Kernel Development in Userspace
The Rump Approach

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Introduction / Motivation

- computers are difficult
  - otherwise this would be a boring conference
- kernel hacking is even more difficult
  - very unforgiving
  - lots can go wrong
  - everything can touch anything
- **motivation**: make this easier
  - at least on NetBSD ;-)

Talk outline

- survey of kernel development techniques
- introduce Runnable Userspace Meta Programs (rump)
- explain why, how, when and when not
- go into some details, provide tips
- introduce some useful tools
- **goal**: give ideas for alternative and easier approach on kernel development

Traditional development vectors: directly on hardware

- the hardcore approach
- typically two machines are used: one for development, one for testing
- environment setup may take a while
  - installing *and* maintaining two systems
- typically serial console/firewire + gdb
- sometimes the only feasible option
  - some stages of device driver development

Traditional development vectors: emulator or virtual machine

- two popular examples: qemu and Xen
- fundamentally same as direct approach
- no Xen dom0 already available?
- no KVM support => qemu is slow'ish
- benefit over hardware approach: no cables necessary

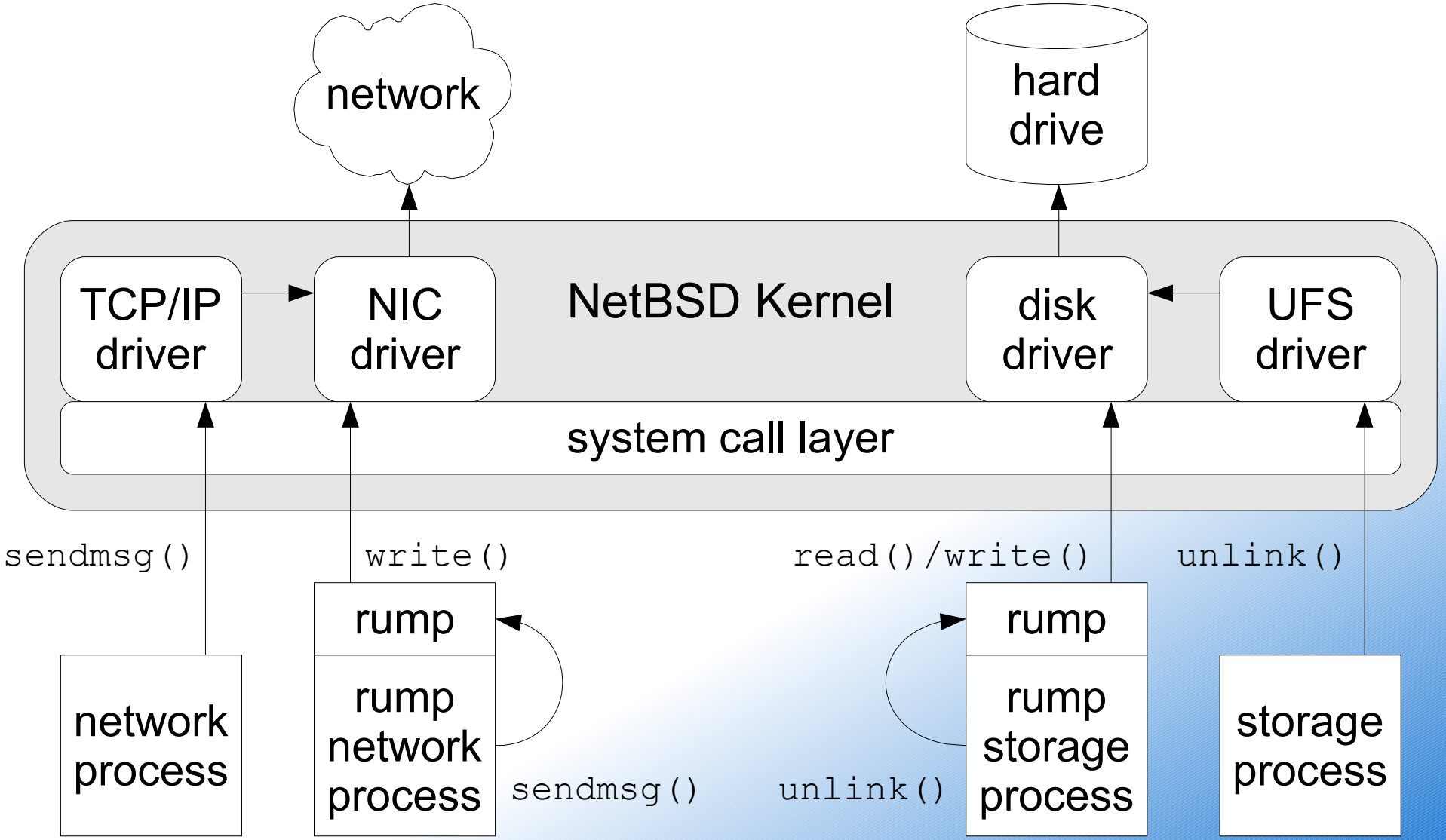
Traditional development vectors: ad-hoc userspace techniques

