

Remote Attestation for Cloud-Based Systems

Dr. Perry Alexander¹ Dr. Andrew Gill¹ Dr. Prasad
Kulkarni¹ Adam Petz¹ Paul Kline¹ Justin Dawson¹
Jason Gevargizian¹ Mark Grebe¹ Edward Komp¹
Edward Bishop²

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

²Southern 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

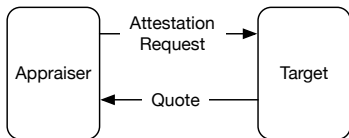
Provide new capabilities that establish and maintain trustworthy cloud-based application deployment

- ▶ 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 - $(\{RS\}_{AIK^-}, SML, \{n, PCRCComp\}_{AIK^-})$
 - ▶ high integrity evidence - $(\langle E, n \rangle, \{|\langle E, n \rangle|, PCR\}_{AIK^-})$
- ▶ Sealing data to state
 - ▶ $\{D, PCR\}_{K^+}$ will not decrypt unless $PCR = \text{current PCR}$
 - ▶ 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

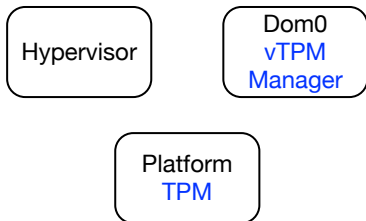
The Cloud Challenge

Chasing the bottom turtle

Platform
TPM

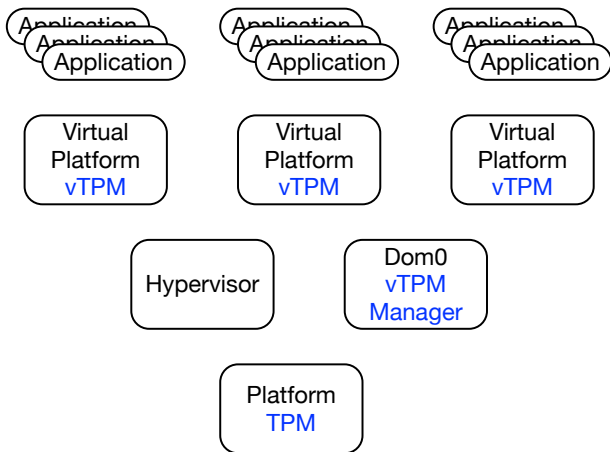
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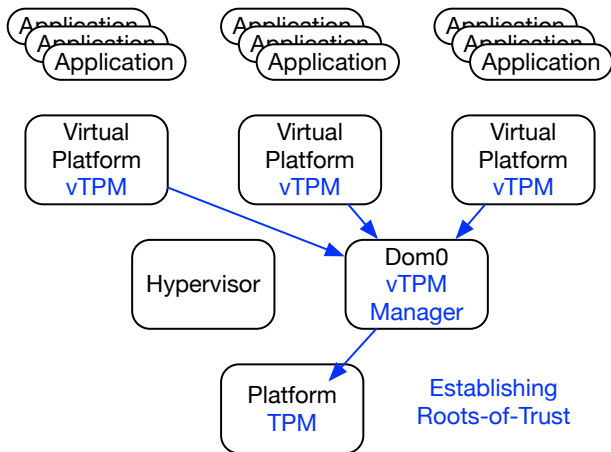
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Chasing the bottom turtle



