Embedded OS for FPGA platform: a Hardware-to-Software Security Overview

Florian Devic[1,2], Lionel Torres[1] and Benoit Badrignans[2]

[1] LIRMM UMR -CNRS 5506, University of Montpellier 2, Montpellier, France
[2] SAS NETHEOS, Montpellier, France

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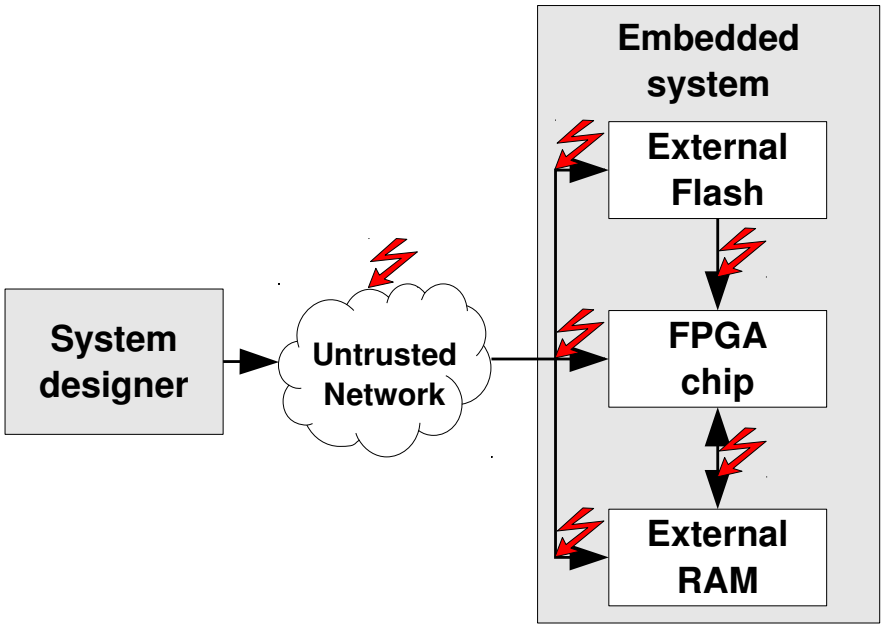
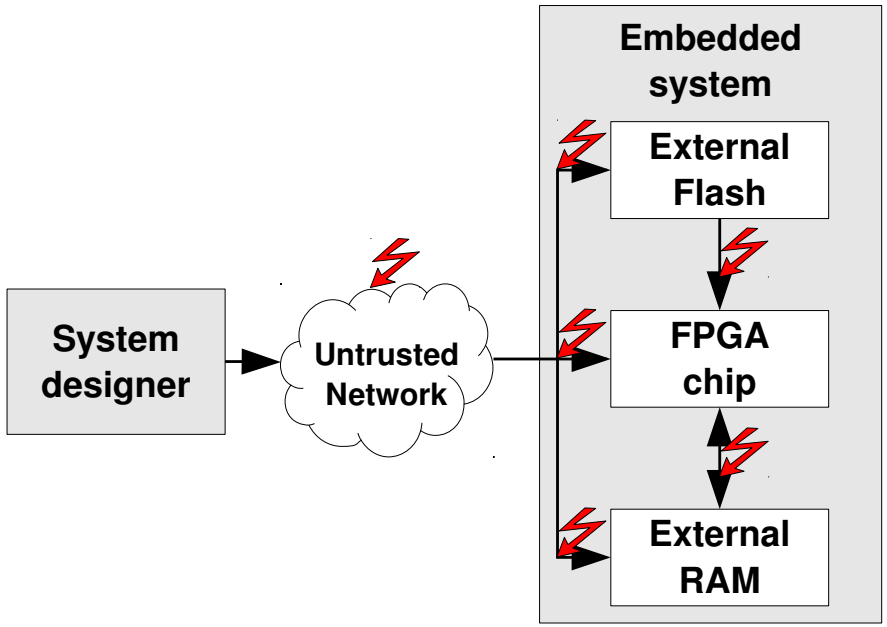


Goals

- Secure the **bitstream**, the **boot** and finally the **execution** of an embedded OS (stored in an external memory) on FPGA.
- **Upgraded** the system through an insecure network.
- Prevents an attacker to execute his own potentially **malicious program** or to **replay** an old bitstream to downgrade the system.



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→ **Man in the middle, off-chip probing and injections**

Outline

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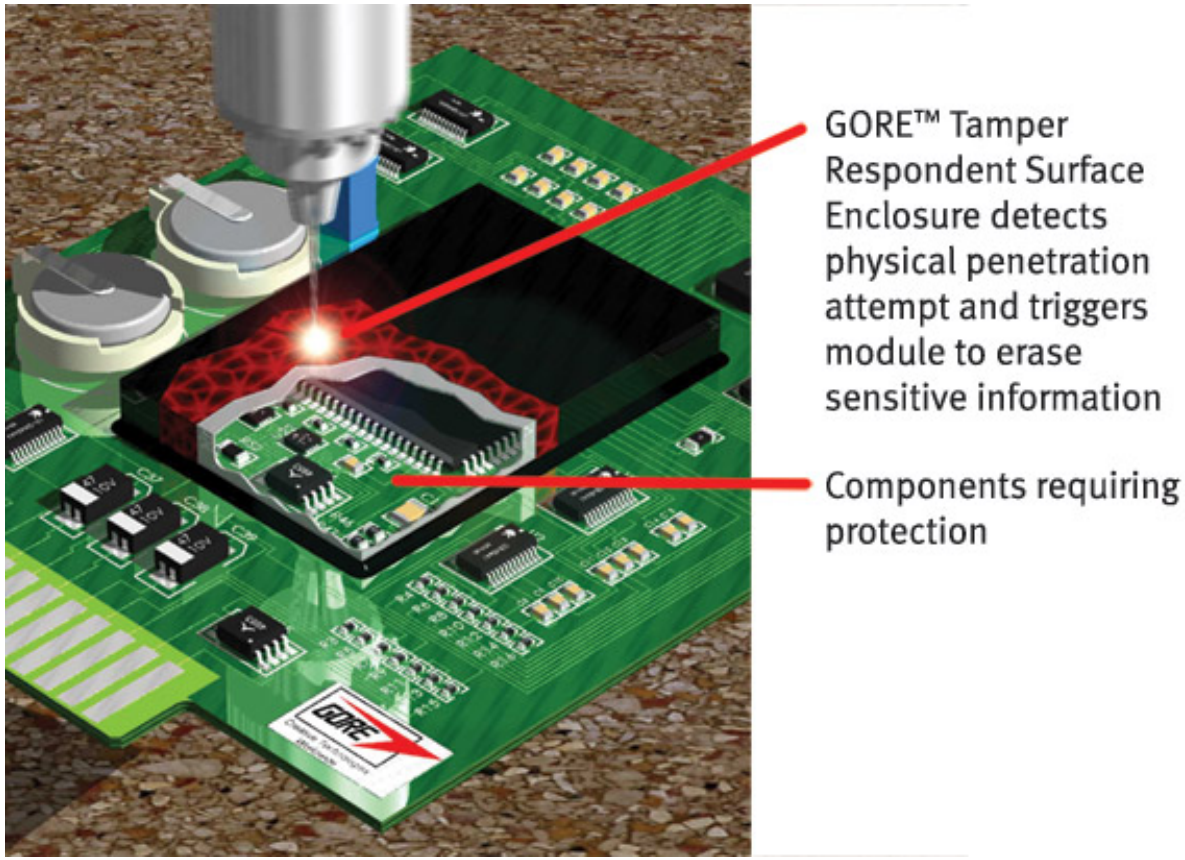
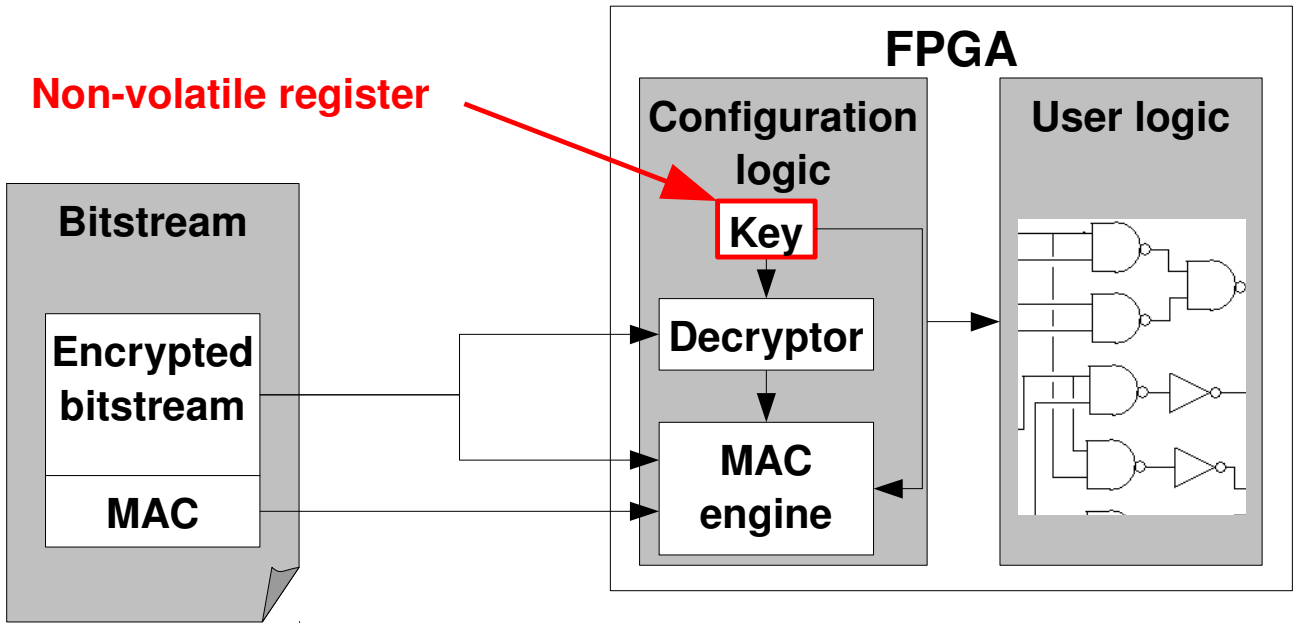
FPGA chip



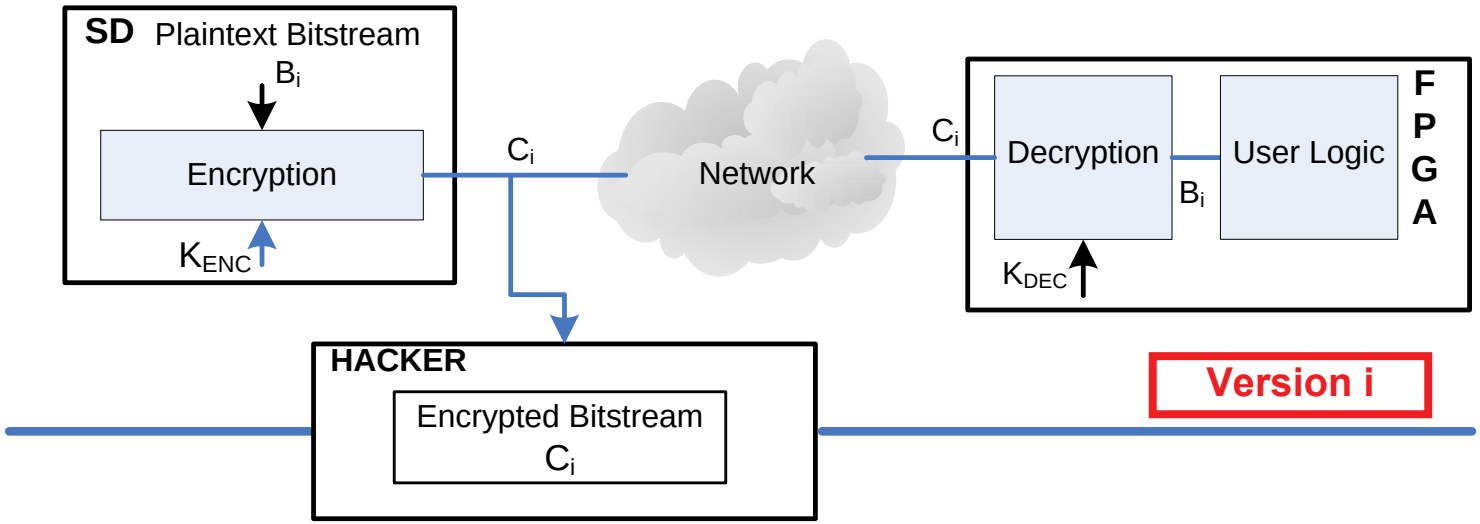
more information on http ://www.gore.com/en_xx/products/electronic/anti-tamper/tamper-surface-enclosure.html

