

# Trust

What it is and how to get it

Dr. Perry Alexander

Information and Telecommunication Technology Center  
Electrical Engineering and Computer Science  
The University of Kansas  
palexand@ku.edu

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## Trust

“An entity can be trusted if it always behaves in the expected manner for the intended purpose [? ]”

## Properties

- ▶ Unambiguous identification
- ▶ Unimpeded operation
- ▶ First-hand observation of good behavior *or* indirect experience of good behavior by a trusted third party

# Necessary Capabilities for Trust

- ▶ *Strong Identification* — An unambiguous, immutable identifier associated with the platform. The identifier is a protected encryption key in the TXT implementation.
- ▶ *Reporting Configuration* — An unambiguous identification mechanism for software and hardware running on the platform. The mechanism is hashing in the TXT implementation

$T^x[y]$  is an homogeneous relation over actors that is true when  $x$  *trusts*  $y$ .  $T^x[y]$  is a preorer:

- ▶ Reflexive -  $\forall x \cdot T^x[x]$
- ▶ Transitive -  $\forall x, y, z \cdot T^y[x] \wedge T^z[y] \Rightarrow T^z[x]$

The transitive property defines *chains of trust*.

The *Trusted Platform Module (TPM)* is a cryptographic coprocessor for trust.

- ▶ Endorsement Key (EK) — factory generated asymmetric key that uniquely identifies the TPM
- ▶ Attestation Instance Key (AIK) — an alias for the EK
- ▶ Storage Root Key (SRK) — user generated asymmetric key that encrypts data associated with the TPM
- ▶ Platform Configuration Registers (PCRs) — registers for storing hashes
- ▶ NVRAM — Non-volatile storage associated with the TPM

# Platform Configuration Registers

- ▶ **Operations on PCRs**

- ▶ Extension — Hash a new value juxtaposed with the existing PCR value
- ▶ Reset — Set to 0
- ▶ Set — Set to a known value

- ▶ **Operations using PCRs**

- ▶ Sealing data — PCR state dependent encryption
- ▶ Wrapping keys — PCR state dependent encryption of a private key
- ▶ Quote — Reporting PCR values to a third party

- ▶ **Properties**

- ▶ Locality — Access control
- ▶ Resettable — Can a PCR be reset
- ▶ Many others that we don't need yet

A *root of trust* provides a basis for transitively building trust. Roots of trust are trusted implicitly.

There are three important Roots of Trust:

- ▶ Root of Trust for Measurement (RTM)
- ▶ Root of Trust for Reporting (RTR)
- ▶ Root of Trust for Storage (RTS)



# Root of Trust for Measurement

A *Root of Trust for Measurement* is trusted to take the base system measurement.

- ▶ A hash function called on an initial code base from a protected execution environment
- ▶ Starts the measurement process during boot
- ▶ In the Intel TXT process the RTM is SENTER implemented on the processor

# Root of Trust for Reporting

A *Root of Trust for Reporting* is trusted to authenticate the base system report or quote

- ▶ A protected key used for authenticating reports
- ▶ In the Intel TXT processes this is the TPM's Endorsement Key (EK)
- ▶ Created and bound to its platform by the TPM foundry
- ▶  $EK^{-1}$  is stored in the TPM and cannot be accessed by any entity other than the TPM
- ▶  $EK$  is available for encrypting data for the TPM
- ▶  $EK^{-1}$  is used for decrypting data
- ▶ Binding of  $EK$  to its platform is maintained by a trusted Certificate Authority (CA)

A *Root of Trust for Storage* is trusted to protect the base stored data

- ▶ Typically a key stored in a protected location
- ▶ In the Intel TXT boot process this is the TPM's Storage Root Key (SRK)
- ▶ Created by TPM\_TakeOwnership
- ▶  $SRK^{-1}$  is stored in the TPM
- ▶  $SRK^{-1}$  cannot be accessed directly and can only be used by the TPM

# One Step from Roots of Trust

Roots of trust are used to build a trusted system from boot.

