The new VVorld

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(and thanks to Marko Zec)
The FreeBSD Project

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OS research and development performed by FreeBSD Project, University of Zagreb, FreeBSD Foundation, NLNet, and other contributors over a decade

Still a work-in-progress, but exciting technology coming soon

Introduction

- About virtualization
- FreeBSD Jails
- Virtualizing a kernel
- A virtualized network stack
- A few application ideas

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What is virtualization?

- Illusion of multiple virtual **X** on one real **X**
  - Virtual memory address spaces
  - VLANs, VPNs, and overlay networks
  - Storage volume management
  - Virtual machines, OS instances
- ... you can solve any problem with another level of indirection ...

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"... a level of indirection..."

Why virtualize?

- Sharing with the illusion of exclusive use
- Consolidation, managed overcommit
- Flexibility in implementation
- Security and robustness
- Administrative delegation

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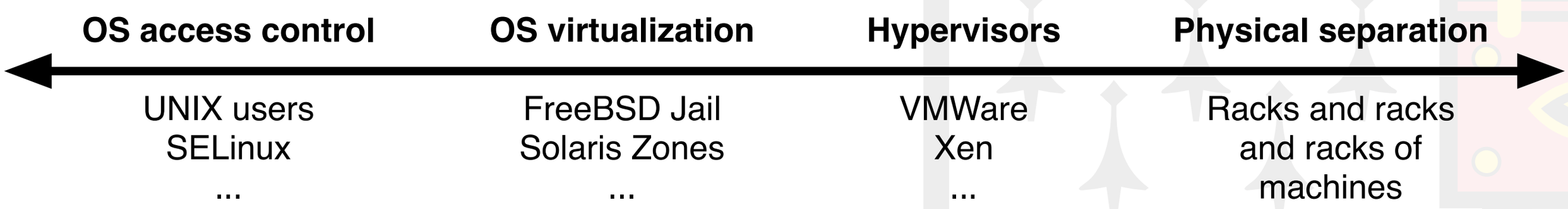
Virtualization spectrum



- Tradeoffs: scheduler integration, efficient sharing, overcommit opportunities, functionality, security/isolation, resource management, administrative delegation, ...

Example:
With OS virtualization you get full scheduler integration, but migration very hard
With Hypervisors you get really bad scheduling, but migration is relatively easy

OS virtualization

- Single OS kernel instance, many userspaces
- Safe root delegation, various constraints
- Efficient resource sharing with overcommit
- No hypervisor/virtual device overhead
- ISP virtual hosting, server consolidation, ...

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History of FreeBSD Jail

1999	Jails merged to FreeBSD 4.x
2002	Virtualized network stack prototype
2006	NLNet/FreeBSD Foundation fund multi-year VIMAGE development project
2007	Jail-friendly ZFS merged from Open Solaris
2008	Multi-IPv4/v6/no-IP patches; VNET integration starts
2009	Hierarchical jail support; FreeBSD 8.0 with highly experimental options VIMAGE shipped

Earliest open source OS virtualization we're aware of

Virtualization work has long timeline

Why change Jail?

- Jail is fast, efficient, secure, useful
- But, Jail "subsets" rather than "virtualizes"
  - For example: employs chroot() internally
    - Some resources subset poorly
    - E.g., System V IPC, loopback interface, ...
- Virtualization is a functional improvement

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Virtualizing OS services

- New abstraction: the **virtual instance**
- **Replicate** global objects per-instance
- **Multiplex** or **replicate** threads, timers
- **Tag** subjects with virtual instances
- Consider **administrative interfaces**
- Examine **privileges** carefully
- Plan **inter-instance plumbing**
- How to **start** and **stop** instances?

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Virtual kernel infrastructure

- Sounds complicated, but some new tools
  - Virtualized global variables
  - Virtualized startup/shutdown
  - Virtualized sysctl MIB entries
  - Virtualization-enhanced debugging
  - Multiplex virtualization onto netisrs

