CaSE: Cache-Assisted Secure Execution on ARM Processors

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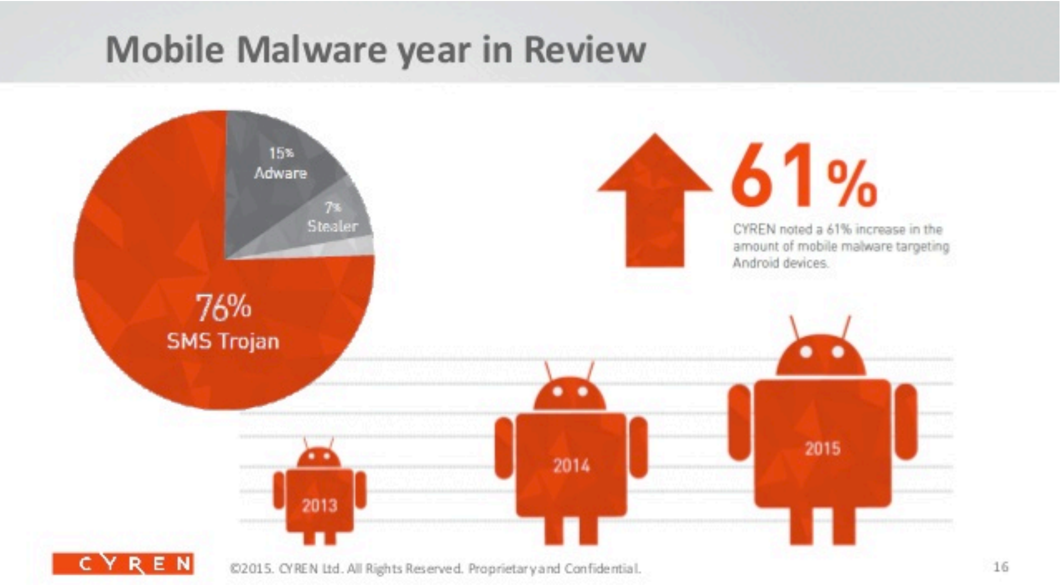
Talk Outline

- ✓ Motivation and Background – Why this work ?
- ✓ Threat Model – What are we defending against ?
- ✓ CaSE: Cache-Assisted Secure Execution – How does it work?
- ✓ CaSE highlight – Challenges ?
- ✓ Evaluation – How did we do ?
- ✓ Conclusion and future Work

Threat to Mobile devices



Mobile Malware year in Review

61%

CYREN noted a 61% increase in the amount of mobile malware targeting Android devices.

CYREN

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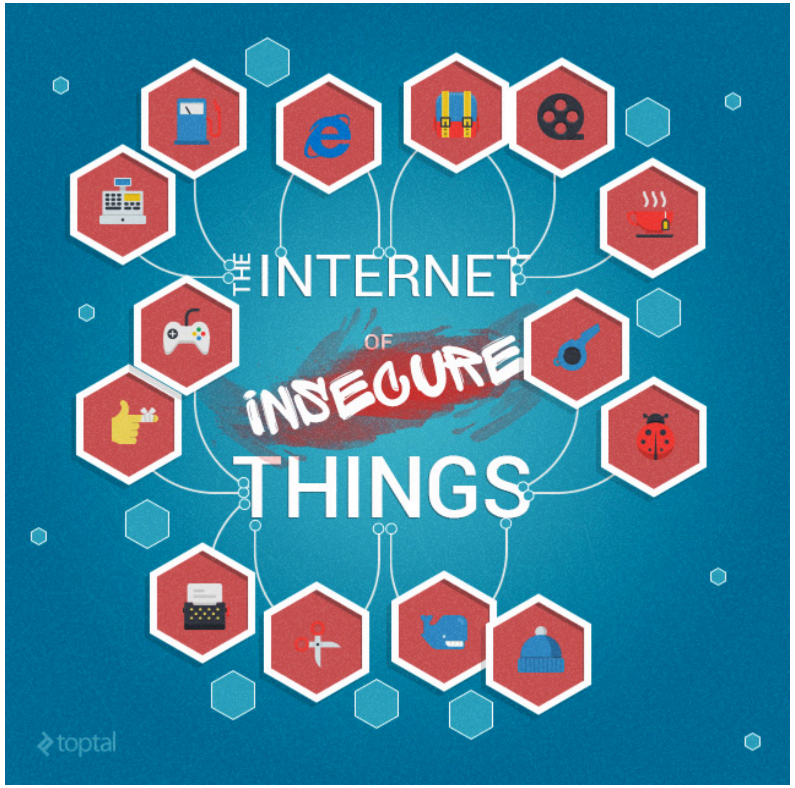
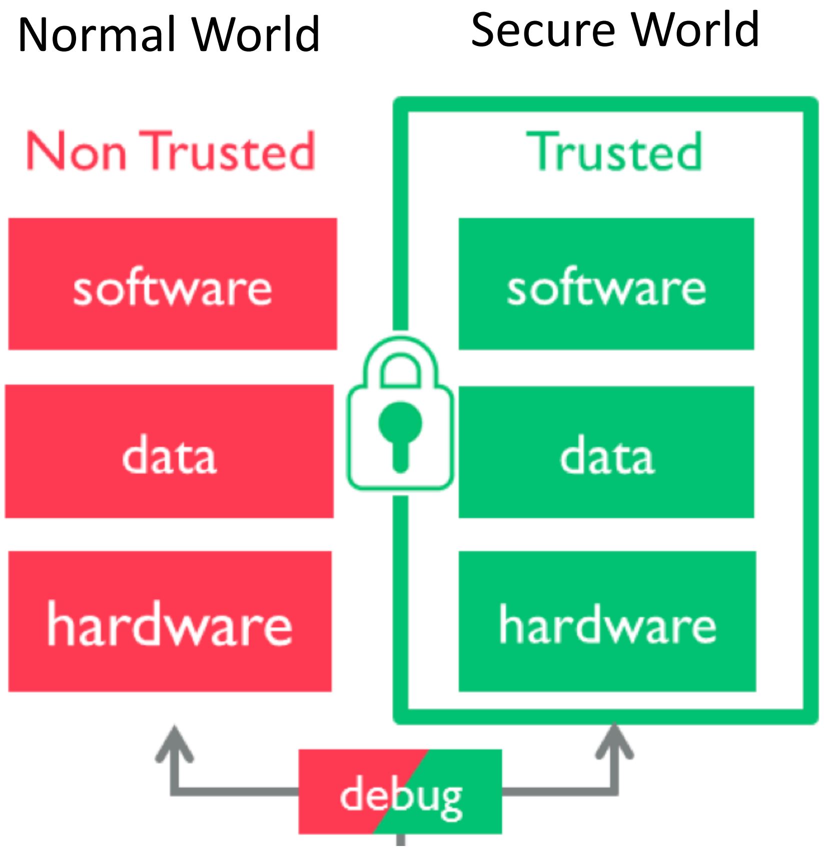


