Tracing on Embedded Boards

For limited systems

Why trace on embedded?

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- Embedded boards have a lot of corner cases
- Visibility into the happenings of the board is key for solving issues

Introducing `trace-cmd`

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- Starts / stops tracing
- Shows the current trace buffer
- Records into a data file for post analysis (and to pass it around)
- Reads the data file
- Much much more
- Full man pages at:
  - https://www.trace-cmd.org/Documentation/trace-cmd/

Example tracing

```
# trace-cmd start -p function -l ‘*lock*’ -n ‘*clock*’
# trace-cmd show
# tracer: function
#
# entries-in-buffer/entries-written: 66426/87886   #P:8
#
#                                _-----=> irqs-off/BH-disabled
#                               / _----=> need-resched
#                              | / _---=> hardirq/softirq
#                              || / _--=> preempt-depth
#                              ||| / _-=> migrate-disable
#                              |||| /     delay
#           TASK-PID     CPU#  |||||  TIMESTAMP  FUNCTION
#              | |         |   |||||     |         |
          <idle>-0       [006] d..3.  7857.354704: rcu_read_lock_sched_held <-lock_release
          <idle>-0       [006] d..3.  7857.354704: rcu_read_lock_sched_held <-lock_acquire
          <idle>-0       [006] d..3.  7857.354704: rcu_read_lock_sched_held <-lock_release
          <idle>-0       [006] d..2.  7857.354705: _raw_spin_lock <-get_next_timer_interrupt
          <idle>-0       [006] d..4.  7857.354705: rcu_read_lock_sched_held <-lock_acquire
          <idle>-0       [006] d..3.  7857.354705: do_raw_spin_trylock <-_raw_spin_lock
```

Example tracing (without filters)

```
# trace-cmd start -p function
# trace-cmd show
# tracer: function
#
# entries-in-buffer/entries-written: 370446/38974811   #P:8
[..]
#           TASK-PID     CPU#  |||||  TIMESTAMP  FUNCTION
#              | |         |   |||||     |         |
          <idle>-0       [003] ..s3.  1526.601458: rcu_read_lock_sched_held <-__do_softirq
          <idle>-0       [003] d.s2.  1526.601459: irqtime_account_irq <-__do_softirq
          <idle>-0       [003] d.s2.  1526.601459: __local_bh_enable <-__do_softirq
          <idle>-0       [003] d..2.  1526.601460: idle_cpu <-__irq_exit_rcu
          <idle>-0       [003] d..2.  1526.601460: tick_nohz_irq_exit <-irq_exit_rcu
          <idle>-0       [003] d..2.  1526.601460: ktime_get <-tick_nohz_irq_exit
          <idle>-0       [003] d..3.  1526.601460: rcu_read_lock_sched_held <-lock_acquire
          <idle>-0       [003] d..3.  1526.601460: rcu_read_lock_sched_held <-lock_release
          <idle>-0       [003] d..3.  1526.601461: rcu_read_lock_sched_held <-trace_hardirqs_on_prep
          <idle>-0       [003] ...2.  1526.601462: cpuidle_reflect <-cpuidle_idle_call
          <idle>-0       [003] ...2.  1526.601462: menu_reflect <-cpuidle_idle_call
          <idle>-0       [003] ...2.  1526.601462: tick_nohz_idle_got_tick <-menu_reflect
          <idle>-0       [003] ...2.  1526.601462: arch_cpu_idle_exit <-do_idle
          <idle>-0       [003] d..2.  1526.601463: arch_cpu_idle_enter <-do_idle
          <idle>-0       [003] d..2.  1526.601463: tsc_verify_tsc_adjust <-arch_cpu_idle_enter
```

Example tracing (function graph)

```
# trace-cmd start -p function_graph
# trace-cmd show
# tracer: function_graph
#
# CPU  DURATION                  FUNCTION CALLS
# |     |   |                     |   |   |   |
 3)   3.480 us    |  rcu_idle_exit();
 3)   0.449 us    |  rcu_read_lock_sched_held();
 3)   0.283 us    |  sched_idle_set_state();
 3)               |  cpuidle_reflect() {
 3)               |    menu_reflect() {
 3)   0.321 us    |      tick_nohz_idle_got_tick();
 3)   1.057 us    |    }
 3)   2.068 us    |  }
 3)   0.301 us    |  arch_cpu_idle_exit();
 3)               |  tick_nohz_idle_exit() {
 3)               |    ktime_get() {
 3)   0.306 us    |      rcu_read_lock_sched_held();
 3)   0.271 us    |      rcu_read_lock_sched_held();
 3)   1.957 us    |    }
 3)   0.261 us    |    nr_iowait_cpu();
 3)               |    __tick_nohz_full_update_tick() {
 3)   0.316 us    |      check_tick_dependency();
```

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trace-cmd allows for offline analysis

- Can record to a file `trace.dat`
- Can add plugins to process events (do things differently)
- Can use tooling to analyse the data
    - The data file is basically a database of events

Recording trace (function graph)

```
# trace-cmd set -n '*[^c]lock*'
# trace-cmd record -p function_graph
[Ctrl^C]
# trace-cmd report
      trace-cmd-2612  [000]  7514.222672: funcgraph_entry:                   |    update_rq_clock() {
      trace-cmd-2612  [000]  7514.222673: funcgraph_exit:         0.236 us   |    }
      trace-cmd-2612  [000]  7514.222673: funcgraph_entry:                   |    dequeue_task_fair() {
      trace-cmd-2612  [000]  7514.222673: funcgraph_entry:                   |      dequeue_entity() {
      trace-cmd-2612  [000]  7514.222673: funcgraph_entry:                   |        update_curr() {
      trace-cmd-2612  [000]  7514.222674: funcgraph_entry:                   |          update_min_vruntime() {
      trace-cmd-2612  [000]  7514.222674: funcgraph_exit:         0.210 us   |          }
      trace-cmd-2612  [000]  7514.222674: funcgraph_entry:                   |          cpuacct_charge() {
      trace-cmd-2612  [000]  7514.222674: funcgraph_exit:         0.211 us   |          }
      trace-cmd-2612  [000]  7514.222674: funcgraph_entry:                   |          __cgroup_account_cputime() {
      trace-cmd-2612  [000]  7514.222675: funcgraph_entry:                   |            preempt_count_add() {
      trace-cmd-2612  [000]  7514.222675: funcgraph_exit:         0.193 us   |            }
      trace-cmd-2612  [000]  7514.222675: funcgraph_entry:                   |            cgroup_rstat_updated() {
      trace-cmd-2612  [000]  7514.222675: funcgraph_exit:         0.190 us   |            }
      trace-cmd-2612  [000]  7514.222675: funcgraph_entry:                   |            preempt_count_sub() {
      trace-cmd-2612  [000]  7514.222676: funcgraph_exit:         0.198 us   |            }
      trace-cmd-2612  [000]  7514.222676: funcgraph_exit:         1.309 us   |          }
      trace-cmd-2612  [000]  7514.222676: funcgraph_exit:         2.554 us   |        }
      trace-cmd-2612  [000]  7514.222676: funcgraph_entry:                   |        __update_load_avg_se() {
      trace-cmd-2612  [000]  7514.222676: funcgraph_exit:         0.197 us   |        }
      trace-cmd-2612  [000]  7514.222676: funcgraph_entry:                   |        __update_load_avg_cfs_rq() {
      trace-cmd-2612  [000]  7514.222677: funcgraph_exit:         0.214 us   |        }
      trace-cmd-2612  [000]  7514.222678: funcgraph_entry:                   |        clear_buddies() {
```

Recording trace (function)

```
# trace-cmd record -p function -n '*[^c]lock*'
[Ctrl^C]
# trace-cmd report
       trace-cmd-2640  [000]  7621.673360: function:             handle_mm_fault
       trace-cmd-2640  [000]  7621.673360: function:                mem_cgroup_from_task
       trace-cmd-2640  [000]  7621.673360: function:             __count_memcg_events
       trace-cmd-2640  [000]  7621.673360: function:                cgroup_rstat_updated
       trace-cmd-2640  [000]  7621.673361: function:             __handle_mm_fault
       trace-cmd-2640  [000]  7621.673361: function:                handle_pte_fault
       trace-cmd-2640  [000]  7621.673361: function:                do_fault
       trace-cmd-2640  [000]  7621.673361: function:                   do_read_fault
       trace-cmd-2640  [000]  7621.673361: function:                      filemap_map_pages
       trace-cmd-2640  [000]  7621.673361: function:                         next_uptodate_page
       trace-cmd-2640  [000]  7621.673361: function:                         filemap_map_pmd
       trace-cmd-2640  [000]  7621.673370: function:                         PageHeadHuge
       trace-cmd-2640  [000]  7621.673370: function:                         do_set_pte
       trace-cmd-2640  [000]  7621.673371: function:                            add_mm_counter_fast
       trace-cmd-2640  [000]  7621.673371: function:                            page_add_file_rmap
       trace-cmd-2640  [000]  7621.673371: function:                               lock_page_memcg
       trace-cmd-2640  [000]  7621.673371: function:                         next_uptodate_page
       trace-cmd-2640  [000]  7621.673371: function:                         PageHeadHuge
       trace-cmd-2640  [000]  7621.673371: function:                         do_set_pte
       trace-cmd-2640  [000]  7621.673371: function:                            add_mm_counter_fast
       trace-cmd-2640  [000]  7621.673371: function:                            page_add_file_rmap
       trace-cmd-2640  [000]  7621.673371: function:                               lock_page_memcg
       trace-cmd-2640  [000]  7621.673371: function:                         next_uptodate_page
       trace-cmd-2640  [000]  7621.673372: function:                         PageHeadHuge
```

Example tracing (without filters)

```
# trace-cmd start -p function
# trace-cmd show
# tracer: function
#
# entries-in-buffer/entries-written: 370446/38974811   #P:8
[..]
#          TASK-PID     CPU#  |||||  TIMESTAMP  FUNCTION
#             | |         |   |||||     |         |
          <idle>-0      [003] ..s3.  1526.601458: rcu_read_lock_sched_held <-__do_softirq
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          <idle>-0      [003] d.s2.  1526.601459: __local_bh_enable <-__do_softirq
          <idle>-0      [003] d..2.  1526.601460: idle_cpu <-__irq_exit_rcu
          <idle>-0      [003] d..2.  1526.601460: tick_nohz_irq_exit <-irq_exit_rcu
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          <idle>-0      [003] d..3.  1526.601460: rcu_read_lock_sched_held <-lock_acquire
          <idle>-0      [003] d..3.  1526.601460: rcu_read_lock_sched_held <-lock_release
          <idle>-0      [003] d..3.  1526.601461: rcu_read_lock_sched_held <-trace_hardirqs_on_prep
          <idle>-0      [003] ...2.  1526.601462: cpuidle_reflect <-cpuidle_idle_call
          <idle>-0      [003] ...2.  1526.601462: menu_reflect <-cpuidle_idle_call
          <idle>-0      [003] ...2.  1526.601462: tick_nohz_idle_got_tick <-menu_reflect
          <idle>-0      [003] ...2.  1526.601462: arch_cpu_idle_exit <-do_idle
          <idle>-0      [003] d..2.  1526.601463: arch_cpu_idle_enter <-do_idle
          <idle>-0      [003] d..2.  1526.601463: tsc_verify_tsc_adjust <-arch_cpu_idle_enter
```

Recording trace (function)

```
# trace-cmd record -p function -n '*[^c]lock*'
[Ctrl^C]
# trace-cmd report
       trace-cmd-2640  [000]  7621.673360: function:             handle_mm_fault
       trace-cmd-2640  [000]  7621.673360: function:                mem_cgroup_from_task
       trace-cmd-2640  [000]  7621.673360: function:             __count_memcg_events
       trace-cmd-2640  [000]  7621.673360: function:                cgroup_rstat_updated
       trace-cmd-2640  [000]  7621.673361: function:             __handle_mm_fault
       trace-cmd-2640  [000]  7621.673361: function:                handle_pte_fault
       trace-cmd-2640  [000]  7621.673361: function:                do_fault
       trace-cmd-2640  [000]  7621.673361: function:                   do_read_fault
       trace-cmd-2640  [000]  7621.673361: function:                      filemap_map_pages
       trace-cmd-2640  [000]  7621.673361: function:                         next_uptodate_page
       trace-cmd-2640  [000]  7621.673361: function:                         filemap_map_pmd
       trace-cmd-2640  [000]  7621.673370: function:                         PageHeadHuge
       trace-cmd-2640  [000]  7621.673370: function:                         do_set_pte
       trace-cmd-2640  [000]  7621.673371: function:                            add_mm_counter_fast
       trace-cmd-2640  [000]  7621.673371: function:                            page_add_file_rmap
       trace-cmd-2640  [000]  7621.673371: function:                               lock_page_memcg
       trace-cmd-2640  [000]  7621.673371: function:                         next_uptodate_page
       trace-cmd-2640  [000]  7621.673371: function:                         PageHeadHuge
       trace-cmd-2640  [000]  7621.673371: function:                         do_set_pte
       trace-cmd-2640  [000]  7621.673371: function:                            add_mm_counter_fast
       trace-cmd-2640  [000]  7621.673371: function:                            page_add_file_rmap
       trace-cmd-2640  [000]  7621.673371: function:                               lock_page_memcg
       trace-cmd-2640  [000]  7621.673371: function:                         next_uptodate_page
       trace-cmd-2640  [000]  7621.673372: function:                         PageHeadHuge
```