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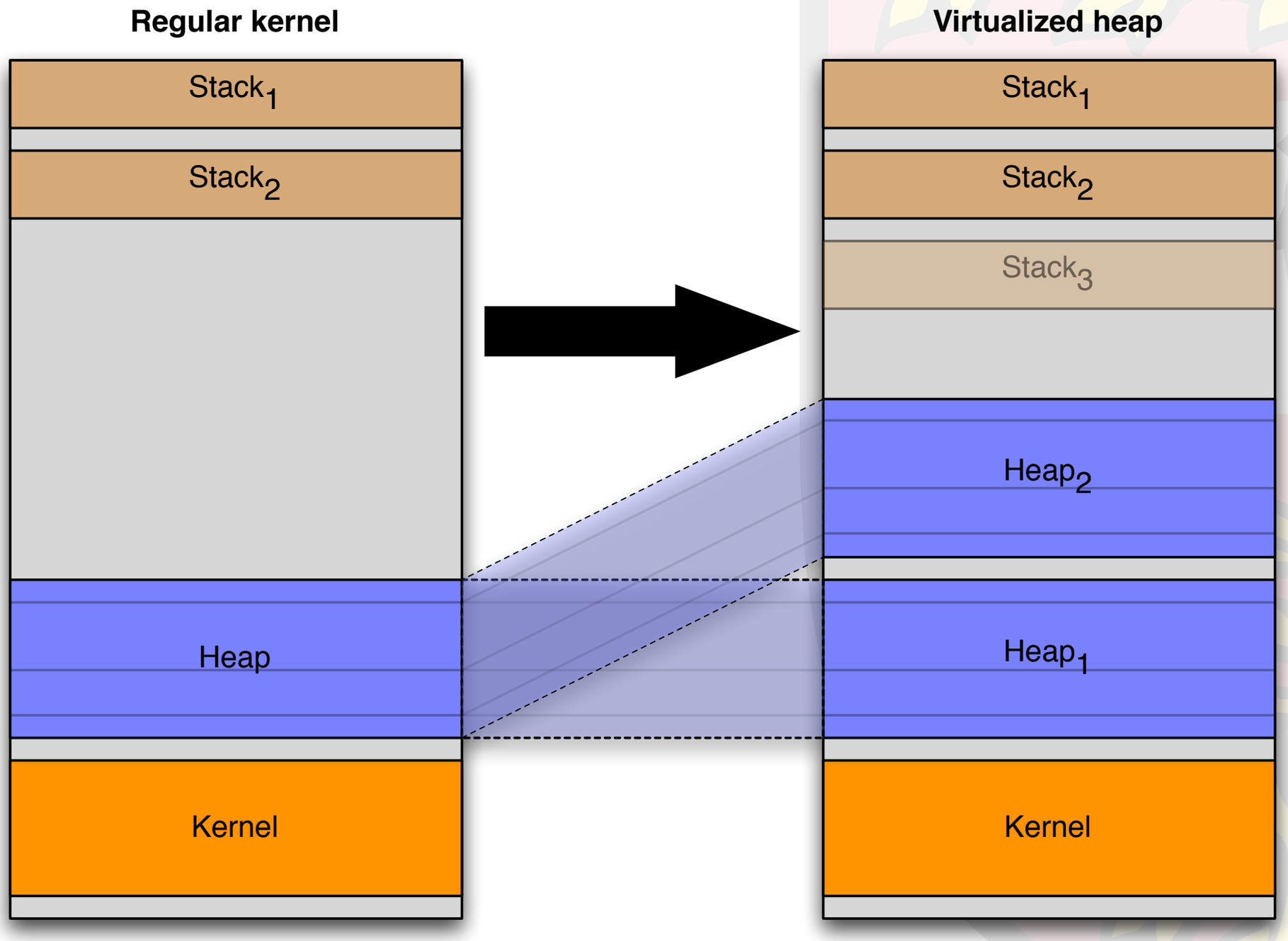
Virtualized heap



Goal: make it easy for us to take one of something and make many

Notice that same layout is used for virtual instances as original

Virtual global variables

- Tag selected globals as **virtual** in source
- Placed in different ELF section when linked
- Each VNET instance gets a copy of section
- Thread context carries VNET reference
- Globals mapped to VNET when accessed
- Can compile to regular globals if desired

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Can compile out during development but still in tree. In fact, default today.

Also valuable for embedded.

```
VNET_DEFINE(struct inpcbhead, ripcb);
VNET_DEFINE(struct inpcbinfo, ripcbinfo);

#define V_ripcb         VNET(ripcb)
#define V_ripcbinfo     VNET(ripcbinfo)

...

void
rip_init(void)
{

        INP_INFO_LOCK_INIT(&V_ripcbinfo, "rip");
        LIST_INIT(&V_ripcb);
```


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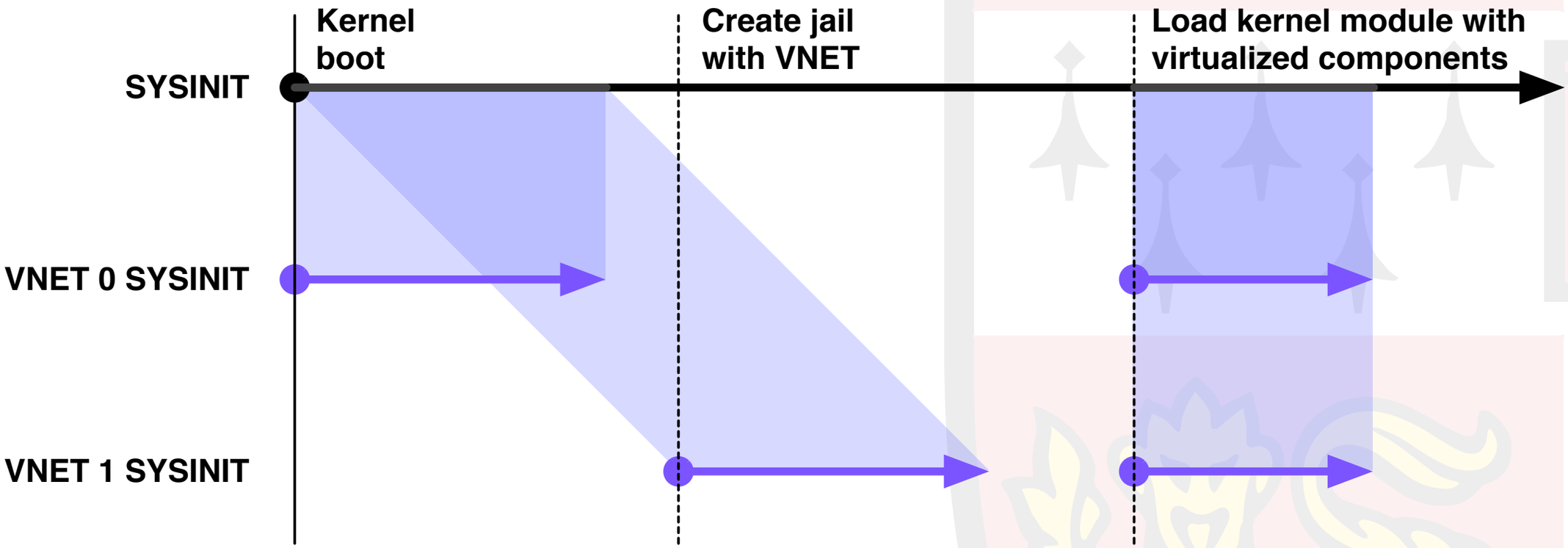
Goal: make virtualized programming natural

