Indications in black = Optional elements

Thomas J. Watson Research Center

Design and Implementation of a TCG-based Integrity Measurement Architecture

Reiner Sailer, Trent Jaeger, Leendert van Doorn, and Xiaolan Zhang
Secure Systems Department

August 2004 | Usenix Security Symposium 2004

• Copyright: 10pt Arial

Overview

- Problem – Runtime integrity guarantees
- Solution – Hierarchical software-stack measurements
  - Load guarantees
  - Property attestation
- Current Implementation
- Future Work

Optional slide number:

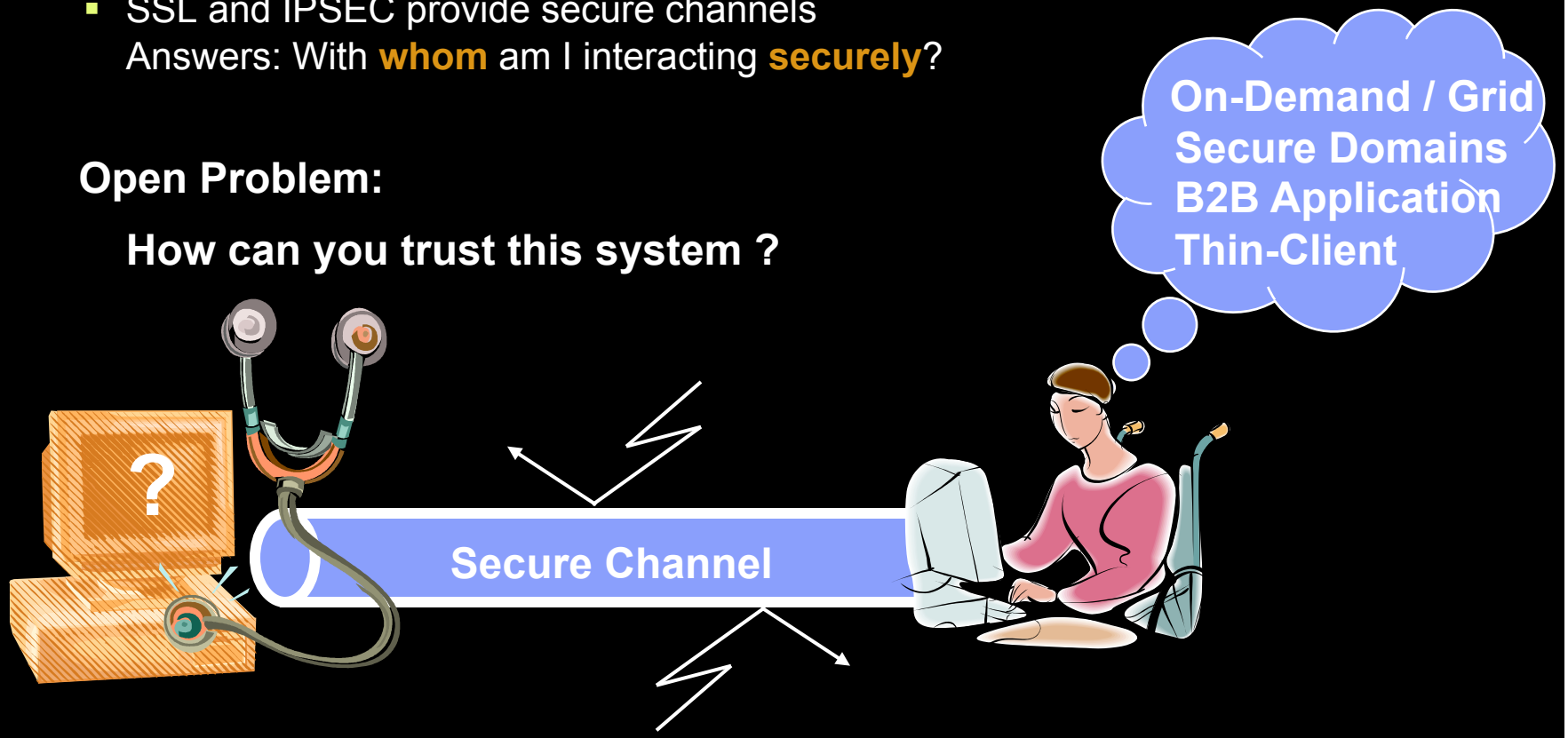
• Copyright: 10pt Arial

Problem – What is the Integrity of a System?

- Insecure networked world
- SSL and IPSEC provide secure channels
  Answers: With **whom** am I interacting **securely**?

Open Problem:

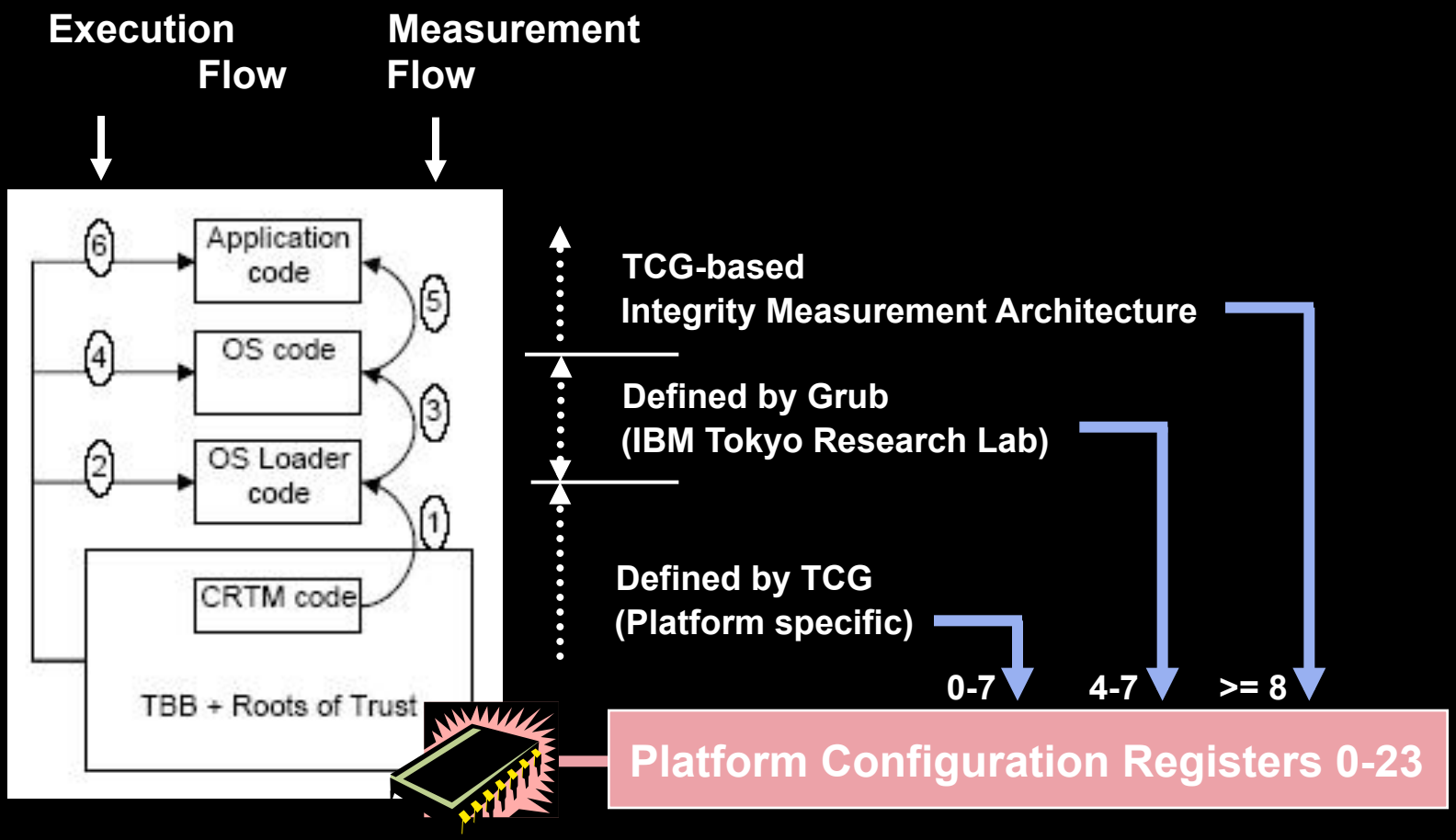
How can you trust this system ?



Optional slide number:

Copyright: 10pt Arial

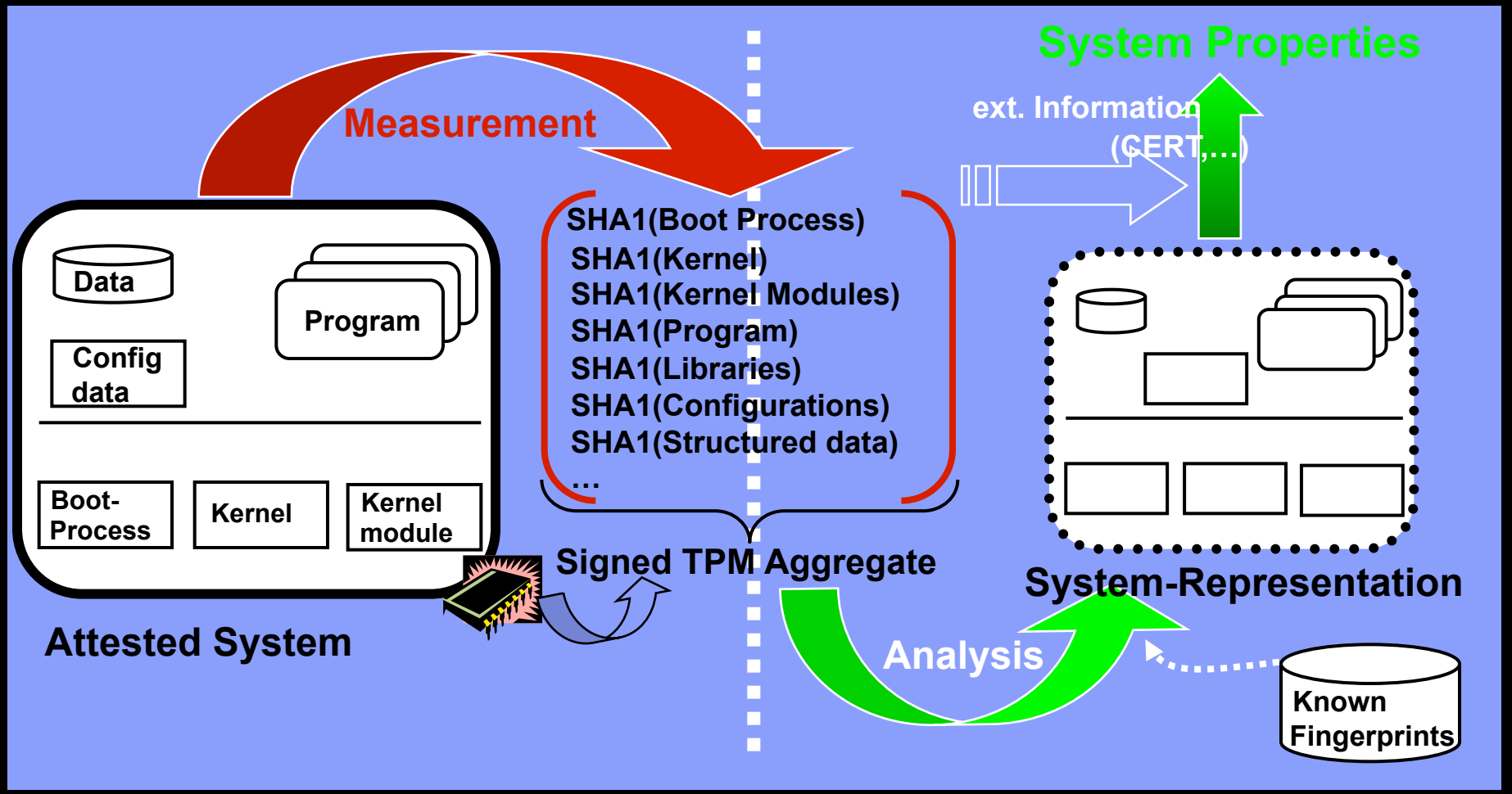
Trusted Computing Group Architecture



Optional slide number:

• Copyright: 10pt Arial

Integrity Measurement Architecture – Solution



Optional slide number:

• Copyright: 10pt Arial

TPM-Based Integrity Measurement Architecture

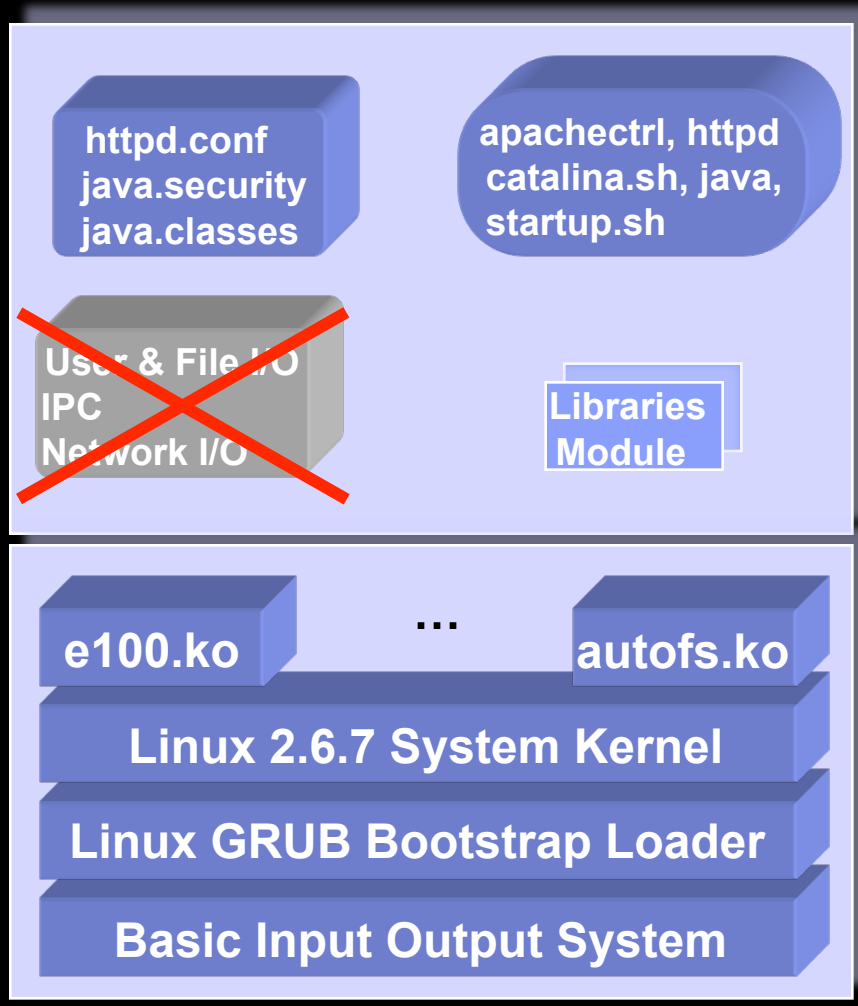
- Achievement of our Integrity Measurement Architecture (IMA)
  Extend TPM-based attestation into the system runtime
  → Attest the Software Stack
- IMA-Guarantees
  - Non-intrusive (not changing system behavior)
  - Load-guarantees for code loaded into the system run-time
  - Detects systems cheating with the measurement list
- Goals
  - Negligible overhead on attested system
  - Usability

Optional slide number:

• Copyright: 10pt Arial

Example: Web Server

- **Executables**
  (Program & Libraries)
  - apachectrl, httpd, java, ..
  - mod_ssl.so, mod_auth.so, mod_cgi.so,..
  - libc-2.3.2.so libjvm.so, libjava.so, …
- **Configuration Files**
  - httpd.conf, html-pages,
  - httpd-startup, catalina.sh, servlet.jar
- **Unstructured Input**
  - HTTP-Requests
  - Management Data