Recording trace (function)

```
# trace-cmd record -p function -n '*[^c]lock*'
[Ctrl^C]
# trace-cmd report -O parent
      trace-cmd-2640  [000]  7621.673360: function:             handle_mm_fault <-- do_user_addr_fault
      trace-cmd-2640  [000]  7621.673360: function:                mem_cgroup_from_task <-- handle_mm_fault
      trace-cmd-2640  [000]  7621.673360: function:             __count_memcg_events <-- count_memcg_events.constprop.0
      trace-cmd-2640  [000]  7621.673360: function:                cgroup_rstat_updated <-- __count_memcg_events
      trace-cmd-2640  [000]  7621.673361: function:             __handle_mm_fault <-- handle_mm_fault
      trace-cmd-2640  [000]  7621.673361: function:                handle_pte_fault <-- __handle_mm_fault
      trace-cmd-2640  [000]  7621.673361: function:                do_fault <-- __handle_mm_fault
      trace-cmd-2640  [000]  7621.673361: function:                   do_read_fault <-- do_fault
      trace-cmd-2640  [000]  7621.673361: function:                      filemap_map_pages <-- do_read_fault
      trace-cmd-2640  [000]  7621.673361: function:                         next_uptodate_page <-- filemap_map_pages
      trace-cmd-2640  [000]  7621.673361: function:                         filemap_map_pmd <-- filemap_map_pages
      trace-cmd-2640  [000]  7621.673370: function:                         PageHeadHuge <-- filemap_map_pages
      trace-cmd-2640  [000]  7621.673370: function:                         do_set_pte <-- filemap_map_pages
      trace-cmd-2640  [000]  7621.673371: function:                            add_mm_counter_fast <-- do_set_pte
      trace-cmd-2640  [000]  7621.673371: function:                            page_add_file_rmap <-- do_set_pte
      trace-cmd-2640  [000]  7621.673371: function:                               lock_page_memcg <-- page_add_file_rmap
      trace-cmd-2640  [000]  7621.673371: function:                         next_uptodate_page <-- filemap_map_pages
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```

Recording trace (function)

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# trace-cmd record -p function -n '*[^c]lock*'
[Ctrl^C]
# trace-cmd report -O parent
       trace-cmd-2640  [000]  7621.673360: function:             handle_mm_fault <-- do_user_addr_fault
       trace-cmd-2640  [000]  7621.673360: function:                mem_cgroup_from_task <-- handle_mm_fault
       trace-cmd-2640  [000]  7621.673360: function:             __count_memcg_events <-- count_memcg_events.constprop.0
       trace-cmd-2640  [000]  7621.673360: function:                cgroup_rstat_updated <-- __count_memcg_events
       trace-cmd-2640  [000]  7621.673361: function:             __handle_mm_fault <-- handle_mm_fault
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       trace-cmd-2640  [000]  7621.673361: function:                do_fault <-- __handle_mm_fault
       trace-cmd-2640  [000]  7621.673361: function:                   do_read_fault <-- do_fault
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       trace-cmd-2640  [000]  7621.673371: function:                               lock_page_memcg <-- page_add_file_rmap
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       trace-cmd-2640  [000]  7621.673371: function:                            add_mm_counter_fast <-- do_set_pte
       trace-cmd-2640  [000]  7621.673371: function:                            page_add_file_rmap <-- do_set_pte
       trace-cmd-2640  [000]  7621.673371: function:                               lock_page_memcg <-- page_add_file_rmap
       trace-cmd-2640  [000]  7621.673371: function:                         next_uptodate_page <-- filemap_map_pages
       trace-cmd-2640  [000]  7621.673372: function:                         PageHeadHuge <-- filemap_map_pages
```

trace-cmd trace.dat files

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  - Offline analysis
  - Run queries on events
    - Make histograms
    - Show latency between related events
- Records much more than what the kernel buffer can hold
  - Trace long sessions
  - Uses splice(2) system call (more on this later)

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- Really useful to have
  - Offline analysis
  - Run queries on events
    - Make histograms
    - Show latency between related events
- Records much more than what the kernel buffer can hold
  - Trace long sessions
  - Uses splice(2) system call (more on this later)
    - Makes it fast!

splice(2) system call

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- Allows transfer of data without copying to/from user space

splice(2) system call

- Connects a file descriptor with a pipe
- Allows transfer of data without copying to/from user space
- Moves pages around inside the kernel without copying

Simple “cp” program

```
int main(int argc, char **argv)
{
	char buf[BUFSIZ];
	int ifd, ofd, r;

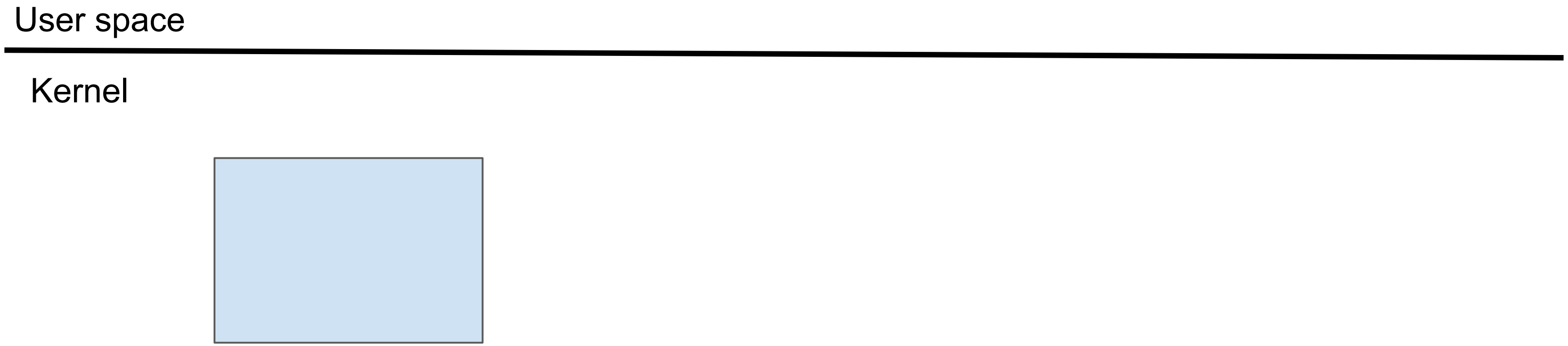
	if (argc < 3)
		exit(-1);
	ifd = open(argv[1], O_RDONLY);
	if (ifd < 0)
		exit(-1);
	ofd = open(argv[2], O_WRONLY | O_TRUNC | O_CREAT, 0644);
	if (ofd < 0)
		exit(-1);

	while ((r = read(ifd, buf, BUFSIZ)) > 0) {
		r = write(ofd, buf, r);
		if (r < 0)
			exit(-1);
	}

	close(ifd);
	close(ofd);
	exit(0);
}
```

Simple “cp” program

```
read(ifd, buf, BUFSIZ)
```



Simple “cp” program

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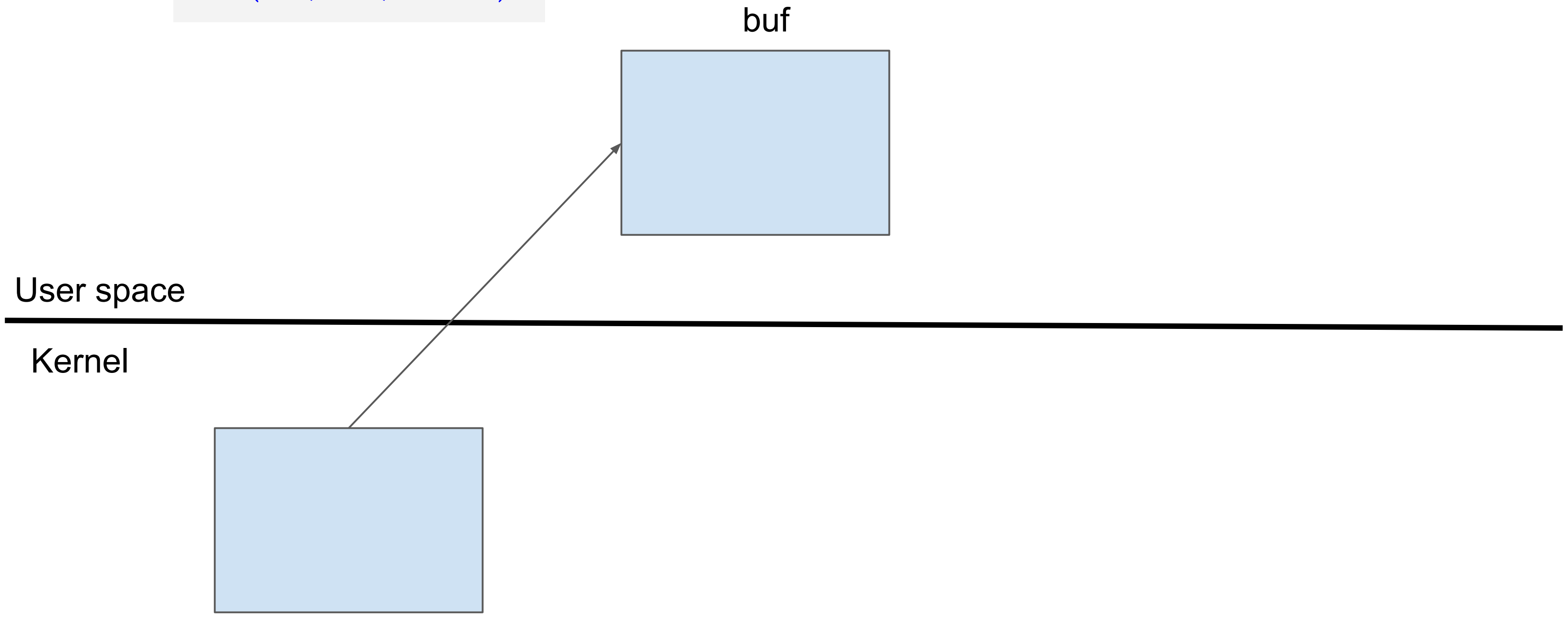
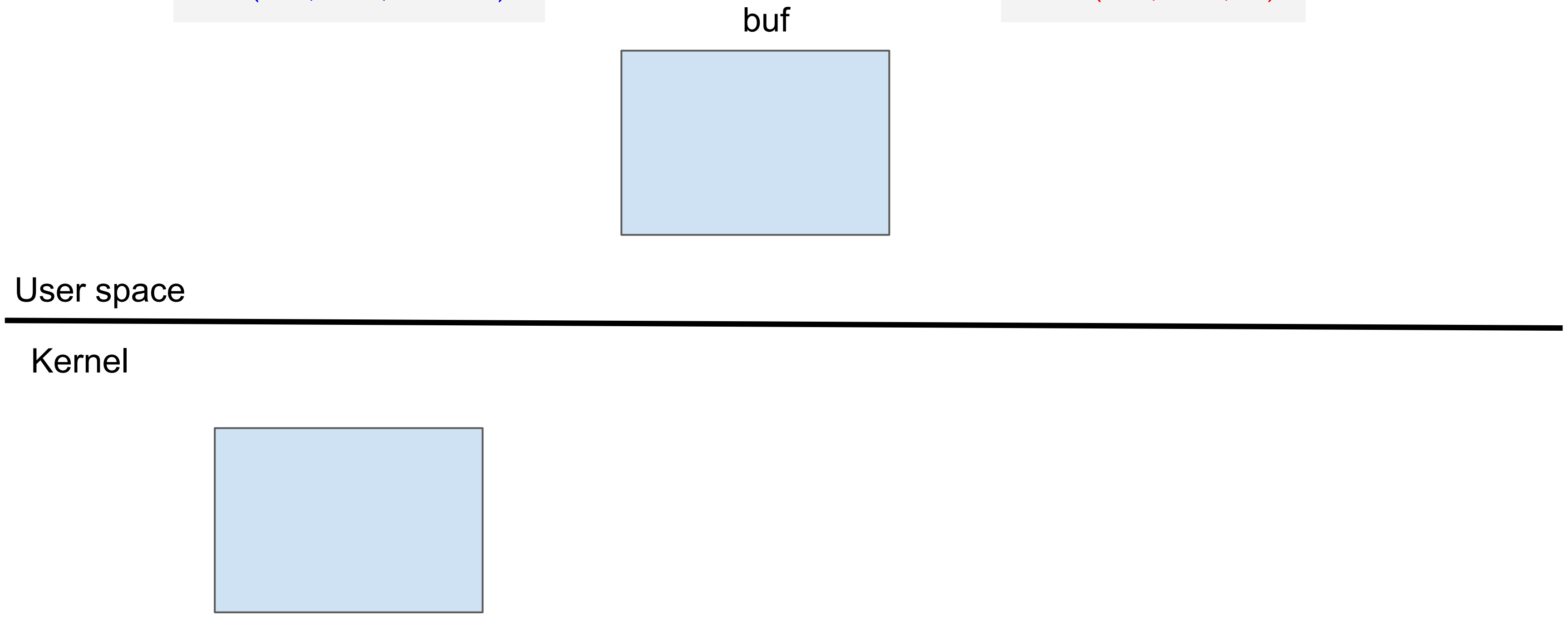