ARM TrustZone – Trusted Execution Environment (TEE)

System Wide Protection

- ✓Divides system resources into two worlds
- ✓Normal World runs the content rich OS
- ✓Secure World runs security critical services
- ✓The protection of resources includes
  - processor, memory and IO devices



Many Products use ARM TrustZone

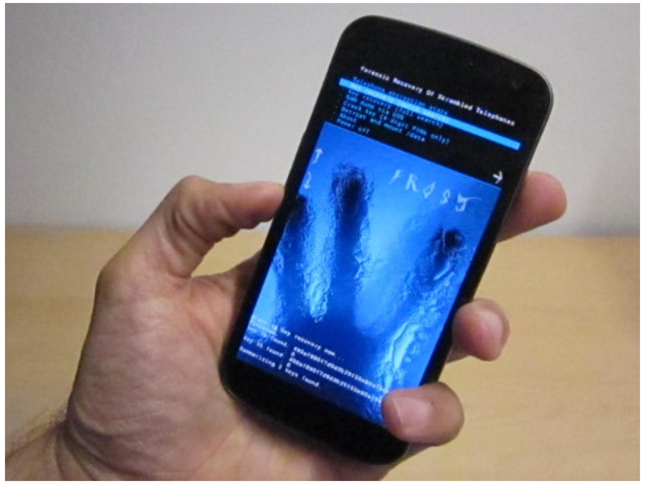
Samsung Knox

TRUSTONIC

sierraware

Smart Devices Going Mobile

Hardware Attacks - Cold Boot Attack


Forensic Recovery Of Scrambled Telephones
RAM Dump via USB
Crack key (4 digit PINs only)
Decrypt and mount /data
About
Power off
FROST

Previous Works on Coldboot Defense

TRESOR	Sec	2011 – Register-based RAM-less AES encryption
Copker	NDSS	2014 – Cache-based RAM-less RSA encryption
PixelVault	CCS	2014 – GPU based RAM-less encryption
Sentry	ASPLOS	2015 – Cache-based RAM-less encryption
Mimosa	S&P	2015 – Transactional-based RAM-less encryption