Virtualized boot



Portions of previously serialized kernel and module startup are now per-VNET

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Tag bits of boot process that now need to be per-VNET.

Module case is interesting, and tricky.

Virtual kernel startup

- Kernel, module startup uses SYSINIT()
  - Functions tagged with special ELF section
  - Sorted and executed "in order"
    - Used for 99% of FreeBSD kernel init
- Some events now need to be virtualized
- Add a new event set, run once per VNET

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```
static void
vnet_igmp_init(const void *unused __unused)
{
        CTR1(KTR_IGMPV3, "%s: initializing", __func__);
        LIST_INIT(&V_igi_head);
}
VNET_SYSINIT(vnet_igmp_init, SI_SUB_PSEUDO,
    SI_ORDER_ANY, vnet_igmp_init, NULL);
```

```
static void
vnet_igmp_uninit(const void *unused __unused)
{
        CTR1(KTR_IGMPV3, "%s: tearing down", __func__);
        KASSERT(LIST_EMPTY(&V_igi_head),
            ("igi list not empty; detached?"));
}
VNET_SYSUNINIT(vnet_igmp_uninit, SI_SUB_PSEUDO,
    SI_ORDER_ANY, vnet_igmp_uninit, NULL);
```


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Again: goal to make it natural.

Five-character change to each to say “do it virtualized”.

What to virtualize?

- Start with a virtual network stack
  - Immediate demand due to Jail limitations
  - Zec 2002 prototype
    - Validate performance of approach
    - Can parallelize over many net modules
- In the future: VIPC, ...

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Virtual network stack

- Jails can have their own network stacks
  - TCP/IP socket bindings, routing table, firewall, IPsec, ...
- Real/virtual interfaces belong to one stack, but may be assigned to child stacks
- Packets float between stacks as needed
- Arbitrary virtual network topologies OK

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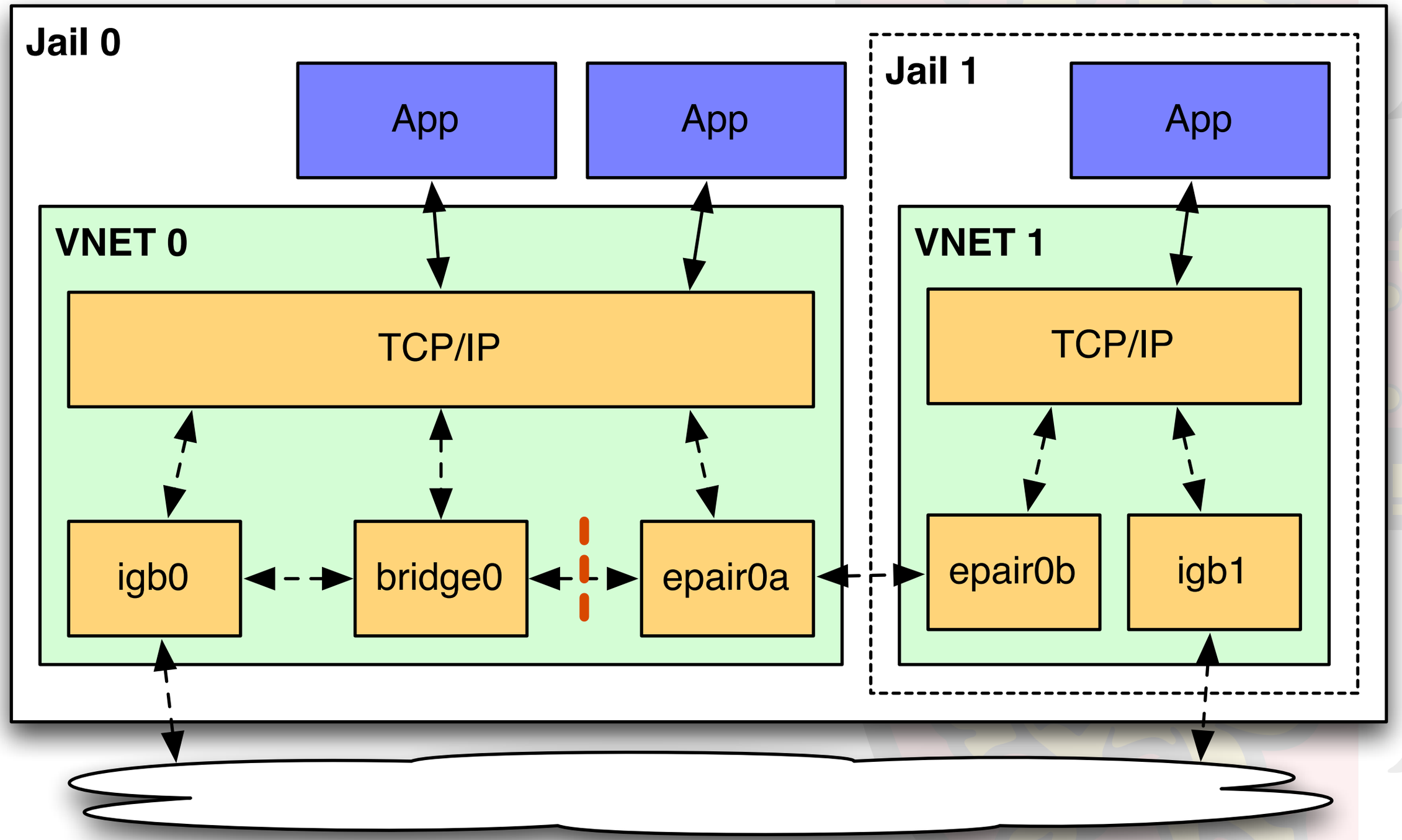
Avoid constructs that require additional copying, context switching, etc.



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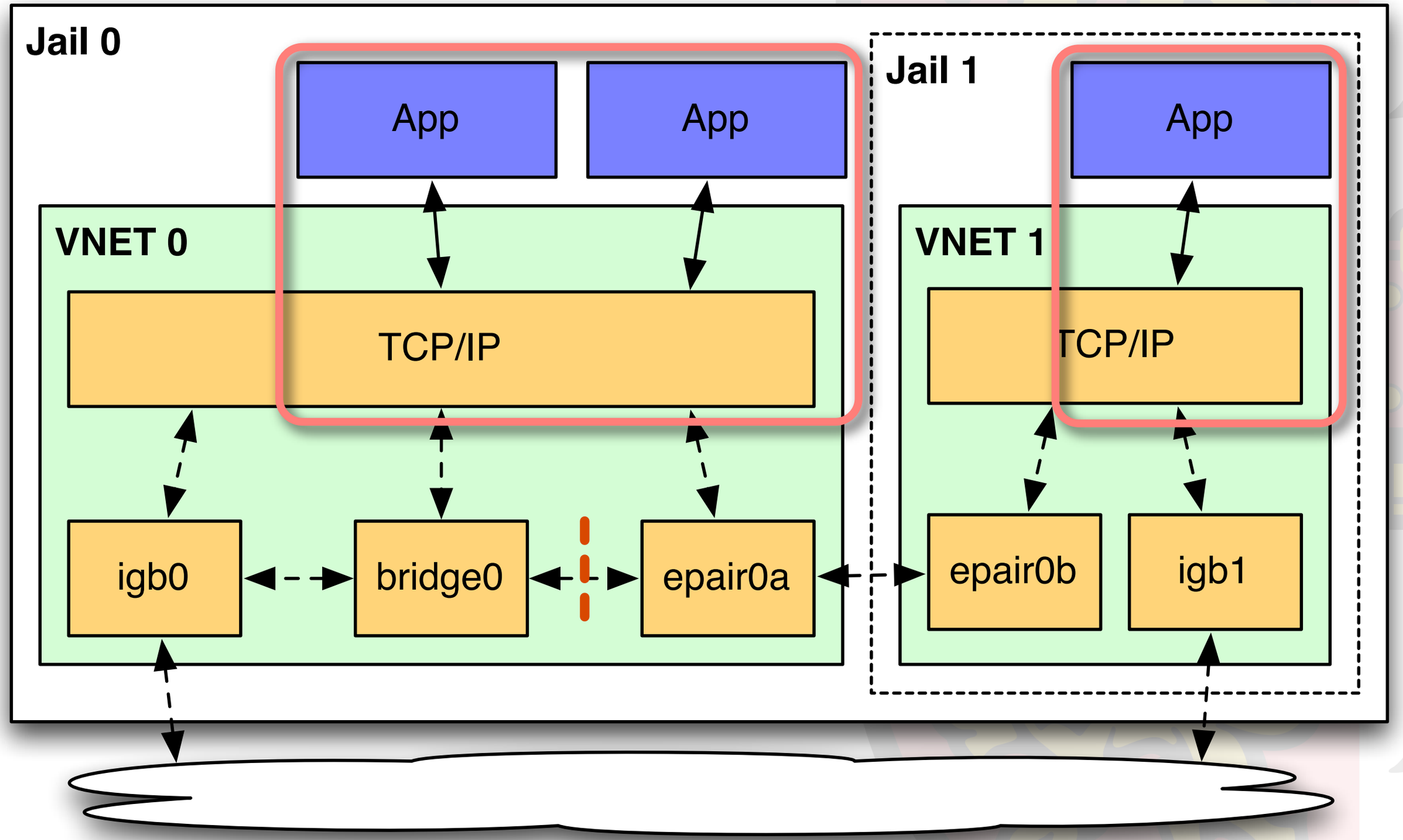
Applications pinned to virtual stacks.