Simple “cp” program

```
read(ifd, buf, BUFSIZ)
```

```
write(ofd, buf, r)
```



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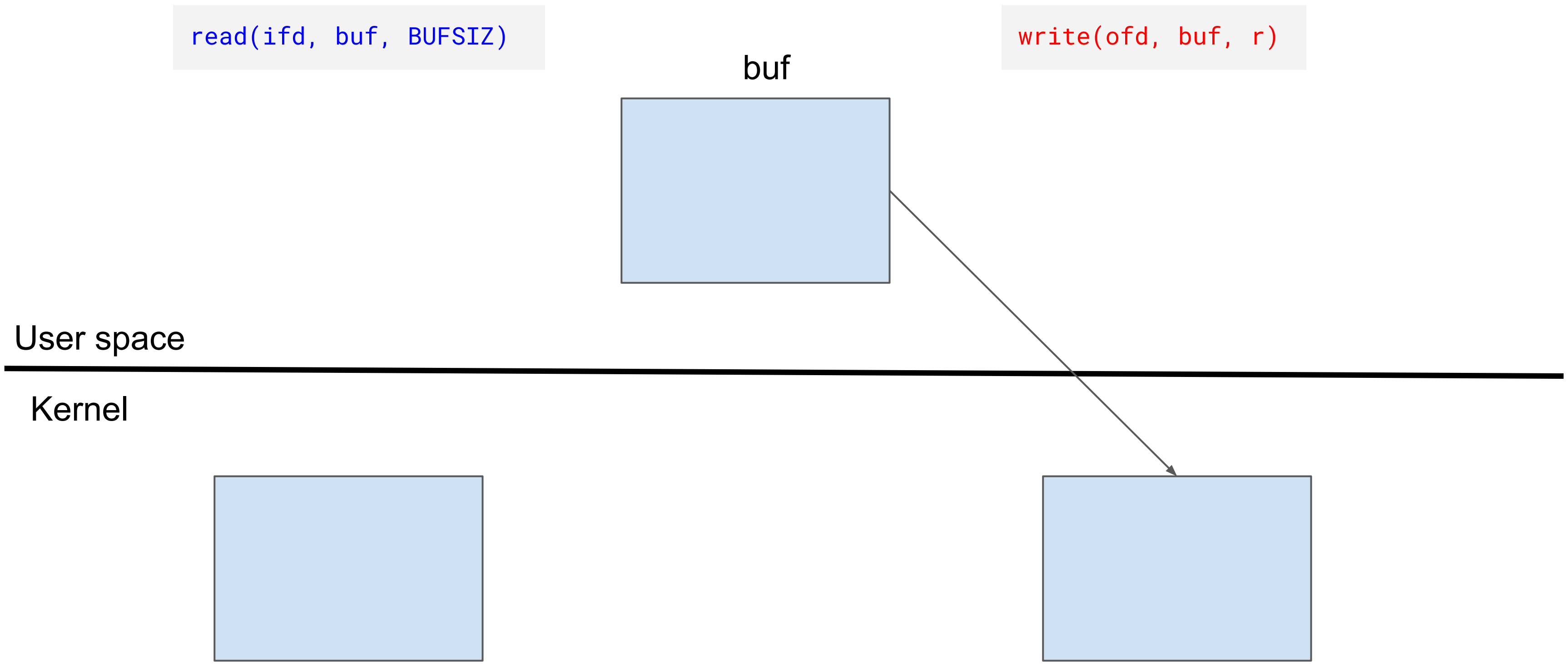


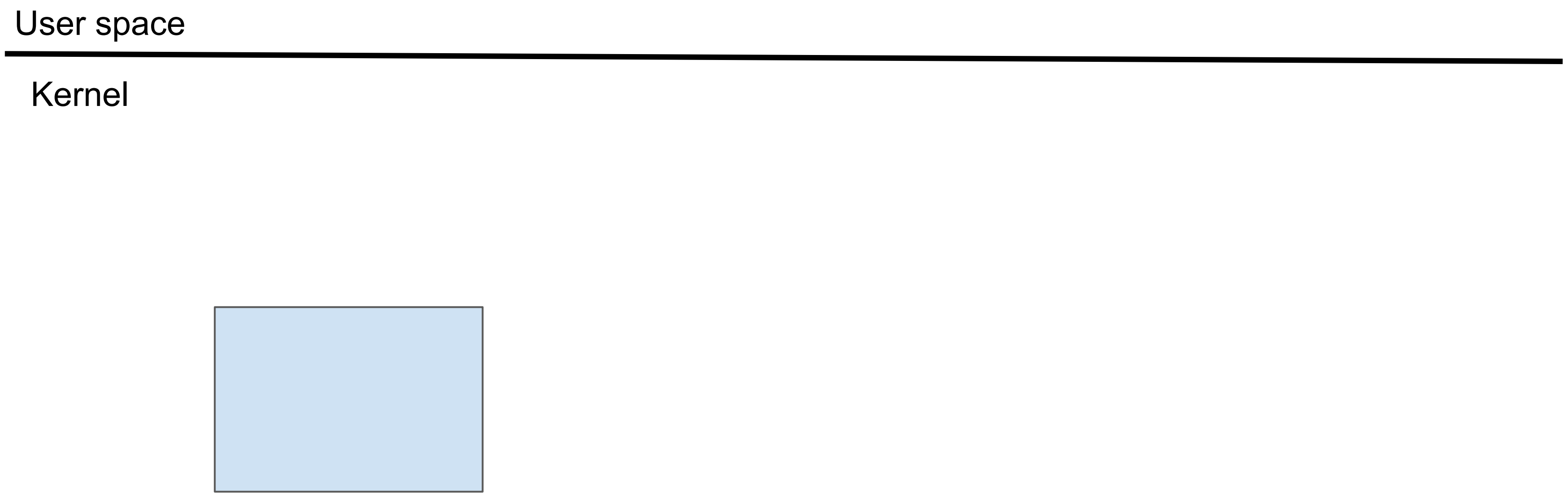
“cp” program with splice

```
int main(int argc, char **argv)
{
        int ifd, ofd, r;
        int brass[2];
        int pipesize;

        if (argc < 3)
                exit(-1);
        ifd = open(argv[1], O_RDONLY);
        if (ifd < 0)
                exit(-1);
        ofd = open(argv[2], O_WRONLY | O_TRUNC | O_CREAT, 0644);
        if (ofd < 0)
                exit(-1);
        if (pipe(brass) < 0)
                exit(-1);
        r = fcntl(brass[0], F_GETPIPE_SZ, &pipesize);
        if (r < 0)
                pipesize = getpagesize();
        for (;;) {
                r = splice(ifd, NULL, brass[1], NULL, pipesize, SPLICE_F_MOVE);
                if (r < 0)
                        exit(-1);
                if (!r)
                        break;
                r = splice(brass[0], NULL, ofd, NULL, r, SPLICE_F_MOVE | SPLICE_F_NONBLOCK);
                if (r < 0)
                        exit(-1);
        }
        close(ifd);
        close(ofd);
        exit(0);
}
```

“cp” program with splice

```
pipe(brass)
```



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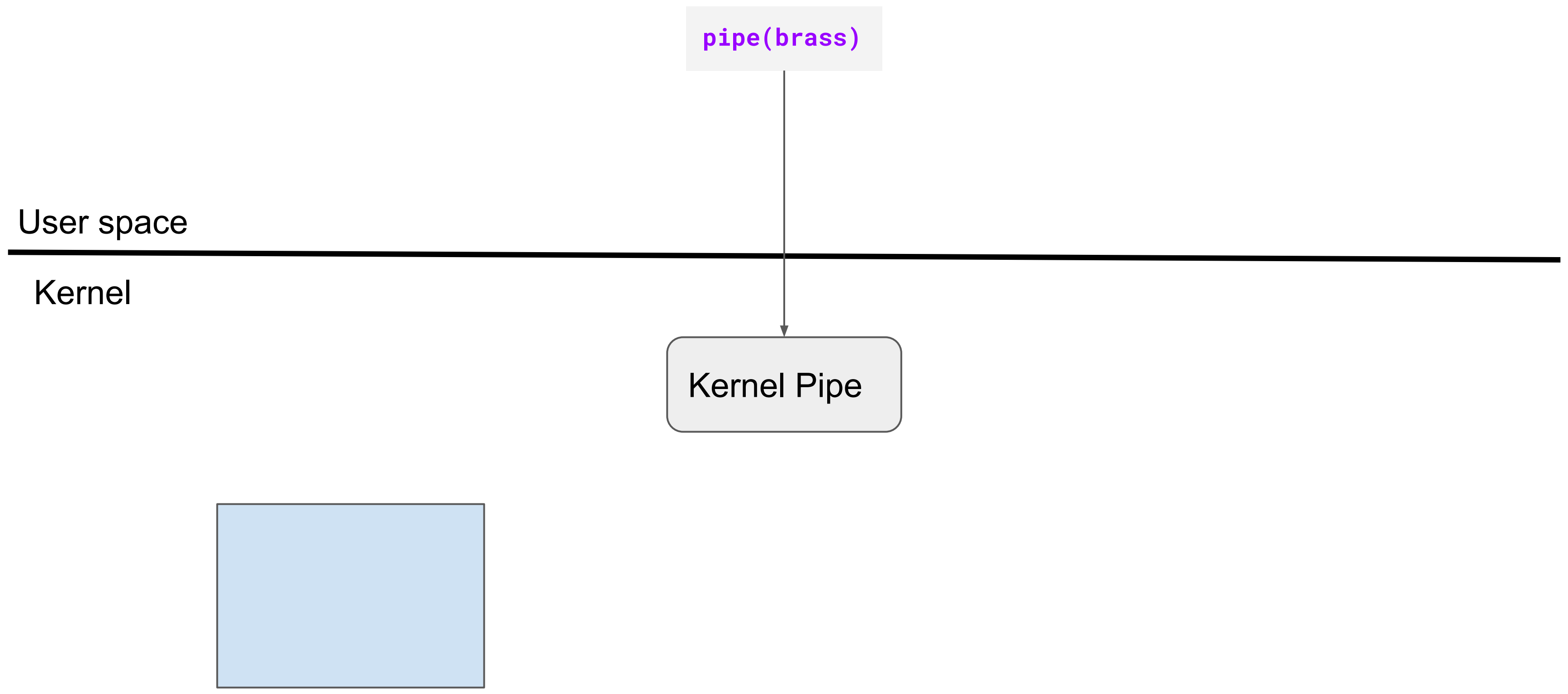

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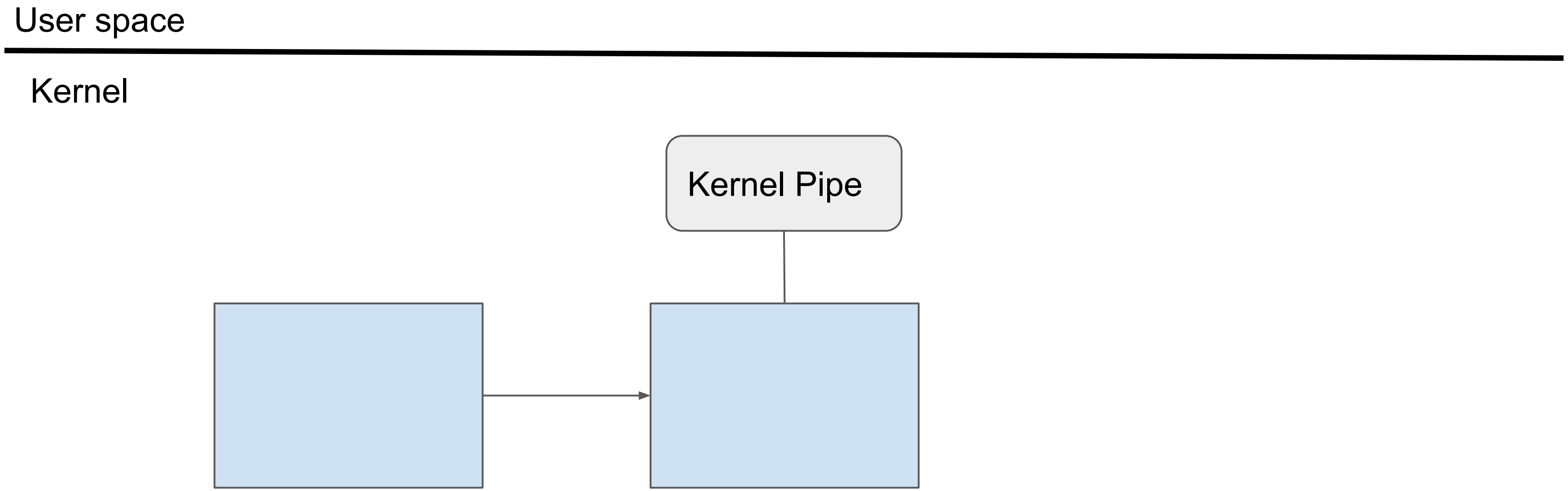

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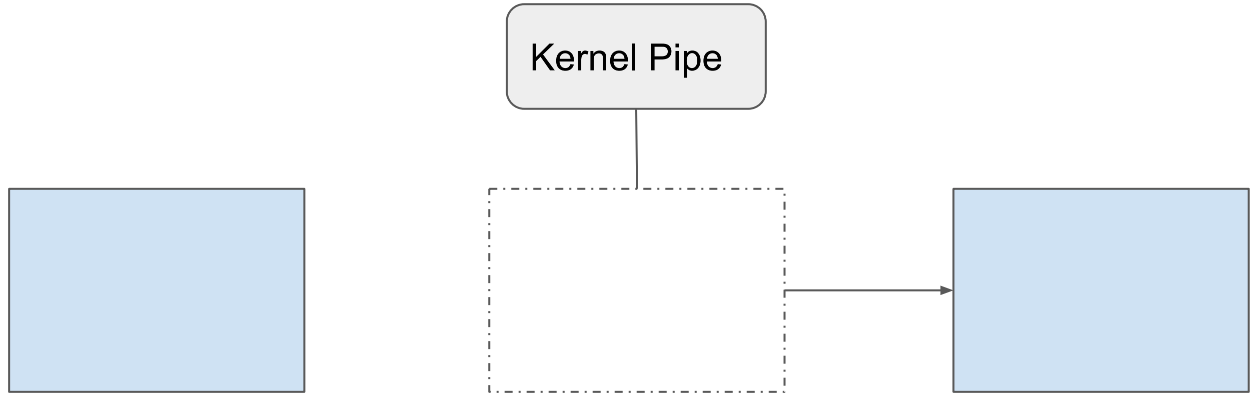
User space

