Unikernels: Paths to Production & Current Research Trends

Hugo Lefeuvre

The University of Manchester

ASPLOS 2022 Unikraft Tutorial, *March 1st*

A Decade of Unikernels...

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EbbRT (OSDI'16)

Lupine Linux (EuroSys'20)

Compatibility

OSv (ATC'14) HermiTux (VEE'19)

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Why?

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- meet production-grade testing standards
- good debuggability

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- Beyond the single trust domain: compartmentalizing Unikraft?

Integration & Scalability

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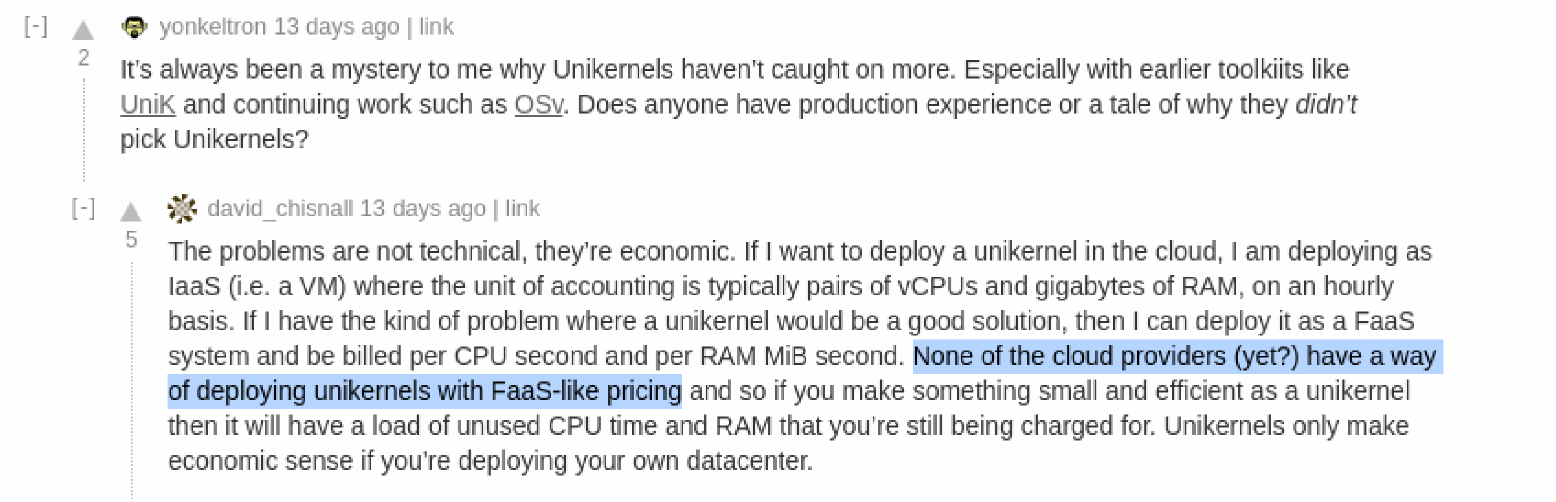
Why no unikernels in production?



[-] ▲ 2 yonkeltron 13 days ago | link

It's always been a mystery to me why Unikernels haven't caught on more. Especially with earlier toolkiits like UniK and continuing work such as OSv. Does anyone have production experience or a tale of why they *didn't* pick Unikernels?

[-] ▲ 5 david_chisnall 13 days ago | link

The problems are not technical, they're economic. If I want to deploy a unikernel in the cloud, I am deploying as IaaS (i.e. a VM) where the unit of accounting is typically pairs of vCPUs and gigabytes of RAM, on an hourly basis. If I have the kind of problem where a unikernel would be a good solution, then I can deploy it as a FaaS system and be billed per CPU second and per RAM MiB second. None of the cloud providers (yet?) have a way of deploying unikernels with FaaS-like pricing and so if you make something small and efficient as a unikernel then it will have a load of unused CPU time and RAM that you're still being charged for. Unikernels only make economic sense if you're deploying your own datacenter.

No good integration.

https://lobste.rs/s/cyyx7a/unikraft_fast_secure_open_source (NOT an official Microsoft comment)

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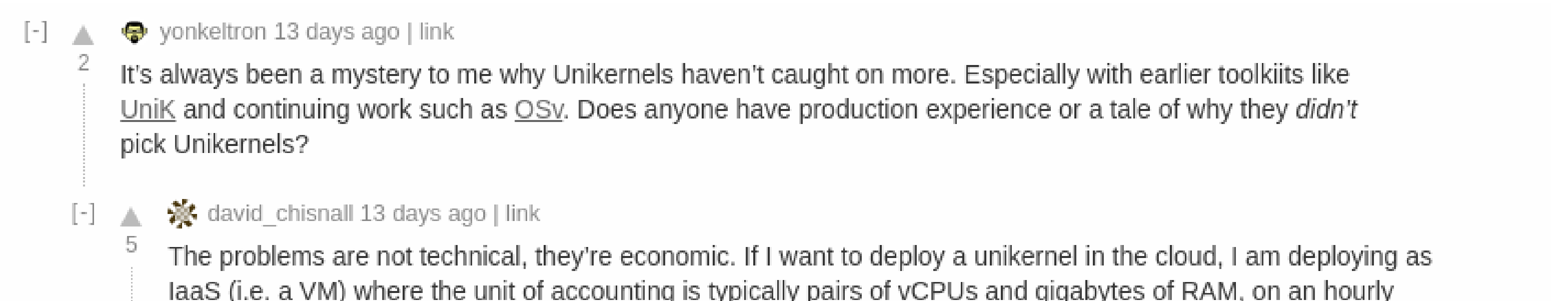

