# Remote Attestation for Cloud-Based Systems

Dr. Perry Alexander[1] Dr. Andrew Gill[1] Dr. Prasad Kulkarni[1] Adam Petz[1] Paul Kline[1] Justin Dawson[1] Jason Gevargizian[1] Mark Grebe[1] Edward Komp[1] Edward Bishop[2]

[1]Information and Telecommunication Technology Center
Electrical Engineering and Computer Science
The University of Kansas

[2]Southern Cross Engineering

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# When should you trust my system?

- You know its identity
  - strong, unambiguous identification
  - asymmetric key cryptography
  - secret key strongly bound to the platform
- You know it is built from good parts
  - strong identification of system configuration
  - boot-time hashes stored in protected memory
  - trusted configuration delivery mechanism
- You know it is behaving as expected
  - direct or trusted indirect observation of good behavior
  - contextual evidence gathered during system operation
  - trusted evidence delivery, storage and evaluation mechanism

Trust is grounded in knowing *identity* and *behavior*.

# Clouds and Trust

Cloud structure complicates knowing identity and behavior

- Applications no longer run "under the desk"
  - platform ownership is gone
  - difficult to directly observe behavior
  - no access to hardware
- Anonymous and changing operating environment
  - hardware is virtualized and invisible
  - migration moves applications and systems
  - identity and measurement cannot be rooted in hardware
- Unknown actors in the same operating environment
  - many virtual platforms on the same physical platform
  - many applications accessing the same resources
  - significant trust in the cloud to separate virtual platforms

# Virtual Blinking Lights

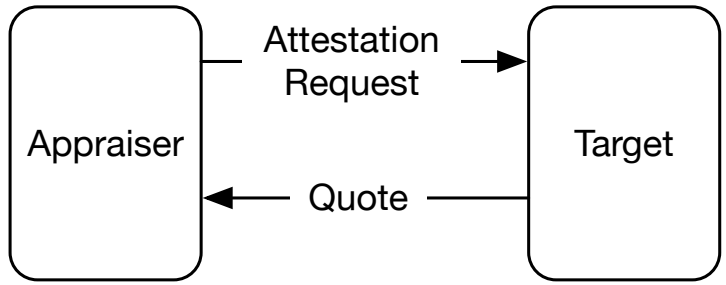
Provide new capabilities that establish and maintain trustworthy cloud-based application deployment

- Establish trust in cloud applications
  - trust in user-space applications
  - trust in cloud infrastructure
  - trust in application cohorts
- Provide a common trust infrastructure
  - standard application architecture
  - flexible communication mechanisms
  - application-specific measurement
  - formally verifiable trust protocols
  - roots-of-trust for storage and reporting
- Integration with existing standards and practices
  - Integration with RedHat Linux, Xen, and OpenStack
  - Uses Trusted Computing Group's TPM and vTPM guidelines
  - Developed in concert with NSA R2X and R2D

# Semantic Remote Attestation

A basic four step process for establishing trust:

- Appraiser requests a quote
  - specifies needed information
  - provides a nonce
- Target gathers evidence
  - measures application
  - gathers evidence of trust
- Target generates quote
  - measurements and evidence
  - original nonce
  - cryptographic signature
- Appraiser assesses quote
  - good application behavior
  - infrastructure trustworthiness

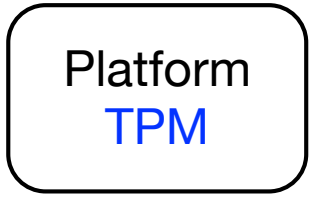


# Trusted Platform Module

- Provides and Protects Roots of Trust
  - Storage Root Key (SRK) - root of trust for storage
  - Endorsement Key (EK) - root of trust for reporting
- Quote generation
  - high integrity quotes - ($\{\|RS\|\}_{AIK^-}$, SML, $\{\|n, PCRComp\|\}_{AIK^-}$)
  - high integrity evidence - ($\langle E, n\rangle$, $\{\||\langle E, n\rangle|, PCR\|\}_{AIK^-}$
- Sealing data to state
  - $\{D, PCR\}_{K^+}$ will not decrypt unless PCR = current PCR
  - data is safe even in the presence of malicious machine
- Binding data to TPMs and machines
  - ($\{K^-\}_{SRK^+}$,K) - $\{D\}_{K^+}$ cannot be decrypted unless $SRK^-$ is installed
  - ($\{J^-\}_{K^+}$,J) - $\{D\}_{J^+}$ cannot be decrypted unless $K^-$ and $SRK^-$ are installed

# The Cloud Challenge

Chasing the bottom turtle



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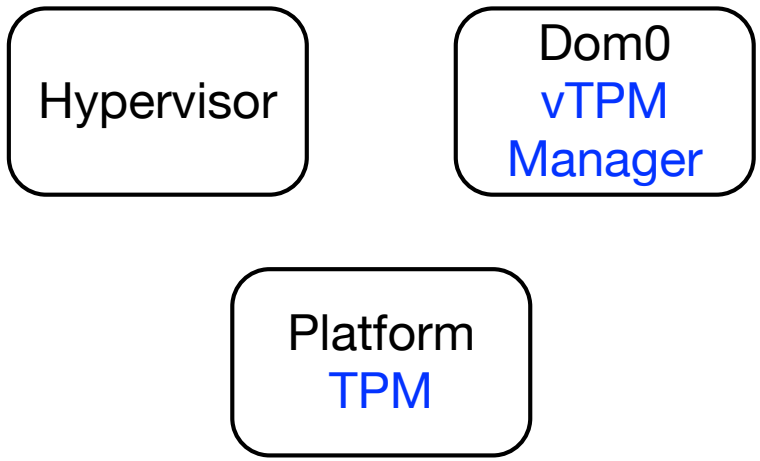