Optional slide number:

• Copyright: 10pt Arial

IMA Implementation – File Measurements

Measurement = SHA1(File Contents) at load time

- **Kernel** measures: kernel modules, programs, and shared libraries
- **Applications** measure their own critical input

  Examples:

  Bash Shell measures: scripts before execution

  Future: Java, Perl, Apache, Jakarta Tomcat …

Advantage

Unique Software-Fingerprints (e.g.sendmail-8.12.8-9.90)

→ **Secure hash represents well known security properties**

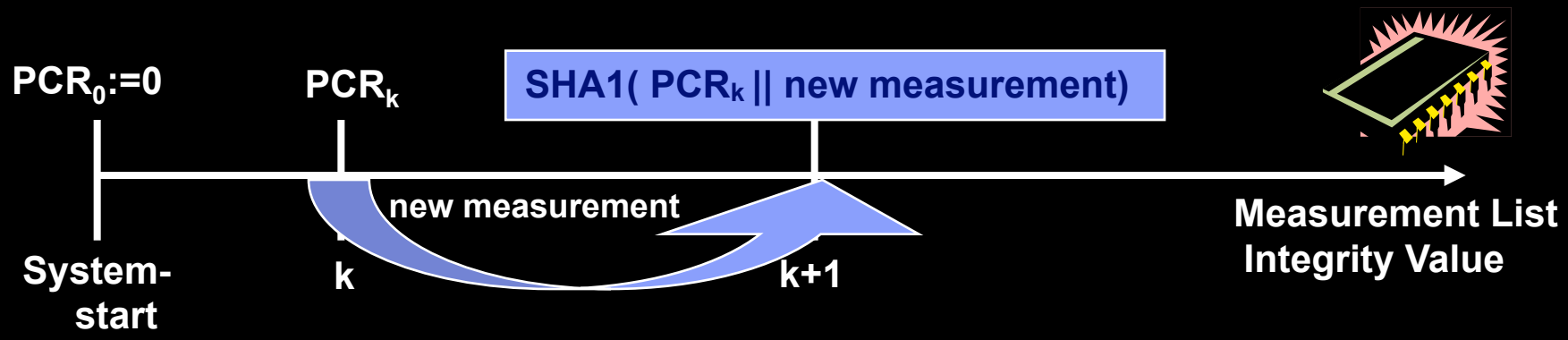
Optional slide number:

• Copyright: 10pt Arial

IMA Implementation – Measurement List Maintenance

Measurement list aggregation:

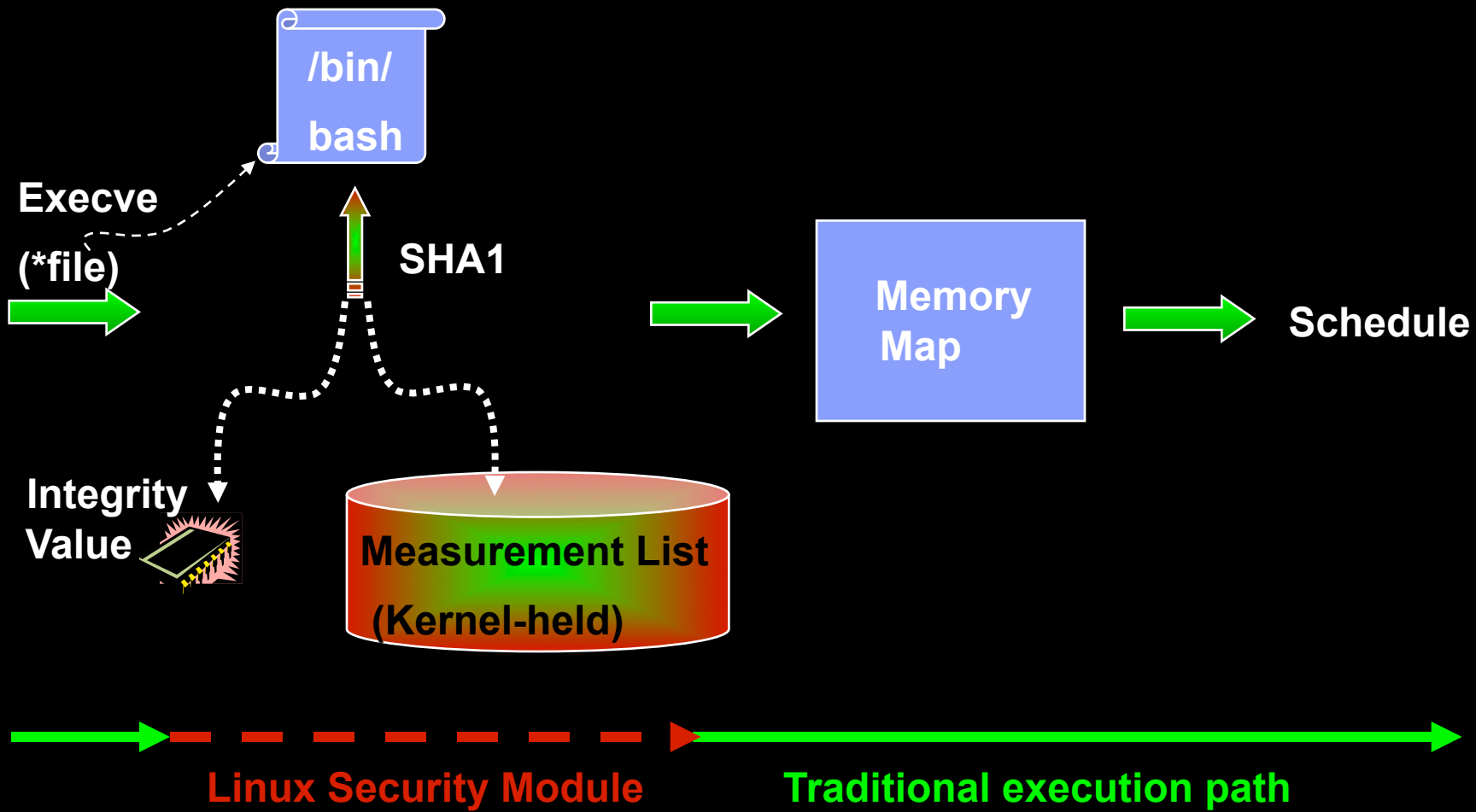
- **Compute** 160bit-SHA1 over the contents of the data (measurement)
- **Adjust** Protected hw Platform Configuration Register (PCR) to maintain measurement list integrity value
- **Add** measurement to ordered measurement list
  - → Executable content is recorded before it impacts the system
  - → That is, before it can corrupt the system