Simple case: assign an ifnet to a jail.
Complex case: virtual interfaces, bridging, firewalls, ...



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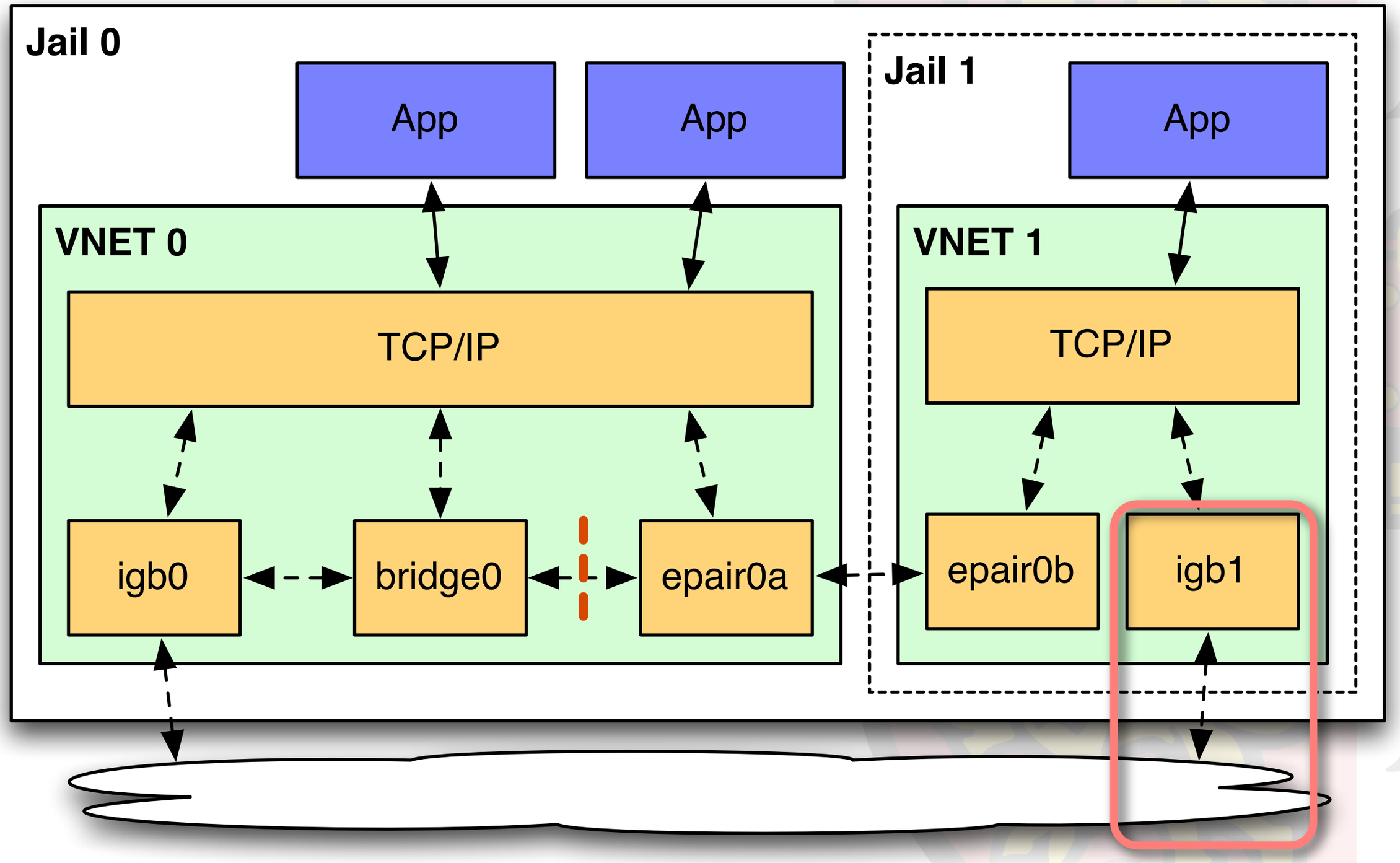

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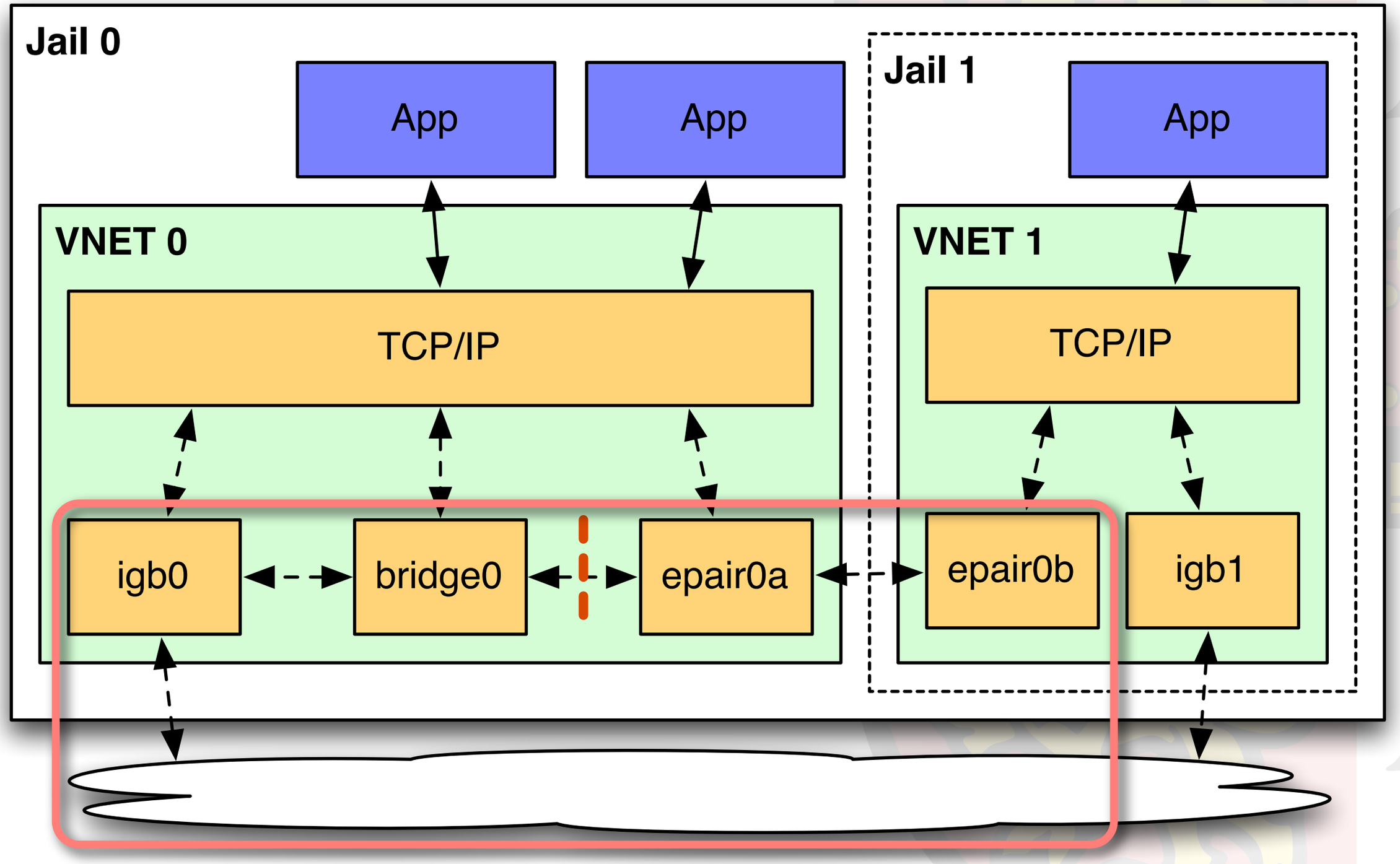

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Really hard problem: shutting down cleanly

- We've been doing that for years, right?
- Actually, no -- we've been booting for years.
- But we've never shut down the network.
- We just power off and it goes away. :-)
- Now we need **destructors**.

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Status

- FreeBSD 8.0 VIMAGE "highly experimental"
  - Known memory leaks on stack shutdown
  - Several known crash conditions
  - Many subsystems not fully virtualized
- Foundation will shortly announce new funding for productionization work
- Goal production-quality VIMAGE in 9.1/9.2

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How to give it a spin

- Update to 8-STABLE or 9-CURRENT
- Compile kernel with "options VIMAGE"
- Simple example:

```
jail -ci vnet path=/jail command=/bin/csh
ifconfig vlan100 vnet <id>
```

- http://wiki.freebsd.org/Image
- WARNING: EXPERIMENTAL

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A few applications

- Network routing research
- Parallel overlay networks
- Large-scale hosting

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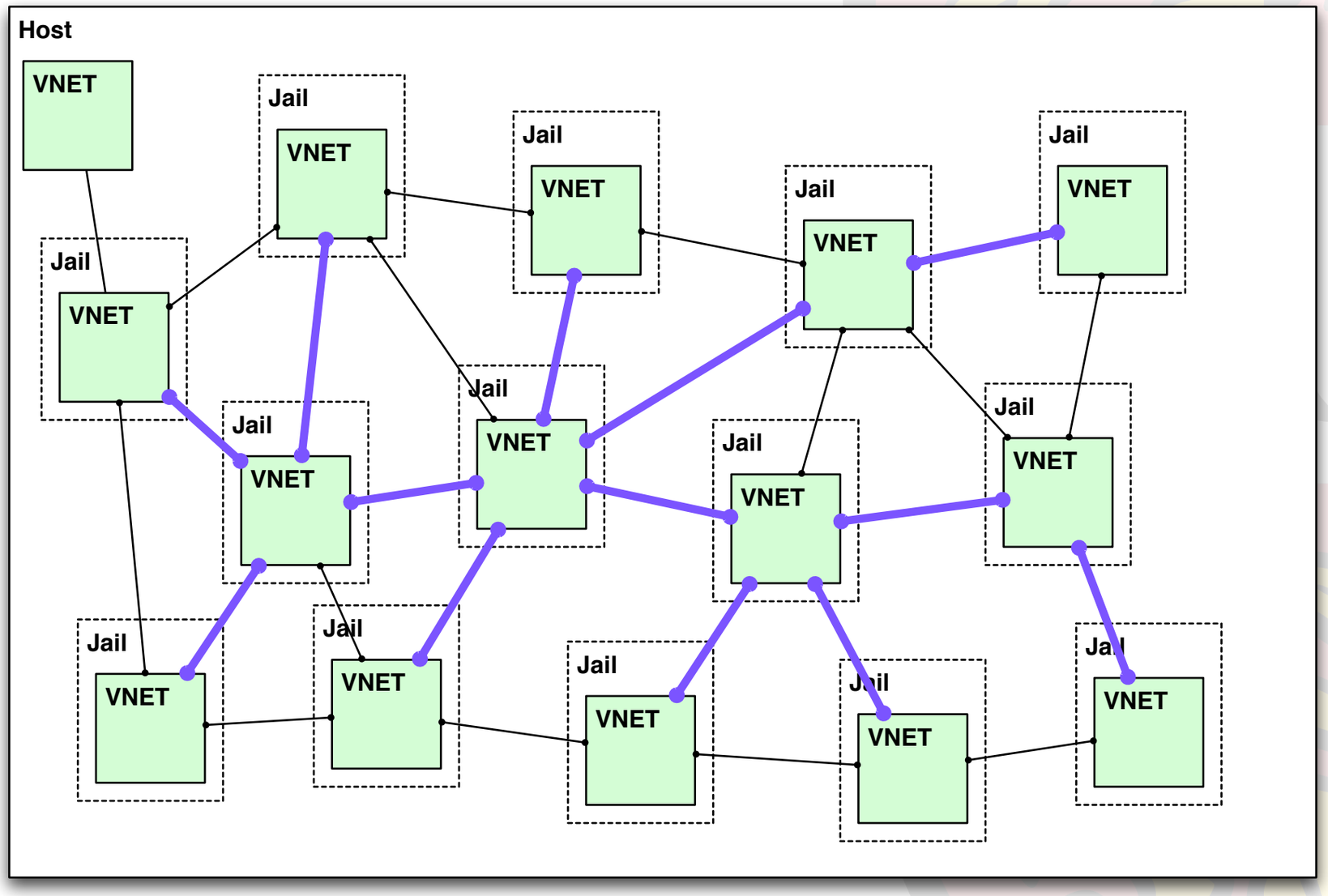
Routing simulation



Trivially simulate thousands of nodes with arbitrary topologies and fully functional, independent network stacks

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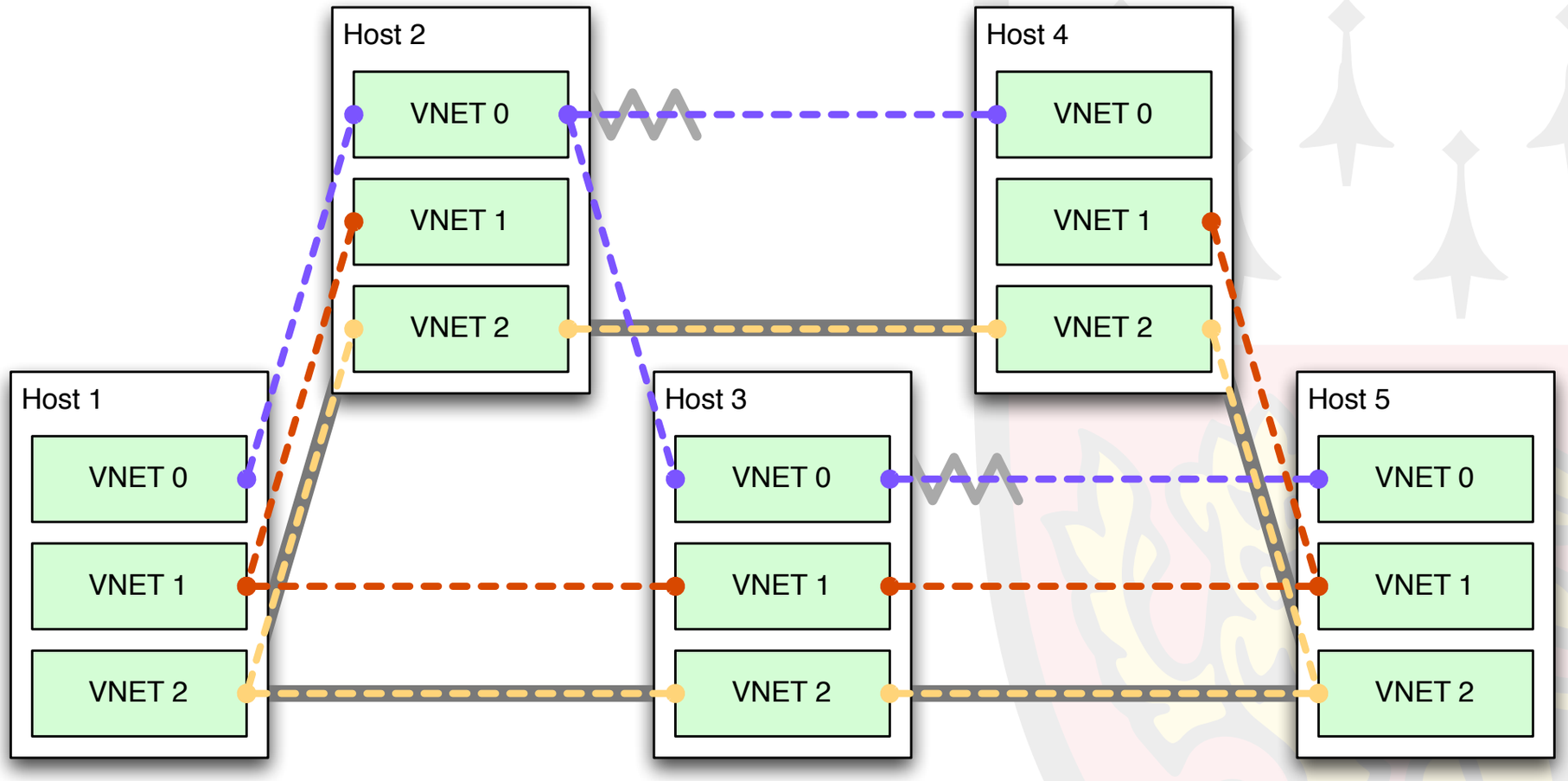