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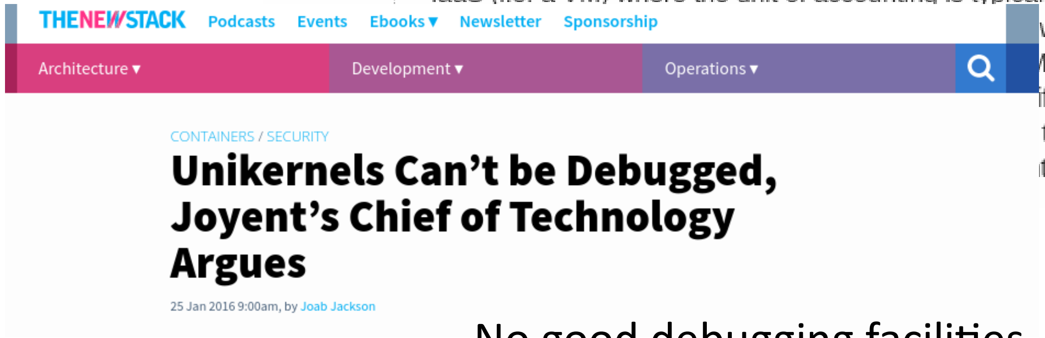

CONTAINERS / SECURITY

Unikernels Can't be Debugged, Joyent's Chief of Technology Argues

25 Jan 2016 9:00am, by Joab Jackson

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Vast engineering effort towards seamless introspection and debugging

S. Kuenzer, M. Rittinghaus @ FOSDEM'22 https://fosdem.org/2022/schedule/event/skuenzer/

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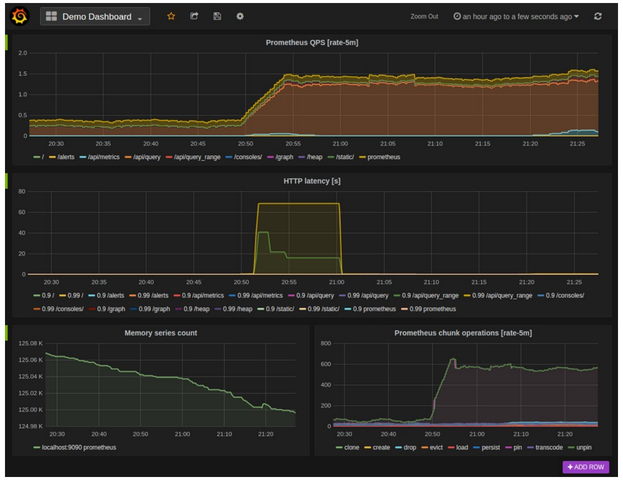

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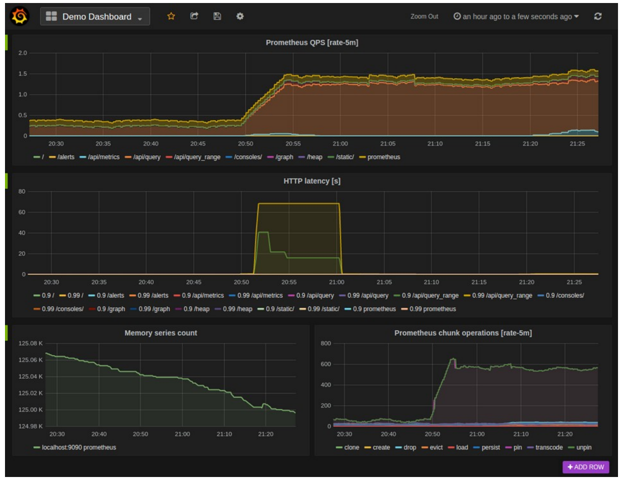

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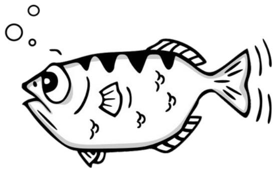

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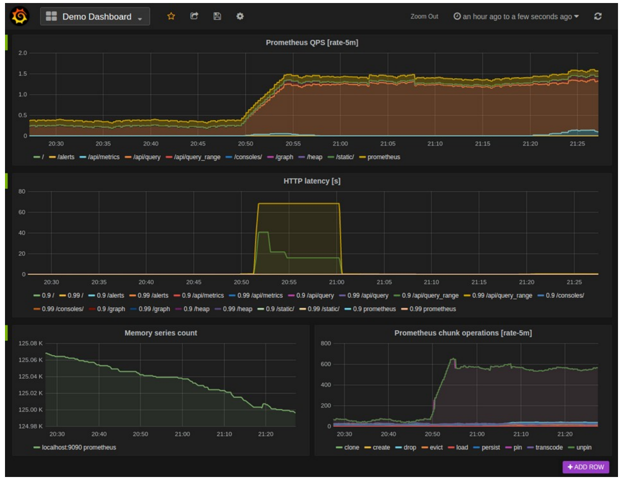

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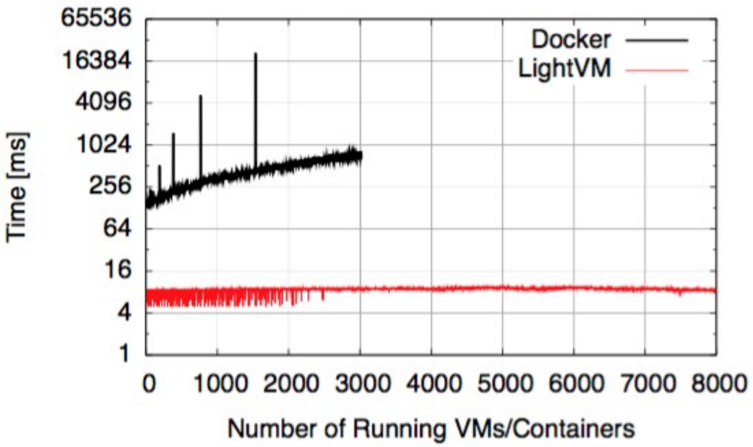

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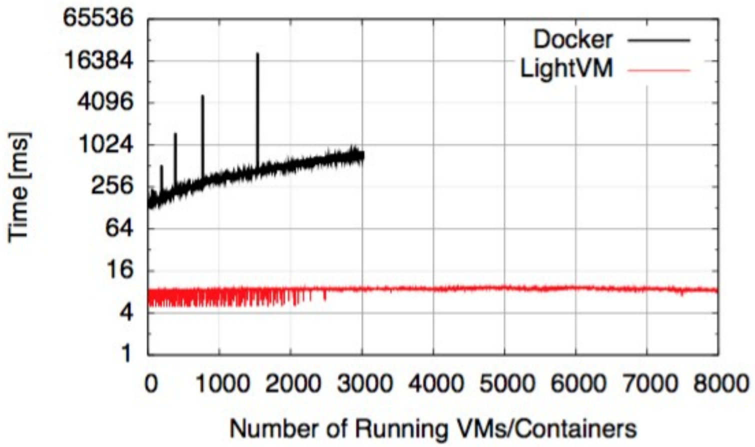