Bitstream confidentiality and integrity



- Prevent cloning
- Prevent reverse engineering
- Prevent modifications

Replay attack



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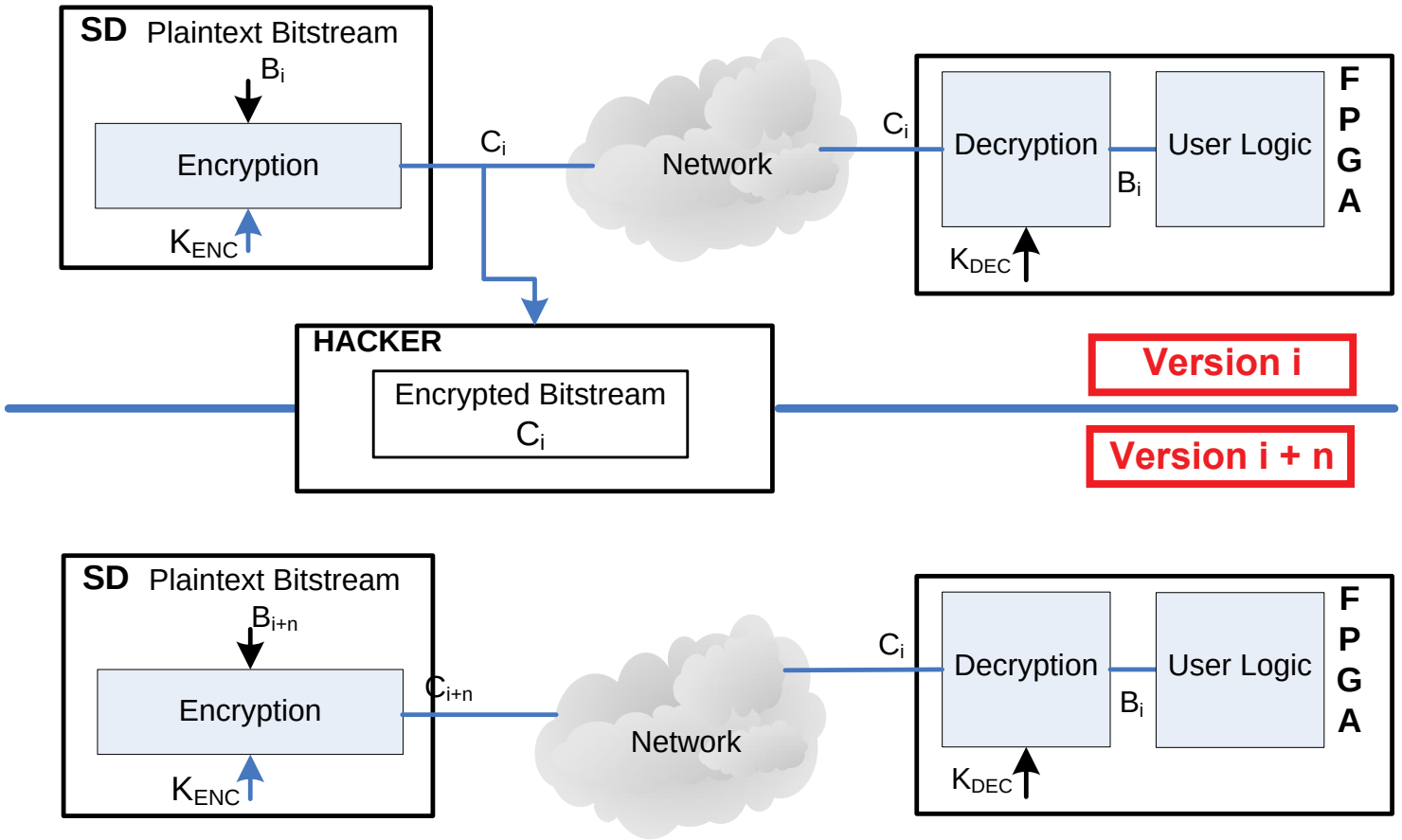

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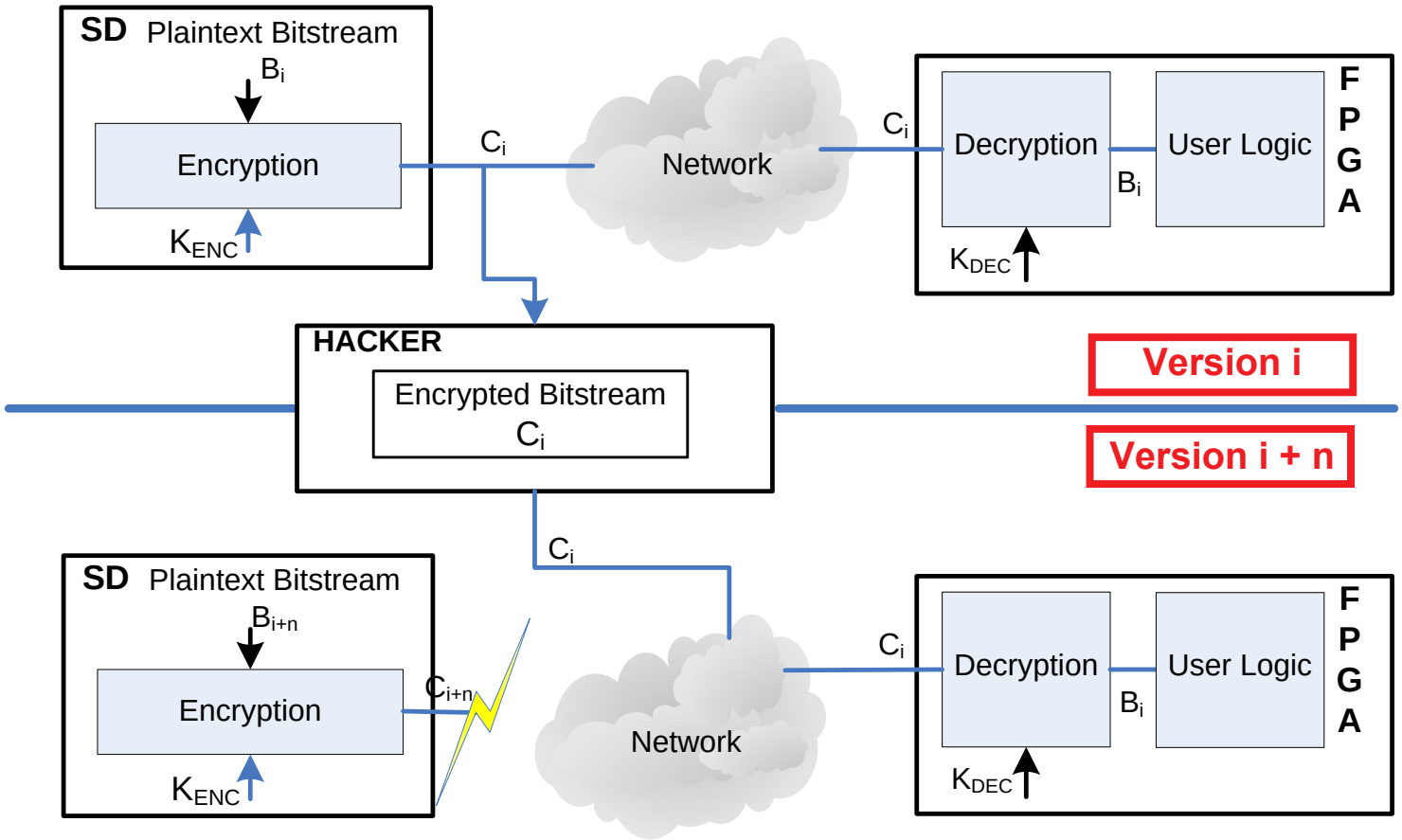
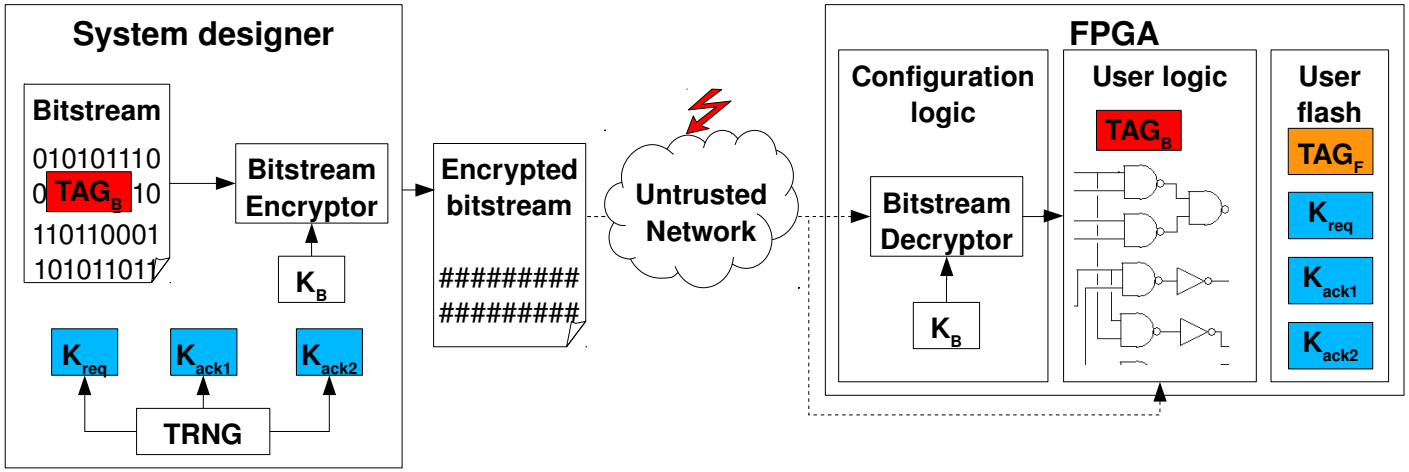


Principle with an embedded Flash



Goal : Lock the FPGA to a dedicated version

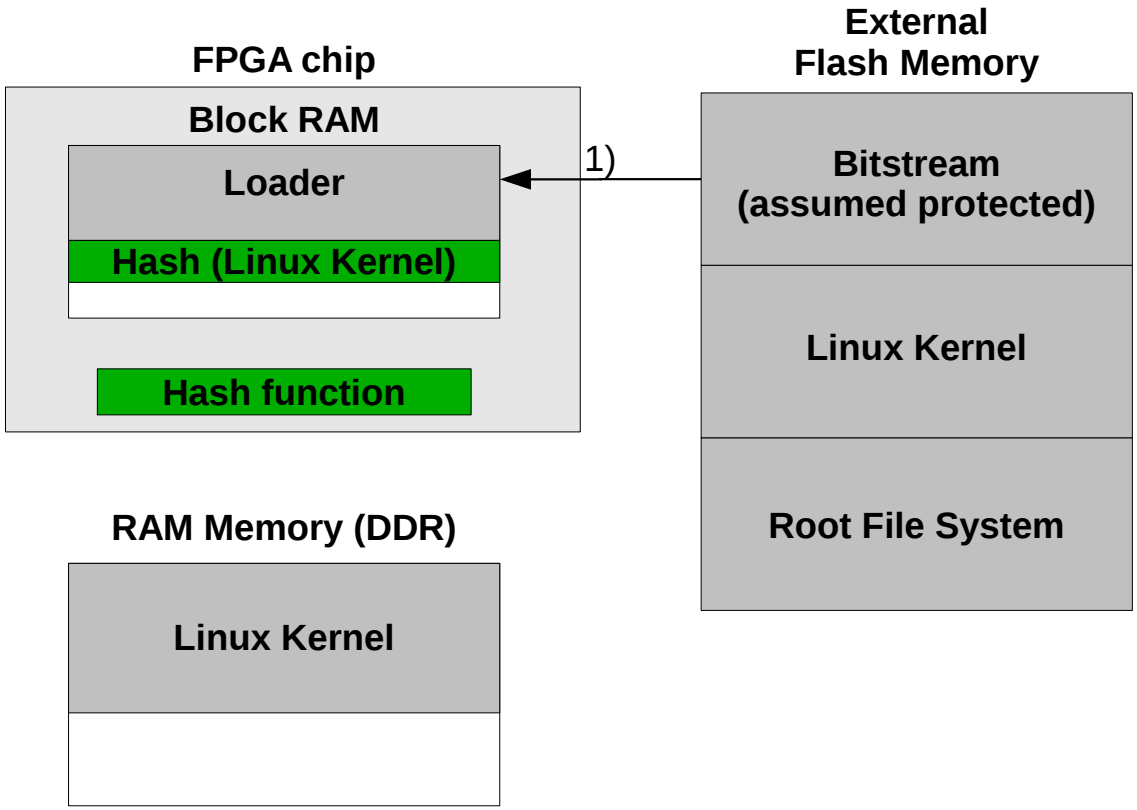
TAG_B and TAG_F are the current bitstream version

- K_{req} : for the Update command
- K_{ack1} : for the Update command acknowledgement
- K_{ack2} : for the new bitstream version startup acknowledgement