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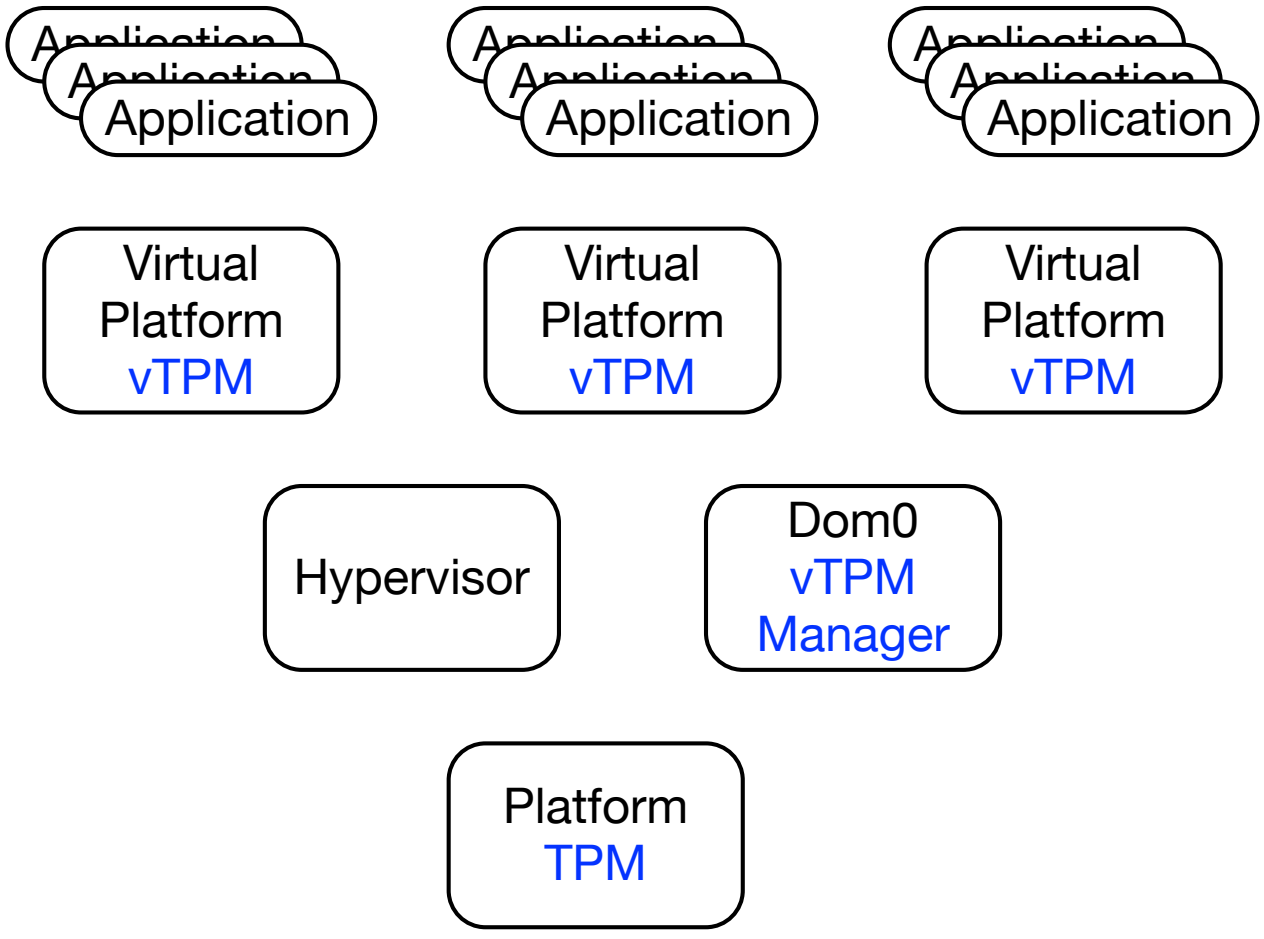