Kernel



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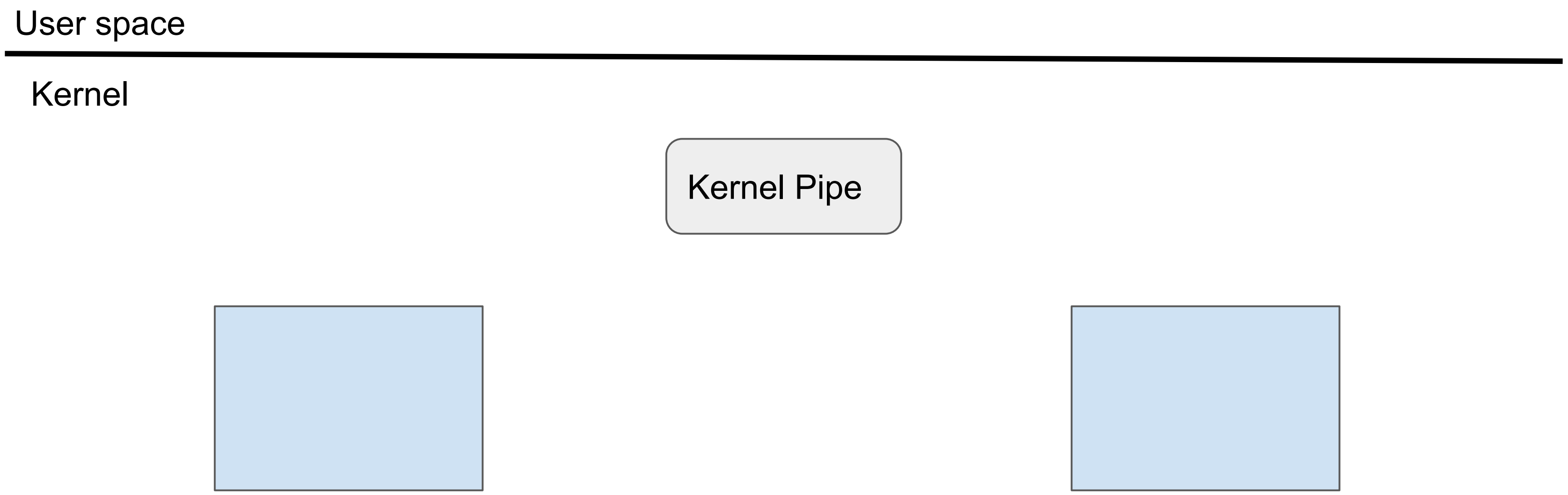

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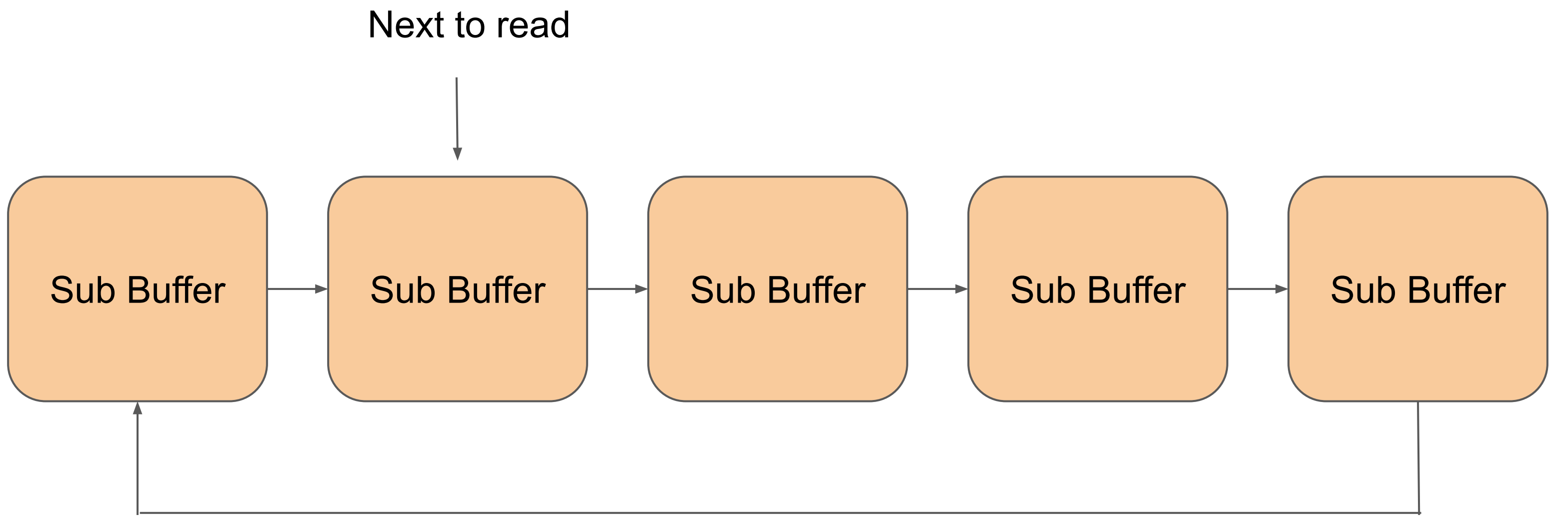
  - True zero copy!

Ftrace ring buffer and splice



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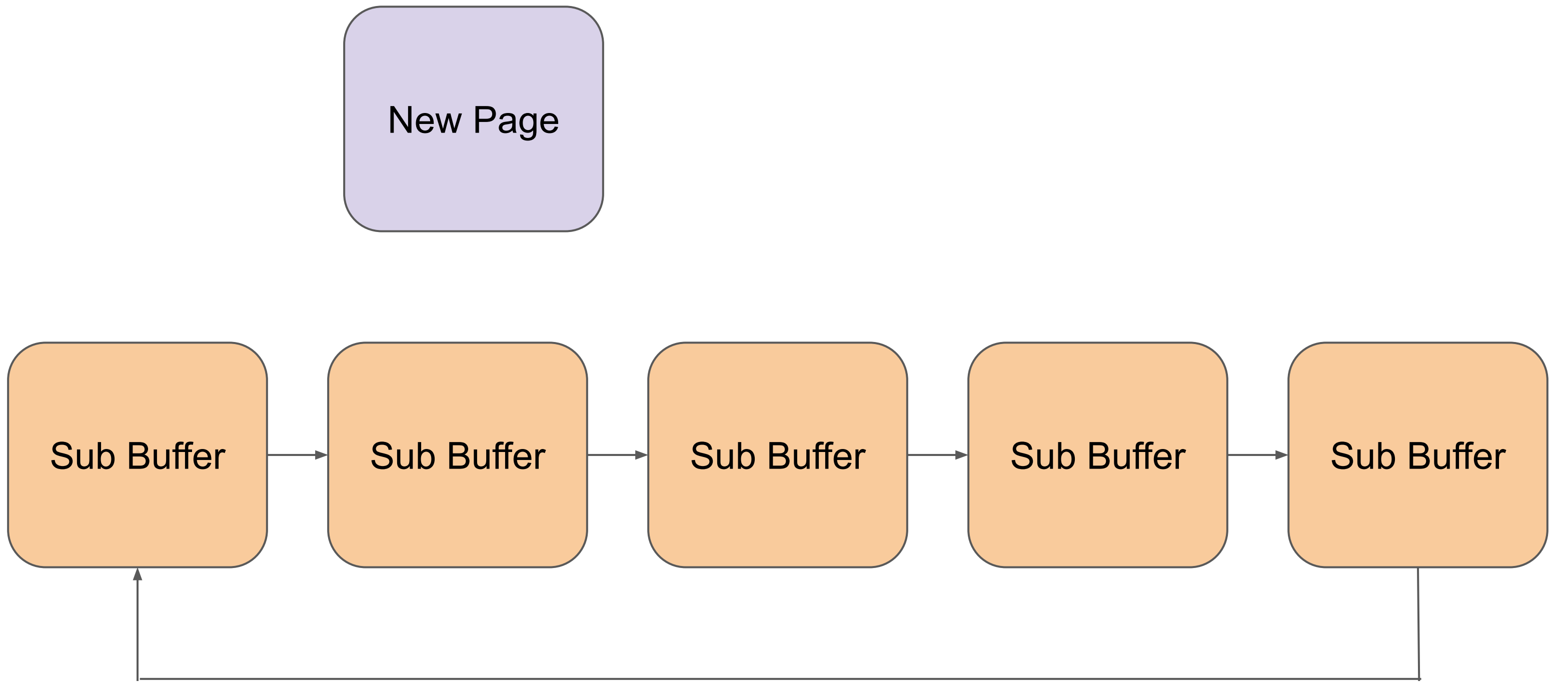

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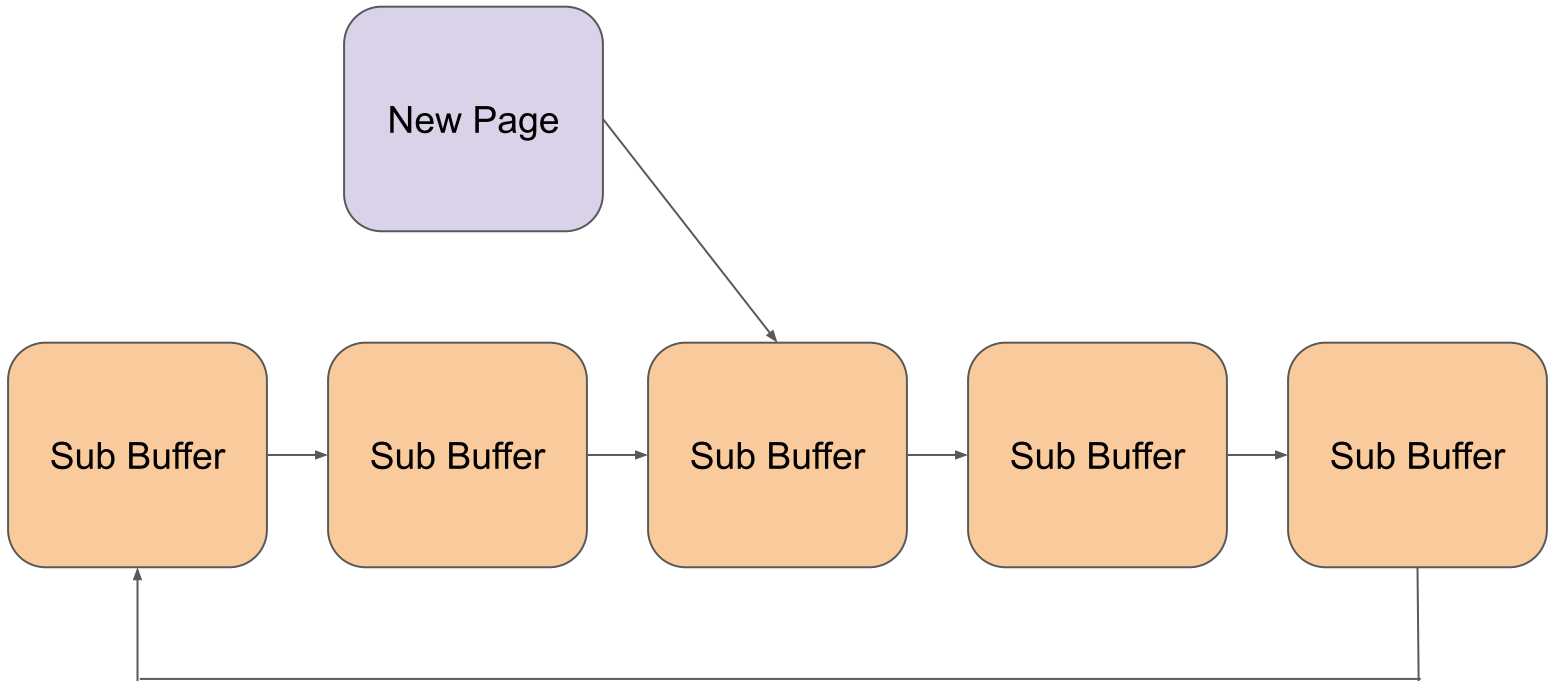

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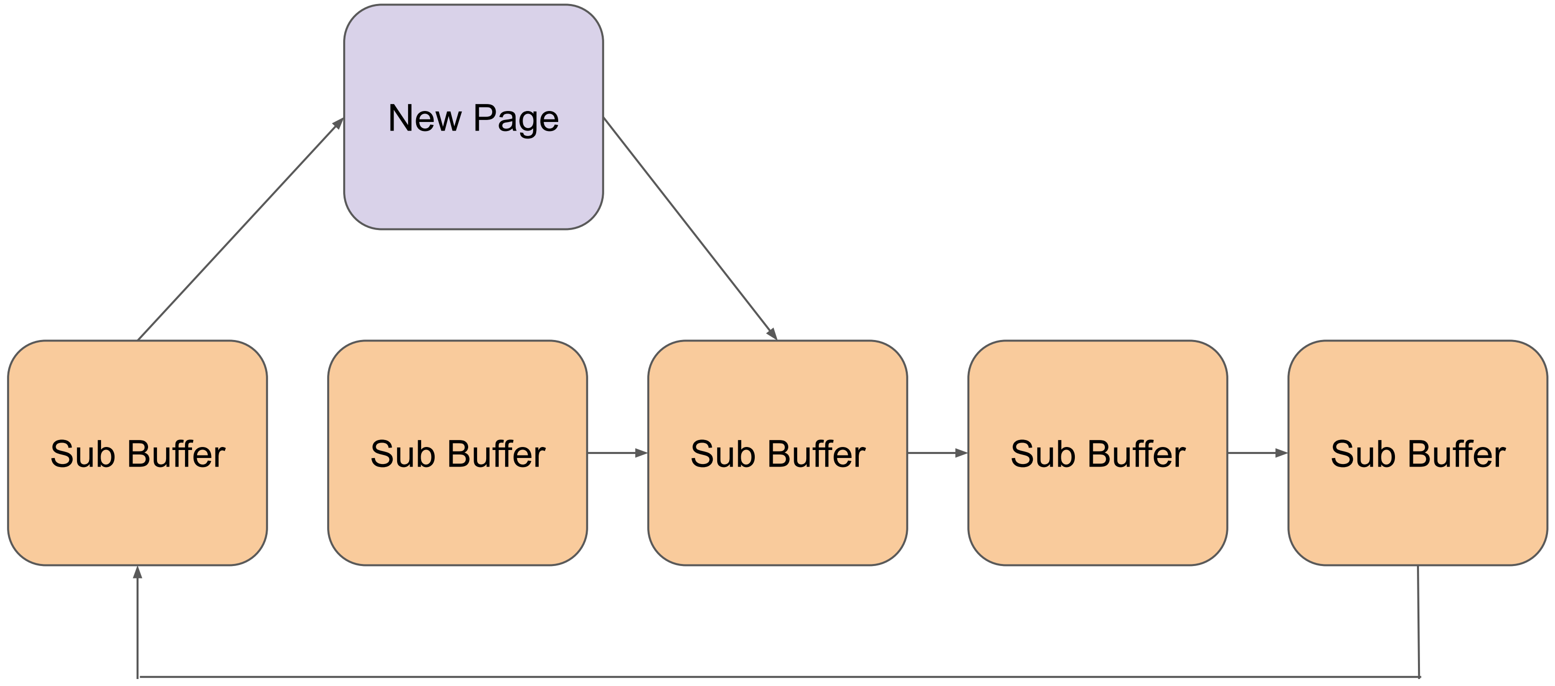

