Safe and Secure User Space Drivers

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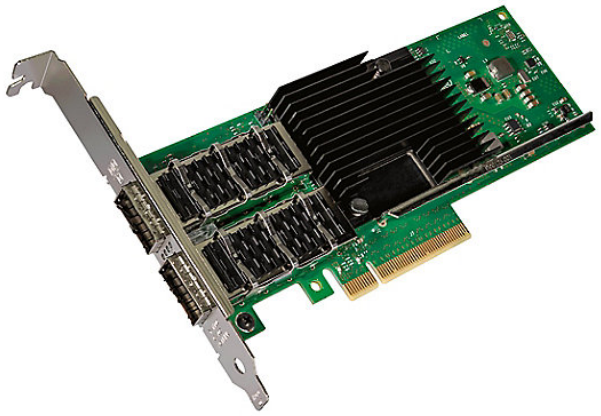
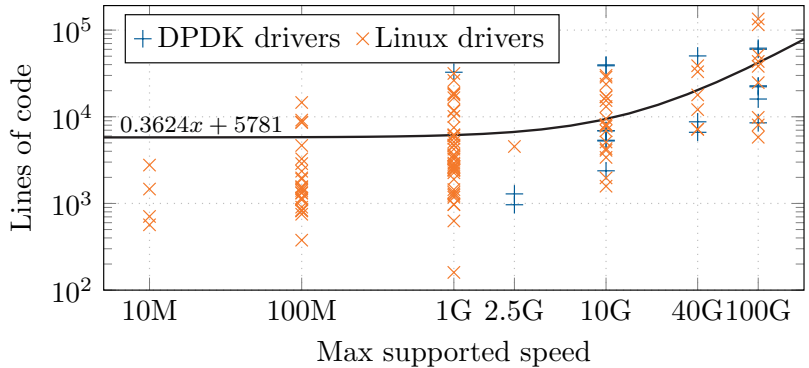
Network drivers



Intel XL710 [Picture: Intel.com]

Network driver complexity is increasing



The ixy driver

- Our attempt to write a simple yet fast user space network driver
- It's a user space driver you can easily understand and read
- Supports Intel ixgbe NICs (82599, X540, Xeon D, ...) and VirtIO
- $\approx$ 1,000 lines of C code, full of references to datasheets and specs
- Intel driver: 38,000 lines in DPDK, 30,000 in Linux
- Small code size makes it ideal for trustworthy systems
- But is C the best language for drivers?

C can cause security problems

Vulnerability Trends Over Time

Year	# of Vulnerabilities	DoS	Code Execution	Overflow	Memory Corruption	Sql Injection	XSS	Directory Traversal	Http Response Splitting	Bypass something	Gain Information	Gain Privileges
1999	19	7		3						1		2
2000	5	3										1
2001	22	6								4		3
2002	15	3		1						1	1	
2003	19	8		2						1	3	4
2004	51	20	5	12							5	12

(...)

2017	454	147	169	52	26			1		17	89	36
2018	166	81	3	28	8					3	17	3
Total	2155	1184	241	347	124			3		111	350	260
% Of All		54.9	11.2	16.1	5.8	0.0	0.0	0.1	0.0	5.2	16.2	12.1

- Screenshot from `https://www.cvedetails.com/`
- Security bugs found in the Linux kernel in the last $\approx$ 20 years

C can cause security problems

- Not all bugs can be blamed on the language
- Cutler et al. analyzed 65 CVEs categorized as code execution in the Linux kernel [1]

[1] C. Cutler, M. F. Kaashoek, and R. T. Morris, "The benefits and costs of writing a POSIX kernel in a high-level language", USENIX OSDI, 2018

C can cause security problems

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Bug type	Num.	Perc.	Can be avoided by a high-level language?
Various	11	17%	Unclear/Maybe
Logic	14	22%	No
Use-after-free	8	12%	Yes
Out of bounds	32	49%	Yes (likely leads to panic)

Table 1: Code execution vulnerabilities in the Linux kernel identified by Cutler et al[1]

[1] C. Cutler, M. F. Kaashoek, and R. T. Morris, "The benefits and costs of writing a POSIX kernel in a high-level language", USENIX OSDI, 2018

Are there preventable bugs in drivers?