F. Devic, B. Bradrignans, and L. Torres, "Secure FPGA Configuration Architecture Preventing System Downgrade" in FPL'10

Outline

Integrity verification



Boot steps :
1) The loader is stored in block RAM at power-up from bitstream
2) The loader copies Kernel from Flash to RAM and compute its hash
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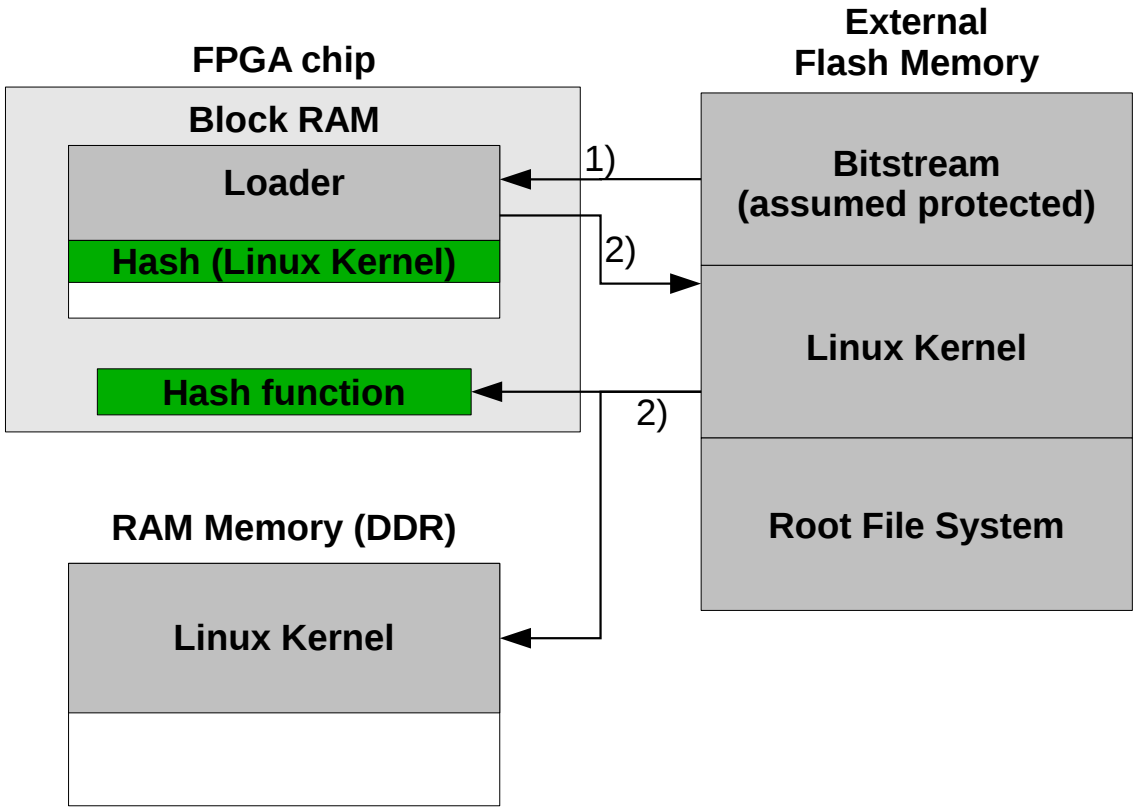
4) The loader branches to the Kernel and Linux boots

Integrity verification



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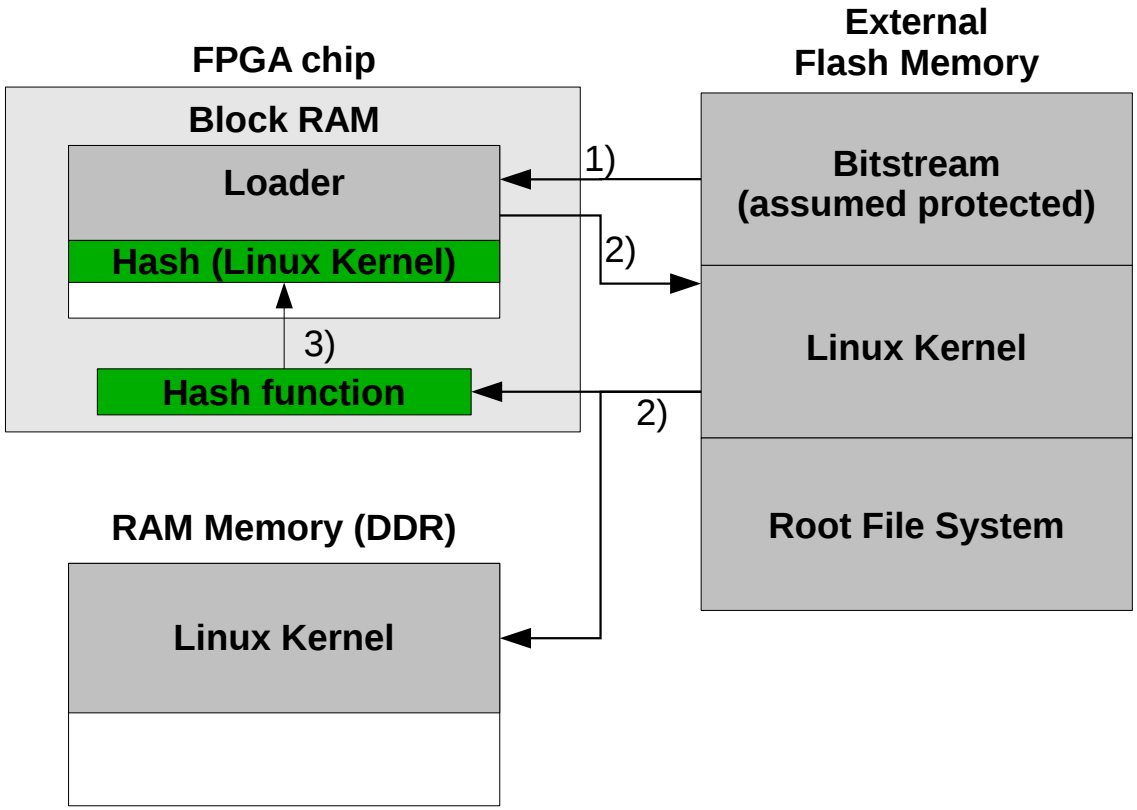

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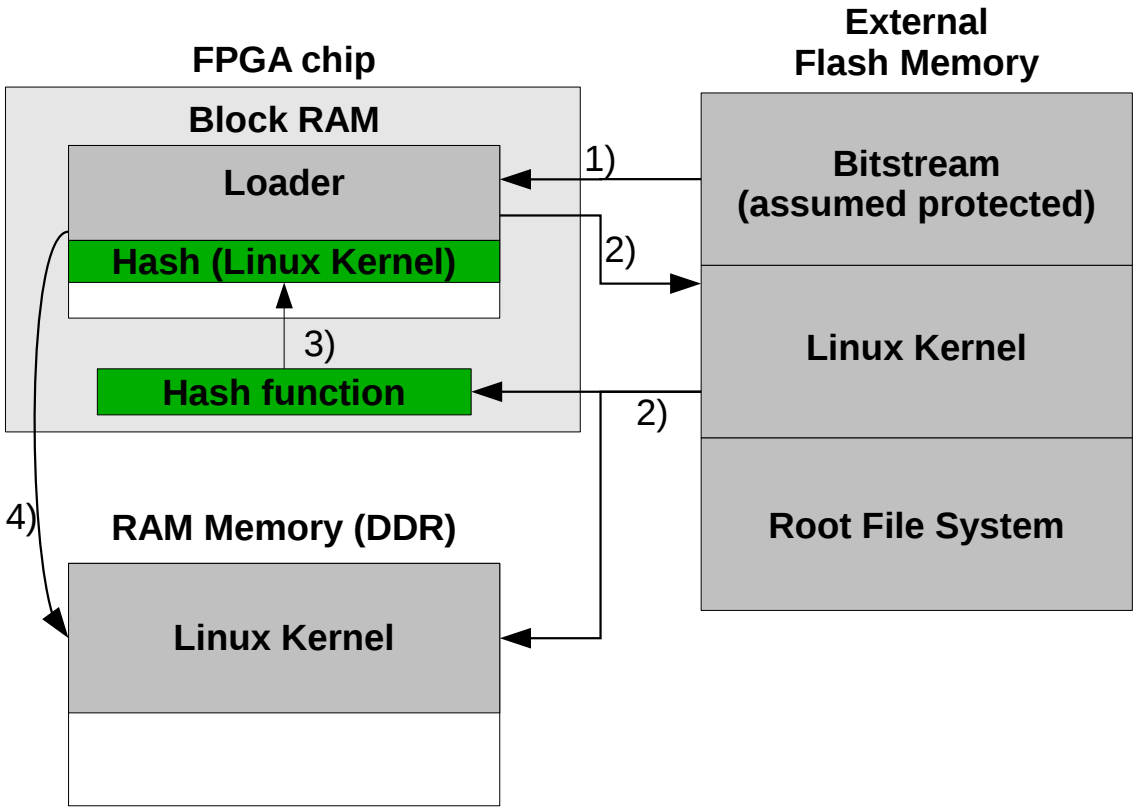

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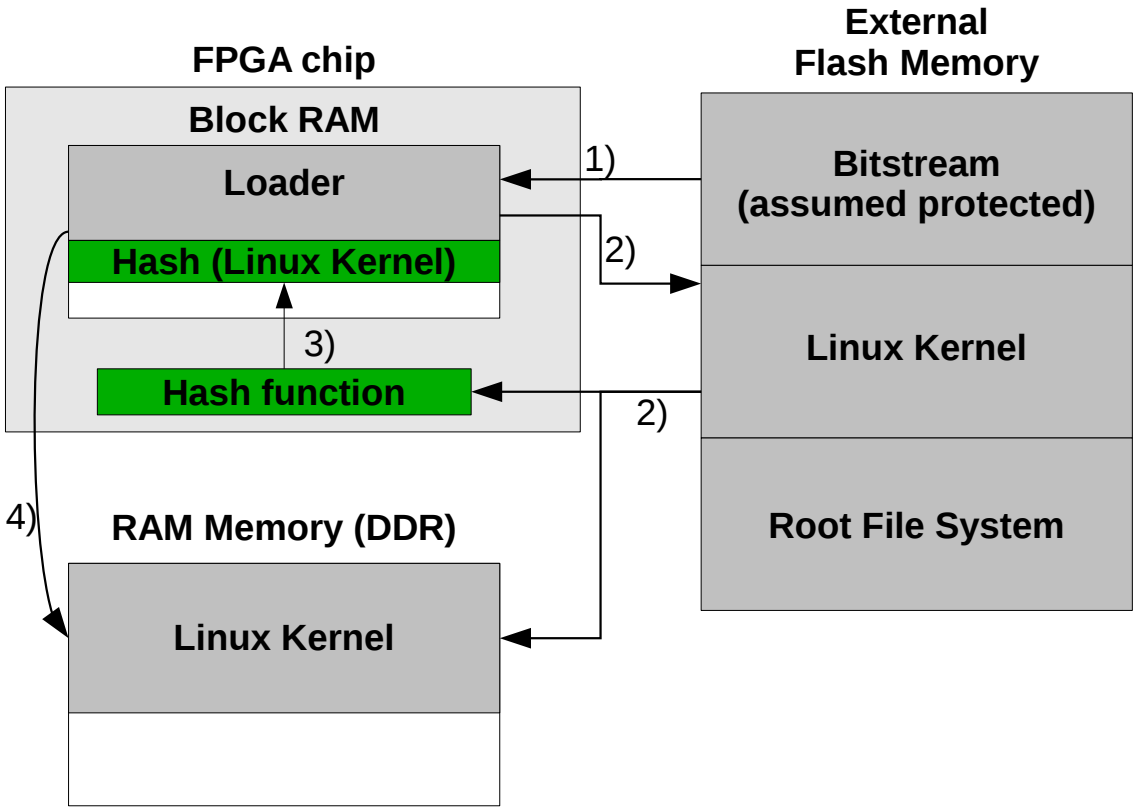

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→ **Changing the kernel requires to change the bitstream**

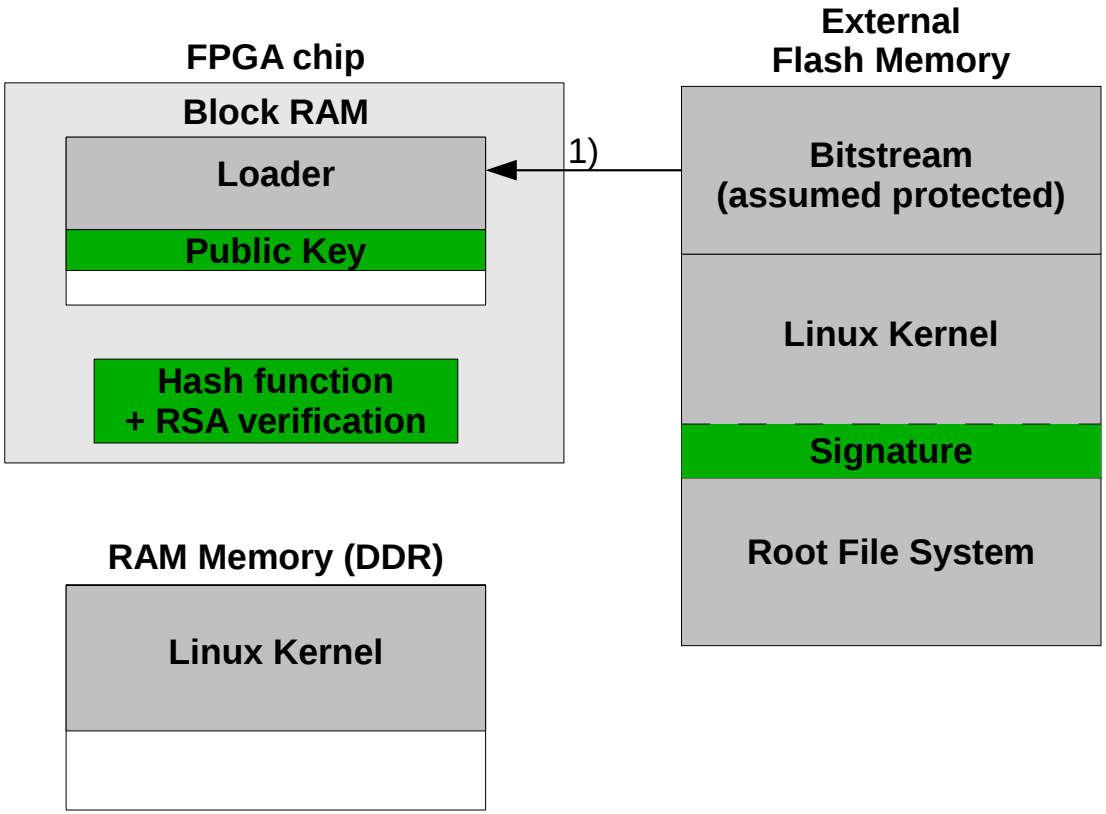
Performance overhead

Results :

Linux kernel = 2.8 MB
Virtex 6 : Processor frequency = 100Mhz
Hash algorithm = Sha-256