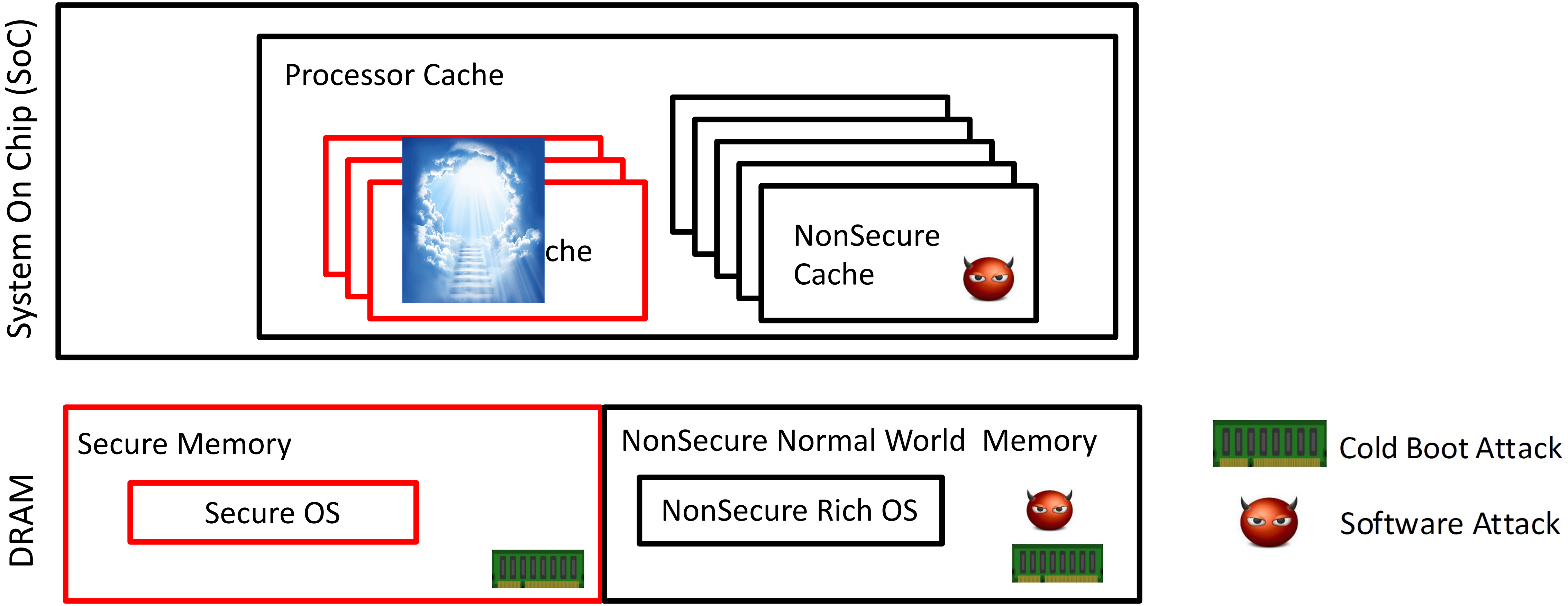
Multi-vector Adversary

Introducing CaSE - Goals

- ✓Defense against Multi-Vector adversary
  - ✓Physical memory disclosure attack – Cold boot
  - ✓Compromised rich OS

- ✓Provide confidentiality and integrity to both the code and data of the binaries in TEE
  - ✓Confidentiality – Protects IP, secret code, sensitive data
  - ✓Integrity – Program behavior

Threat Model



System On Chip (SoC)

Processor Cache

che

NonSecure Cache

DRAM

Secure Memory

Secure OS

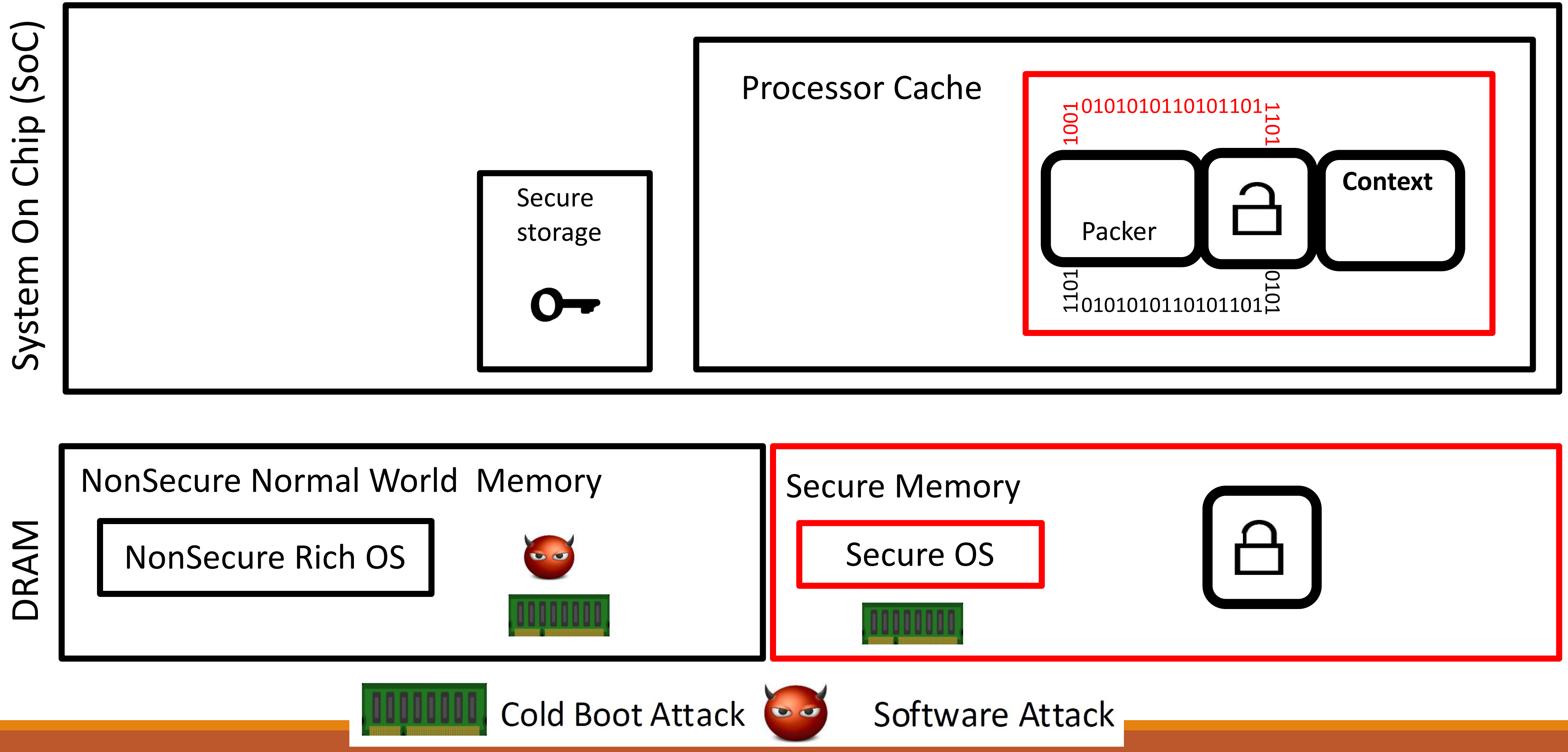
NonSecure Normal World Memory

NonSecure Rich OS

Cold Boot Attack

Software Attack

Case-Assisted Execution in Secure World



System On Chip (SoC)

