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Virtualization at the Edge

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Laboratory for High-Performance Experimental Systems and Architecture (HExSA)

Argonne/IIT Research Seminar - March 30, 2022

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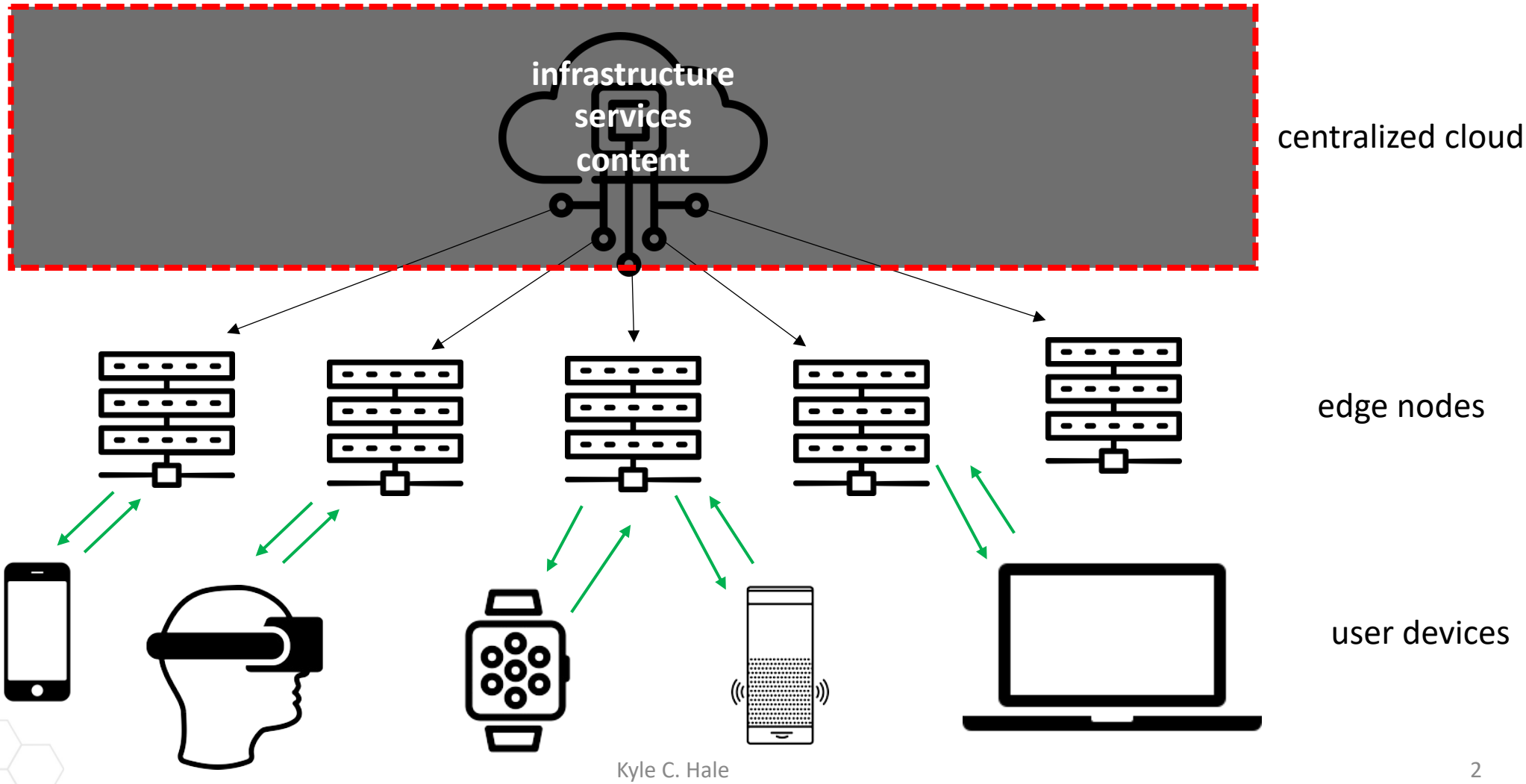
The Cloud is Decentralizing: Services and Infrastructure at the Edge



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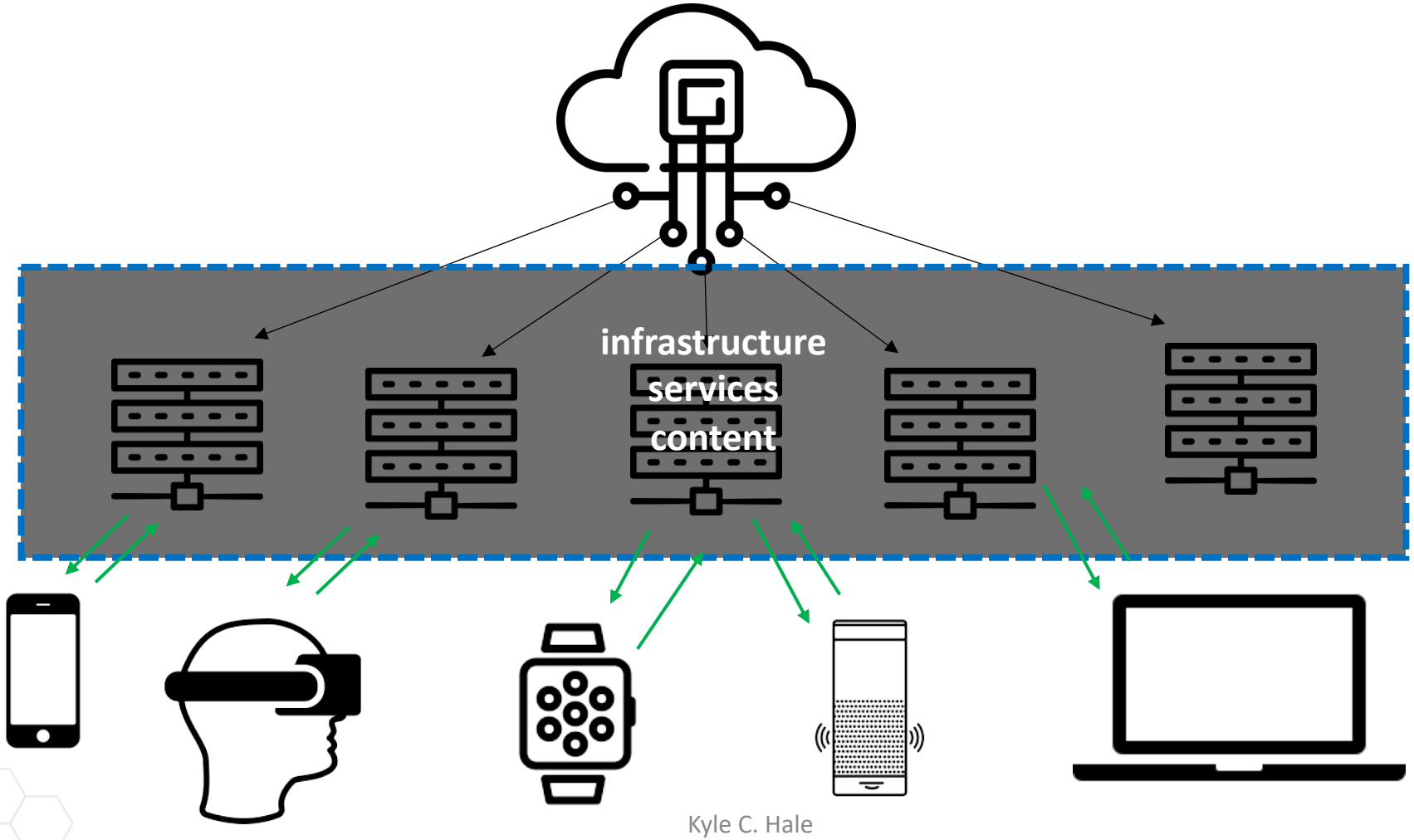

centralized cloud

edge nodes

user devices

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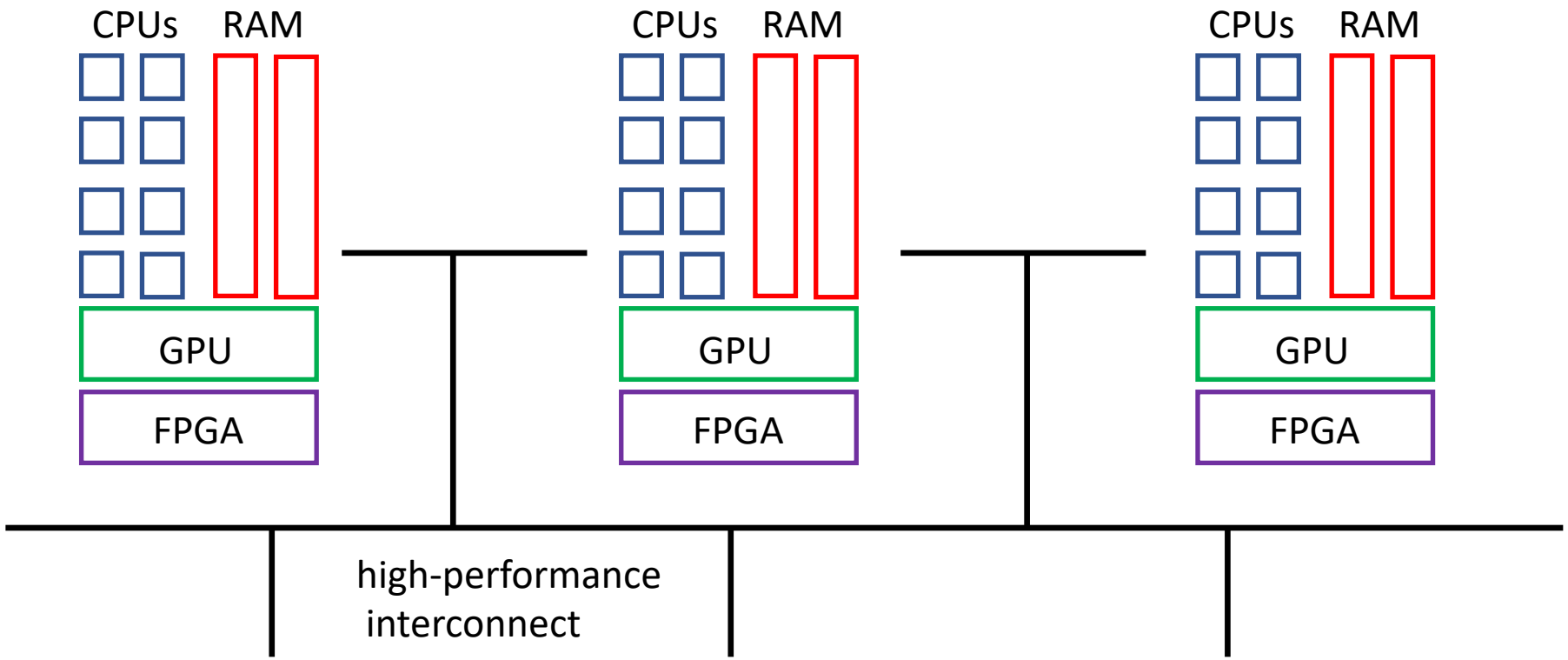
Resources are becoming *disaggregated* in the datacenter