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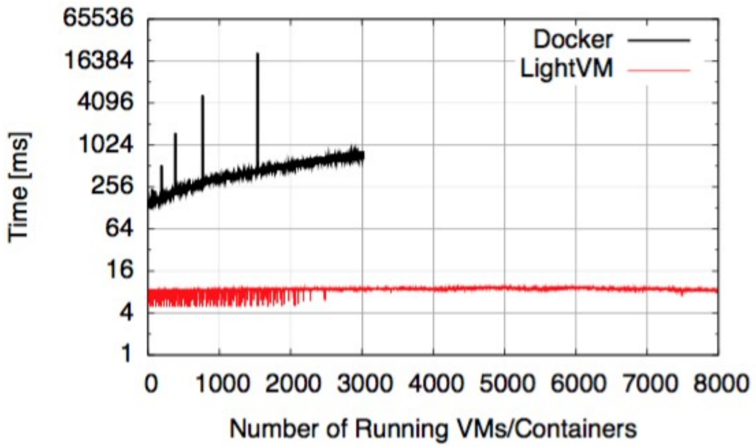

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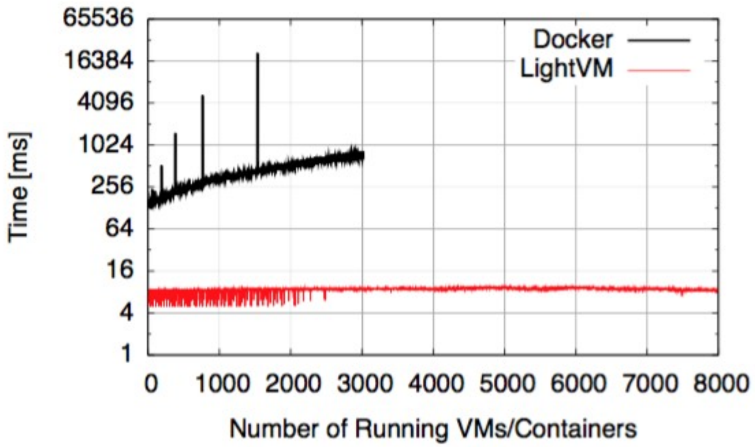
With such density: how do things look on the networking side? Have hypervisors really been thought for this kind of usage?



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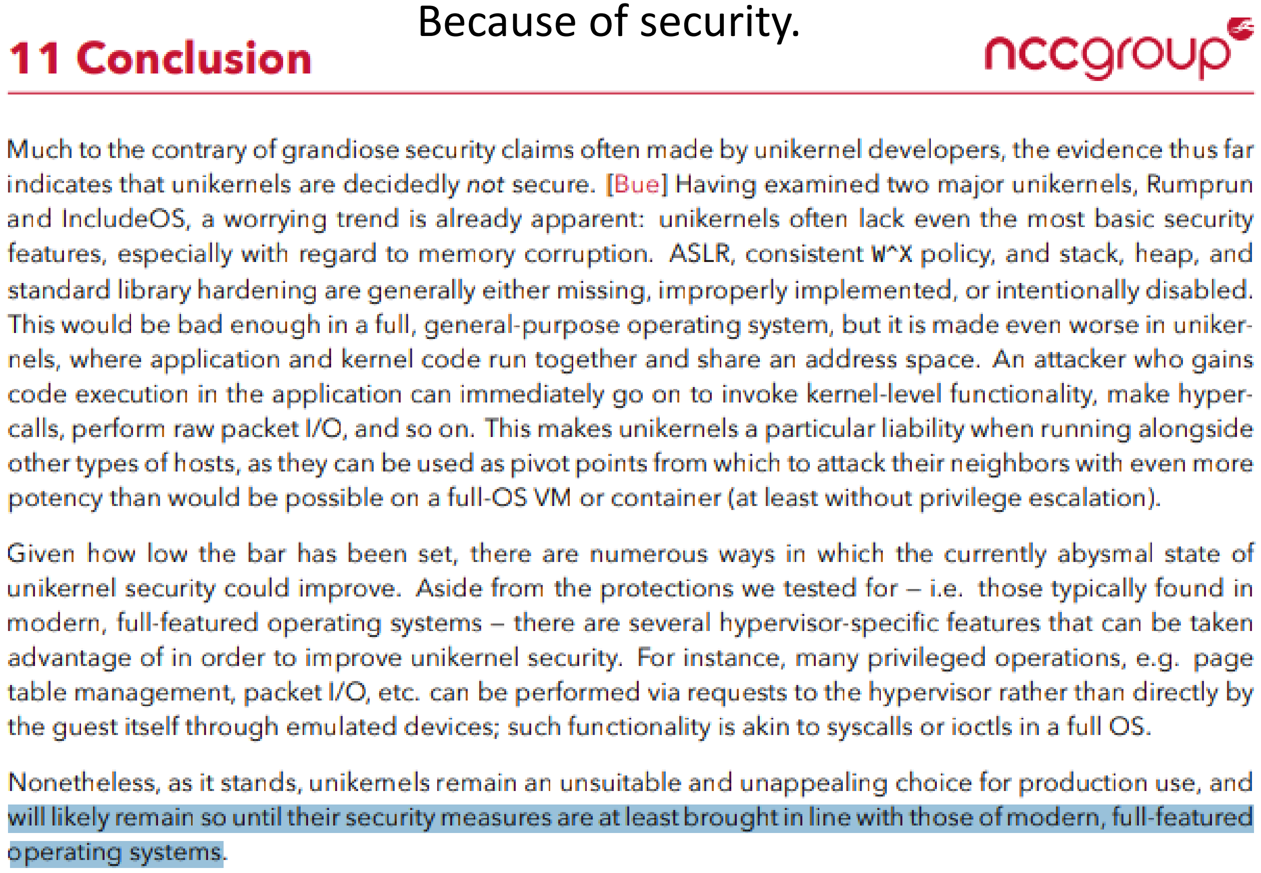
Security & Stability

Security and Stability

Why no unikernels in production?

