CE 874 - Secure Software Systems

Secure Architecture III

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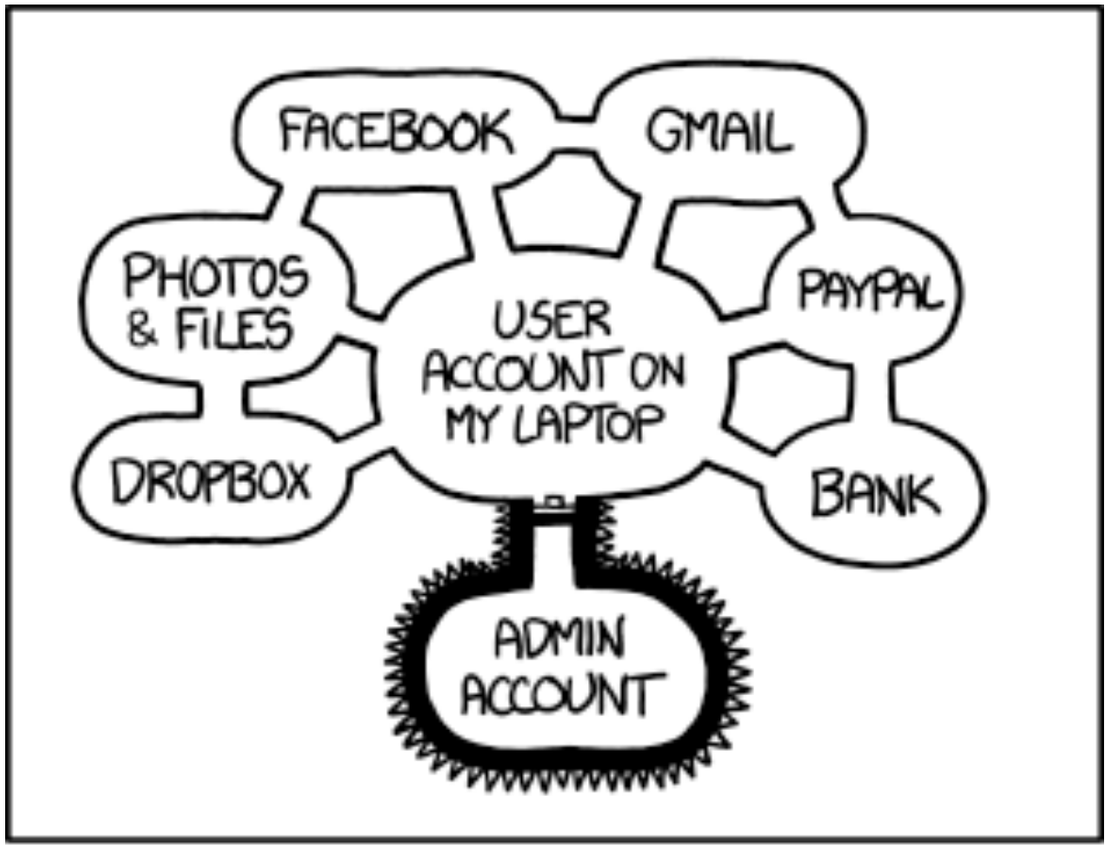
Acknowledgments: Some of the slides are fully or partially obtained from other sources. A reference is noted on the bottom of each slide, when the content is fully obtained from another source. Otherwise a full list of references is provided on the last slide.

Secure Architecture

- How to come up with a secure architecture?
- What design principals is should be followed?
- What are the available mechanisms?
- How do you trust the code getting executed?



IF SOMEONE STEALS MY LAPTOP WHILE I'M LOGGED IN, THEY CAN READ MY EMAIL, TAKE MY MONEY, AND IMPERSONATE ME TO MY FRIENDS,

BUT AT LEAST THEY CAN'T INSTALL DRIVERS WITHOUT MY PERMISSION. xkcd.com

Bootstrapping Trust in Commodity Computers,

Bryan Parno, Jonathan McCune, Adrian Perrig, IEEE S&P, 2010

A Travel Story

A Travel Story

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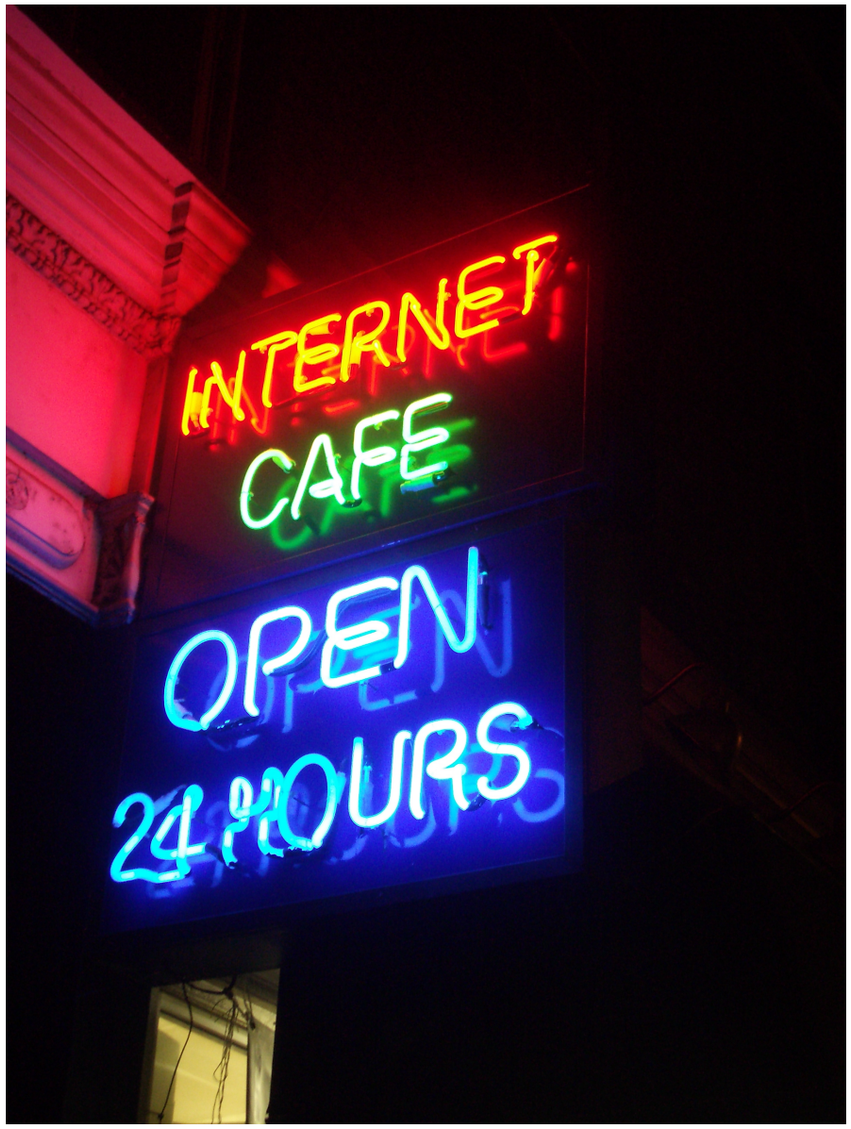

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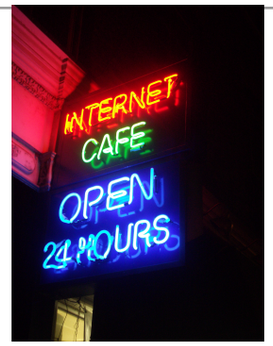

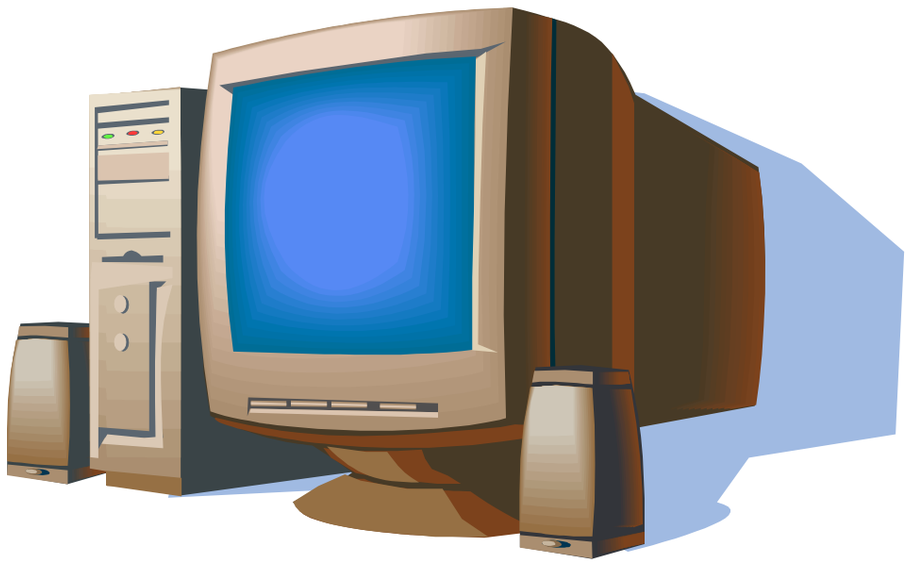

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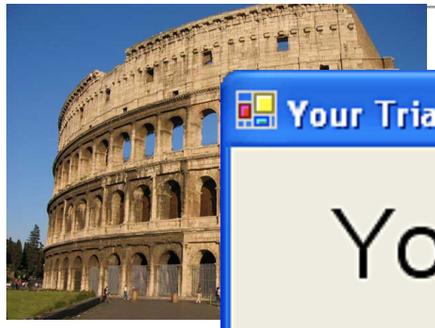
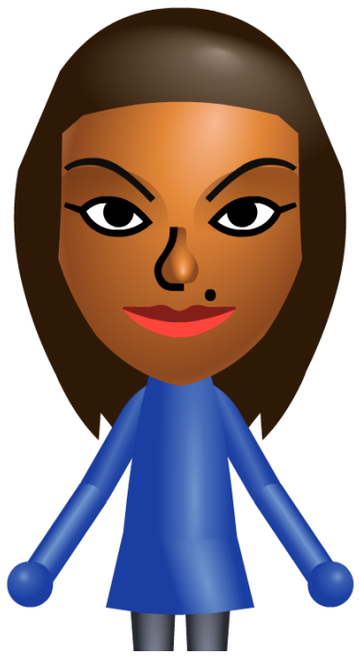
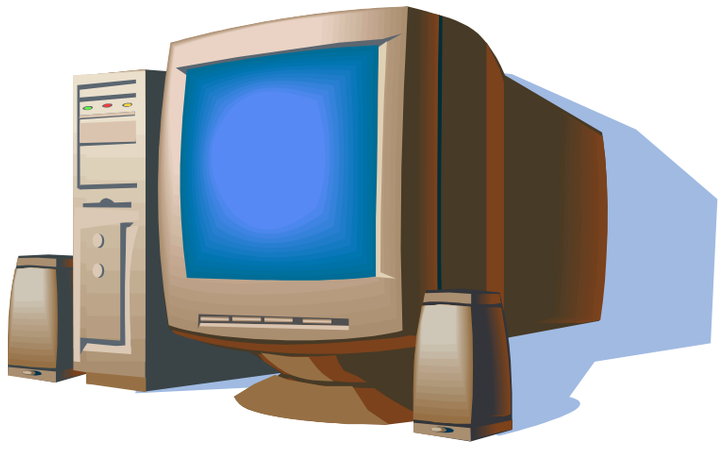


Trust is Critical





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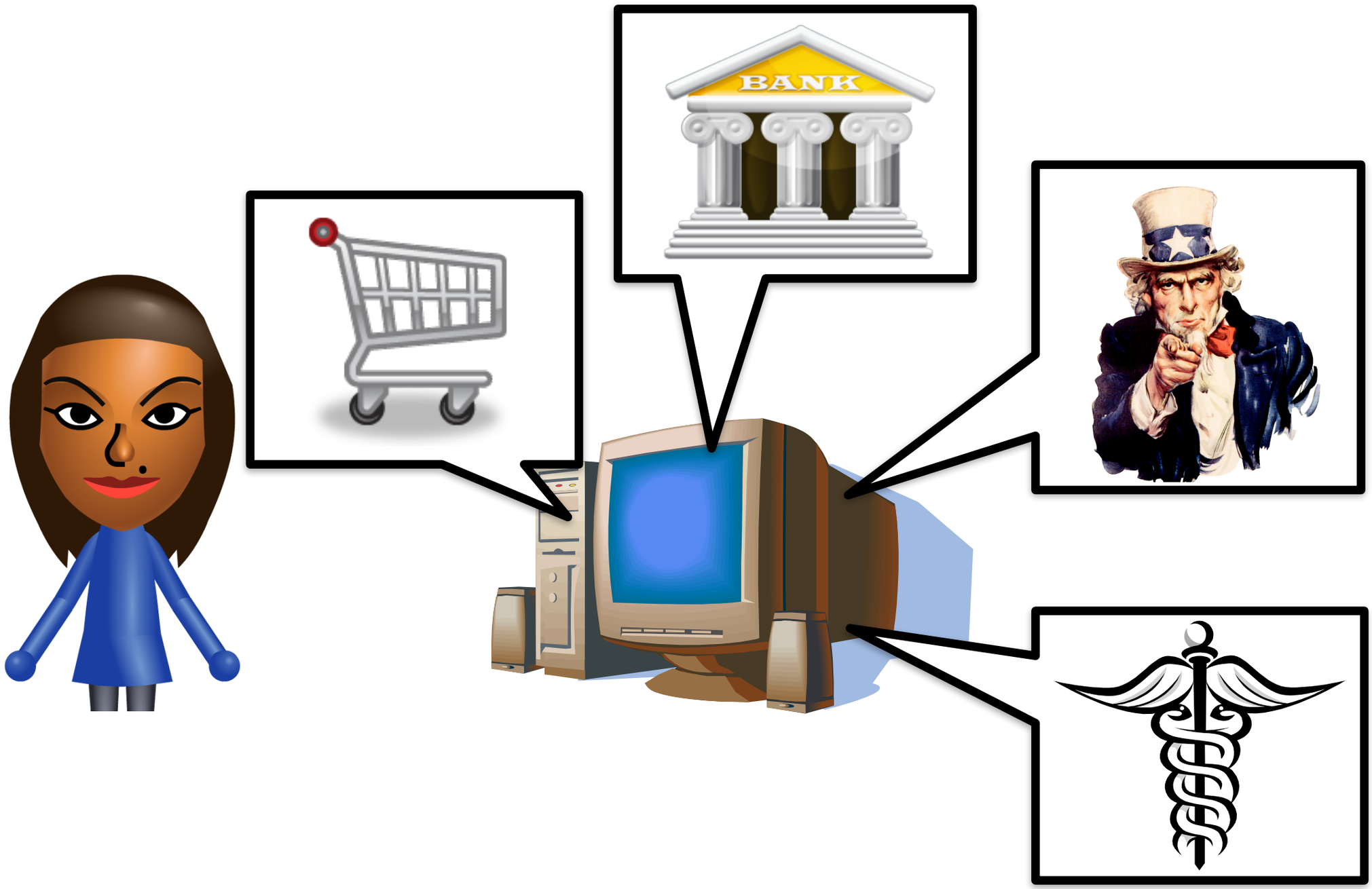

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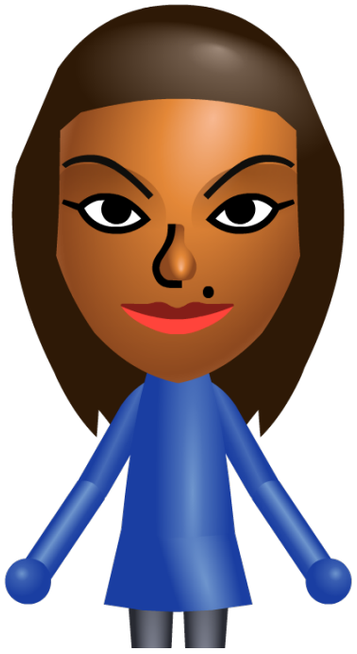
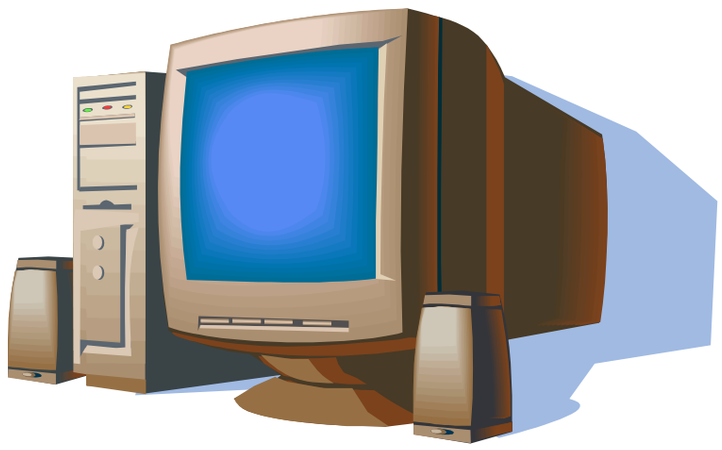
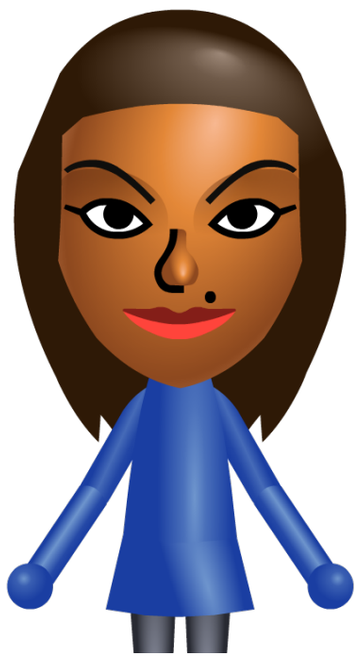
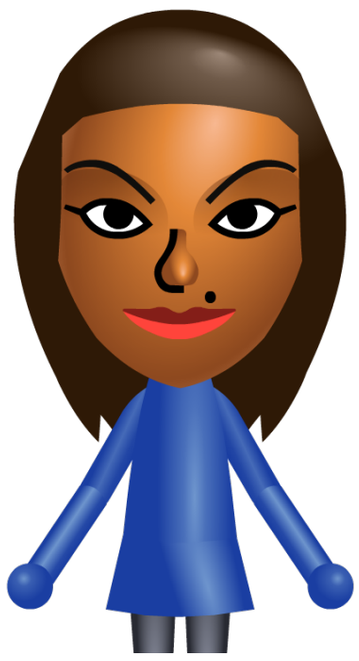
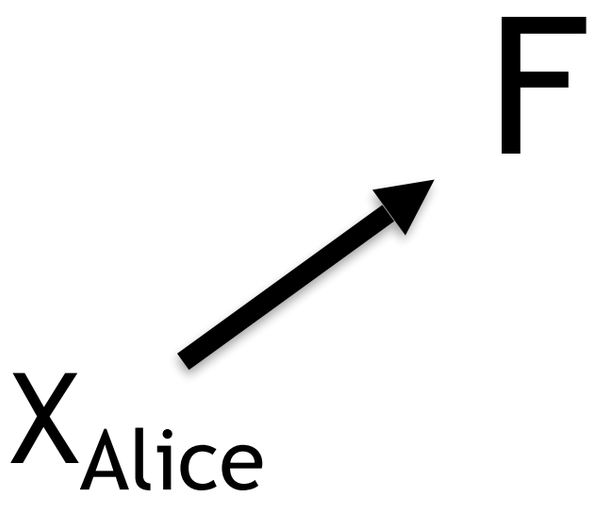


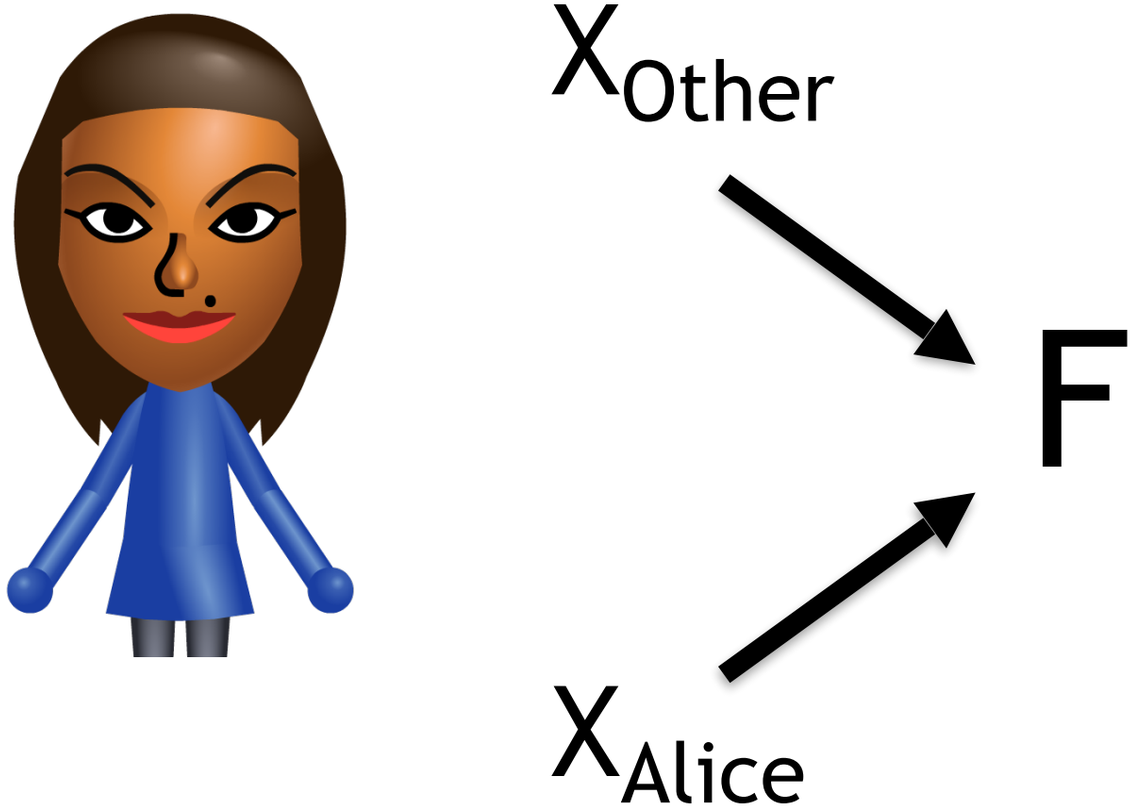


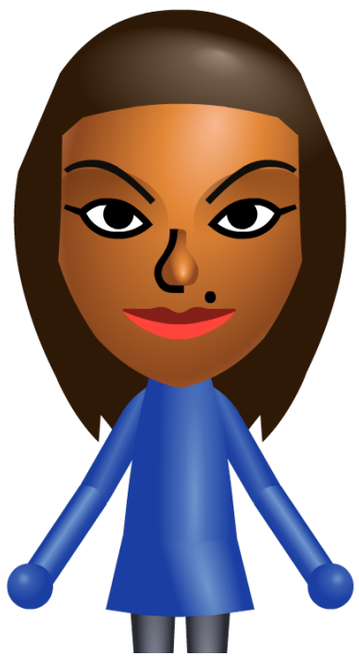


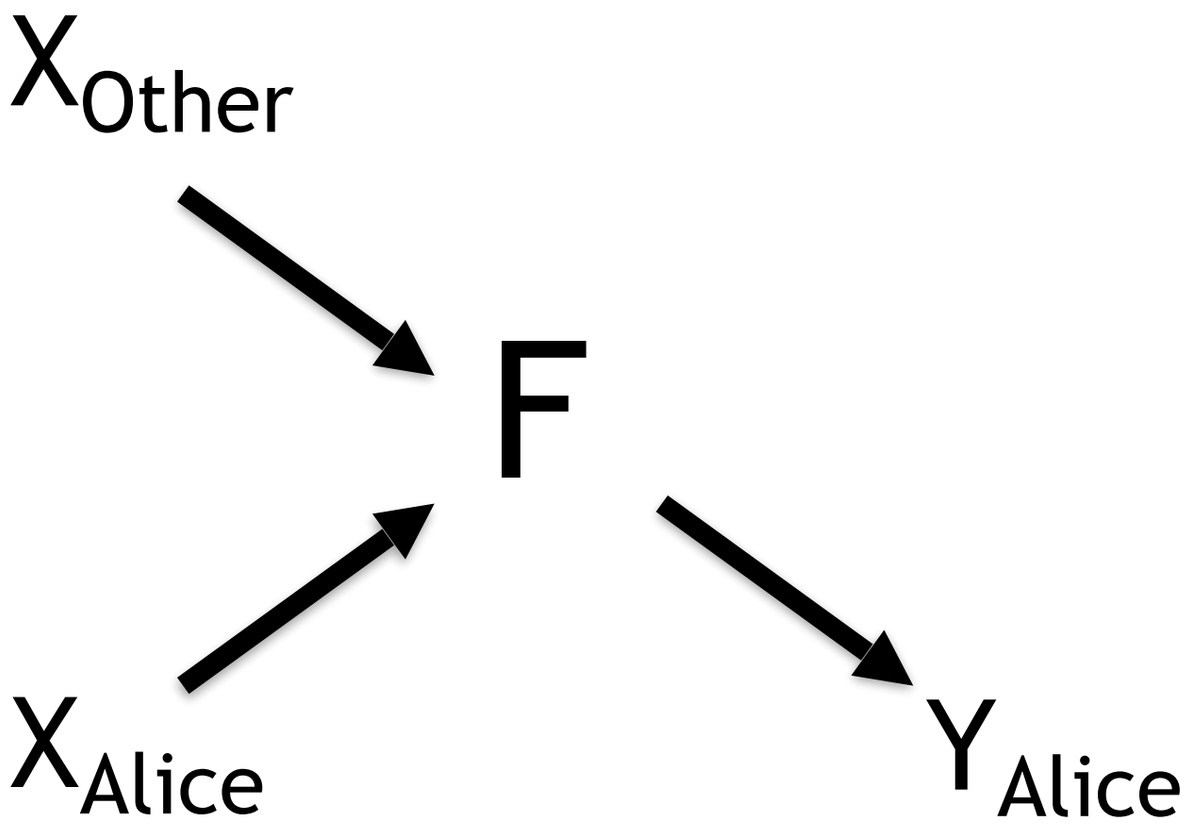
F

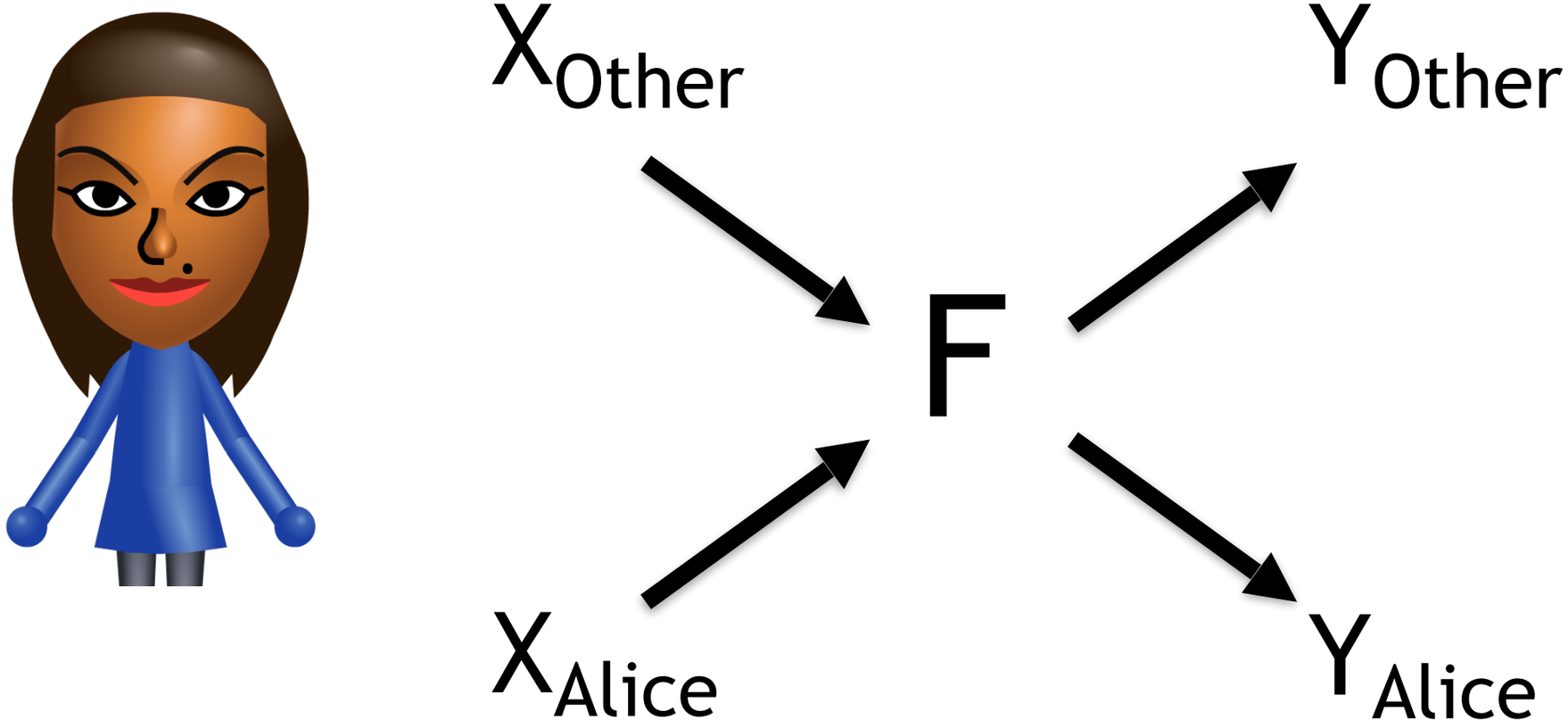



F
X_{Alice}

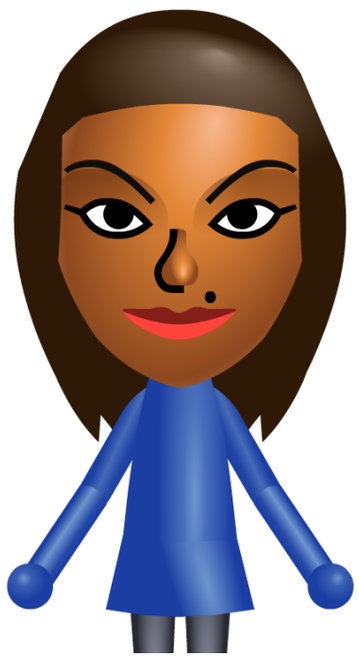

X_{Other}
F
X_{Alice}

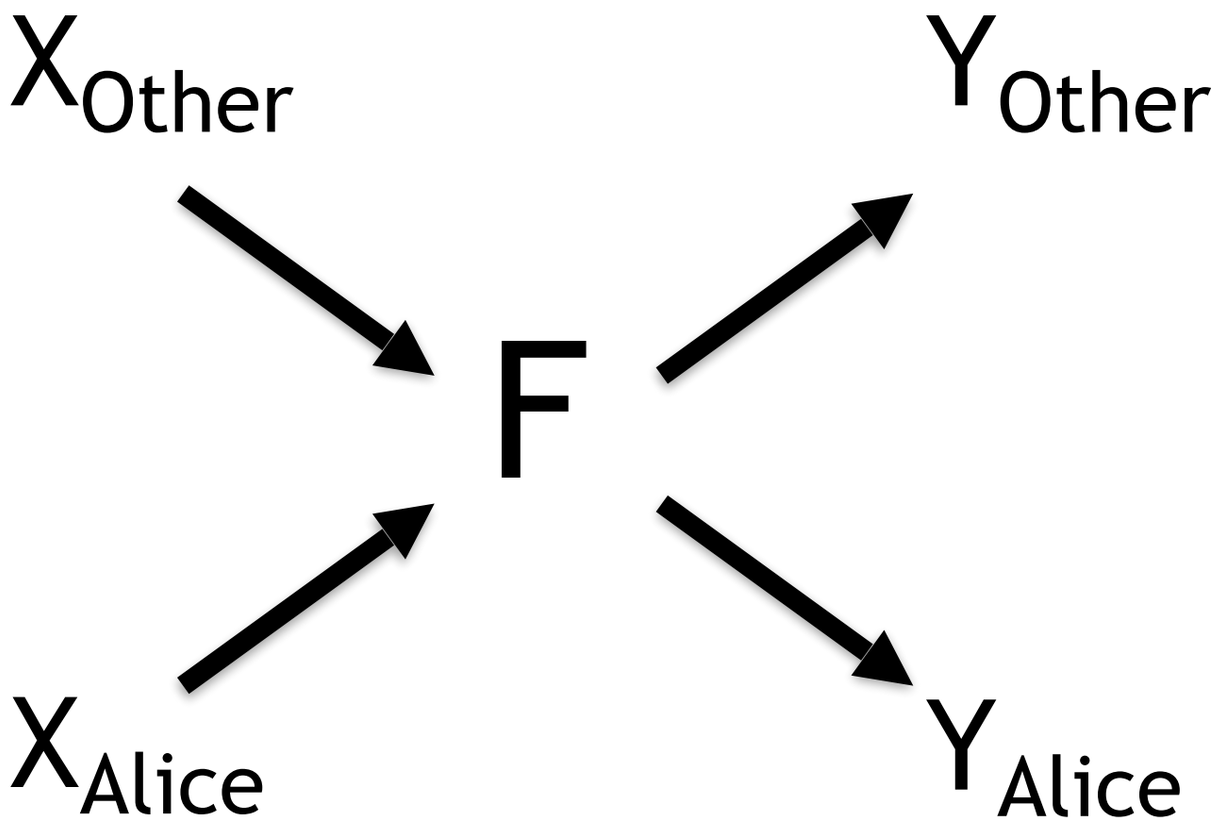



X_{Other}
F
X_{Alice}
Y_{Alice}

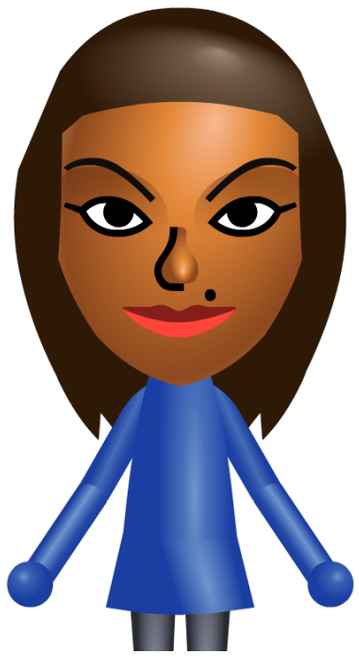

X_{Other}
Y_{Other}
F
X_{Alice}
Y_{Alice}

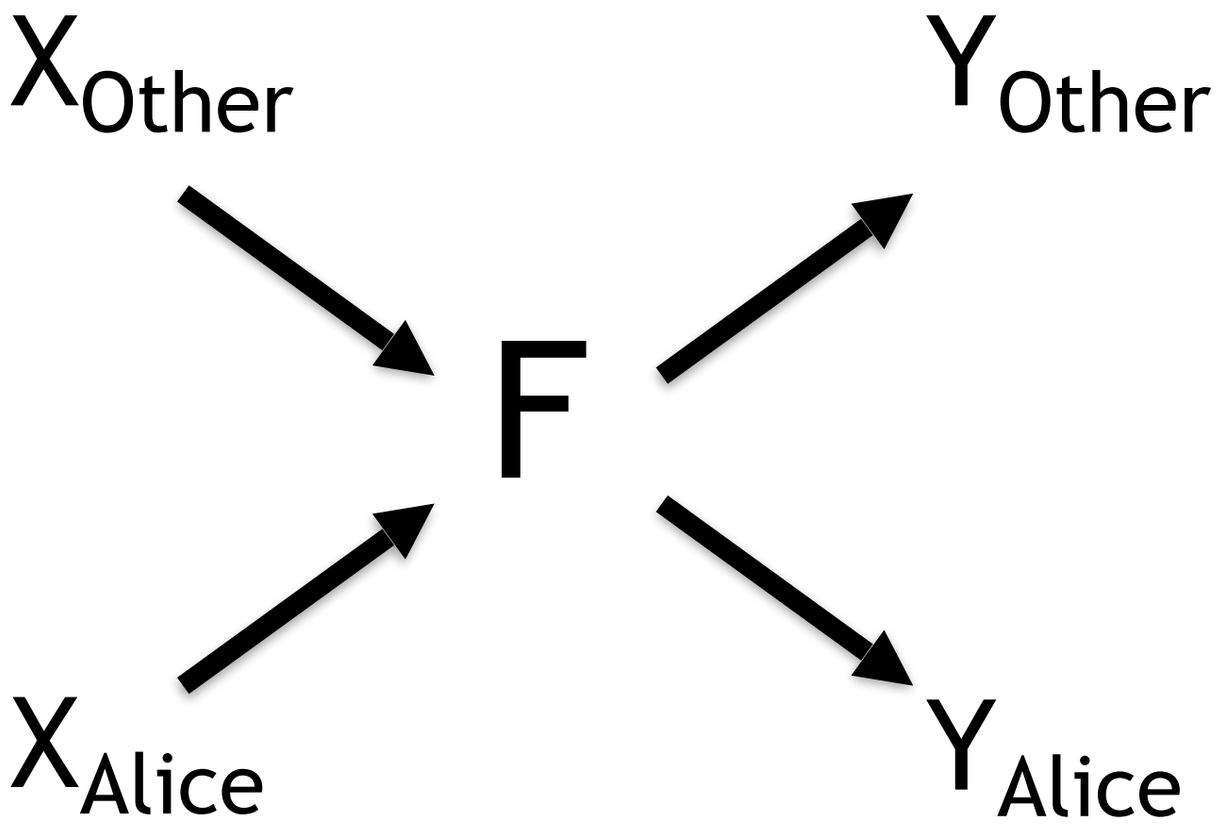
Does program P compute F?