IP	# Cycles	Boot time Overhead	Throughput	Gain
Soft SHA-256	295 860 775	2,959 s	0,95 MB/s	ref.
Hard SHA-256	38 376 545	0,384 s	7,29 MB/s	x7,7
+ DMA transfer	4 221 304	0,042 s	66,67 MB/s	x70

Adding flexibility



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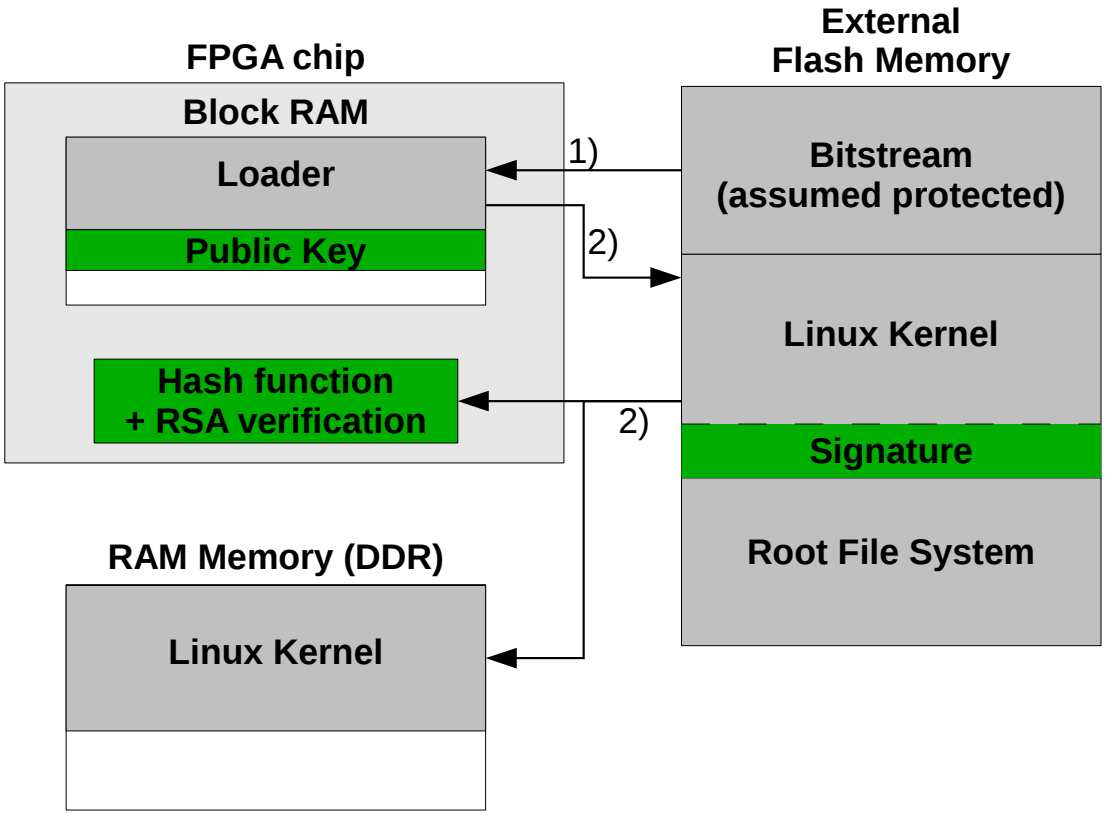

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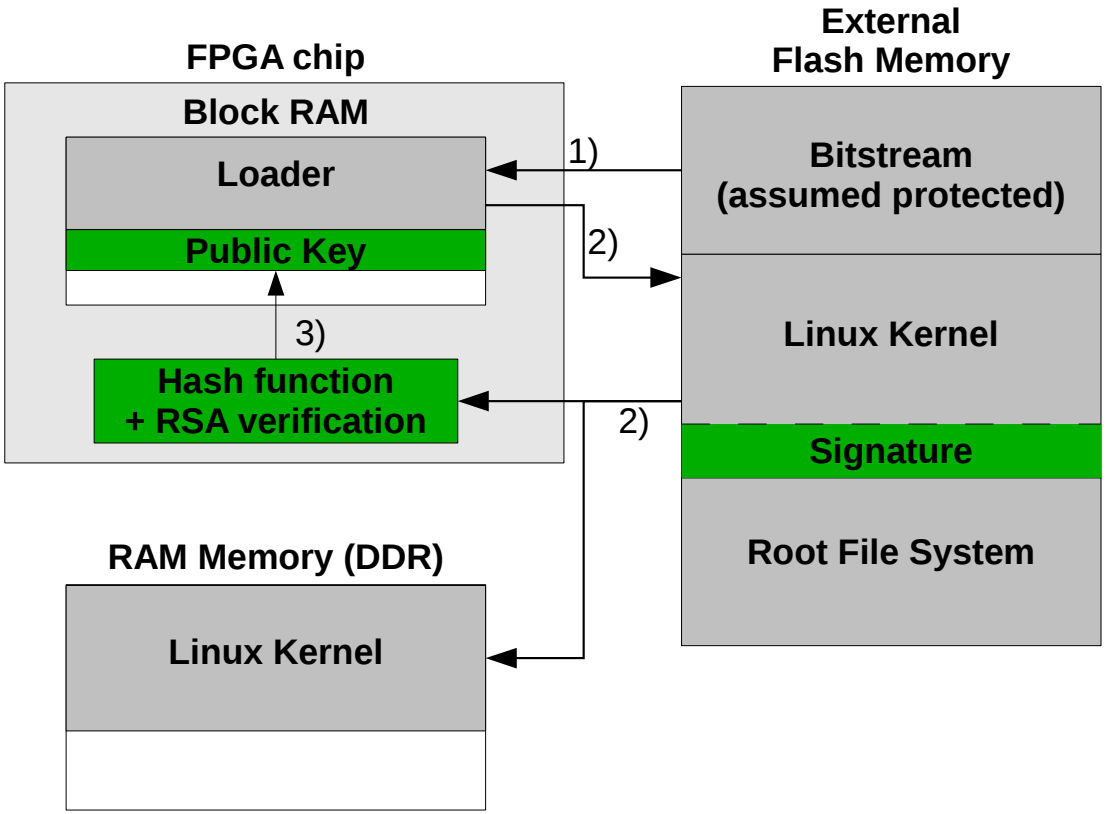

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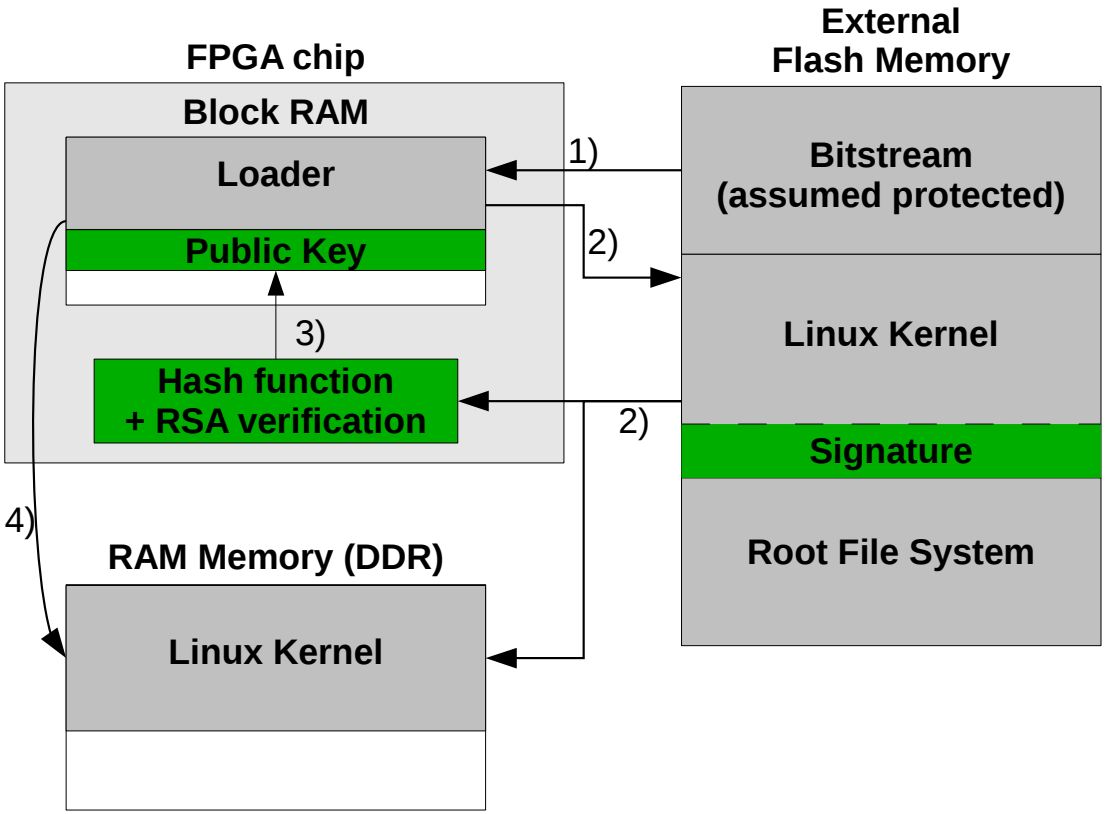

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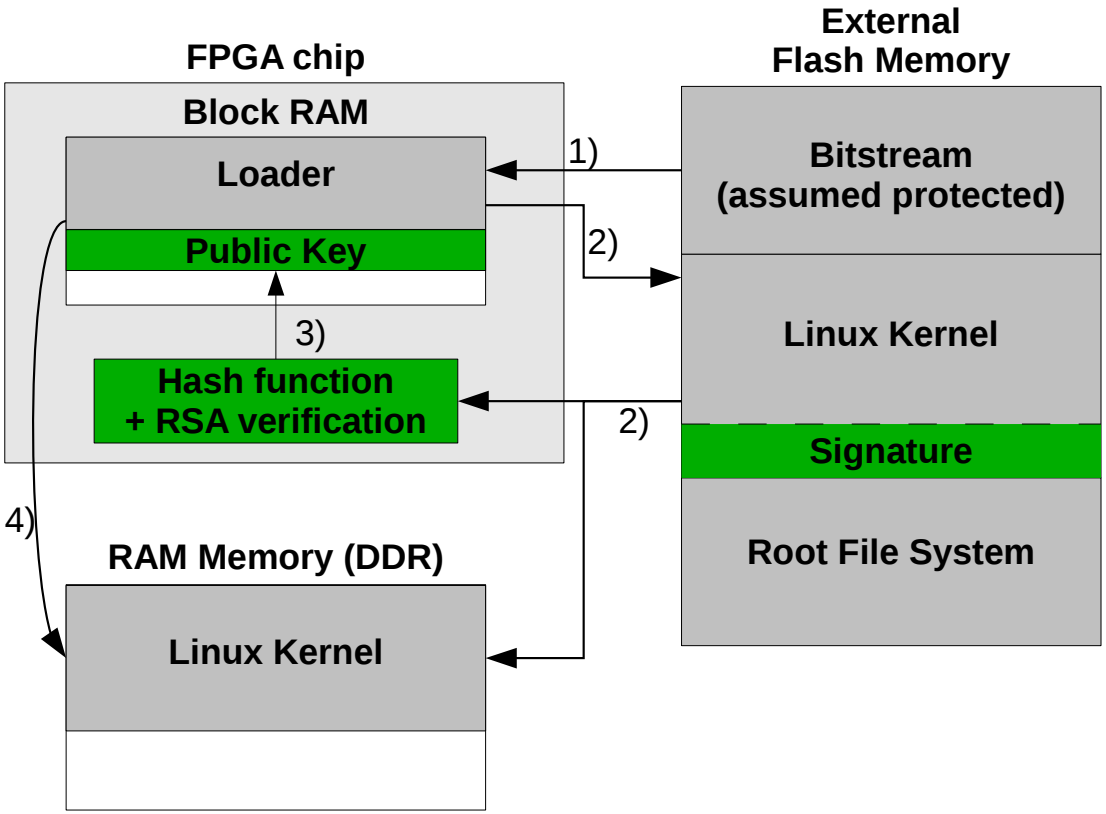

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→ **This flexibility makes the kernel vulnerable to replay attacks**

Security concerns

IP	# Cycles	Boot time Overhead	Throughput	Gain
RSA-1024	92 867	0,001 s	N/A	N/A

Discussion

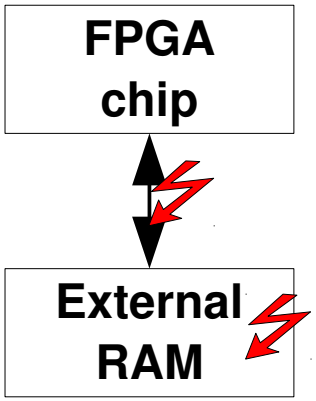
- This flexibility makes the kernel **vulnerable to replay** attacks.
- In case of **critical security update** of the kernel, it is possible to **regenerate an asymmetric key-pair** and update the bitstream.
- *Possibility to store the key-pair in the user non-volatile memory : kernel protected against replay attacks without change the bitstream.*

Area overhead

	Details				Total				
Strategies	**Components**	**Slice FF**	**Slice LUT**	**BRAM**	**Slice FF**	**Slice LUT**	**BRAM**	***Fraction of V6 VLX240T***	
Base system (or with soft SHA-256)	Microblaze	3 196	3 874	19					
	Cache	6	14	16					
	DDR3	5 091	4 245	11					
	Flash	479	389						
	PLB	178	657		***8 950***	***9 179***	***46***	***6% + 11% de BRAM***	
+ Hard SHA-256	SHA (+wrapper)	1 509	1 897	1					
	Interrupt ctrl.	190	180		***10 649***	***11 256***	***47***	***7% + 11% de BRAM***	**+1%**
+ DMA	Central DMA	561	799		***11 210***	***12 055***	***47***	***8% + 11% de BRAM***	**+1%**
+ RSA-1024	RSA (+wrapper)	684	989	4	***11 894***	***13 044***	***51***	***9% + 12% de BRAM***	**+1%**

