* change in value will change the hash unpredictably!
  - Did it update the date, or add a rootkit? We can't tell!
- Extremely difficult to predict
  - Holy grail of measurement: golden values reflecting good/bad state
  - Real-world systems generally more chaotic
- Improving predictability, reliability area of active work
  - Research: property-based attestation
  - Industry: standardized measurement techniques and targets
- Still useful!
  - "Are you the same as you were yesterday?"
  - "Are you running our 'gold disk'?"

What We'll Cover

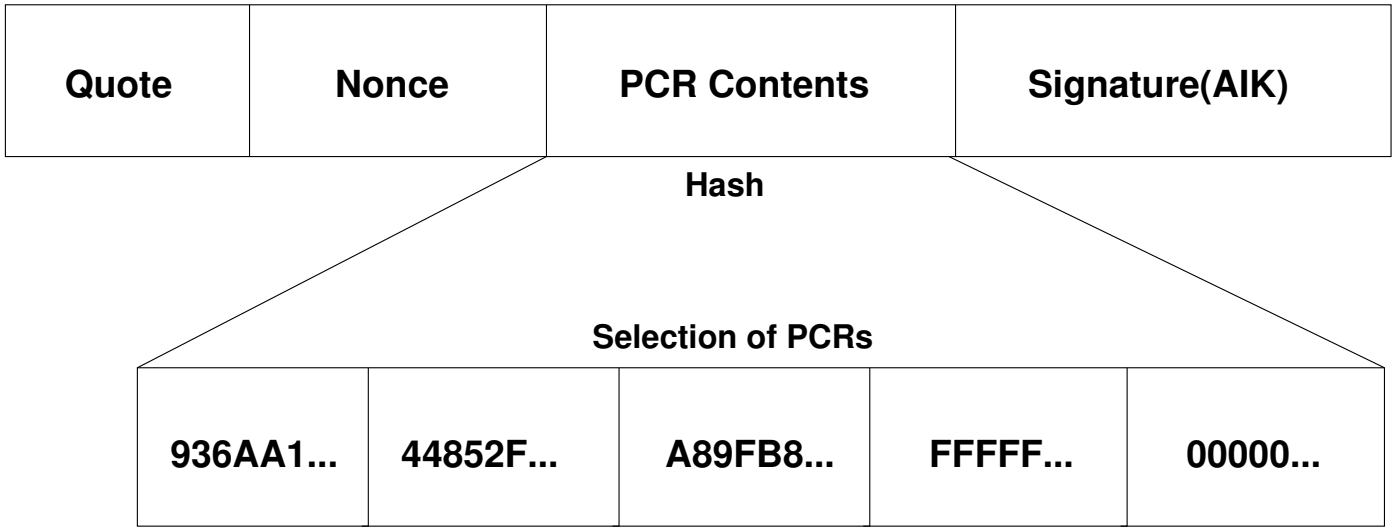
- Review and deep dive: PCRs and Locality
- Attestation
- Machine authentication

What Is Attestation, Again?

Attestation: *the presentation of verifiable evidence about a machine to a remote party*