Optional slide number:

• Copyright: 10pt Arial

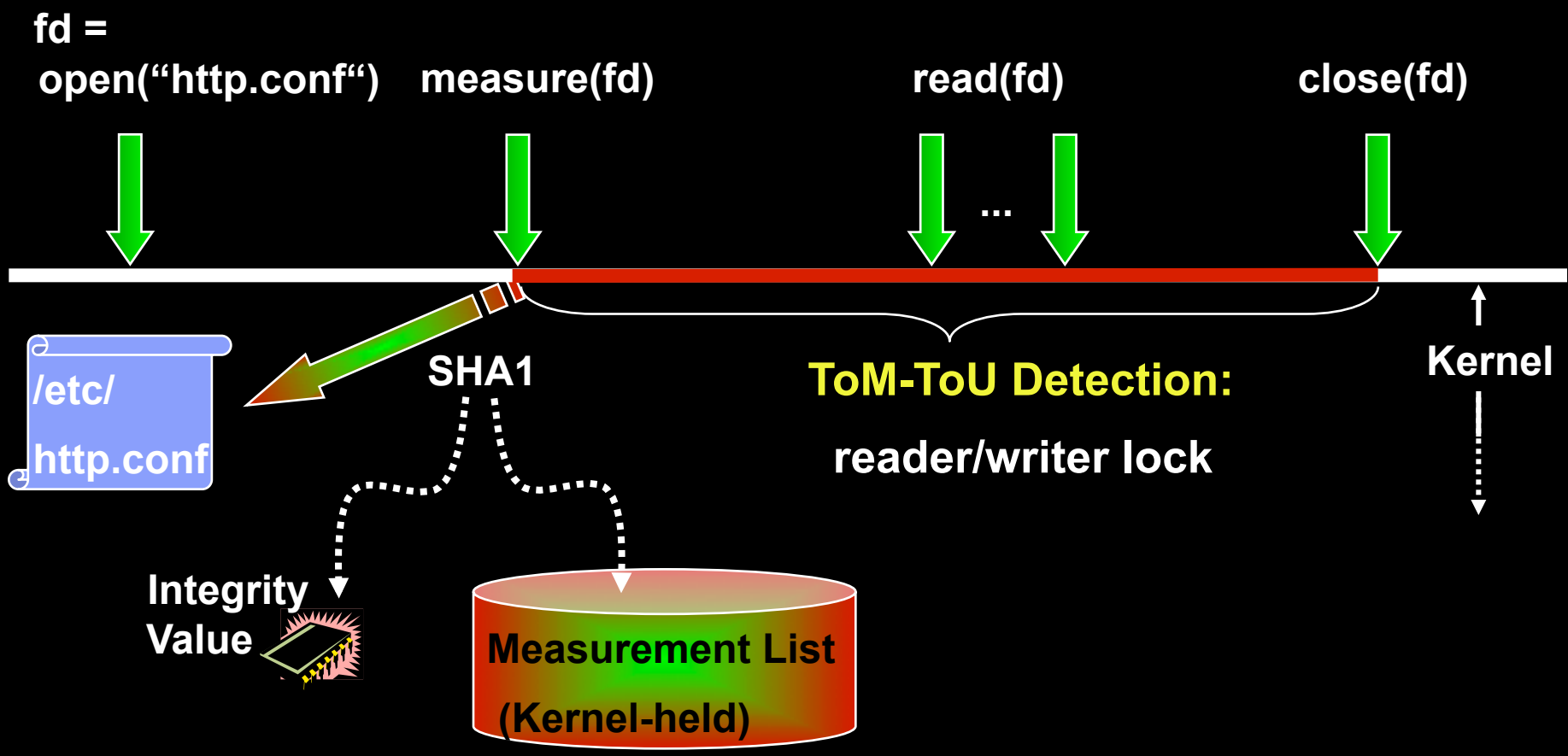
IMA Implementation – Measurements by the Kernel



Optional slide number:

• Copyright: 10pt Arial

IMA Implementation – Measurements by Applications



Optional slide number:

• Copyright: 10pt Arial

Example: Rootkit compromise analysis

Measurement List	Fingerprint DB
000 : D6DC07881A7EFD58EB8E9184CCA723AF4212D3DB	boot_aggregate
001 : 84ABD2960414CA4A448E0D2C9364B4E1725BDA4F	init
002 : 194D956F288B36FB46E46A124E59D466DE7C73B6	ld-2.3.2.so
003 : 7DF33561E2A467A87CDD4BB8F68880517D3CAECB	libc-2.3.2.so
...	...
110 : F969BD9D27C2CC16BC668374A9FBA9D35B3E1AA2	syslogd
...	