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- We looked at these 40 preventable bugs
- 39 of them were in drivers (the other was in the Bluetooth stack)

Should drivers for trustworthy systems be written in C?

- If you have a choice: probably not

Should drivers for trustworthy systems be written in C?

- If you have a choice: probably not
- User space drivers can be written in any language!
- But are all languages an equally good choice?
- Is a JIT compiler or a garbage collector a problem in a driver?

We wrote full user space drivers in these languages

Goals for our implementations

- Implement the same feature set as our C reference driver
- Use a similar structure like the C driver
- Write idiomatic code for the selected language
- Use language safety features where possible
- Quantify trade-offs for performance vs. safety

- This allows us to compare different languages for safety-critical systems

Language comparison: Overview

Language	Main paradigm	Memory management	Compilation
Rust	Imperative	Ownership/RAII	(LLVM) Compiled
Go	Imperative	Garbage collection	Compiled
C#	Object-oriented	Garbage collection	JIT
Swift	Protocol-oriented	Reference counting	(LLVM) Compiled
OCaml	Functional	Garbage collection	Compiled
Haskell	Functional	Garbage collection	(LLVM) Compiled
Python	Imperative	Garbage collection	Interpreted

Table 2: Language overview

Language comparison: Safety properties

	General memory		Packet buffers		
Language	**Bounds checks**	**Use after free**	**Bounds checks**	**Use after free**	**Int overflows**
C	✗	✗	✗	✗	✗
Rust	✓	✓	(✓)[1]	✓	(✓)[4]
Go	✓	✓	(✓)[1]	(✓)[3]	✗
C#	✓	✓	(✓)[1]	(✓)[3]	✗
Swift	✓	✓	✗[2]	(✓)[3]	✓
Haskell	✓	✓	(✓)[1]	(✓)[3]	✗
OCaml	✓	✓	(✓)[1]	(✓)[3]	✗
Python	✓	✓	(✓)[1]	(✓)[3]	✗

[1] Bounds enforced by wrapper, constructor in unsafe code
[2] Bounds only enforced in debug mode
[3] Buffers are never free'd, only returned to a memory pool
[4] Disabled by default, proposed to be enabled by default in the future

Table 3: Language-level protections against classes of bugs in our drivers

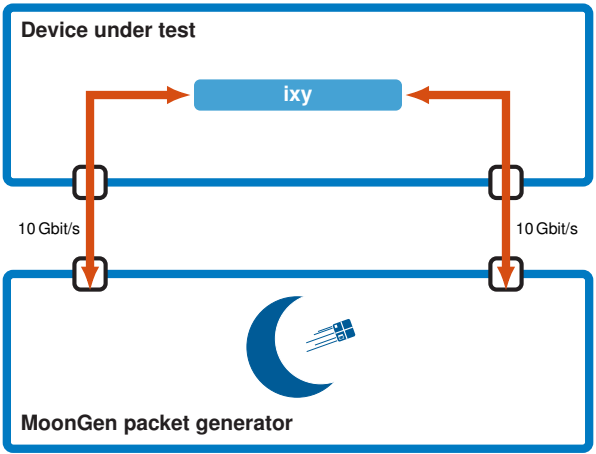
Language comparison: Implementation sizes

Lang.	Lines of code[1]	Lines of C code[1]	Code size (gzip[2])
C	831	831	12.9 kB
Rust	961	0	10.4 kB
Go	1640	0	20.6 kB
C#	1266	34	13.1 kB
Swift	1506	0	15.9 kB
Haskell	1001	0	9.6 kB
OCaml	1177	28	12.3 kB
Python	1242	(Cython) 77	14.2 kB