Does program P compute F?
Is F what the programmer intended?



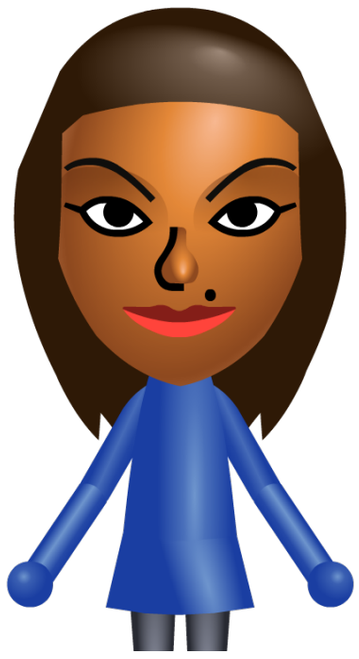


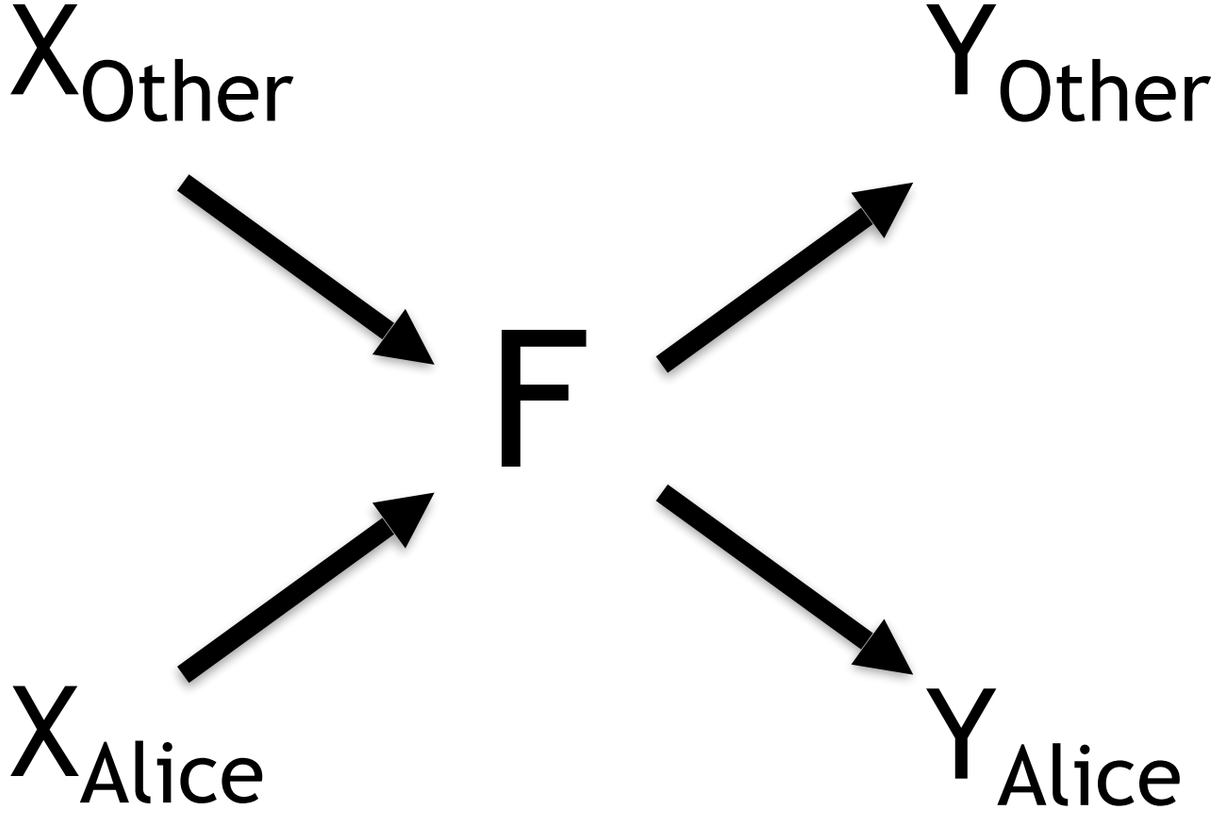
Does program P compute F?

Is F what the programmer intended?

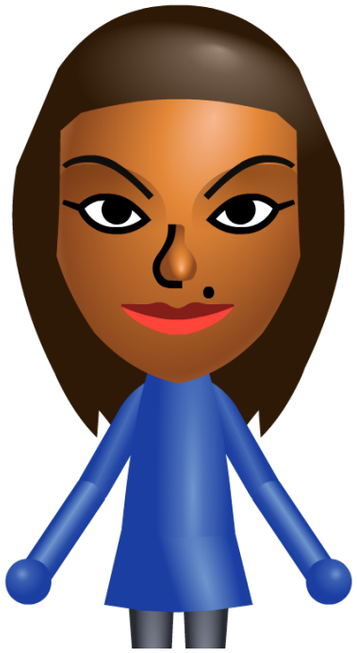
Bootstrapping Trust

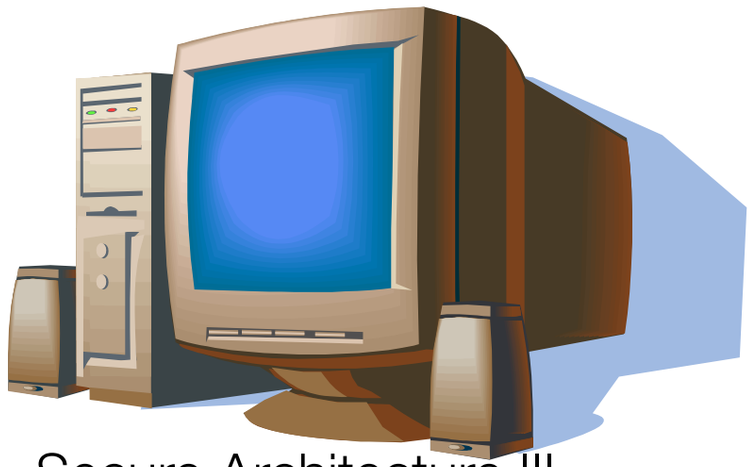
What F will this machine compute?





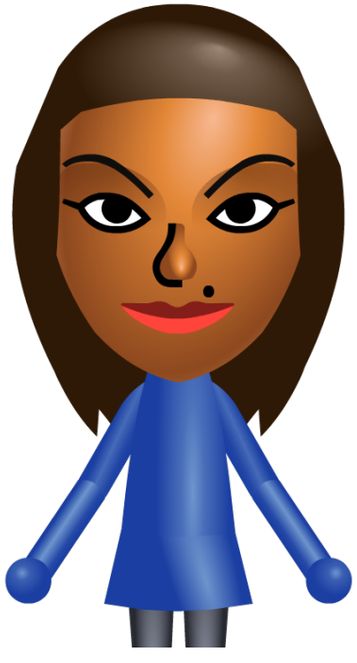
Bootstrapping Trust is *Hard*!





Bootstrapping Trust is *Hard*!

- Challenges:
  - Hardware assurance
  - Ephemeral software
  - User Interaction



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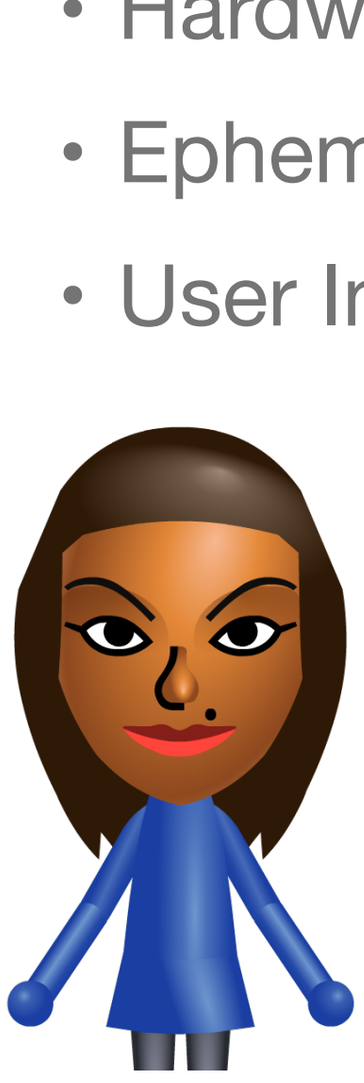

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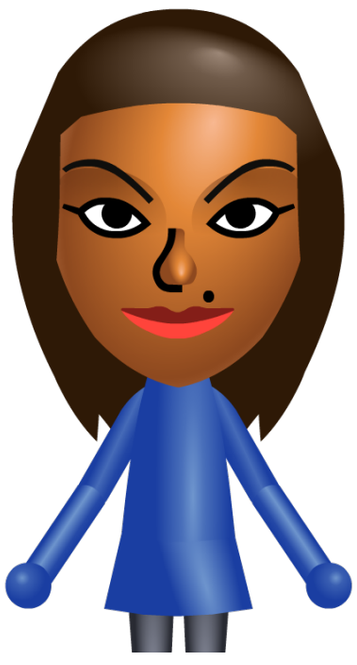

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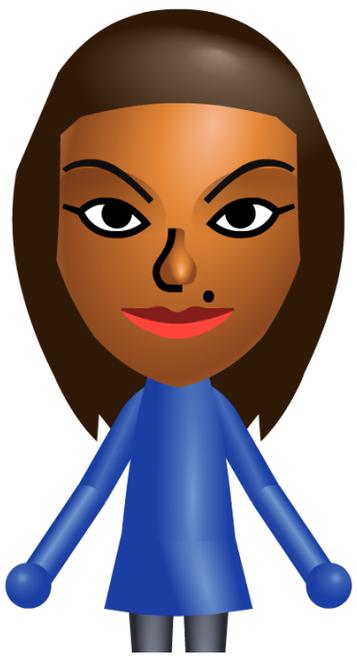

Safe?

Bootstrapping Trust is *Hard*!

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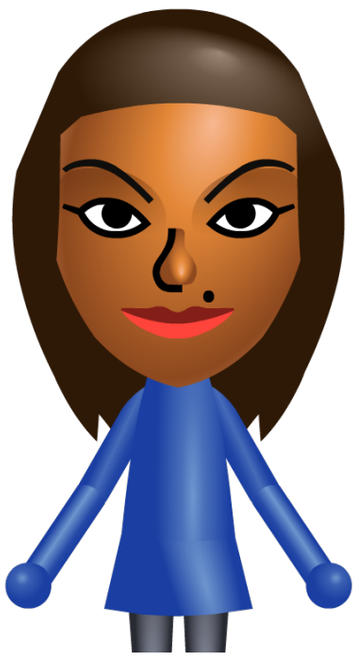

Safe?

Yes!

Bootstrapping Trust is *Hard*!

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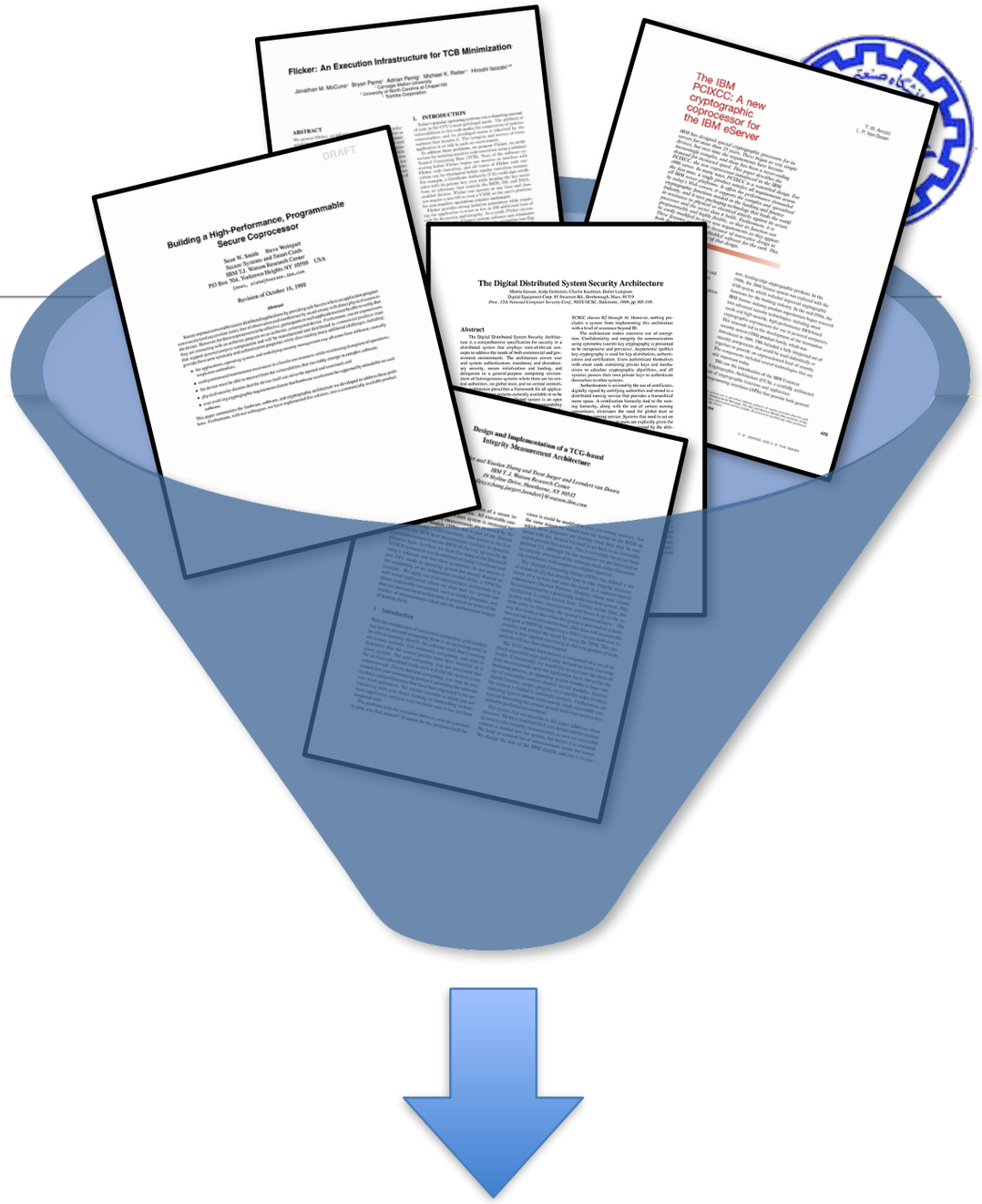



Bootstrapping Trust in Commodity Computers

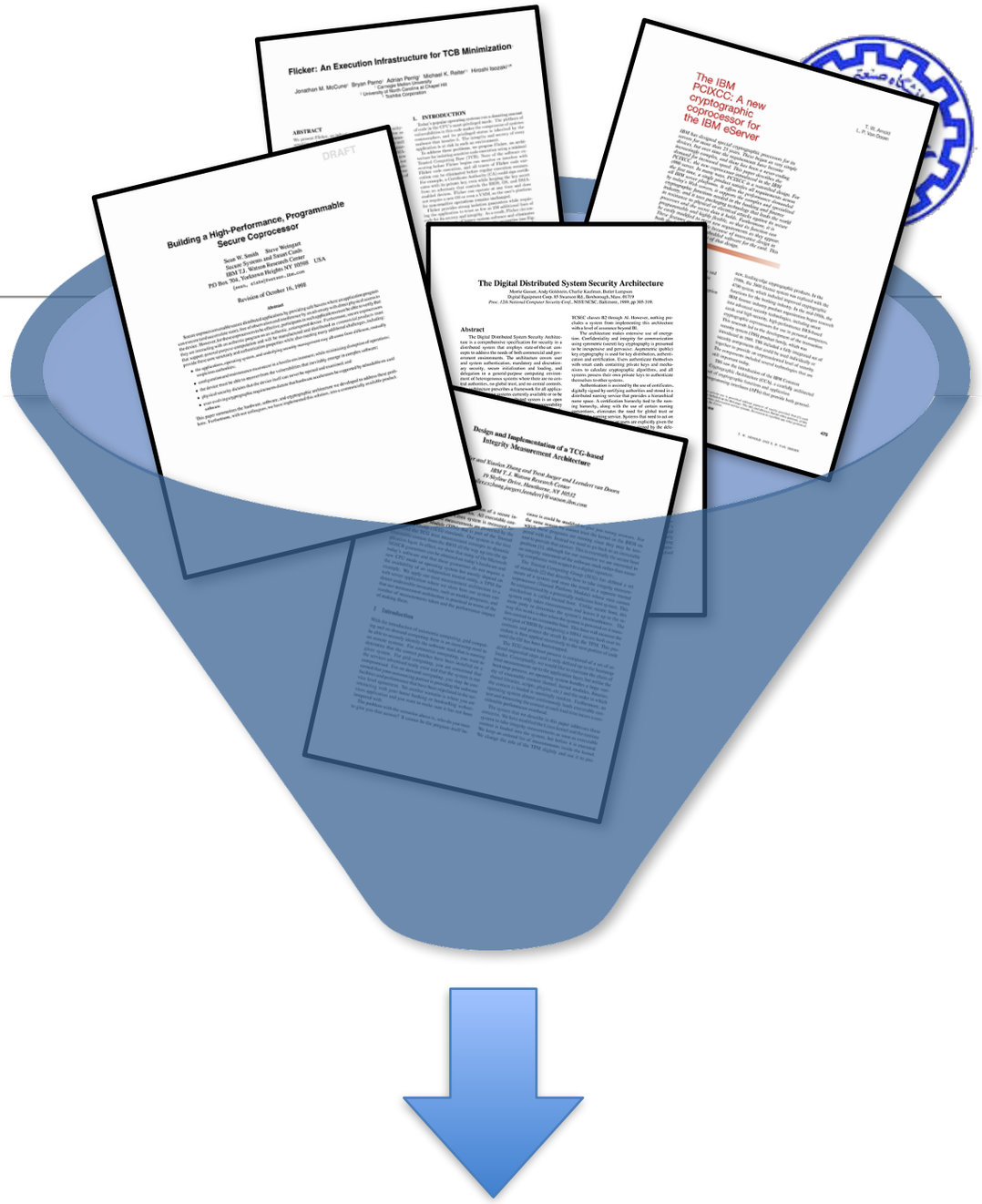
Bryan Parno Jonathan M. McCune Adrian Perrig
CyLab, Carnegie Mellon University

Abstract

1 Introduction

In the paper…

- Bootstrapping foundations



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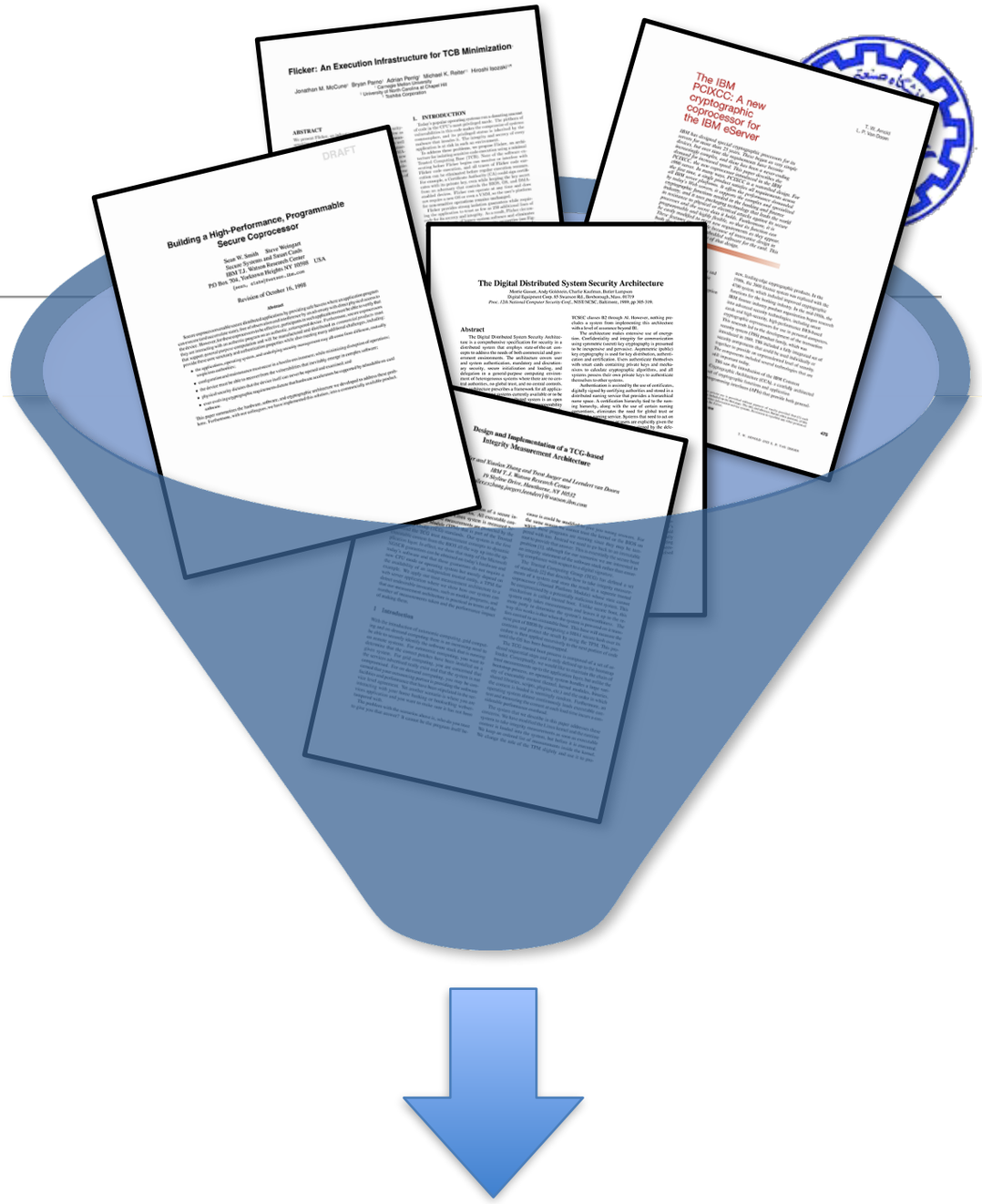
- Bootstrapping foundations
- Transmitting bootstrap data



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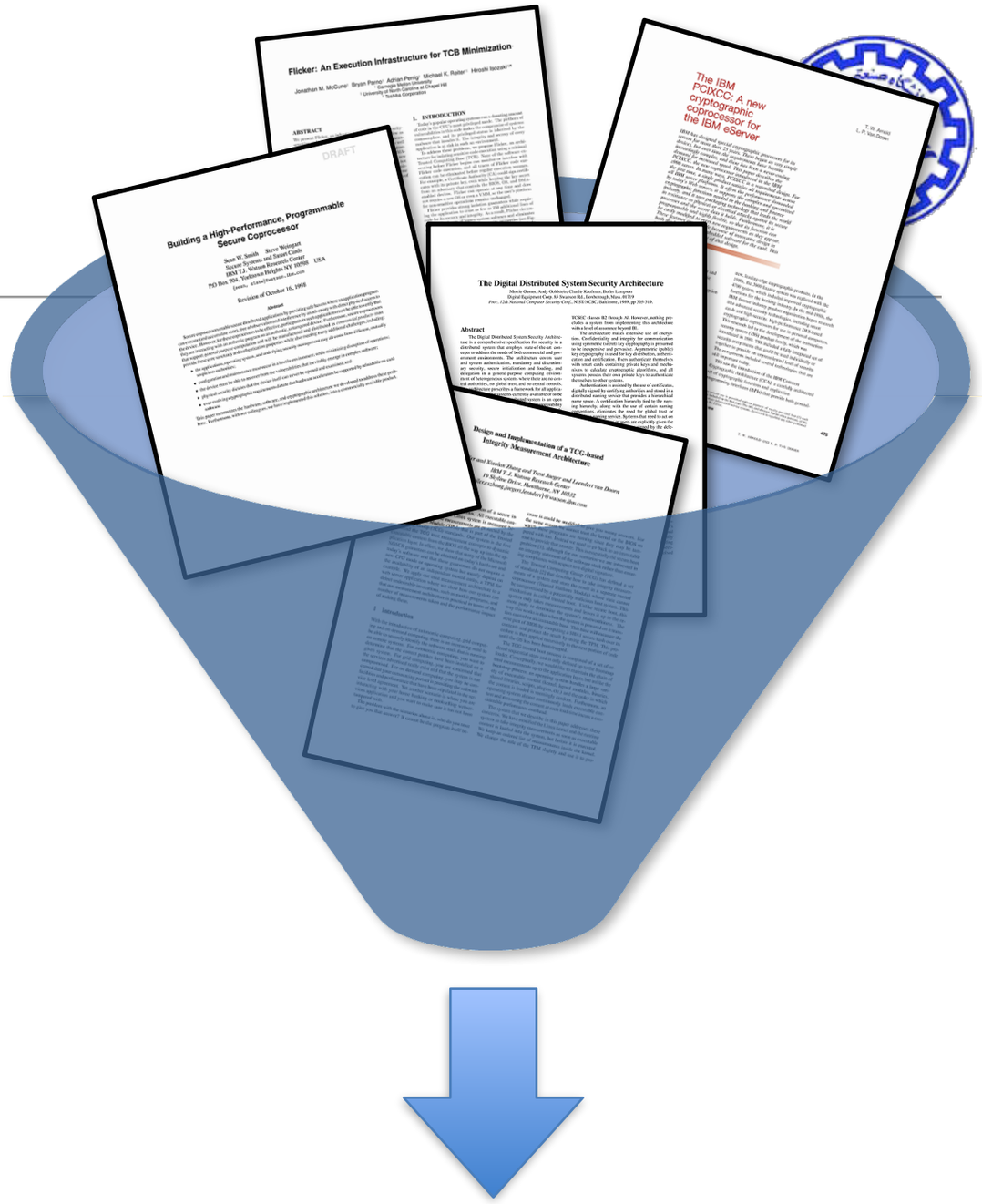

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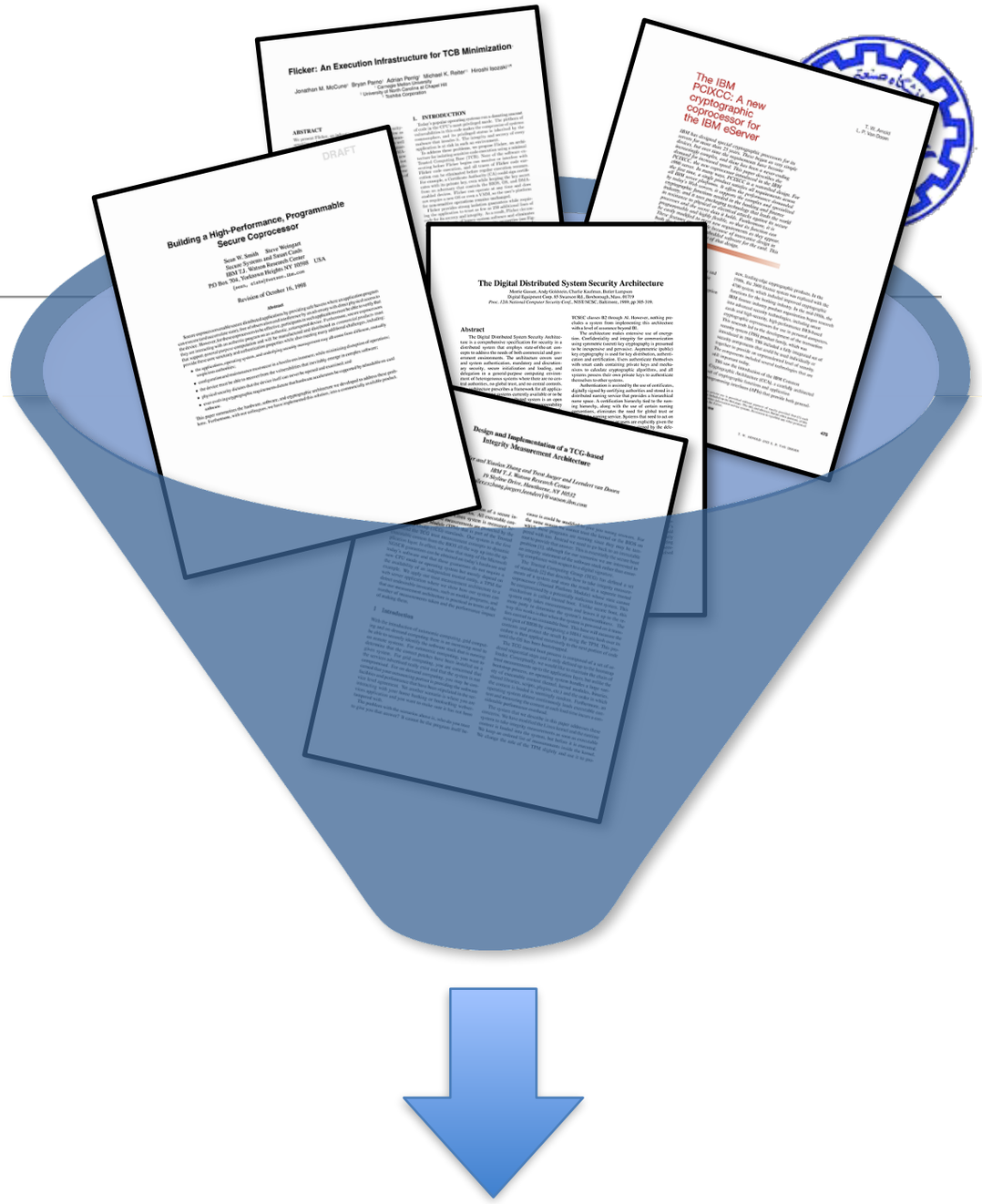