(a) THE GOOD CASE

...	
110 : F969BD9D27C2CC16BC668374A9FBA9D35B3E1AA2	syslogd
... :	...
525 : 4CA3918834E48694187F5A4DAB4EECD540AA8EA2	syslogd-LRK5
...	

(b) LRK5-COMPROMISED SYSLOGD

Optional slide number:

• Copyright: 10pt Arial

Results

Attested System:

- Implementation: ~ 5000 LOC (LSM kernel module)
- About 400-600 measurements for Fedora C2, Apache, Jakarta Tomcat, etc.
- Measurement Overhead

	Kernel	Application	Likelihood
Clean Hit	~ 0.1 μs	~ 5 μs	>> 99 %
New (TPM) Measurement	~ 5 ms + SHA1 (~80MB/s)	~ 5ms + SHA1 (~80MB/s)	<< 1 %

Attestation service:

- Known Fingerprint DB ~ 20 000 Fingerprints (RedHat 9.0, Fedora, ES3)
- Attestation: 1-2 second "latency" (unoptimized demonstration)

Optional slide number:

• Copyright: 10pt Arial

Ongoing & Future Work

Open-Source Integrity Measurement Architecture

→ **LSM kernel module**

Isolation of unknown or distrusted measurements

→ **Measure Information flow between executables**

Predict future system states

→ **Measure SELinux policy and enforcement**

Optional slide number:

• Copyright: 10pt Arial

Thank You!

Further Information

http://www.research.ibm.com/secure_systems_department/projects/tcglinux

Optional slide number:

• Copyright: 10pt Arial

BACKUP

Optional slide number:

• Copyright: 10pt Arial

Trusted Platform Module (TPM)

- Trusted Computing Group – Industry Consortium
  → open interface specification of TPM (current version 1.2)
- Independent Manufacturers for TPM chips, glued onto system
- TPM offers protected hw registers (and more)
- TPM includes Public Endorsement Key
  - Endorsement key signature provides identity and integrity
  - Endorsement key certificate includes platform information
- TCG specifies use of TPM to realize:
  - o Hardware Platform Certification
  - o Boot Configuration attestation up to boot-loader

Optional slide number:

• Copyright: 10pt Arial

Indications in black = Optional elements

IMA Implementation (V) – Measurement list

Real measurement list (cat /proc/tcg/measurements):