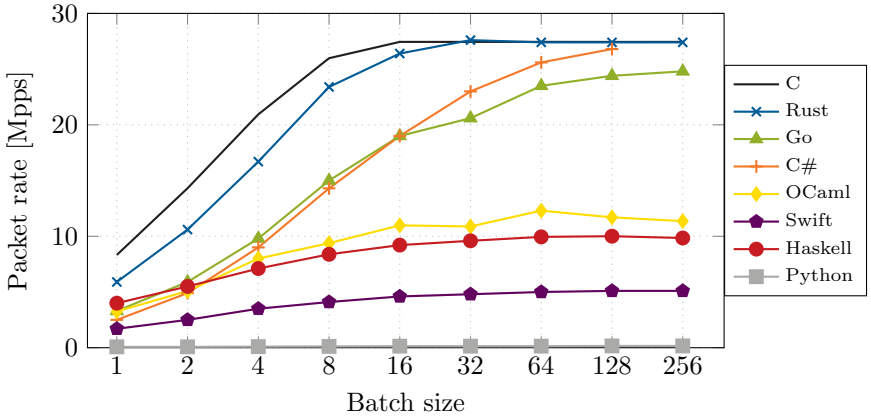
[1] Excluding empty lines and comments, counted with `cloc`
[2] Compression level 6

Table 4: Size of our implementations (w/o register offset constants, stripped features not found in all drivers)