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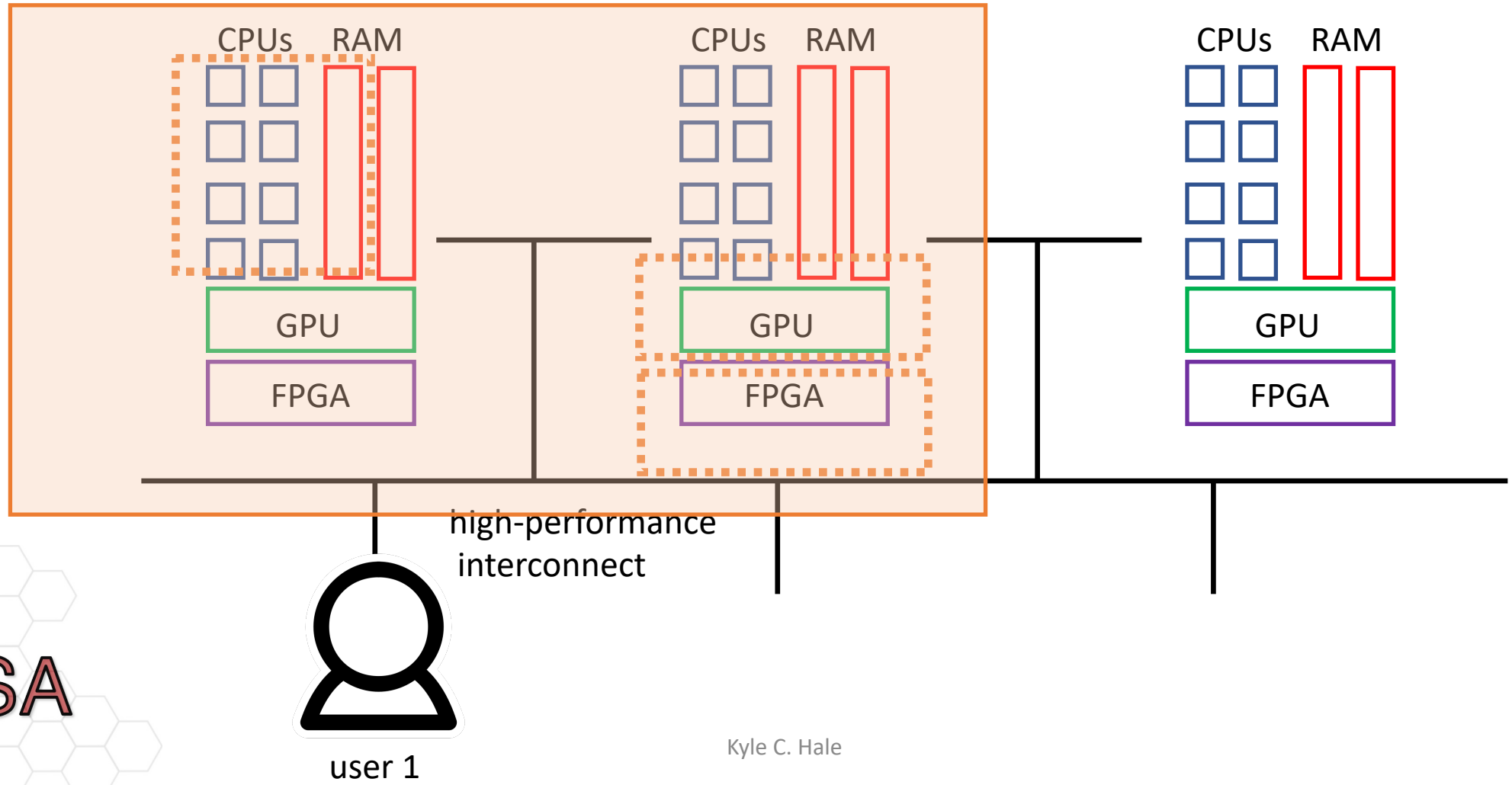

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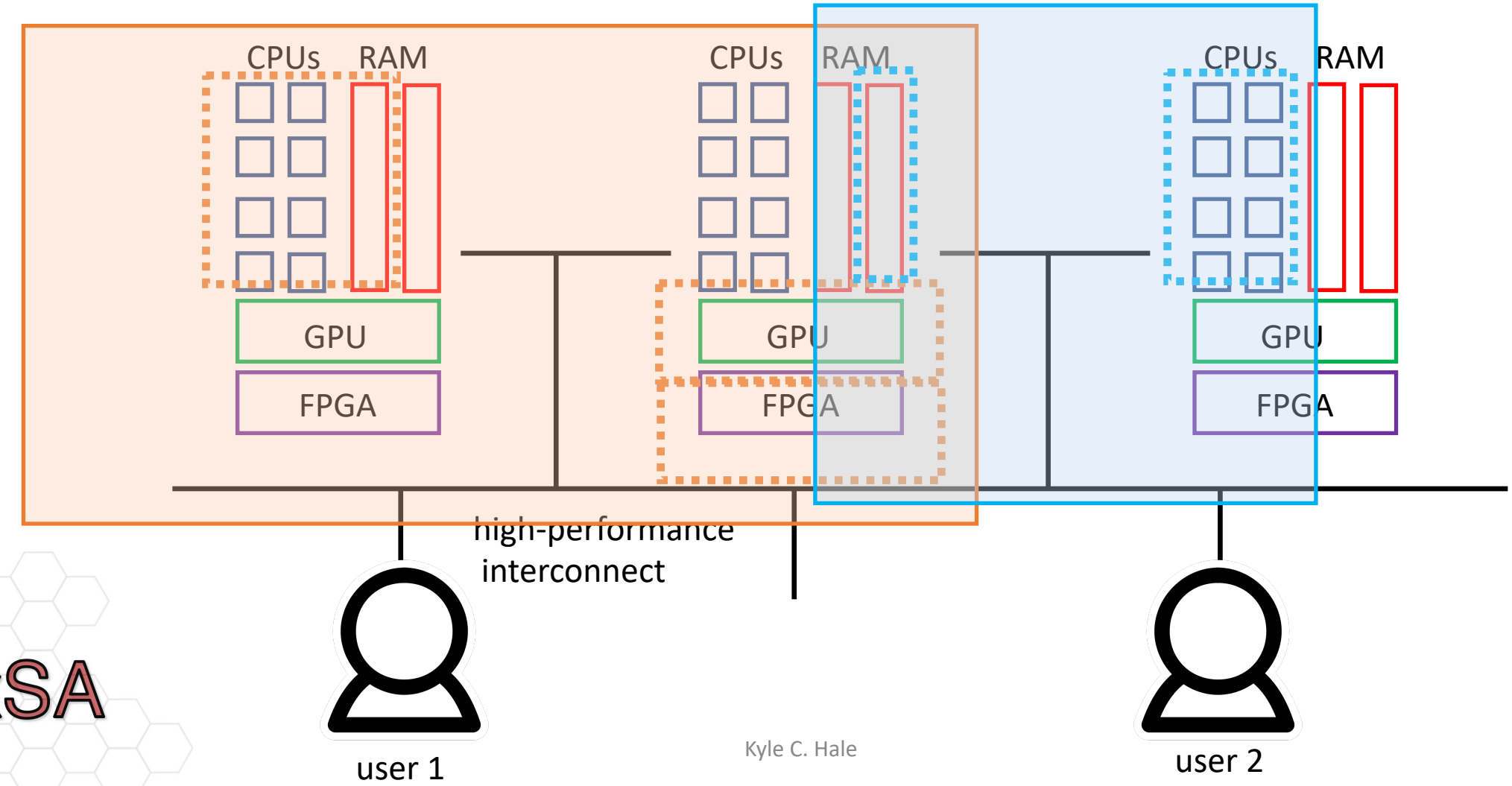

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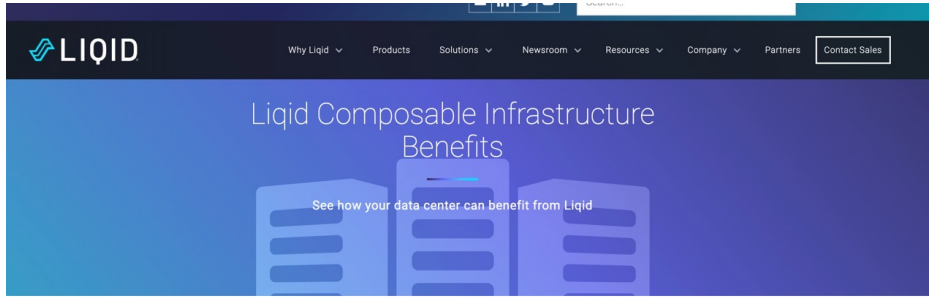
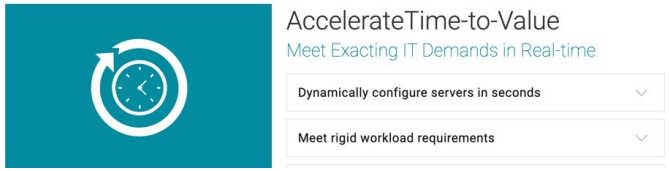
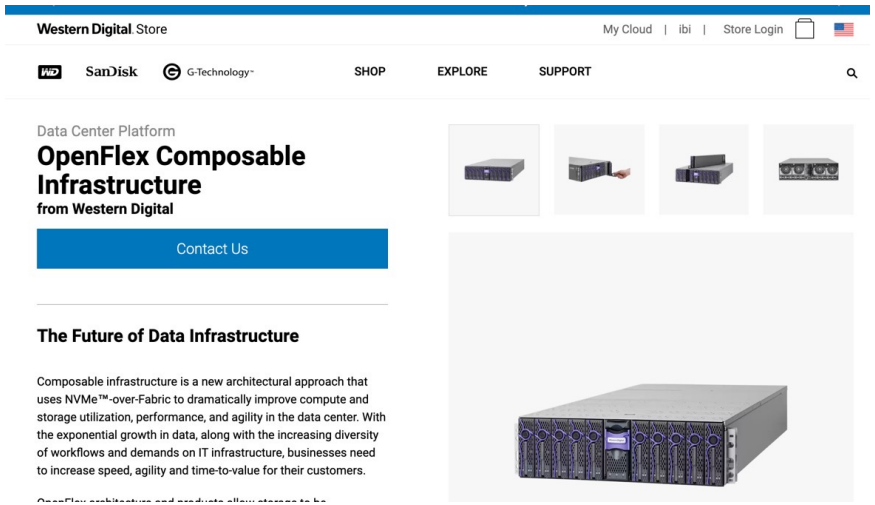
Composable Infrastructure