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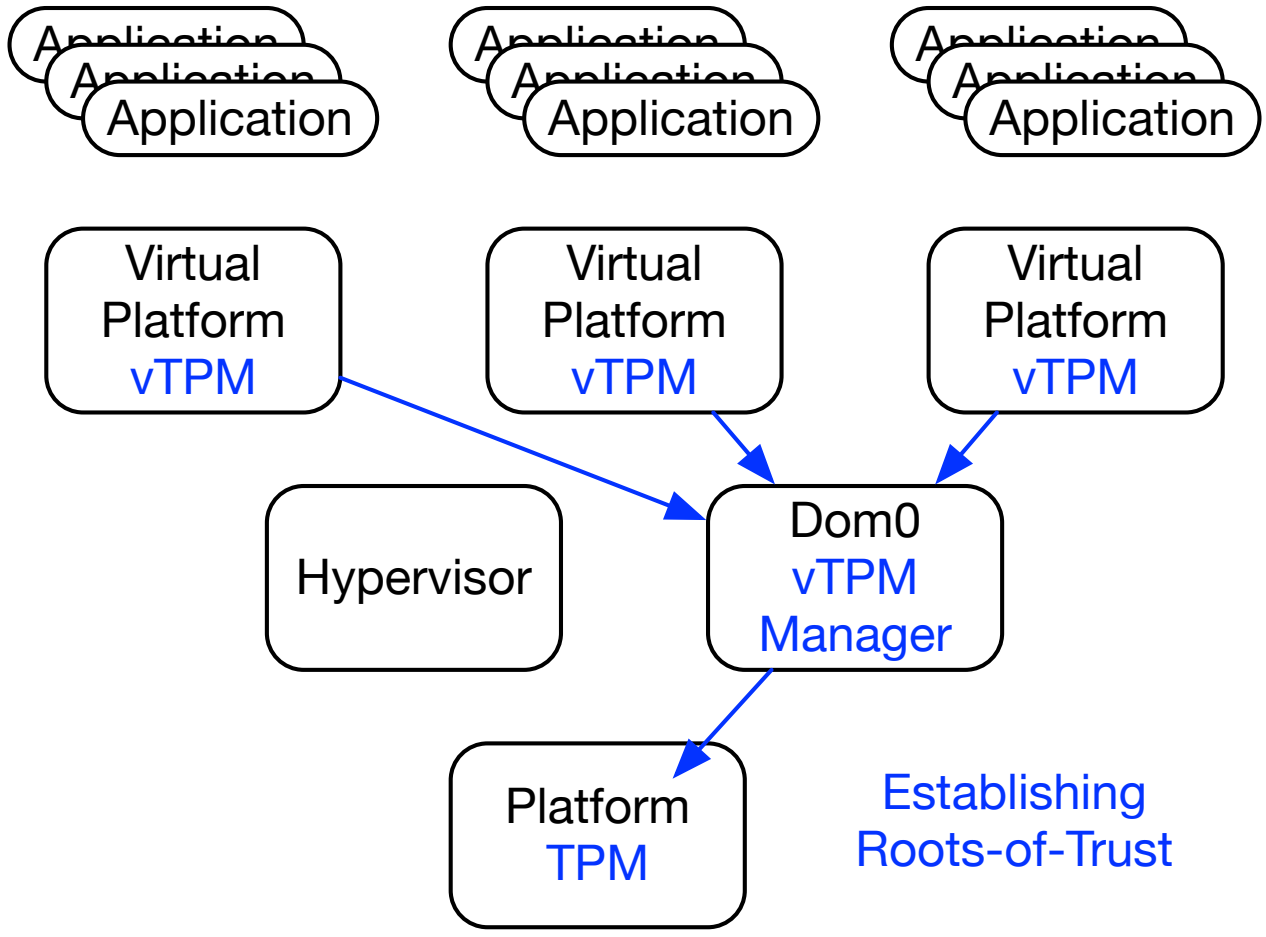

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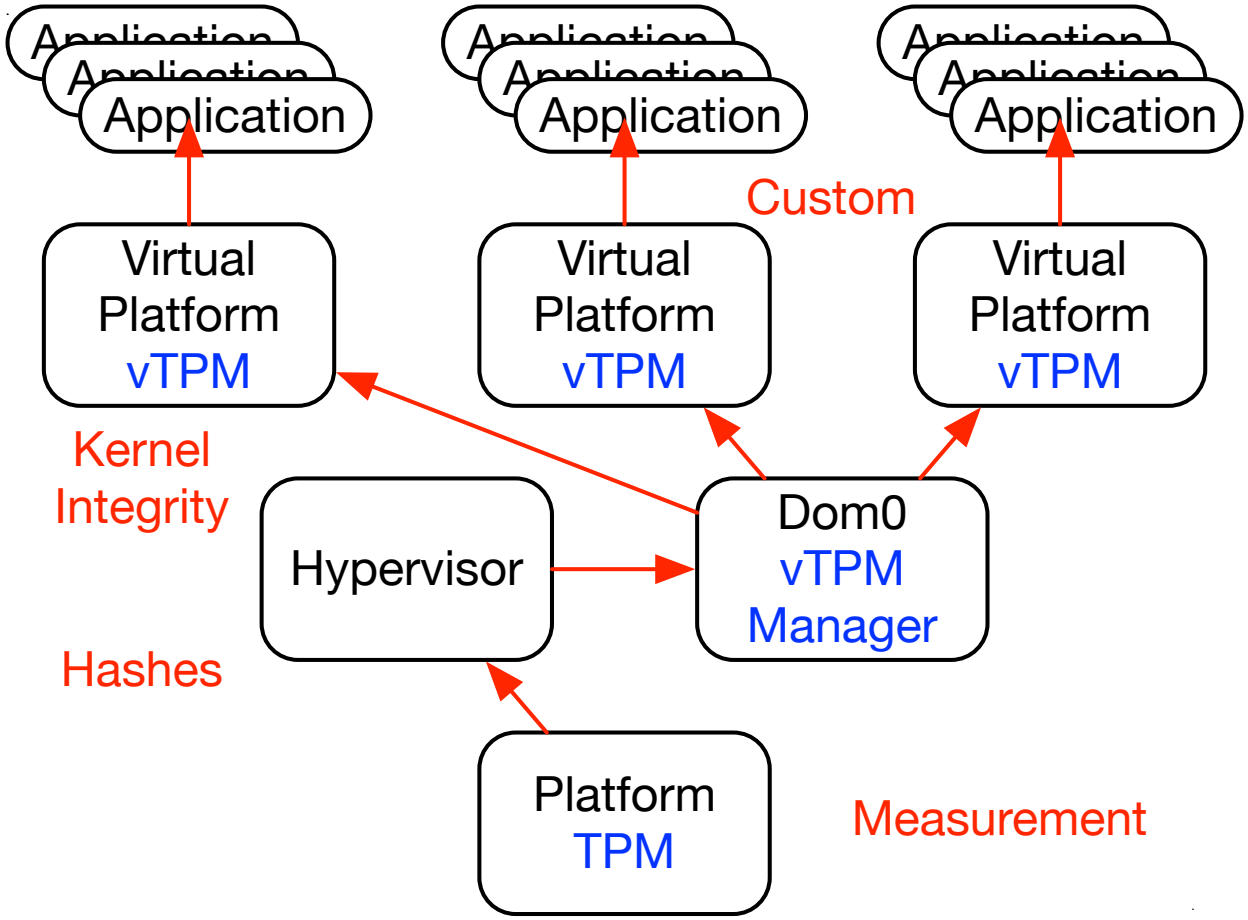