Outline

RAM protection : Merkle-tree



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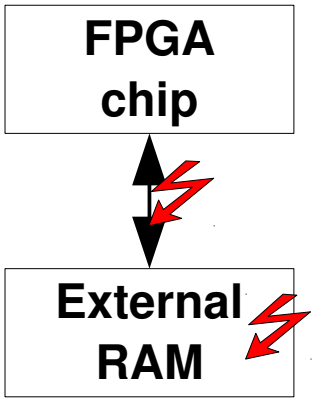

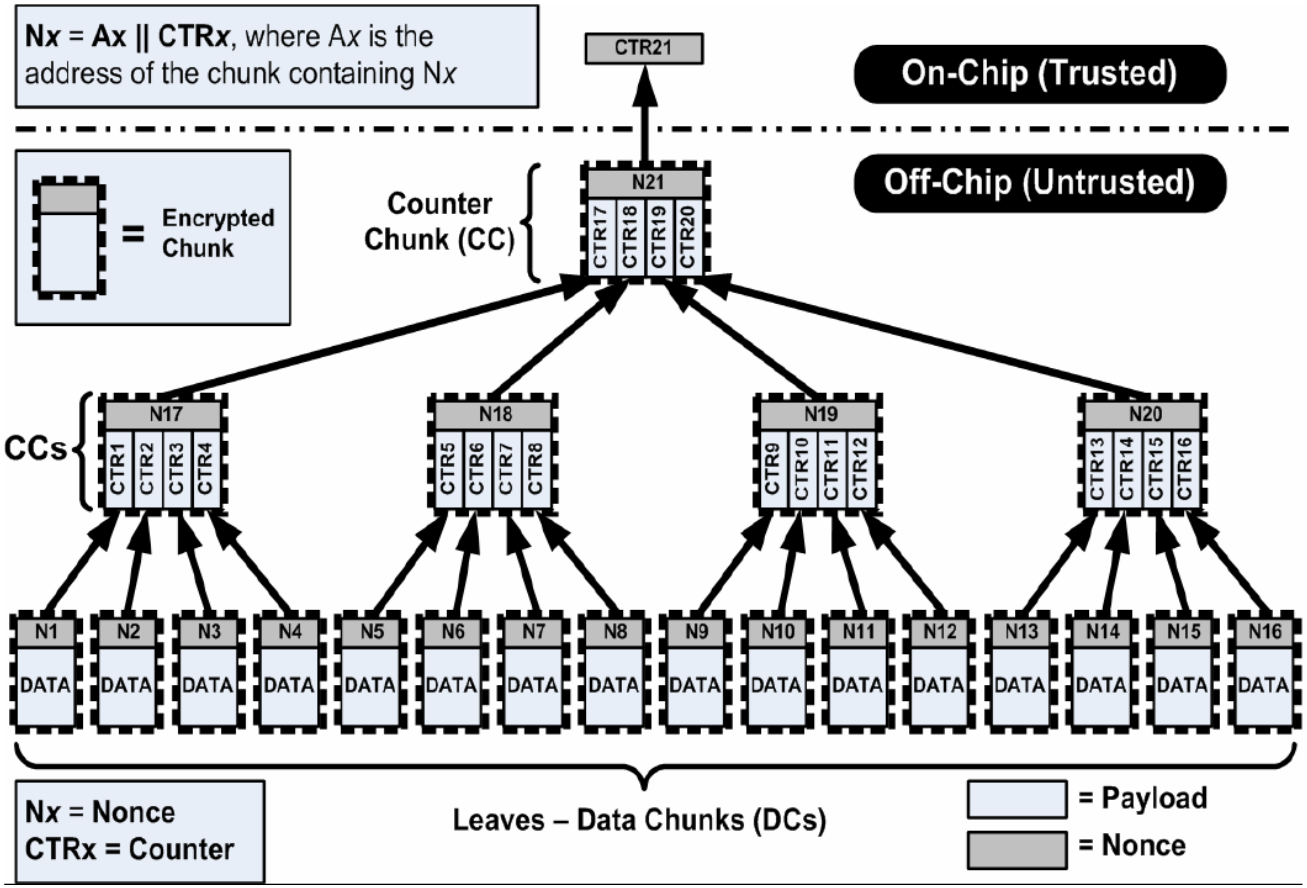

R. Elbaz, D. Champagne, R. Lee and L. Torres, "TEC-Tree : A Low-Cost, Parallelizable Tree for Efficient Defense Against Memory Replay Attacks" in CHES'07

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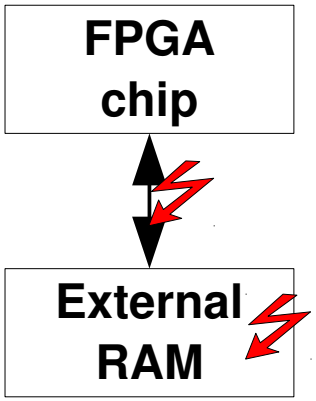
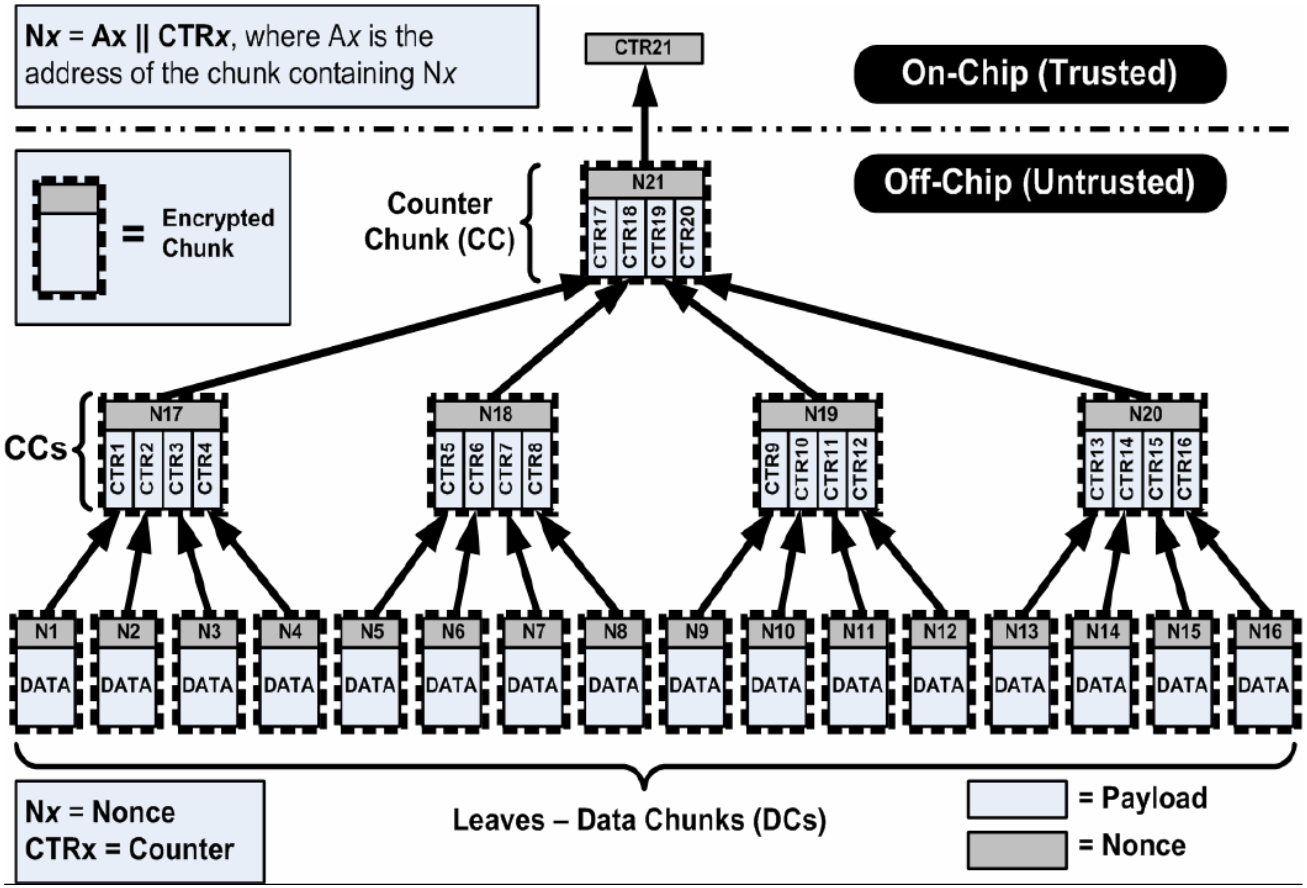


Preventing :

- replaces
- replays
- modifications
- data decryptions



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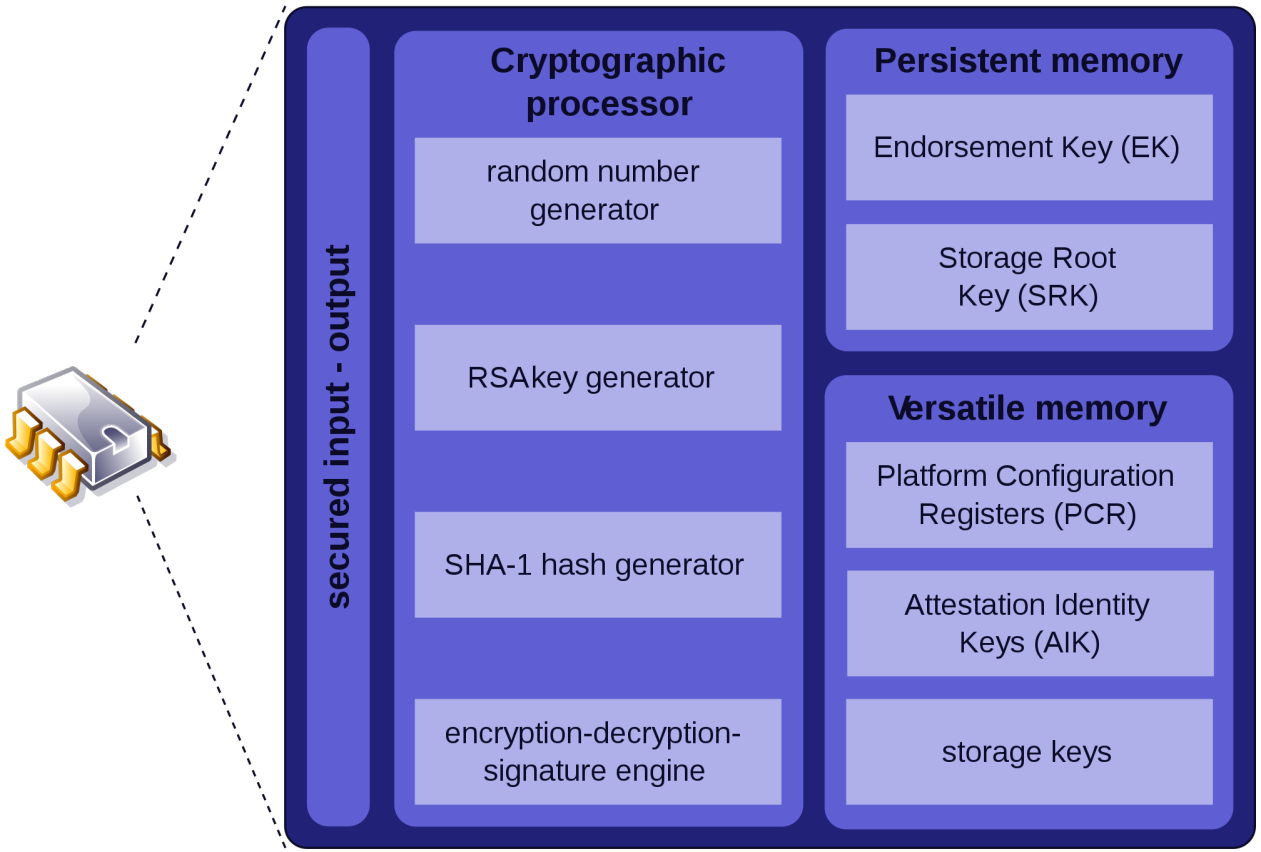
TPM : Trusted Platform Module