Because of security.



11 Conclusion

nccgroup

Much to the contrary of grandiose security claims often made by unikernel developers, the evidence thus far indicates that unikernels are decidedly *not* secure. [Bue] Having examined two major unikernels, Rumprun and IncludeOS, a worrying trend is already apparent: unikernels often lack even the most basic security features, especially with regard to memory corruption. ASLR, consistent `W^X` policy, and stack, heap, and standard library hardening are generally either missing, improperly implemented, or intentionally disabled. This would be bad enough in a full, general-purpose operating system, but it is made even worse in unikernels, where application and kernel code run together and share an address space. An attacker who gains code execution in the application can immediately go on to invoke kernel-level functionality, make hypercalls, perform raw packet I/O, and so on. This makes unikernels a particular liability when running alongside other types of hosts, as they can be used as pivot points from which to attack their neighbors with even more potency than would be possible on a full-OS VM or container (at least without privilege escalation).

Given how low the bar has been set, there are numerous ways in which the currently abysmal state of unikernel security could improve. Aside from the protections we tested for – i.e. those typically found in modern, full-featured operating systems – there are several hypervisor-specific features that can be taken advantage of in order to improve unikernel security. For instance, many privileged operations, e.g. page table management, packet I/O, etc. can be performed via requests to the hypervisor rather than directly by the guest itself through emulated devices; such functionality is akin to syscalls or ioctls in a full OS.

Nonetheless, as it stands, unikemels remain an unsuitable and unappealing choice for production use, and will likely remain so until their security measures are at least brought in line with those of modern, full-featured operating systems.

https://www.nccgroup.com/globalassets/our-research/us/whitepapers/2019/ncc_group-assessing_unikernel_security.pdf

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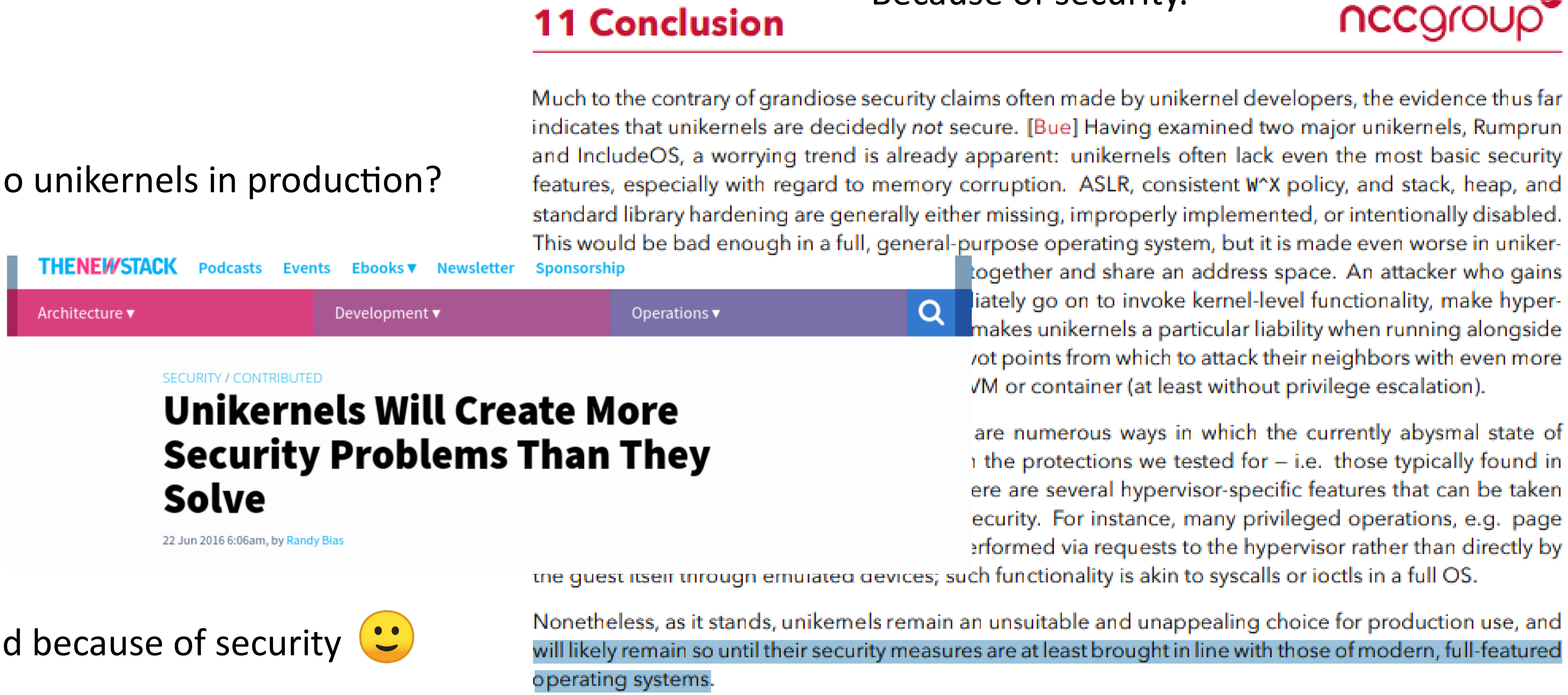

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SECURITY / CONTRIBUTED

Unikernels Will Create More Security Problems Than They Solve

22 Jun 2016 6:06am, by Randy Bias

...and because of security 🙂

https://www.nccgroup.com/globalassets/our-research/us/whitepapers/2019/ncc_group-assessing_unikernel_security.pdf
https://thenewstack.io/unikernels-will-create-security-problems-solve/