- ▶ Power On Reset
- ▶ Resettable PCRs are reset to -1
- ▶ SENTER resets selected PCRs to 0
  - ▶ Specified as resettable
  - ▶ PCRs in locality 4 or lower
  - ▶ *Only* SENTER can reset locality 4 PCRs
- ▶ SENTER hashes SINIT into PCR 18
  - ▶ RTM generates the first measurement
  - ▶ RTS stores the first measurement in PCR 18

# Two Steps from Roots of Trust

- ▶ SINIT measures the Secure Launch Environment (SLE)
  - ▶ SINIT uses measurement policy stored in the TPM NVRAM
  - ▶ SINIT measured by RTM stored in RTS, thus trusted
- ▶ SINIT returns control to SENTER
- ▶ SENTER invokes the SLE
  - ▶ SLE elements are hashed into PCRs
  - ▶ SLE core measures and starts the operational environment

- ▶ Trust is transitive
  - ▶  $T^x[y] \wedge T^y[z] \Rightarrow T^x[z]$
  - ▶ Construct chains of trust
  - ▶ Remember “directly observed or indirectly observed by a trusted third party”
- ▶ Roots of Trust define the “root” for trust
  - ▶ Use Roots of Trust to establish base for chain
  - ▶ RTM generates a trusted first measurement
  - ▶ RTS protects first measurement
  - ▶ RTR signs base quote for appraiser (eventually)
- ▶ Extend chains of trust by measuring before executing

## 1. Power On

- ▶ PCRs reset to -1

## 2. SENTER is called (RTM)

- ▶ SENTER resets PCRs to 0
- ▶ SENTER hashes SINIT into PCR 18 (RTS)

## 3. SINIT is called (Trusted)

- ▶ Review access control modeling objectives
  - ▶ modeling platform MAC
  - ▶ modeling local access control
- ▶ Overview access control policy definition
  - ▶ design and modeling assumptions
  - ▶ platform boot policy definition
  - ▶ local policy definitions
- ▶ Overview models
  - ▶ domain and system models
  - ▶ communication model
  - ▶ theorems and status
- ▶ Identify next steps
  - ▶ runtime and moving beyond the SVP line
  - ▶ adding M&A detail



# Access Control Modeling Objectives

What we're about here

Reporting joint work with Geoffrey Brown, Indiana University (submitted) in which we verify two physical layer protocols.

- ▶ Biphase Mark Protocol (BMP)
- ▶ 8N1 Protocol

These protocols are used in data transmission for CDs, Ethernet, and Tokenring, etc. as well as UARTs.

- ▶ Correctness is reasonably difficult to prove due to many real-time constraints.
- ▶ Many previous formal modeling/verification efforts for these protocols.

Some normal text goes here  
just for introduction

- ▶ Appraisal
- ▶ Measurement
- ▶ Attestation
- ▶ vTPM

Why is this column getting  
higher?

Maybe it's not  
Center alignment seems best.

I like this for two column test  
and graphics

Getting higher???

# Big Picture

Armor Architecture

## Introduction to $\text{\LaTeX}$

Beamer is a  $\text{\LaTeX}$ class for creating presentations that are held using a projector...”

This is a definition

Not really a proof.

1. This is a step



## Not really a proof.

1. This is a step
2. This is another step



## Not really a proof.

1. This is a step
2. This is another step
3. This is a third step
4. This is a third step
5. This is a third step
6. This is a third step



- ▶ Item 1 followed by a pause



- ▶ Item 1 followed by a pause
- ▶ Item 3 followed by a pause

- ▶ Item 1 followed by a pause
- ▶ Item 2 followed by a pause
- ▶ Item 3 followed by a pause

- ▶ BMP has been verified in PVS twice and required
  - ▶ 37 invariants and 4000 individual proof directives (initially) in the one effort
  - ▶ 5 hours just to *check* the proofs in the other effort
  - ▶ A formal specification and verification of an independent real-time model in both efforts
- ▶ BMP has been verified in (the precursor to) ACL2 by J. Moore and required
  - ▶ A significant conceptual effort to fit the problem in the logic, arguably omitting some salient features of the model
  - ▶ The statement and proof of many antecedent results
  - ▶ J. Moore reports this as one of his “best ideas” in his career

# Not Your Father's Theorem-Prover

The verifications are carried out in the SAL infinite-state bounded model-checker that combines SAT-solving and SMT decision procedures to *prove* safety properties about infinite-state models.