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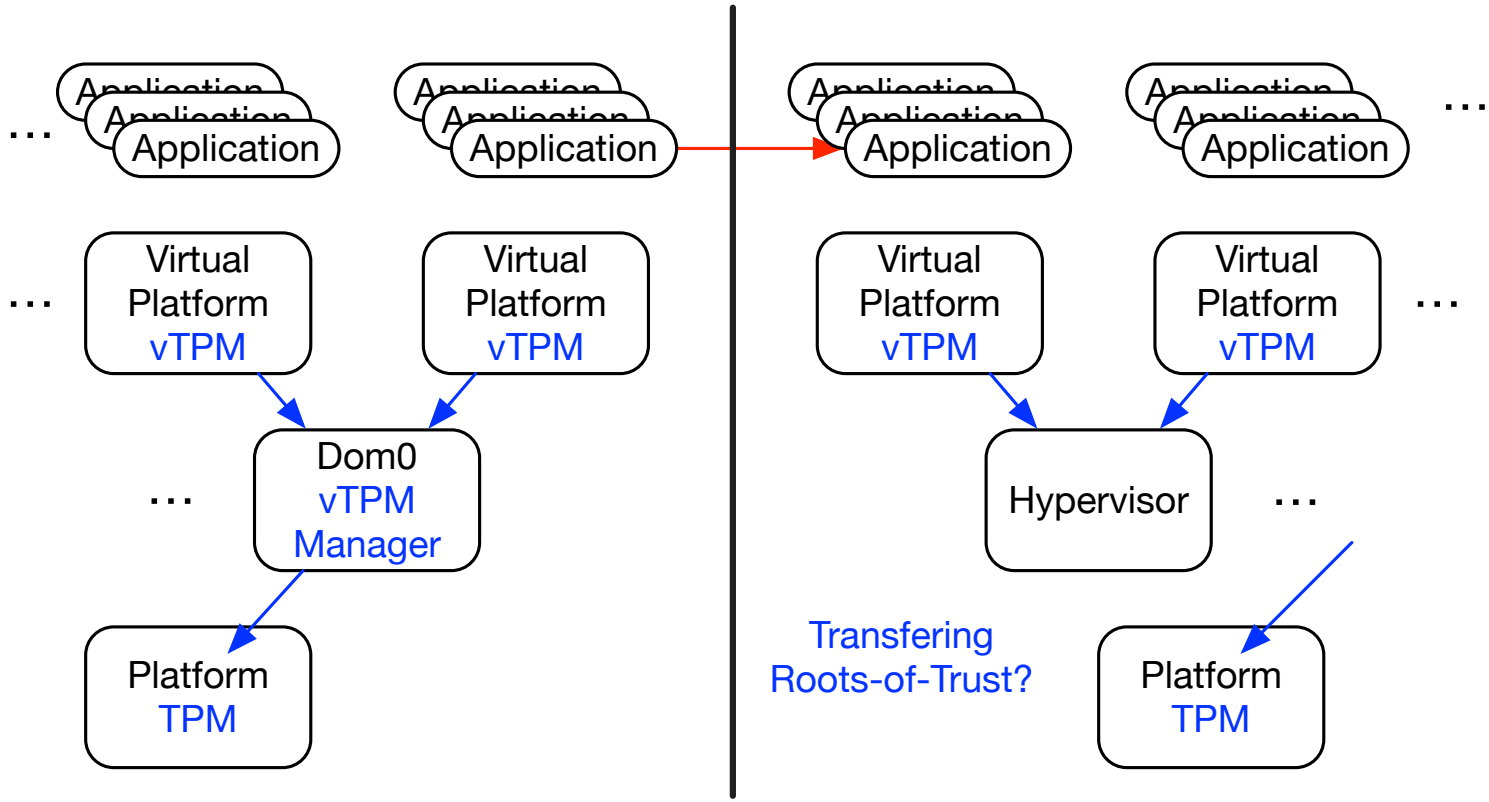