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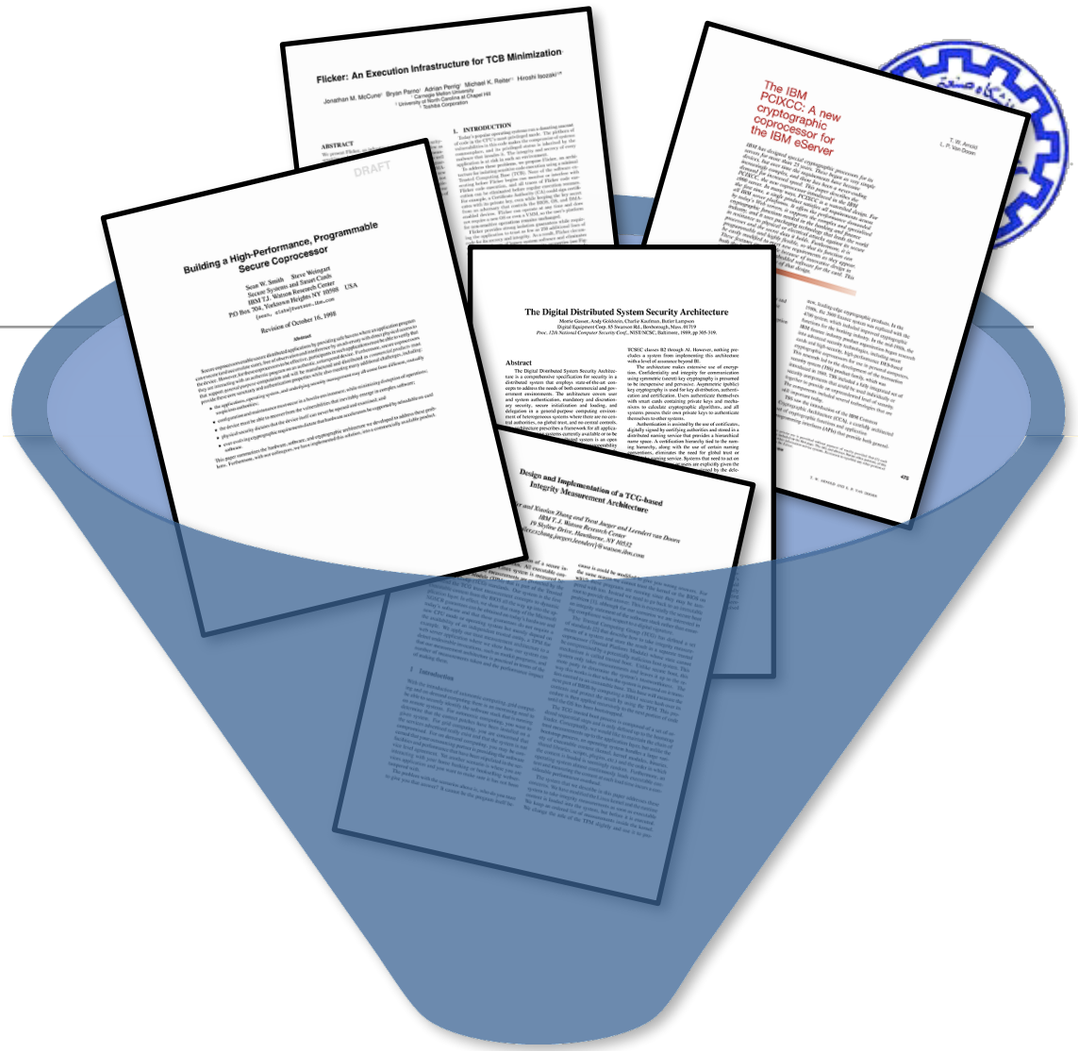
- Applications



In the paper…

- Bootstrapping foundations
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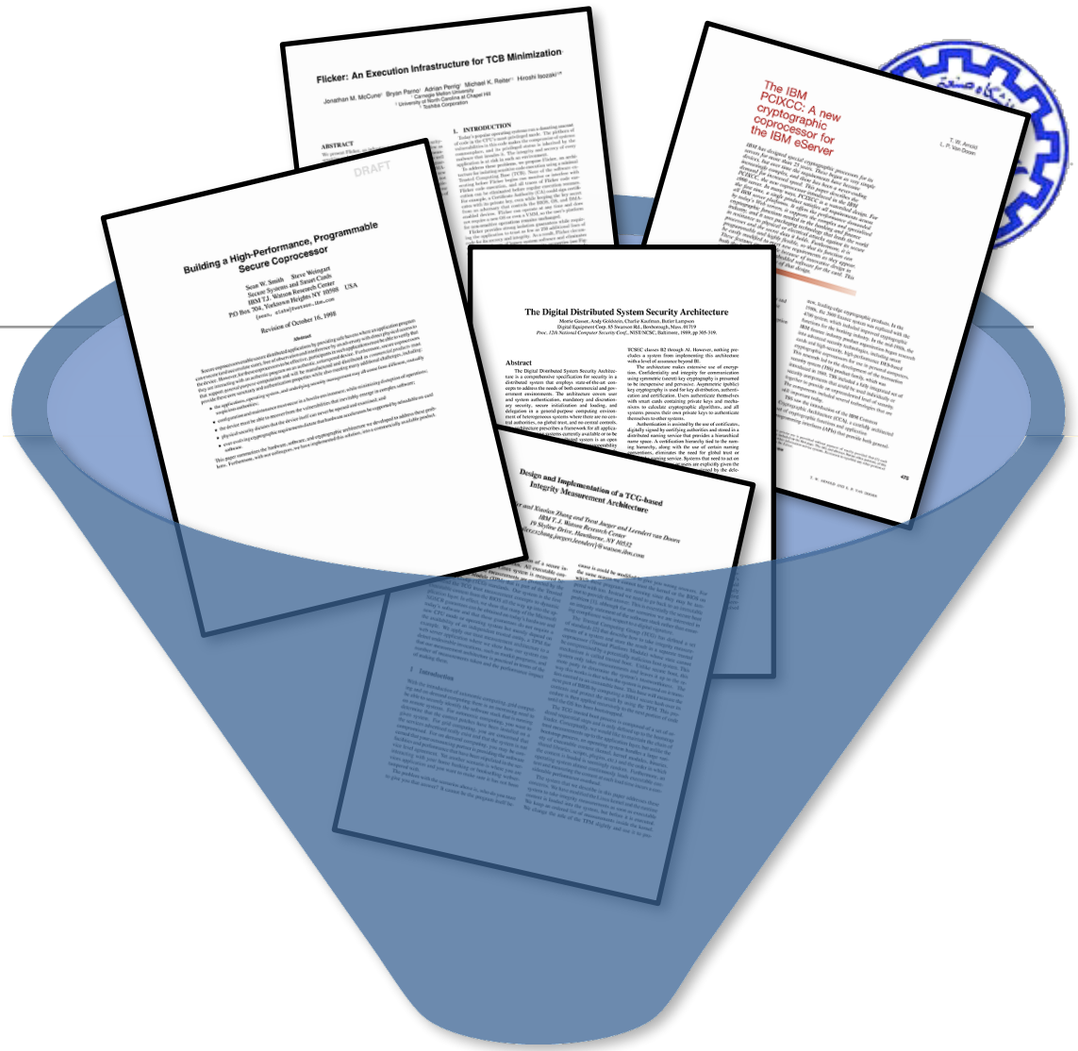
- Human factors

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- Human factors
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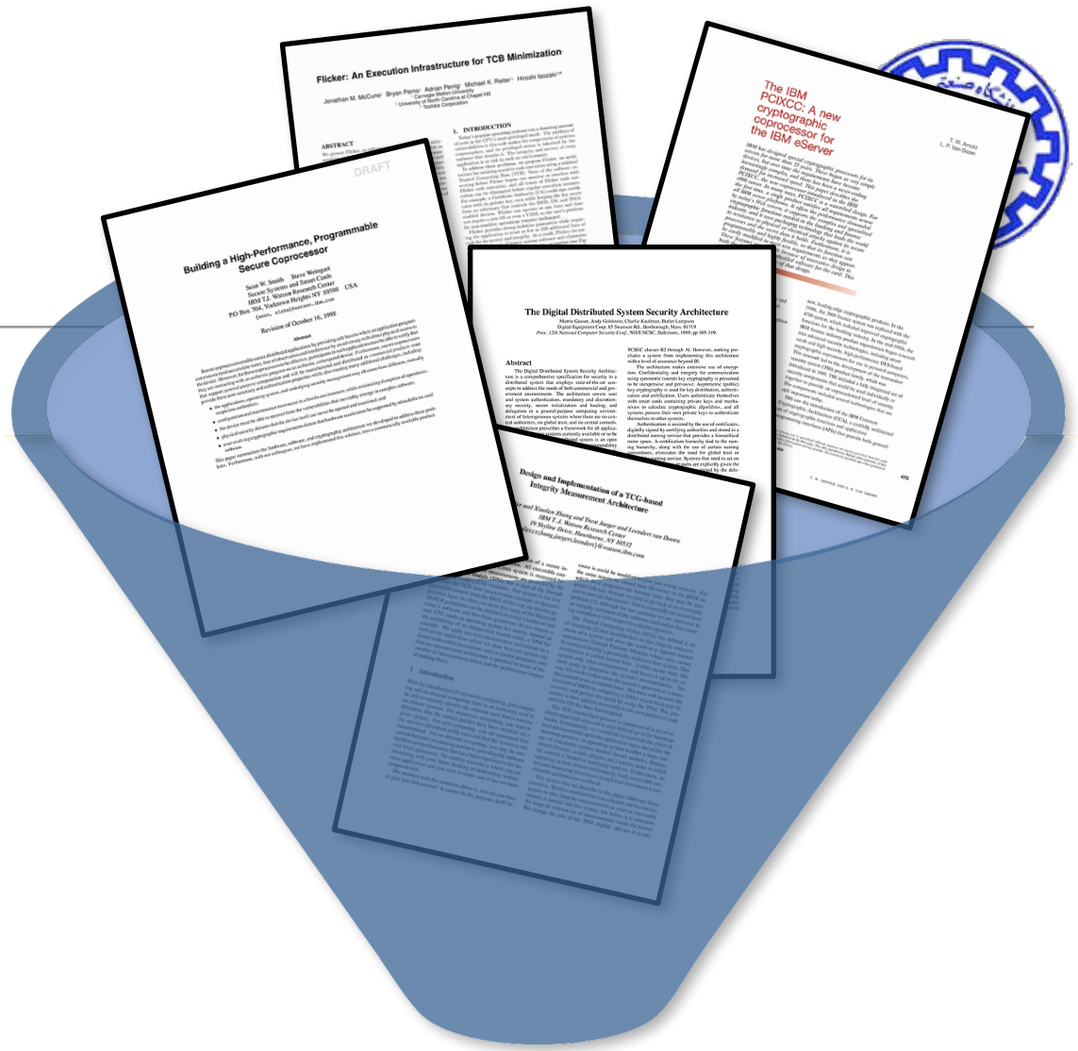


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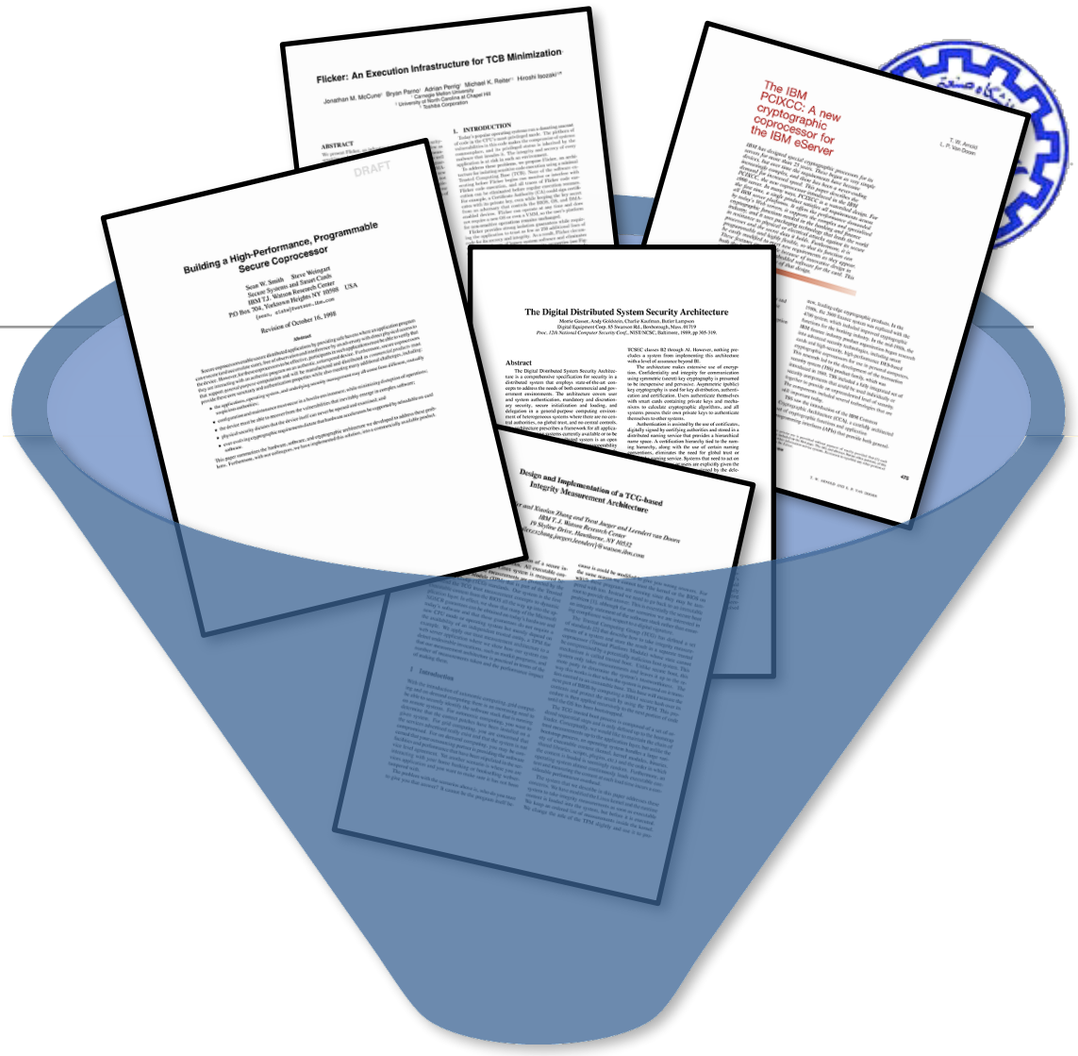
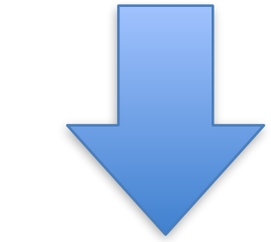
- Future directions



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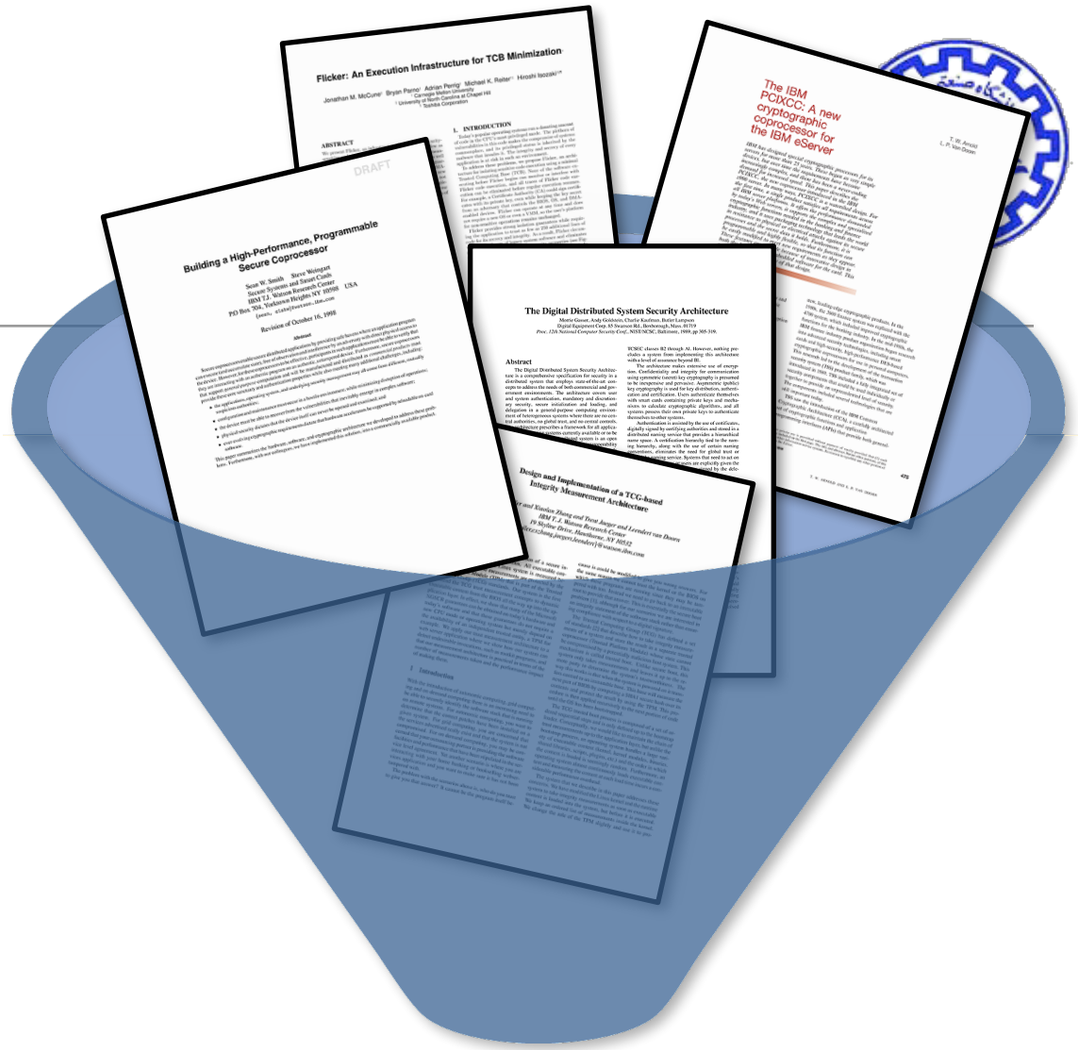

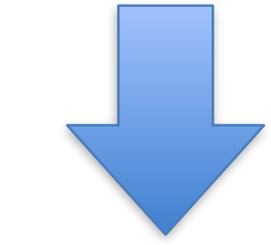


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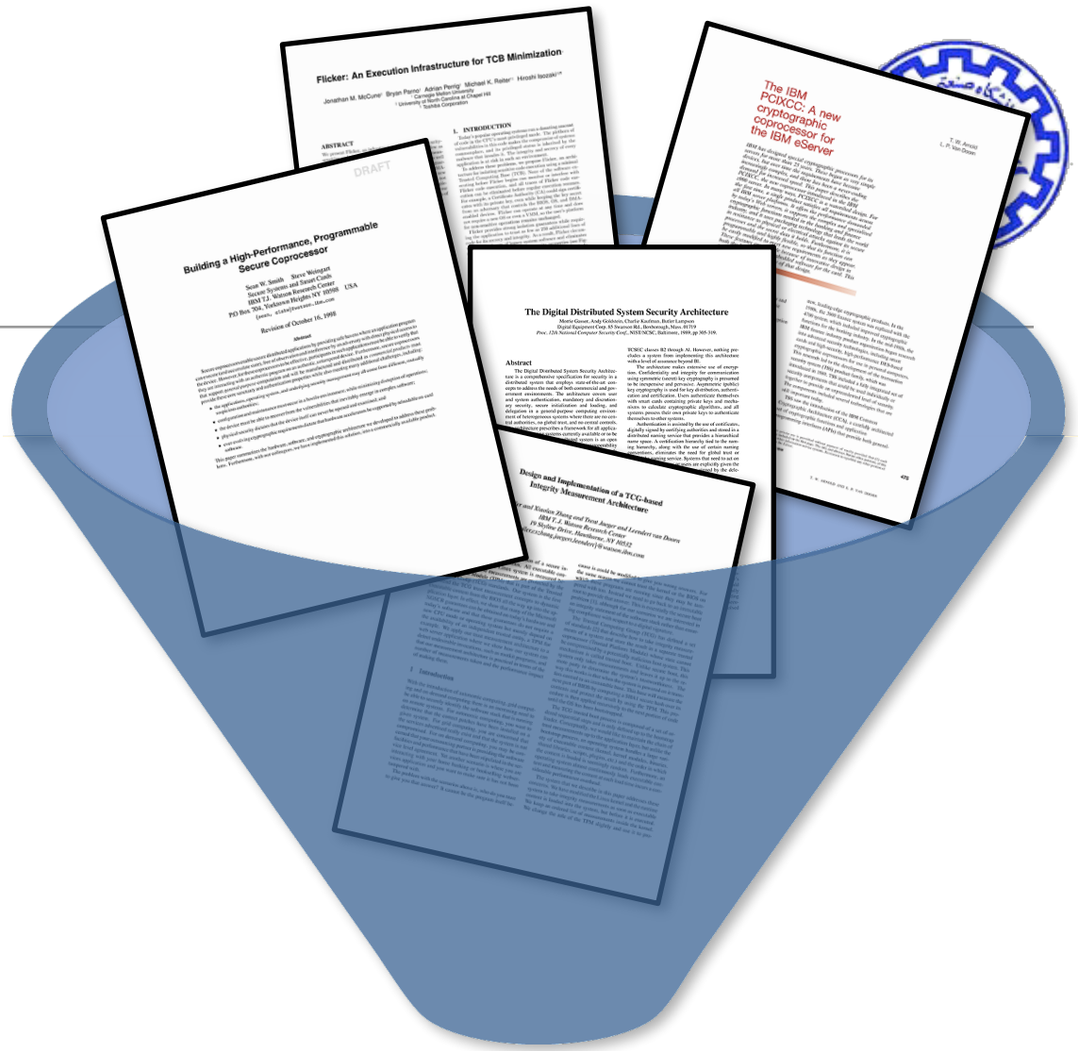
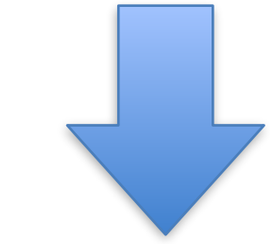
In the paper…

- Bootstrapping foundations
- Transmitting bootstrap data
- Interpretation
- Validation
- Applications
- Human factors
- Limitations
- Future directions
- … and much more!



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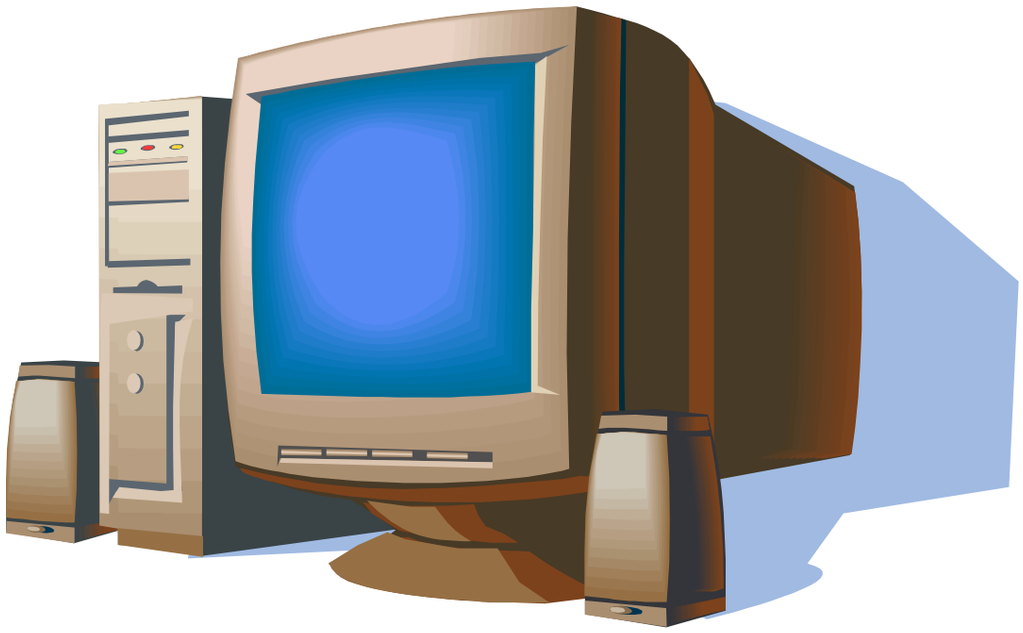
Abstract

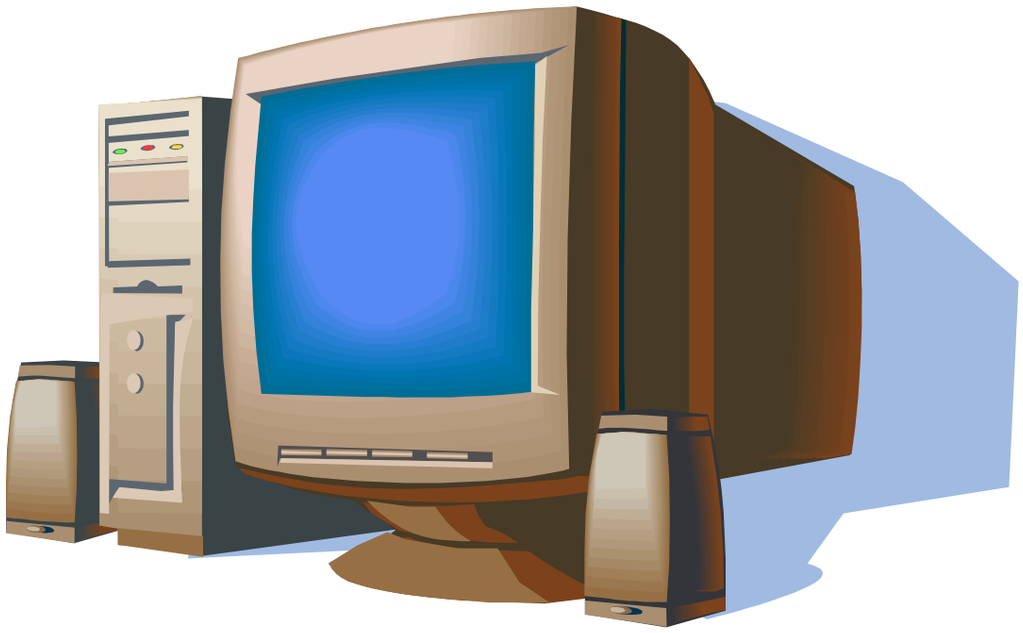
1 Introduction

1) Establish Trust in Hardware



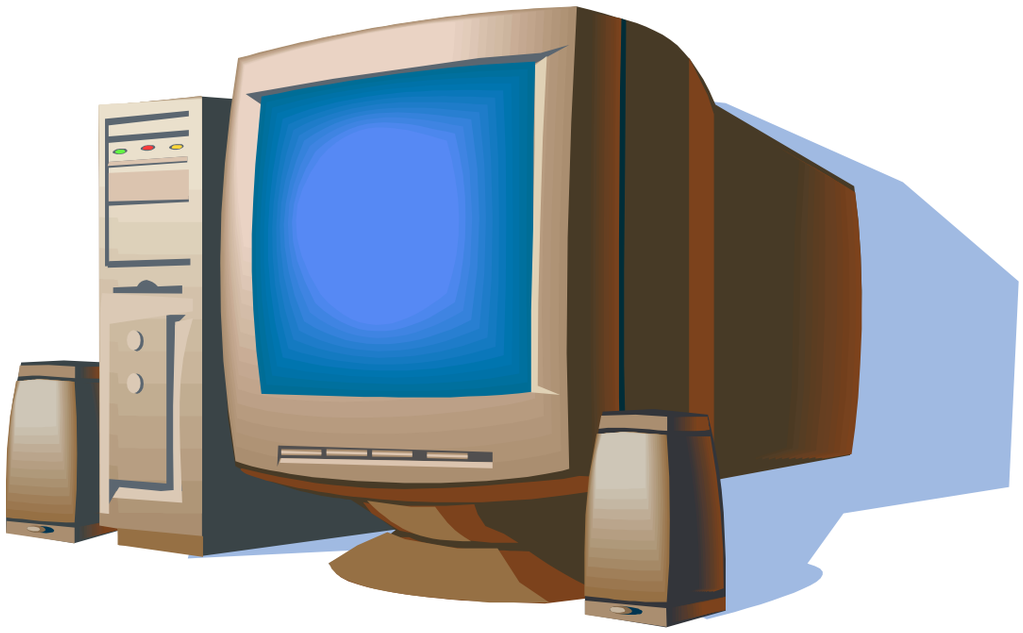
1) Establish Trust in Hardware

- Hardware is durable



1) Establish Trust in Hardware

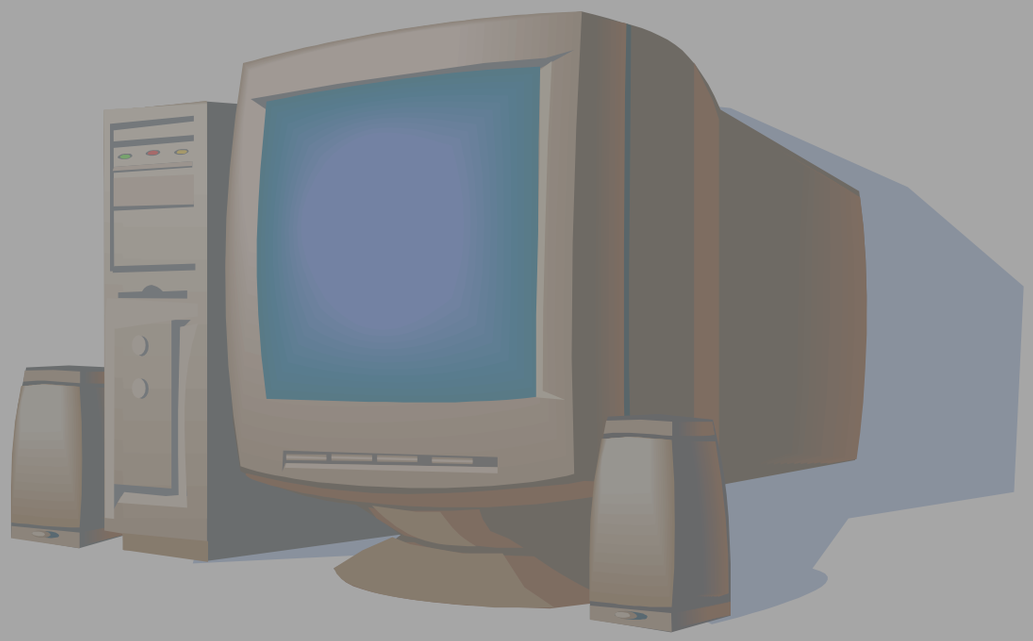
- Hardware is durable
- Establish trust via:
  - Trust in the manufacturer
  - Physical security



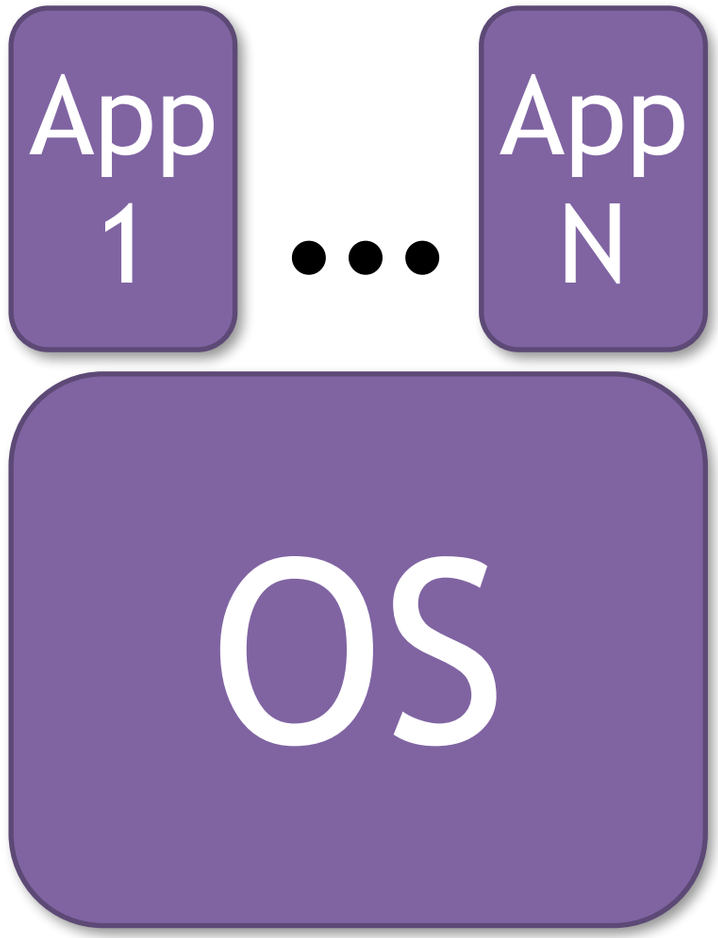
1) Establish Trust in Hardware

- Hardware is durable

Open Question: Can we do better?