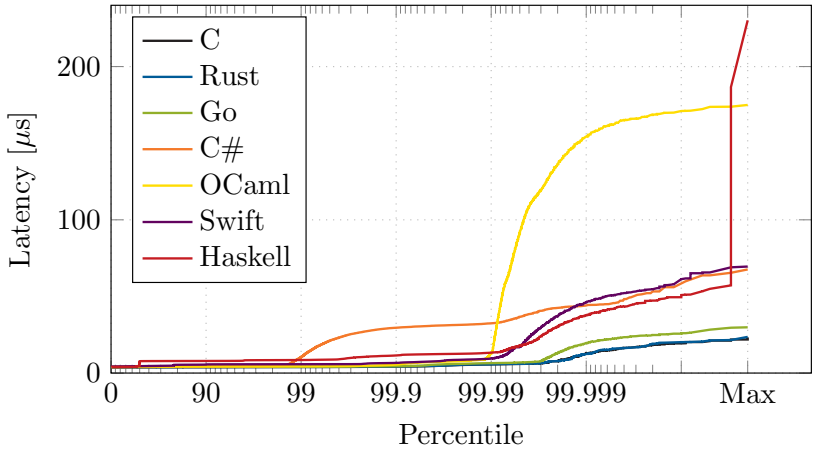
Performance comparison: Test setup



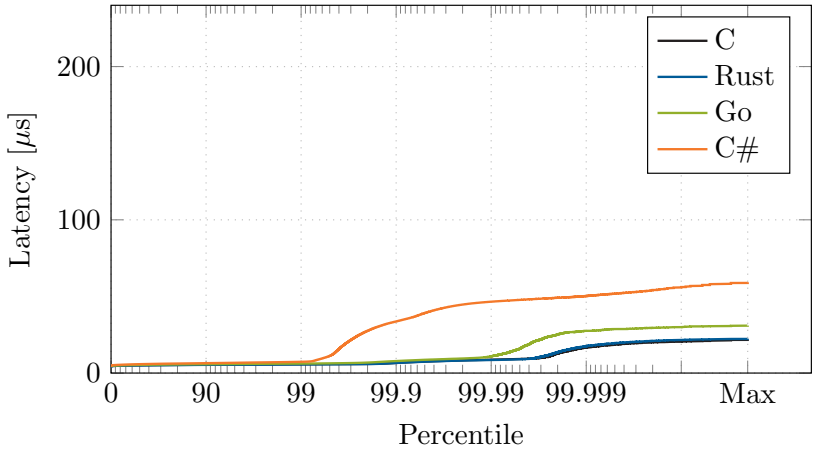
Batching at 3.3 GHz CPU speed



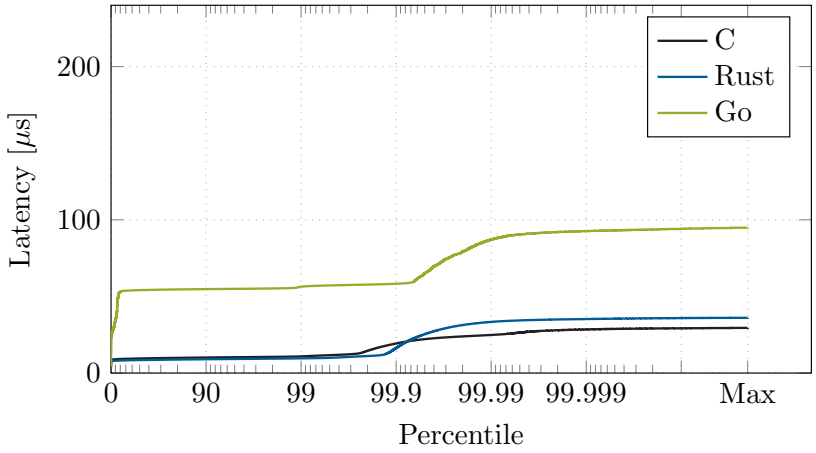
Tail latency at 1 Mpps



Tail latency at 10 Mpps



Tail latency at 20 Mpps



Languages for code in trustworthy systems

- Rust
  - Fast, no garbage collector
  - Low-level: Easy to reason about performance
  - Safest language of the evaluated languages
- Go
  - Fast, low-latency garbage collector
  - Garbage collector tuned for sub-millisecond latency
  - Easier and faster to write than Rust

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  - Easier and faster to write than Rust
- Other languages
  - Implement critical parts in different languages in redundant systems
  - Functional languages for easier formal verification

Conclusions

- High-level languages can prevent entire classes of bugs
- High-level languages are suitable for low-level code
- Drivers are becoming more and more complex, simpler drivers reduce attack surface

- Paper about safer drivers under submission to SIGCOMM
- Code for all drivers available on GitHub:
  `https://github.com/ixy-languages/ixy-languages`

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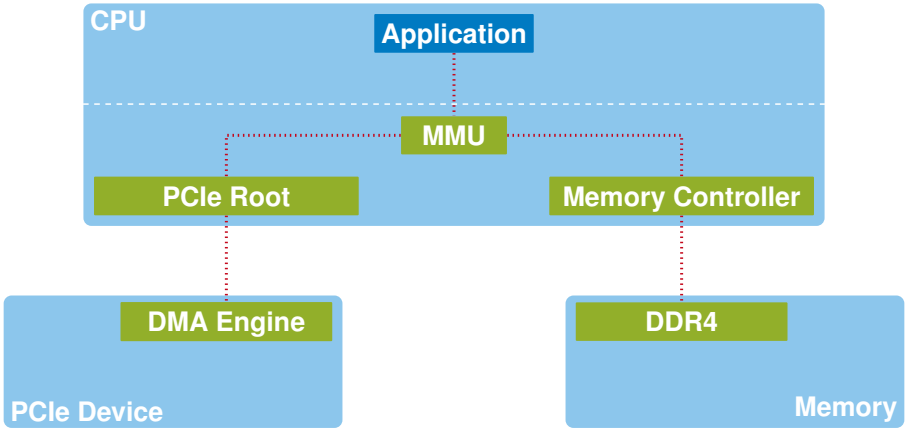
- Yes, we can
- But it's not really secure

Memory access on modern systems



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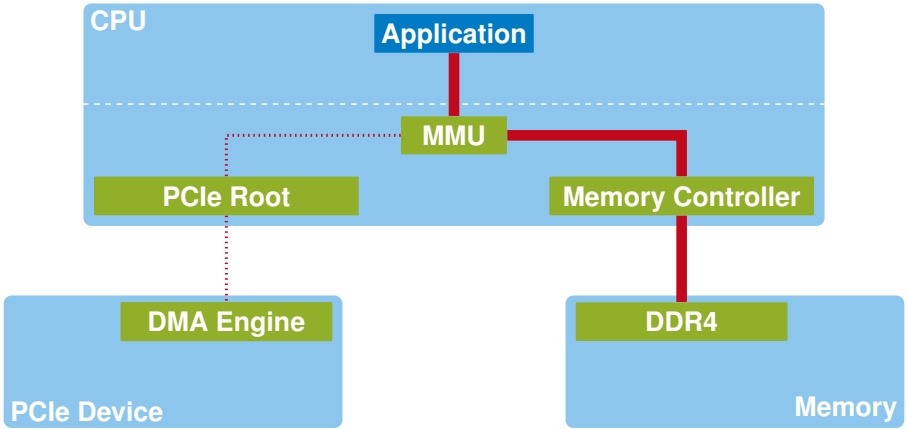