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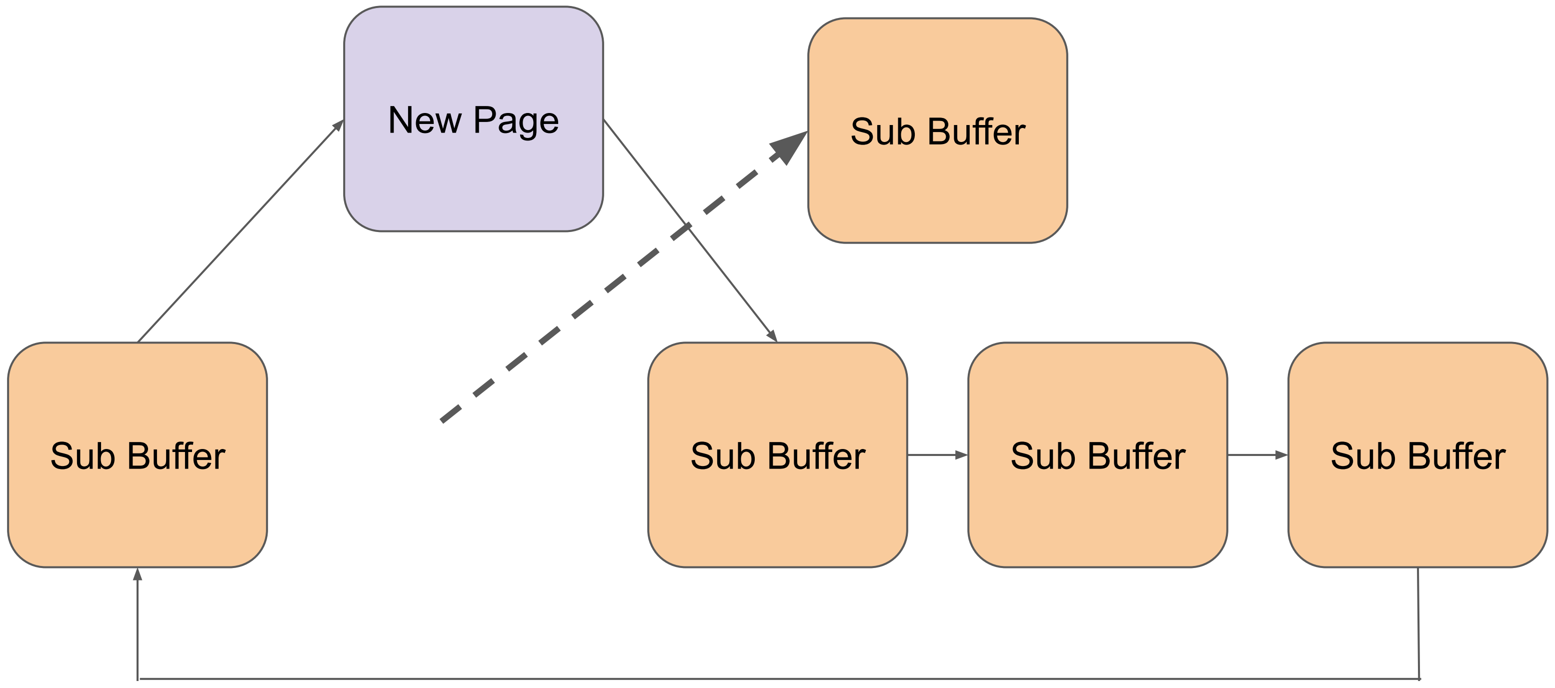

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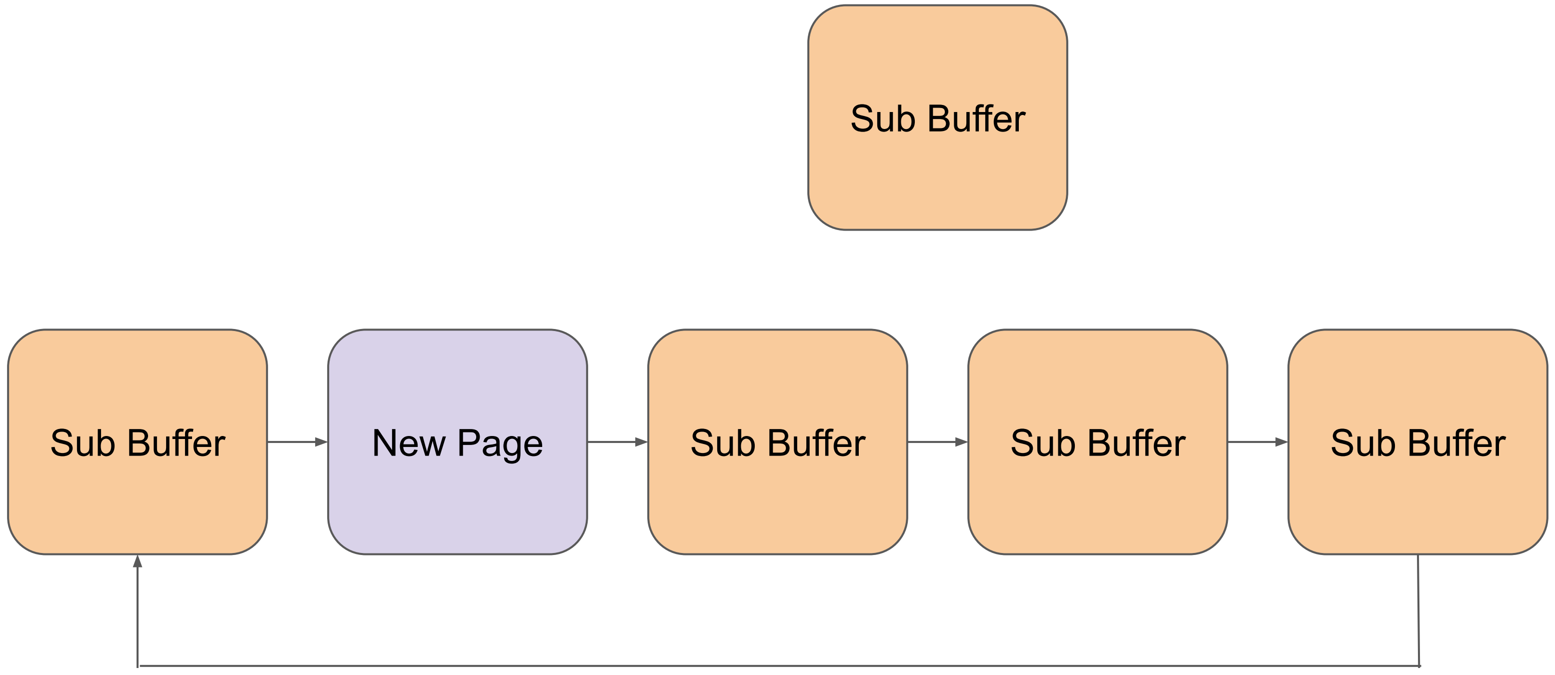

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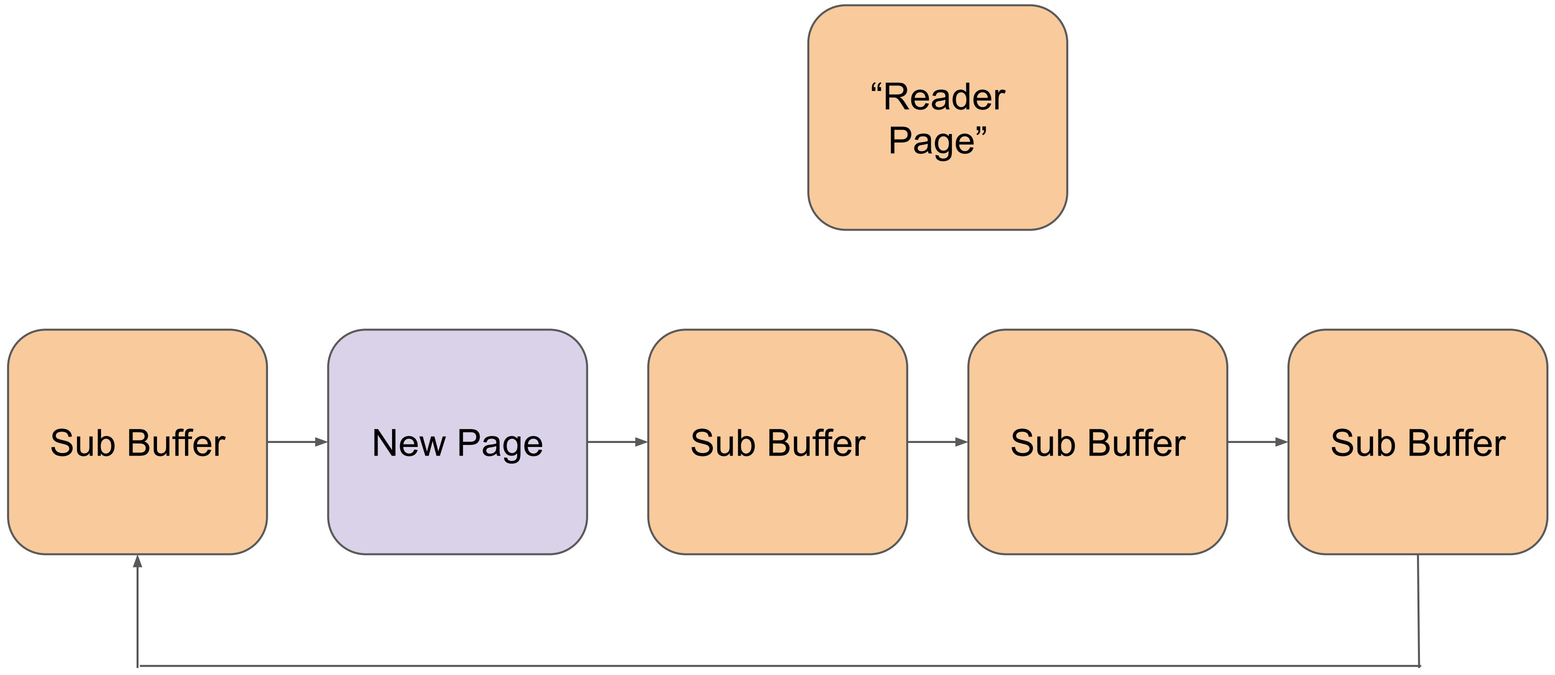

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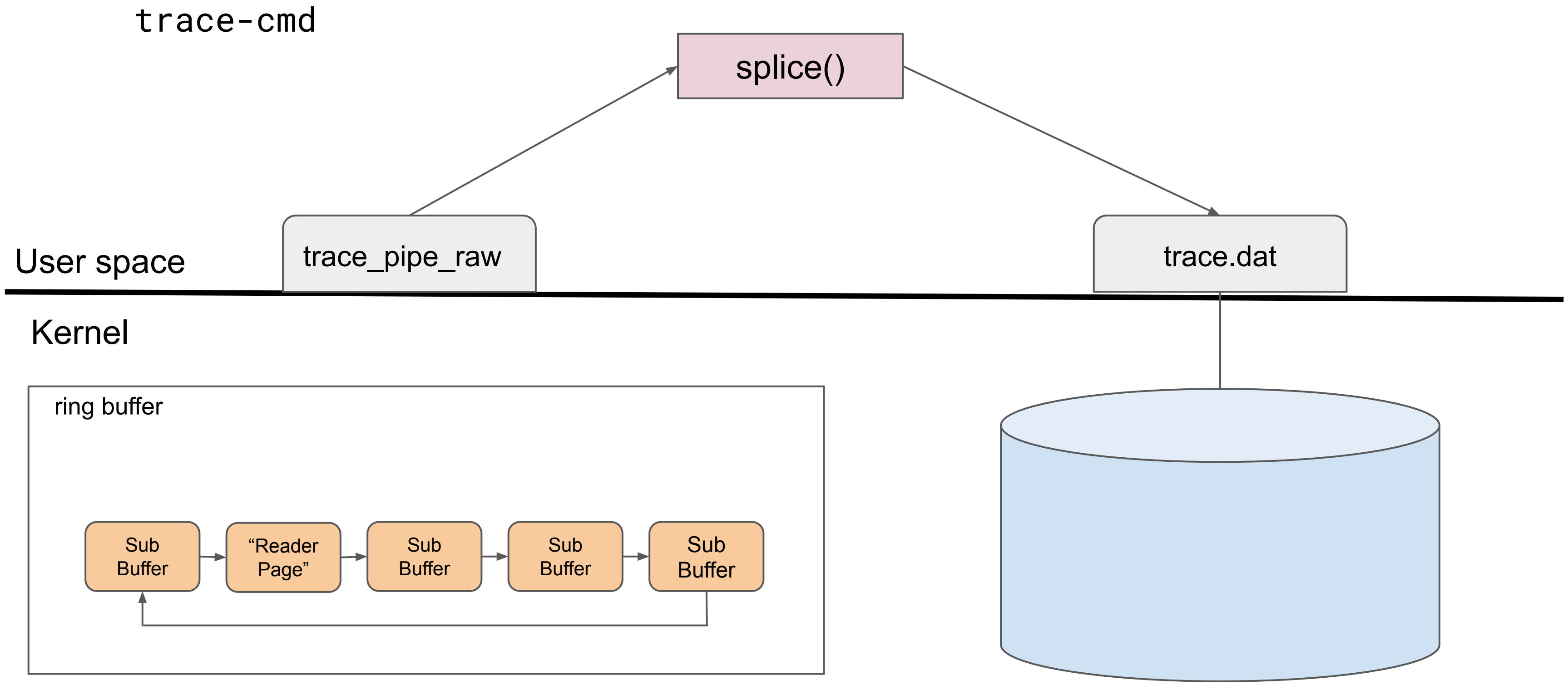
- Send it over a socket (over the network)