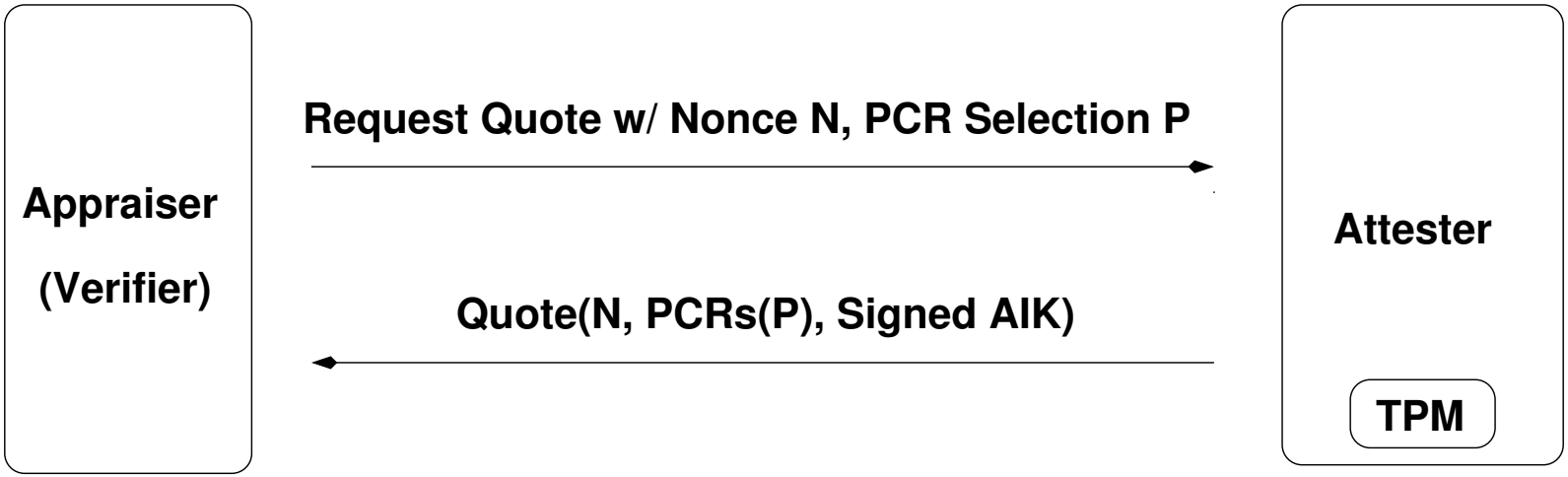
- In TPM context, evidence generally means PCRs
  - Can be augmented; we'll talk more about that
- Verifier (also called *appraiser*) can inspect PCRs, verify chain of trust
  - Trust in high-level components based on good low-level measurements
- Primary tool is *Quote*: signed report of current PCR values
- Any cryptographically verifiable evidence of PCR state counts

Quotes



- Data structured to distinguish from other TPM data
  - Slightly abstracted here for simplicity
- Nonce for freshness, provided by requestor
- Hash of current PCR values
  - Selection of any subset as desired
  - Full record of PCR contents should be provided for verification
- Should be signed using an AIK
  - **Insecure to sign with signing or legacy keys**