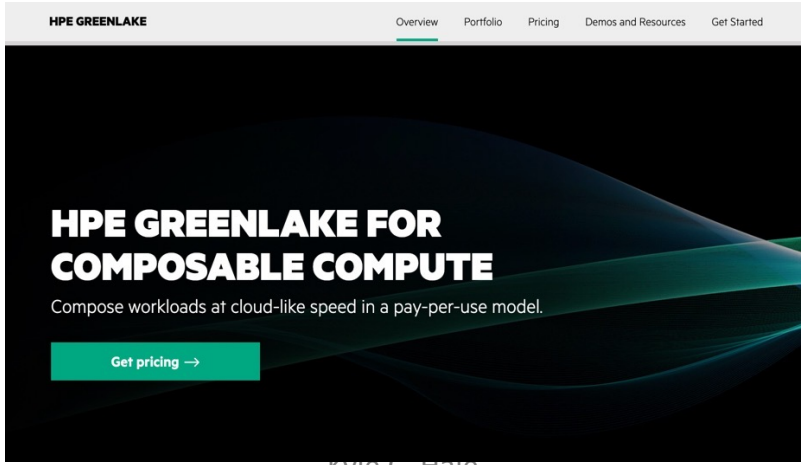




source: https://www.liqid.com/why-liqid/benefits



source: https://www.westerndigital.com/products/data-center-platforms/openflex-composable-infrastructure



https://www.hpe.com/us/en/greenlake/composable-compute.html

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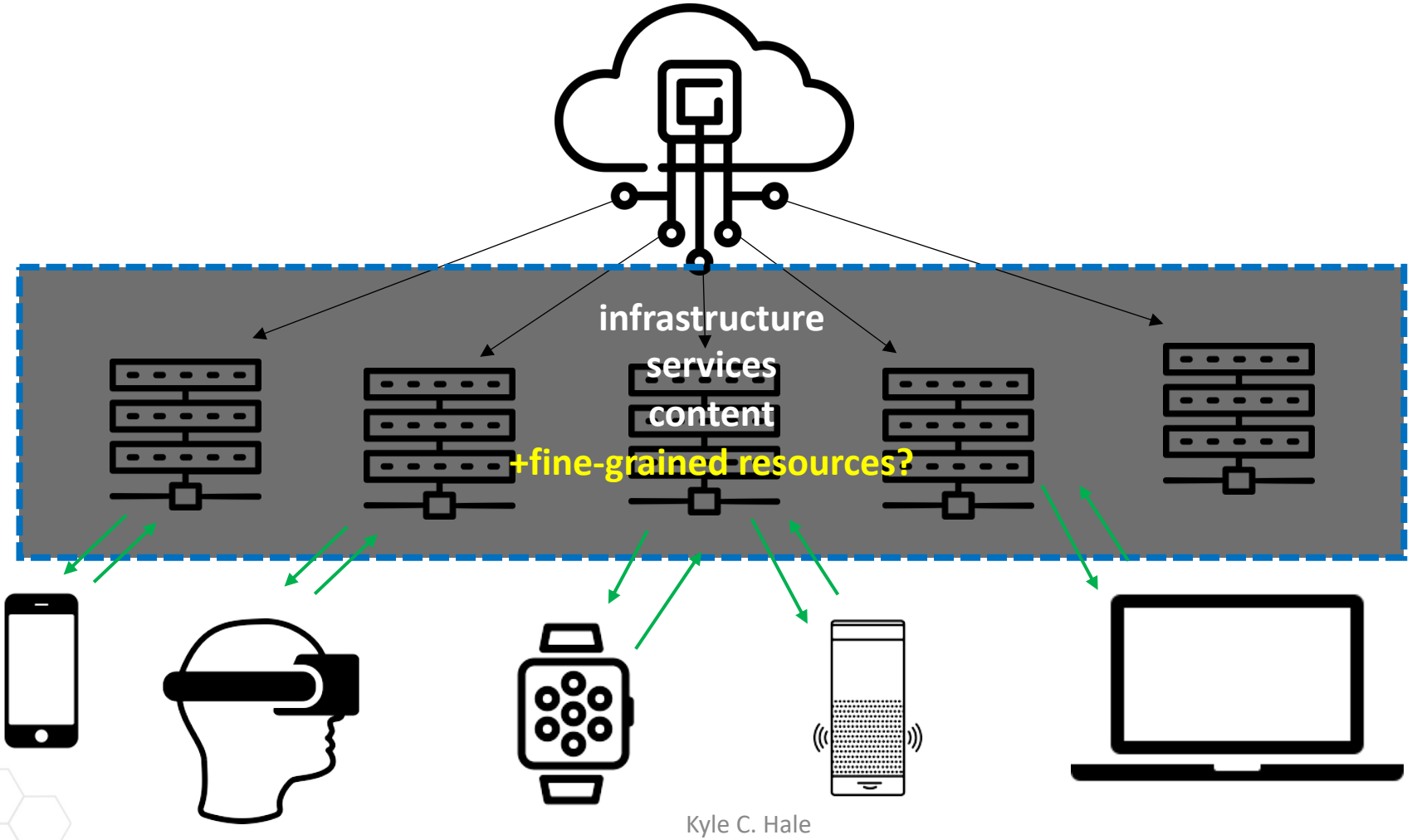
Disaggregation at the Edge



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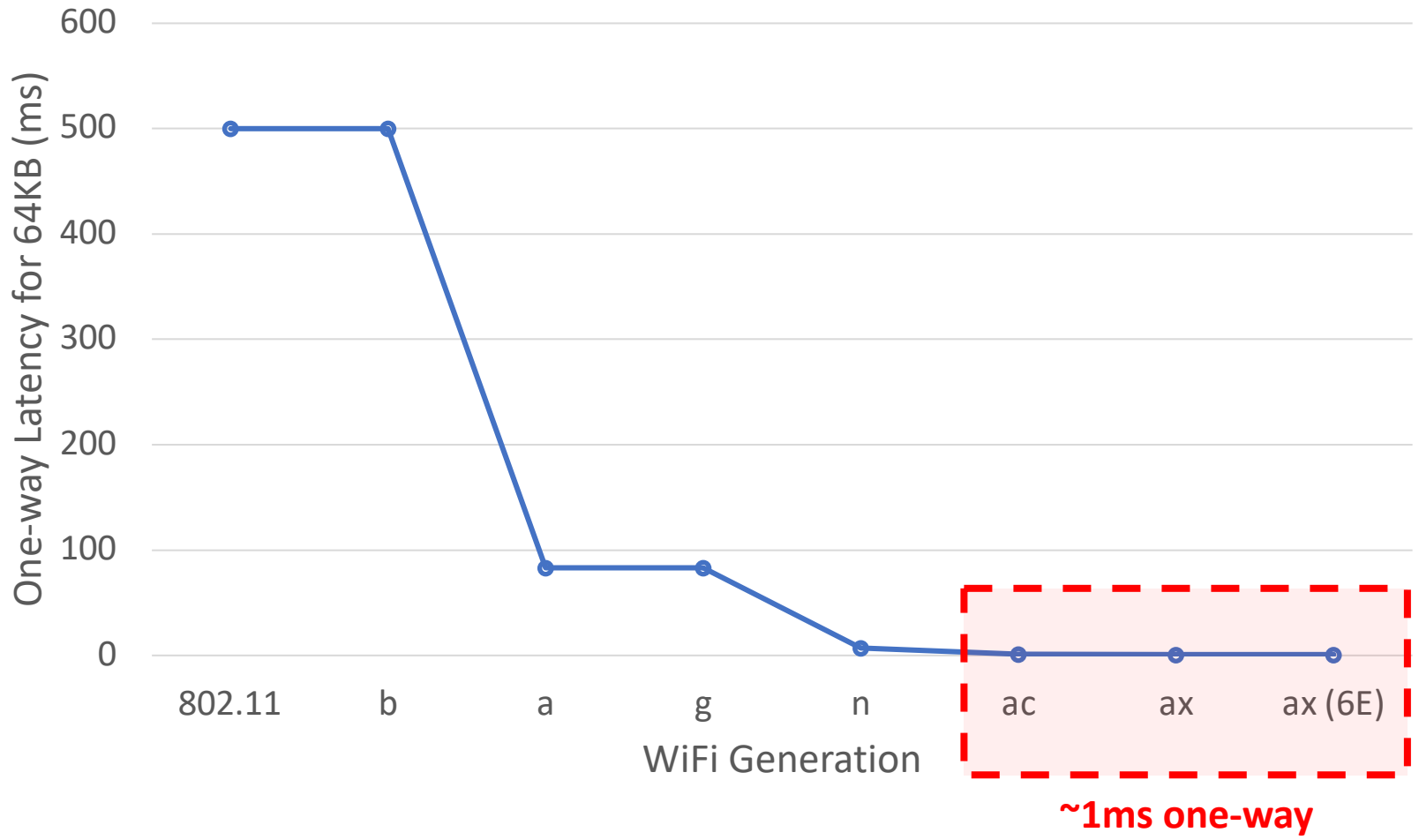
To date, there have been no compelling mass-market applications that require low latencies that cannot be achieved as a web service and that also are too computationally or energy intensive for modern smart phones to run locally. This might be a "chicken or the egg" problem: the lack of cyber foraging infrastructure could potentially be hindering the development of such applications. Later, we discuss one emerging class of applications that could prove to be the compelling application that cyber foraging needs.

R.K. Balan and J. Flinn, "Cyber Foraging Fifteen Years Later," IEEE Pervasive Computing, 16(3), July 2017.

What's Changed?