# New Enabling Technologies

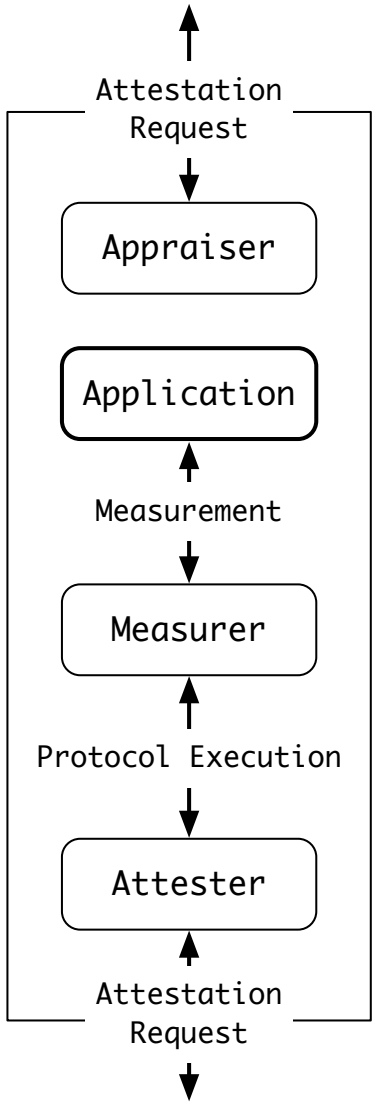
ArmoredSoftware will provide new technologies for system trust

- Trustworthy protocol execution
  - executable and analyzable protocol representation
  - privacy policy compliant attestation protocol negotiation
  - verifiable remote attestation protocol execution
- Application specific measurement
  - scriptable general purpose measurement engine
  - compile-time assistance for measurer synthesis
  - specialized measurement bundled with applications
- Lightweight trust infrastructure
  - strong identity establishment and maintenance
  - abstract communications capability
  - migration-sensitive vTPM infrastructure

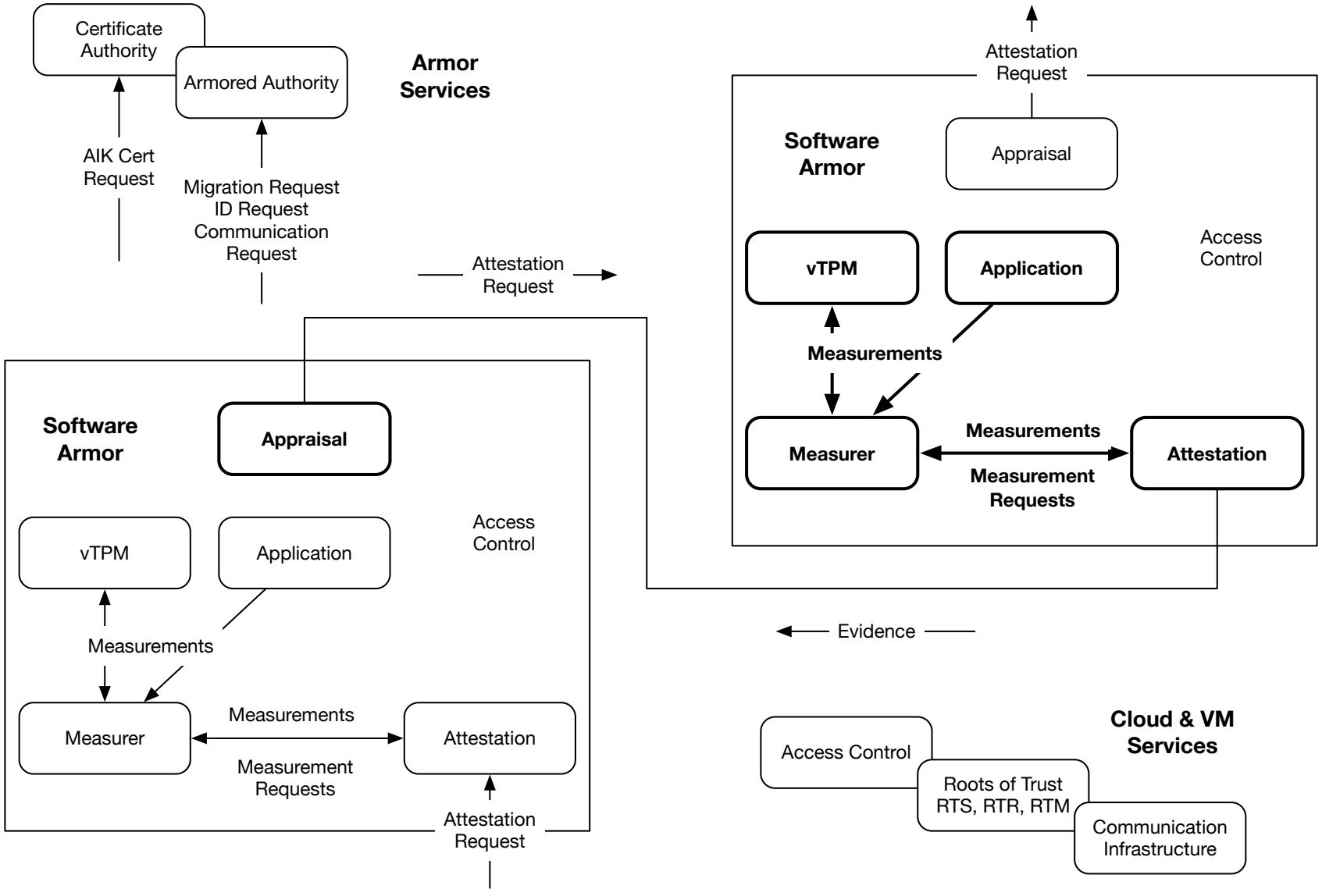
# Armored Application Architecture

M&A targeted to an application

- Appraiser makes attestation requests
- Attester responds to attestation requests
- Measurer gathers evidence from application
- Influenced by the *Trusted Research Platform* and *Principles of Remote Attestation*