Using a Quote

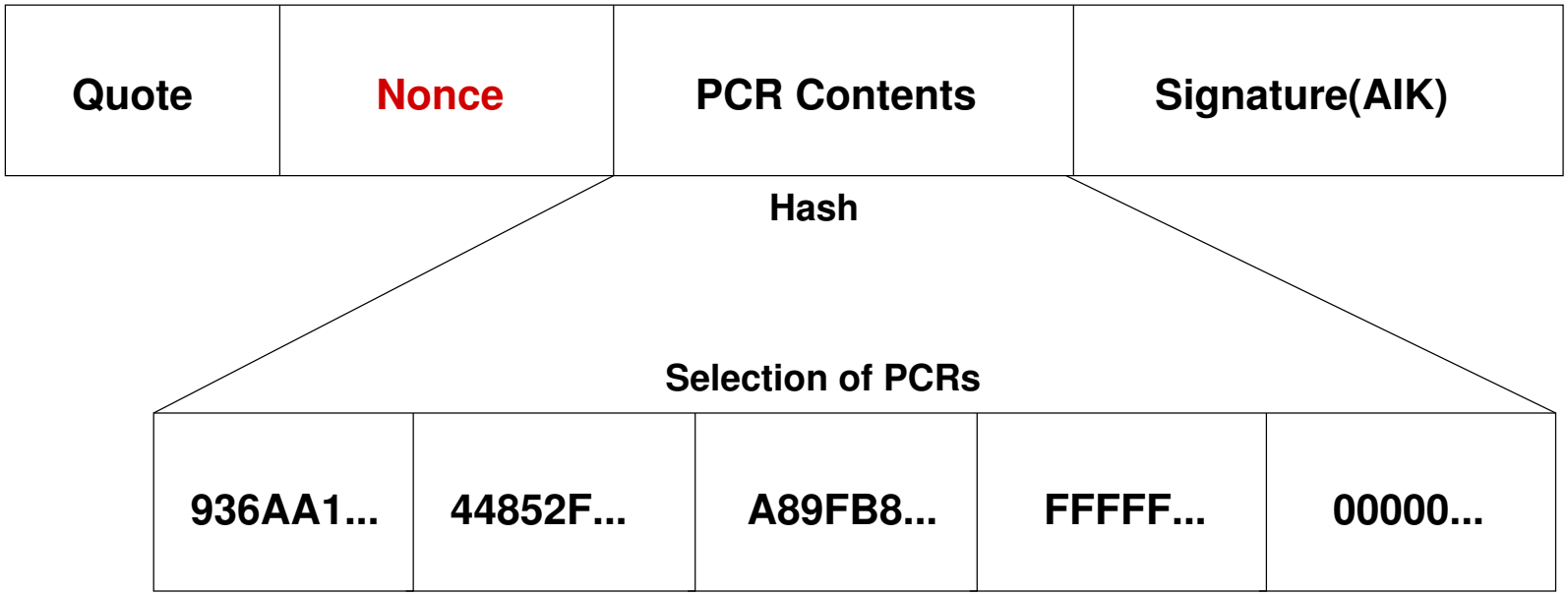


- Many variations, but all follow fundamental structure
- Attester decides:
  - Willing to provide this appraiser with that state info?
- Appraiser decides:
  - Is quote valid, and from legitimate TPM?
  - Is nonce the same one I provided? If fresh, proves quote current.
  - Are PCRs in state I approve of?

Including User Data In Attestation

- Sometimes, we want more than just boot-time system data
  - Add runtime measurements from applications (e.g. config checker)
  - Associate application data with good state (e.g. financial programs)
  - Tie external data to machine, now (e.g. user smartcard)
- Several approaches; simplest is to incorporate into quote
  - We'll cover the others next