- Virtualization technology has improved significantly
- Infrastructure provisioning has become more sophisticated (NB serverless research)
- Composable infrastructure
- Hardware design more democratic
- AR/VR/XR is here

…also, wireless latency continues to drop



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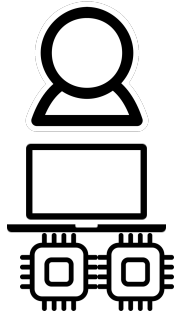
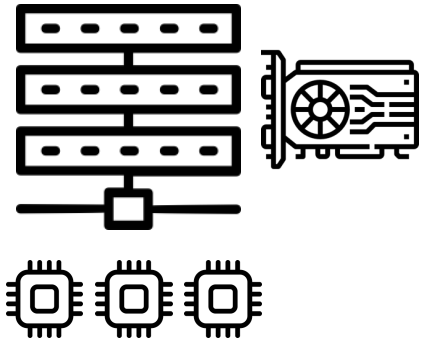
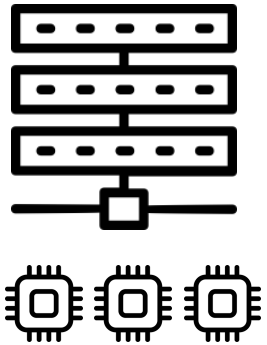
Ephemeral Single-System Image at the Edge





location 1



location 2

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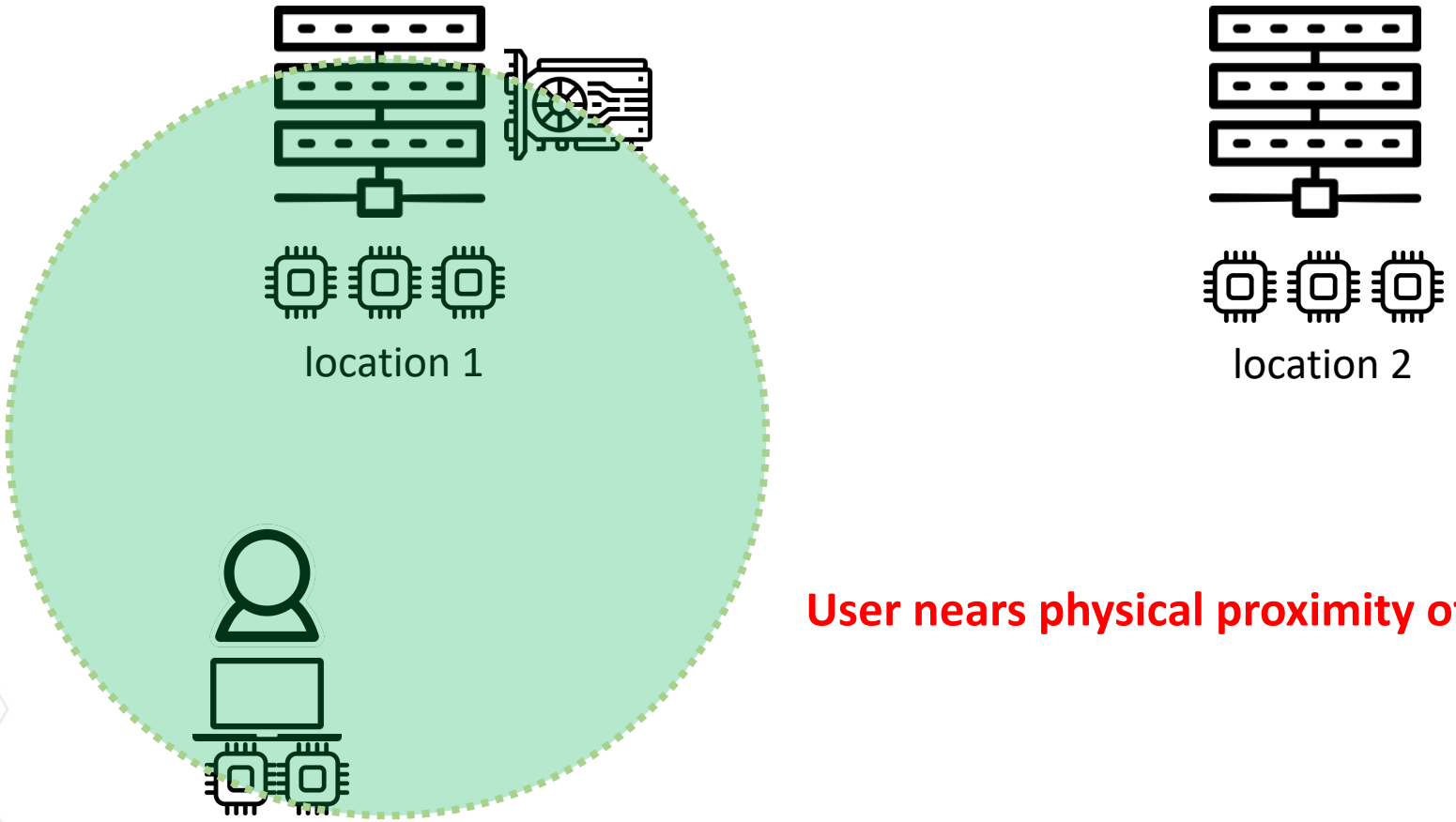

User nears physical proximity of edge system

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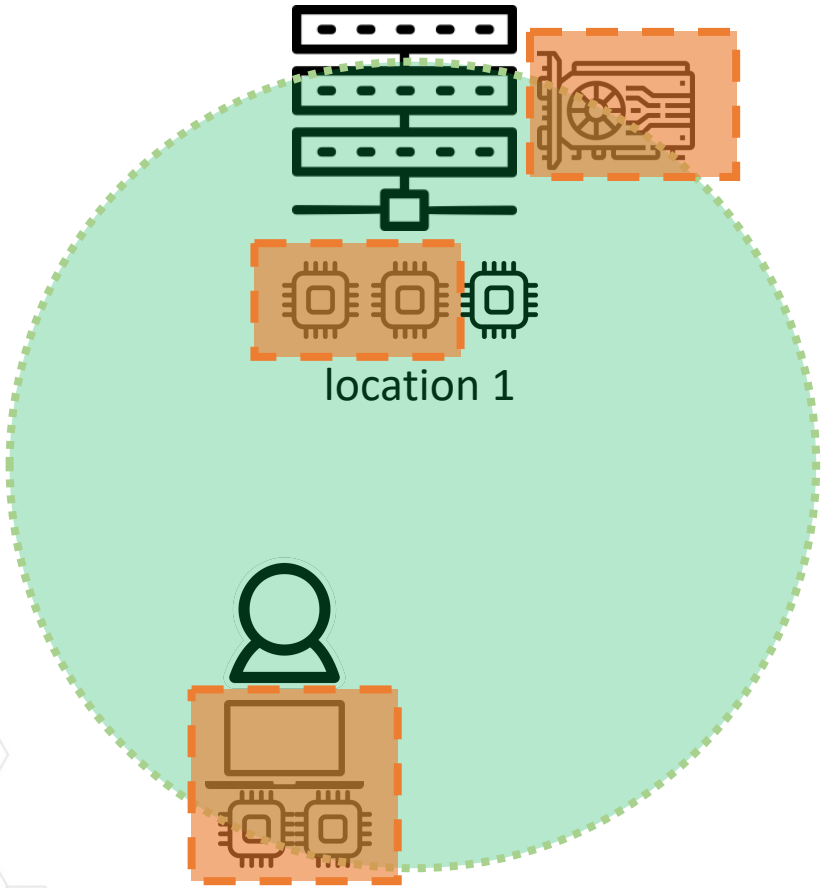
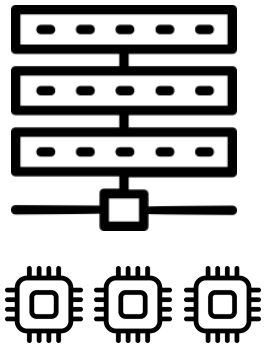
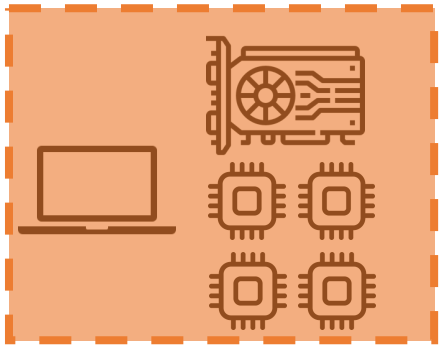




Resources coalesced into one logical system



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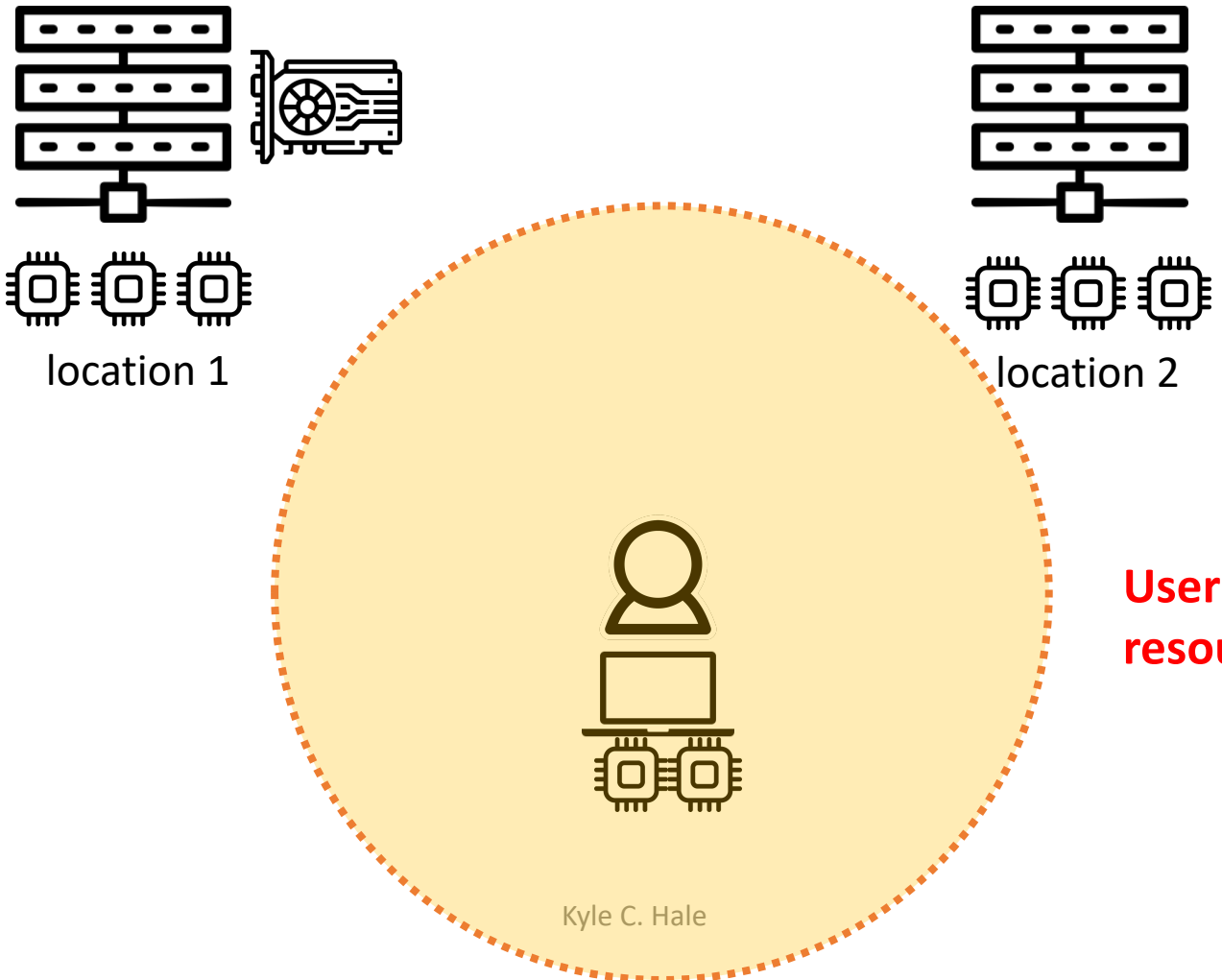