Secure storage

Processor Cache

1001 0101010110101101 1101

Packer

Context

1101 0101010110101101 0101

DRAM

NonSecure Normal World Memory

NonSecure Rich OS

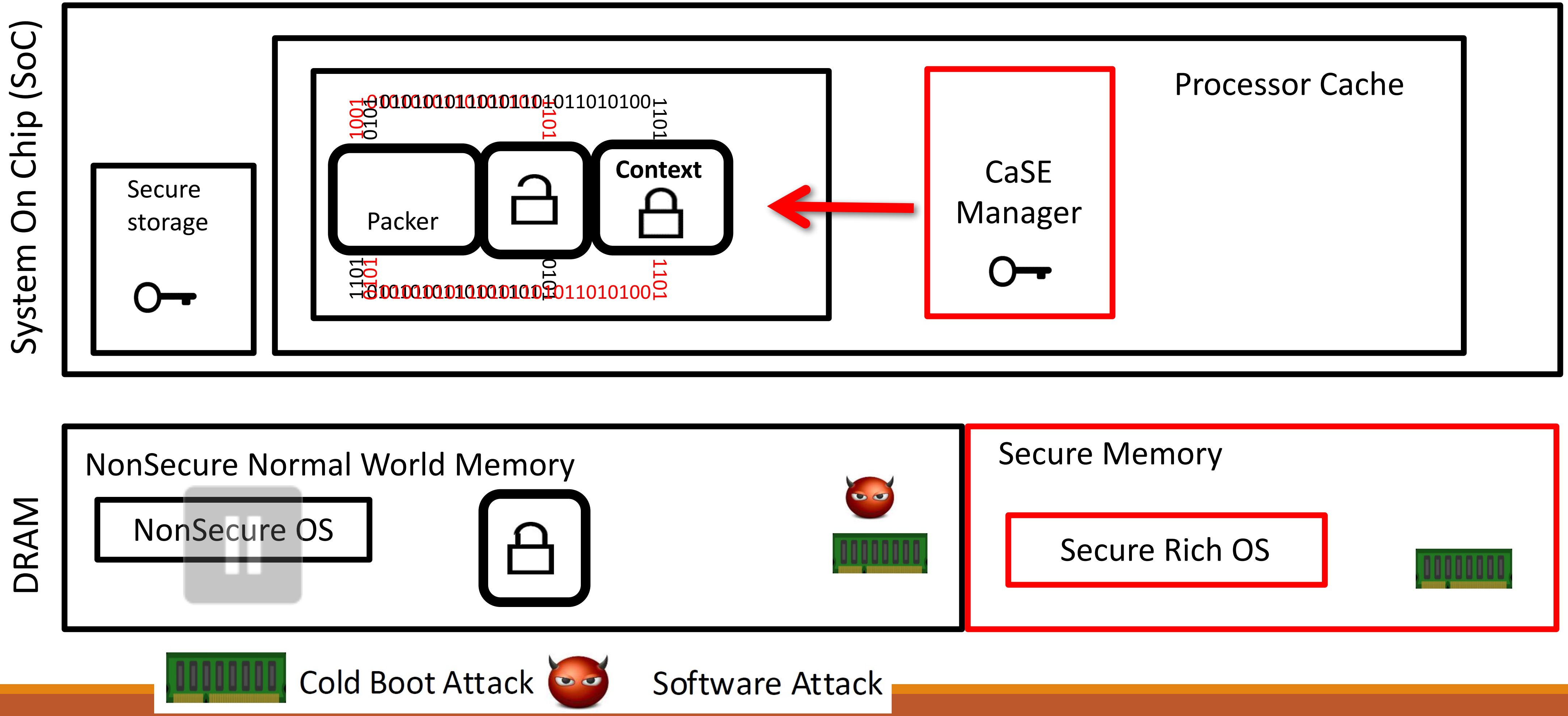
Secure Memory

Secure OS

Cold Boot Attack

Software Attack