Getting in Line with Mainstream OSes

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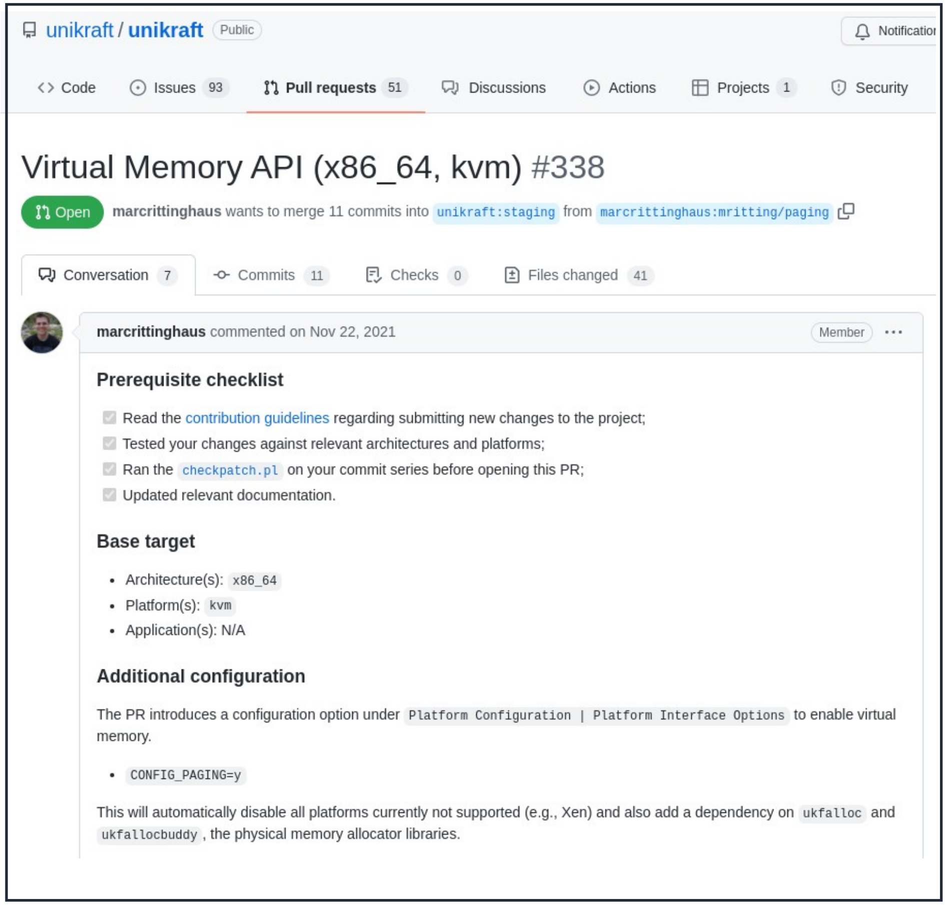
Write or Execute



Virtual Memory API (x86_64, kvm) #338

marcrittinghaus wants to merge 11 commits into `unikraft:staging` from `marcrittinghaus:mritting/paging`

marcrittinghaus commented on Nov 22, 2021

Prerequisite checklist

- ☑ Read the contribution guidelines regarding submitting new changes to the project;
- ☑ Tested your changes against relevant architectures and platforms;
- ☑ Ran the `checkpatch.pl` on your commit series before opening this PR;
- ☑ Updated relevant documentation.

Base target

- Architecture(s): `x86_64`
- Platform(s): `kvm`
- Application(s): N/A

Additional configuration

The PR introduces a configuration option under `Platform Configuration | Platform Interface Options` to enable virtual memory.