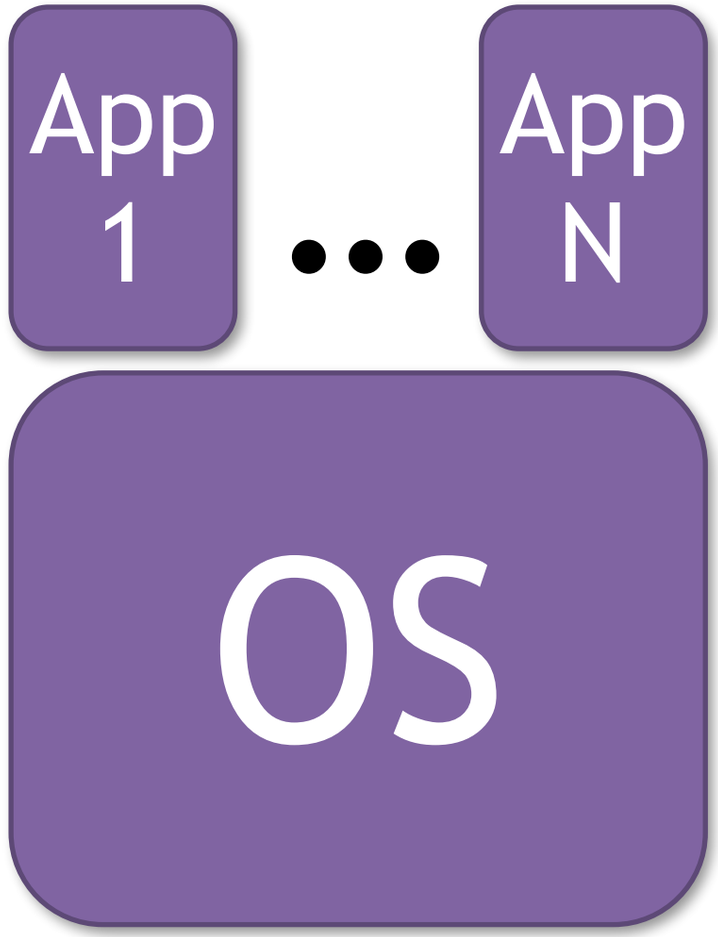


2) Establish Trust in Software



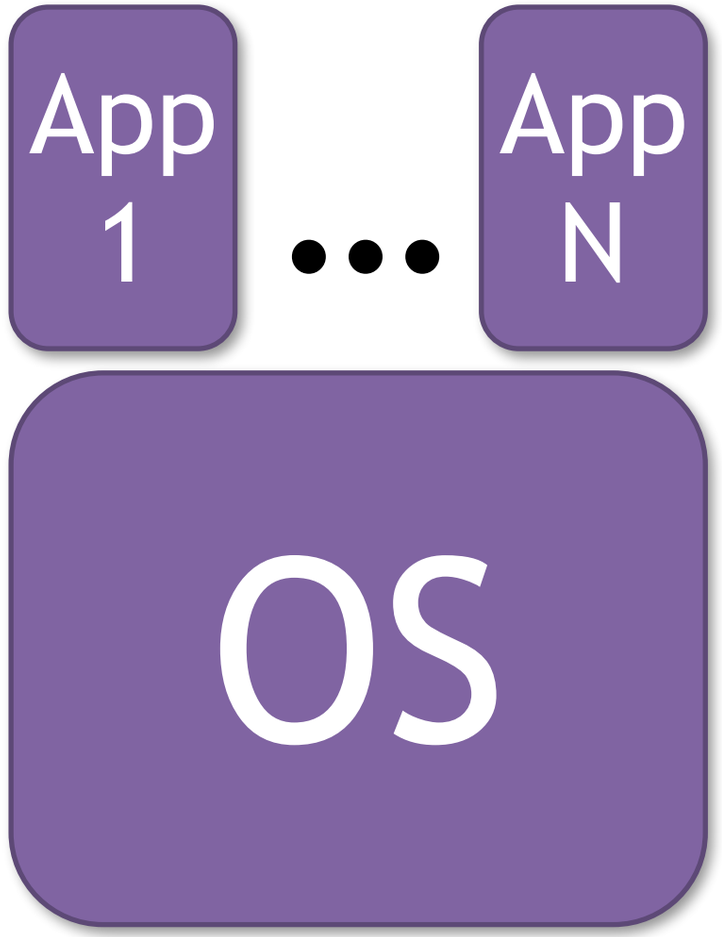
2) Establish Trust in Software

- Software is ephemeral



2) Establish Trust in Software

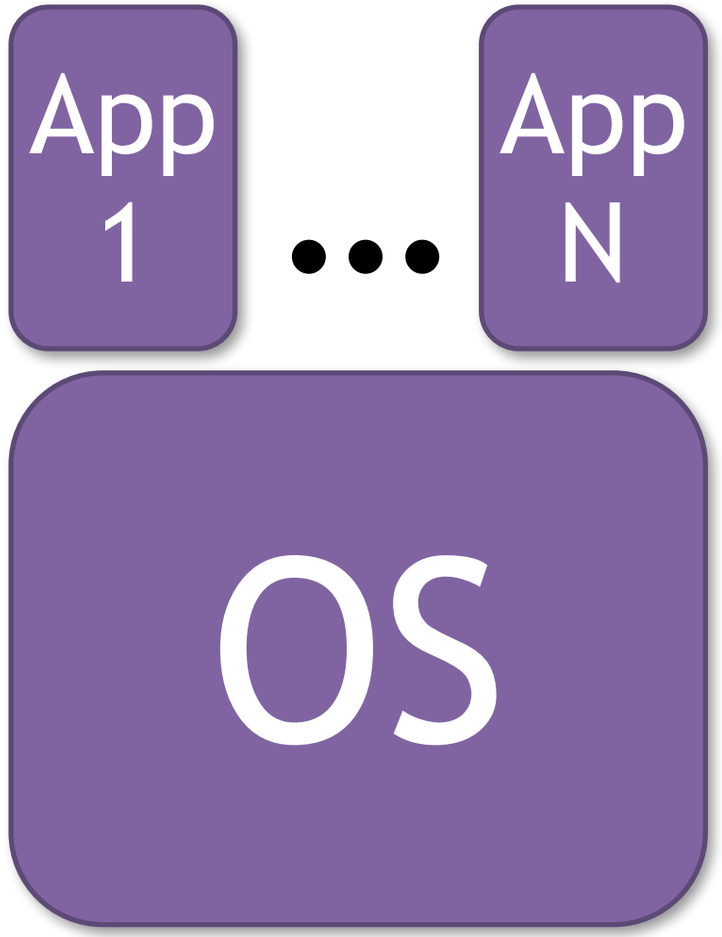
- Software is ephemeral
- We care about the software currently in control



2) Establish Trust in Software

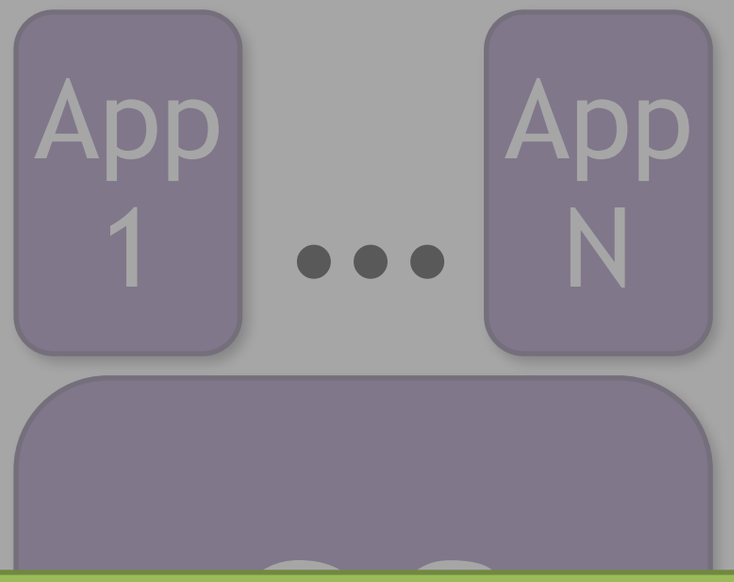
- Software is ephemeral
- We care about the software currently in control
- Many properties matter:
  - Proper control flow
  - Type safety
  - Correct information flow

  ...



2) Establish Trust in Software

- Software is ephemeral
- We care about the software currently in control
- Many properties matter:
  - Proper control flow
  - Type safety



Which property matters most?

A Simple Thought Experiment

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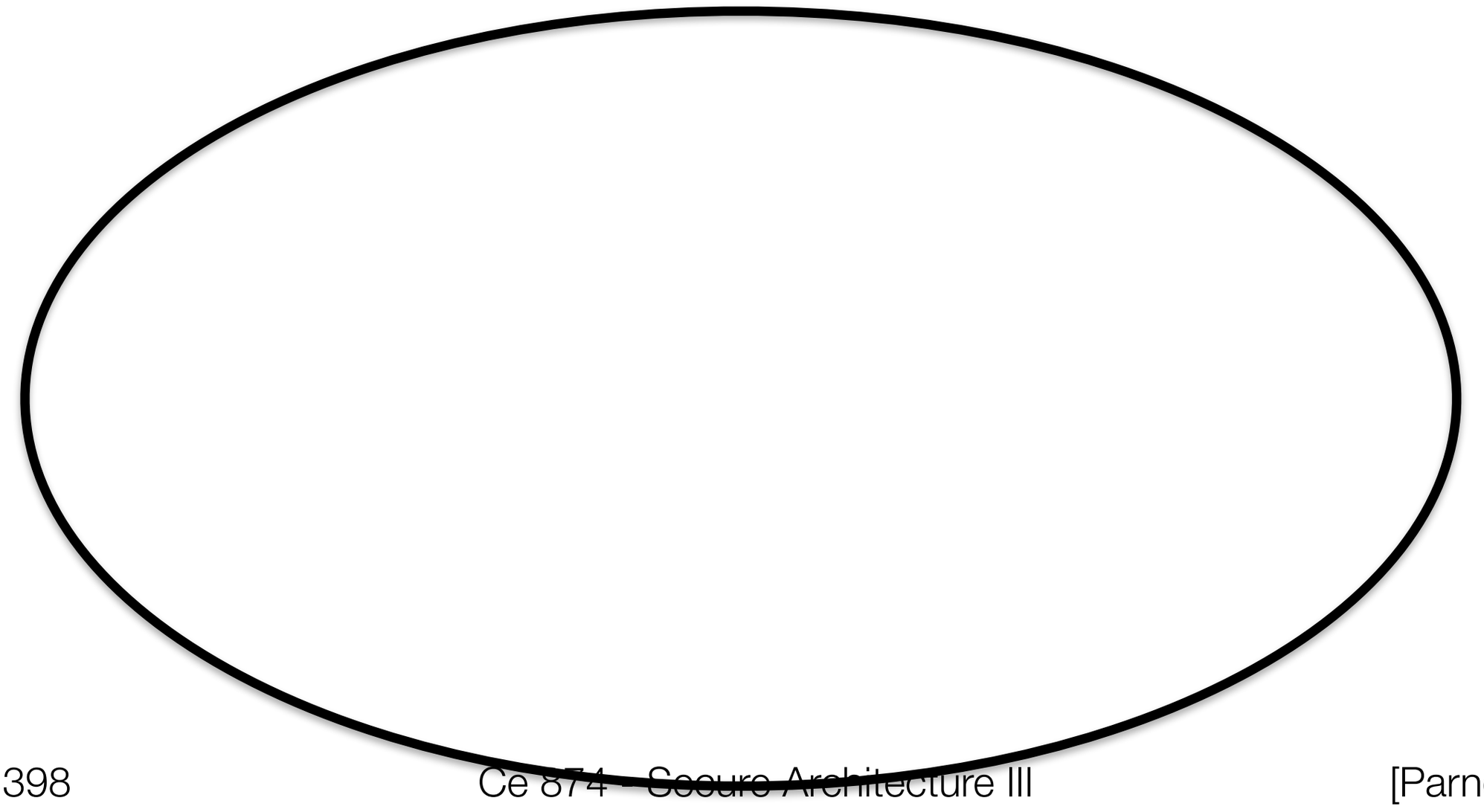

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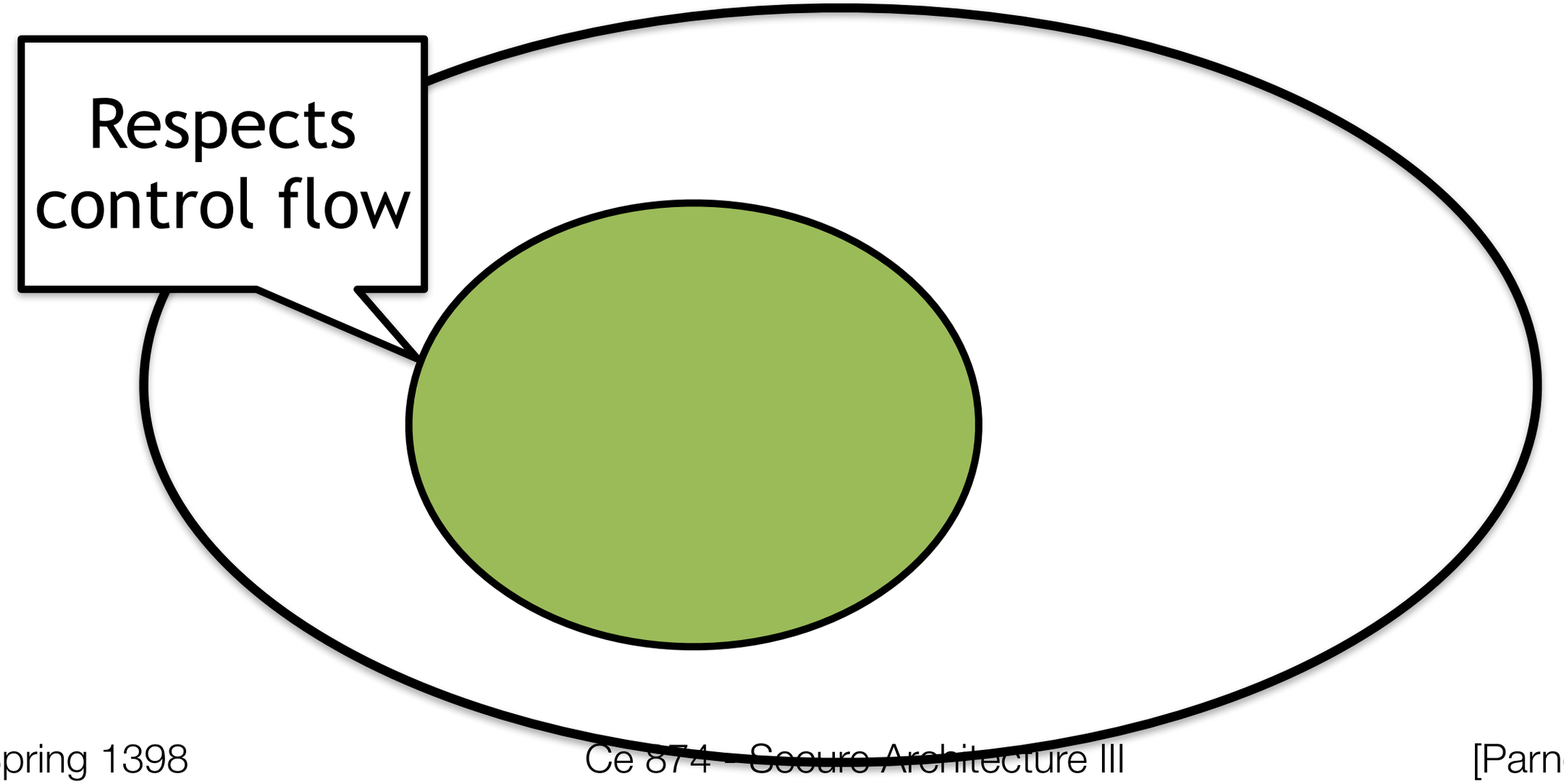

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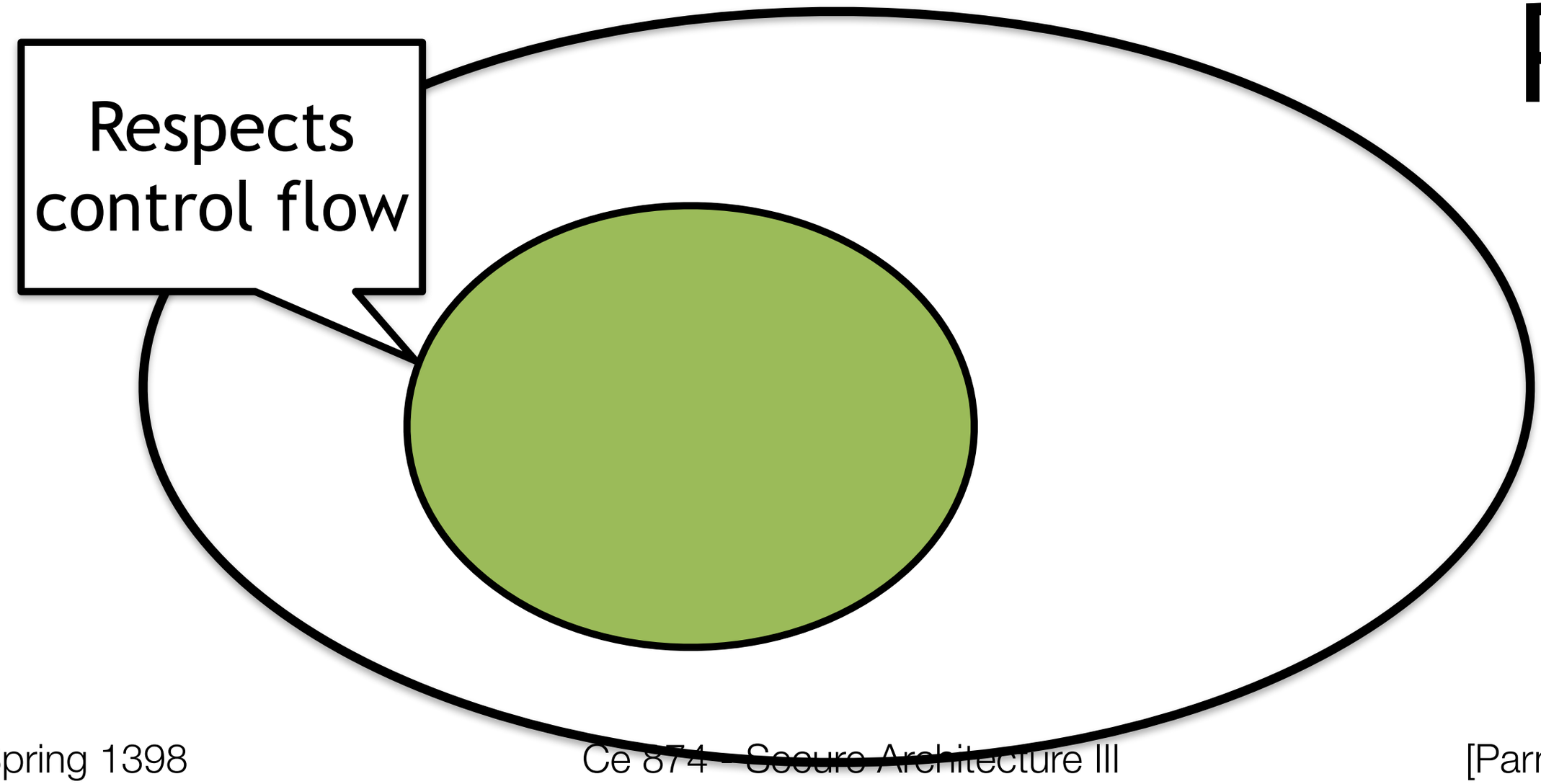

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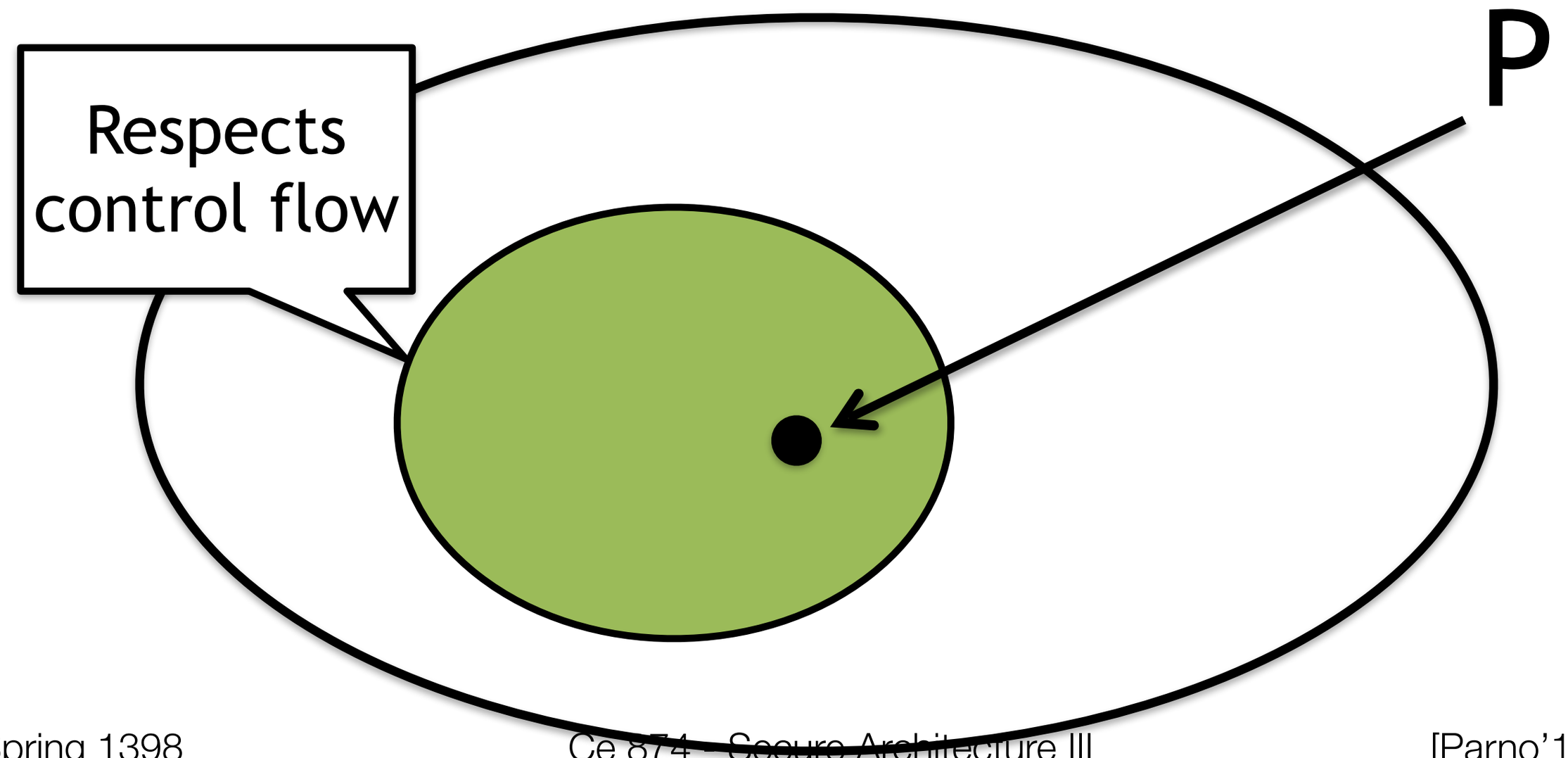

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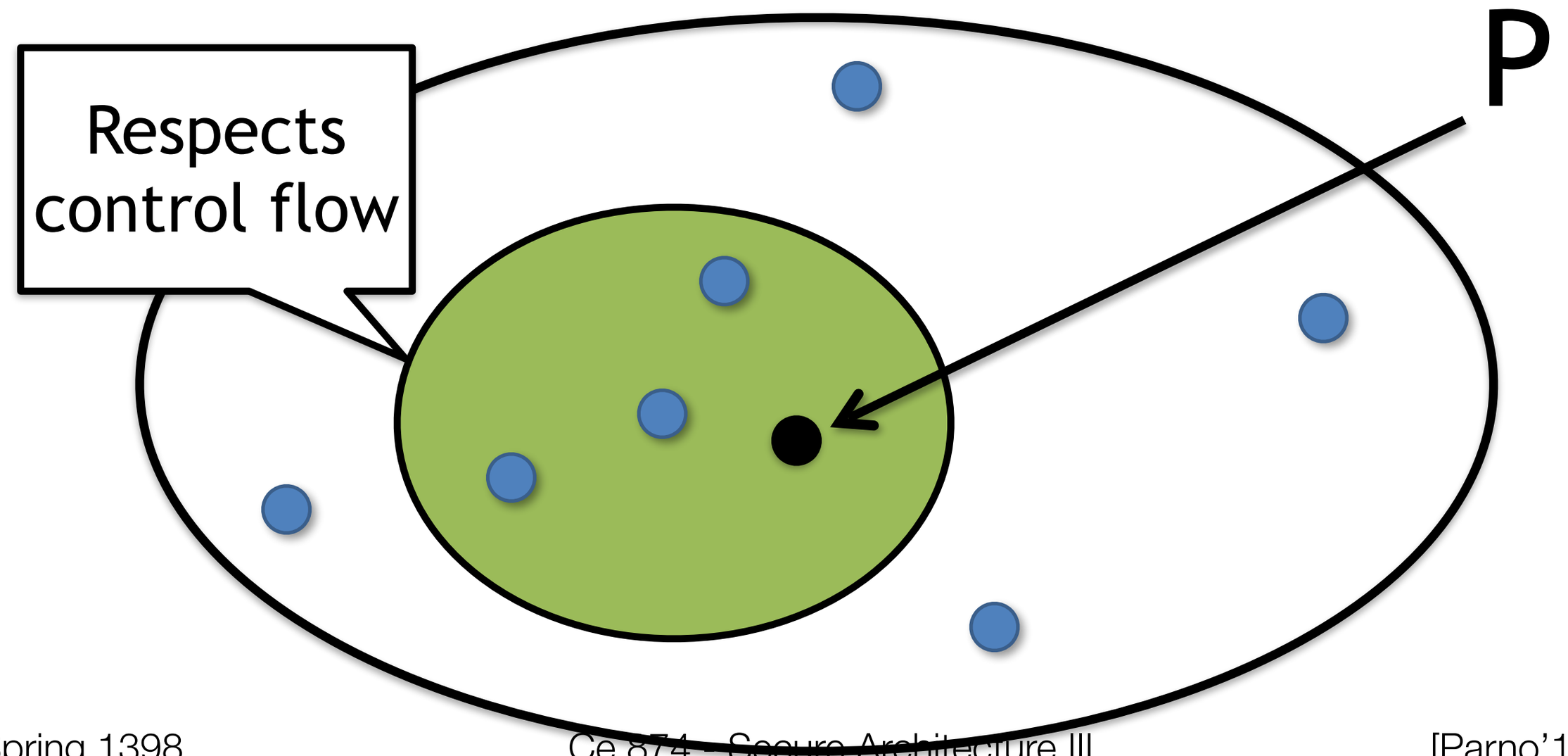

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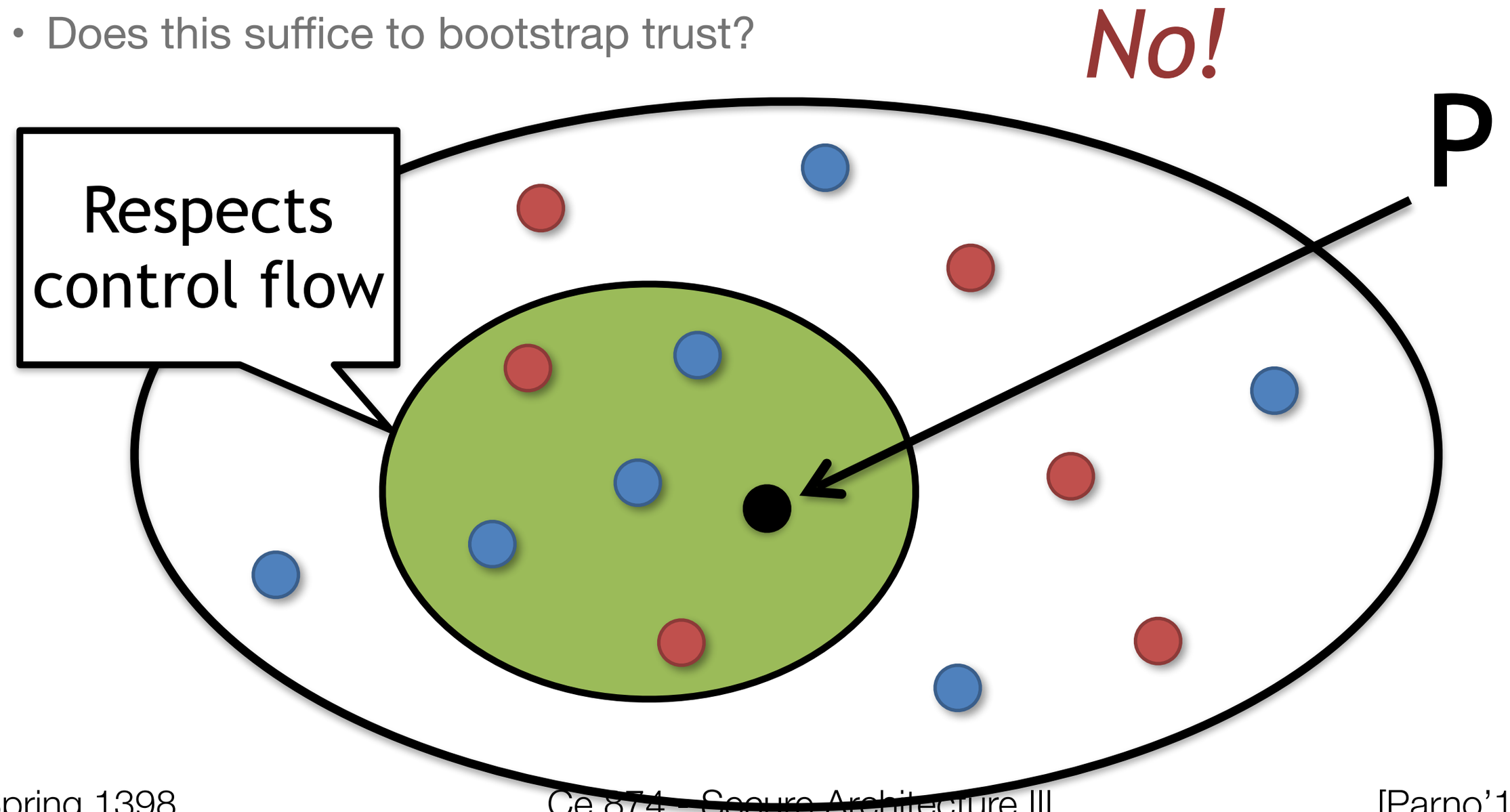

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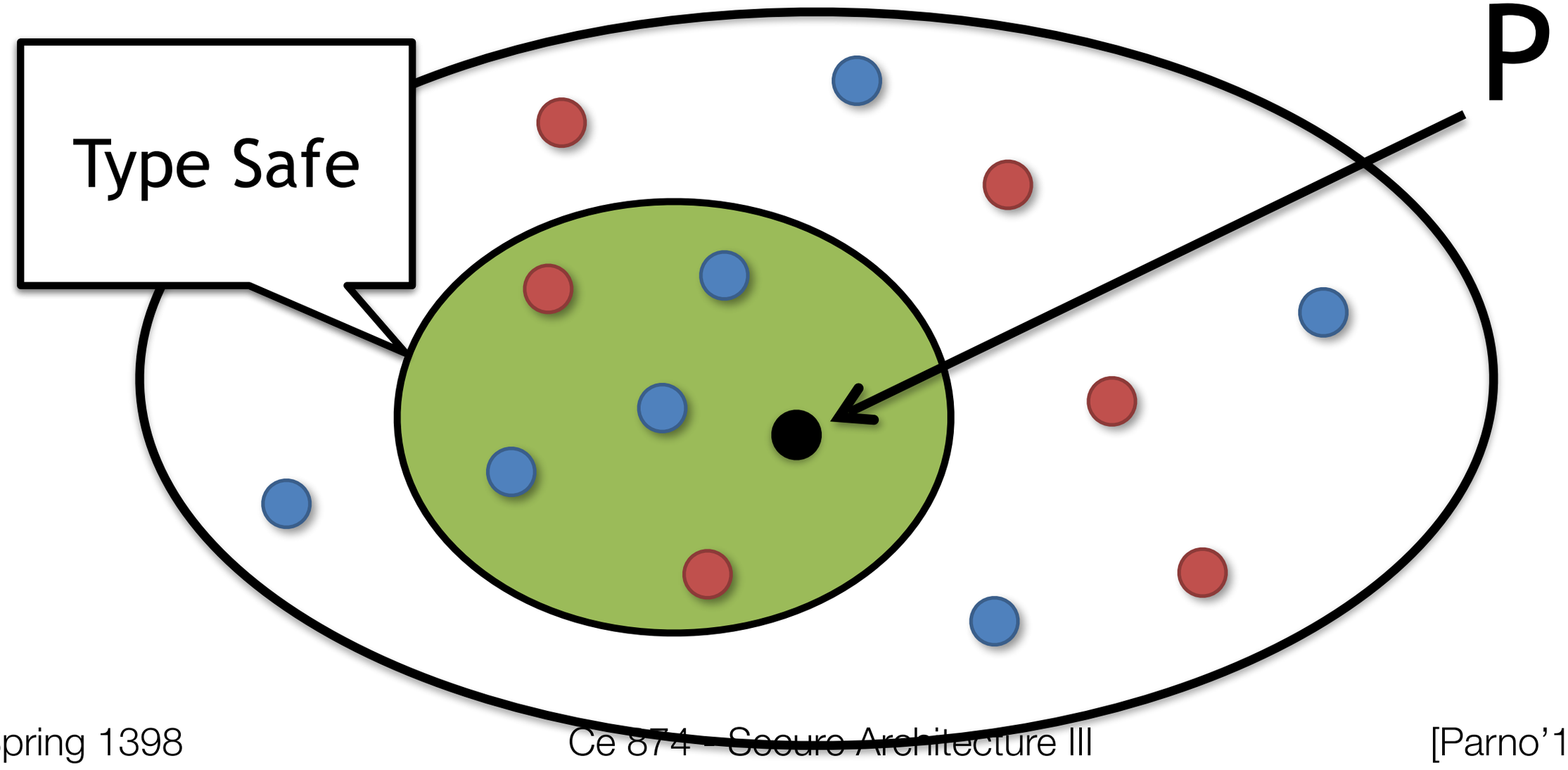

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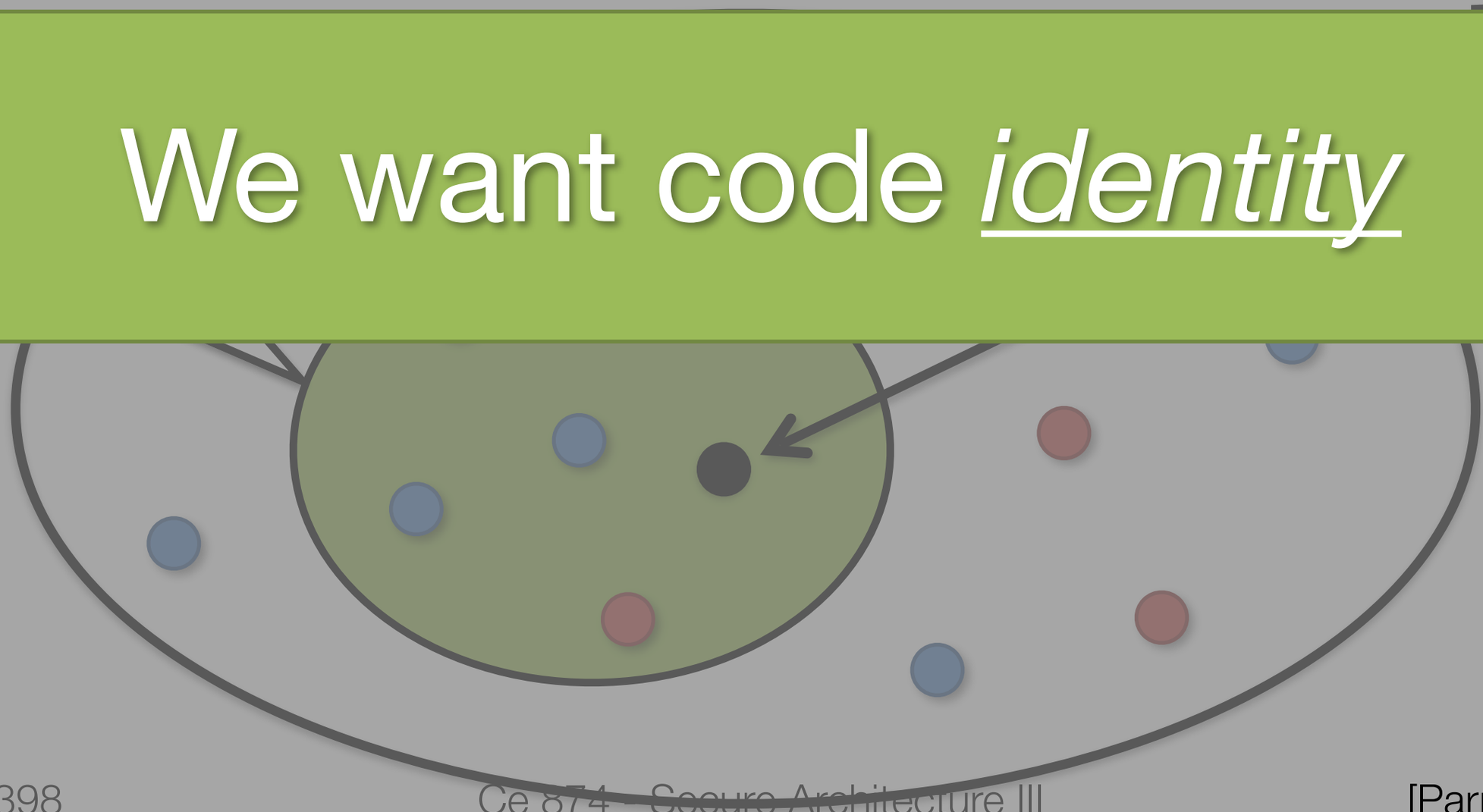
We want code *identity*



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- Often condensed into a hash of the above

Code Identity as Trust Foundation

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- From code identity, you may be able to infer:
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- Reverse is not true!