How NOT to Include User Data

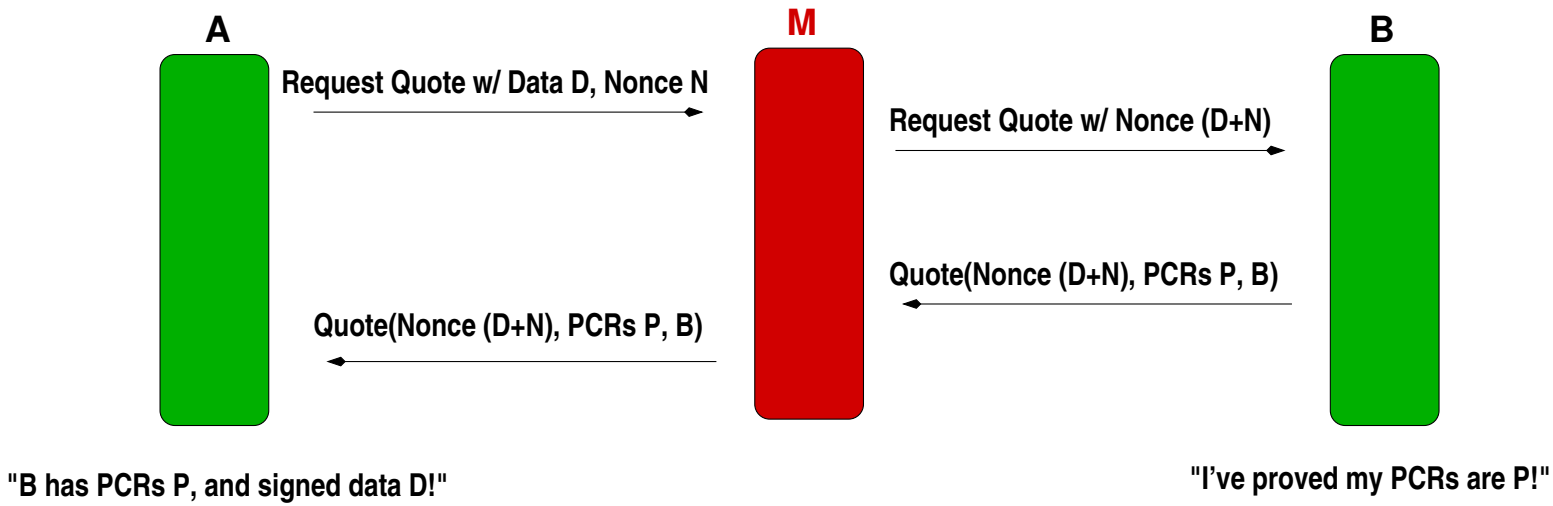


Common approach: replace nonce with user data, or hash(nonce, data)

Do not do this!

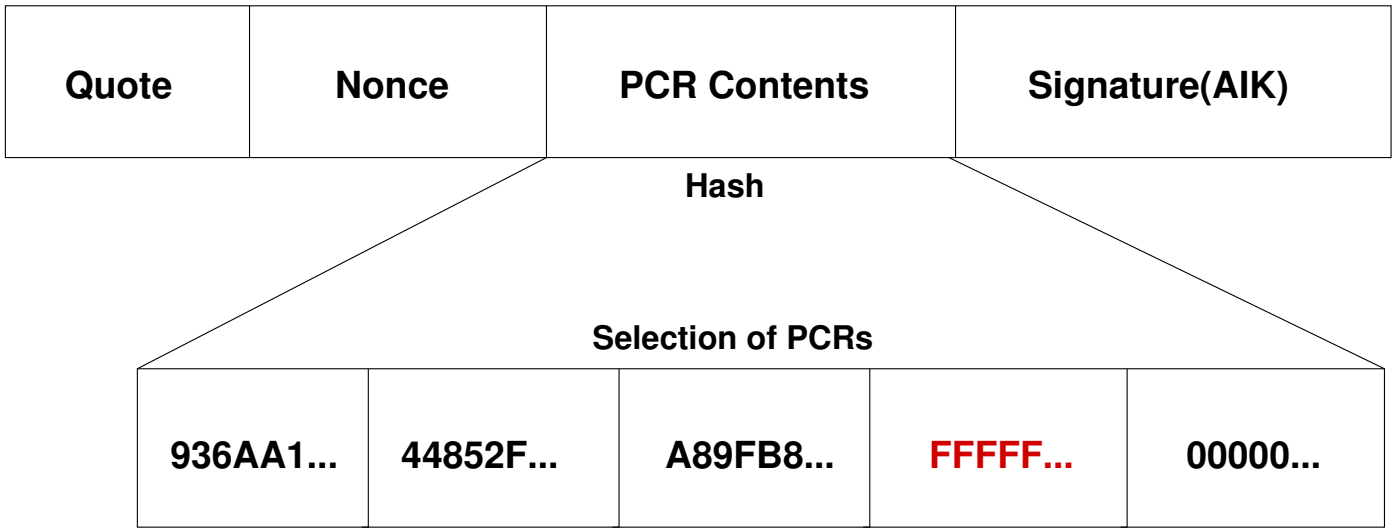
- Nonces are intended for freshness only
- Adding meaning enables a man-in-the-middle attack!

The Nonce-Data Attack



- B can't distinguish random nonce from one with user data
- A assumes B has signed something that B has never seen
- **This is the flaw in TNC's PTS-to-IF-M protocol.**
- Only occurs if multiple quote protocols on same network, but:
  - Other quote applications are powerful, and should not be eliminated
  - Other people may break your protocol accidentally!
  - Do you really have that much control over your network?