Case-Assisted Execution in Normal World



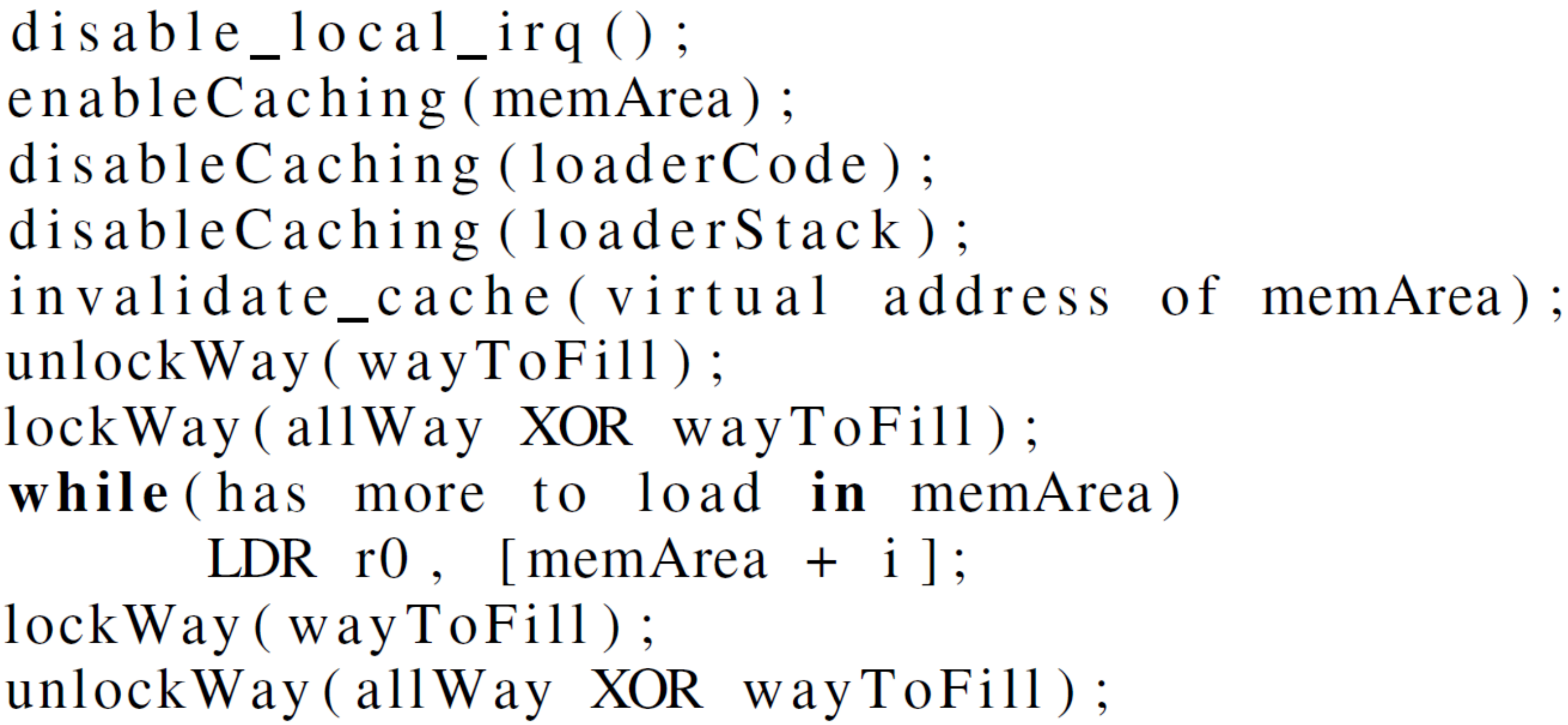
Controlling the Cache

- ✓Cache Locking is available through L2 cache lockdown CP15 coprocessor

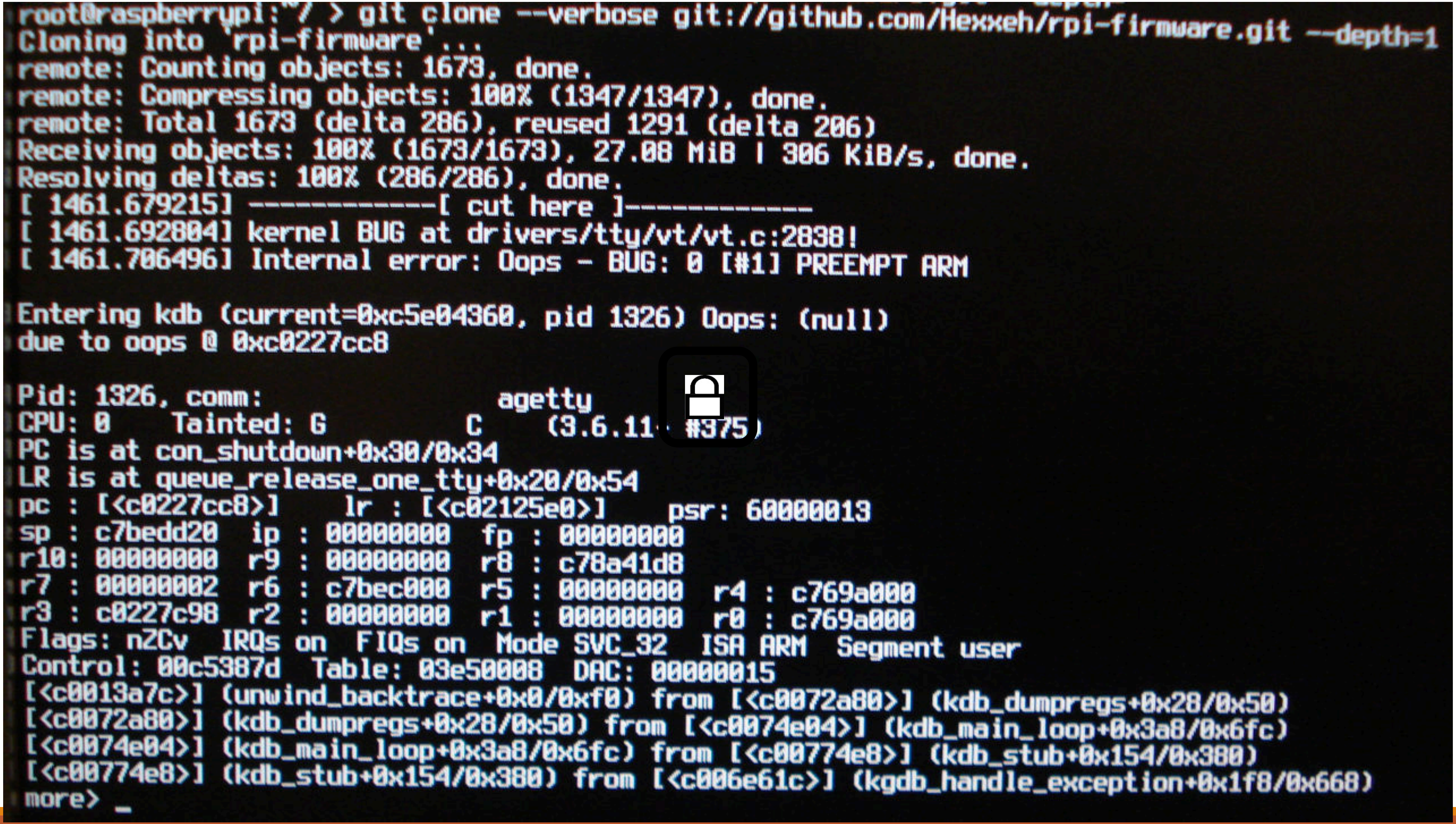
- ✓The granularity of locking is per cache way