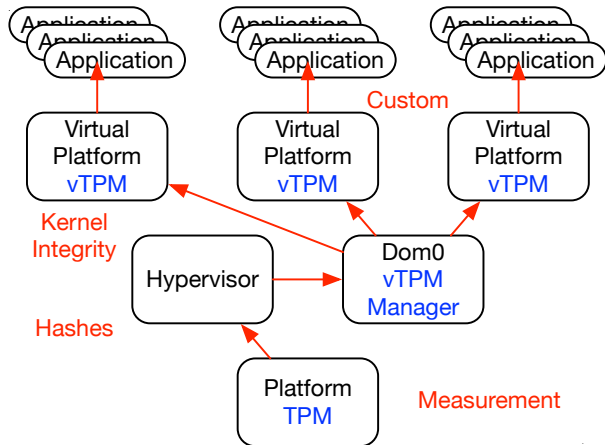
The Cloud Challenge

Chasing the bottom turtle



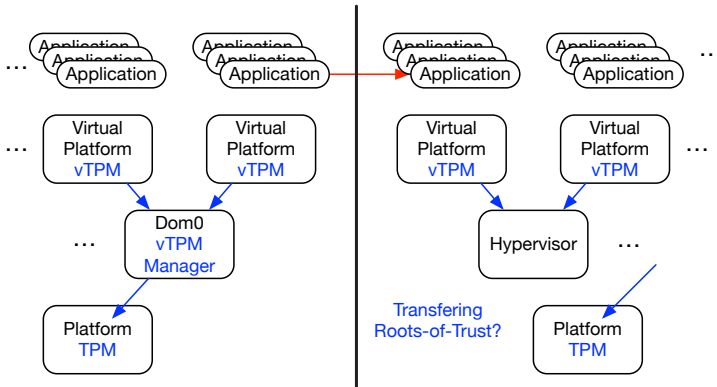
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The Cloud Challenge

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New Enabling Technologies

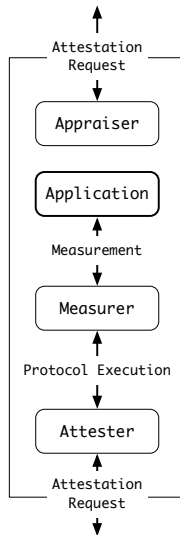
ArmoredSoftware will provide new technologies for system trust