User leaves environment, resources relinquished

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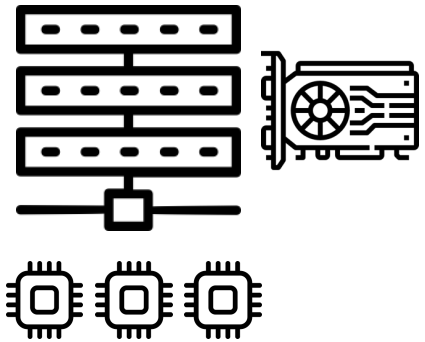

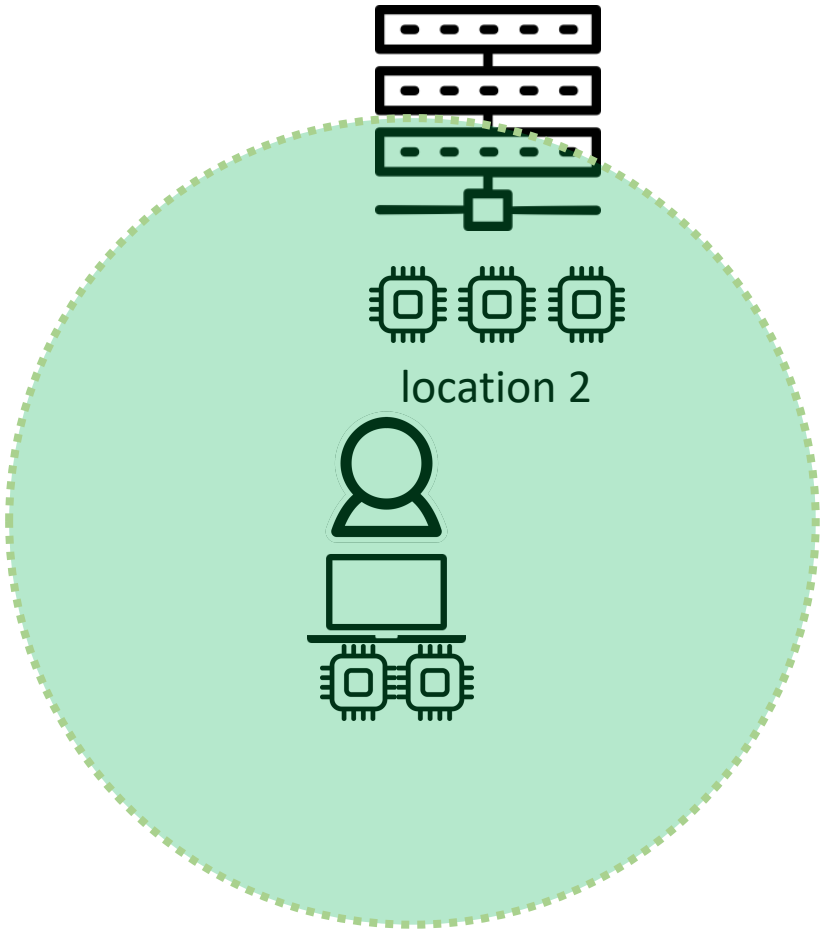

User approaches another edge system

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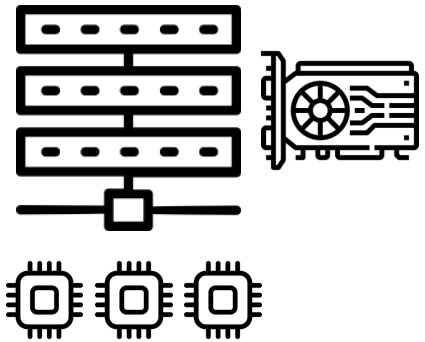
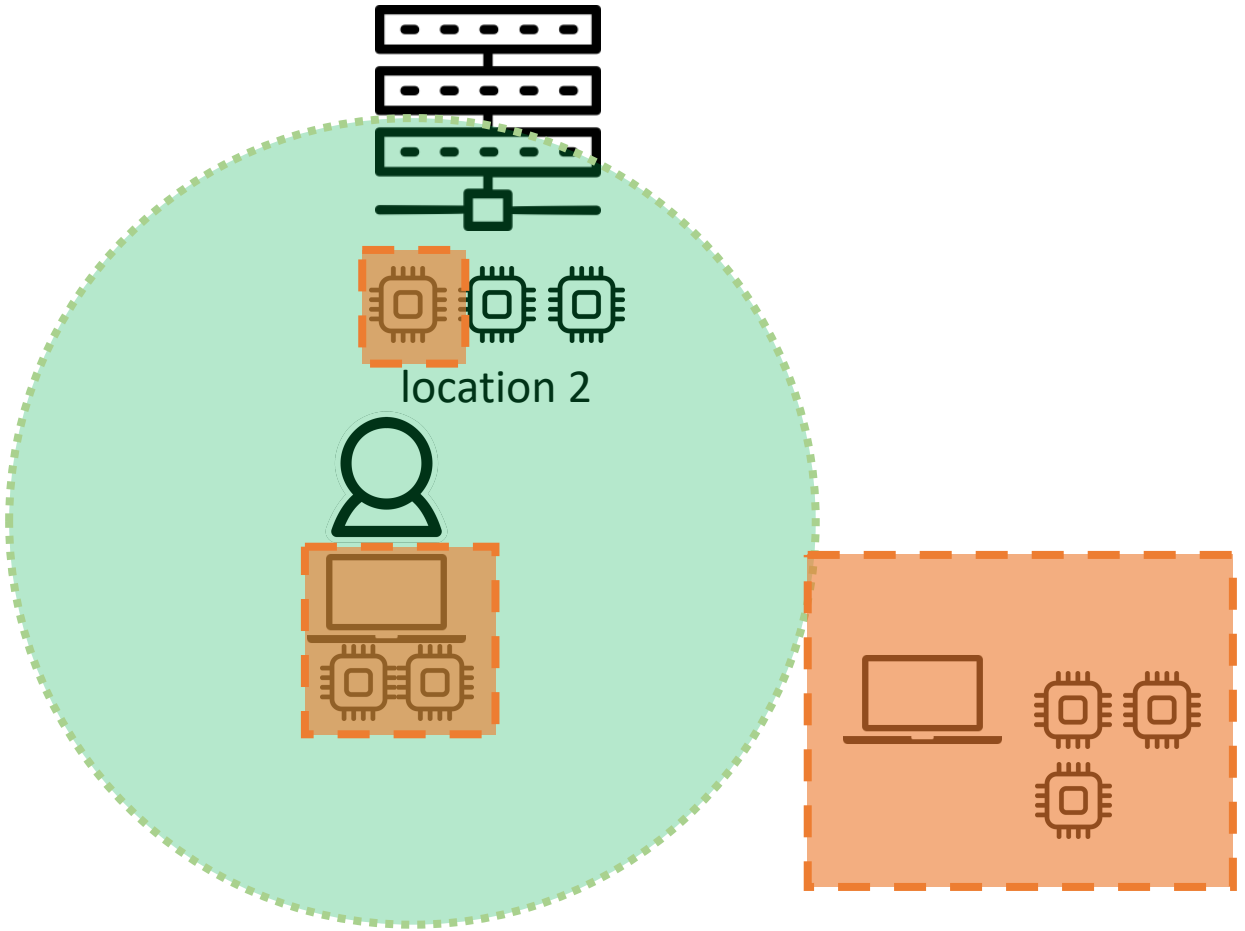
Coalescent Computing

Ephemeral Single-System Image at the Edge

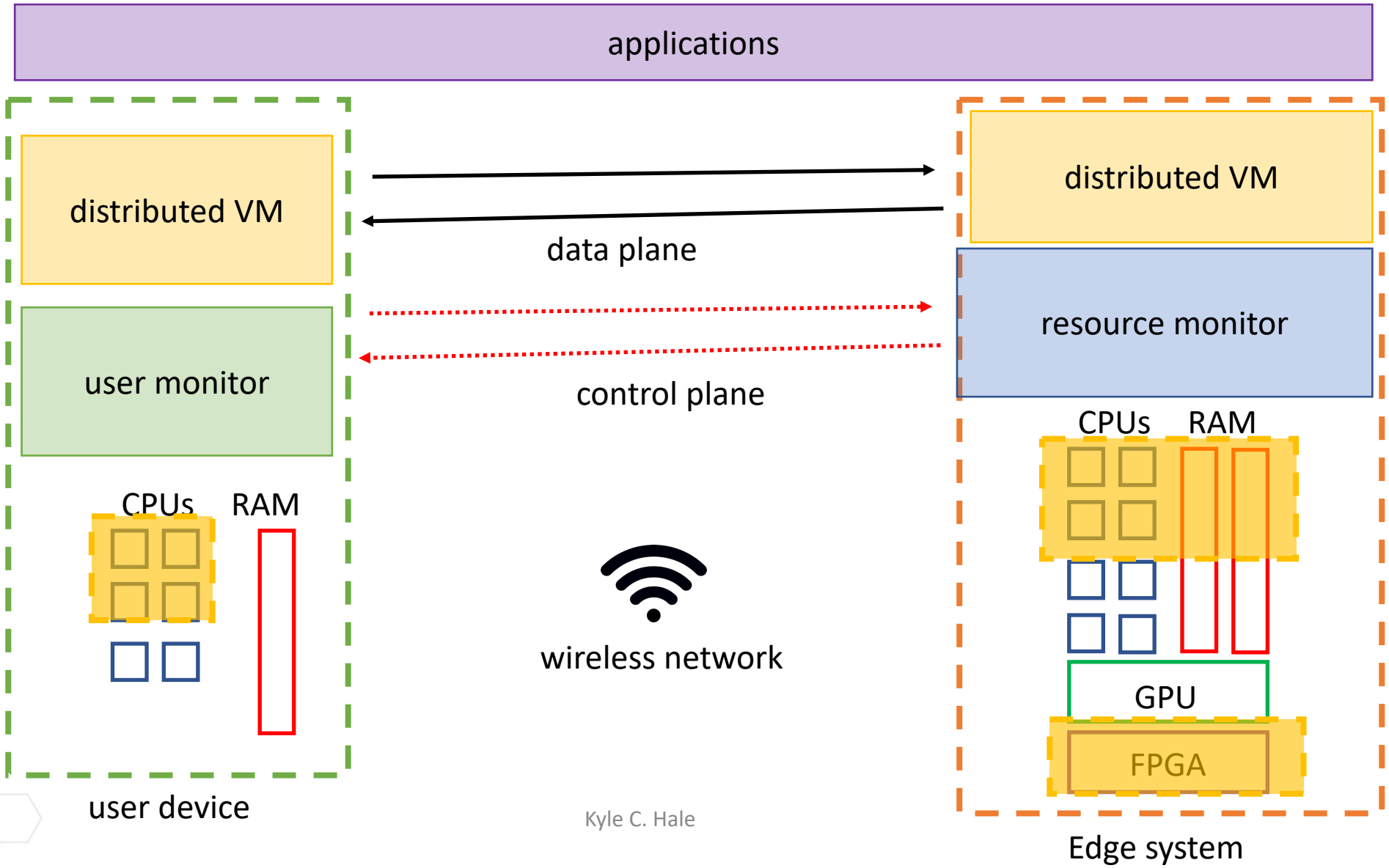




Resources coalesced again, subject to performance, policy constraints

[Hale, Coalescent Computing, APSys '21]

Coalescent System Software



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Current Work

- Adapting DSM-based approaches to the edge (e.g., GiantVM)
- Building a prototype co-designed hypervisor/OS for CC
- Applying PL techniques for coalescent offloading policies (collab. with Stefan Muller)

Virtines

Isolating Functions at the Hardware Limit (to appear in EuroSys ‘22)

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Developer-Friendly, Fast, Function Isolation

- Function isolation
  - Web browsers – sandboxing [CVE-2009-2555, CVE-2009-2935, CVE-2017-2505...]
  - Serverless/FaaS – containers, vms
  - DB *UDF* - high level languages
- Low latency Startup, Short Lived Runtime
  - Spawn and manage many functions w/o significant impact
- Easy programming interface

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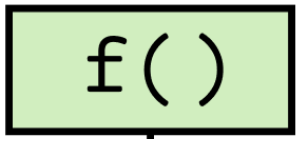
What might function isolation look like?