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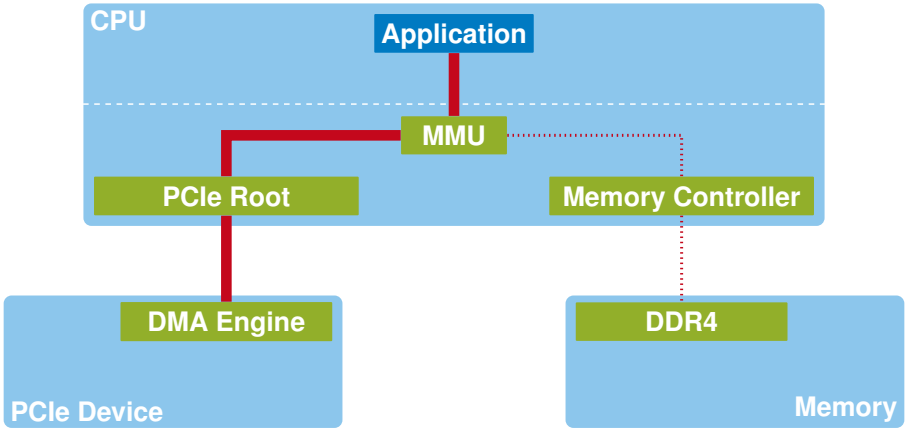

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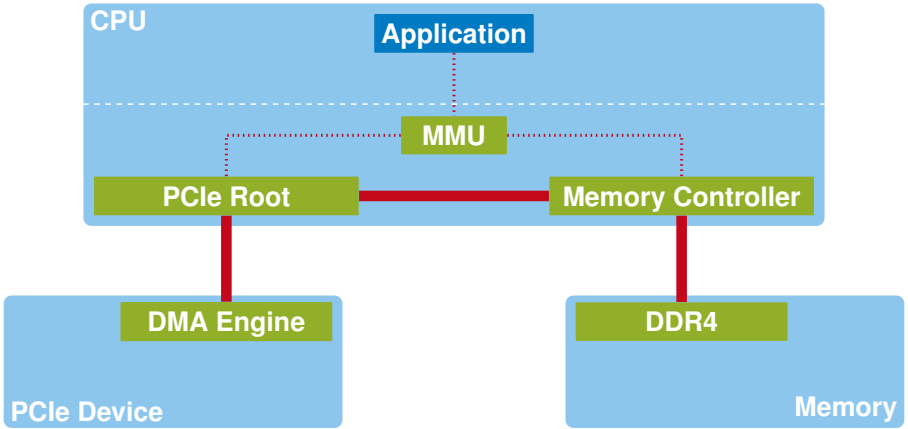

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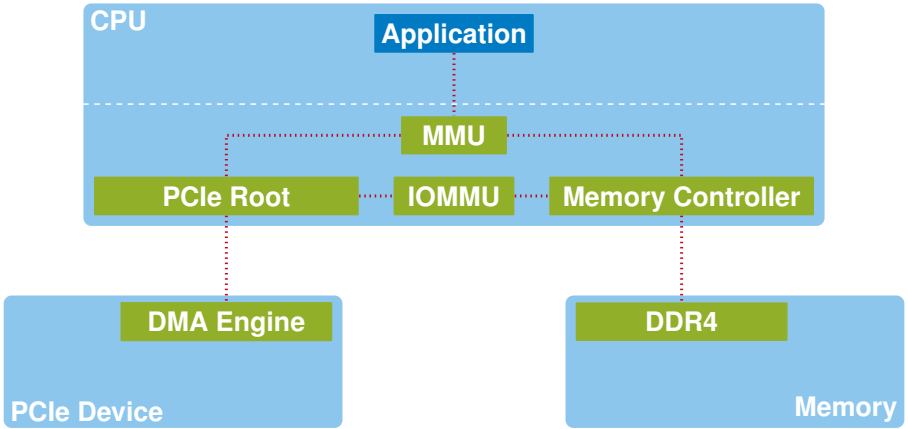

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