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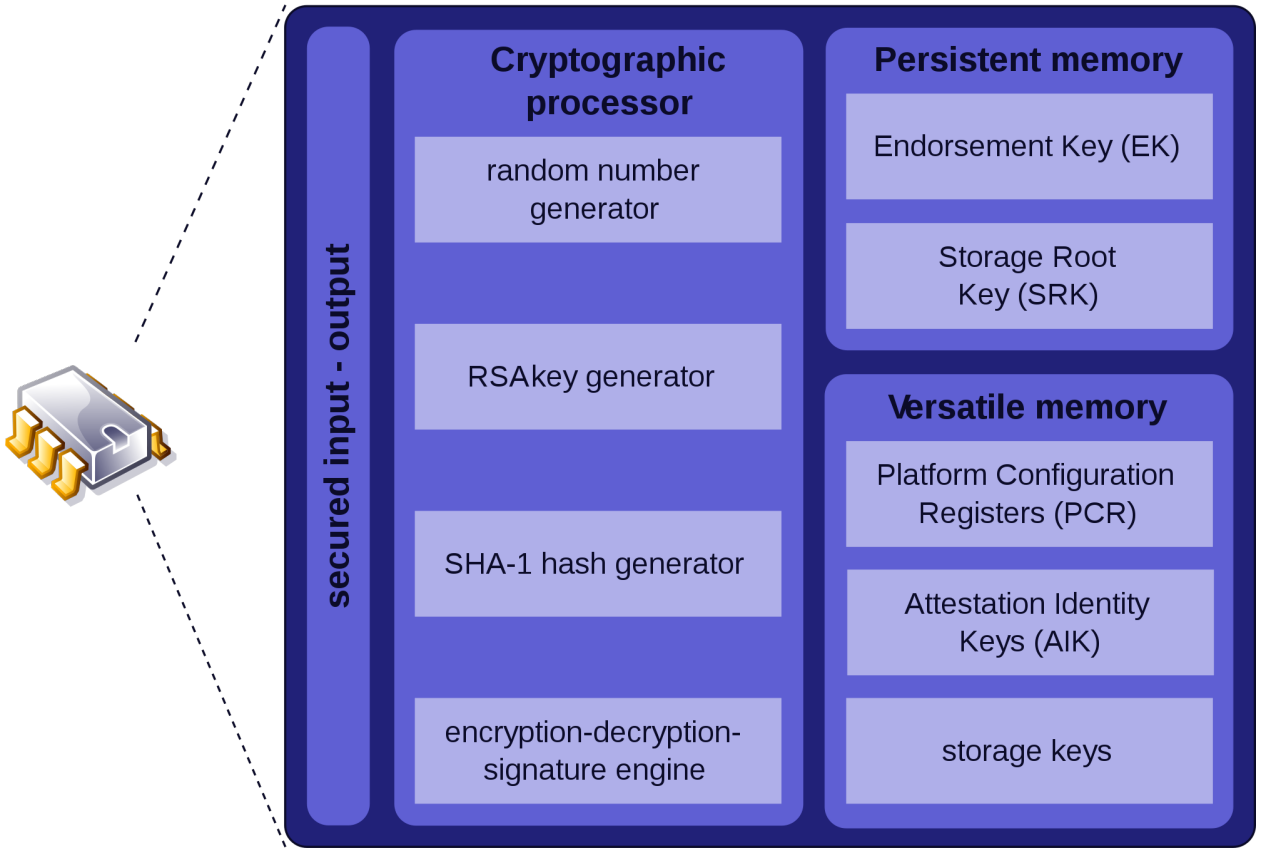
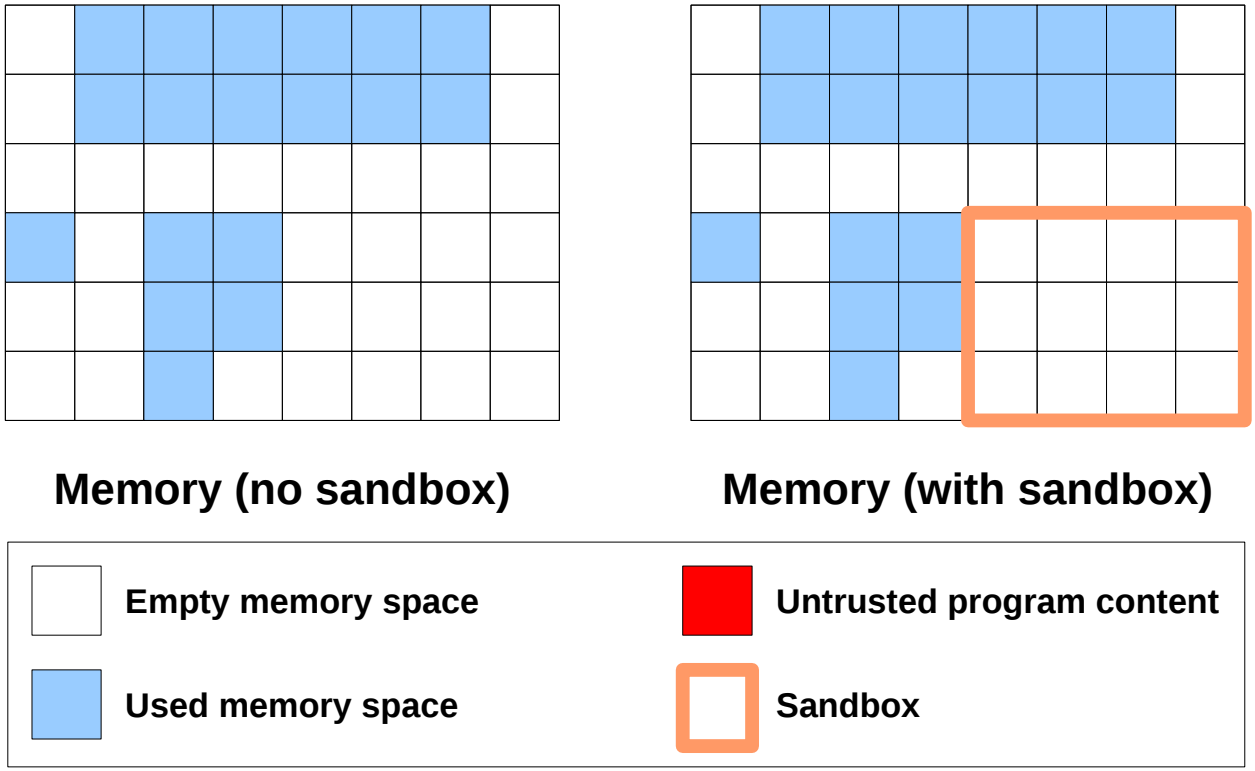
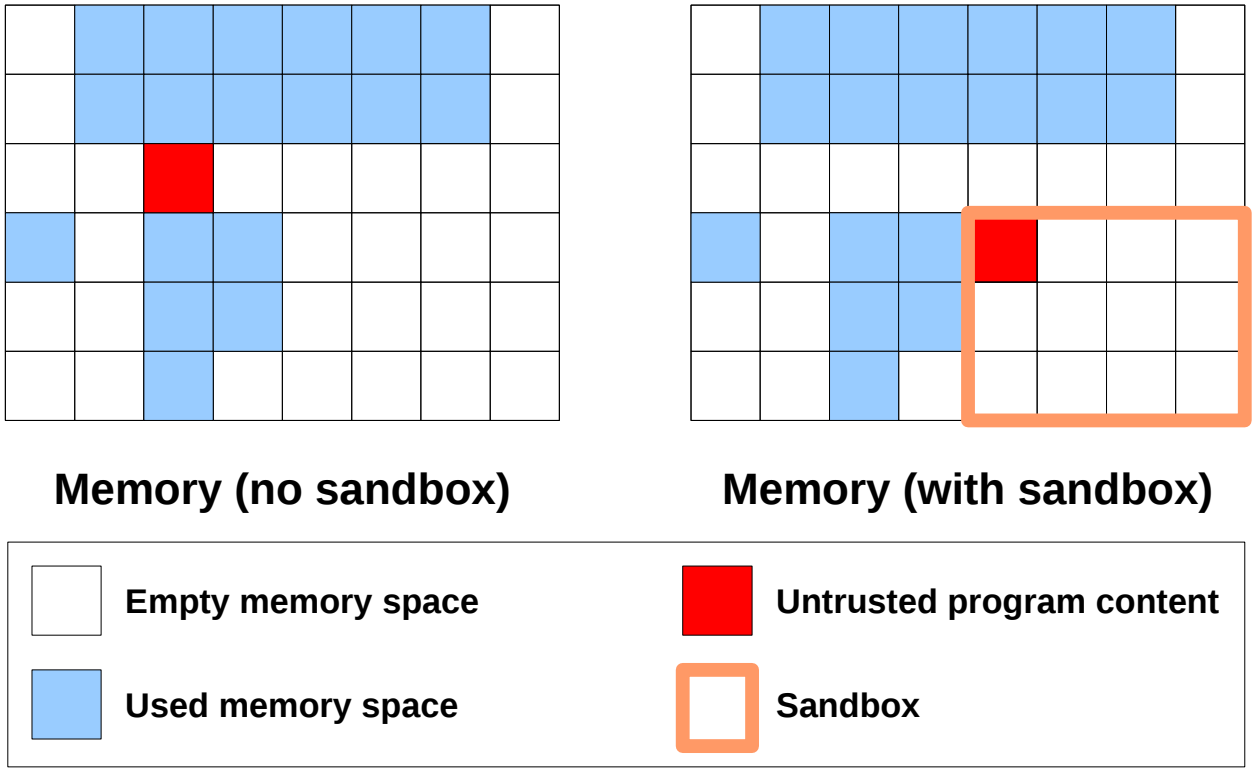


→ **Can be implemented in the FPGA**

Sandboxing


Memory (no sandbox)
Memory (with sandbox)
Empty memory space
Used memory space
Untrusted program content
Sandbox