- Ephemeral state by default (call stack)
- `return` destroys the context



Macro Goals

Function Granularity

Low Latency Startup

Easy to integrate

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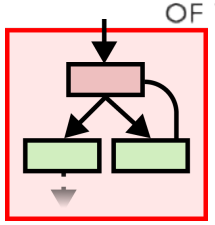
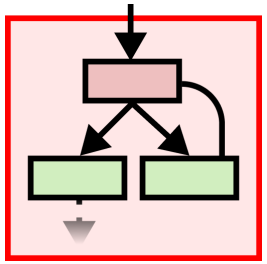
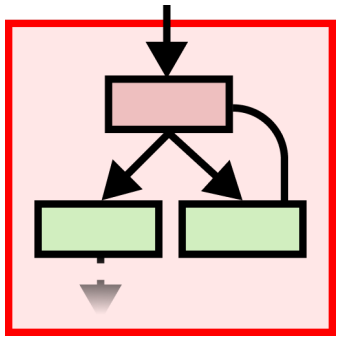
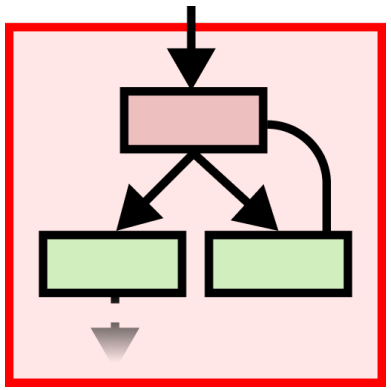
Virtines: Virtual Subroutines

- **Hardware-virtualized** isolated functions
- ***Microsecond*** level boot times
- Paravirtualization
- General purpose

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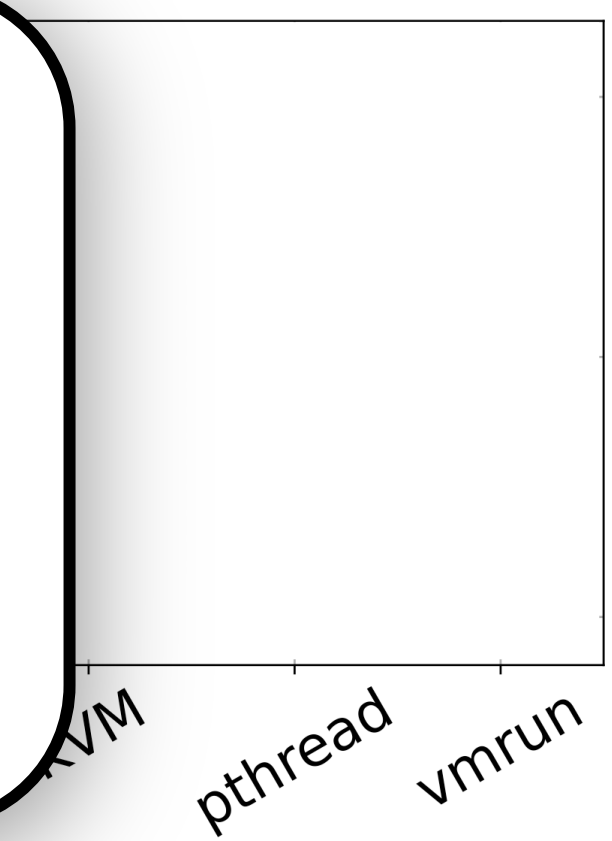
The *lower bounds* of virtualization

It's not the hardware that's expensive…

- What is the laten
  VM creation?
  - HW/SW state

SW VM Allocation is ***expensive***

VM Interaction is ***cheap***



(on AMD EPYC 7281)

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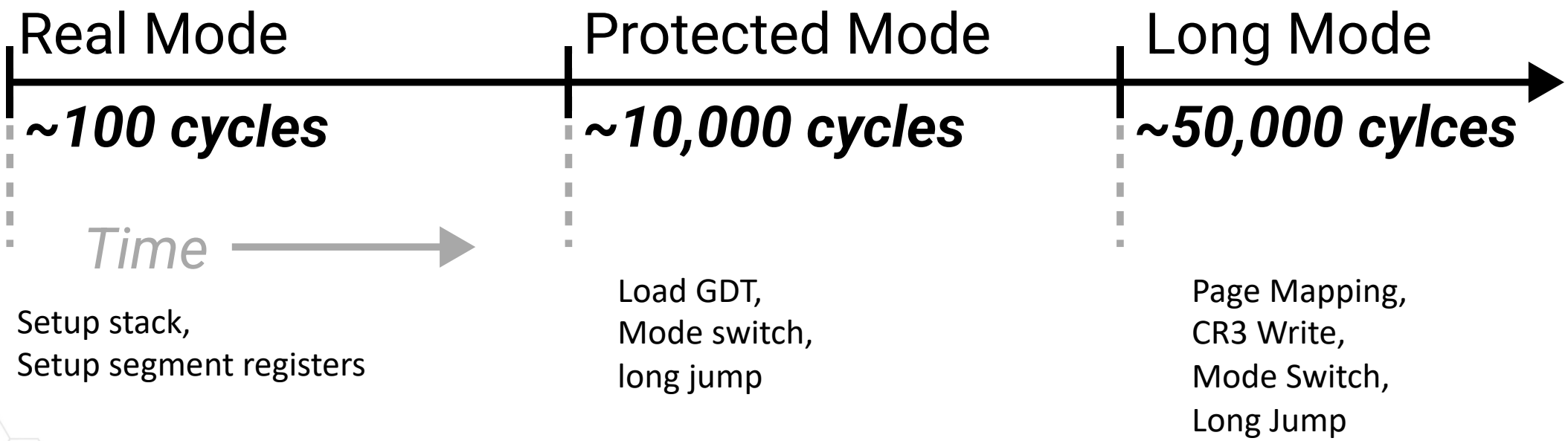
Bootstrapping woes



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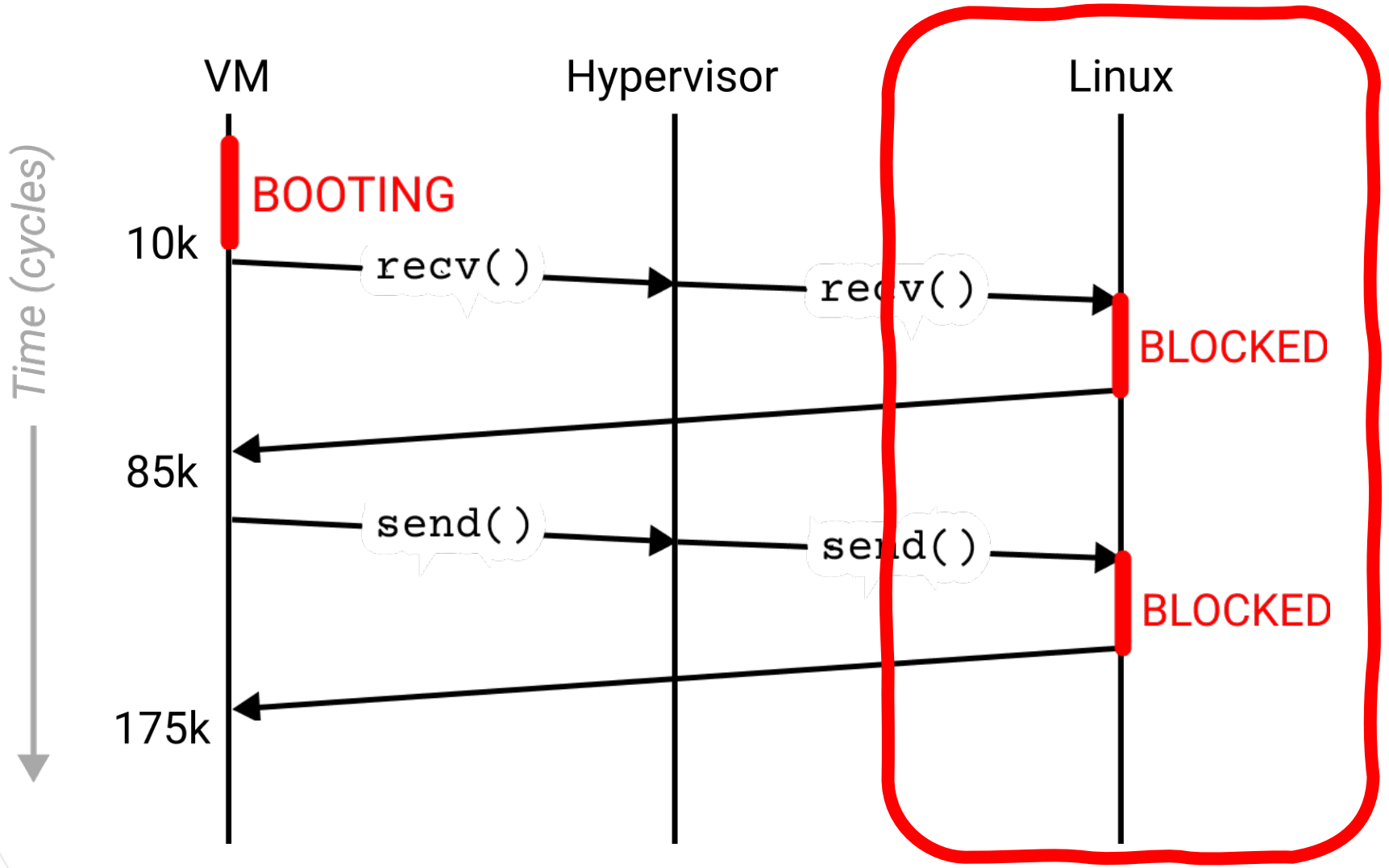
Traditional I/O is *very* expensive