- ✓On Cortex-A8, which has 8 way total 256KB L2 unified cache

SoC-Bound Execution – Cache Locking

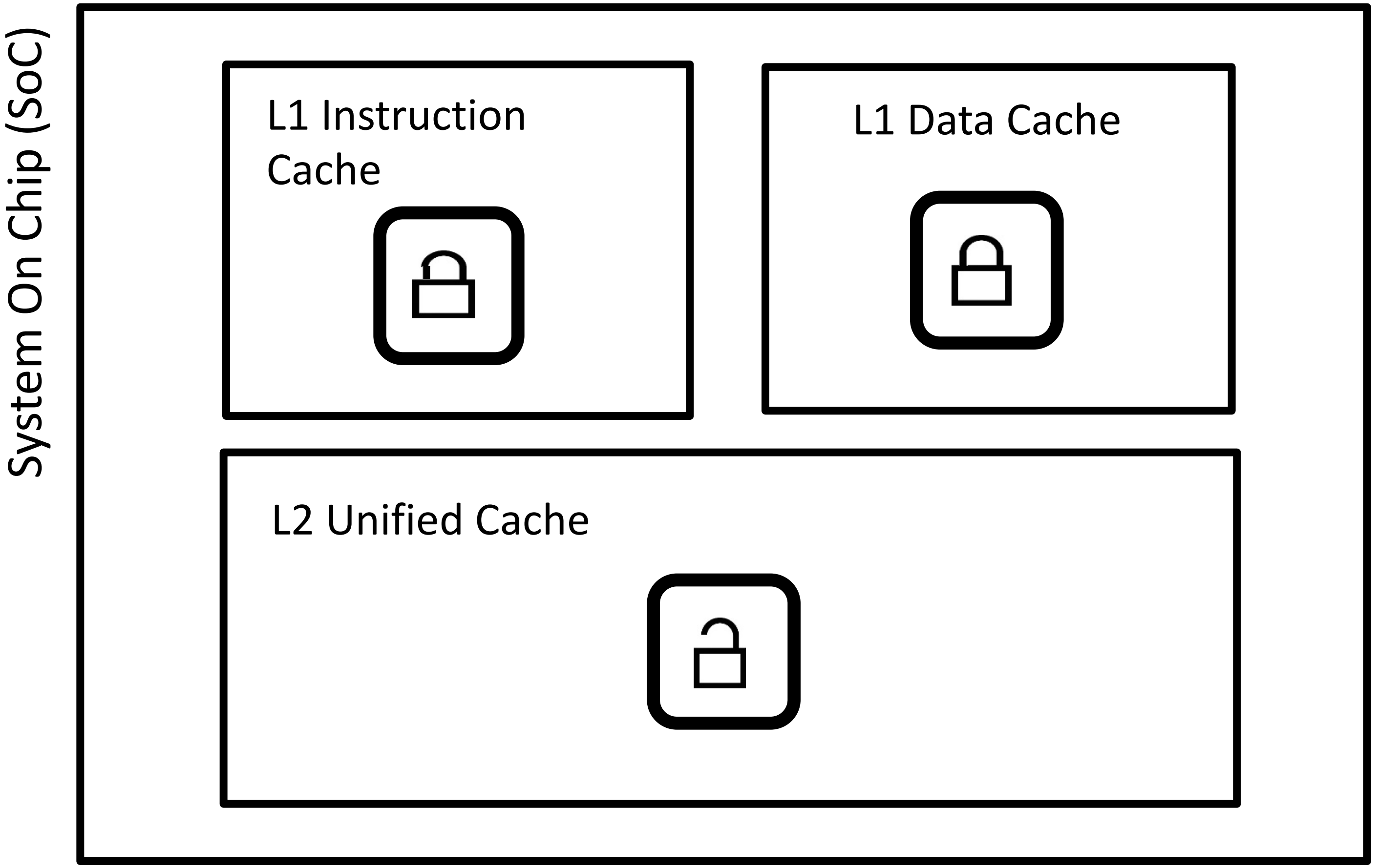


```
disable_local_irq();
enableCaching(memArea);
disableCaching(loaderCode);
disableCaching(loaderStack);
invalidate_cache(virtual address of memArea);
unlockWay(wayToFill);
lockWay(allWay XOR wayToFill);
while(has more to load in memArea)
        LDR r0, [memArea + i];
lockWay(wayToFill);
unlockWay(allWay XOR wayToFill);
```