- massage component under development to run as part of a userspace program
- compile and run in userspace
- simplify/ignore some kernel interfaces
- apply `#ifdef` liberally
- file systems are well-known employers of this strategy, e.g. FFS and ZFS

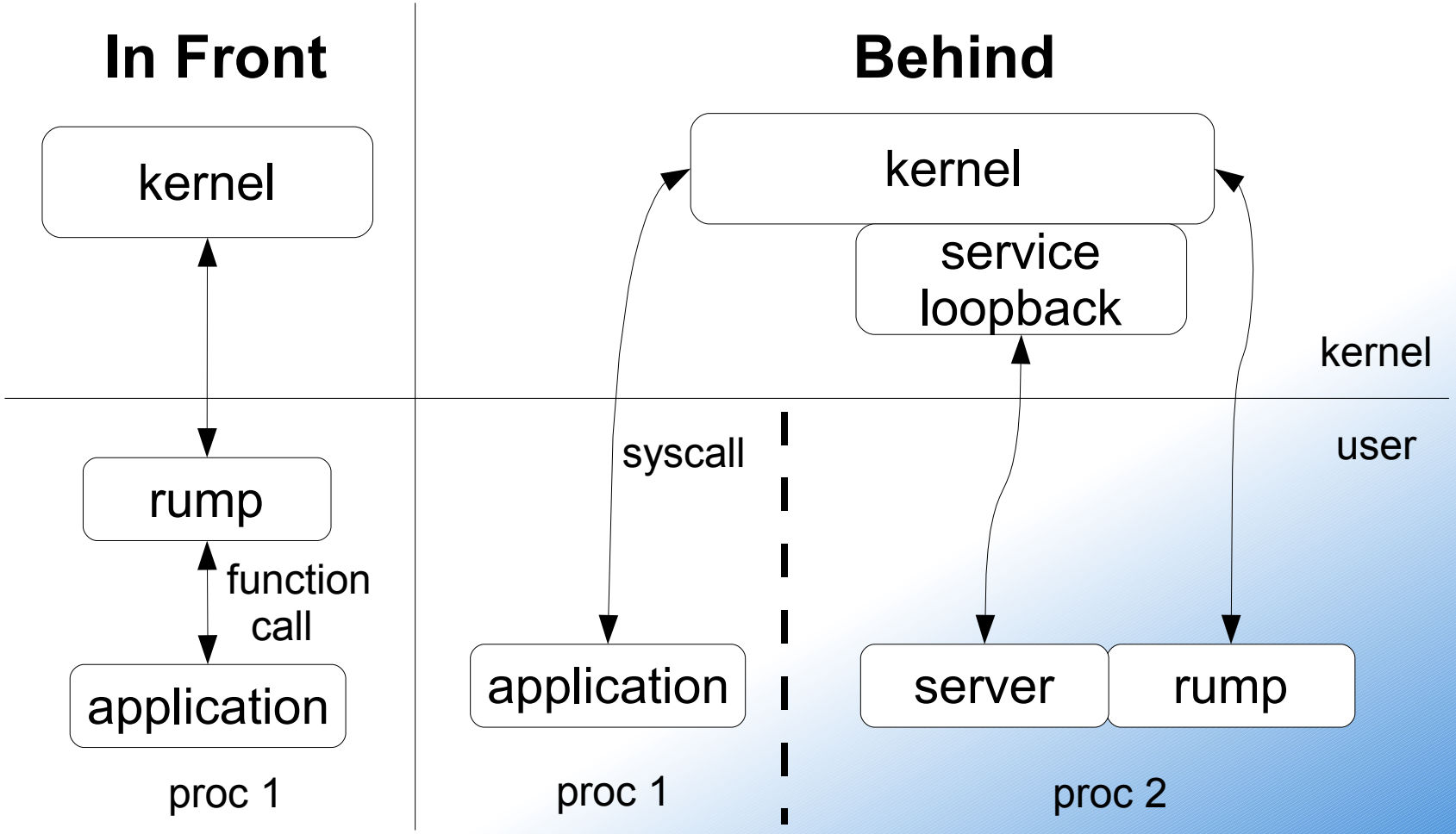
Runnable Userspace Meta Programs

- **observation**: most kernel code does not need to run in the kernel (cf. microkernels)
- make kernel code runnable in userspace
- kernel source module x still depends on interfaces provided by modules y, z and å
- some code depends on hardware access
- **solution**: split code into components to handle dependencies, reimplement code unnecessary for userspace (e.g. pmap)