# System-Level Architecture

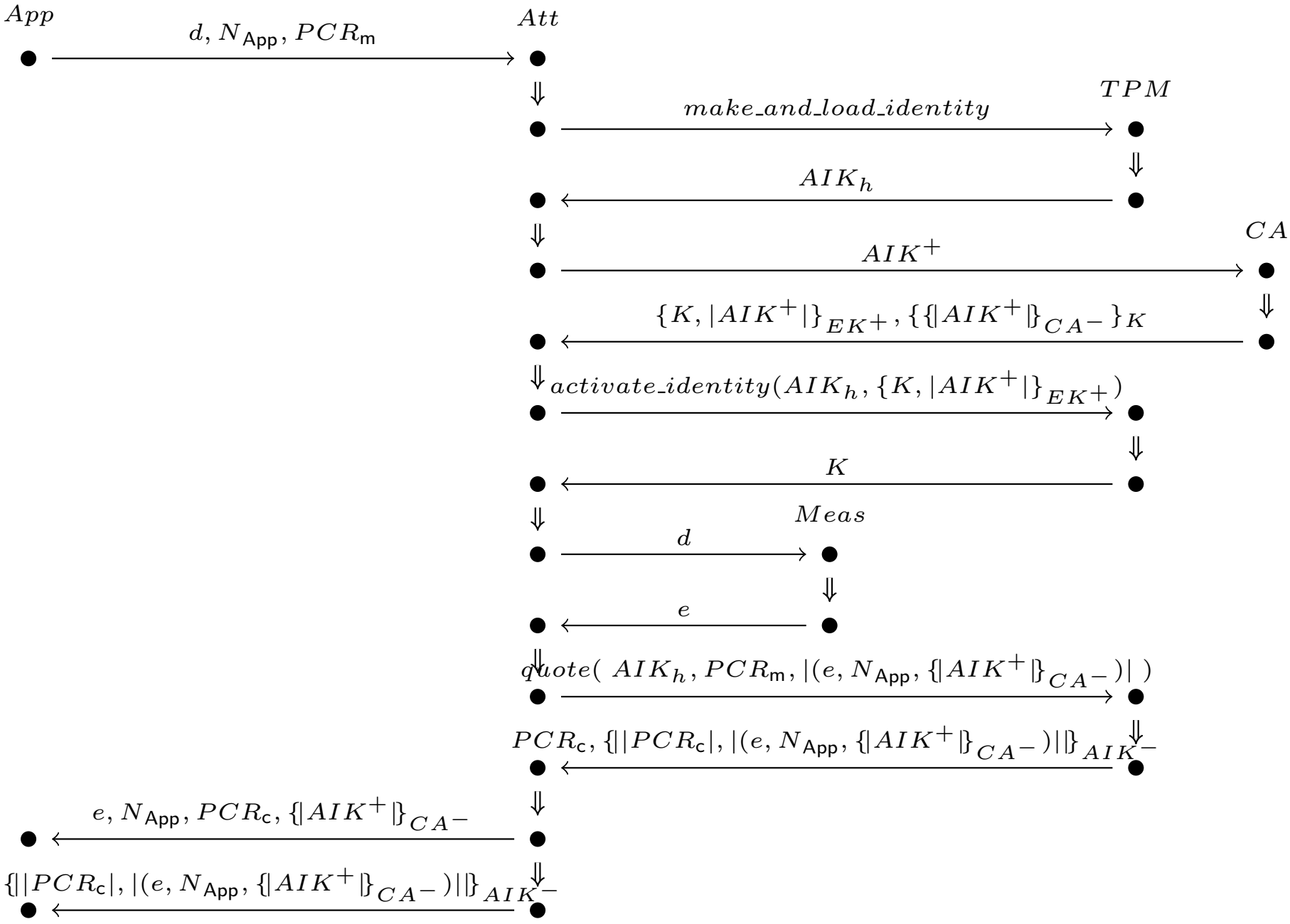


# Trustworthy Protocol Execution

Negotiation and execution

- Representation and execution
  - protocols as first-class language structures
  - generates evidence of trusted execution
  - respects privacy policies
  - formal semantics
- Attestation Protocol Negotiation
  - appraiser and attester agree on an attestation protocol
  - appraiser needs information for assessment
  - attester protects target assets
- Attestation Protocol Execution
  - invokes measurement routines to gather evidence of behavior
  - packages evidence to ensure evidence integrity and confidentiality
  - generates meta-evidence to ensure process integrity