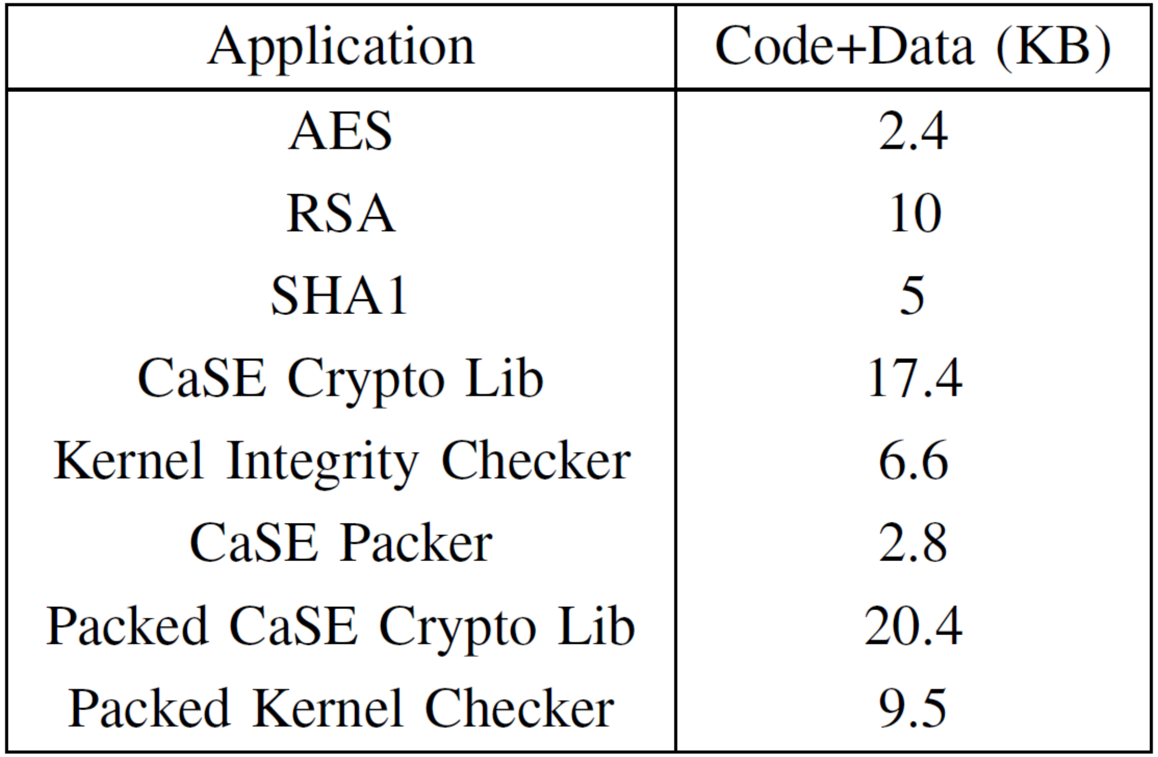


```
root@raspberrypi:~/ > git clone --verbose git://github.com/Hexxeh/rpi-firmware.git --depth=1
Cloning into 'rpi-firmware'...
remote: Counting objects: 1673, done.
remote: Compressing objects: 100% (1347/1347), done.
remote: Total 1673 (delta 286), reused 1291 (delta 206)
Receiving objects: 100% (1673/1673), 27.08 MiB | 306 KiB/s, done.
Resolving deltas: 100% (286/286), done.
[ 1461.679215] ------------[ cut here ]------------
[ 1461.692804] kernel BUG at drivers/tty/vt/vt.c:2838!
[ 1461.706496] Internal error: Oops - BUG: 0 [#1] PREEMPT ARM

Entering kdb (current=0xc5e04360, pid 1326) Oops: (null)
due to oops @ 0xc0227cc8

Pid: 1326, comm:                agetty
CPU: 0    Tainted: G         C    (3.6.11 #375)
PC is at con_shutdown+0x30/0x34
LR is at queue_release_one_tty+0x20/0x54
pc : [<c0227cc8>]    lr : [<c02125e0>]    psr: 60000013
sp : c7bedd20  ip : 00000000  fp : 00000000
r10: 00000000  r9 : 00000000  r8 : c78a41d8
r7 : 00000002  r6 : c7bec000  r5 : 00000000  r4 : c769a000
r3 : c0227c98  r2 : 00000000  r1 : 00000000  r0 : c769a000
Flags: nZCv  IRQs on  FIQs on  Mode SVC_32  ISA ARM  Segment user
Control: 00c5387d  Table: 03e50008  DAC: 00000015
[<c0013a7c>] (unwind_backtrace+0x0/0xf0) from [<c0072a80>] (kdb_dumpregs+0x28/0x50)
[<c0072a80>] (kdb_dumpregs+0x28/0x50) from [<c0074e04>] (kdb_main_loop+0x3a8/0x6fc)
[<c0074e04>] (kdb_main_loop+0x3a8/0x6fc) from [<c00774e8>] (kdb_stub+0x154/0x380)
[<c00774e8>] (kdb_stub+0x154/0x380) from [<c006e61c>] (kgdb_handle_exception+0x1f8/0x668)
more> _
```