The (big) picture



A different view



Available components

- kernel core (rumpkern, -lrump)
- most file systems (rumpvfs, -lrumpvfs)
  - FFS (-lrumpfs_ffs), NFS (-lrumpfs_nfs), tmpfs (-lrumpfs_tmpfs) etc.
- networking (rumpnet, -lrumpnet)
  - networking subroutines (-lrumpnet_net)
  - TCP/IP (-lrumpnet_inet)
- system calls for each component

When to use

- debugging a supported component
- developing new code
- testing
- playing around

- application uses
  - beyond the scope of this presentation

When to not use

- rump *complements* existing methods
  - not a general solution
- desired component not available
  - you might attempt to add support, though
- desired component depends on interaction with unsupported component
  - e.g. virtual memory and page remapping
- desired component uses hardware directly

gdb and rump

- gdb can be used on a rump like on any userspace program
- backtrace, break, single-step, examine data, examine core dump, ...
- gdb on threaded programs currently suboptimal on NetBSD
  - env variable `RUMP_THREADS` set to 0

    disallows threads creation in rump

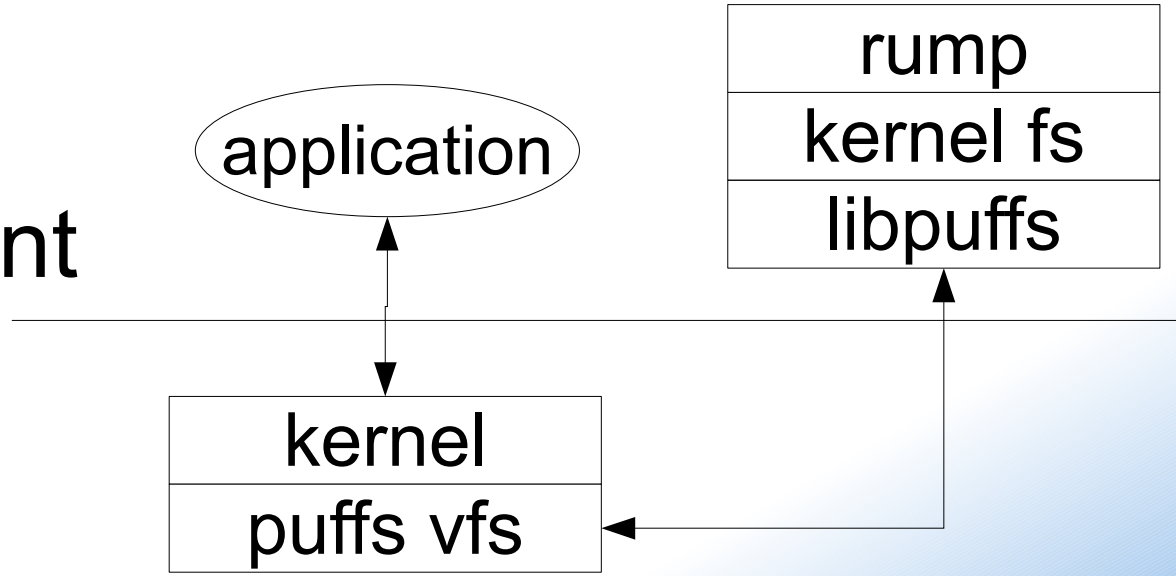
Examples of other tools

- gprof
- valgrind
- eletricfence, dmalloc
  - depends on which implementation of the memory allocator you use

File system tools

rump_$fs

- userspace mount
  - uses puffs
- *any* application



fs-utils (by Arnaud Ysmal)

- use rump syscalls to implement POSIX file system utils (ls, cp, etc.)
- does not require mounting