What Can Code Identity Do For You?

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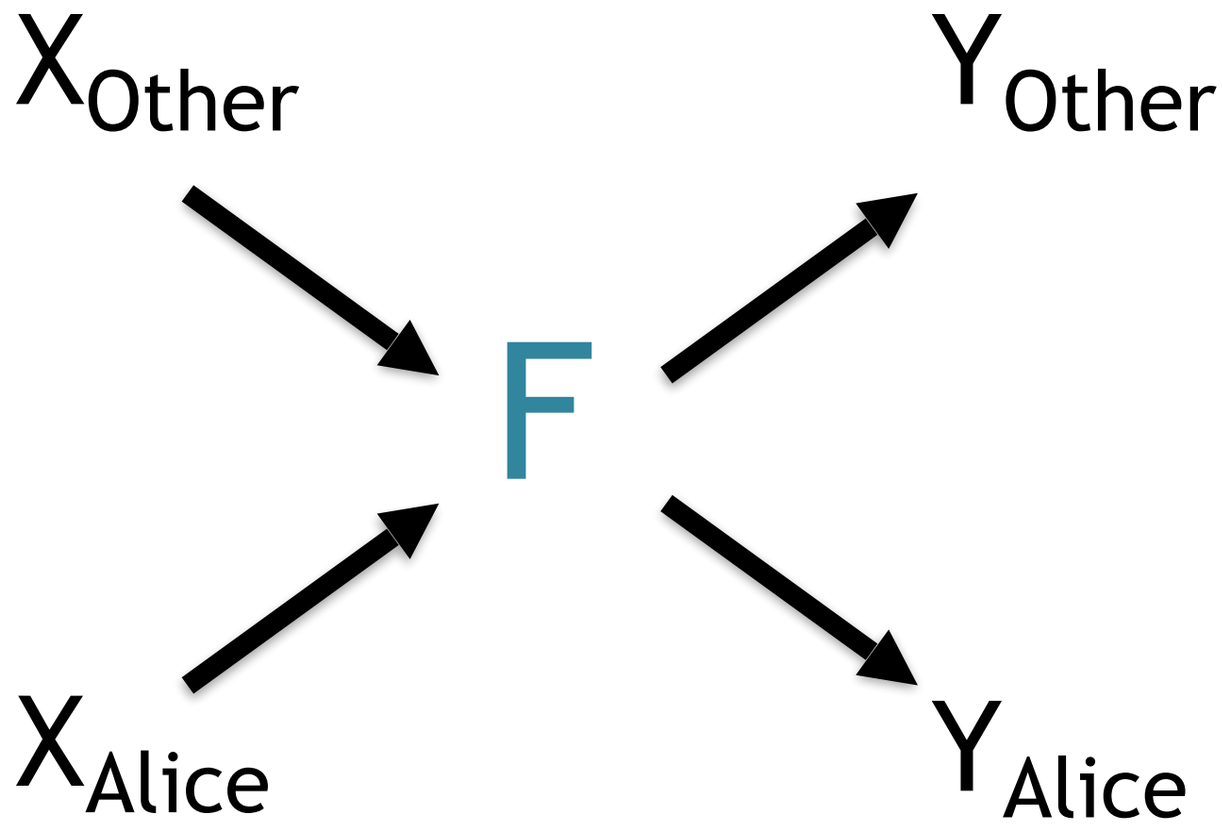

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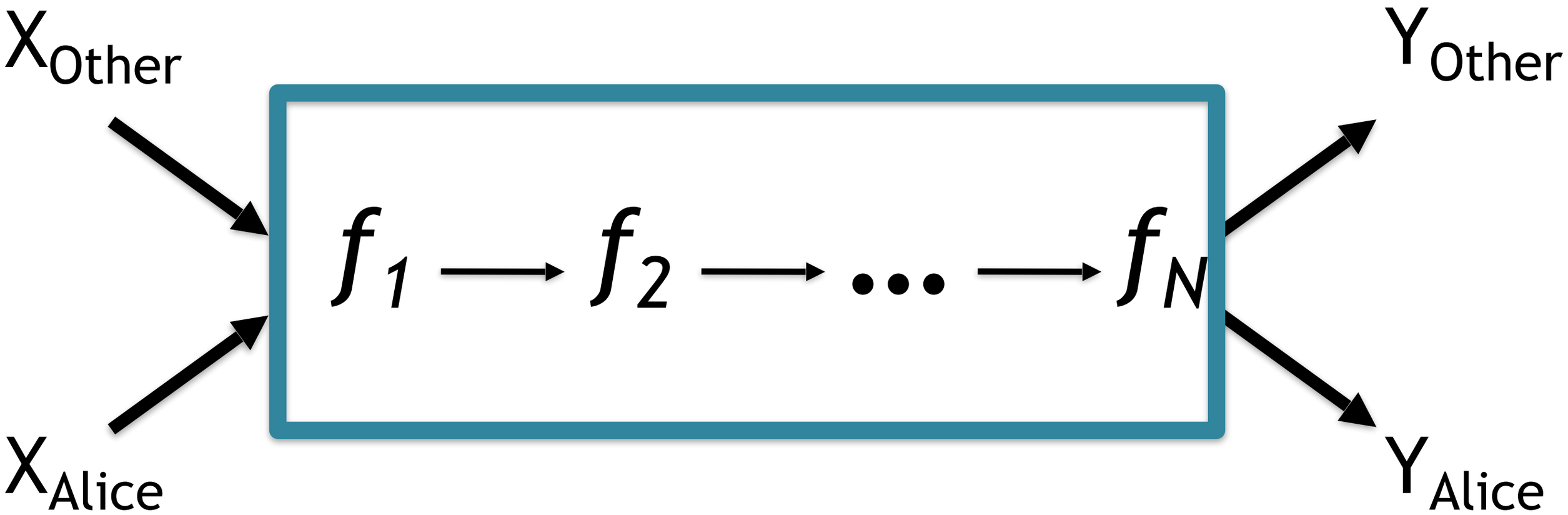

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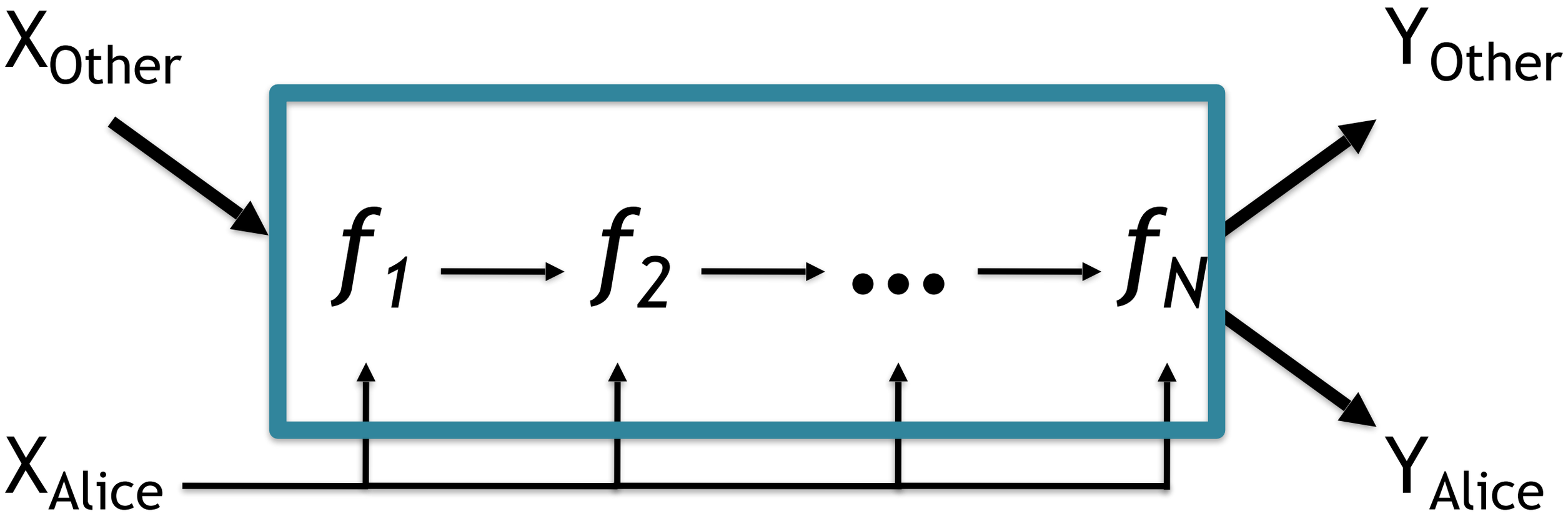

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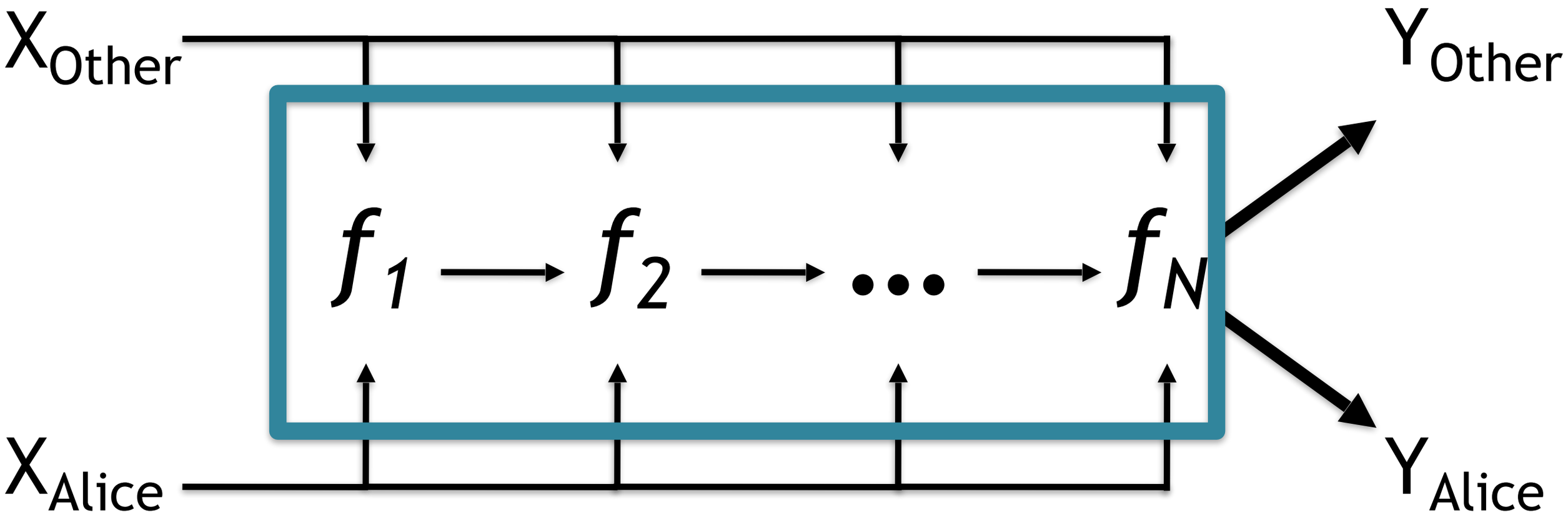

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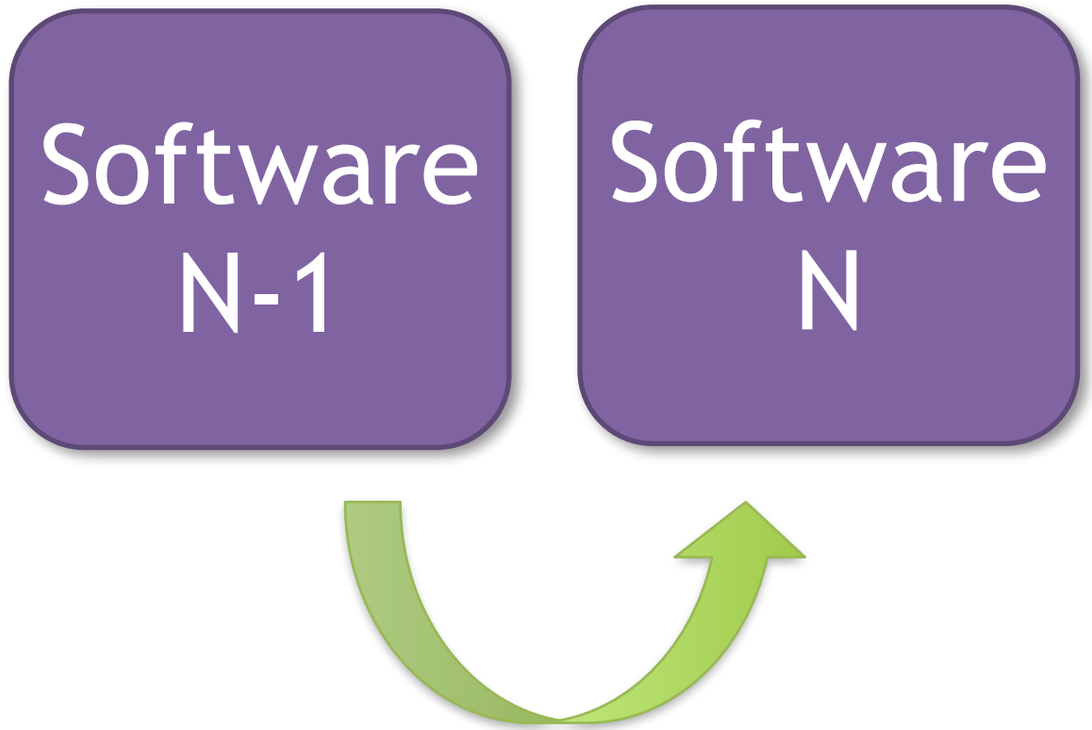

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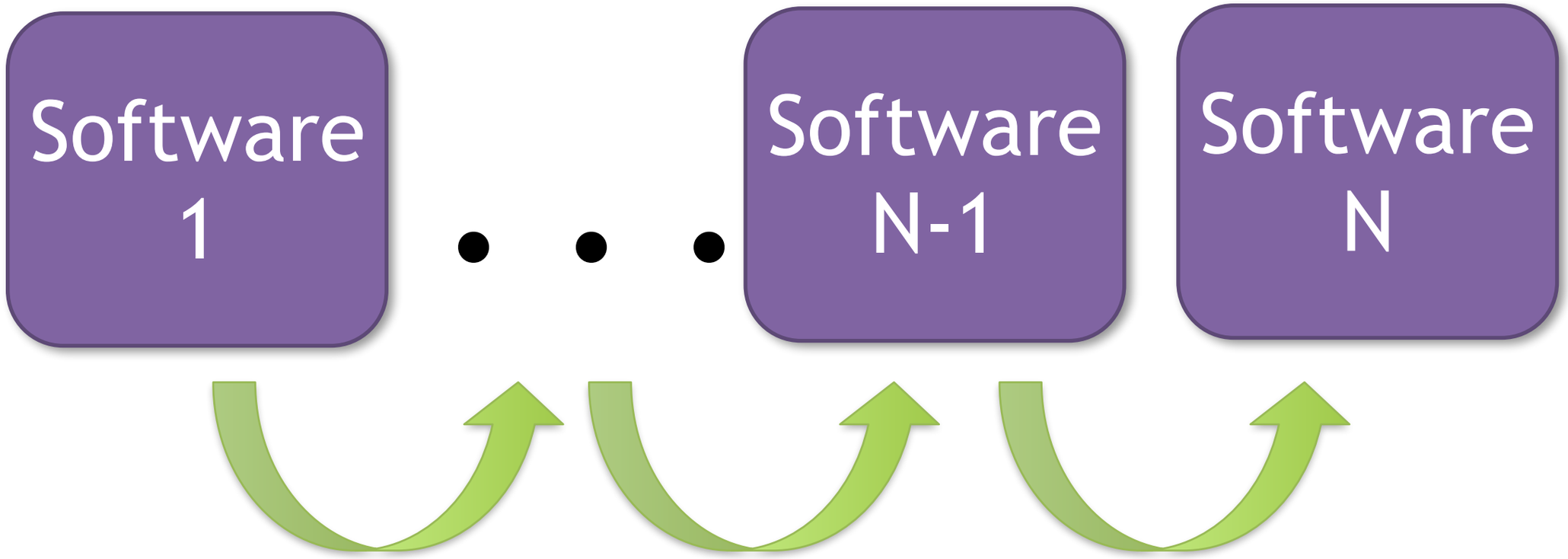

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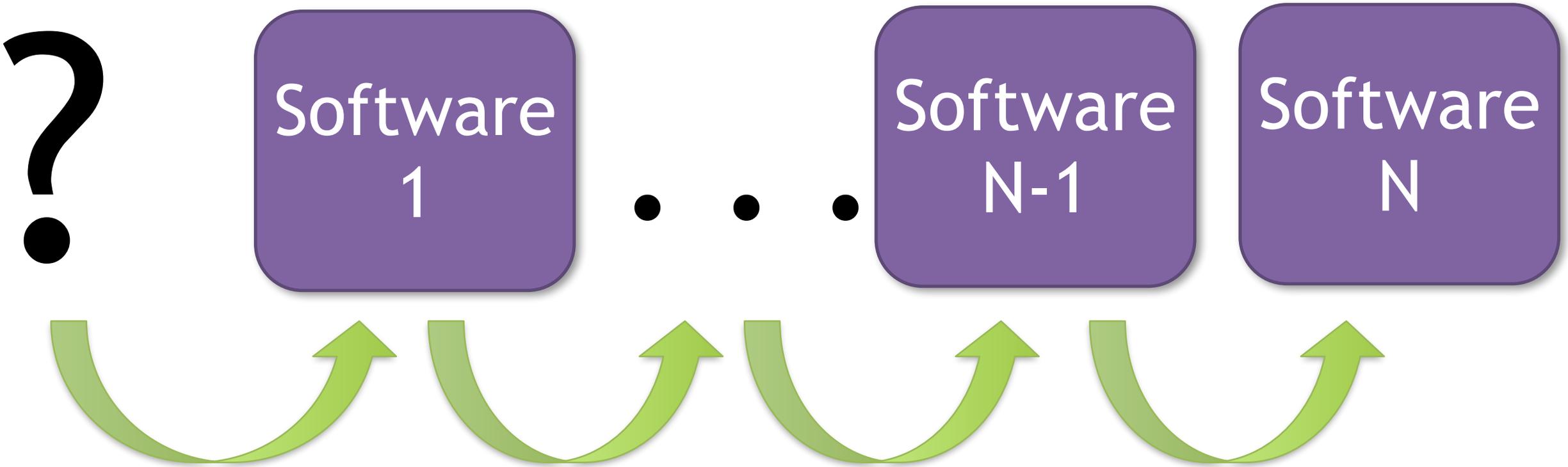

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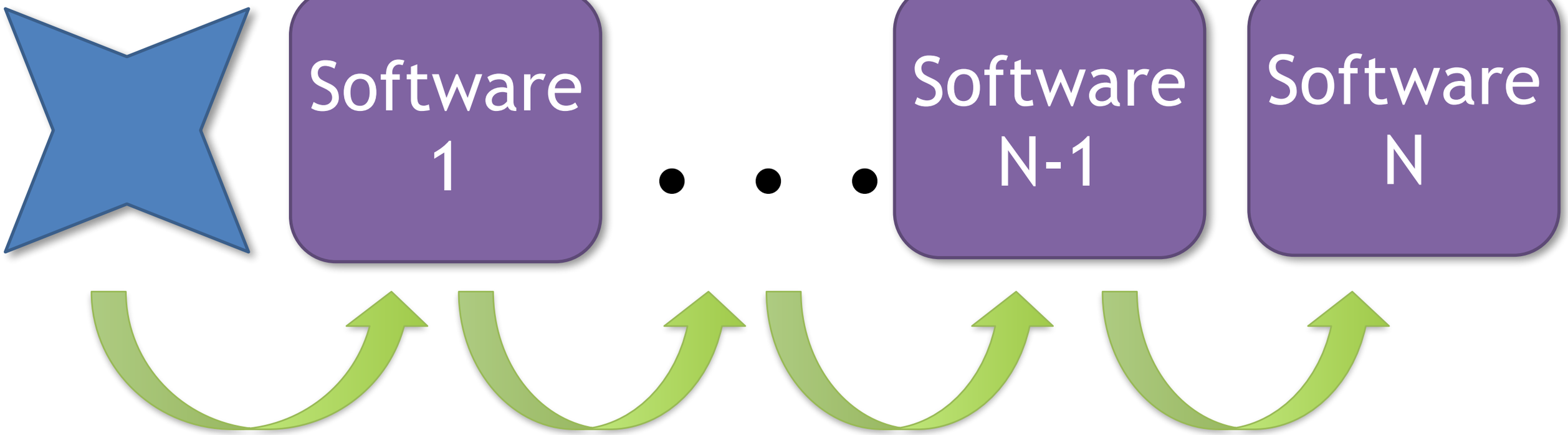

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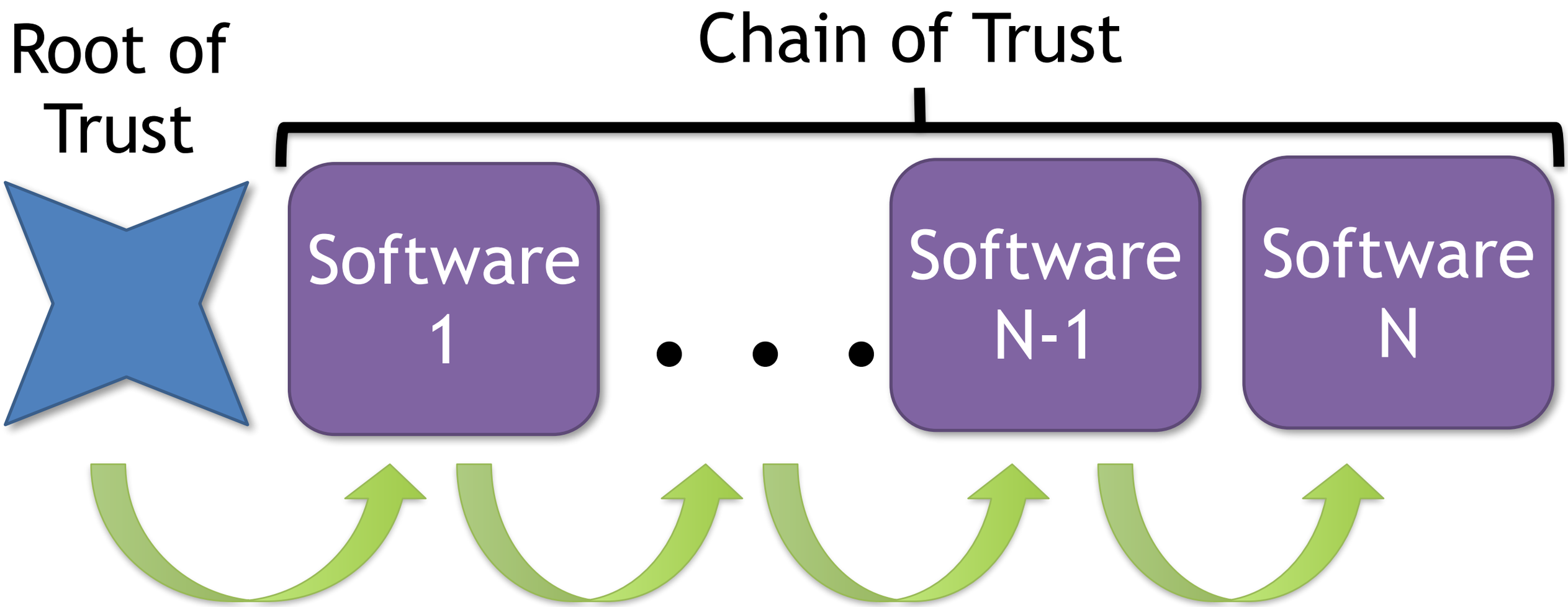

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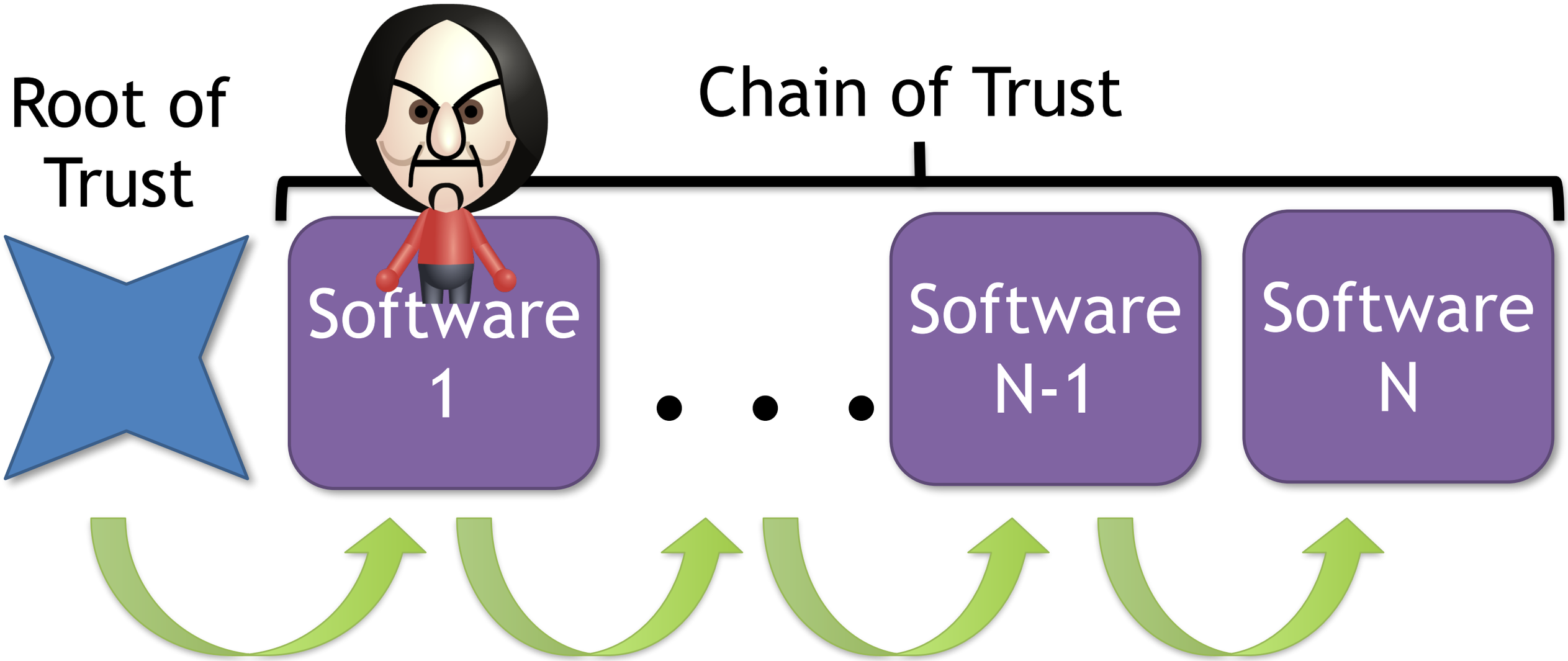
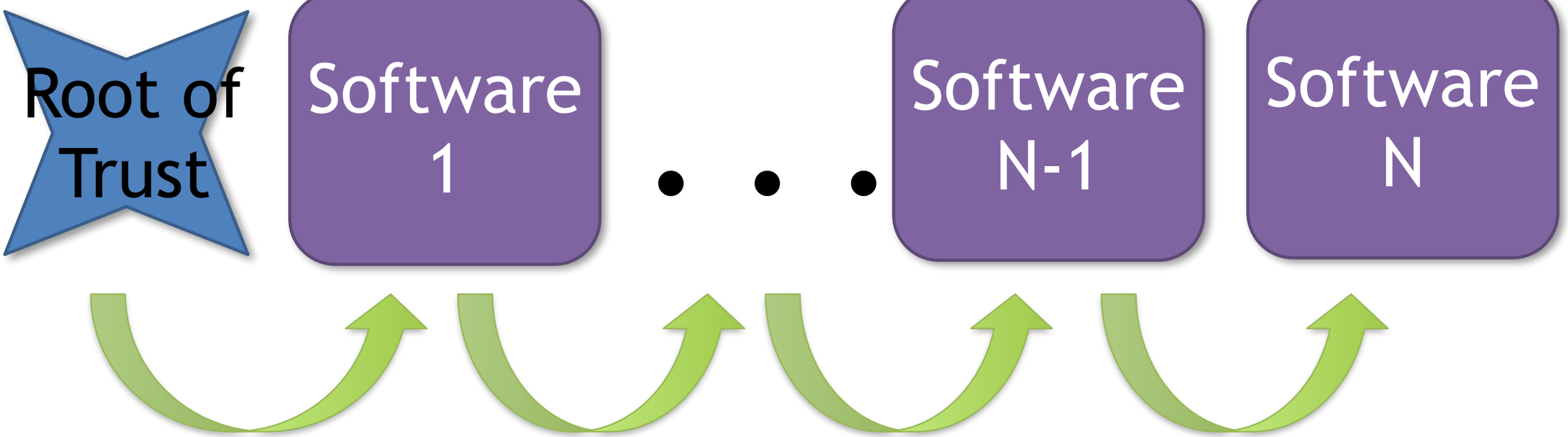


Trusted Boot: Recording Code Identity



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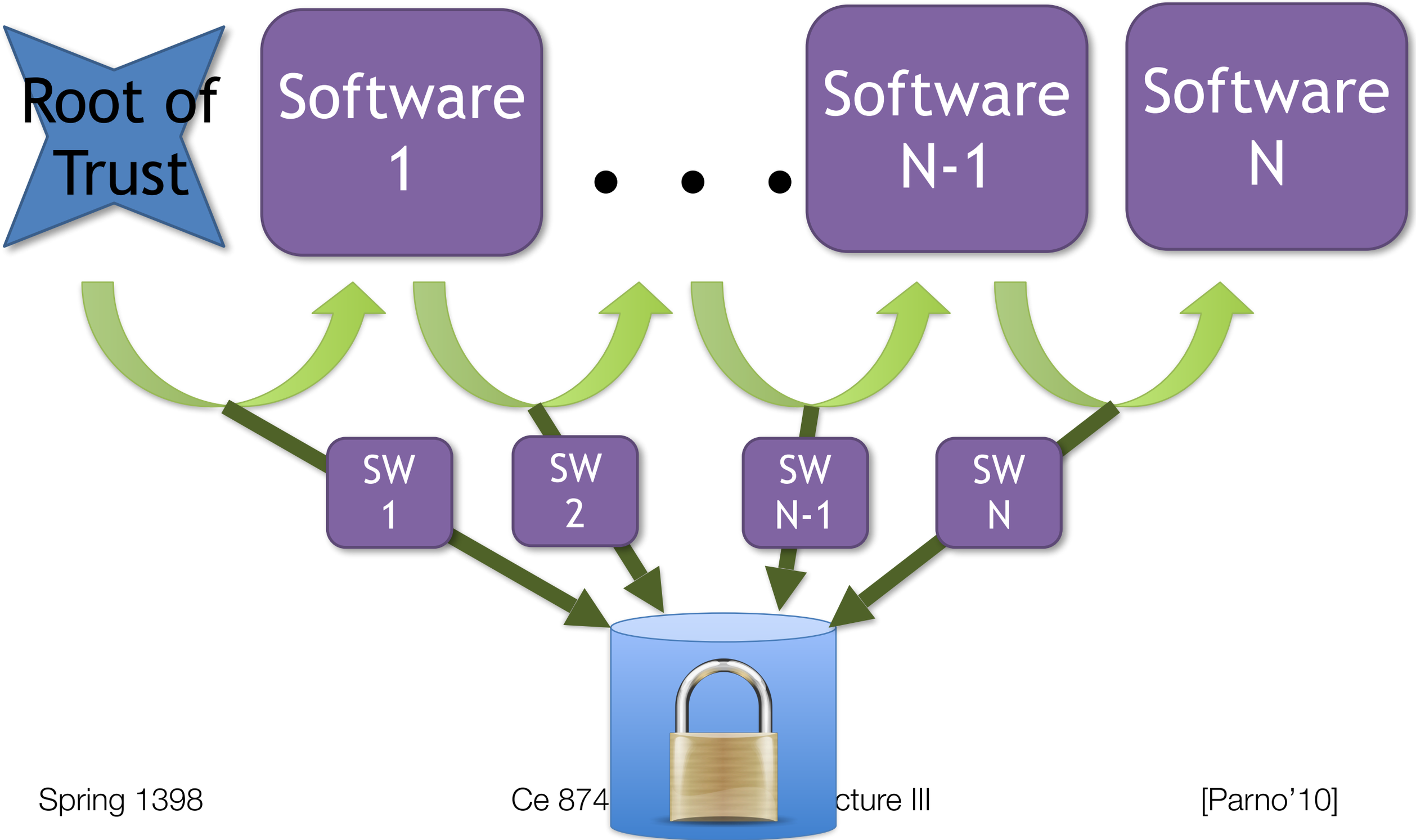