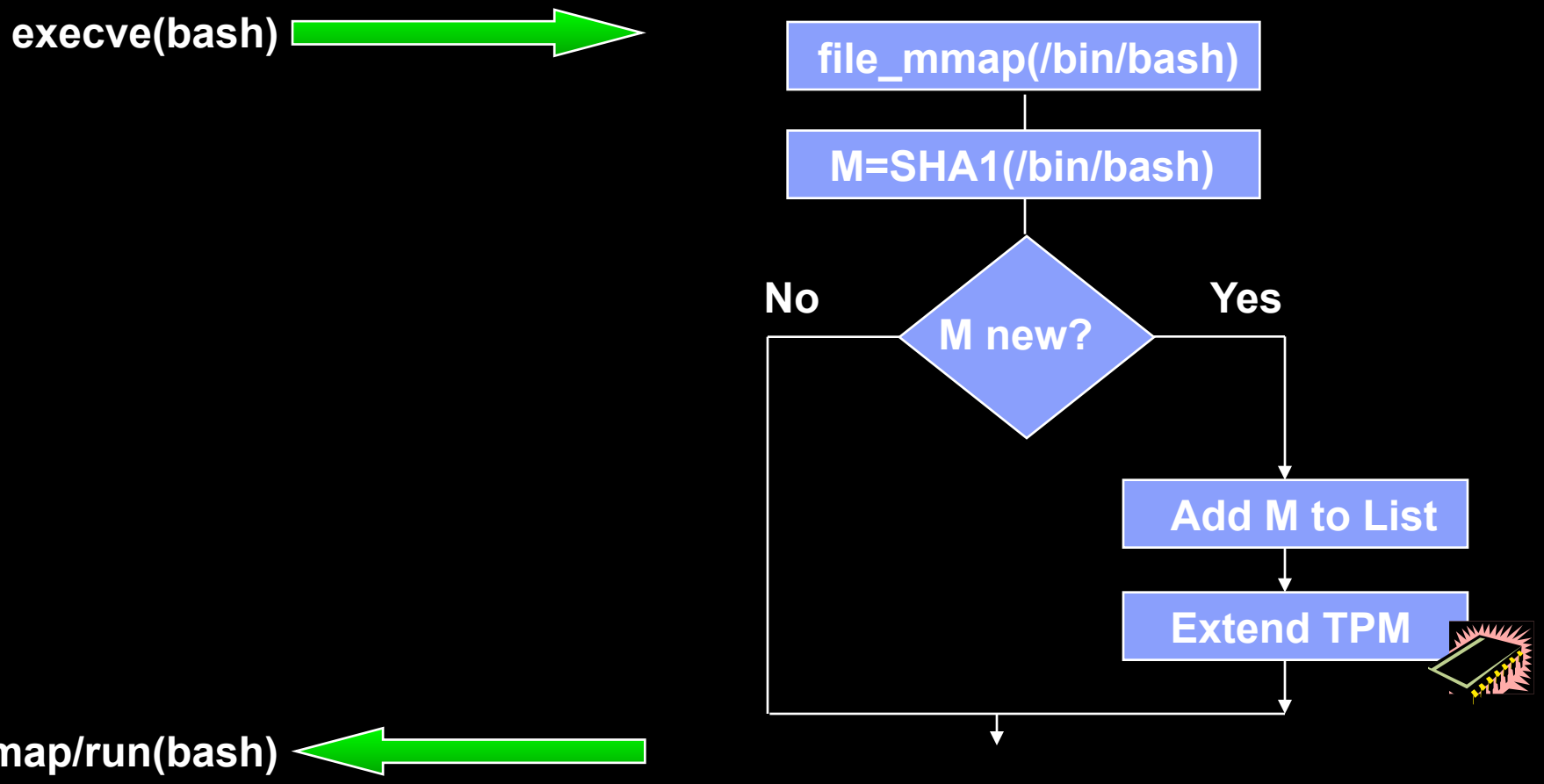
```
#000: D6DC07881A7EFD58EB8E9184CCA723AF4212D3DB    boot_aggregate
#001: 84ABD2960414CA4A448E0D2C9364B4E1725BDA4F    init                [executable]
#002: 9ECF02F90A2EE2080D4946005DE47968C8A1BE3D    ld-2.3.2.so         [library]
#003: 336536B0E22FF762BB539D7FCB7CD283D4622342    libc-2.3.2.so       [library]
#004: A4DC5EDF06698646CD76916F16E95C37E55DC12B    bash                [executable]
...
#027: 2AC8FD6000DDEAA7BD10D7D4E3CE56868100980D    clock               [bashsource]
#028: C0F7BCEF34A2AA7DAECC2B1648C02FB7CFEC9A3D    hwclock             [executable]
...
#070: 01B33D515C3B23F1AB0BAEF845F0A3CA079E9A1E    rc                  [bashscript]
#071: CEBA19AE012DBC2E1A3E428070D2C90A695F1AA4    runlevel            [executable]
#072: 2998794AD01E6D145EA7EF96A831B05584298ED4    egrep               [bashscript]
#073: 68464F40452AB4B63707C3925CA7EC71A7E3B72D    kudzu               [bashscript]
#074: 4CAFF329BF20F736E9E14B4123E0E5F88D8D418D    lang.sh             [bashsource]
...
#080: 147D5593003A8A0DDFA3B27430734F804F388168    parport             [module]
#081: F94054C5C1B38136C72FB1A56EE6F100AB090115    parport_pc          [module]
...
#244: D312491B8247E897D708407543B5369D12E0DA7C    rc.local            [bashscript]
#245: BB2CEA2BA56CCC3D20BDECA554D2976DA0D5AAB3    mingetty            [executable]
...
```

Optional slide number:

• Copyright: 10pt Arial

Indications in black = Optional elements

Measurement Implementation (II) – Example



Optional slide number:

• Copyright: 10pt Arial

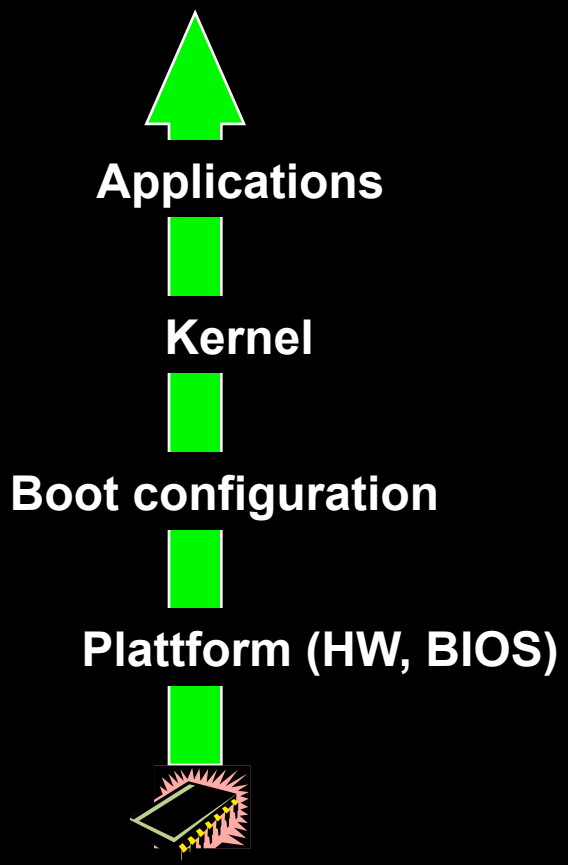
TPM Register Example

```
Manufacturer: 0x41544d4c
TCG version: 1.1
Firmware version: 0.6
PCRs: 16
DIRs: 2
Slots: 10
DIR-00: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
DIR-01: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR-00: 8F 99 36 66 55 E5 09 69 AF FB 3B 08 C9 F6 9B 38 7E 62 D3 75
PCR-01: 99 7D 7E DD 91 D3 8D BE 19 1F 78 F2 1A 4C 7E 9C 65 C6 BA 61
PCR-02: EB B3 BA AE E7 57 4B B6 37 AA AB 67 0F 9A C1 BC EB 6F 80 F3
PCR-03: 04 FD EC DD 50 1D AF 0F 62 4C 1F 99 60 12 CF 30 44 FF 46 10
PCR-04: BC 68 F2 66 F8 B7 5E 55 8C D2 74 70 B7 0B 53 20 0B 48 0F AB
PCR-05: DF 82 43 3F B8 7C 24 09 31 B0 8A 39 B9 63 4A 48 58 A7 FB 97
PCR-06: 04 FD EC DD 50 1D AF 0F 62 4C 1F 99 60 12 CF 30 44 FF 46 10
PCR-07: 31 20 AA 10 F2 D4 23 E9 4D 2C 59 3A 00 1B 02 44 42 B1 DE 65
PCR-08: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR-09: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00

PCR-10: 51 69 57 67 92 71 56 BB 18 D2 5C 9B 87 CB 01 C8 45 FD 7D 65

PCR-11: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR-12: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR-13: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR-14: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
PCR-15: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Type: Atmel TPM
Bus controller: Intel ICH4 LPC
```