Virtualized overlay infrastructure



Multiple network stacks allow router/bridge/VAP nodes to implement complex policies using minimal hardware

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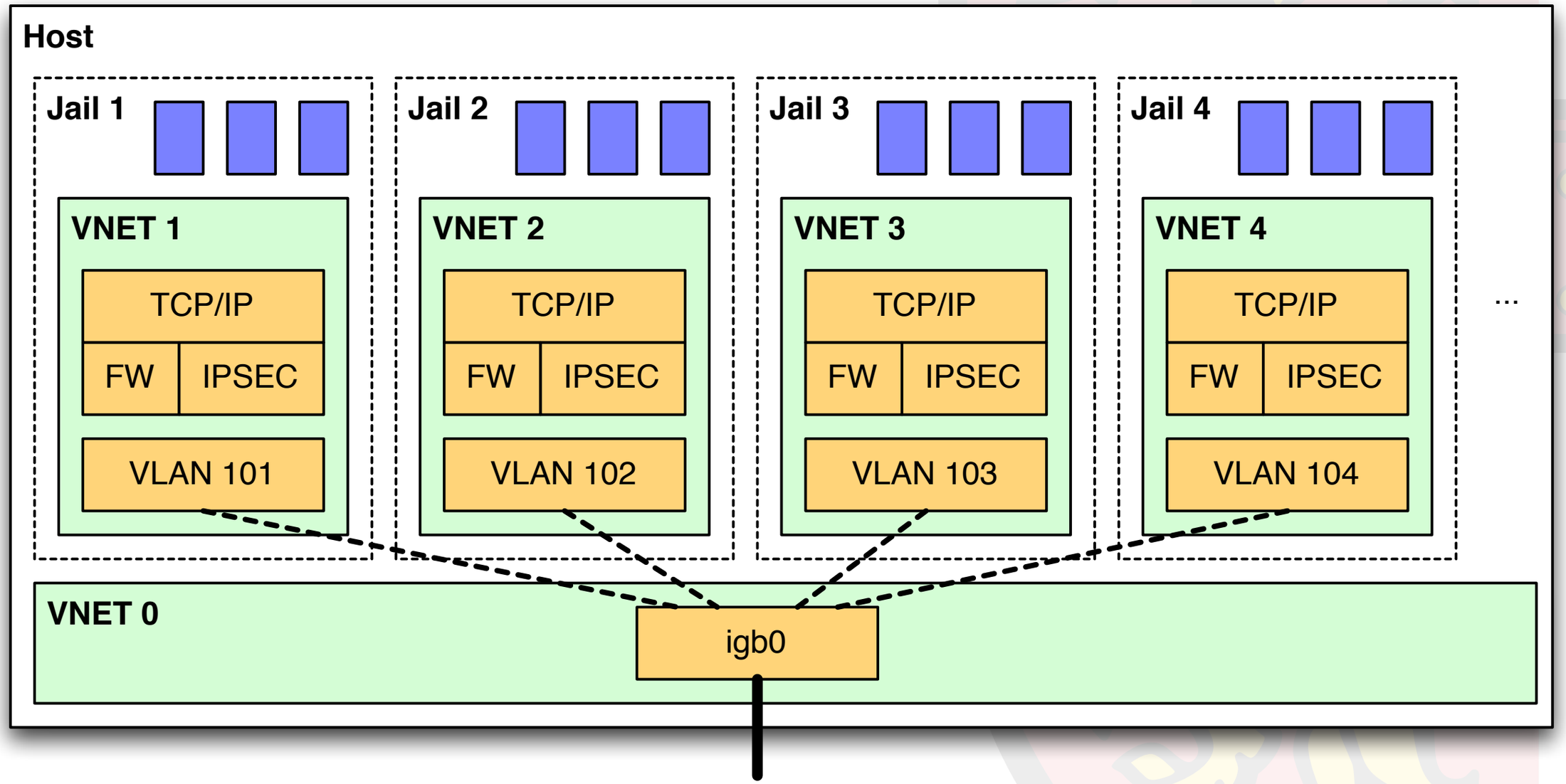
Large-scale hosting



Jails each have their own fully delegated connection tables, routing tables, firewalls, IPsec, ...

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Nested jails, with and without VNETs

Some other ideas

- Efficient server consolidation
  - 500K memory overhead vs. 256M+ VM
- Virtualized appliances
  - Multi-instance appliances, such as file stores, firewalls, filters, ...
- Neat: Debian/kFreeBSD on VNETs

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2MB with ZFS or nullfs providing efficient storage, before applications

Conclusion

- Virtual kernel features, such as a virtual network stack, finally becoming a reality
- Prototype operates with increasing stability and little performance overhead
- Adds to virtualization menu; can be combined with other techniques like Xen
- Coming soon(ish)...

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Cleverly, we are able to take advantage of many virtualization-centric hardware optimizations.

For example: MAC address filtering with RSS.