- Try to make a VM feel like real hardware
  - Requires large device drivers
  - Lots of VM Exits for single ops (Expensive!)
- Paravirtualization
  - Codesigned, VM aware of the Hypervisor
  - I/O via ***hypercalls***

HTTP server using hypercalls



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Wasp: an implementation of Virtines

Wasp

- A micro-hypervisor library
- Abstracts hardware specific interfaces
- Lean
- ***Heavily optimized***

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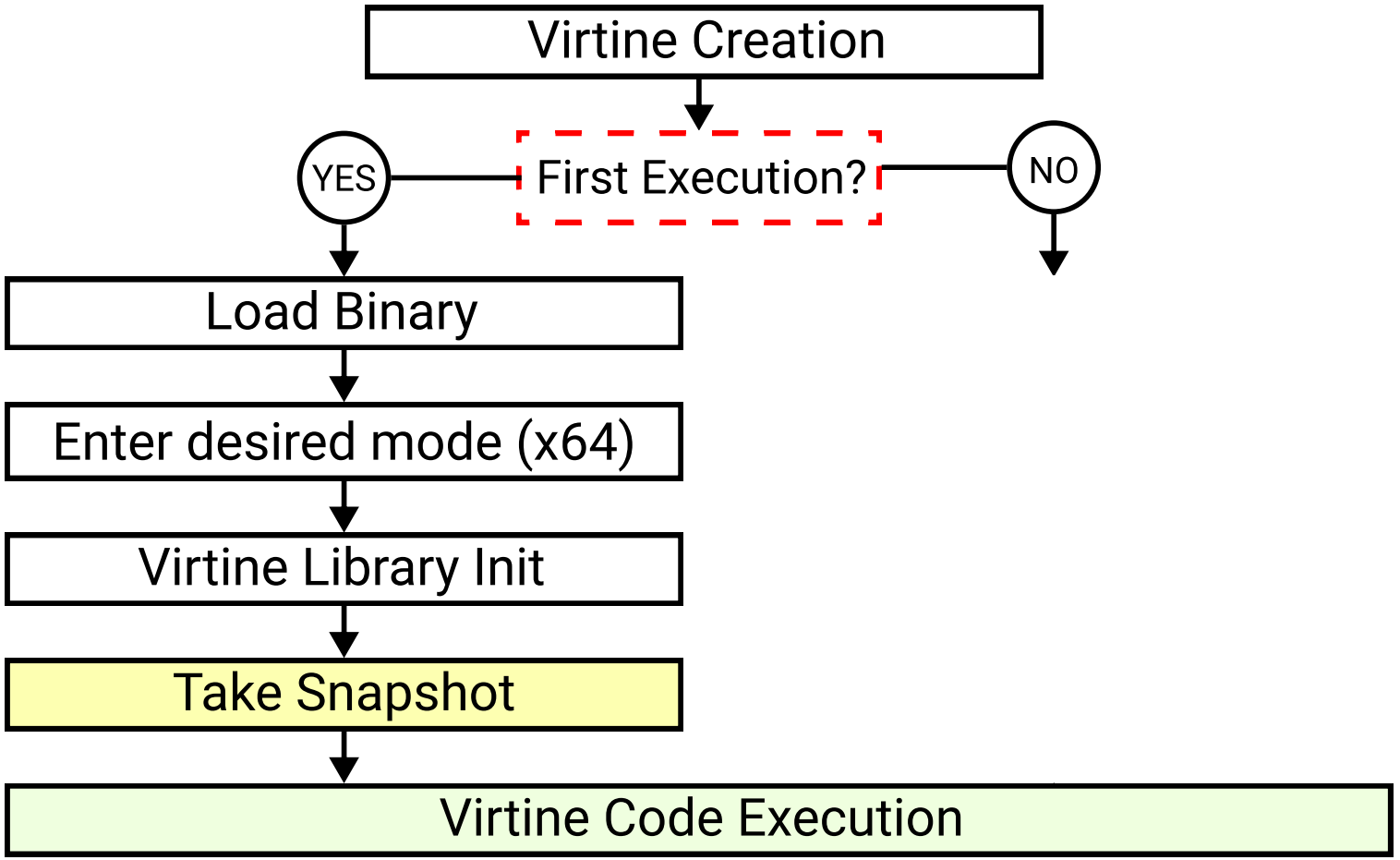
Allocating virtines with Wasp



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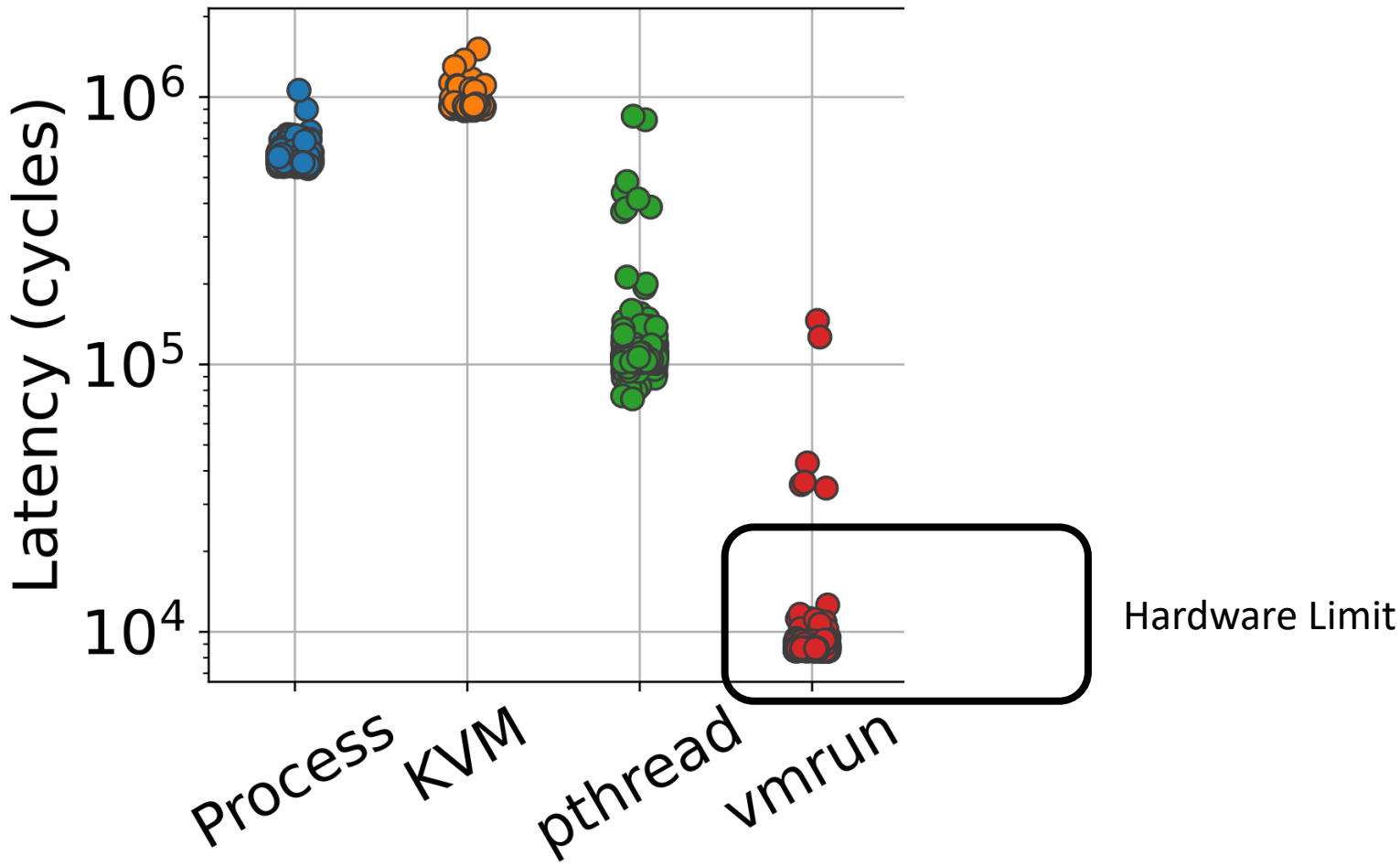
Wasp is close to the hardware limit



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C Language Extension

```
void db_run_udf(db_udf_t *code) {
  // ...
}
```

```
virtine void db_run_udf(db_udf_t *code) {
  // ...
}
```

- Default-deny access to host services
- Custom LLVM module pass to compile and manage virtines

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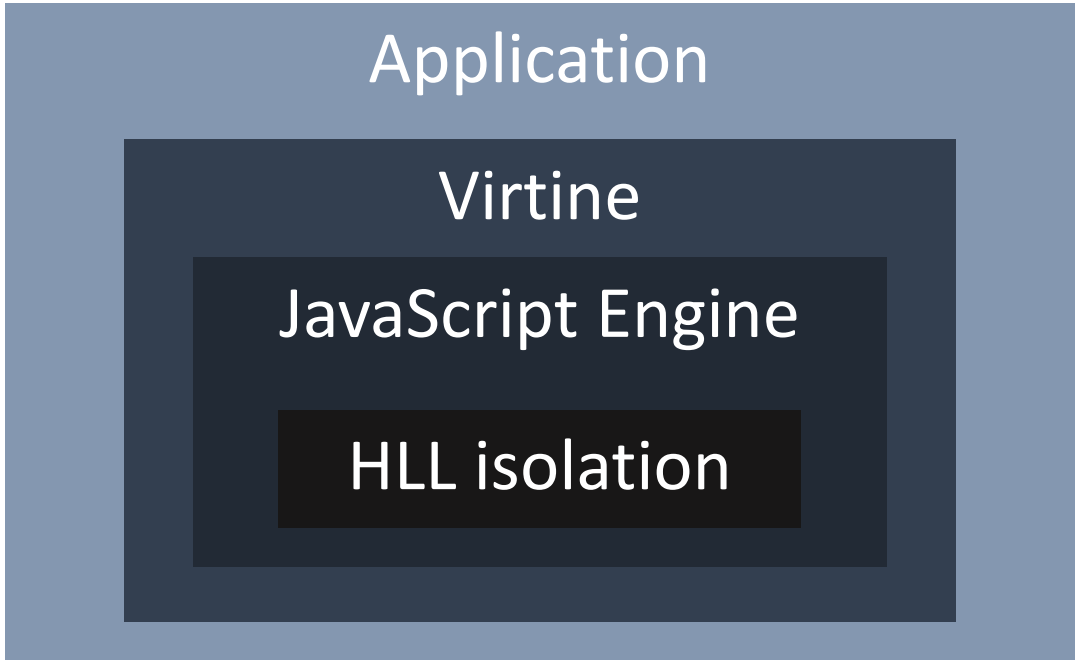
Duktape JavaScript Engine