Attestation:
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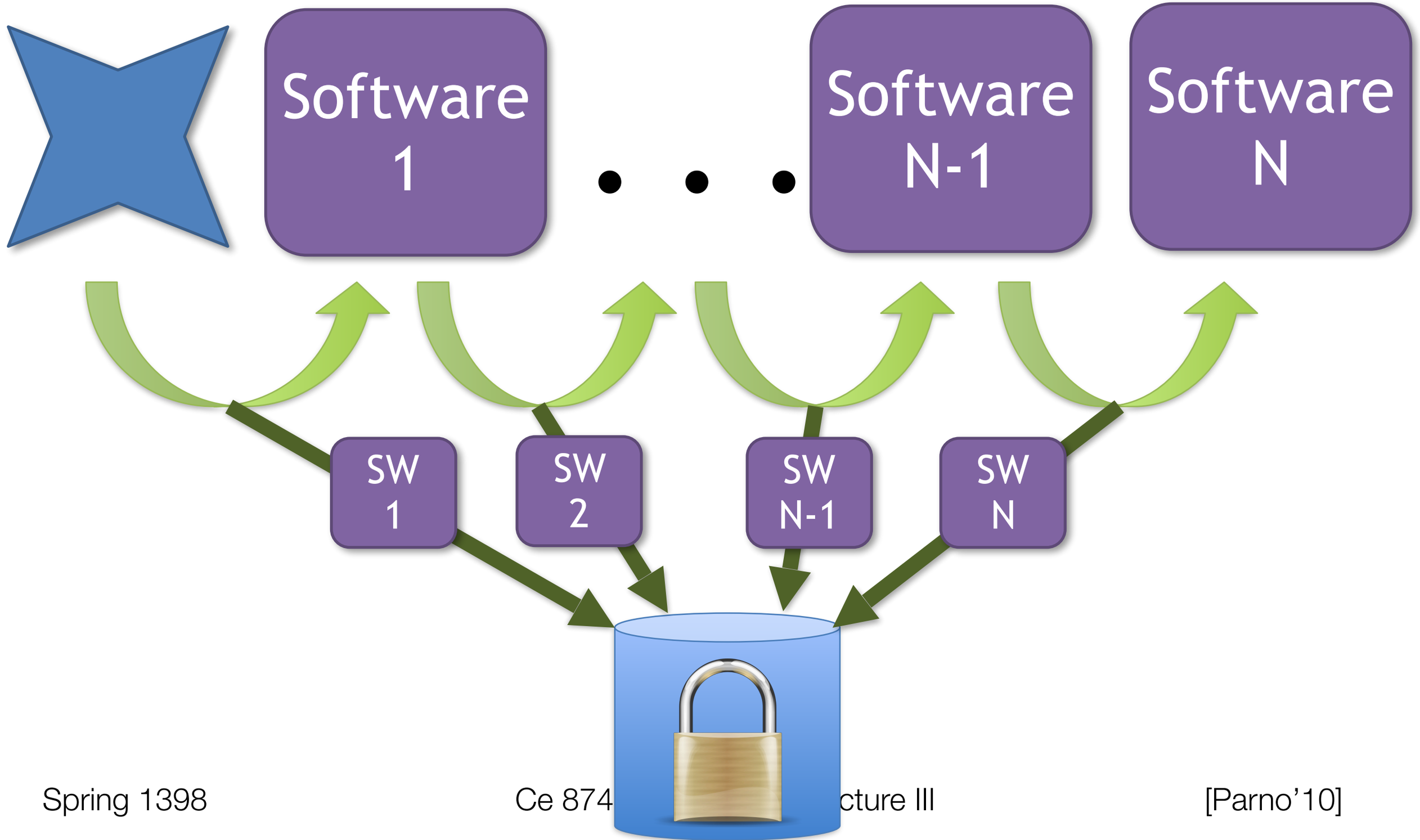

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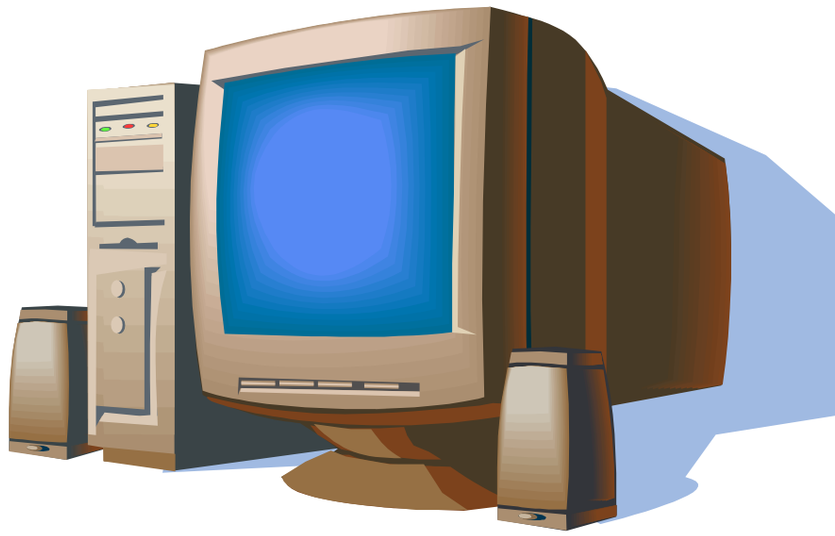

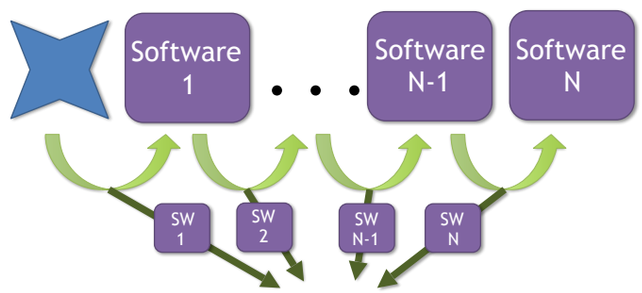

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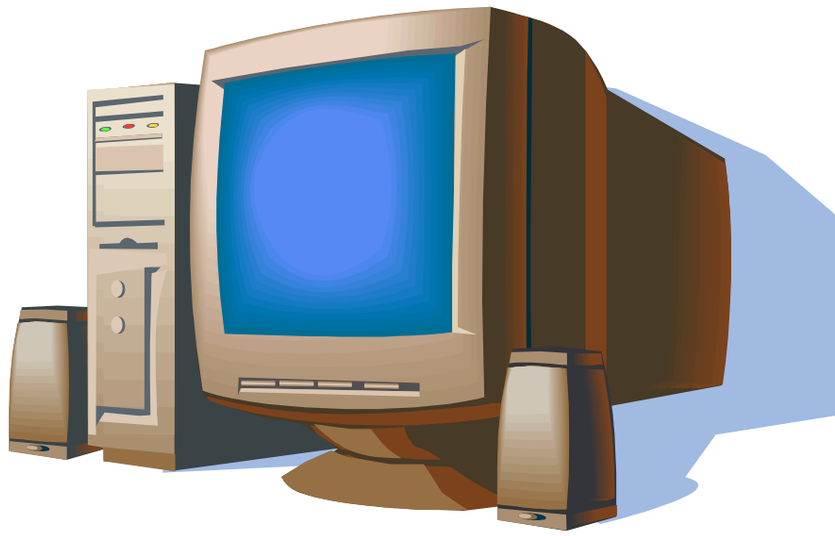
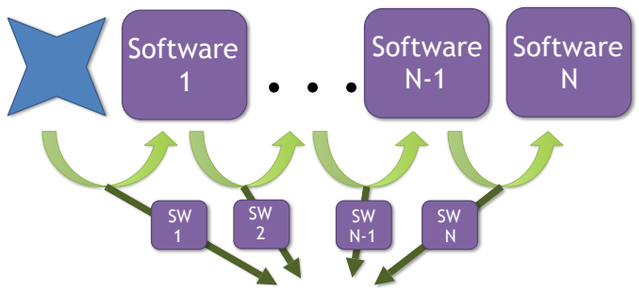
random #





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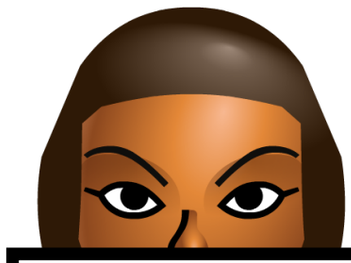
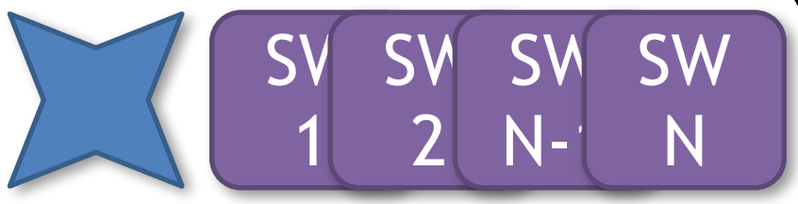


Sign K_{priv} (

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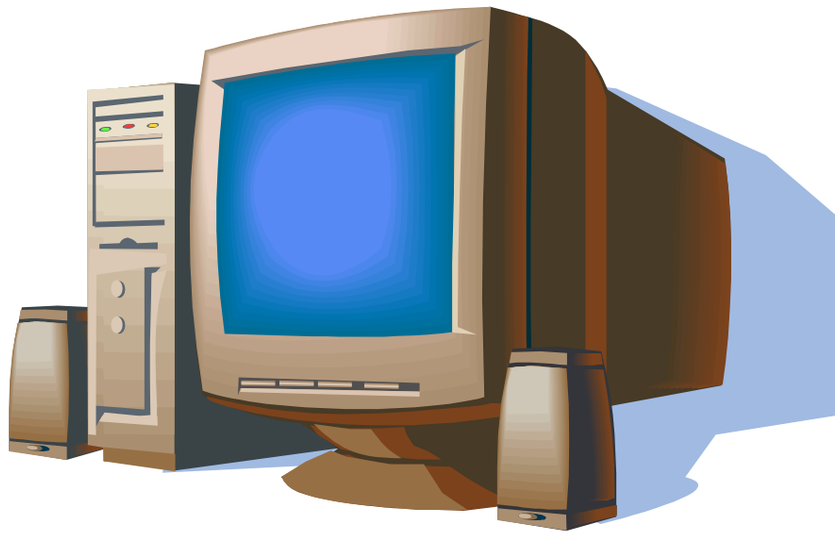

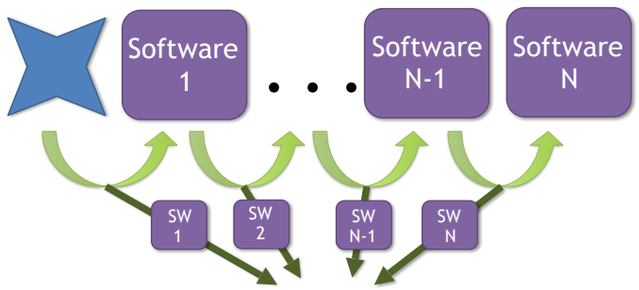

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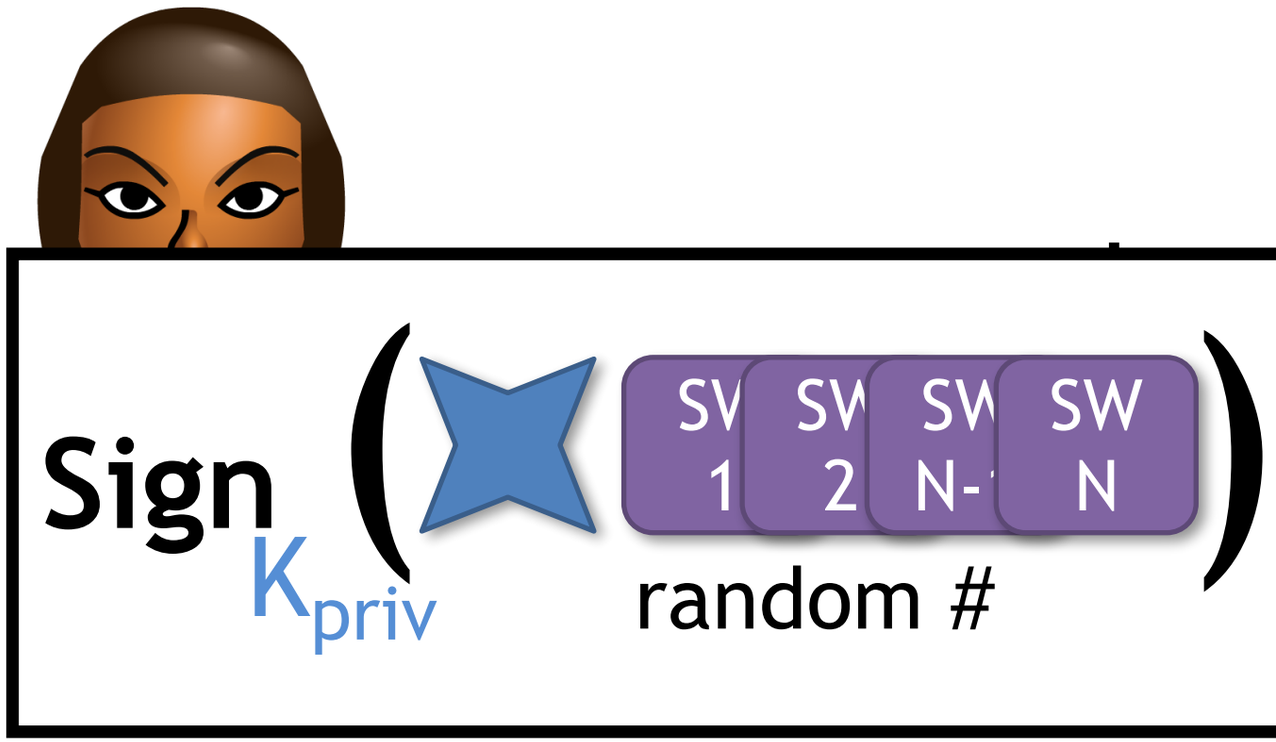

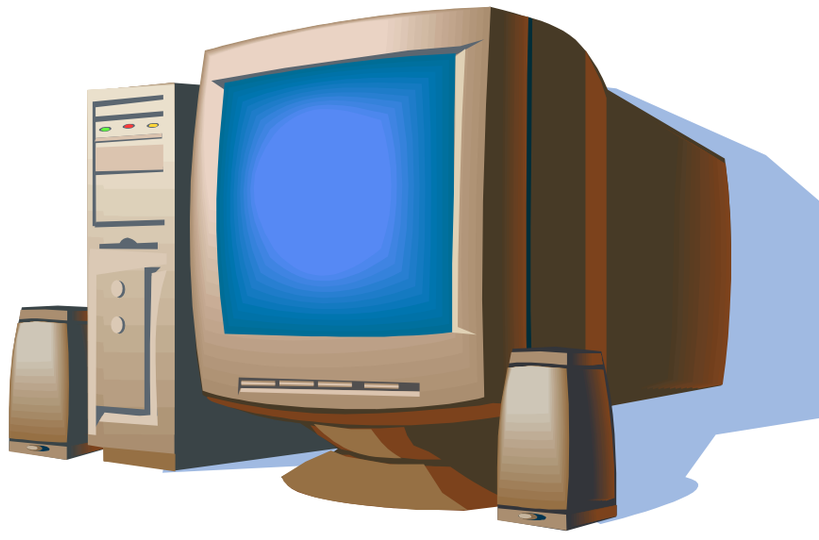

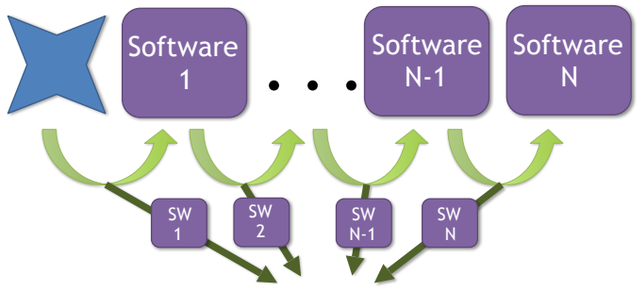

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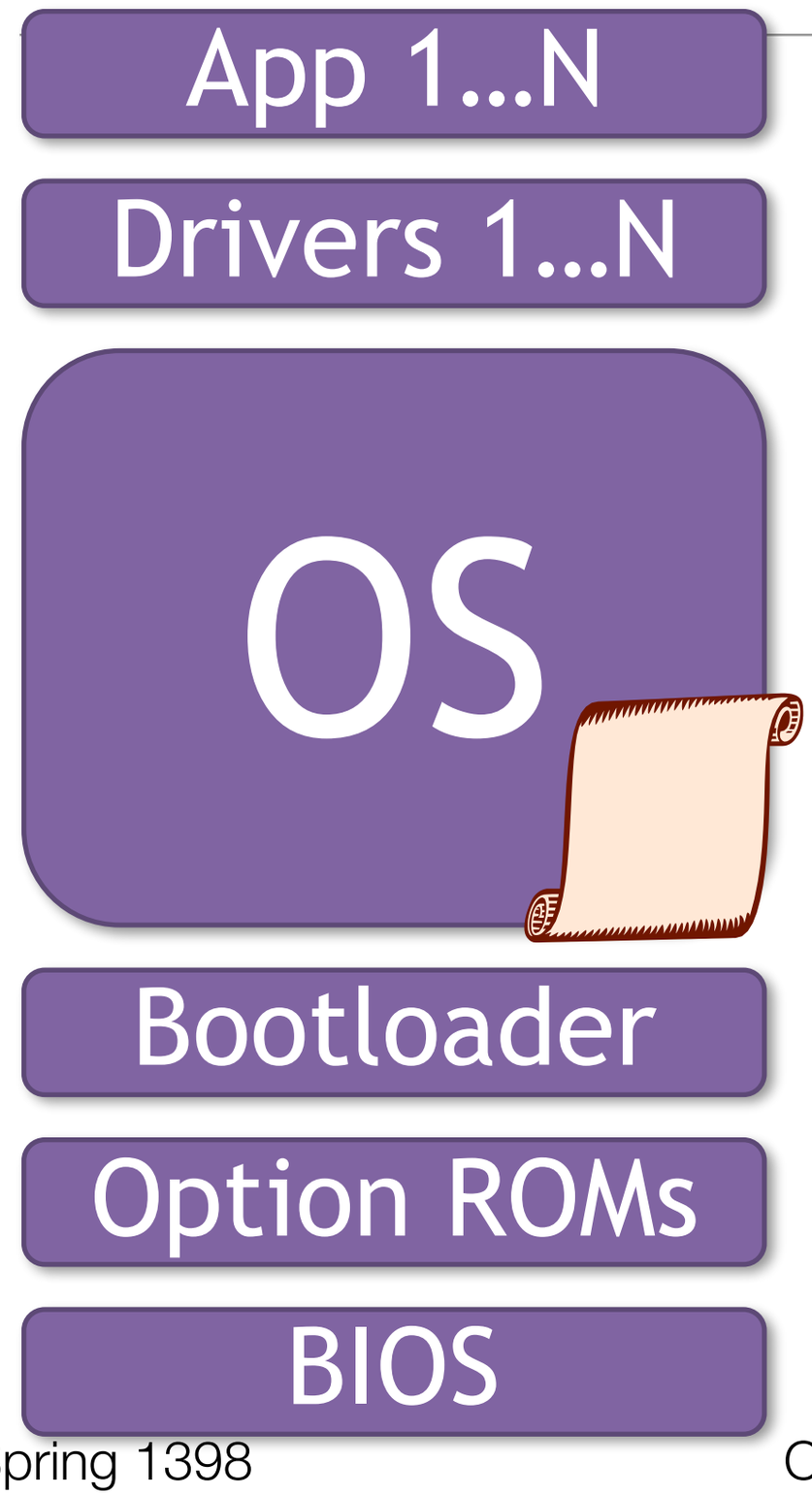

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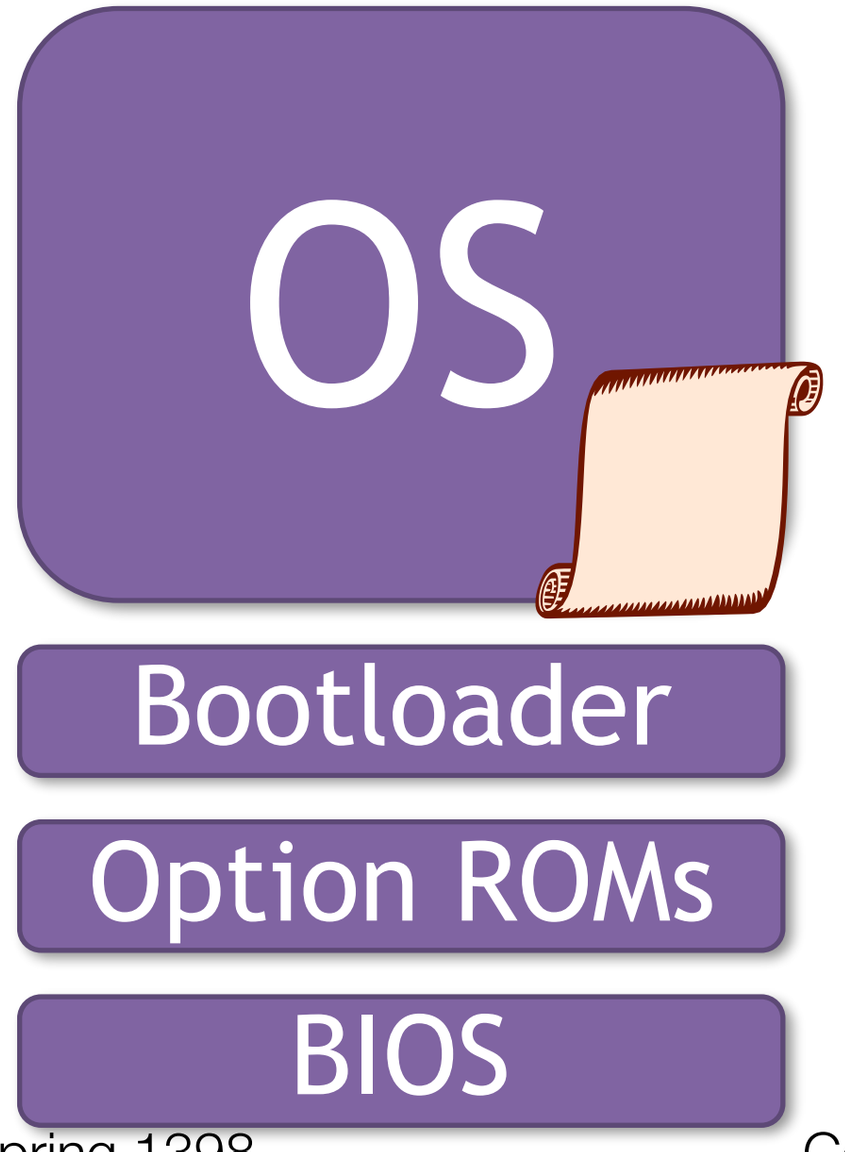

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Virtual Machine

Virtual Machine Monitor

Bootloader

Option ROMs

BIOS

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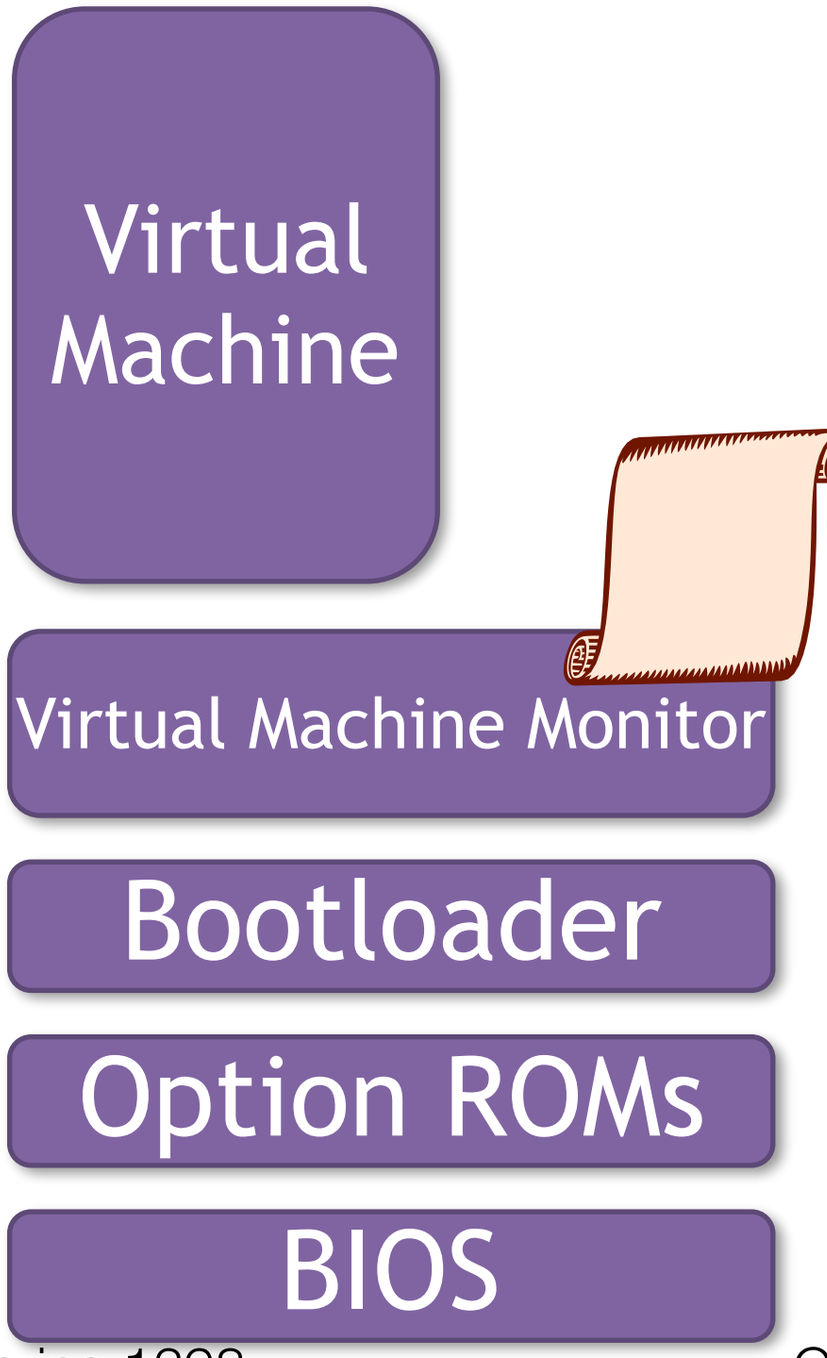

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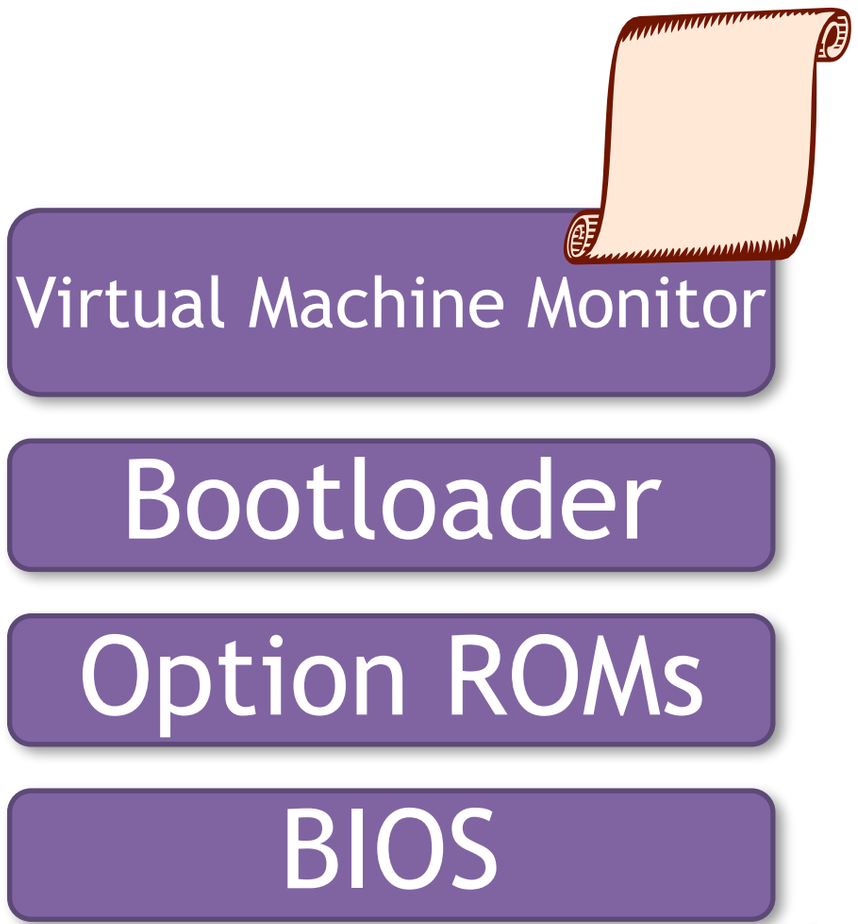

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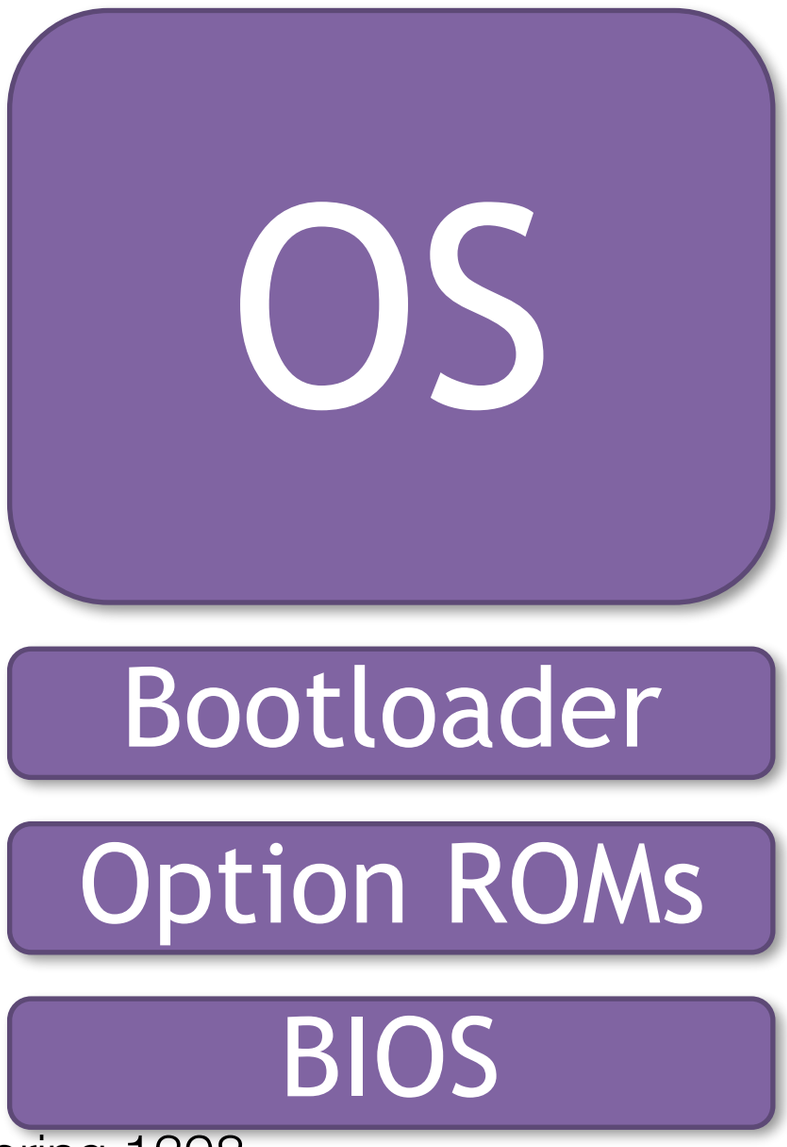

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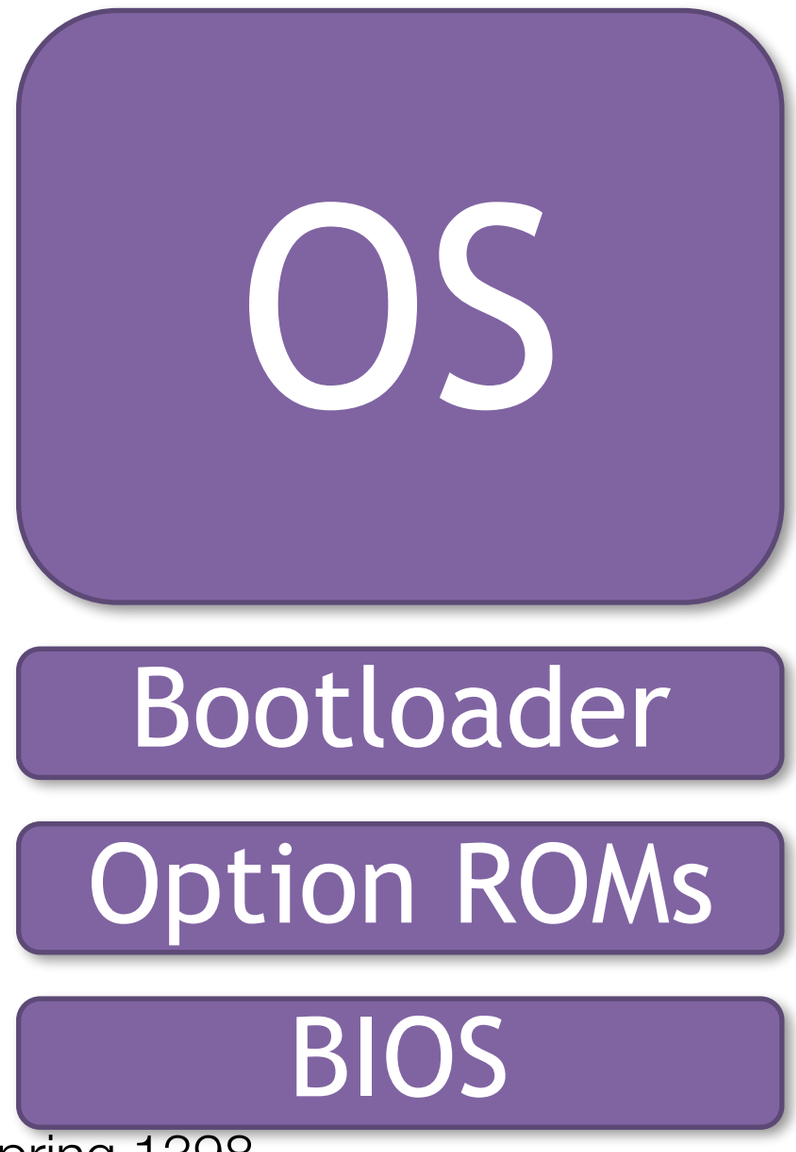