- ▶ 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

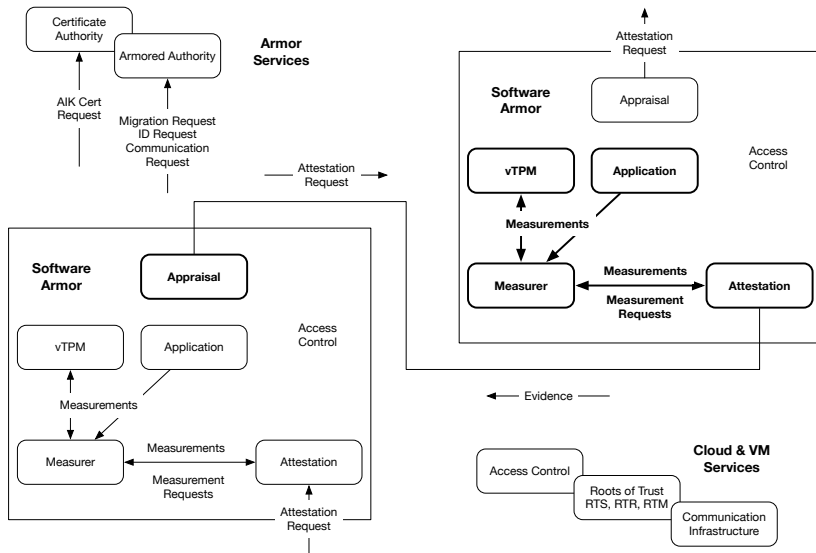
Armored Application Architecture

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

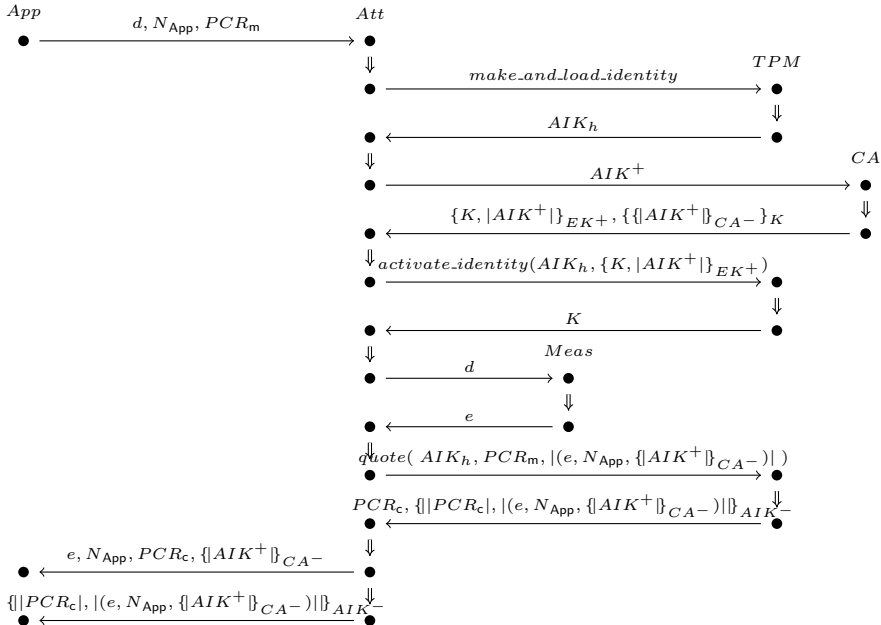


Trustworthy Protocol Execution

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

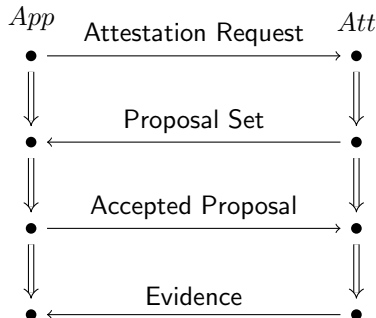
- ▶ First-class structure for protocols
 - ▶ encapsulates a protocol-centered computation
 - ▶ semantics provide a basis for static analysis
 - ▶ based loosely on the Reader monad
- ▶ Abstract communication primitives
 - ▶ extended RPC-style capability
 - ▶ requests remote execution
 - ▶ defines `send`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

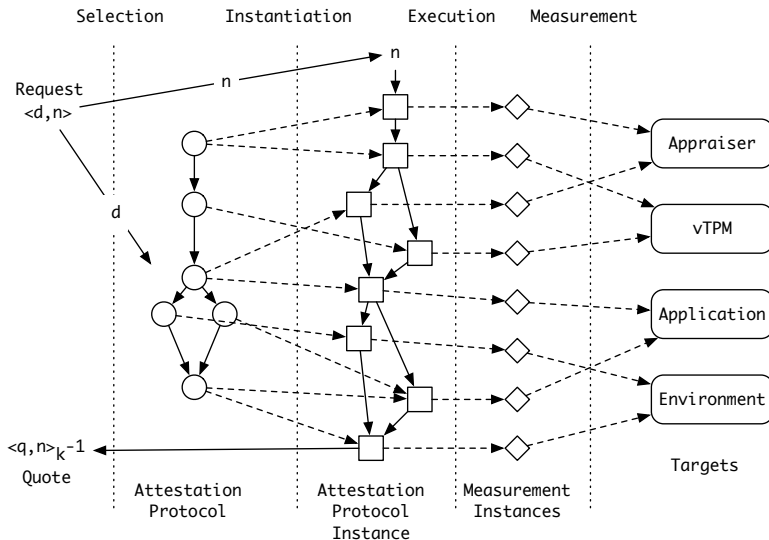
```
((ID,SIGHASH,SIGSRC),  
  do { id <- getVCID;  
        sig <- getSigFileEvidence;  
        src <- getSigFileSrc;  
        e <- createEvidence(id,sig,src);  
        returnEvidence(e) })
```

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:

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

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