Sandboxing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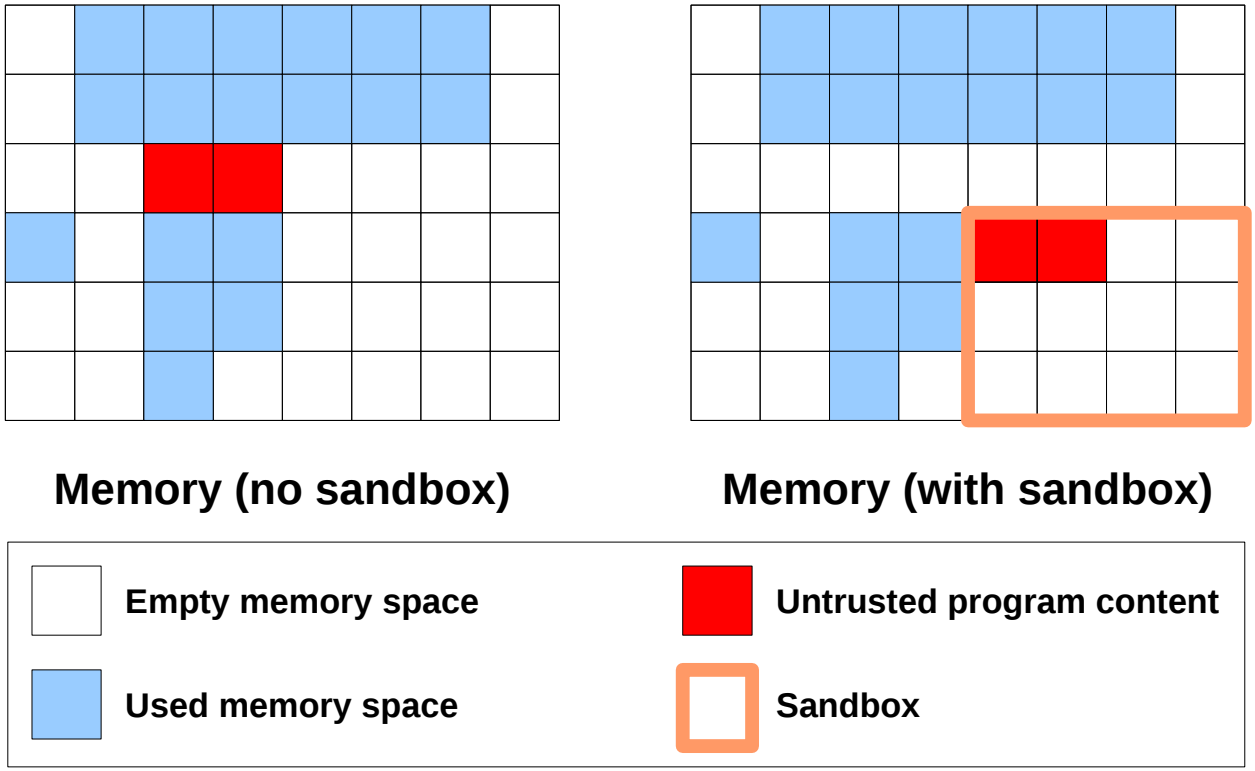
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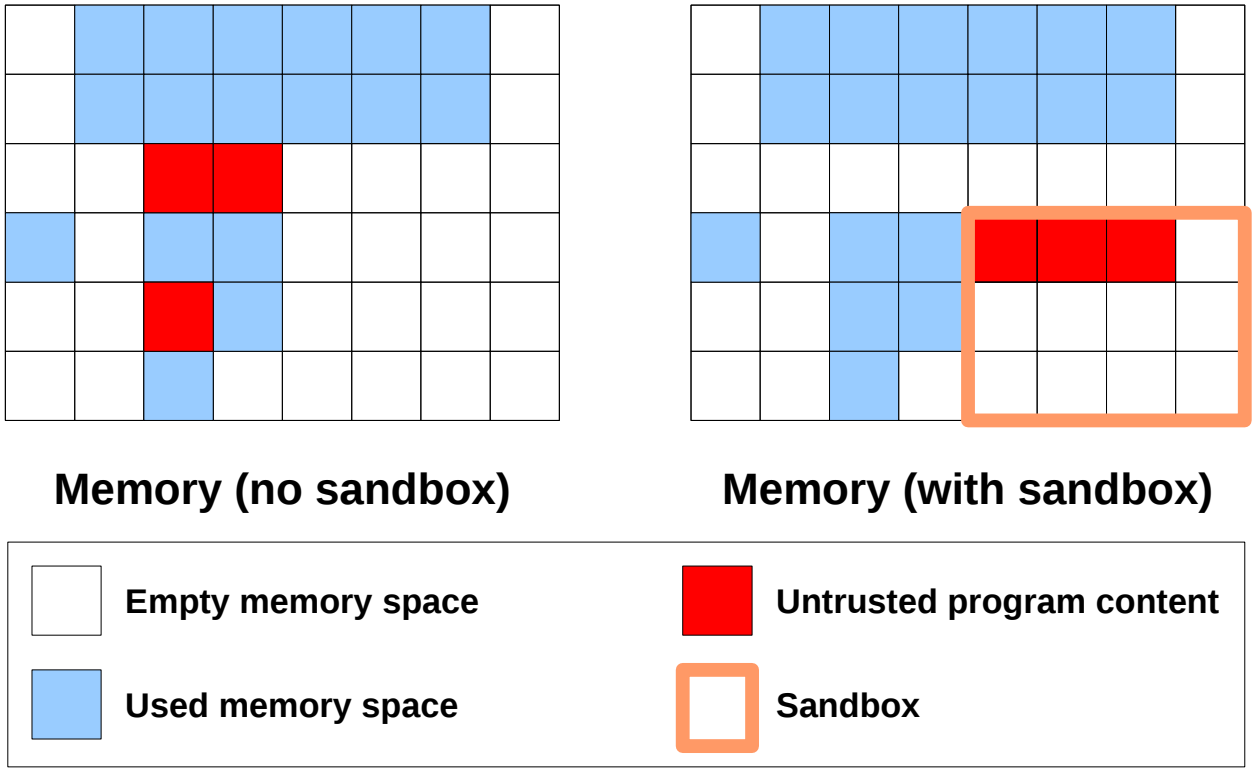
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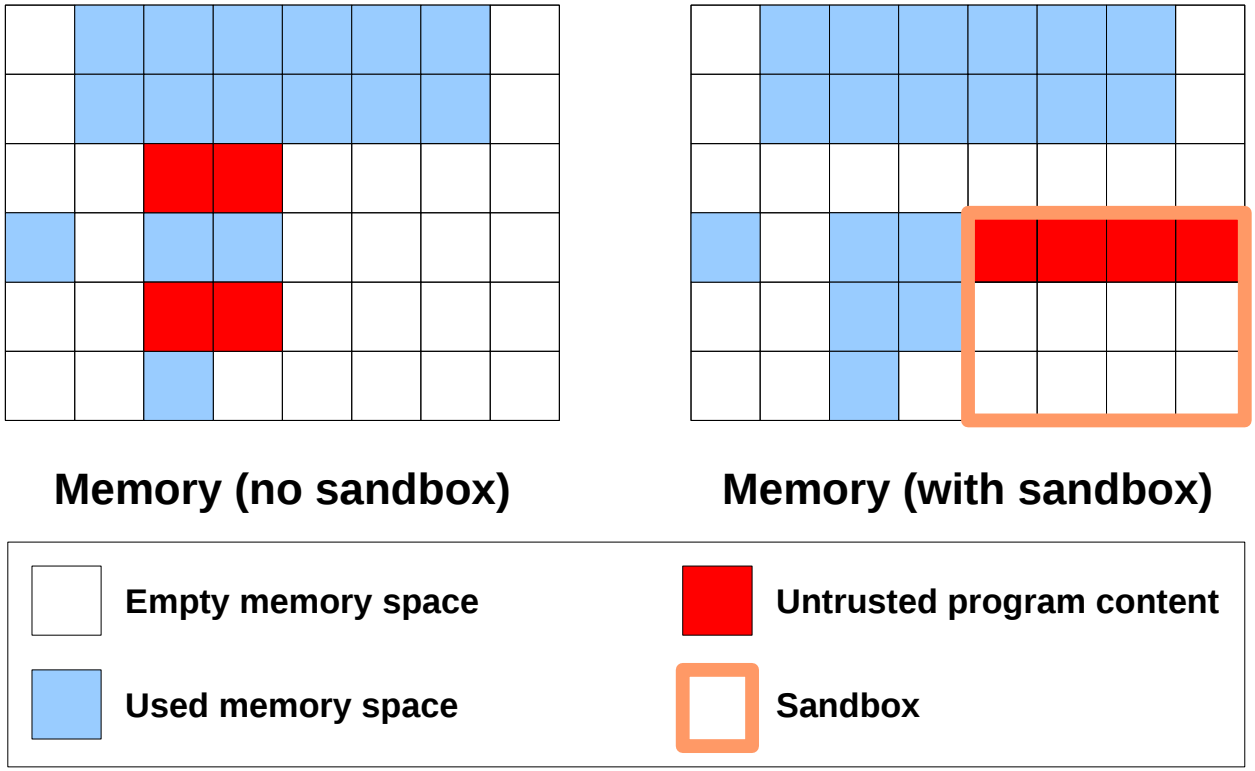
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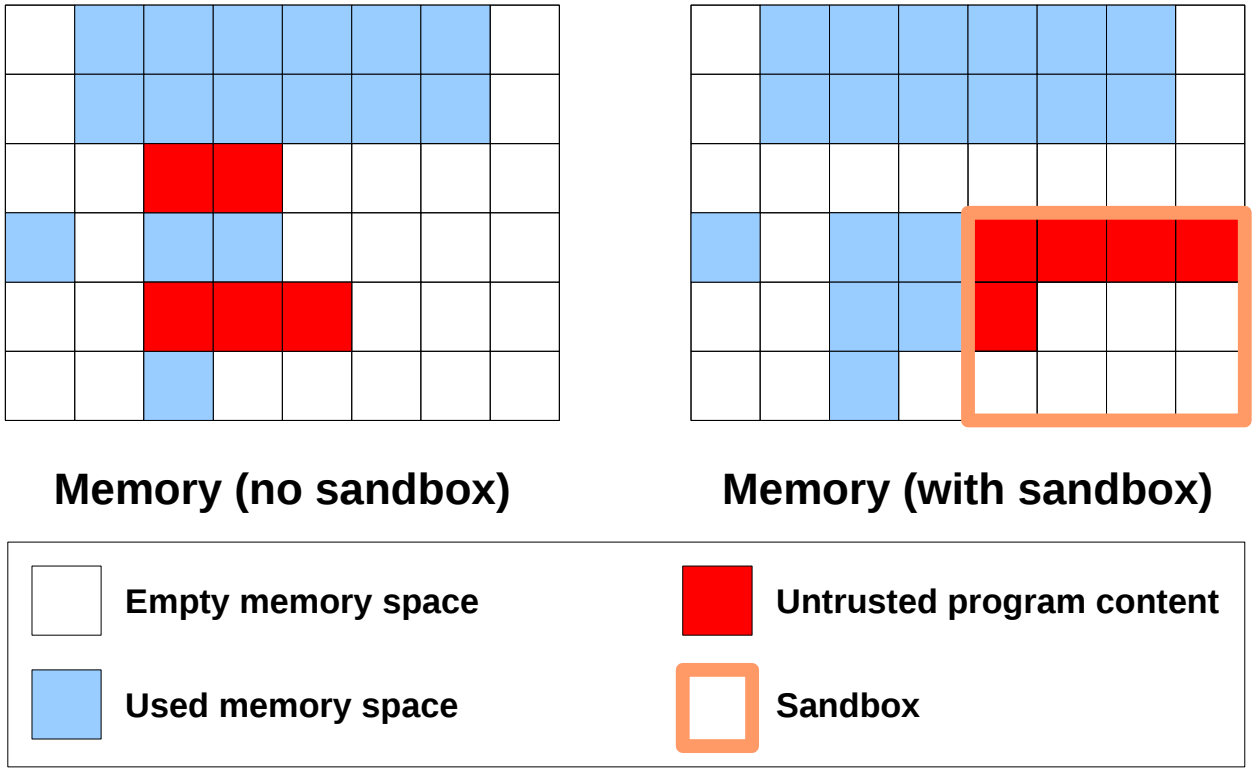
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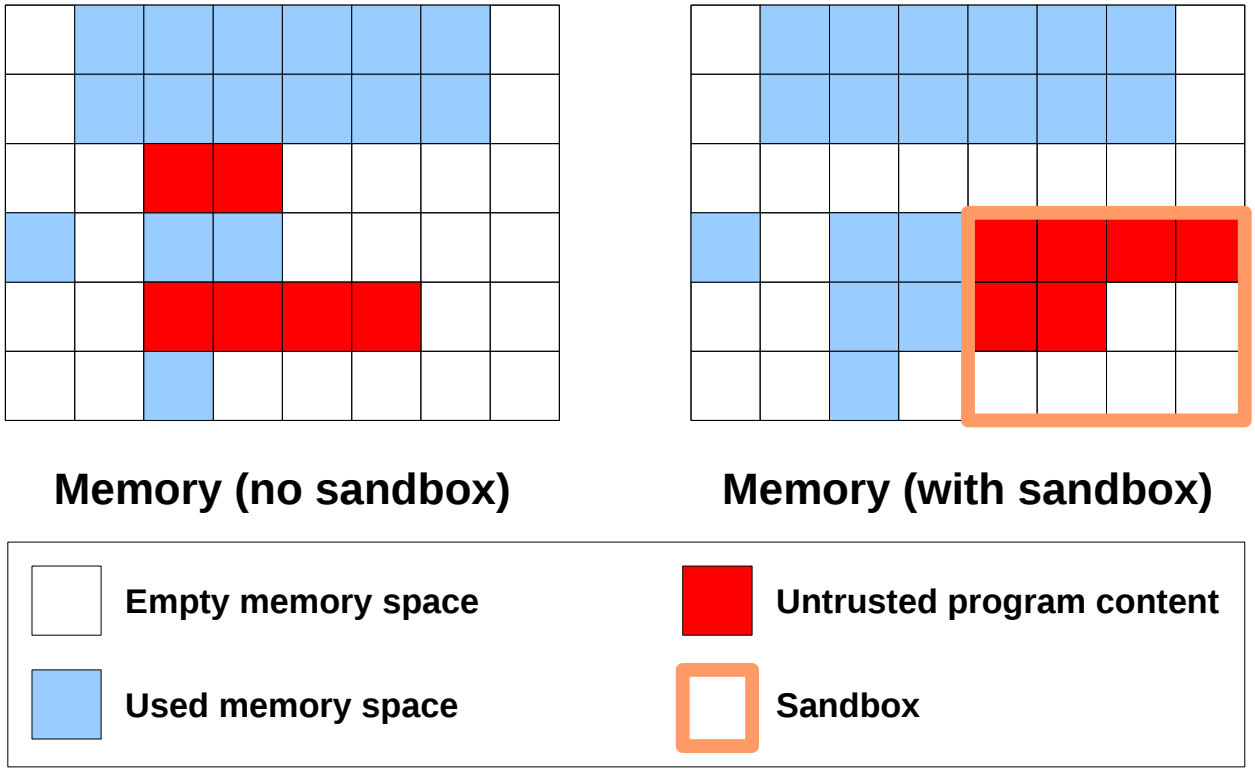
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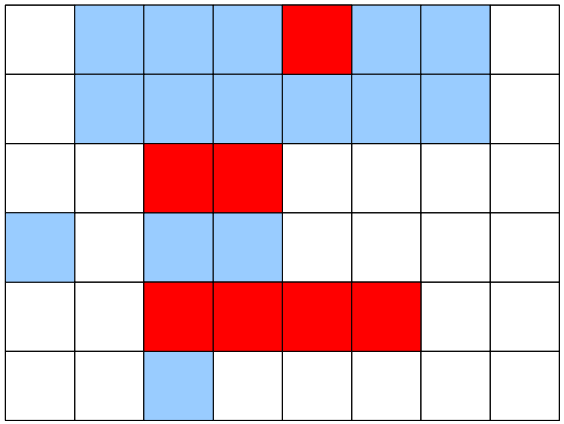

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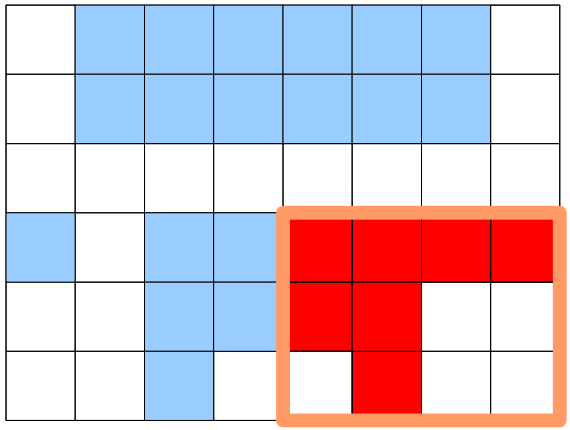

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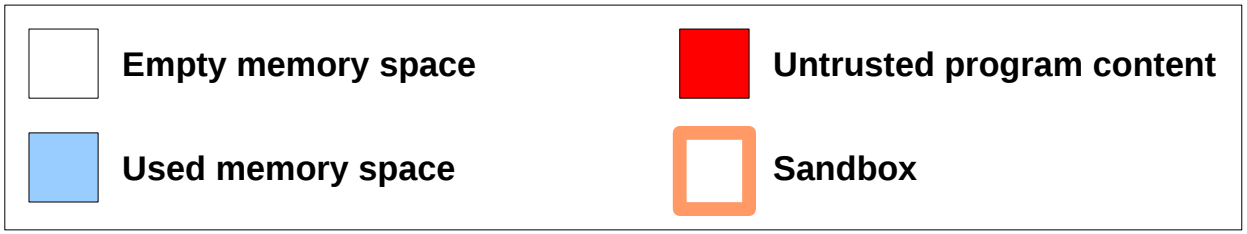