How to Safely Include User Data



- Extend data into an otherwise unused PCR
  - Unlike quote, extend not generally network-accessible!
  - Adversary would need platform access to forge
- Remotely verifiable, without changing overall meaning
- Note: Often wise to include freshness within data as well
  - Is this anti-virus report from today? Or yesterday?
- These can be used as long-term signatures!
  - "At the time this was signed, these were the PCR values"

Selecting the Right PCRs for Data

Broadly, two kinds of PCRs:

- Resettable
  - Can be reset to known values
  - Generally, reset before each use
  - **Resettable PCRs are good default for data**
- Non-resettable
  - Reset only on system boot
  - Note: Time since last boot not easy to determine!

Resettable	Non-Resettable
No history	History since boot
Low verifier overhead	Usable for offline updates
Good for one-offs	Good for audit logs

Beyond Quotes: Other Forms of Attestation

- Two primary categories:
  - PCR constraints on keys
  - PCR constraints on data
- Both of these share a common requirement:
  - "Good" PCR values must be known in advance
- Side note: whenever PCRs constrained, locality can be also
  - Very useful for certain DRTM applications, such as Flicker

Attestation with PCR-Constrained Keys

Previously discussed:

- Any TPM key can have PCR constraints associated with it
- Keys can only be used when PCRs match constraints
- CertifyKey allows remote party to verify constraints

Put together:

- Create a key with PCR constraints X.
- Certify the key with your choice of AIK.
- Now, whenever key used, remote party knows PCRs contain X.

PCR-Constrained Key Use Cases

- "When this data was signed, X was true"
  - Good for any case where X implies properties of data; e.g:
  - Certifying correct handling of sensitive data
  - Performing hard-to-verify or security-sensitive operations
- "When this data was encrypted, X was true"
  - Good for tracking possession over multiple boots
  - Good for evaluating data sources
  - Note: not for encrypting to remote platforms! (Seal, not bind)
- "When this data is decrypted, X will be true"
  - Good for ensuring state on receipt
  - Covered in more detail on next slide

Attestation with PCR-Constrained Data

- Sealing (local) allows PCR constraints on encrypted data
  - Can also Bind (remote), but constraints on key, not data
- Useful for data protection!
  - Know both target machine and target state at time of receipt
  - No simultaneous communication required– can create at any time
  - "You can only receive this data if you're in an acceptable state"
- If PCRs predictable, can encrypt to future state
  - Remote: "If you update, you'll gain access"
  - Local: Normal operation can encrypt to secure-mode code
  - Local: Secure-mode app A can encrypt to secure-mode app B
- Can be used to make data only accessible during windows of time
  - e.g., disk decryption key sealed to non-resettable PCRs containing default values; filled in as machine boots

Why no NVRAM attestation?

NVRAM can be constrained to PCR values; why can't it be used to attest?

- Evidence must be *remotely verifiable*.
- Owner sets NVRAM constraints; no way to directly verify!
  - Keys can be certified with CertifyKey
  - Sealed or Bound data can be directly inspected
  - Owner would need to issue certificate; not a standard process
- Proof of access: read data from NVRAM
  - Unless asymmetric key pair, verification requires knowledge of secret
  - If key pair, just use key constraints!
  - If not, certifying association between secret and state leaks info
- Generally, can only attest meaningfully to owner
  - Small enough use case to not worry about

PCR constrained NVRAM very useful! But not for remote attestation.

Attestation Summary

Attestation: *the presentation of verifiable evidence about a machine to a remote party*

- Any verifiable report of PCR contents can be used for attestation
- Quote is primary attestation tool
  - Signed report of current PCR state
  - Can be used to also sign user data via extended PCRs
  - Generally, use resettable PCR for signing data
  - **Never** use quote nonce to sign data!
- PCR constrained keys or data can be used for specialized applications

What We'll Cover

- Review and deep dive: PCRs and Locality
- Attestation
- Machine authentication

What is Machine Authentication?

- Remotely verifiable proof of machine identity
- Useful in many enterprise contexts
- Strict subset of attestation!
  - Attestation: "What is the state of machine X?"
  - Authentication: "Is this machine X?"
- Most TPM keys can be used for machine authentication.
  - TPM soldered to motherboard
  - Keys crytographically bound to TPM
  - All key activity must happen on that machine!