# Privacy CA Attestation



# EDSL for Trusted Protocols

First-class protocol structures

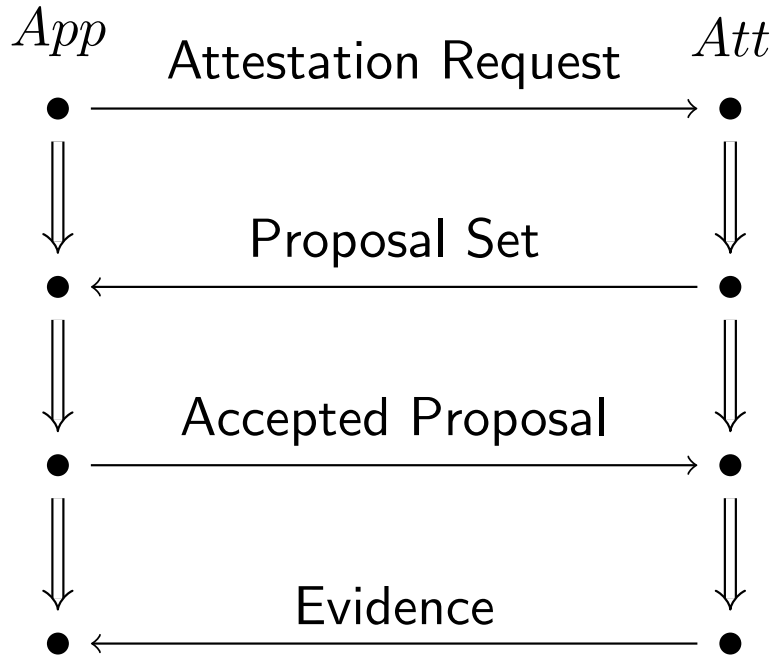
- First-class structure for protocols
  - encapsulates a protocol-centered computation
  - semantics provide a basis for static analysis
  - based loosely on the `Reader` monad
- Abstract communication primitives
  - extended RPC-style capability
  - requests remote execution
  - defines `send` and `receive` operations
  - abstracts away communication details

```
do {
     f(x);
     y <- f(x);
     z <- send a y;
     y <- receive a
}
```

# Negotiating a Protocol

Respecting privacy

- Typical negotiation
  - request sent to Attester
  - Attester generates proposal
  - Appraiser selects protocol
  - Attester executes protocol
- Three kinds of requests
  - execute protocol 22
  - provide {`OS_config`, `http_stat`, `firewall_stat`}
  - execute protocol `do { ... }`
- Three negotiation criteria
  - ability to satisfy the request
  - satisfaction of appraiser and attester privacy policies
  - previously obtained evidence



# Negotiation Protocol

Request and Select

- Requests an attestation
- Receives proposals
- Selects from proposals

```
do { send t r;
     q <- receive t;
     e <- case {p:q | (policy? p)} of
            ∅ : None
            p : send t (choose p)
          end;
     case e of
       Some v : (appraise v)
       None : None
     end }
```

Negotiation is a protocol that can itself be selected or negotiated

# Negotiation Results

- Evidence and Protocol pairs
- Satisfies privacy policy of attester
- Provide some or all of requested information

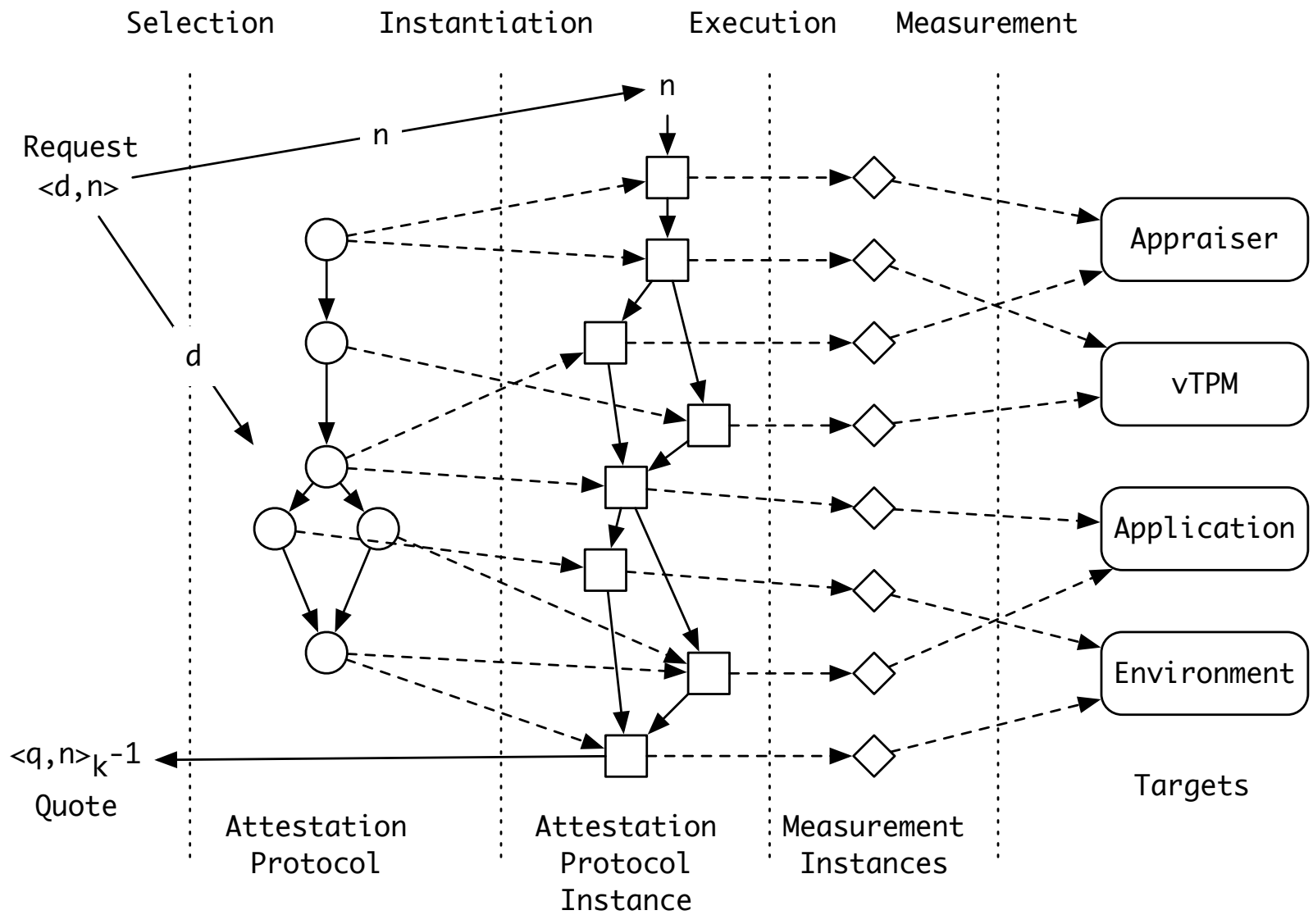
```
((ID,SIGHASH,SIGSRC),
 do { id <- getVCID;
      sig <- getSigFileEvidence;
      src <- getSigFileSrc;
      e <- createEvidence(id,sig,src);
      returnEvidence(e) })
```