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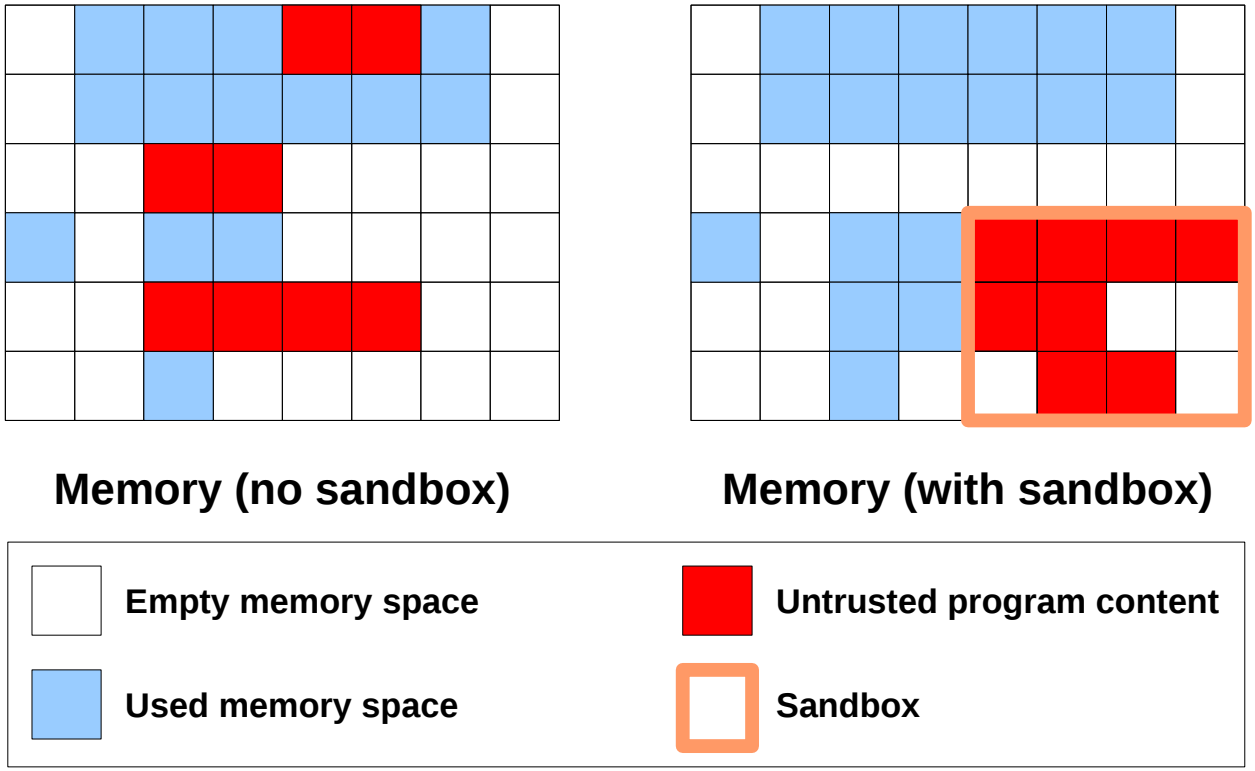
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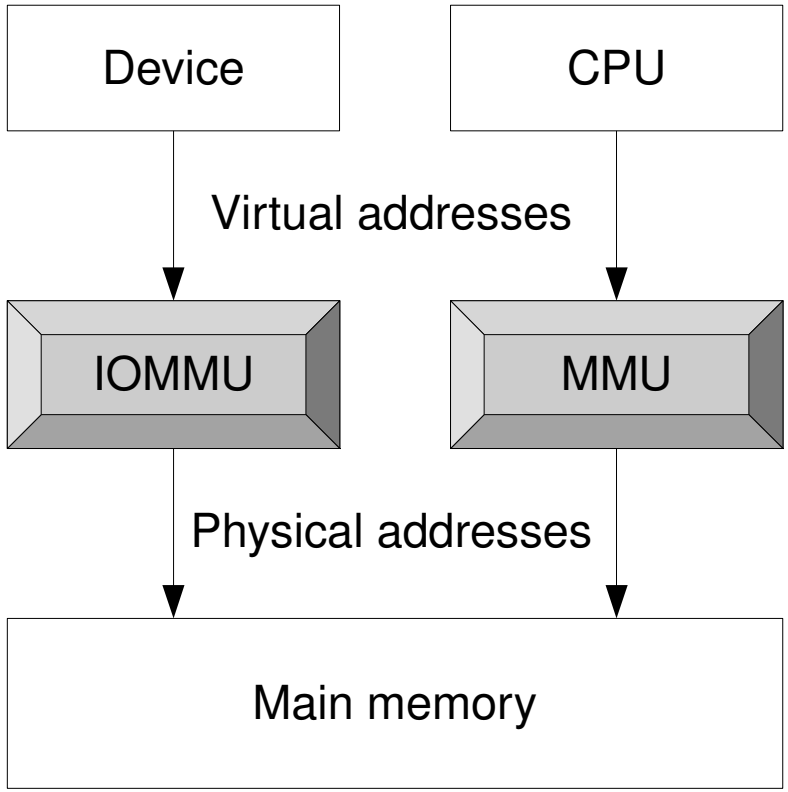
Memory rights management



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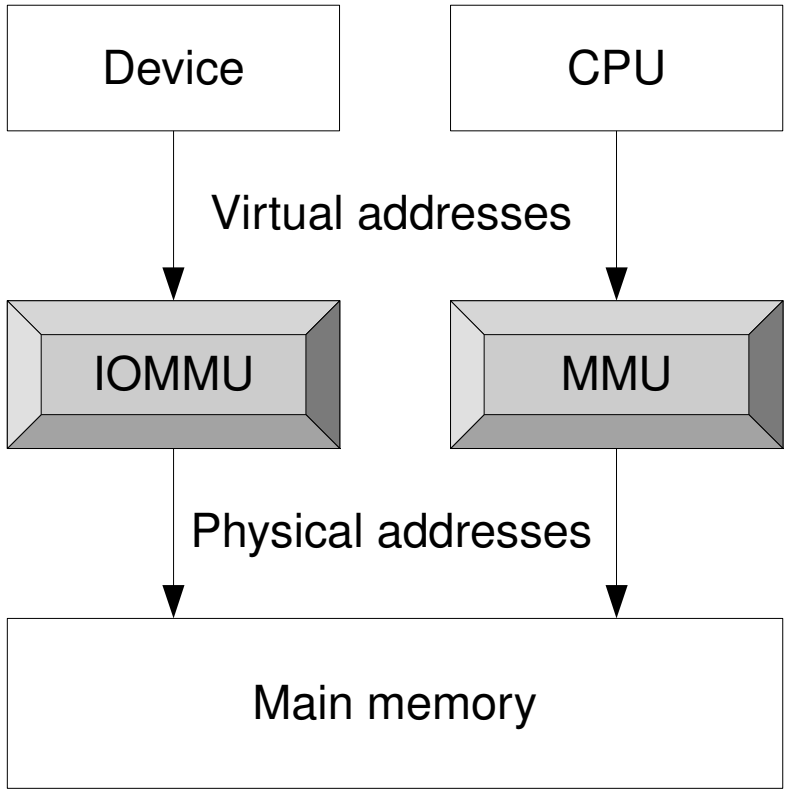
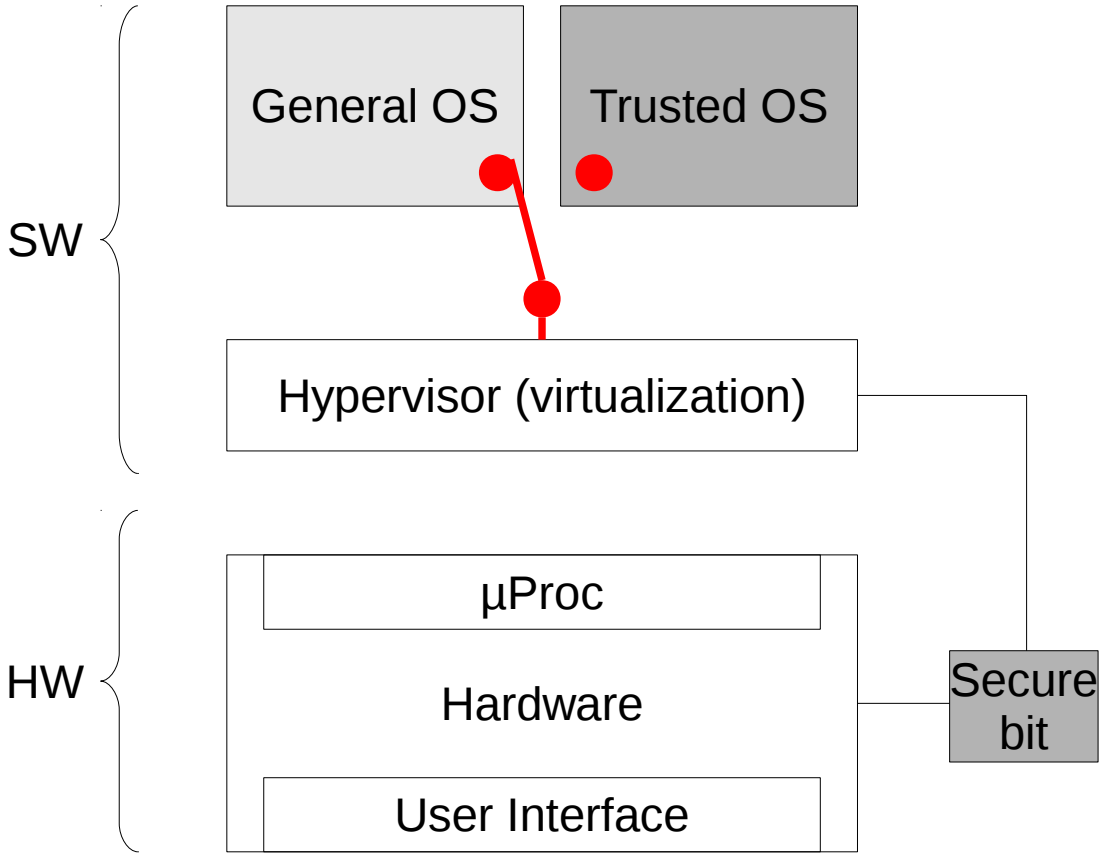


→ **Vulnerabilities**

F. L. Sang, E. Lacombe, V. Nicomette, and Y. Deswarte, "Analyse de l'efficacité du service fourni par une IOMMU" in SSTIC'10

Virtual machines

example : TrustZone (ARM)



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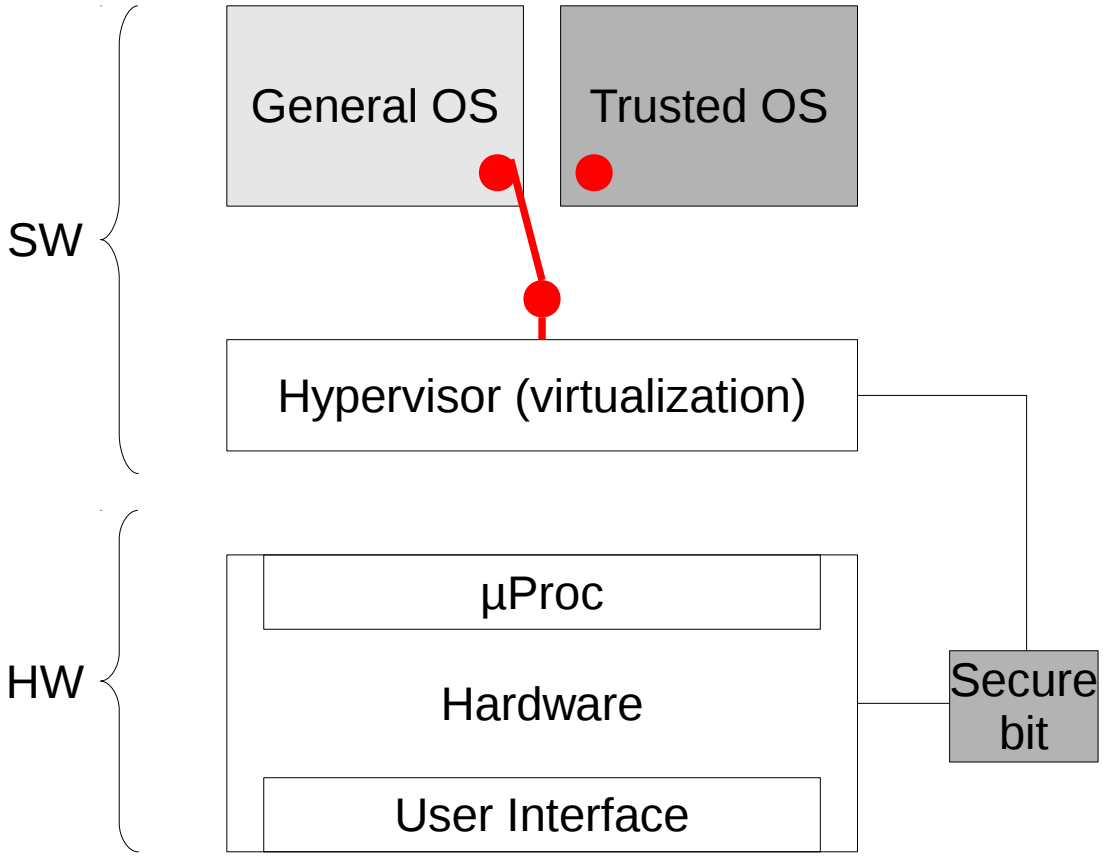

→ **Vulnerabilities**

Outline

Conclusion and future works

- Complete protection : very difficult
  - Large attack surface : Bitstream $\rightarrow$ OS
  - Multidisciplinary skills : Avoid security holes
- RAM protection : high performance overhead
- OS : difficult to trust and certify

Conclusion and future works

Thank you for your attention ! ! !