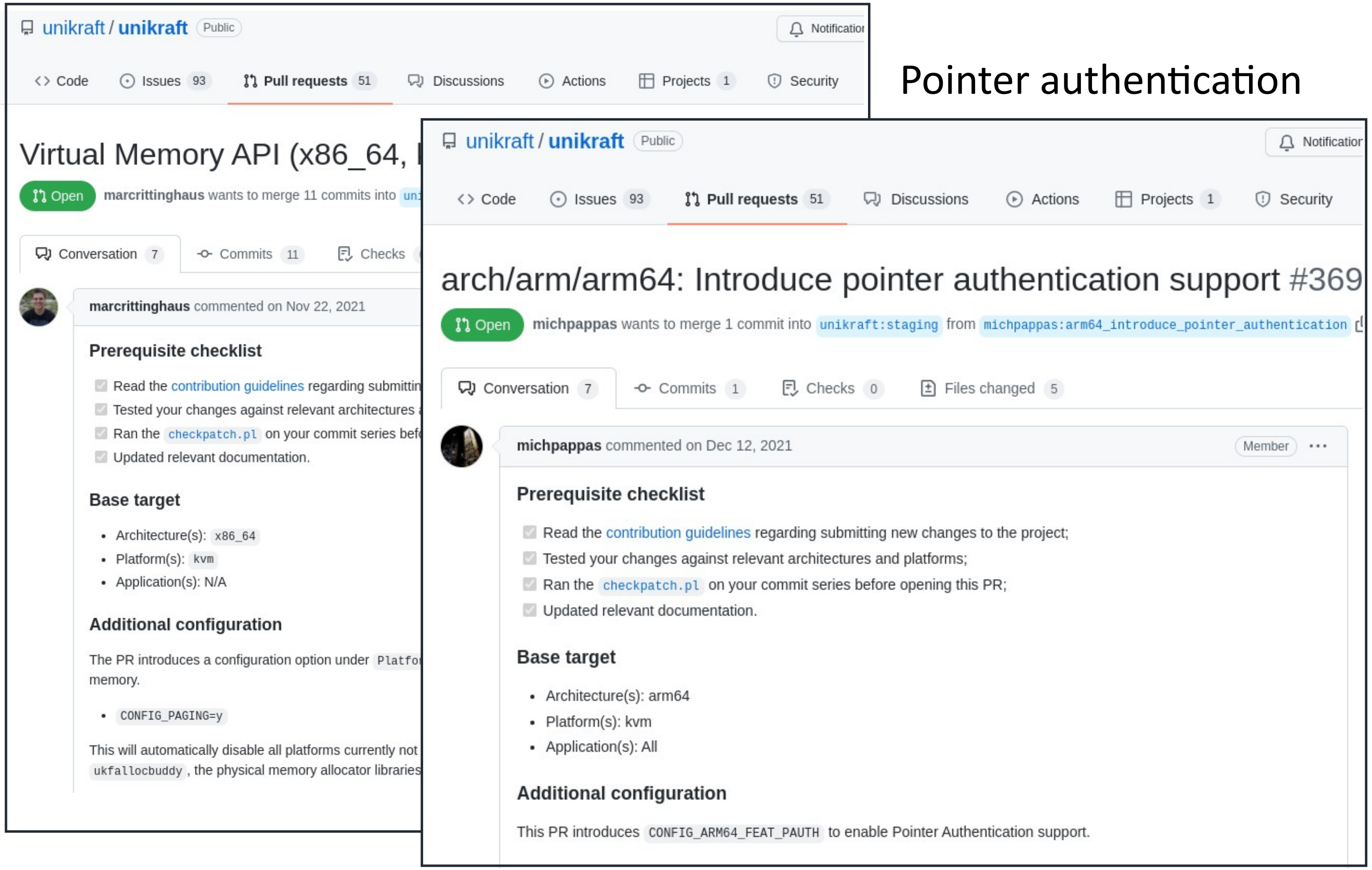
- `CONFIG_PAGING=y`

This will automatically disable all platforms currently not supported (e.g., Xen) and also add a dependency on `ukfalloc` and `ukfallocbuddy`, the physical memory allocator libraries.

Getting in Line with Mainstream OSes

Write or Execute

Pointer authentication



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The PR introduces a configuration option under `Platfo` memory.

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This will automatically disable all platforms currently not `ukfallocbuddy`, the physical memory allocator libraries

arch/arm/arm64: Introduce pointer authentication support #369

michpappas wants to merge 1 commit into `unikraft:staging` from `michpappas:arm64_introduce_pointer_authentication`

michpappas commented on Dec 12, 2021

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Base target

- Architecture(s): arm64
- Platform(s): kvm
- Application(s): All

Additional configuration

This PR introduces `CONFIG_ARM64_FEAT_PAUTH` to enable Pointer Authentication support.

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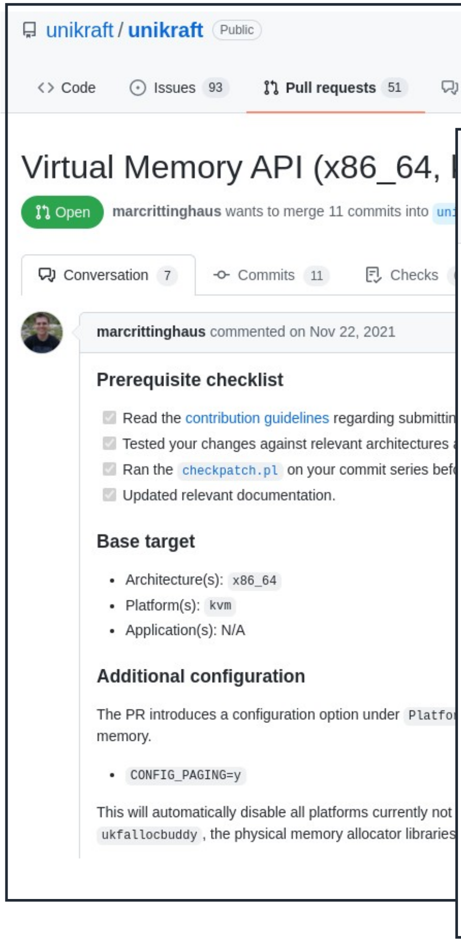

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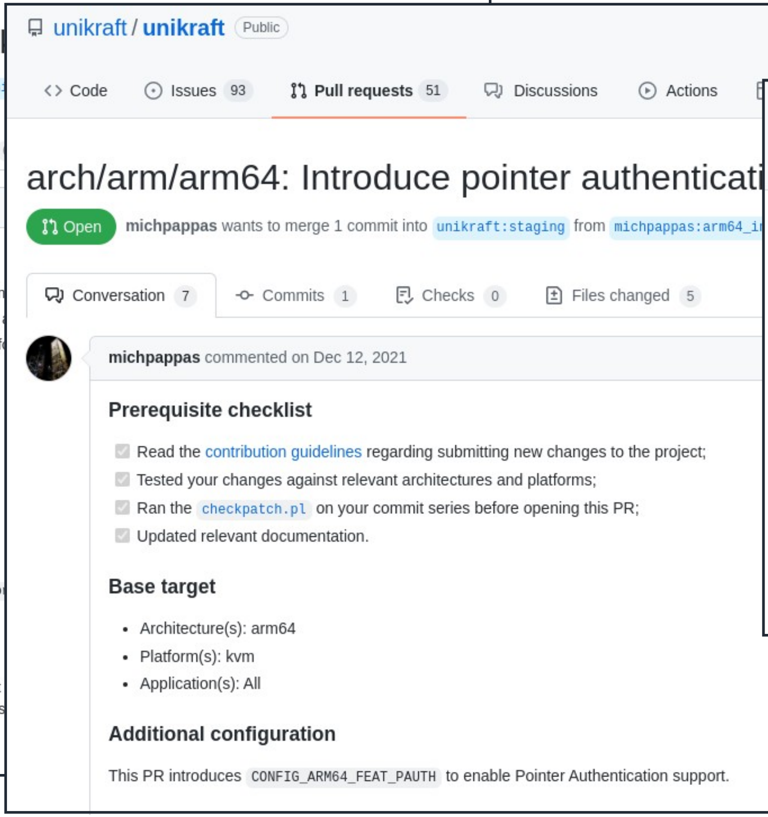