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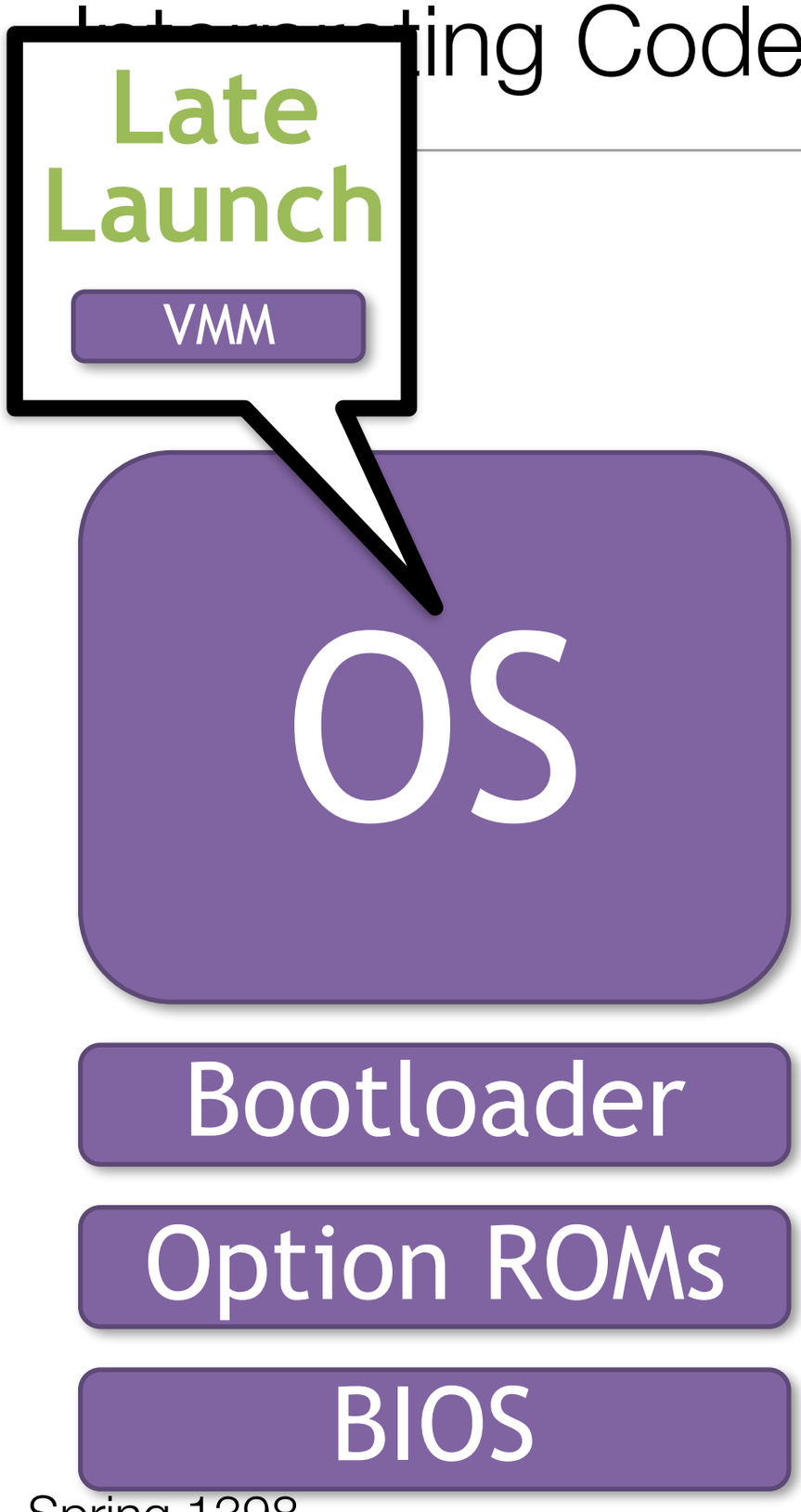

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Interpreting Code Identity

Traditional

[Gasser et al. ‘89], [Sailer et al. ‘04]

Policy Enforcement

[Marchesini et al. ‘04], [Jaeger et al. ’06]

Virtualization

[England et al. ‘03], [Garfinkel et al. ‘03]

Virtual Machine Monitor

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Flicker

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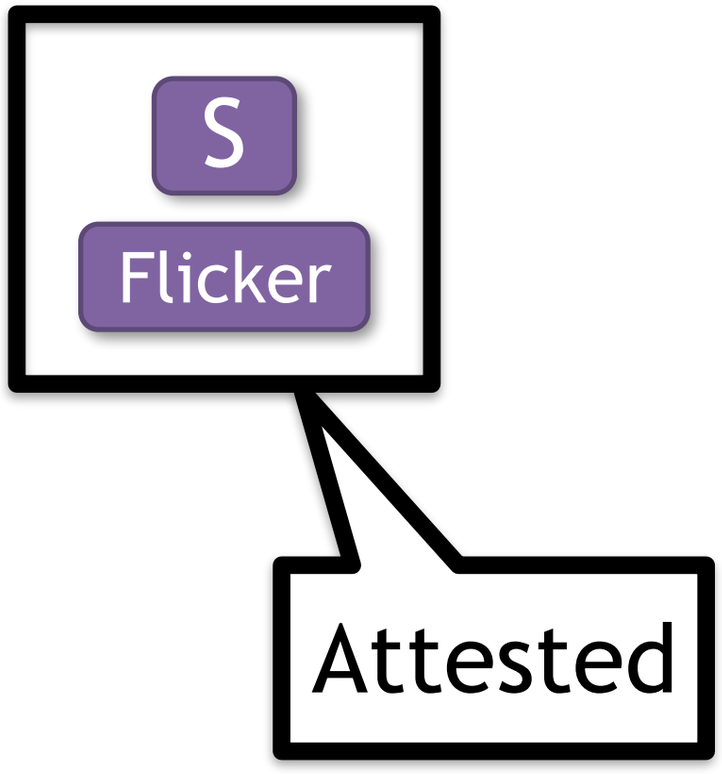

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Interpreting Code Identity

App 1…N

Drivers 1…N

OS

Bootloader

Option ROMs

BIOS

S

Flicker

Load-Time vs. Run-Time Properties

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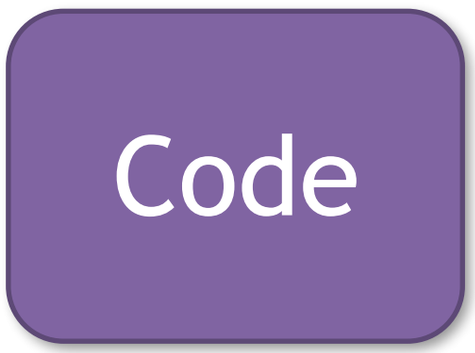

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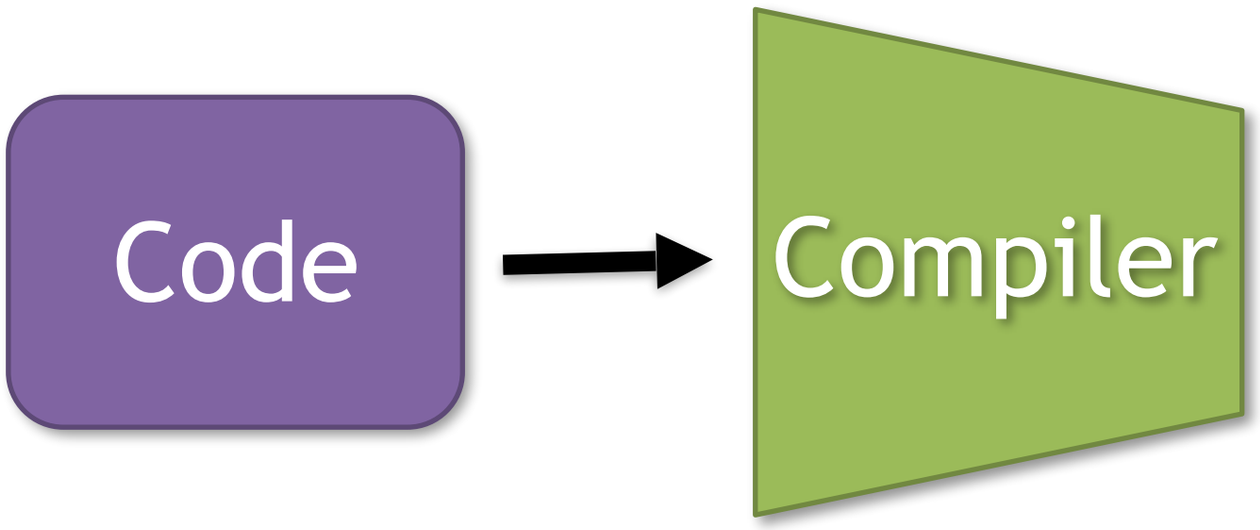

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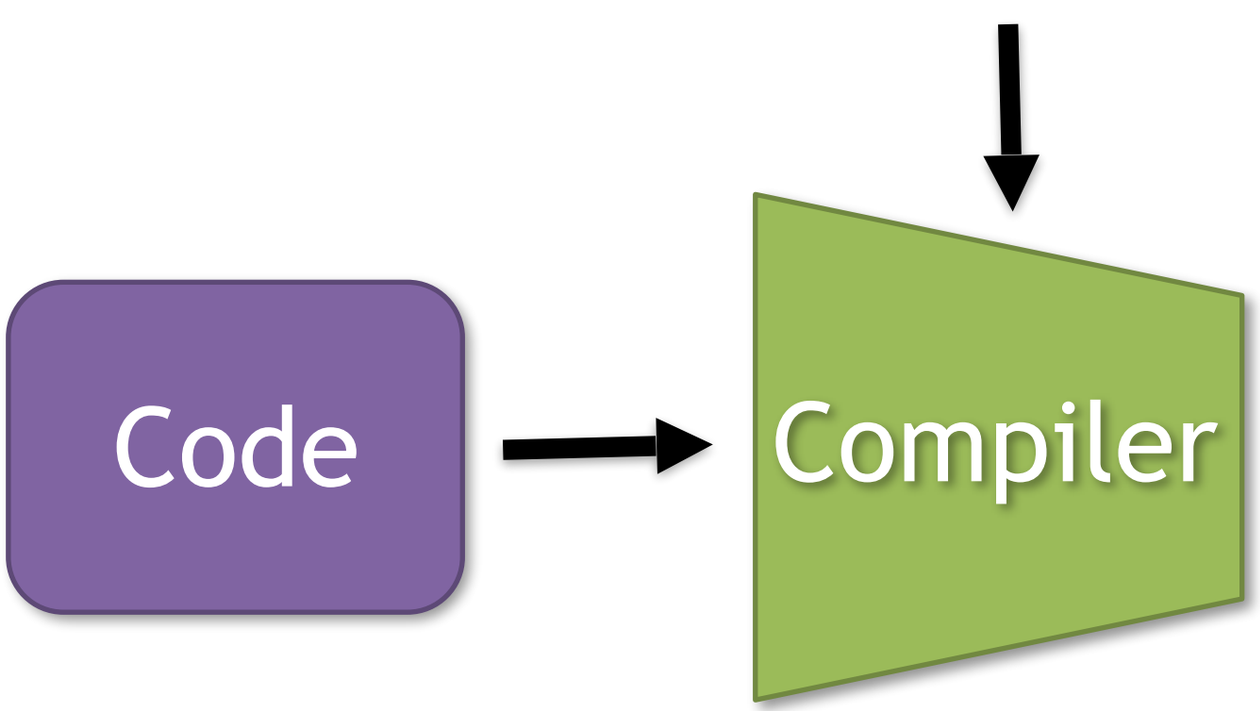
Run-Time Policy



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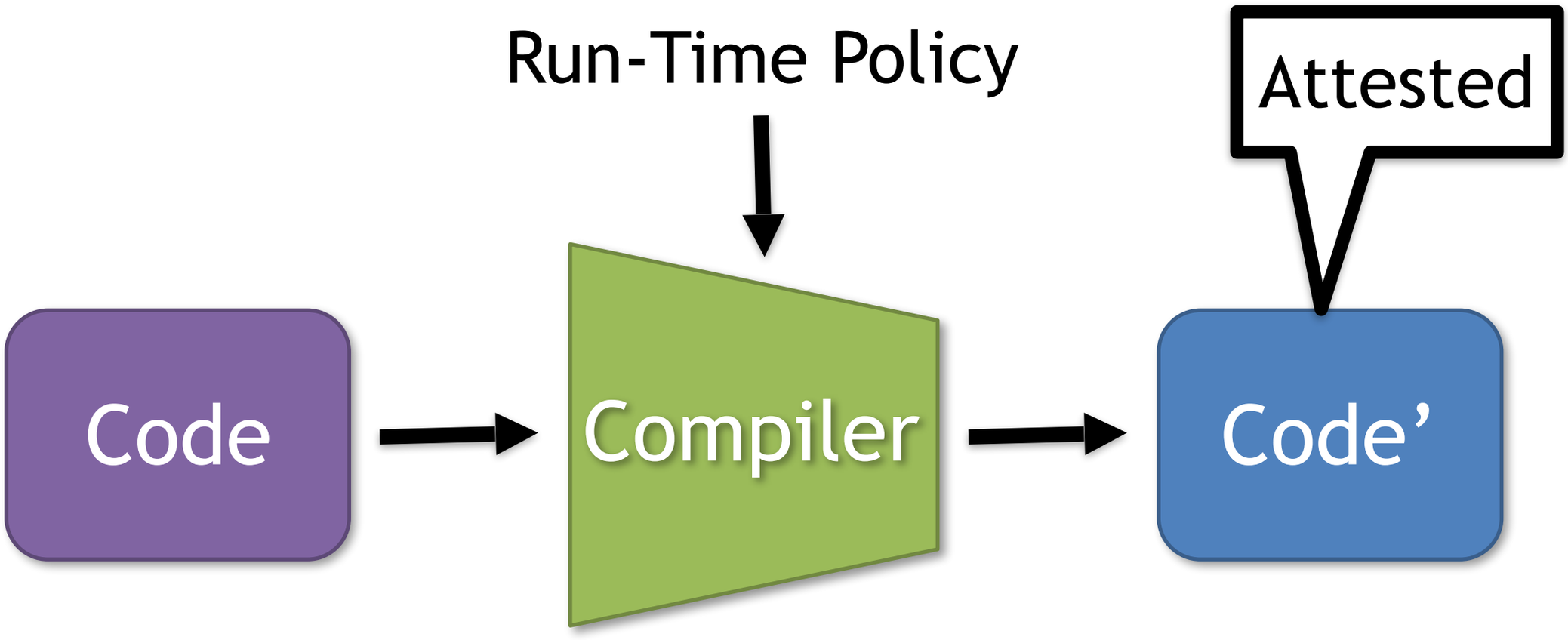

Load-Time vs Run-Time Properties

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[Erlingsson et al. ‘06]

[Haldar et al. ‘04], [Kil et al. ‘09]

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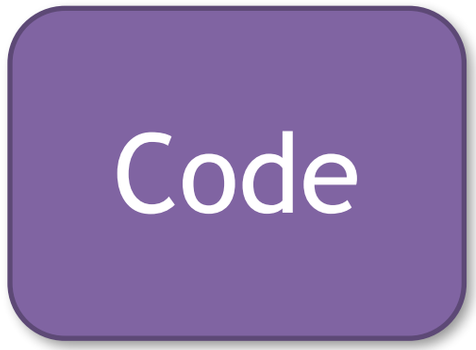

[Parno’10]

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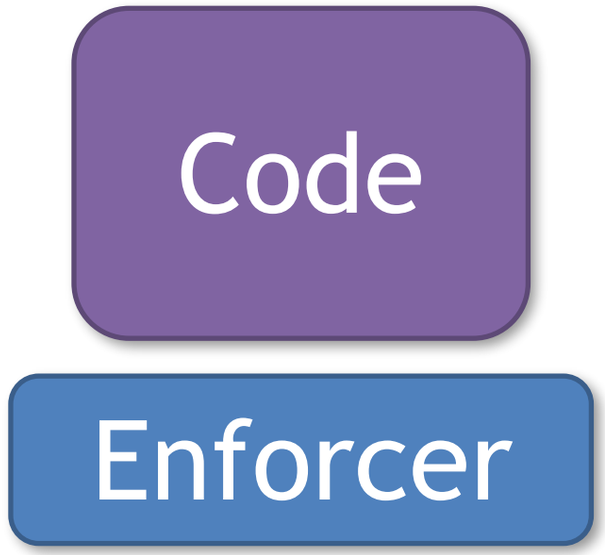

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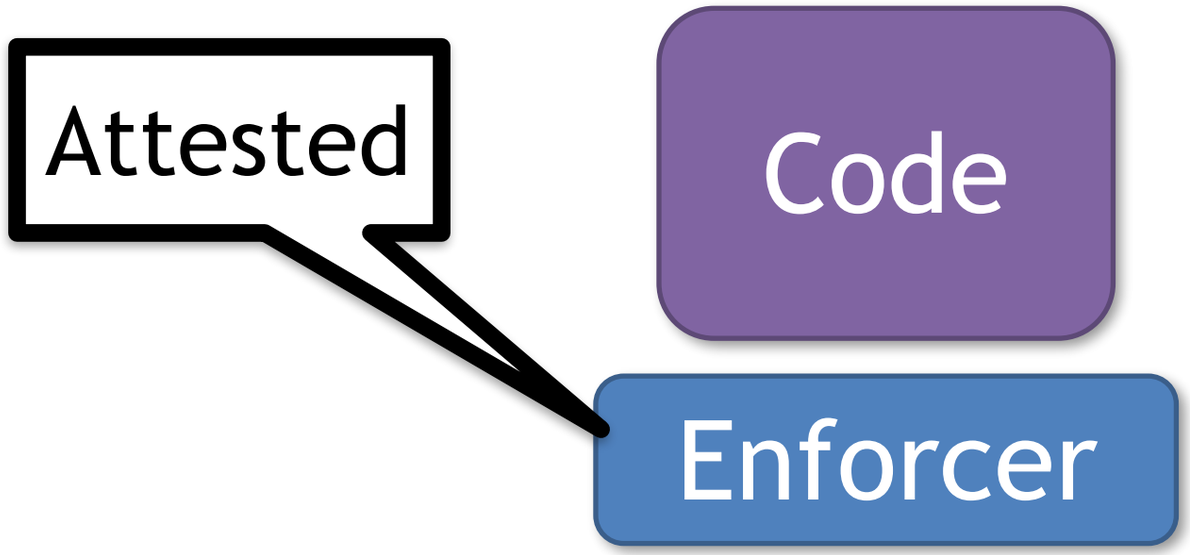

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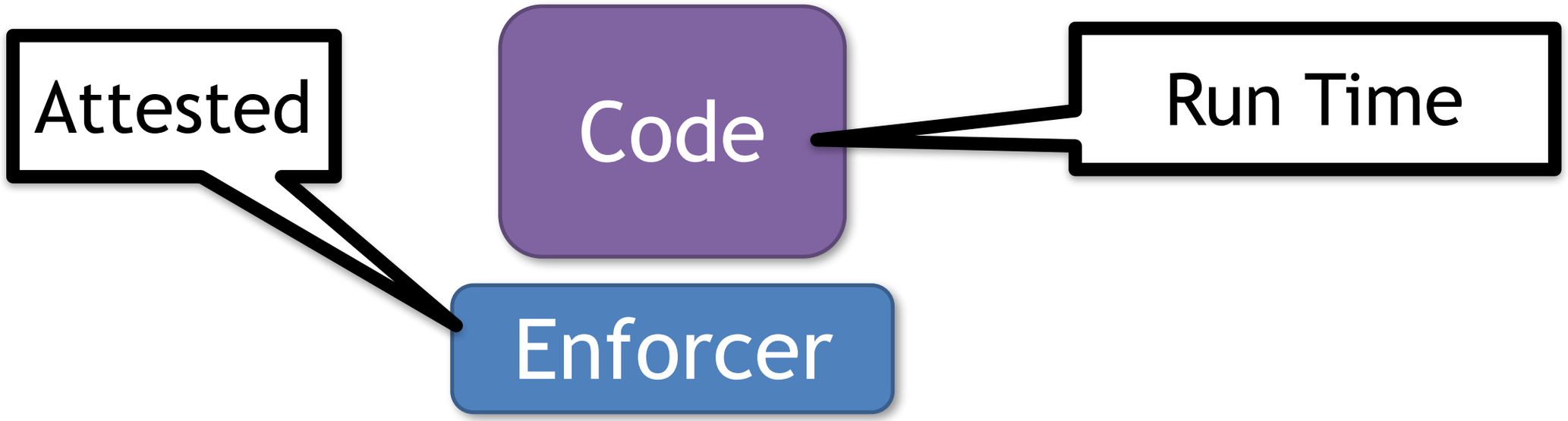

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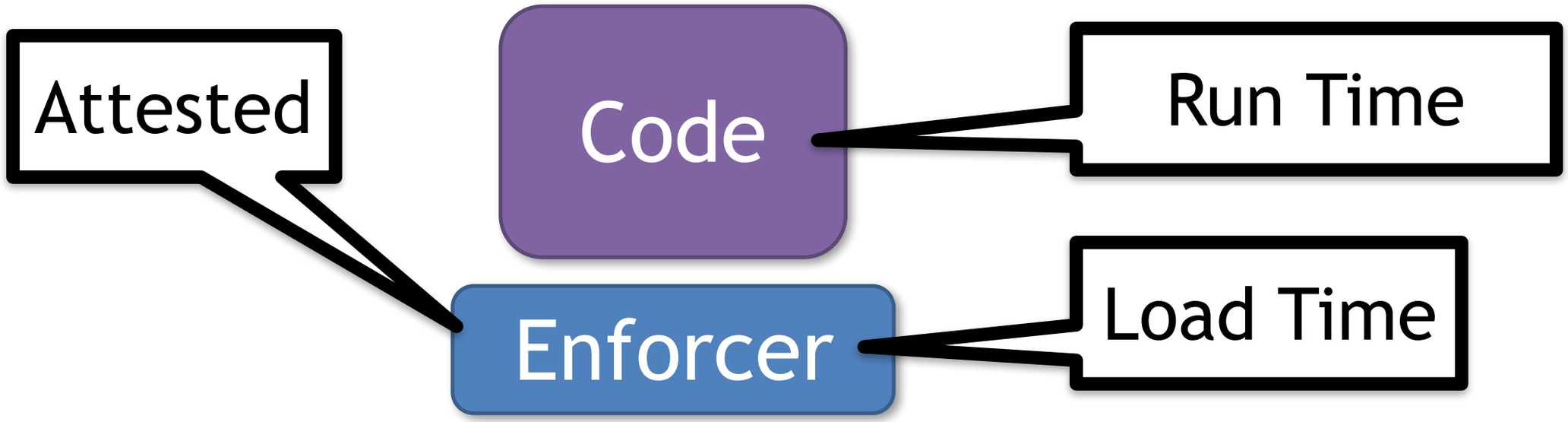


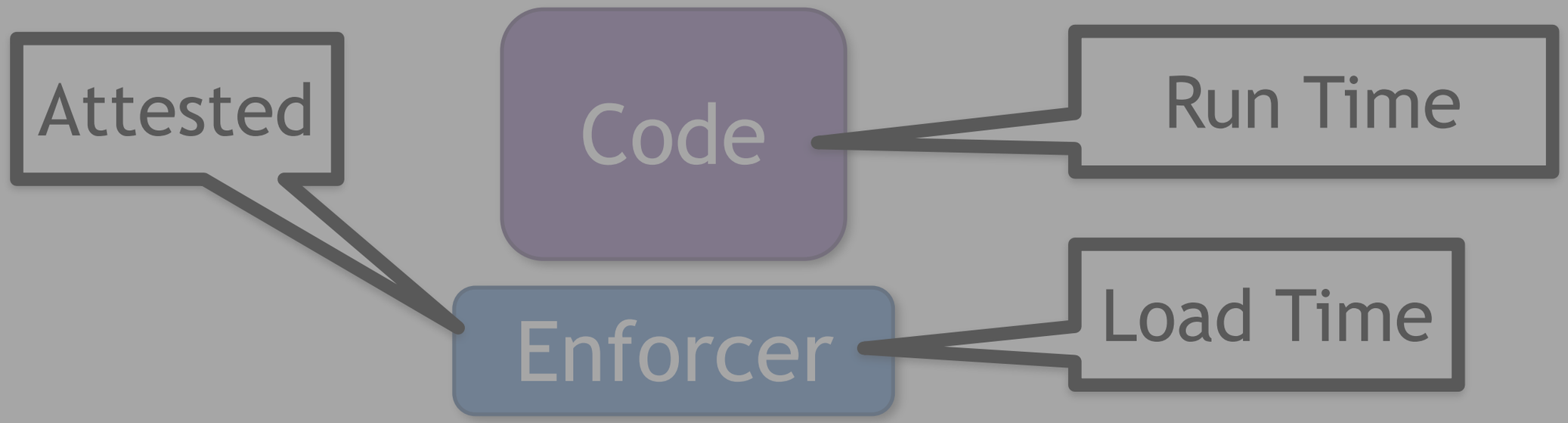
[Parno’10]

Load-Time vs Run-Time Properties

- Code identity provides load-time guarantees
- What about run time?

Open Question:

How can we get complete run-time properties?



Roots of Trust

Cheaper

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Cheaper

- General purpose
- Tamper responding

[Weingart ‘87]
[White et al. ‘91]
[Yee ‘94]
[Smith et al. ‘99]

•••

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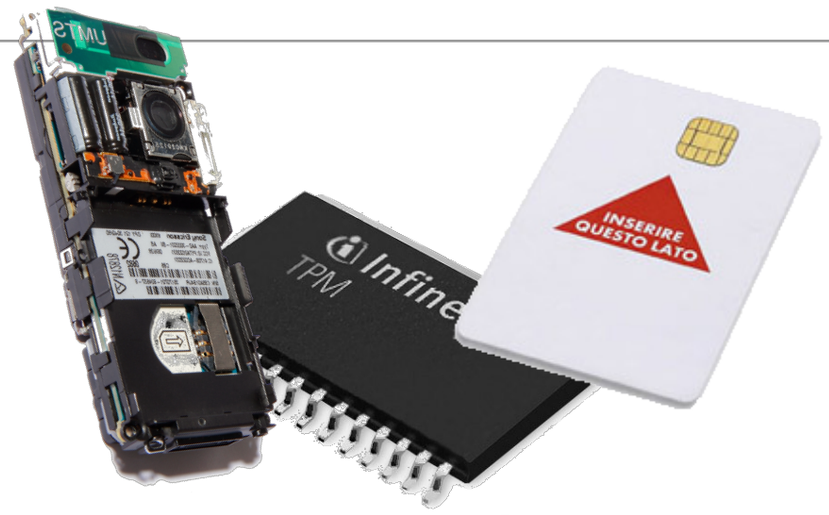

- General purpose
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…

- General purpose
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[ARM TrustZone ‘04]
[TCG ‘04]
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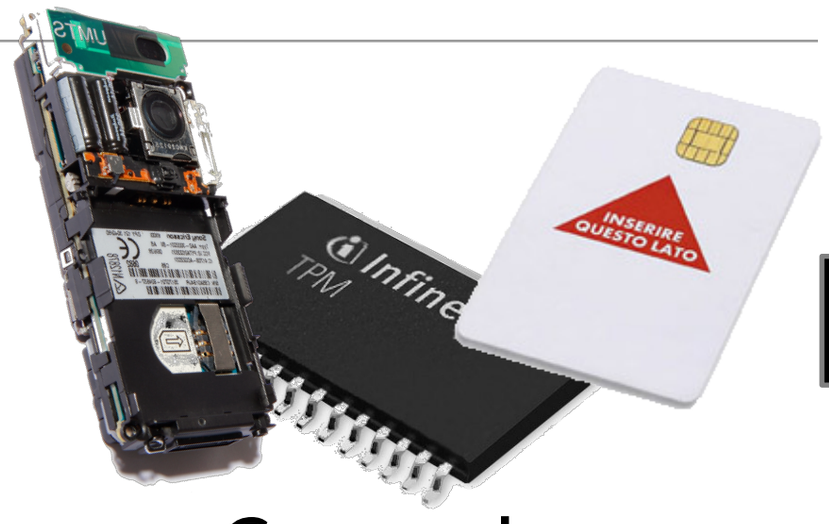

- General purpose
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[ARM TrustZone ‘04]
[TCG ‘04]
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•••

- Special purpose

[Chun et al. ‘07]
[Levin et al. ‘09]

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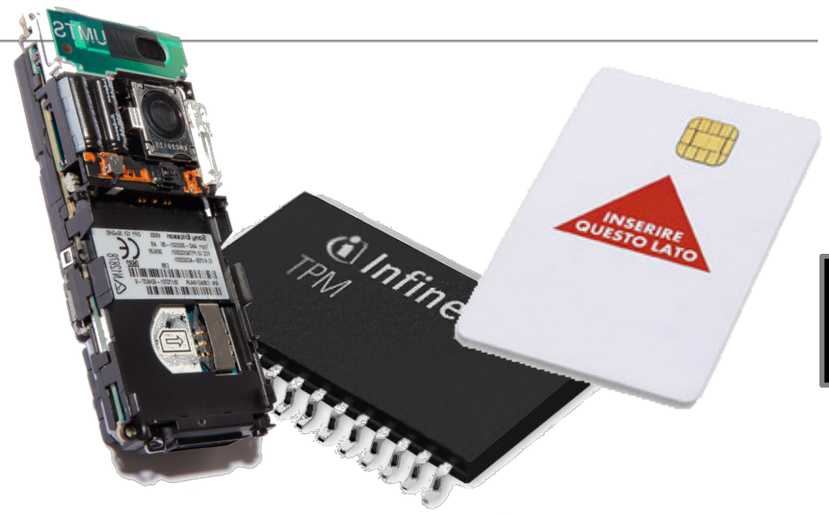

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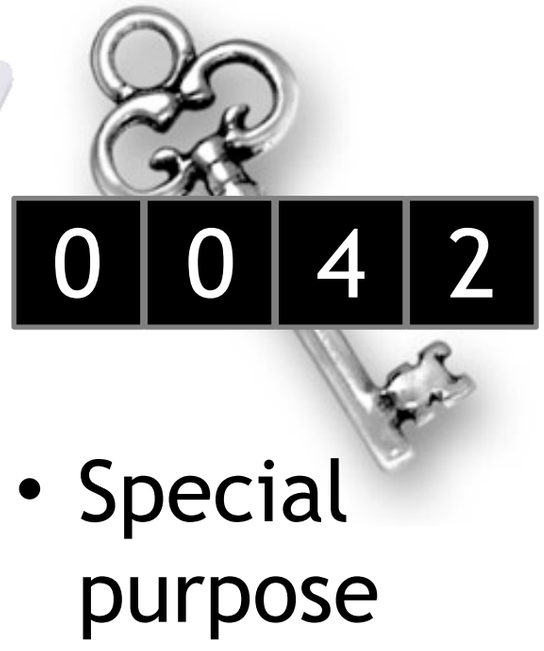

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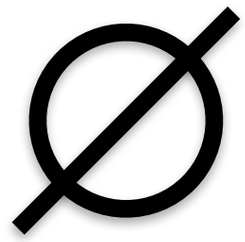

- Timing-based attestation
- Require detailed HW knowledge

[Spinellis et al. ‘00]
[Seshadri et al. ‘05]

•••

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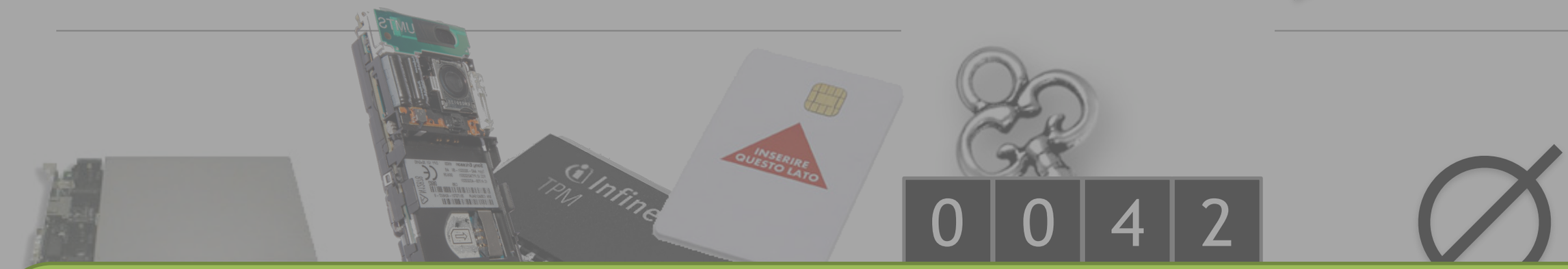

Open Question:

What functionality do we need in hardware?