# Reified Protocol

Generated negotiation protocol code (currently by hand):

```
P = CreateChannel (AChannel "attesterChan") Target
    $ Send ANRequest (AChannel "attesterChan")
    $ Receive (Var "counterOffer") (AChannel "attesterChan")
    $ CalculateFinalRequest (Var "finalReq")
                            ANRequest
                            (Var "counterOffer")
    $ Send (Var "finalReq") (AChannel "attesterChan")
    $ Receive (Var "finalConfirmation")
              (AChannel "attesterChan")
    $ Case (Var "finalConfirmation") [(Var "finalReq")]
           (HandleFinalChoice (Var "result") (Var "finalReq")
           (Result (Var "result")))
           (Stuck "finalConf and finalReq match error")
```

# Performing Measurement and Attestation



# Single Realm Attestation

Protocol for gathering virus checker evidence

```
do { id <- getVCID;
     sig <- getSigFileEvidence;
     src <- getSigFileSrc;
     e <- createEvidence(id,sig,src);
     returnEvidence(e) }
```

and generates evidence of the form:

$$\langle (id, sig, src), \{\!|\,|(id, sig, src)|, PCRComp_0\,|\!\}_{AIK_0^-} \rangle$$

Appraisal replays the protocol up to crypto operations with known good measurements

# Multi-Realm Attestation

Nested attestation requests evidence from the signature server directly:

```
do { id <- getVCID;
     sig <- getSigFileEvidence;
     src <- getSigFileSrc;
     srcEvidence <- send src r;
     e <- createEvidence(id,sig,src,srcEvidence)
     returnEvidence(e)
}
```

and generates bundled evidence:

$$\text{let} \quad b \quad = \langle (e), \{\!|\,|e|, PCRComp_1\,|\!\}_{AIK_1^-} \rangle \text{ in}$$
$$\langle (id, sig, src, b), \{\!|\,|(id, sig, src, b)|, PCRComp_0\,|\!\}_{AIK_0^-} \rangle$$

# Trusting Evidence

Why bundling is hard

- Trusting evidence
  - hashes and TPM quotes
  - measure and appraise the attestation infrastructure
  - gather evidence of good protocol execution
- Trusting bundled evidence
  - appraisers do not know the source of evidence *a priori*
  - no global name space for evidence sources
  - bundled appraisals vs bundled evidence
- Trusting the appraiser
  - negotiated protocols must satisfy privacy policies
  - trust may not be transitive for applications and infrastructure
  - global policy is not an answer

# Current Status

Demos available

- Attestation and Appraisal development
  - CA-Based attestation protocol execution example
  - simple dynamic appraisal of attestation results
  - integrated negotiation protocol and attestation protocols
- Measurement development
  - HotSpot-based Java VM run time measurements
  - detect and report several runtime anomalies
  - standard mechanism for extending measurement capabilities
- Infrastructure development
  - vchan, TCP/IP and socket communication infrastructure
  - initial certificate authority implementation
  - language-based interface with TPM 1.2
  - integrated Berlios TPM emulator
  - JSON-based data exchange formats

# Ongoing Work

Goals for 2015

- Establish roots-of-trust and trust argument
  - measured launch and remeasurement of ArmoredSoftware
  - establish trust in the Xen/OpenStack infrastructure
- Executable protocol representation and protocol semantics
  - evidence of proper execution
  - static trust analysis
  - protocol-centered appraisal
- More capable measurement
  - compiler directed measurement
  - continuous measurement—tripping and trending
- Publicly available libraries and infrastructure

# References