Remote Attestation for Cloud-Based Systems

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May 6, 2015

Clouds and Trust

- The promises of the cloud are substantial
  - reduced hardware and software costs
  - reduced resource consumption
  - improved availability and reliability
- The structure of the cloud complicates assurance
  - not under the desk
  - ambiguous and changing runtime environment
  - unknown and unknowable actors in the same environment
- Is trust possible in the cloud environment?
  - unambiguous identification
  - confirmation of uninhibited execution
  - direct or trusted indirect observation of good behavior

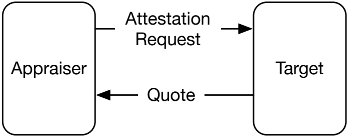
Virtual Blinking Lights

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

- Establish trust in cloud applications
    - trust in cloud infrastructure
    - trust in user-space applications
    - trust in application cohorts
- Promote informed decision making
    - confirm data confidentiality
    - confirm execution and data integrity
- Autonomous run-time response and reconfiguration
    - respond to attack, failure, reconfiguration, and repair
    - appraisal informs response

Semantic Remote Attestation

- 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

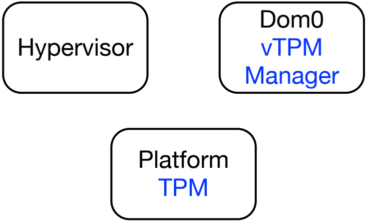
The Cloud Challenge

Chasing the bottom turtle

Platform
TPM

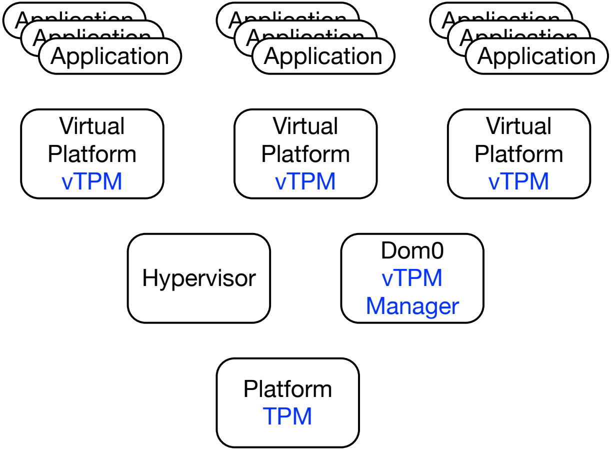
The Cloud Challenge

Chasing the bottom turtle



The Cloud Challenge

Chasing the bottom turtle



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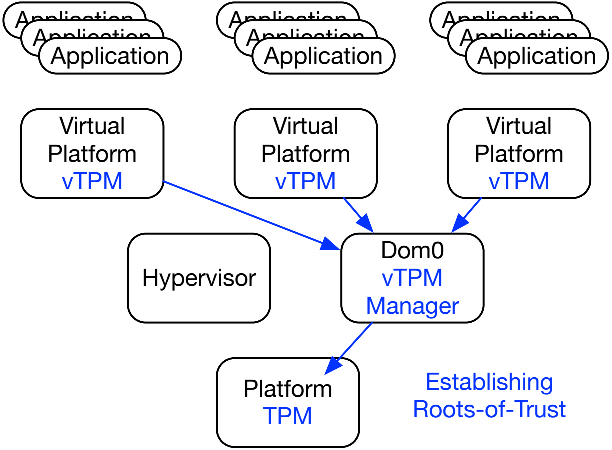
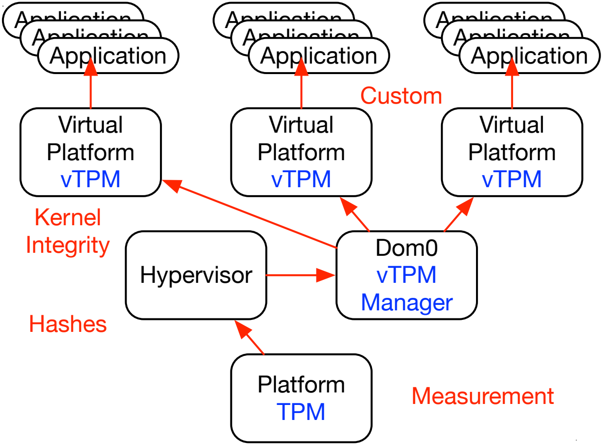