trace-cmd, ftrace and splice



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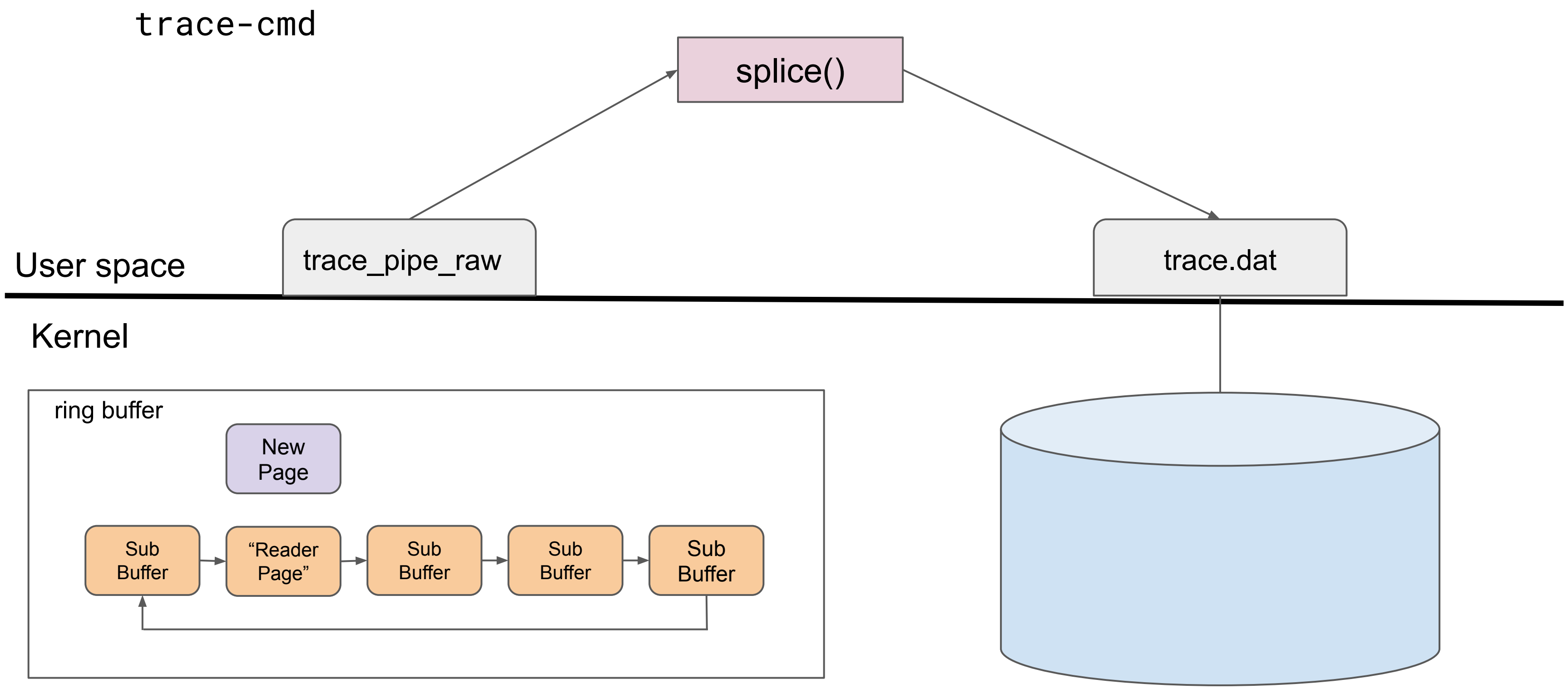

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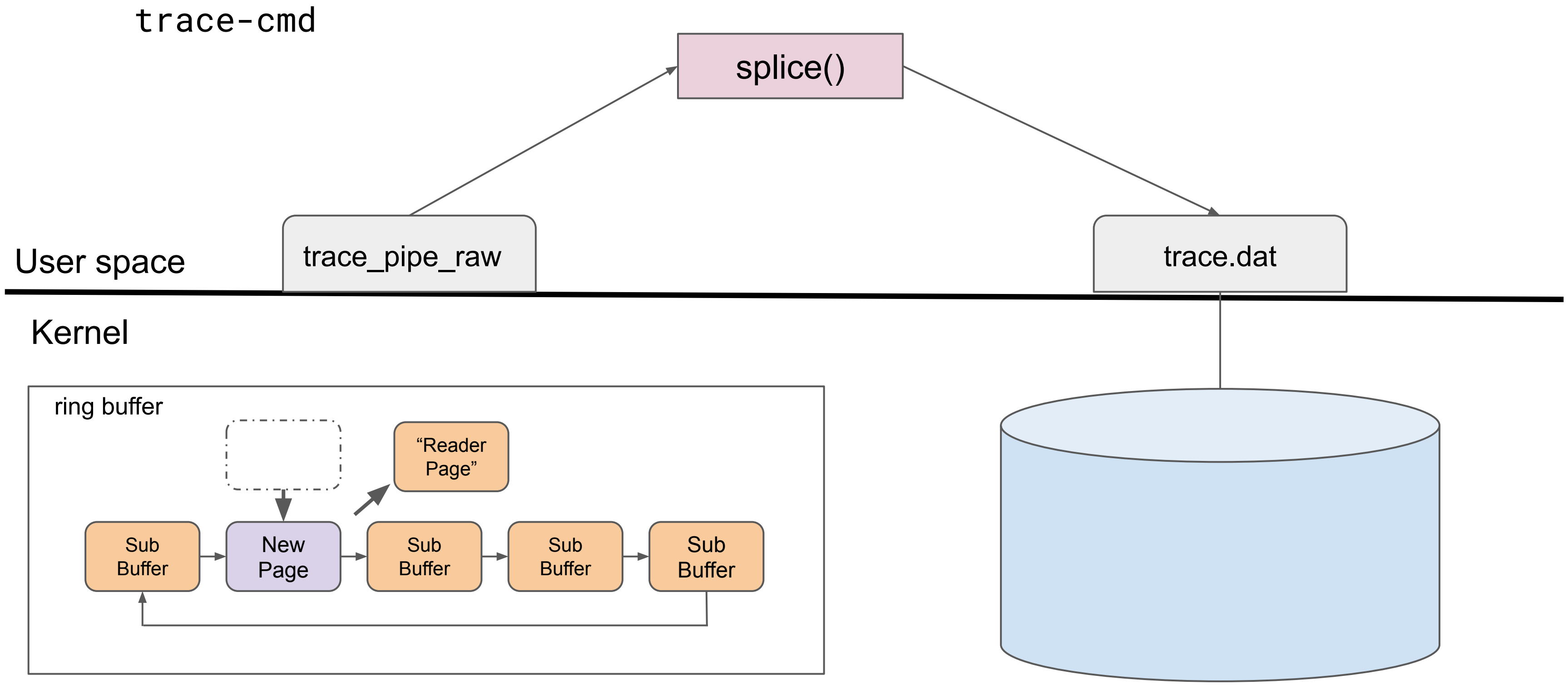

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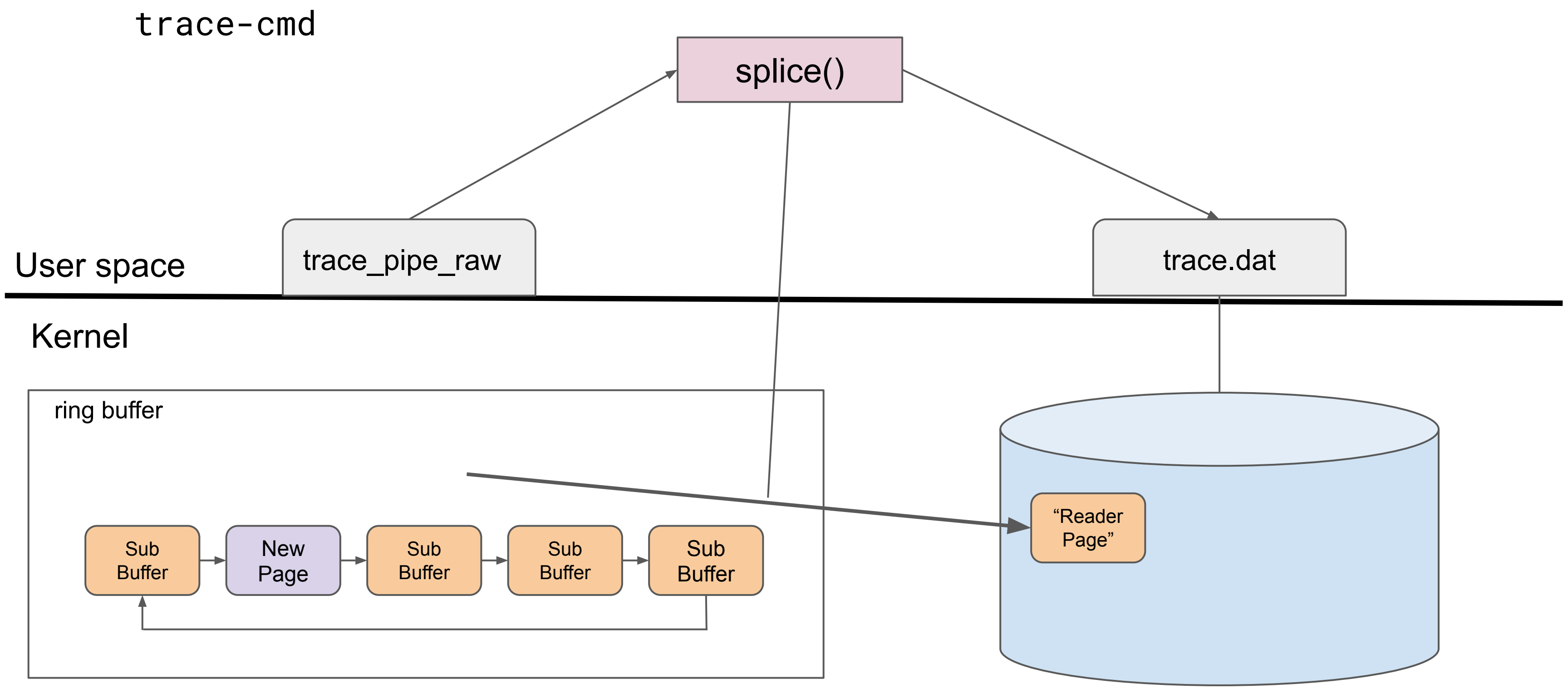

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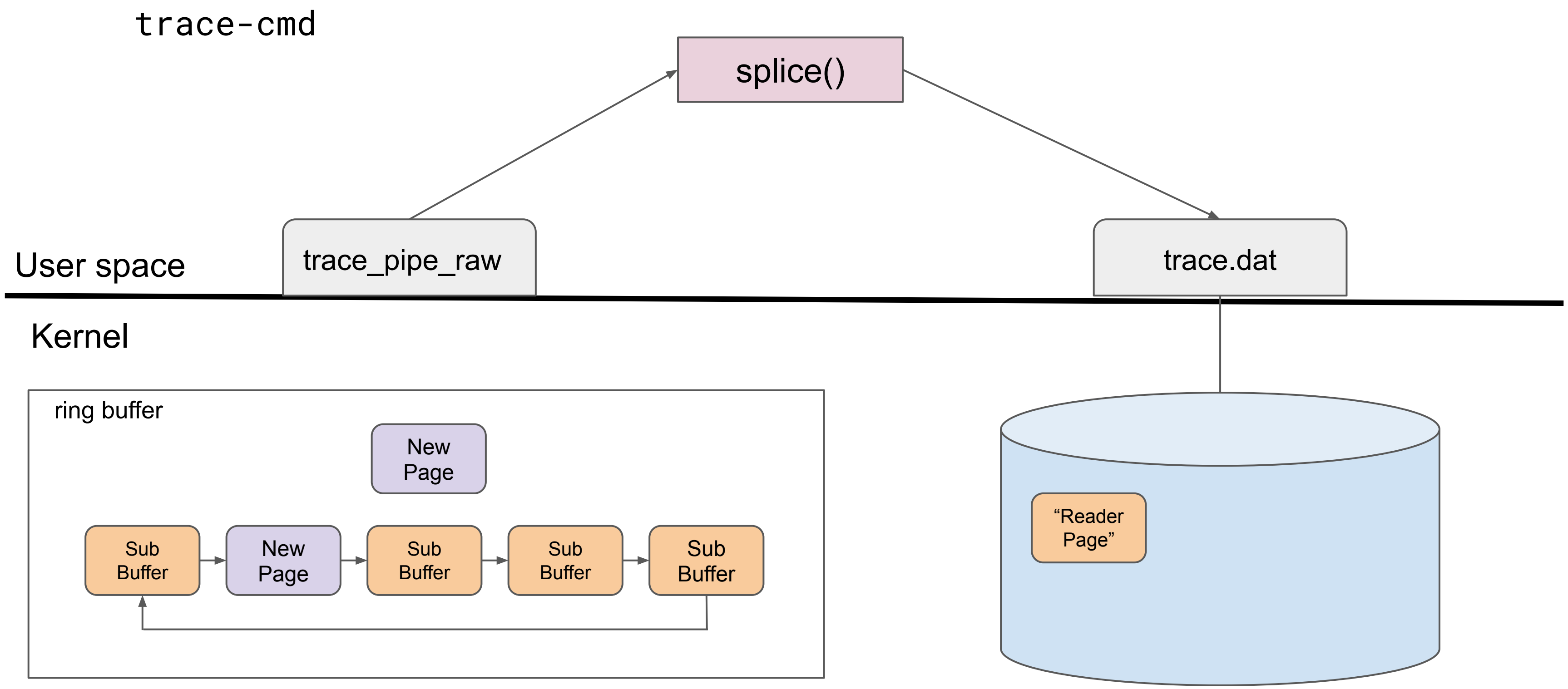