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- ☑ Read the contribution guidelines regarding submitting new changes to the project;
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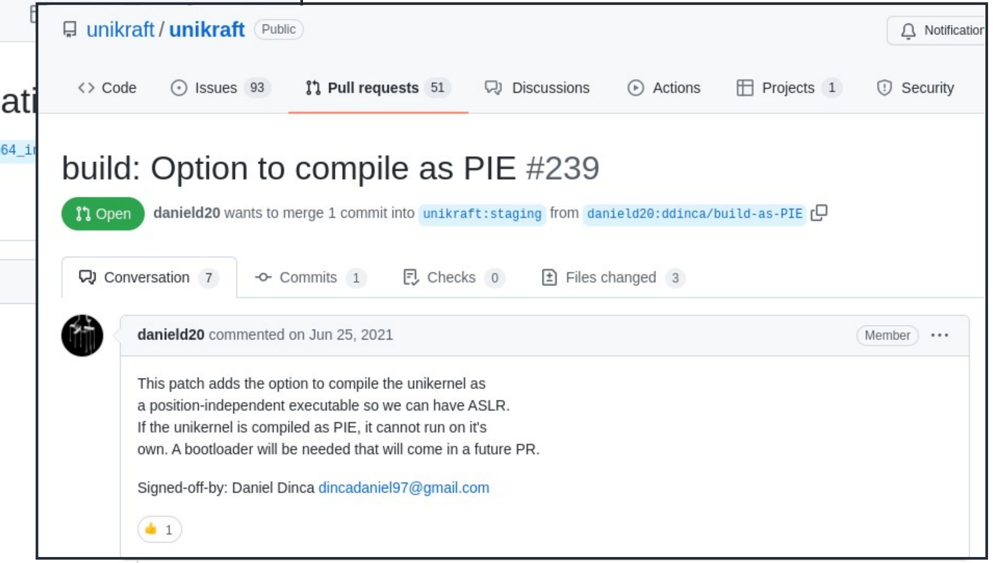
Base target

- Architecture(s): arm64
- Platform(s): kvm
- Application(s): All

Additional configuration

This PR introduces `CONFIG_ARM64_FEAT_PAUTH` to enable Pointer Authentication support.

ASLR



build: Option to compile as PIE #239

Open danield20 wants to merge 1 commit into `unikraft:staging` from `danield20:ddinca/build-as-PIE`

danield20 commented on Jun 25, 2021

This patch adds the option to compile the unikernel as
a position-independent executable so we can have ASLR.
If the unikernel is compiled as PIE, it cannot run on it's
own. A bootloader will be needed that will come in a future PR.

Signed-off-by: Daniel Dinca dincadaniel97@gmail.com

Getting in Line with Mainstream OSes

Write or Execute

... and stack protection, KASan, etc.

Pointer authentication

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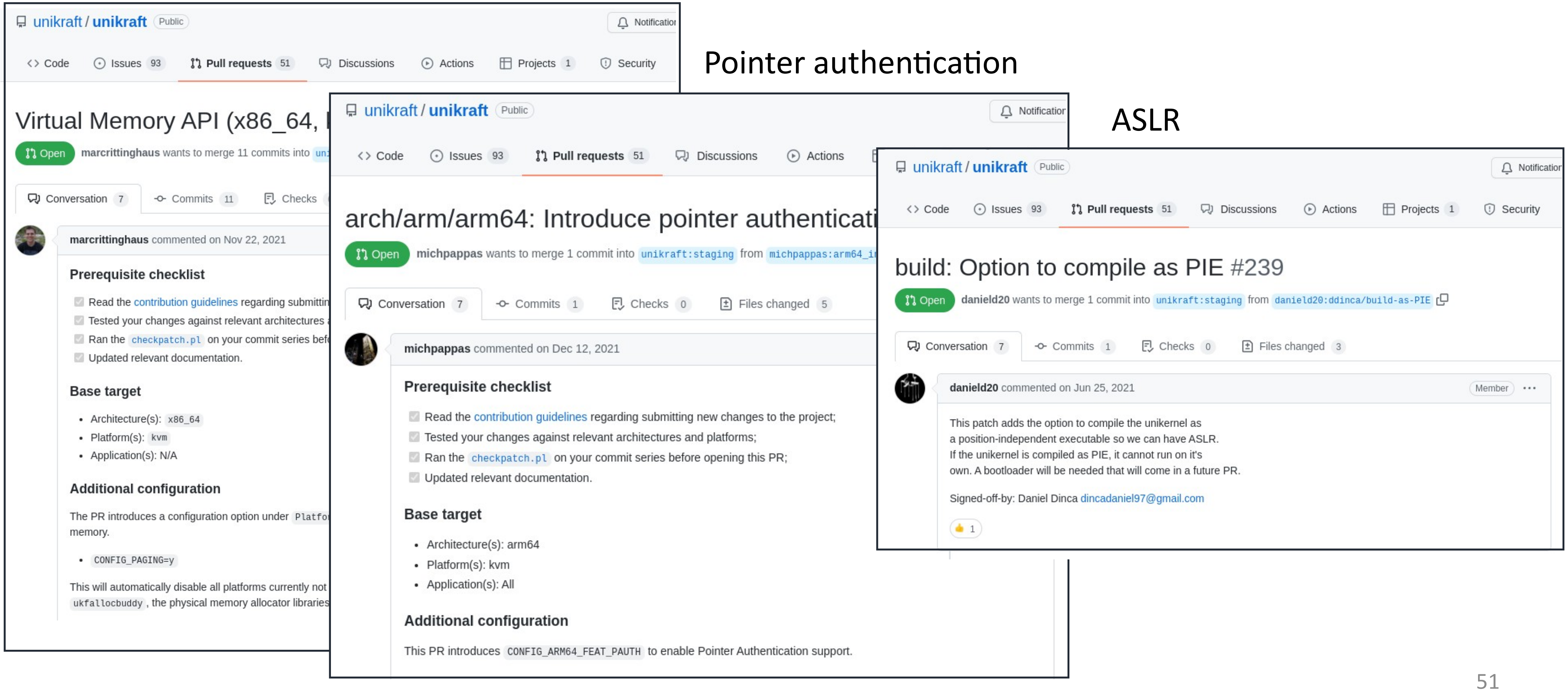

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Conversation 7 · Commits 11 · Checks

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- `CONFIG_PAGING=y`

This will automatically disable all platforms currently not `ukfallocbuddy`, the physical memory allocator libraries

