Experiments on automation of formal verification of devices at the binary level

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INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

Section 1

Motivation

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Security critical systems

Privacy

- Smartphones
- Smart TVs

Integrity

- Hospital equipment
- Traffic control systems
- Power plants

Security critical systems

Privacy

- Smartphones
- Smart TVs

Integrity

- Hospital equipment
- Traffic control systems
- Power plants

Problem: complex systems almost always contain bugs

Security critical systems - vulnerable

Security critical systems - vulnerable

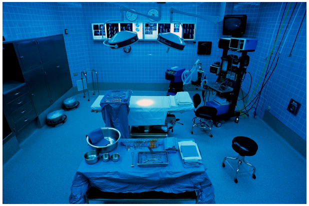

Figure: "It's Insanely Easy to Hack Hospital Equipment" [4]

Security critical systems - vulnerable

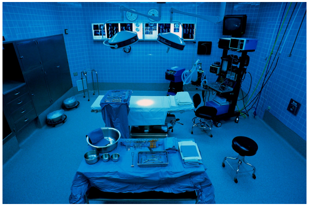

Figure: "It's Insanely Easy to Hack Hospital Equipment" [4]

- Remote control of equipment

Security critical systems - vulnerable

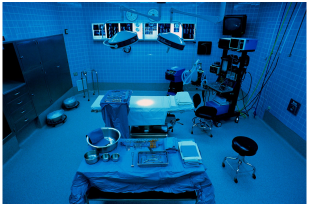

Figure: "It's Insanely Easy to Hack Hospital Equipment" [4]

Figure: "Remote Exploitation of an Unaltered Passenger Vehicle" [1, 2]

- Remote control of equipment

Security critical systems - vulnerable

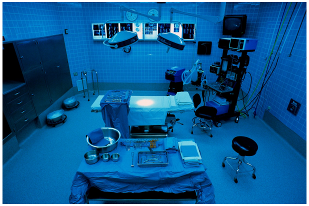

Figure: "It's Insanely Easy to Hack Hospital Equipment" [4]

Figure: "Remote Exploitation of an Unaltered Passenger Vehicle" [1, 2]

- Remote control of equipment
- Total control of drive system

Secure operating systems

seL4

Security. Performance. Proof.

[1] https://sel4.systems/Info/FAQ/proof.pml

Secure operating systems

Formal proof[1]:

- The binary code correctly implements its **abstract specification**.
- The specification guarantees **integrity** and **confidentiality**.

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Secure operating systems

Security. Performance. Proof.

Formal proof[1]:

- The binary code correctly implements its **abstract specification**.
- The specification guarantees **integrity** and **confidentiality**.

- **Integrity**: data cannot be *changed* without permission.
- **Confidentiality**: data cannot be *read* without permission.

[1] `https://sel4.systems/Info/FAQ/proof.pml`

Secure operating systems

Proof assumptions[2]:

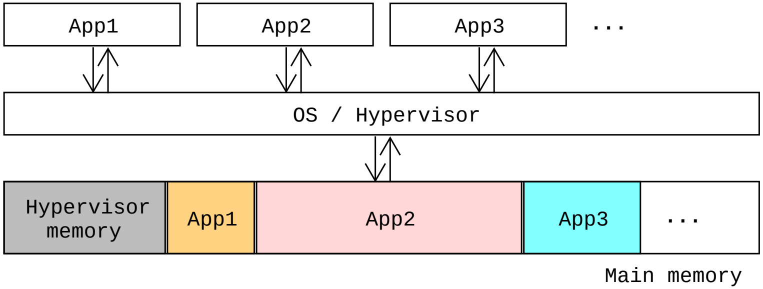
2 https://docs.sel4.systems/FrequentlyAskedQuestions#is-sel4-proven-secure

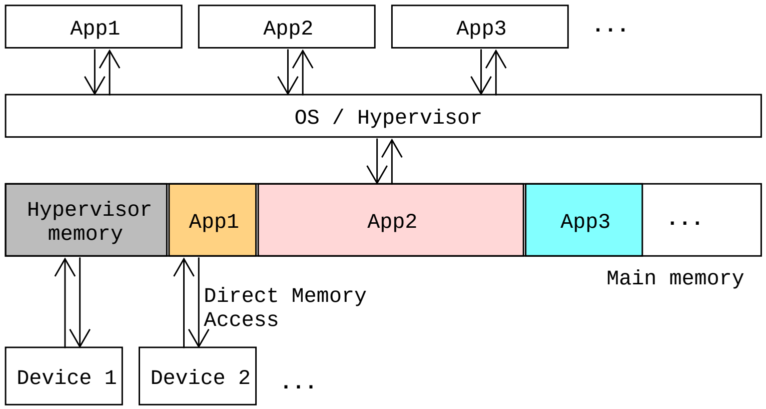
Secure operating systems

Proof assumptions[2]:

- Use of Direct Memory Access (DMA) is excluded, or only allowed for **trusted drivers that have to be formally verified by the user**.

[2] `https://docs.sel4.systems/FrequentlyAskedQuestions#is-sel4-proven-secure`


App1
App2
App3
...
OS / Hypervisor
Hypervisor memory
App1
App2
App3
...
Main memory


App1
App2
App3
...
OS / Hypervisor
Hypervisor memory
App1
App2
App3
...
Main memory
Direct Memory Access
Device 1
Device 2
...