Tracing embedded boards

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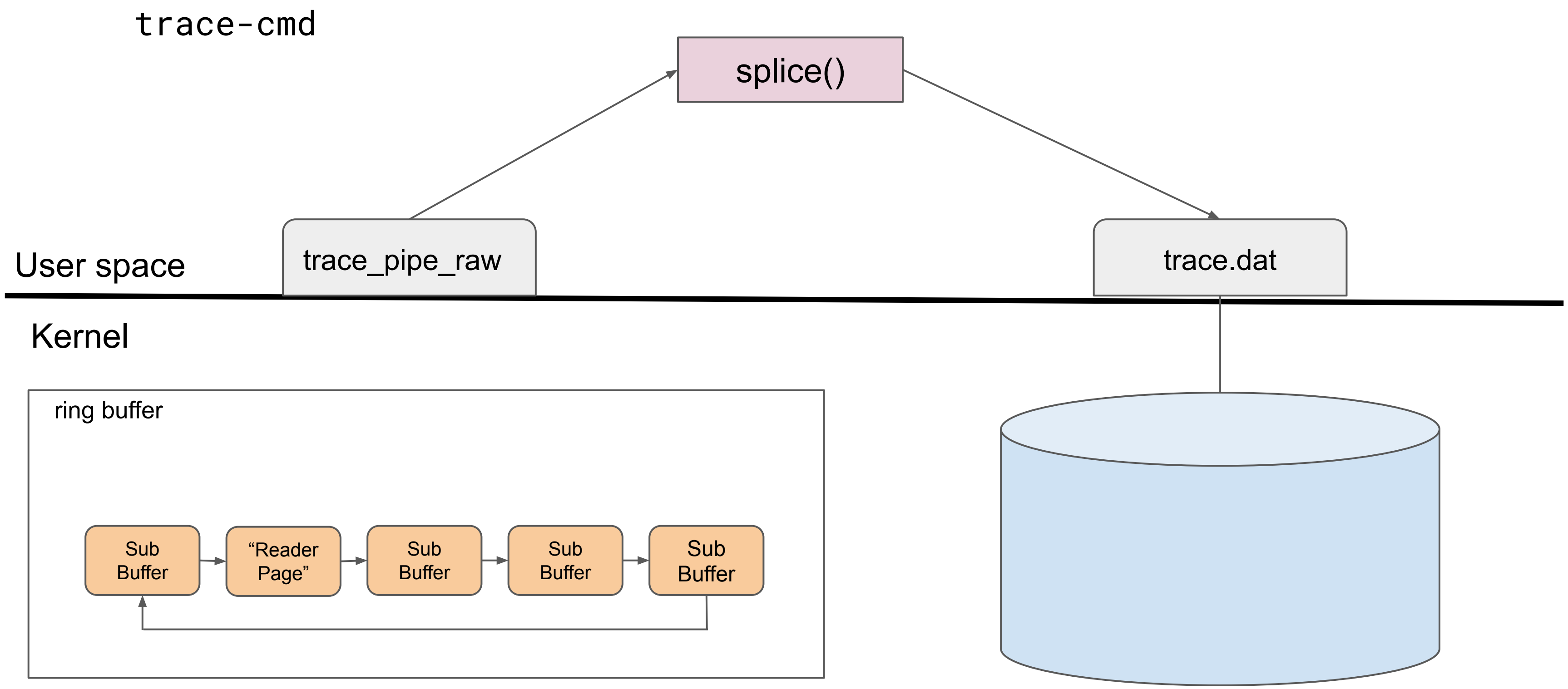
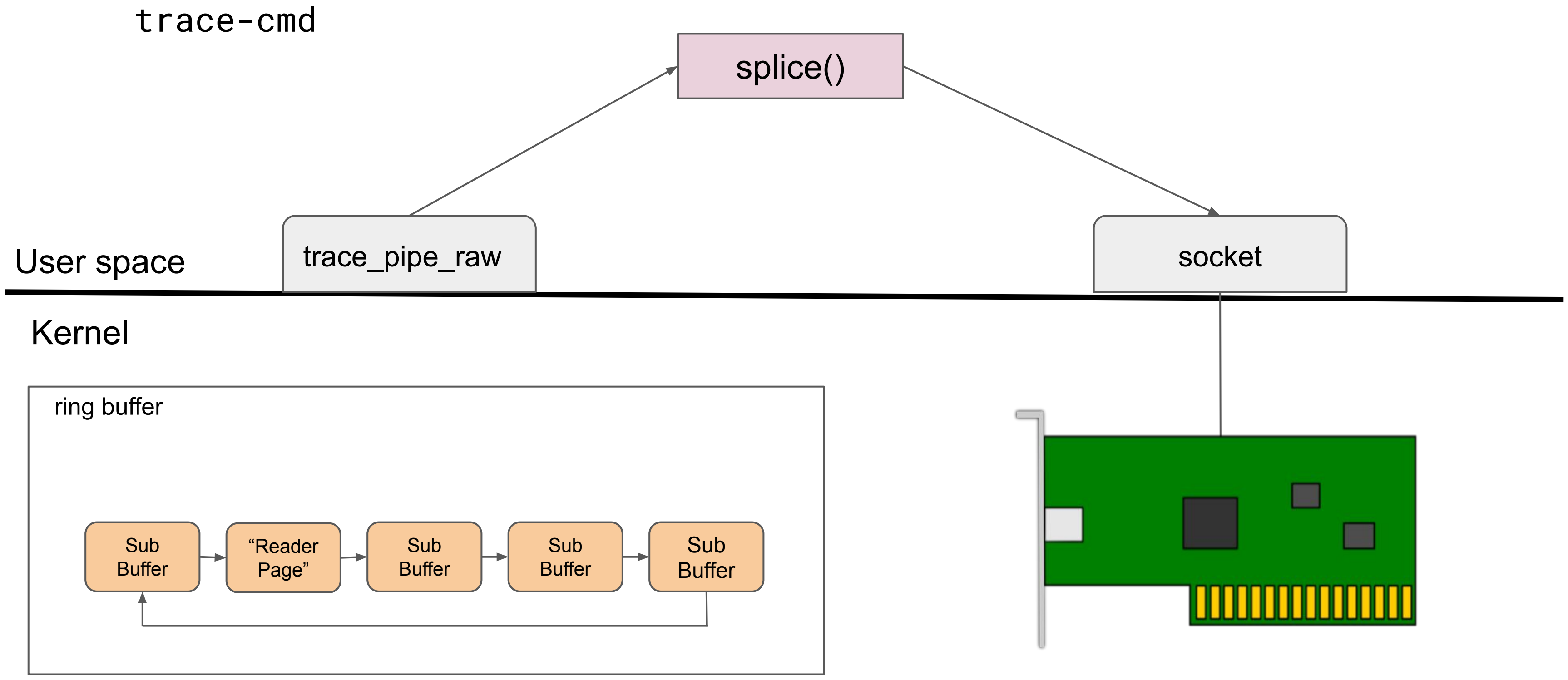
- But what happens when there’s little or no disk space
- Need to send it someplace else.

trace-cmd, ftrace and splice



trace-cmd, ftrace and splice, and the network



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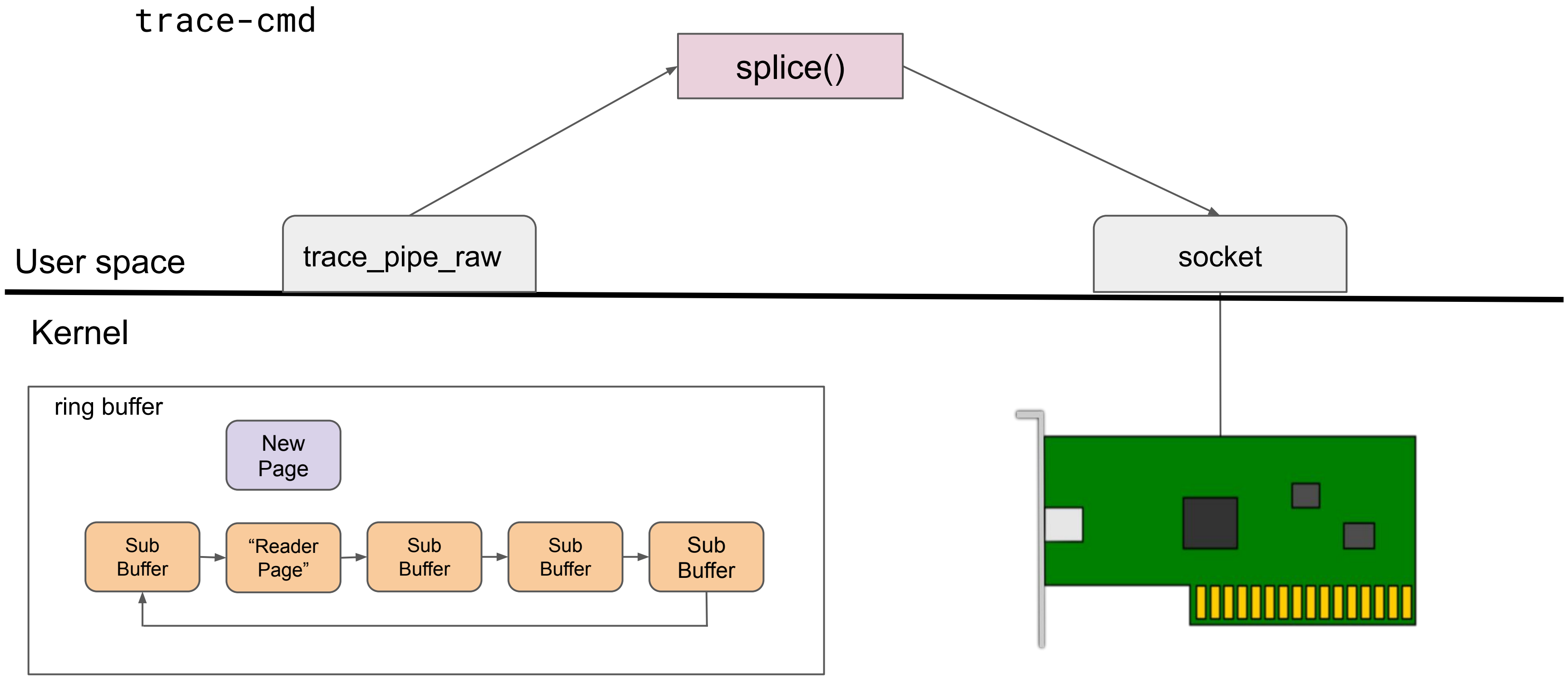

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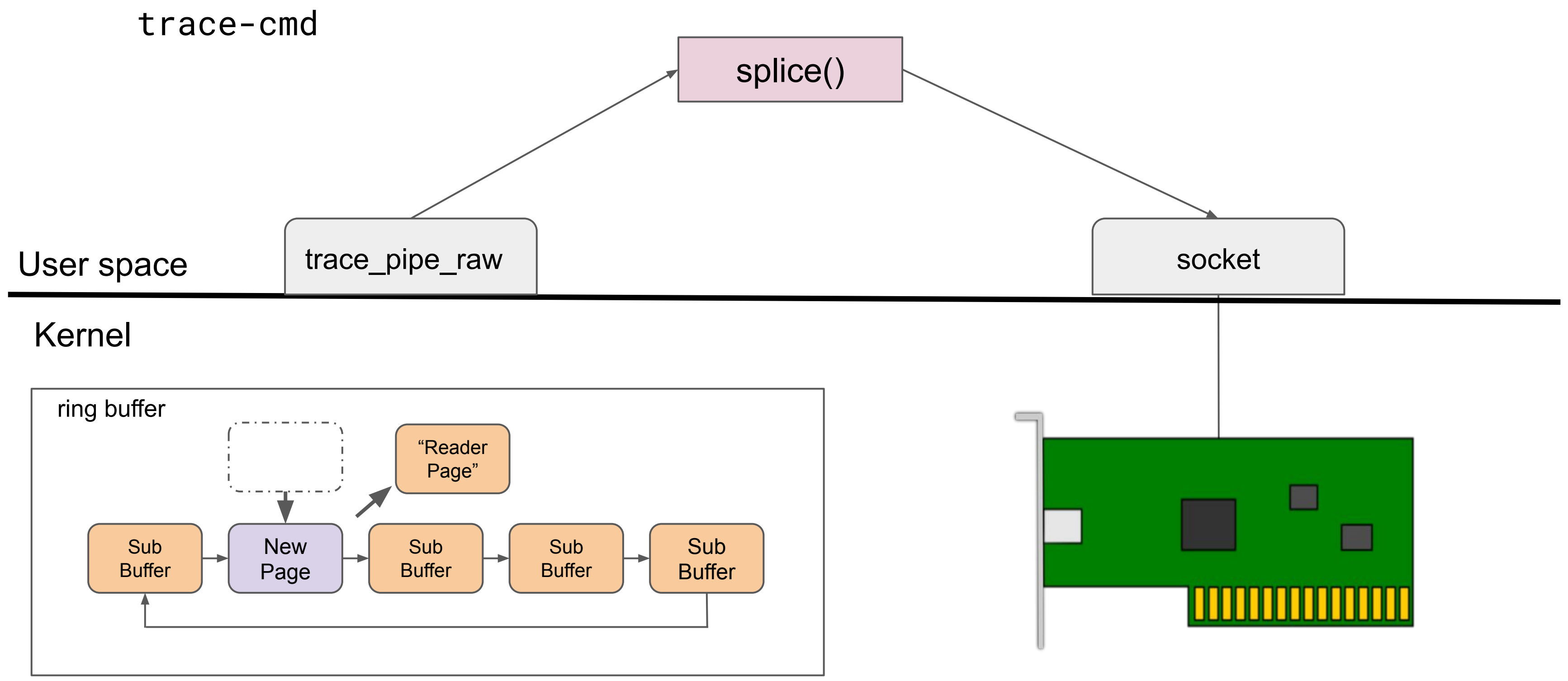