Optional slide number:

• Copyright: 10pt Arial

Recap



Future (Ongoing) Work

- **Integrity Measurement Architecture**

  Open-Source IMA

  → LSM kernel module

  Information flow analysis

  → Attestation space partitioning

  → Intergration of information flow into the LSM kernel module

  Attest Policy Enforcement

  → Predictable properties

  → SELinux-Integration (subject, object label)

Optional slide number:

• Copyright: 10pt Arial

Indications in black = Optional elements

Integrity Measurement Architecture – Validation

Detecting Cheating Systems

1. **send 160bit-nonce (unpredictable)**

2.a **receive measurement list**

2.b **receive $\{nonce, PCR\}_{TPM\_Signature}$**

3. **validate TPM_Signature and nonce**

4. **validate list (virtual extension)**

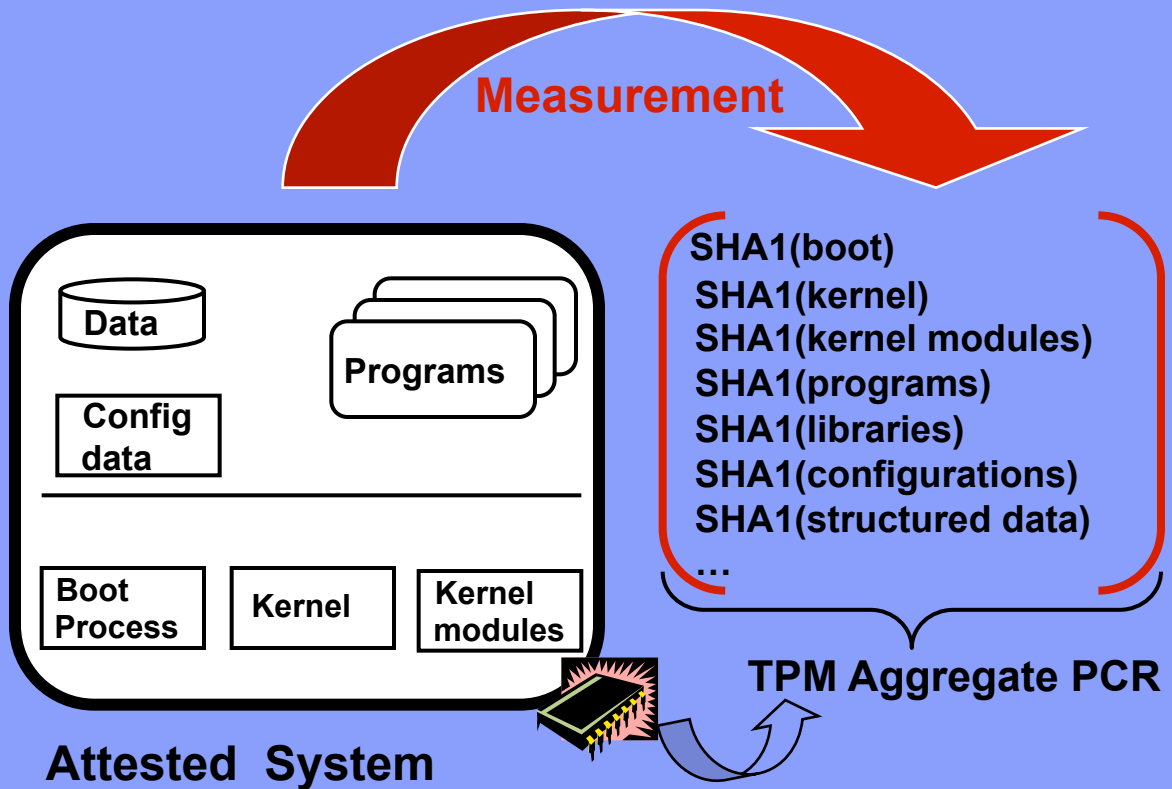
Tampering with the signed PCR is recognized in 3

Tampering with the list is recognized in 4

Optional slide number:

• Copyright: 10pt Arial

IMA – Software Stack Measurements



Optional slide number:

• Copyright: 10pt Arial