responding	defenses		detailed HW knowledge
[Weingart ‘87]	[ARM TrustZone ‘04]	[Chun et al. ‘07]	[Spinellis et al. ‘00]
[White et al. ‘91]	[TCG ‘04]	[Levin et al. ‘09]	[Seshadri et al. ‘05]
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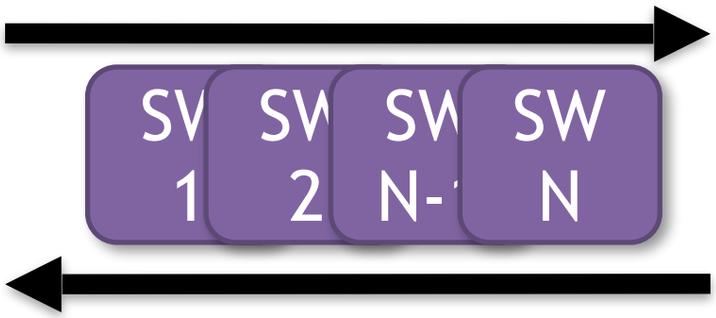
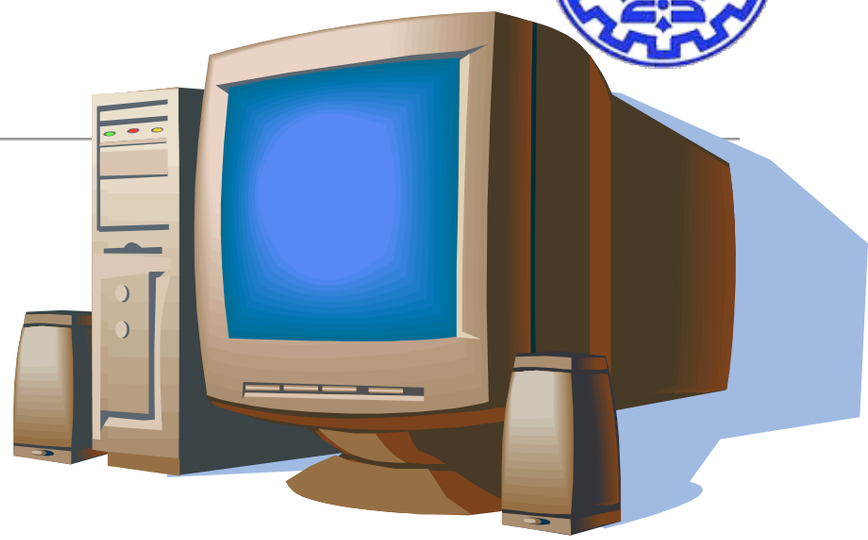
…	…		…

Human Factors





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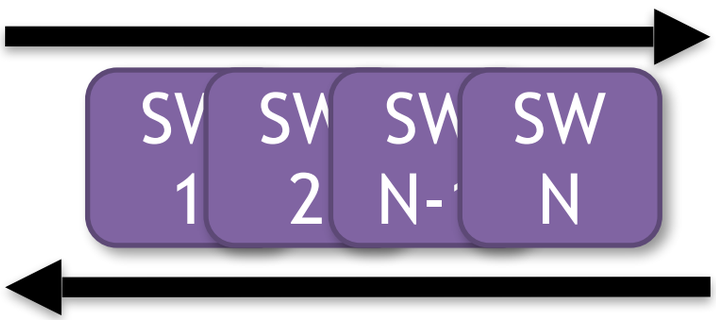
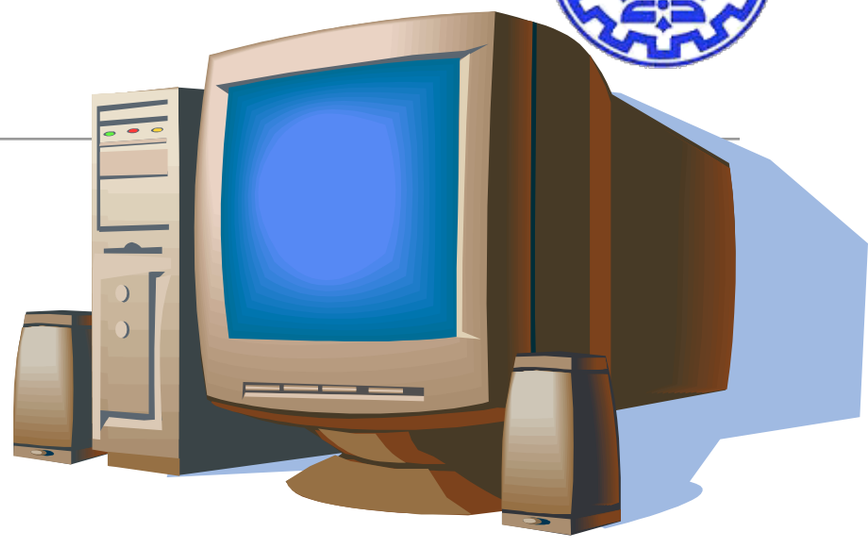
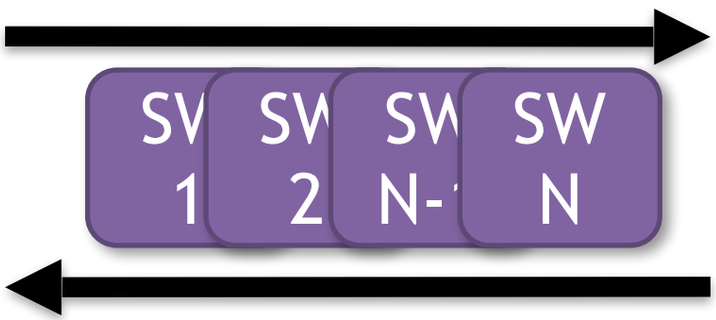


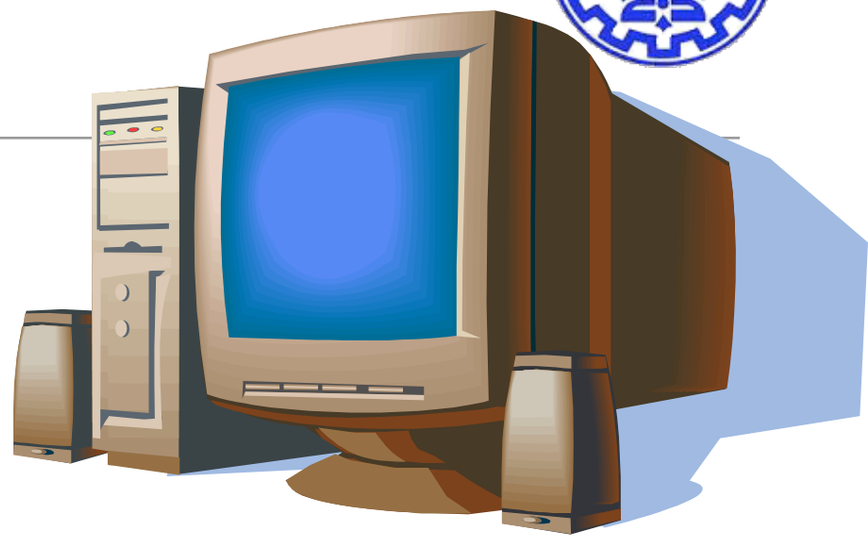


Open Questions:

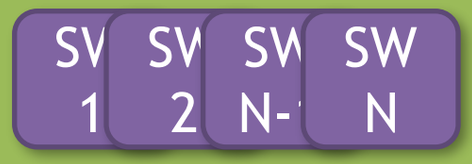
[Parno'10]

Human Factors



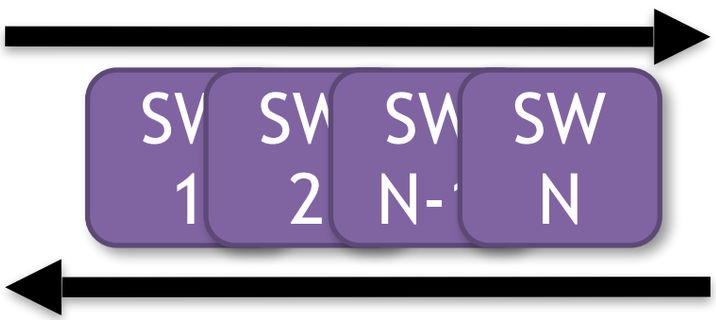


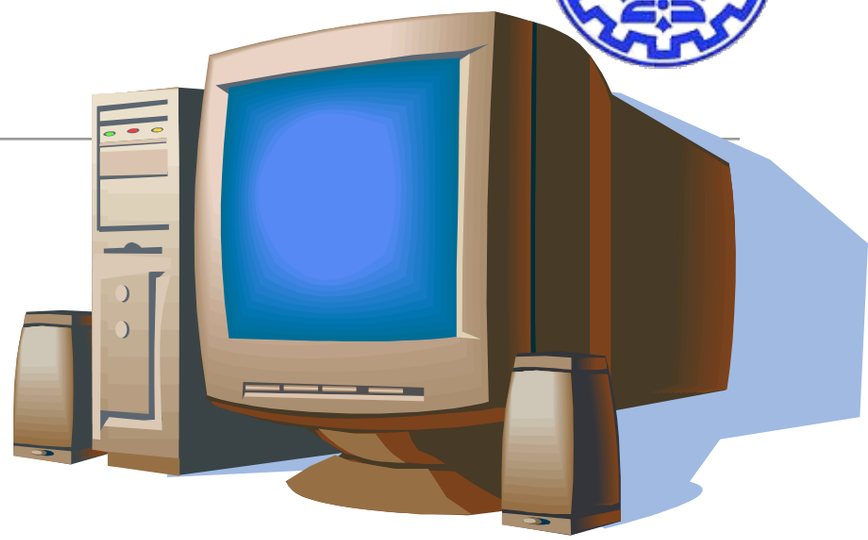
Open Questions:

How should 

be communicated to Alice?

Human Factors





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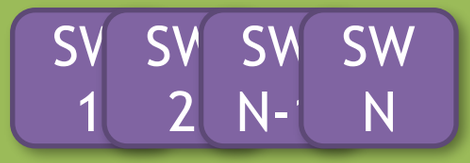
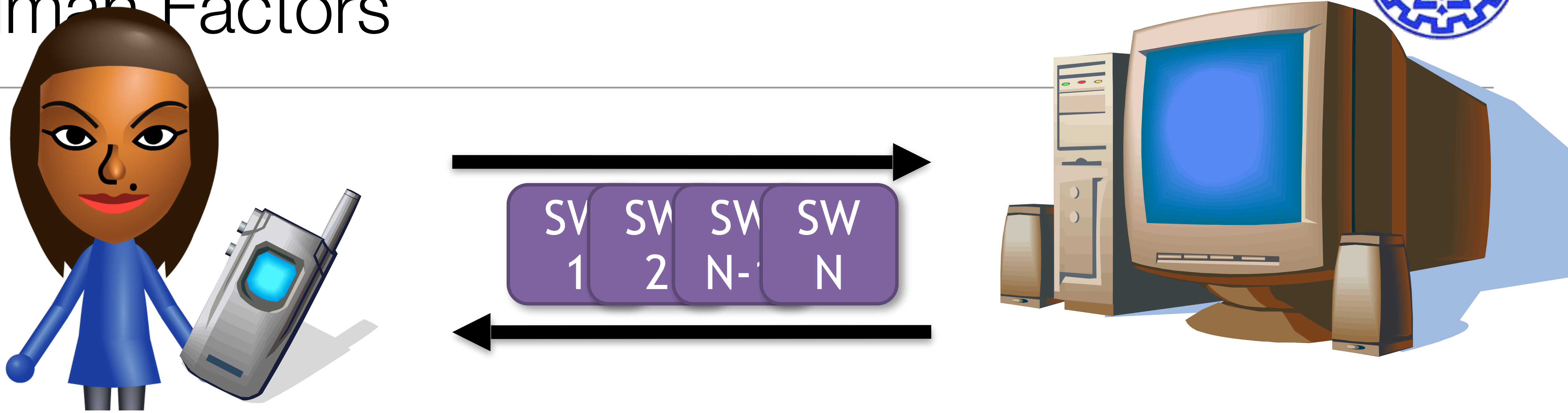
How should 

be communicated to Alice?

What does Alice do with a failed attestation?

Human Factors



Open Questions:

How should  be communicated to Alice?

What does Alice do with a failed attestation?

How can Alice trust her device?

[Parno'10]

Conclusions

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- **Code identity** is critical to bootstrapping trust

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A Bad Dream: Subverting Trusted Platform Module

While You Are Sleeping, Seunghun Han, Wook Shin, Jun-Hyeok Park, and HyoungChun Kim, Usenix Security 2018

Trusted Computing Group (TCG)

- Defines global industry specifications and standards
- Is supportive of a hardware root of trust
  - Trusted Platform Module (TPM) is the core technology
  - TCG technology has been applied to Unified Extensible Firmware Interface (UEFI)

Trusted Platform Module (TPM) (1)

- Is a tamper-resistant device
- Has own processor, RAM, ROM, and non-volatile RAM
  - It has own state separated from the system
- Provides cryptographic and accumulating measurements functions
  - Measurement values are accumulated to Platform Configuration Registers (PCR #0~#23)

Trusted Platform Module (TPM) (2)

- Is used to determine the trustworthiness of a system by investigating the values stored in PCRs
  - A local verification or remote attestation can be used
- Is used to limit access to secret data based on specific PCR values
  - “Seal” operation encrypts secret data with the PCRs of the TPM
  - “Unseal” operation can decrypt the sealed data only if the PCR values match the specific values

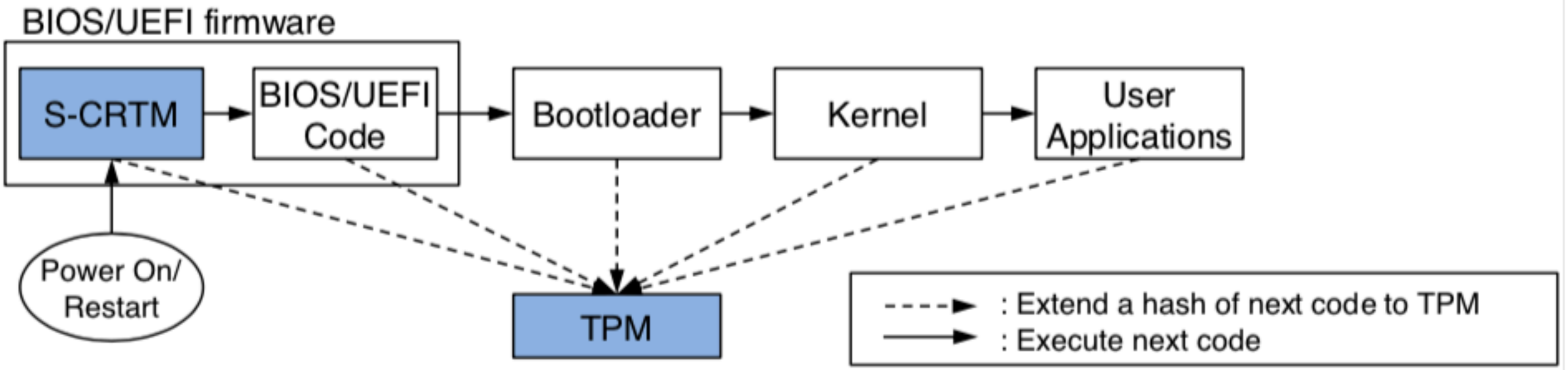
Root of Trust for Measurement (RTM)

- Sends integrity-relevant information (measurements) to the TPM
  - TPM accumulates the measurements to a PCR with the previously stored value in the PCR
    - **Extend: PCRnew = Hash(PCRold || Measurementnew)**
- The CPU controlled by Core RTM (CRTM)
  - The CRTM is the first set of instructions when a new chain of trust is established

Static and Dynamic RTM (SRTM and DRTM)

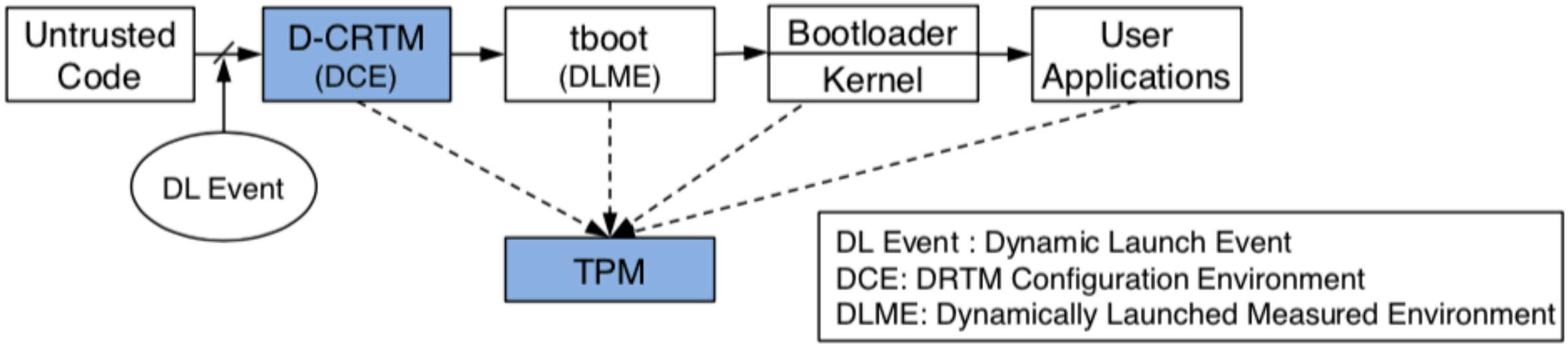
- SRTM is started by static CRTM (S-CRTM) when the host platform starts at **POWER-ON** or **RESTART**
- DRTM is started by dynamic CRTM (D-CRTM) at runtime **WITHOUT** platform **RESET**
- They extend measurements (hashes) of components to PCRs **BEFORE** passing control to them

Static Root of Trust for Measurement



Dynamic Root of Trust for Measurement

(Intel Trusted Execution Technology)



PCR Protection

- PCRs contains measurement results of a system
- They **MUST NOT** be reset by disallowed operations
  - Static PCRs (PCR #0~#15) can be reset only if the host resets
  - Dynamic PCRs (PCR #17~#19) can be reset only if the host initializes the DRTM
- If PCRs are reset by attackers, they can reproduce specific PCR values by replaying hashes
  - They can steal the secret and deceive the local and remote
- verification

PCR protection mechanisms work properly

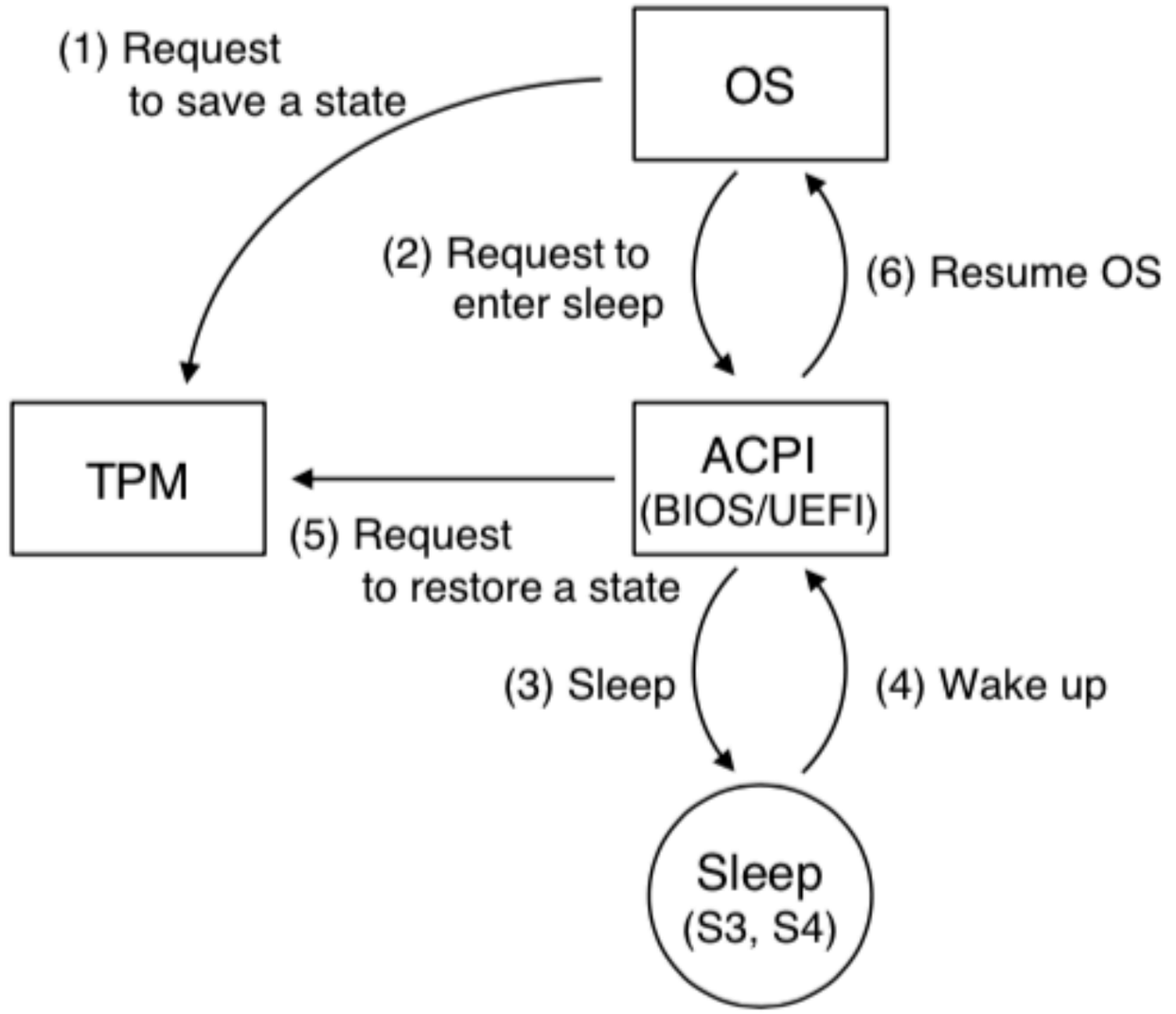
UNTIL YESTERDAY

Assumptions and Threat Model

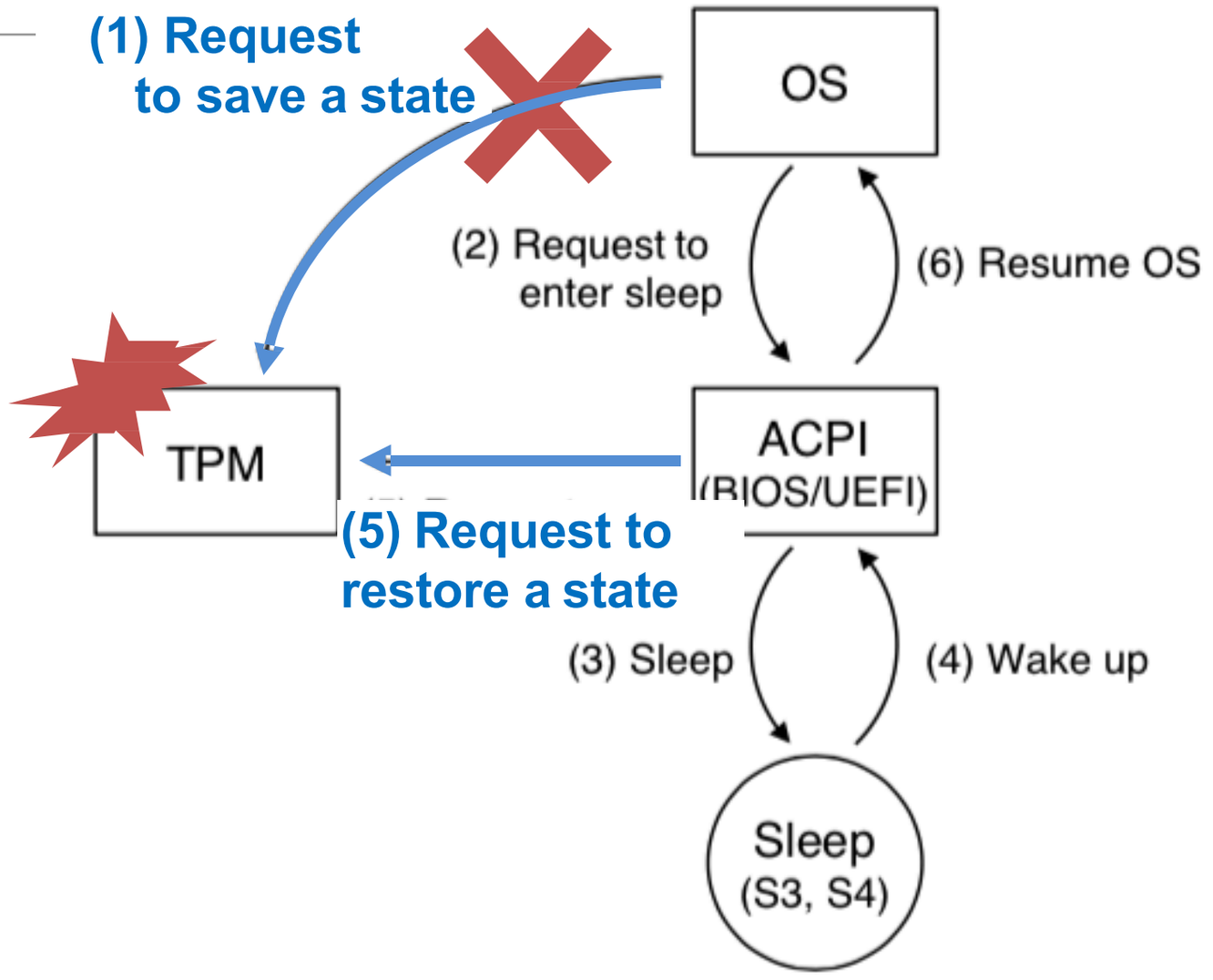
- The system measures boot components using the SRTM and DRTM
  - The measurement results stored in PCRs are verified by a remote verifier
  - The modifications of boot components are detected
- The attackers already gain a root privilege and try to compromise the whole system
  - They try to hide the breach and retain the root privilege
  - They cannot access the system circuit physically
  - They cannot flash the firmware with arbitrary code

Advanced Configuration and Power Interface (ACPI)

- Defines power states and hardware register sets
  - Global states
    - G0 (Working), G1 (Sleeping), G2 (Soft-off), G3 (Mechanical-off)
  - Sleeping states
    - S0: Working
    - S1: Power on Suspend (CPU cache flushed, CPU stops execution)
    - S2: Same as S1, CPU is powered off
    - S3: Sleep, **All devices are powered off except RAM**
    - S4: Hibernation, All devices are powered off



ACPI Sleep Process with TPM



The Grey Area vulnerability (CVE-2018-6622)

The Grey Area Vulnerability (CVE-2018-6622)

What is the "corrective action"?

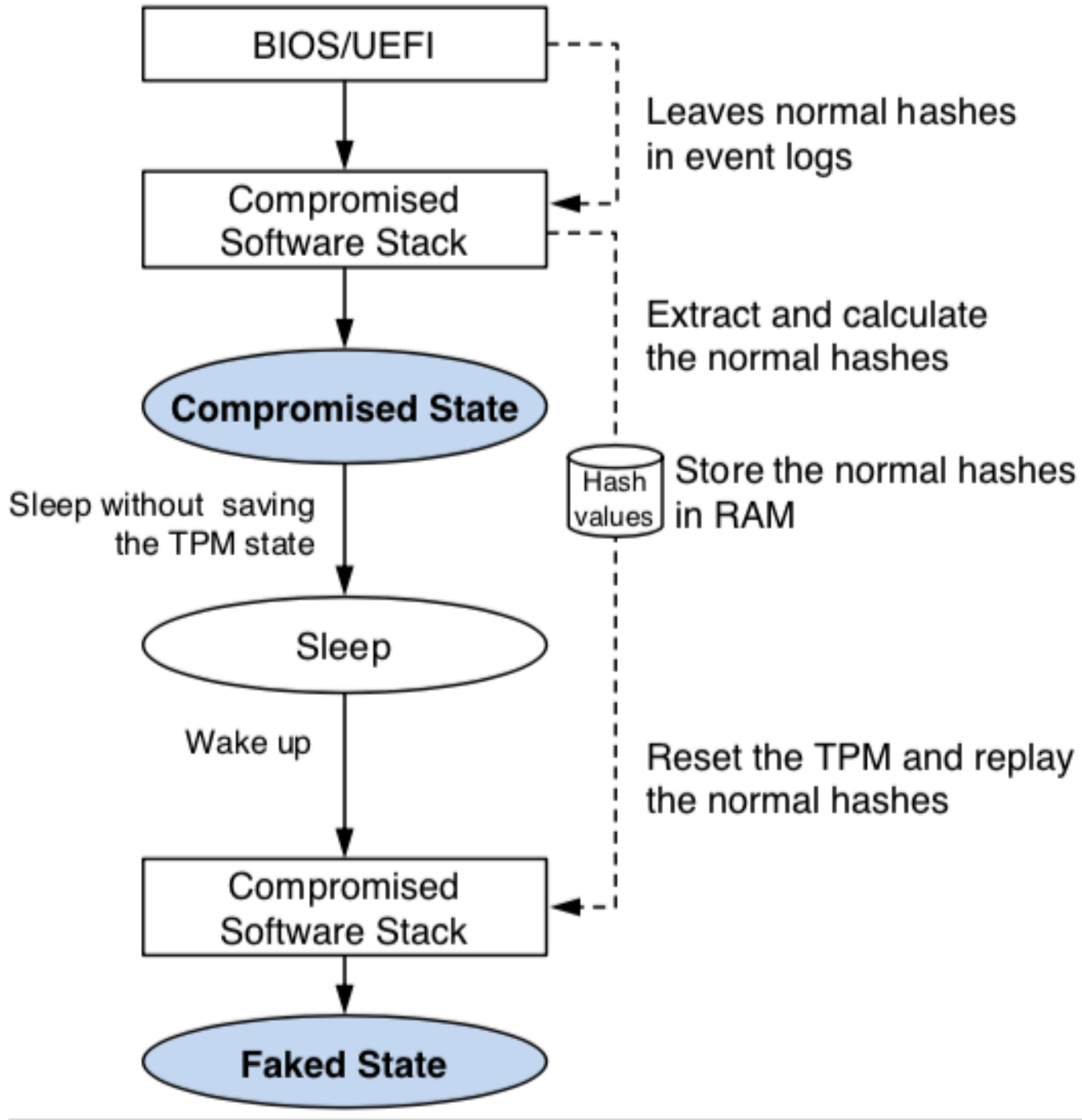
If the TPM receives Startup(STATE) that was not preceded by Shutdown(STATE), then there is no state to restore and the TPM will return TPM_RC_VALUE. The CRTM is expected to take corrective action to prevent malicious software from manipulating the PCR values such that they would misrepresent the state of the platform. The CRTM would abort the Startup(State) and restart with Startup(CLEAR).

This means "reset the TPM"

The startup behavior defined by this specification is different than TPM 1.2 with respect to Startup(STATE). A TPM 1.2 device will enter Failure Mode if no state is available when the TPM receives Startup(STATE). This is not the case in this specification. It is up to the CRTM to take corrective action if it the TPM returns TPM_RC_VALUE in response to Startup(STATE).

Trusted Platform Module Library Part1: Architecture

Exploit of the Grey Area Vulnerability



Evaluation – The Grey Area Vulnerability

PC No.	Vendor	CPU (Intel)	PC and mainboard model	BIOS Ver. and release date	TPM Ver.	TPM vendor and firmware Ver.	SRTM attack
1	Intel	Core i5-5300U	NUC5i5MYHE	MYBDEWi5v.86A, 2017.11.30	2.0	Infineon, 5.40	Y
2	Intel	Core m5-6Y57	Compute Stick STK2mv64CC	CCSKLm5v.86A.0054, 2017.12.26	2.0	NTC, 1.3.0.1	Y
3	Dell	Core i5-6500T	Optiplex 7040	1.8.1, 2018.01.09	2.0	NTC, 1.3.2.8	Y
4	GIGABYTE	Core i7-6700	Q170M-MK	F23c, 2018.01.11	2.0	Infineon, 5.51	Y
5	GIGABYTE	Core i7-6700	H170-D3HP	F20e, 2018.01.10	2.0	Infineon, 5.61	Y
6	ASUS	Core i7-6700	Q170M-C	3601, 2017.12.12	2.0	Infineon, 5.51	Y
7	Lenovo	Core i7-6600U	X1 Carbon 4th Generation	N1FET59W (1.33), 2017.12.19	1.2	Infineon, 6.40	N
8	Lenovo	Core i5-4570T	ThinkCentre m93p	FBKTCPA, 2017.12.29	1.2	STMicroelectronics, 13.12	N
9	Dell	Core i5-6500T	Optiplex 7040	1.8.1, 2018.01.09	1.2	NTC, 5.81.2.1	N
10	HP	Xeon E5-2690 v4	z840	M60 v02.38, 2017.11.08	1.2	Infineon, 4.43	N
11	GIGABYTE	Core i7-6700	H170-D3HP	F20e, 2018.01.10	1.2	Infineon, 3.19	N

Countermeasures – The Grey Area Vulnerability

- **Disable S3 sleeping state** option in BIOS menu
  - Brutal, but simple and effective
- Revise TPM 2.0 specification to **enter failure mode** if there is no state to restore
- Revise TPM 2.0 specification to **define "corrective action" in detail**
  - A long time to revise and apply to the TPM or BIOS/UEFI firmware, but fundamental solutions

Countermeasures – The Lost Pointer Vulnerability

- **Apply our patch to tboot**
  - https://sourceforge.net/p/tboot/code/ci/521c58e51eb5be105a29983742850e72c44ed80e/
- **Update tboot to the latest version**

Conclusion

- Two vulnerabilities that can subvert the TPM using S3 sleeping state were found
  - The Grey Area Vulnerability: CVE-2018-6622
  - The Lost Pointer Vulnerability: CVE-2017-16837
- Attackers can deceive the local and remote verification with the vulnerabilities
  - They also can unseal the seal secret and steal it
- We have contacted manufacturers and contributed a patch to tboot project to solve the vulnerabilities

Acknowledgments/References

- [Parno'10] Bootstrapping Trust in Commodity Computers, Bryan Parno, Jonathan McCune, Adrian Perrig, Slides IEEE S&P, 2010
- [Han'18] A Bad Dream: Subverting Trusted Platform Module While You Are Sleeping, Seunghun Han, Wook Shin, Jun-Hyeok Park, and HyoungChun Kim, Slides, Usenix Security 2018