- ▶ Theorem-proving efforts took multiple engineer-months if not years to complete.
- ▶ Our initial effort in SAL consumed about *two engineer-days*.  
...and we found a significant bug in a UART application note.

# Parameterized Timing Constraints

SMT allows for *parameterized* proofs of correctness. The following are example constraints from the BMP verification:

TIME: TYPE = REAL;

TPERIOD: TIME = 16;

TSAMPLE: INTEGER = 23;

**TSETTLE**: {x: TIME |  
                  0 <= x  
                  AND (x + TPERIOD < TSAMPLE)  
                  AND (x + TSAMPLE + 1 < 2 \* TPERIOD)};

**TSTABLE**: TIME = TPERIOD - TSETTLE;

**ERROR**: {x: TIME |  
                  (0 <= x)  
                  AND (TPERIOD + TSETTLE < TSAMPLE\*(1-x))  
                  AND (TSAMPLE\*(1+x) + (1+x) + TSETTLE < 2 \* TPERIOD)};

RSAMPMAX: TIME = TSAMPLE \* (1 + ERROR);

RSAMPMIN: TIME = TSAMPLE \* (1 - ERROR);

RSCANMAX: TIME = 1 + ERROR;

RSCANMIN: TIME = 1 - ERROR;

- ▶ Parser
- ▶ Simulator
- ▶ Symbolic model-checker (BDDs)
- ▶ Witness symbolic model-checker
- ▶ Bounded model-checker
- ▶ Infinite-state bounded model-checker
- ▶ Future releases include:
  - ▶ Explicit-state model-checker
  - ▶ MDD-based symbolic model-checking

All of which are “state-of-the-art”

Please direct your attention to the whiteboard.

# Timeout Automata<sup>1</sup> (Semantics)

An *explicit* real-time model.

- ▶ Vocabulary:
  - ▶ A set of state variables.
  - ▶ A *global clock*,  $c \in \mathbb{R}^{0\leq}$ .
  - ▶ A set of *timeout* variables  $T$  such that for  $t \in T$ ,  $t \in \mathbb{R}^{0\leq}$ .
- ▶ Construct a transition system  $\langle S, S^0, \rightarrow \rangle$ :
  - ▶ States are mappings of all variables to values.
  - ▶ Transitions are either *time transitions* or *discrete transitions*.
    - ▶ Time transitions are enabled if the clock is less than all timeouts. Updates clock to least timeout.
    - ▶ Discrete transitions are enabled if the clock equals some timeout. Updates state variables and timeouts.

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<sup>1</sup>B. Dutertre and M. Sorea. Timed systems in SAL. *SRI TR*, 2004.



# Disjunctive Invariants

Even with  $k$ -induction, getting a sufficiently strong invariant is still hard! *Disjunctive invariants* help. A disjunctive invariant can be built iteratively from the counterexamples returned for the hypothesized invariant being verified.

```
t0: THEOREM system |-  
  G( ( (phase = Settle)  
      AND (rstate = tstate + 1)  
      AND (rclk - tclk - TPERIOD > 0)  
      AND (tclk + TPERIOD + TSTABLE - rclk > 0))  
    OR  
    ( (phase = Stable)  
      AND (rstate = tstate + 1)  
      AND (rclk - tclk - TSETTLE > 0)  
      AND (tclk + TPERIOD - rclk > 0)  
      AND (rdata = tdata))  
      .  
      .  
      .
```