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System software verification

Objective: show absence of errors in modelisation of real systems

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Formal proof

machine checkable proofs using
rigorous semantic

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Non proof-producing verification

specialized programs or procedures that check a given property

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$\rightarrow$ produced theorems are trustworthy

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specialized programs or procedures that check a given property

Classic bug-prone software
$\rightarrow$ need tests, less trustworthy

System software verification

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Examples: HOL4, Coq, Isabelle

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System software verification

Objective: show absence of errors in modelisation of real systems

Formal proof	**Non proof-producing verification**
machine checkable proofs using rigorous semantic	specialized programs or procedures that check a given property
Use small reliable kernels $\rightarrow$ produced theorems are trustworthy	Classic bug-prone software $\rightarrow$ need tests, less trustworthy
Examples: HOL4, Coq, Isabelle	SMT solvers, model checkers

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Network Interface Controller (NIC)

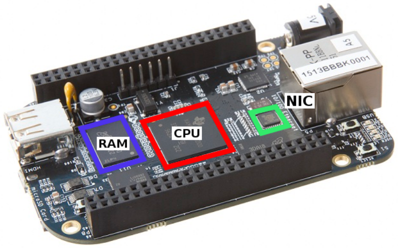
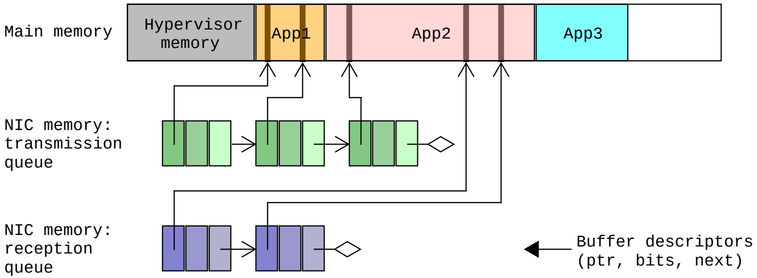
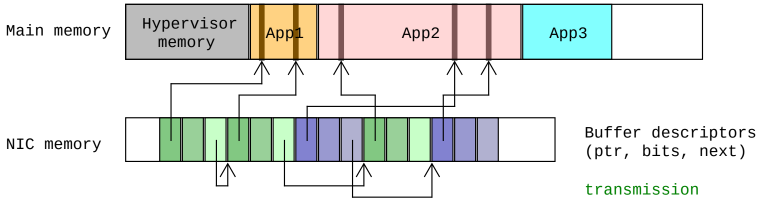


Figure: BeagleBone Black.

Network Interface Controller (NIC)


Main memory
Hypervisor memory
App1
App2
App3
NIC memory: transmission queue
NIC memory: reception queue
Buffer descriptors (ptr, bits, next)

Network Interface Controller (NIC)

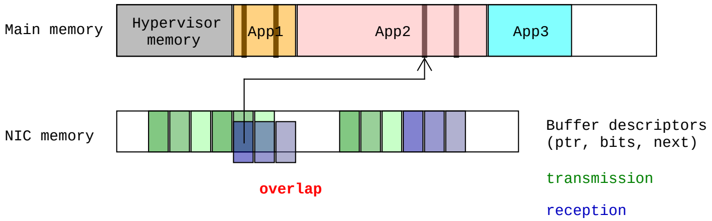


Buffer descriptors
(ptr, bits, next)

transmission

reception

Network Interface Controller (NIC)



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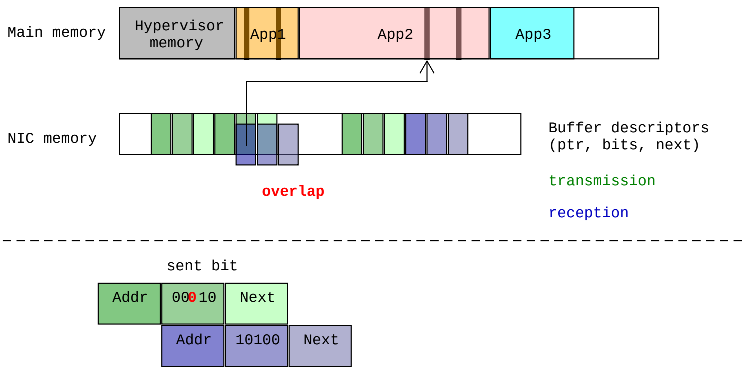

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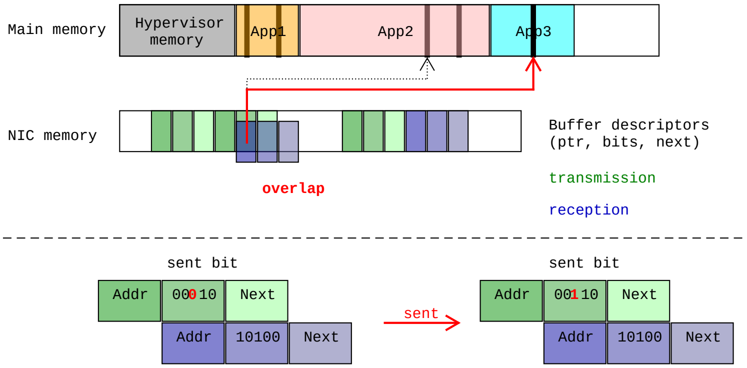

Research question

Can we apply traditional software verification techniques and tools to show security properties of hardware devices?

Section 2

Automatic contract-based verification pipeline

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Title

- Transition system
- Loop-free
- Verification = prove invariants
- (Show CFG?)

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HT - WP -> SMT

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Example: invariant

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Proof-producing verification

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Conclusion

Questions

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Andy Greenberg.
Hackers remotely kill a jeep on the highway—with me in it.

Dr Charlie Miller and Chris Valasek.
Remote exploitation of an unaltered passenger vehicle.
page 91.

Thomas Tuerk.
Interactive theorem proving (ITP) course.

Kim Zetter.
It's insanely easy to hack hospital equipment.