Establishing Roots-of-Trust

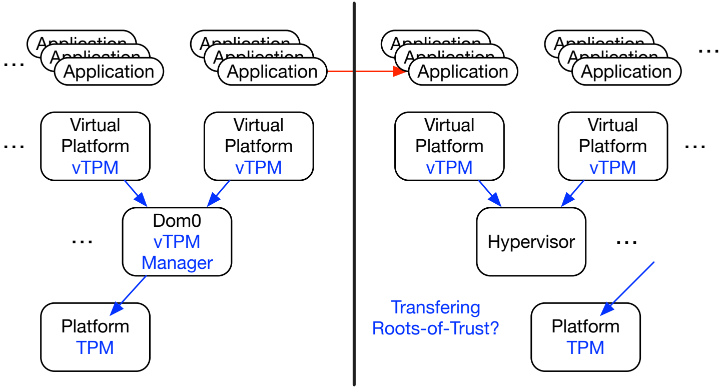
The Cloud Challenge

Chasing the bottom turtle



The Cloud Challenge

Chasing the bottom turtle



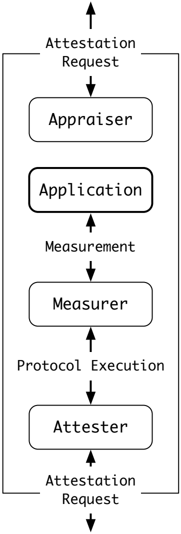
Enabling Technologies

- Trustworthy protocol execution
  - executable and analyzable protocol representation
  - generates evidence of trustworthiness
  - negotiates attestation details
  - designed for highly focused appraisal
- Application specific measurement
  - managed and traditional execution environments
  - compile-time assistance for measurer synthesis
  - specialized measurement bundled with applications
- Lightweight trust infrastructure
  - abstract communications capability
  - migration support
  - strong identity

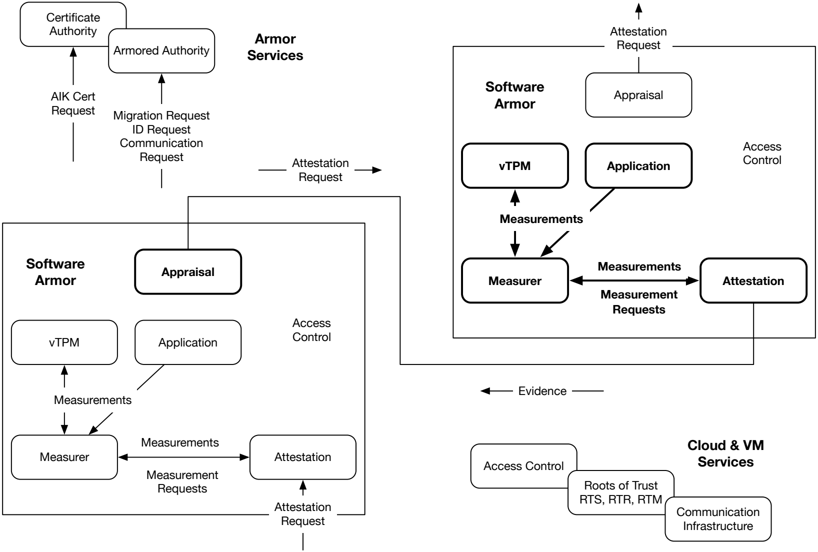
Armored Application Architecture

M&A targeted to an application

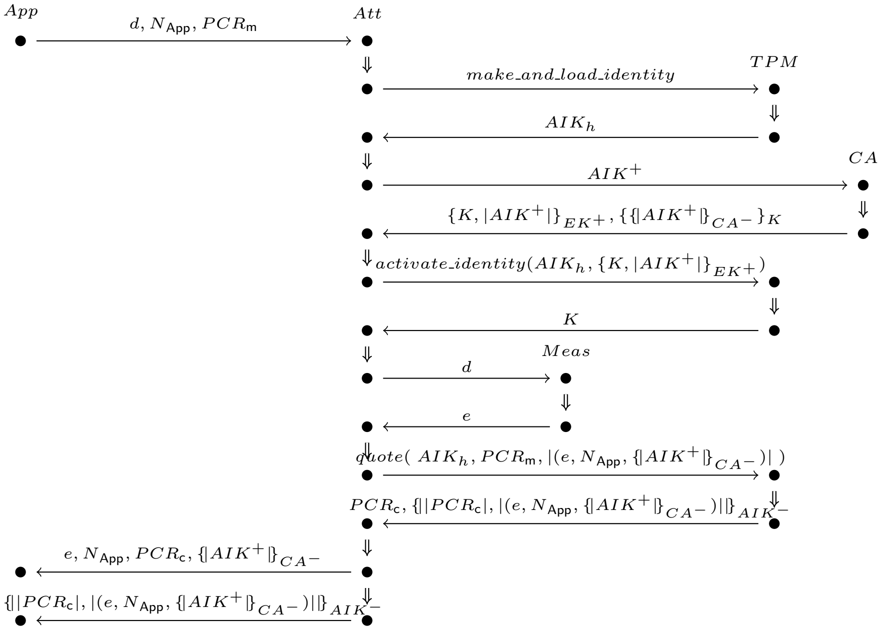
- Appraiser makes attestation requests
- Attester responds to attestation requests
- Measurer gathers evidence from application
- Influenced by the *Trusted Research Platform* and *Principles of Remote Attestation*



