

Remote Attestation for Cloud-Based Systems

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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

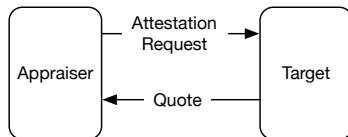
Virtual Blinking Lights

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, $\{n, PCRCComp\}_{AIK^-}$)
 - ▶ 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 = 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

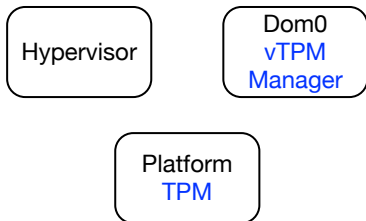
The Cloud Challenge

Chasing the bottom turtle

Platform
TPM

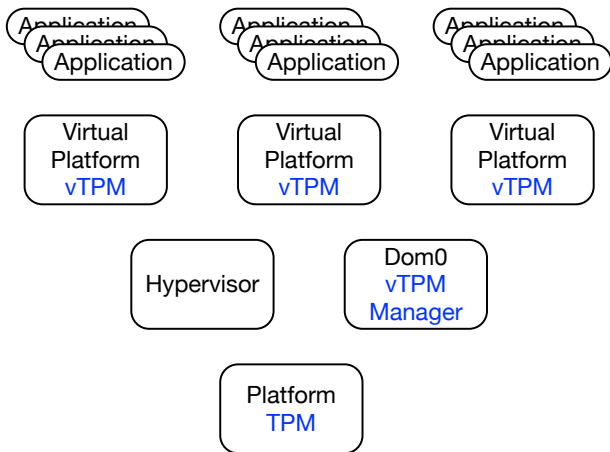
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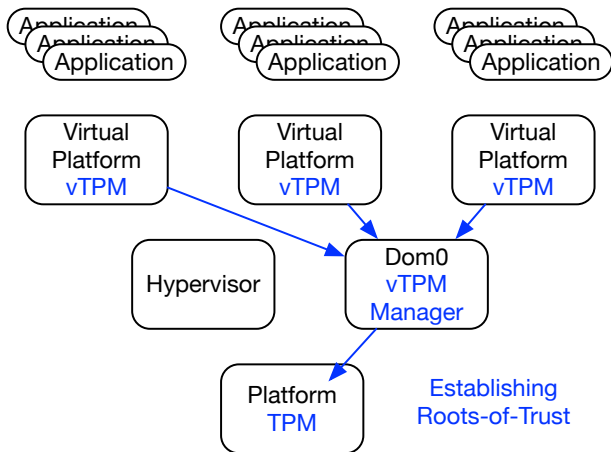
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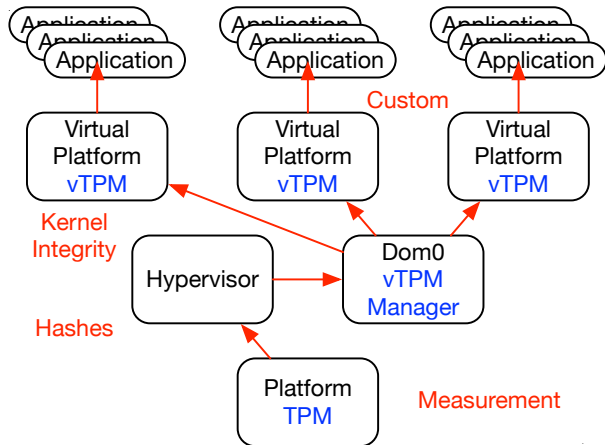
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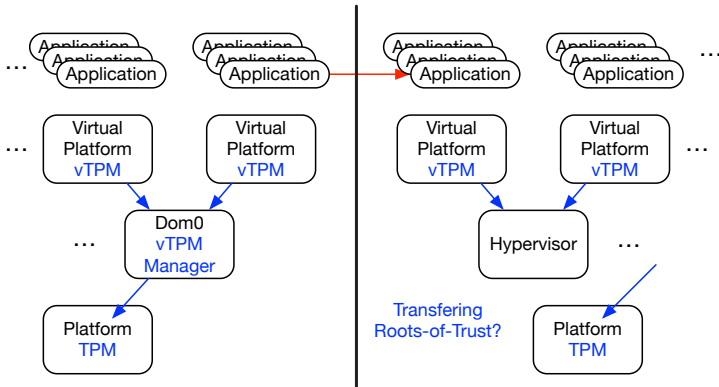
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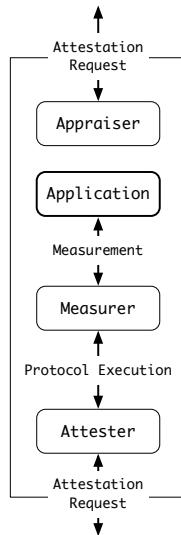
Enabling Technologies