Self Modifying Program

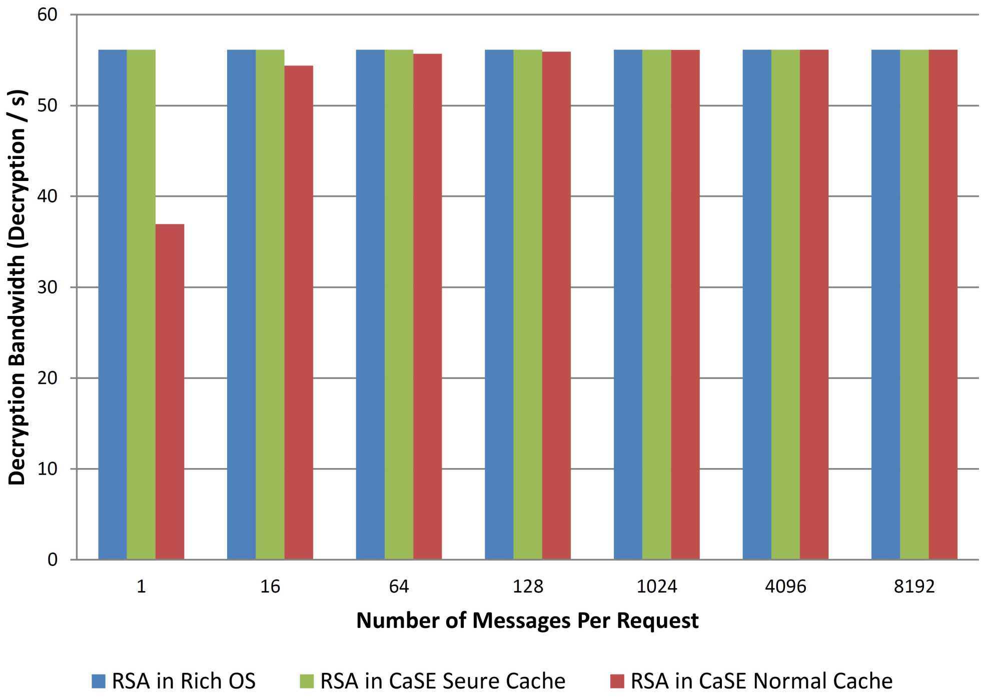


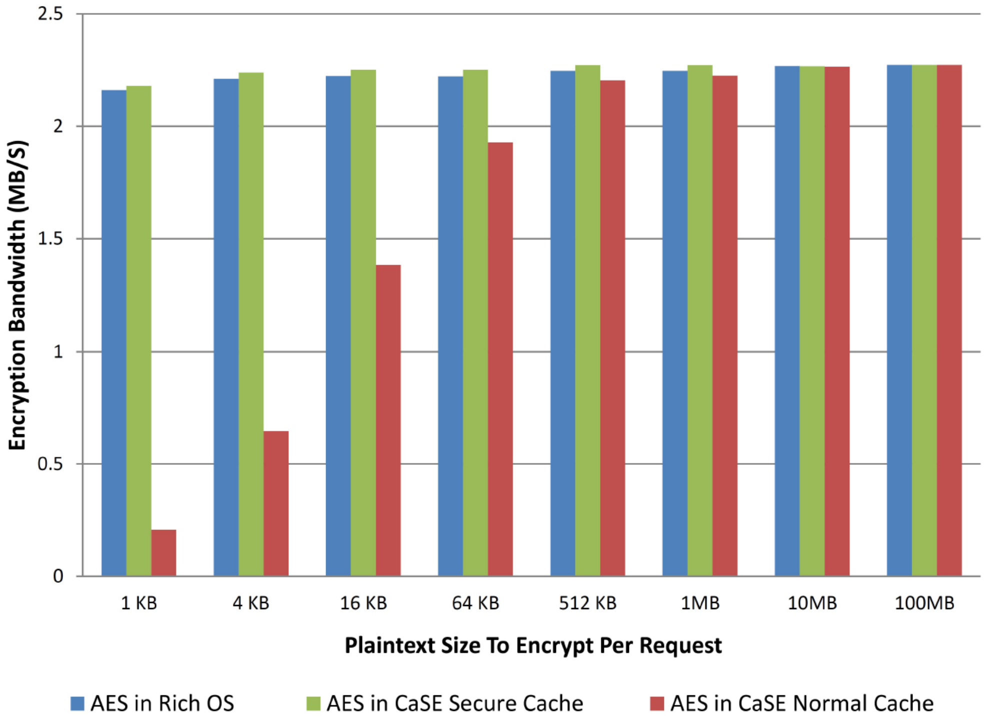
Feasibility of using Cache as Memory



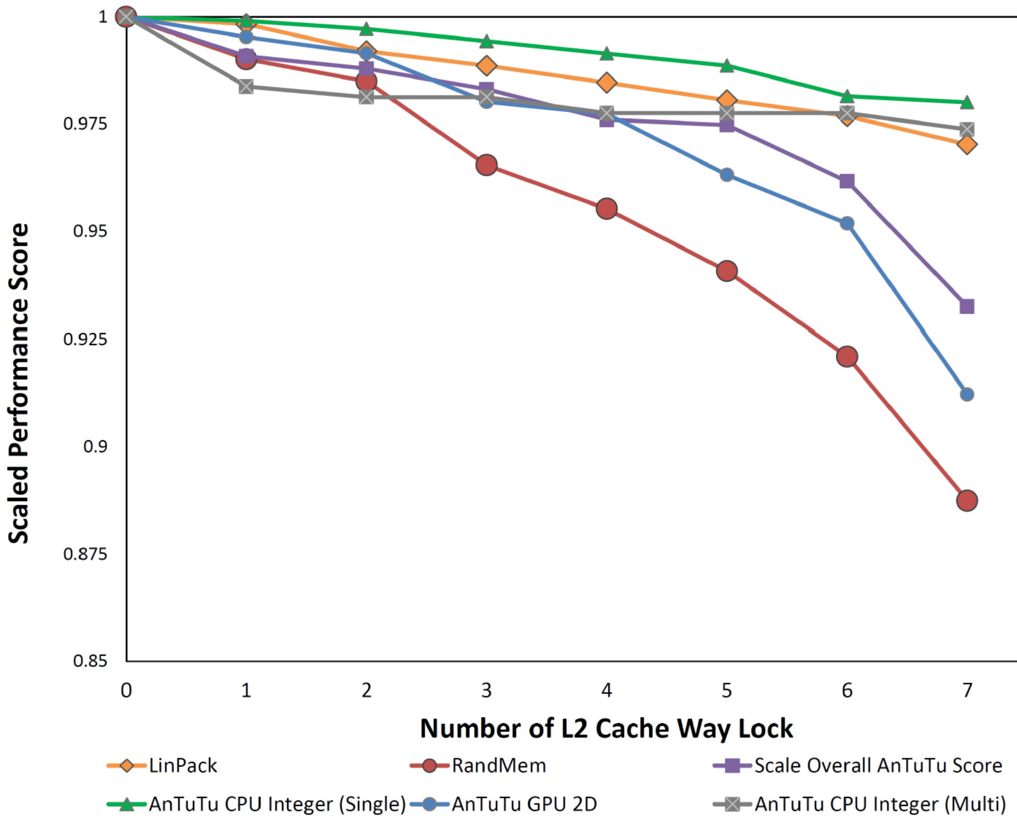
Application	Code+Data (KB)
AES	2.4
RSA	10
SHA1	5
CaSE Crypto Lib	17.4
Kernel Integrity Checker	6.6
CaSE Packer	2.8
Packed CaSE Crypto Lib	20.4
Packed Kernel Checker	9.5

Performance Impact to the Application





Performance Impact to the System



Conclusion

- ✓A secure cache-assisted SoC-bound execution framework
  - ✓Provide confidentiality and integrity to sensitive code and data of applications
  - ✓Protect against both software attacks and cold boot attack.
- ✓In the future, we would like to further study efficient method to provide OS support to the TEE.