Types of Machine Authentication

Two primary types:

- Signing-based
- Decryption-based

Signing-Based Machine Authentication

- The most intuitive form of machine authentication
- "Machine X signed Y"
- Easy to use to derive trust in Y
- We'll focus on non-attestation signatures
  - Remember, attestation will get you auth for free!
  - But involves overhead you often don't want.

Choosing the right key for authentication is not as easy as it sounds!

- Signing keys
- Identity keys

Signing Key Choices

- Signing keys come in several varieties!
- Choice of key properties can make or break security.
  - Key length: 512-2048 bits; should be 2048
  - Migratability: **must be non-migratable for authentication**
  - Signature scheme: SHA1, DER, INFO
    - Note: all RSA keys; scheme determines what kind of data can be signed

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  - Signature scheme: SHA1, DER, INFO
    - Note: all RSA keys; scheme determines what kind of data can be signed
    - **Security critical!**

Signature Schemes

SHA1 Signs only 20-byte chunks of data. (SHA-1 hash length!) Will sign user data or TPM data, but **should never be trusted to sign TPM data, as forgery is trivial.**

DER Signs DER-formatted data. Will only sign user data. Should ensure that nothing these sign appear to be TPM data.

INFO Signs data in custom TPM wrapper format. Designed to be a more flexible alternative to identity keys. **Vulnerable to SHA-1 collision attack. Do not use.**

Using Signing Keys for Machine Authentication

- `TPM_Sign` command
- Sign arbitrary user-provided data in key-appropriate format
- SHA1 or DER signatures can often be dropped into existing protocols
  - Use TPM key instead of software key; get machine auth for free
  - Note: slow! Do not use for high-frequency operations
- Associate any data with machine

Using Identity Keys for Machine Authentication

- Identity keys intended for TPM authentication
- **Identity keys are the only secure choice for TPM data**
  - Quotes, CertifyKey certs, audit logs
  - All imply machine auth
- As with signing keys, associate all signed data with machine
- To sign only user data:
  - Extend user data into PCRs; perform quote of only those PCRs
  - Note: high overhead for a simple signature!
- Best used for attestation or TPM-specific functions, however:
- It is not possible to misconfigure an identity key, making them easier to verify!

Verification is Critical

Trust requires a target: trust for what?

- When evaluating TPM signatures, it is critical to ask:
  - Is this data making any claims about TPM state or keys?
  - If so, is this key one I should trust for that purpose?
  - **Never trust a signing key without considering both key and data.**
- This is also the core question when evaluating attestation target!

Types of Machine Authentication

Two primary types:

- Signing-based
- Decryption-based

Decryption-Based Machine Authentication

- We prove identity by demonstrating secret possession
- Decrypting data proves possession of private key
- Remote party can prove identity by creating encrypted challenge
  - If challenge is decrypted and used, proves possession
- We use binding keys for this
  - Storage keys for local data only!