Demystifying *rumpns*

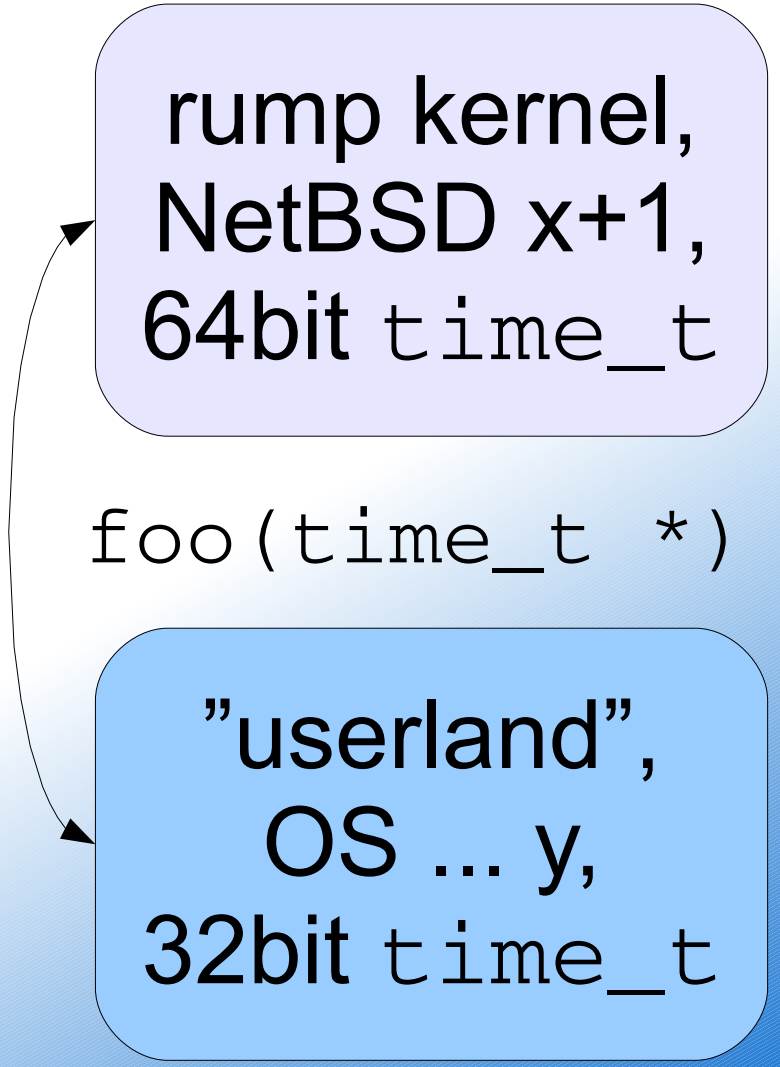
- kernel and application linker namespaces are normally disjoint
  - e.g. malloc() can exist in both without conflicts
- rump stuffs both under the same roof
  - possibility of conflicts
- => kernel symbols prefixed with ”rumpns”
- linker complains: no rumpns_garven_deh
  - missing garven_deh, not rumpns_garven_deh

Interfacing with the ”kernel”

- kernel function prototypes not available directly in userspace
  - they would be wrong anyway due to rumpns
- rump interfaces (e.g. `rump_init()`)
- syscalls (e.g. `rump_sys_open()`)
- vfs/vnode (e.g. `RUMP_VOP_SETATTR()`)
- user-defined, must provide ”rumpns” prototype for the compiler

ABI mix&match

- possible to run rump on non-matching NetBSD system version
- also possible on non-matching OS
- problem is interfacing
  - types with different size



Link sets

- entries placed in a certain section of the object file are unified by the static linker
- the kernel can traverse the entries runtime
- **problem:** scheme not fully compatible with dynamic shared objects
- **effect:** link set entries only from first DSO on linker line are visible
- **solution**(?): traverse link sets manually

Networking stack testing

- generate complex routed networks within a single machine
  - scales to thousands of nodes
  - script to generate&configure routing tables, interface addresses, etc.
- convert test applications to use rump
  - e.g. Apache took an hour or so
  - no preexisting tools yet

Tests and regression tests

- kernel tests usually run against live kernel
- test crash can crash the system
  - bad for batch testing
  - even worse for fault injection
- no need to: 1) compile kernel 2) update target environment 3) boot kernel 4) boot userland 5) run test program
  - very rapid incremental development

Repeating problems in rump

- most kernel problems easily repeatable
  - based on experience
- really sensitive timing problems might be problematic
  - or they might not be
- kernel bug or rump bug?

Example: real life fs problem

- mkdir returned ENOSPC with >4TB free
- solution:
  - mount with rump_ffs
  - put a breakpoint into ufs_mkdir
  - single-step and locate problem, fix
- rump enabled debugging the problem on a production system by a non-fs developer

Conclusions

- rump helps kernel development in its target cases
  - complements traditional methods
- short test cycle
- userspace tools
- makes the kernel more approachable
  - allows users to submit better bug reports

More info

- http://www.NetBSD.org/docs/rump/
- src/sys/rump in NetBSD source tree
- NetBSD mailing lists
- BSDCan 2009 paper
  - and other papers

- questions?