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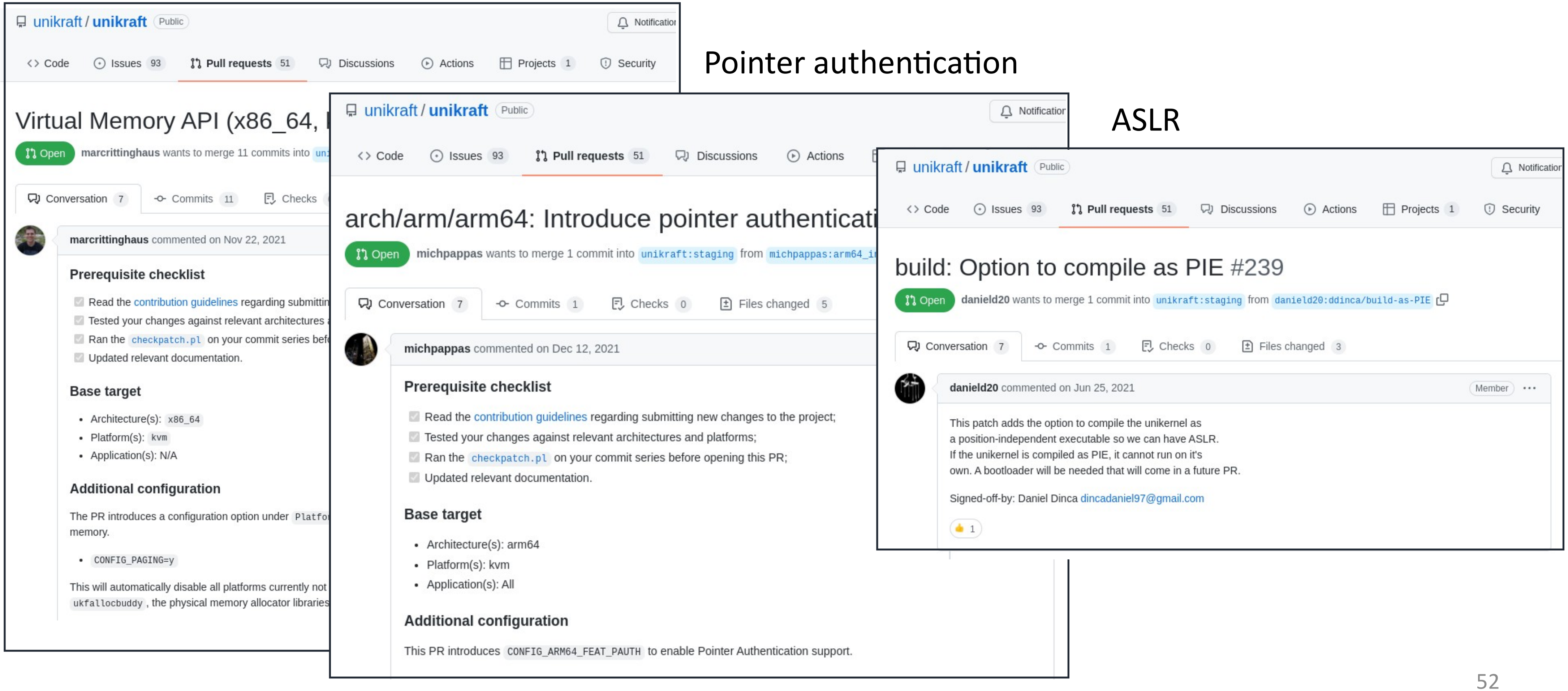

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Concourse

Significant efforts on continuous testing:

- CI/CD pipeline tests patches systematically (Concourse)
- Application-level tests but also kernel unit-tests (`uktest`)

A. Jung @ FOSDEM'22
https://fosdem.org/2022/schedule/event/massive_unikernel_matrices_with_unikraft_concourse_and_more/

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  - Coverage measurement (no Kcov, porting to gcov not without changes)
  - Not every system call is fully implemented
- How does unikernel fuzzing impact the architecture of fuzzers?
- How to design a fuzzer that's **ready to "plug and play" in any POSIX OS**?

Not "just" a matter of porting Syzkaller to Unikraft

In the Works: Automatic Specialization

Another end of the "testing" topic: how do you determine **how good a configuration really is**?

A. Jung et al. @ APSys'21 https://www.youtube.com/watch?v=YLf86gcHW4E

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Unikernels pitch specialization:

- Your best Nginx configuration is not your best SQLite configuration
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The number of possible configurations: astronomical scale

- Small subset of configuration options (Nginx) ~ 10^{13}
- How do you explore this? Can you use optimization algorithms? ML?

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And at the same time we see (re-)appearing a lot of lightweight isolation mechanisms (protection keys, HW capabilities, SFI, etc.)

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This is what initially motivated our work FlexOS: can we reconcile unikernels/libOSes with isolation to obtain a new OS model that offers not only specialization **towards performance, but also towards safety**?

H. Lefeuvre et al. @ ASPLOS'22, come to our talk Thursday morning!
(also @ FOSDEM'22 https://fosdem.org/2022/schedule/event/tee_flexos/)

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This is what initially motivated our work FlexOS: can we reconcile unikernels/libOSes with isolation to obtain a new OS model that offers not only specialization **towards performance, but also towards safety**?

Other groups explored this direction: CubicleOS (also ASPLOS, 2021). Explore intra-unikernel isolation with Intel MPK.

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How about Compatibility?

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Growing number of supported system calls: now 170+
As a point of comparison, Graphene (Gramine) also supports about ~170

To be clear: Unikraft is neither fully Linux compatible, nor fully POSIX compliant!

- The good old `fork()` problem
- Not all system calls are fully implemented

But **do you really need to be fully compatible** to be useful?

Graphene/Gramine: https://gramineproject.io/

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Many applications that use unsupported features tend to be bad candidates for unikernelization anyways (system admin tools, heavily multiprocess apps that cannot use threads).

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And in 2022, it is.

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Given the benefits of Unikraft, a week of porting is a minor annoyance.
All you need is a good application test-suite (but you have one, right? 🙂)

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Conclusion

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Unikraft is not there yet. But it's progressing, and we hope to see it reaching full maturity in the coming year

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Over time, doing all this engineering proved **fruitful on the research side**

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What will the broader systems community build with Unikraft?

Pushing Unikernels to Production!

Unikraft Community: https://unikraft.org/
Unikraft Cloud: https://unikraft.io/
Code: https://github.com/unikraft