System-Level Architecture



Privacy CA Attestation


App
Att
$d, N_{\mathsf{App}}, PCR_{\mathsf{m}}$
TPM
$make\_and\_load\_identity$
AIK_h
CA
AIK^+
$\{K, |AIK^+|\}_{EK^+}, \{\{\!|AIK^+|\!\}_{CA^-}\}_K$
$activate\_identity(AIK_h, \{K, |AIK^+|\}_{EK^+})$
K
$Meas$
d
e
$quote(\ AIK_h, PCR_{\mathsf{m}}, |(e, N_{\mathsf{App}}, \{\!|AIK^+|\!\}_{CA^-})|\ )$
$PCR_{\mathsf{c}}, \{\!||PCR_{\mathsf{c}}|, |(e, N_{\mathsf{App}}, \{\!|AIK^+|\!\}_{CA^-})||\!\}_{AIK^-}$
$e, N_{\mathsf{App}}, PCR_{\mathsf{c}}, \{\!|AIK^+|\!\}_{CA^-}$
$\{\!||PCR_{\mathsf{c}}|, |(e, N_{\mathsf{App}}, \{\!|AIK^+|\!\}_{CA^-})||\!\}_{AIK^-}$

EDSL for Protocol

First-class protocol structures

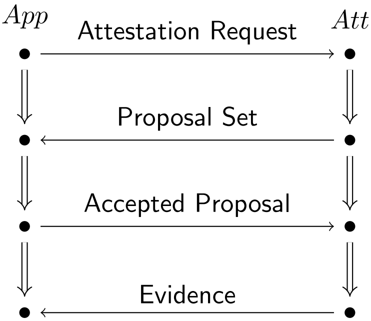
- First-class structure for protocols
  - encapsulates a protocol-centered computation
  - semantics provide a basis for static analysis
  - based loosely on the `Reader` monad
- Abstract communication primitives
  - extended RPC-style capability
  - requests remote execution
  - defines `send` and `receive`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

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

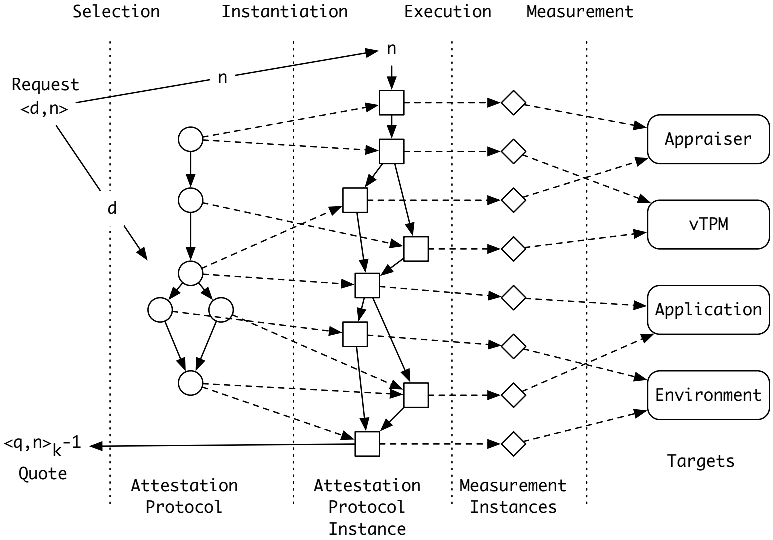
```
((ID,SIGHASH,SIGSRC),
 do { id <- getVCID;
      sig <- getSigFileEvidence;
      src <- getSigFileSrc;
      e <- createEvidence(id,sig,src);
      returnEvidence(e) })
```

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:

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

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

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