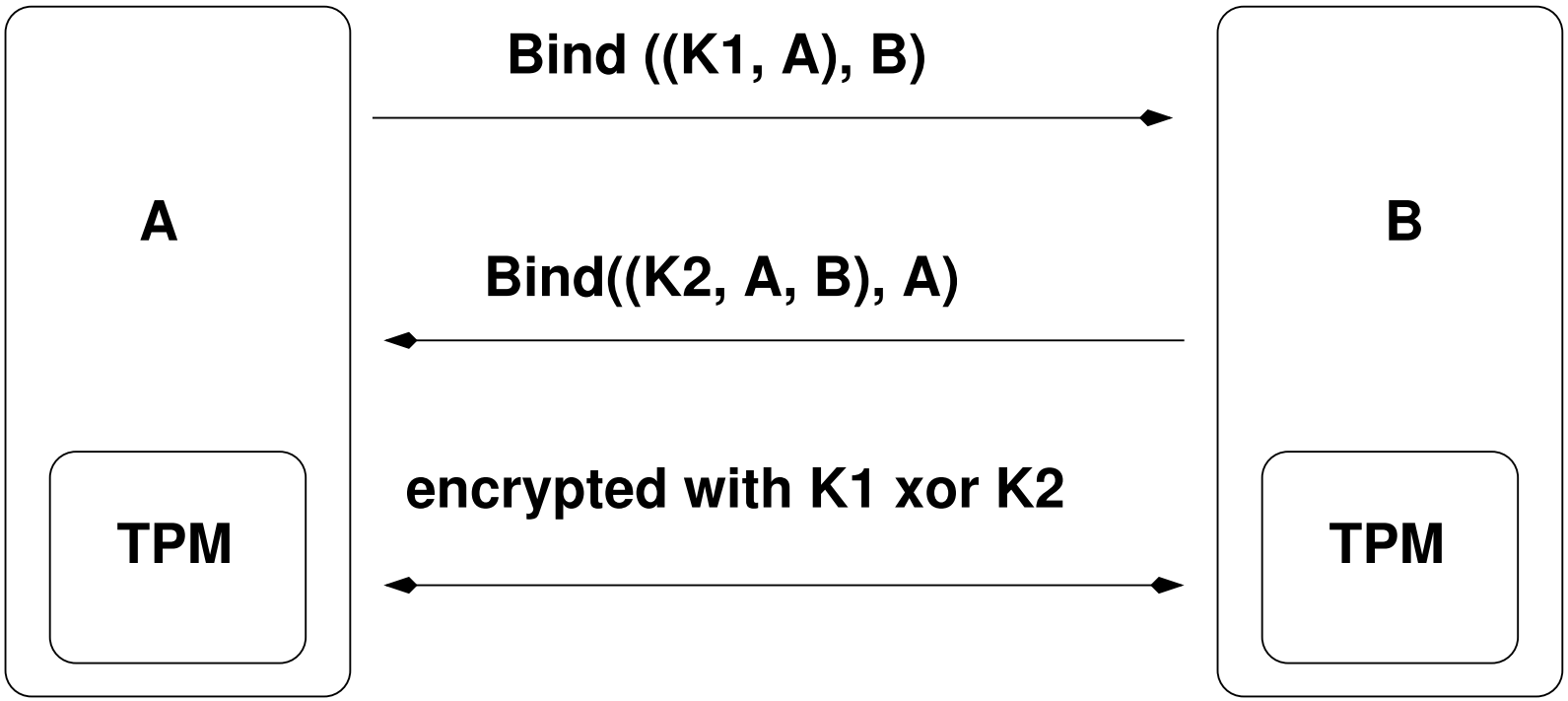
Authenticated Data Delivery

- Simplest form of decryption-based authentication
- Take data intended for target; *Bind* with target binding key
  - Note: `TPM_Unbind` is a TPM operation; Bind is not
  - For practical purposes, large data usually encrypted with symmetric key; symmetric key is bound
- Encrypted data can now be made public; only target can make use of
- Note: Can also perform attestation by binding to PCR-constrained key

Decryption-Based Authentication Protocols

- Many protocols encrypt a secret to prove identity!
  - Nonces, keys, session ID
- Powerful approach: Use TPM key to establish shared session key
  - Public key operations expensive
  - Use to set up shared secret symmetric key
- Simplest possible protocol: bind session key, send to authentication target
- Usually, however, want *mutual authentication*: both parties identified

A Sample Decryption-Based Attestation Protocol



- A knows only B will know K1
- B knows only A will know K2
- Secure channel can be built with combined key

Machine Authentication Summary

- Machine authentication provides proof of machine identity
- Signing or decryption based
- Use SHA1 or DER signing keys for most user data
- Use identity keys for TPM data or high-security applications
- Use binding keys to guarantee data recipient identity

What We've Covered

- Review and deep dive: PCRs and Locality
- Attestation
- Machine authentication

Summary

If you want...	use key type...	with...
Attestation	Identity	Quote
Signing-based Authentication	Signing	Sign
Decryption-based Authentication	Binding	Bind

Questions?