- ▶ 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

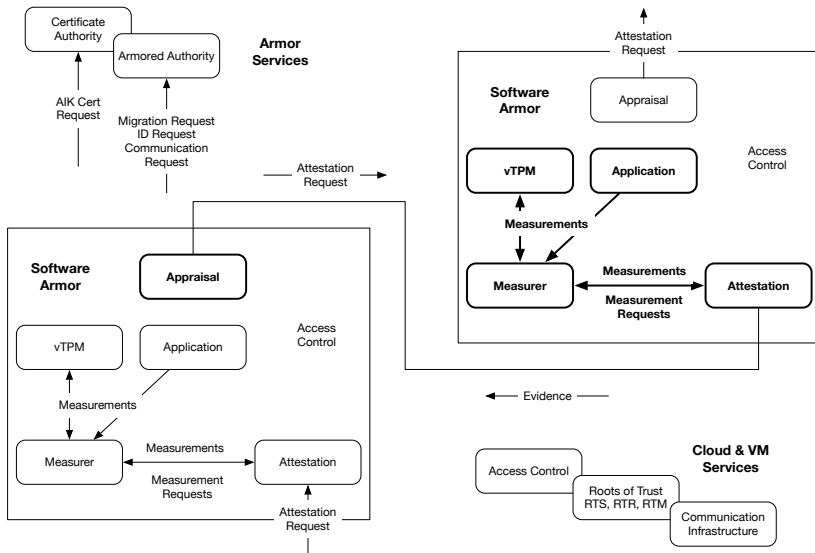
Armored Application Architecture

M&A targeted to an application

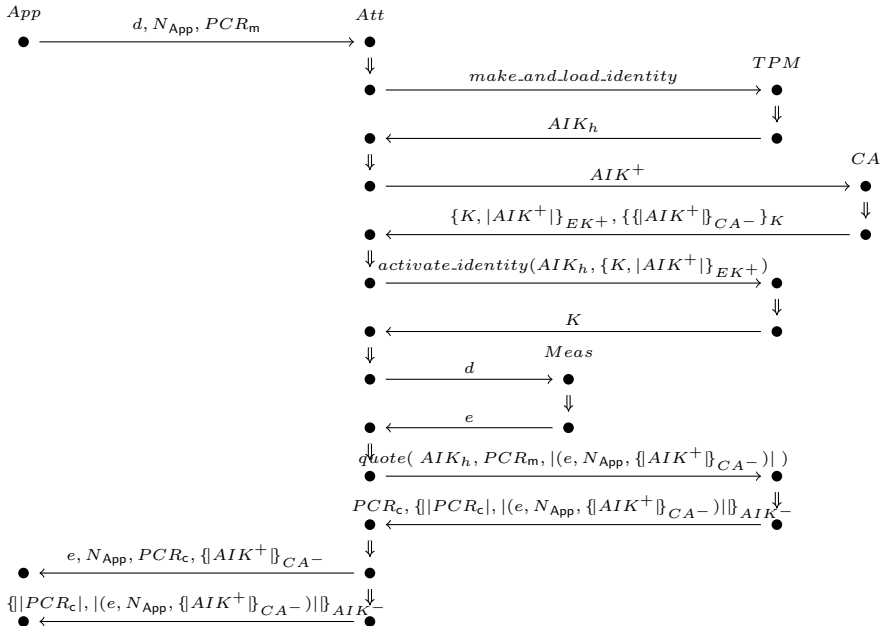
- ▶ Appraiser makes attestation requests
- ▶ Attester responds to attestation requests
- ▶ Measurer gathers evidence from application
- ▶ Influenced by the *Trusted Research Platform* and *Principles of Remote Attestation*



System-Level Architecture



Privacy CA Attestation



EDSL for Protocol

First-class protocol structures

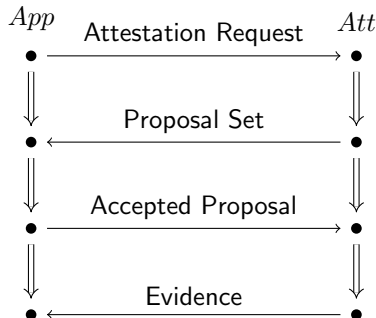
- ▶ First-class structure for protocols
 - ▶ encapsulates a protocol-centered computation
 - ▶ semantics provide a basis for static analysis
 - ▶ based loosely on the Reader monad
- ▶ Abstract communication primitives
 - ▶ extended RPC-style capability
 - ▶ requests remote execution
 - ▶ defines `send`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

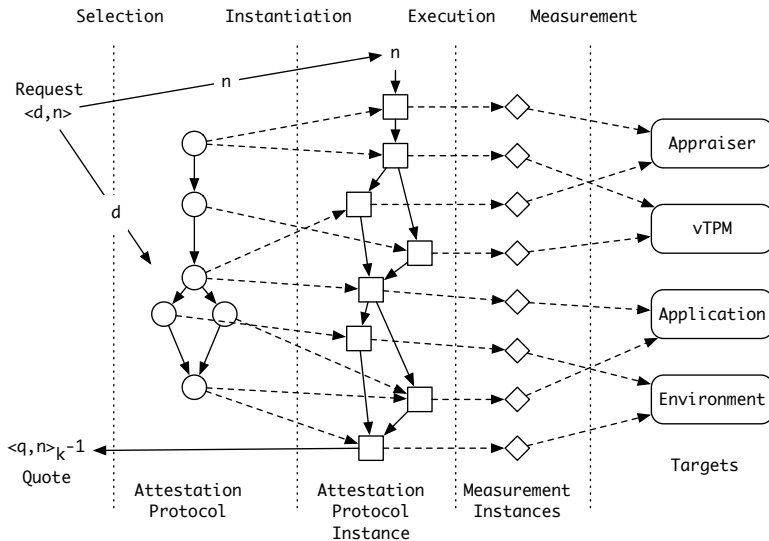
```
((ID,SIGHASH,SIGSRC),  
  do { id <- getVCID;  
        sig <- getSigFileEvidence;  
        src <- getSigFileSrc;  
        e <- createEvidence(id,sig,src);  
        returnEvidence(e) })
```

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:

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

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