- **Duktape** JavaScript Engine: https://duktape.org/
  - Embeddable, Portable



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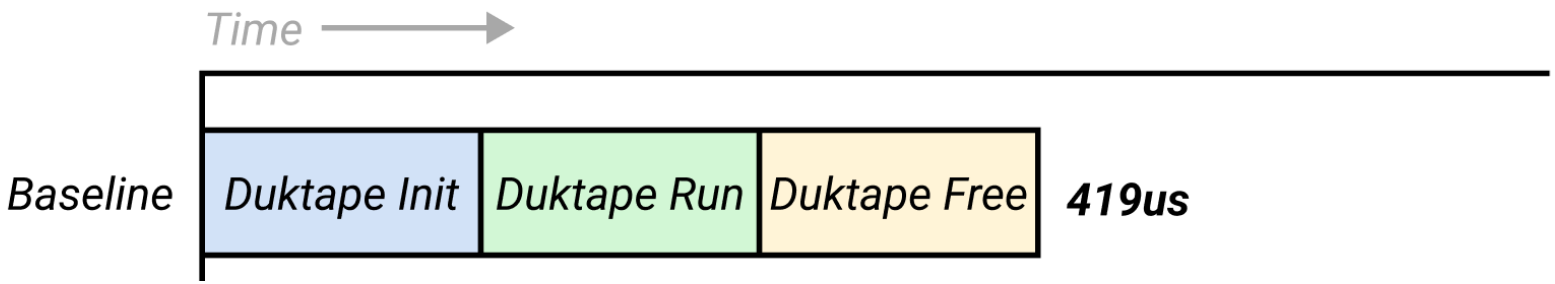
Do our latency optimizations work?



Effectiveness of language extensions

```
void handl                                    ) {
  // ...
}


virtine v                                    (int fd) {
  // ...
}
```

Baseline: **50us,** σ≈10us

Virtines: **80us**, σ≈30us

How easy is it to integrate?

- ~20 lines of code changed
  - Mostly glue logic
- Significantly slower... But we expect that
- 21kb

```
virtine void do_vpaes_cbc_encrypt(
    struct virtine_aes_state *state,
    const AES_KEY key,
    int encrypt) {
  // ...
}
```

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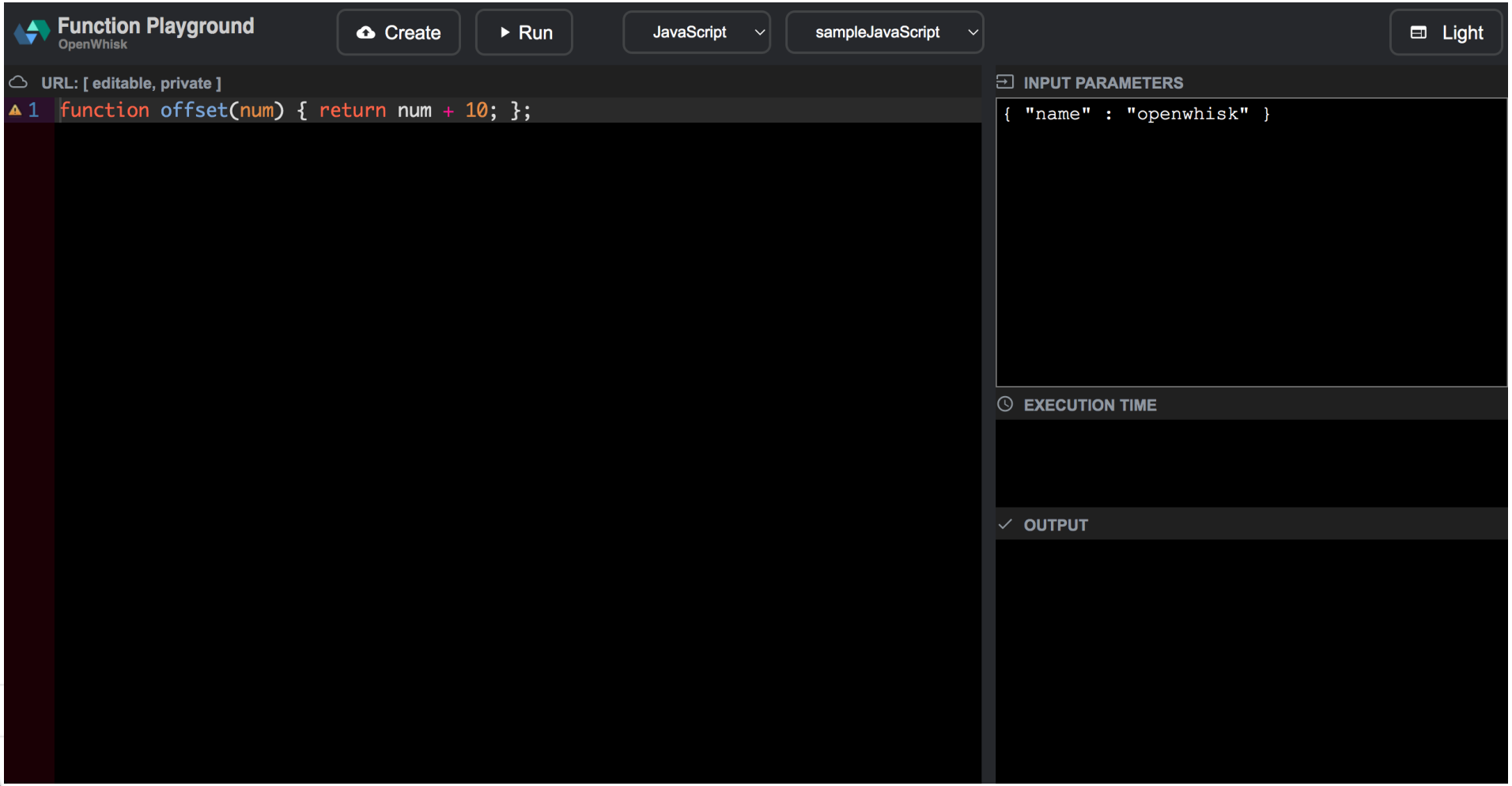
Serverless Virtines

- OpenWhisk/AWS Lambda are good examples of modern serverless platforms
- Weak isolation between function instances!
- We developed our own using vitrines (based on OW)

Serverless Platform Interface



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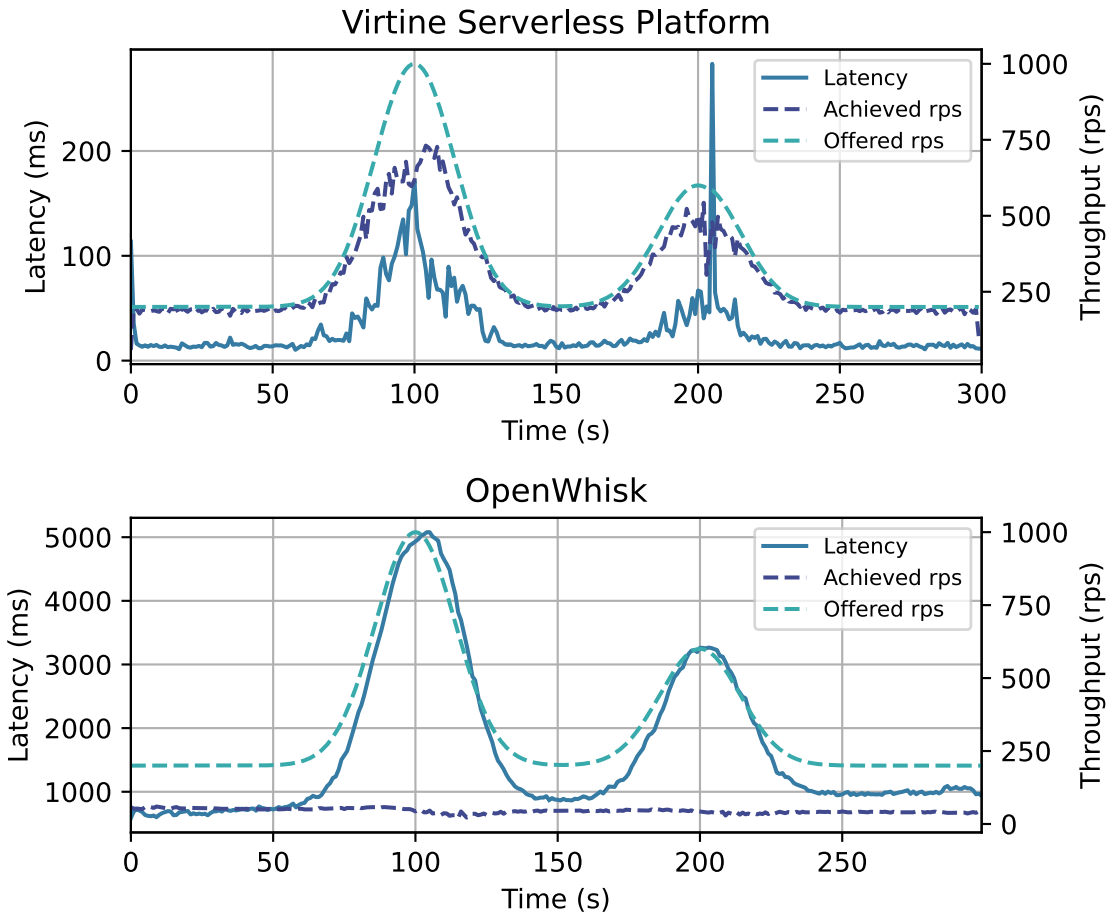
We can use virtines as drop-in replacement for containers!



Isolating Functions at the Hardware Limit with Virtines

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Abstract

An important class of applications, including programs that leverage third-party libraries, programs that use user-defined functions in databases, and serverless applications, benefit from isolating the execution of untrusted code at the granularity of individual functions or function invocations. However, existing isolation mechanisms were not designed for this use case; rather, they have been adapted to it. We introduce

Keywords: virtines, virtualization, isolation

ACM Reference Format:
Nicholas C. Wanninger, Joshua J. Bowden, Kirtankumar Shetty, Ayush Garg, and Kyle C. Hale. 2022. Isolating Functions at the Hardware Limit with Virtines. In *Seventeenth European Conference on Computer Systems (EuroSys '22), April 5–8, 2022, RENNES, France.* ACM, New York, NY, USA, 19 pages. https://doi.org/10.1145/3492321.3519552

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Thanks!

- HExSA Lab: hexsa.halek.co
- Thanks to MD Ali, Conghao Liu, Brian Tauro, Stefan Muller
- Virtines code available: **github.com/virtines**
- **Thanks to Nick Wanninger (virtines lead author)**
  - Email: ncw@u.northwestern.edu
  - Website: https://nickw.io
- Also Josh Bowden, Kirtan Shetty, Ayush Garg

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