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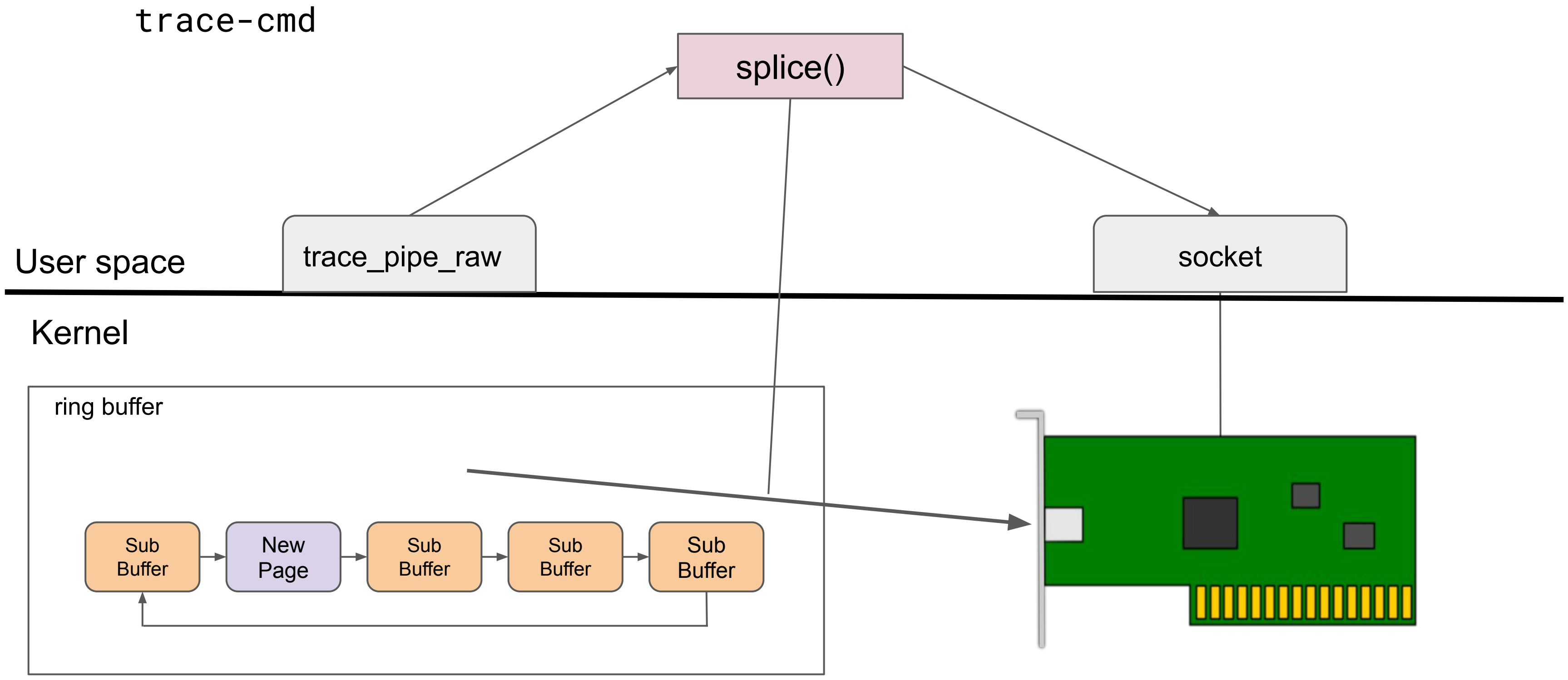

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- Decide to record over the network
- Created `trace-cmd listen`

trace-cmd listen

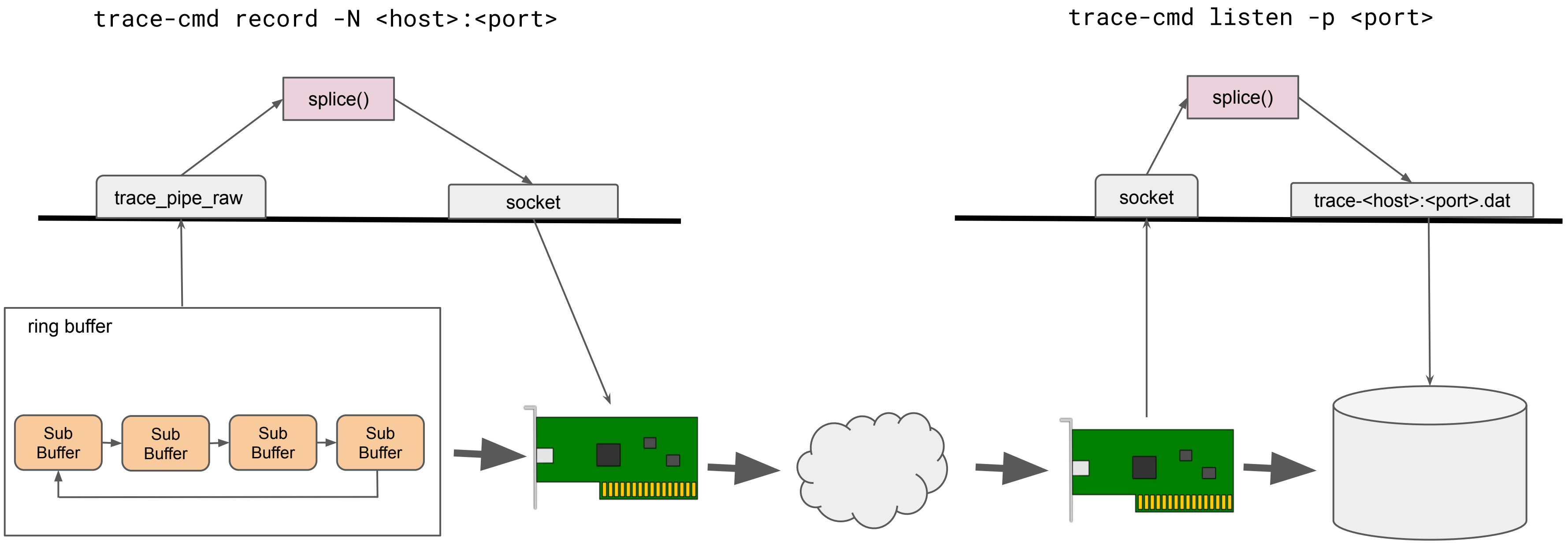
On the server:

```
$ trace-cmd listen -p 22222
```

On the target:

```
# trace-cmd record -N <host>:2222 -e sched -e irq -e timer
```

trace-cmd, ftrace and splice, and the network



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  - Does not synchronize any events with the workstation (listener)

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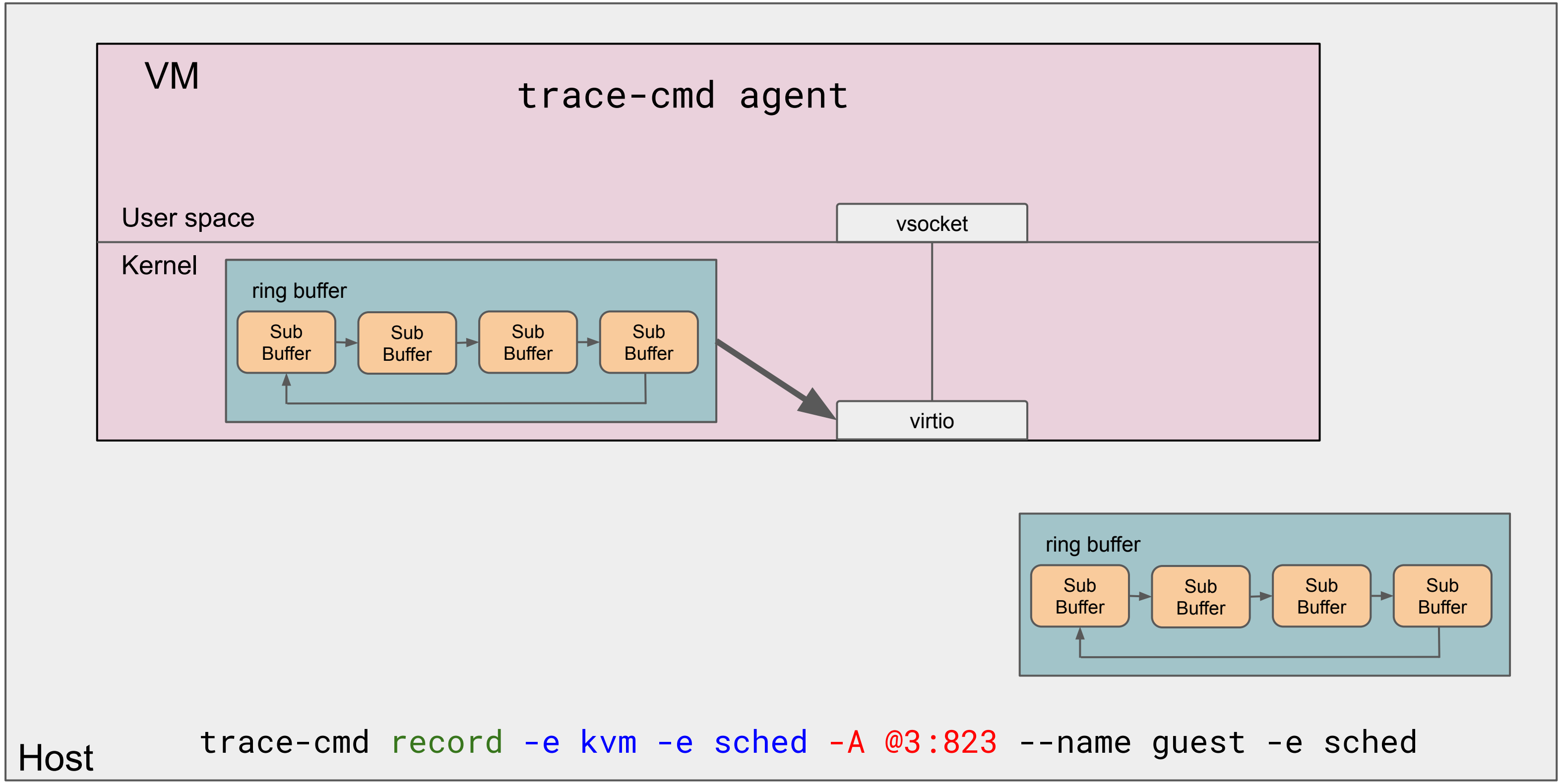
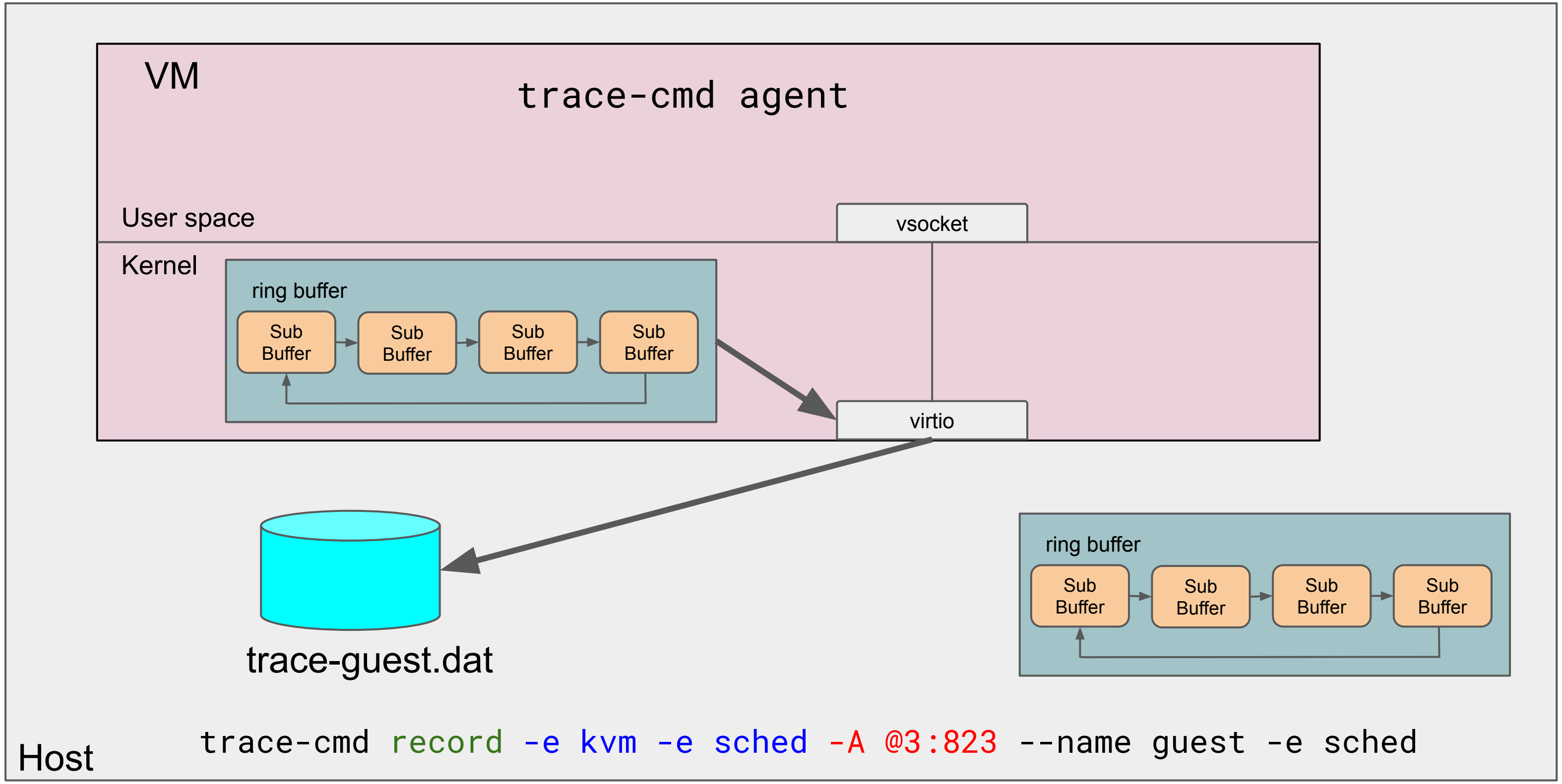
  - Now can use network sockets!

trace-cmd agent



```
trace-cmd record -e kvm -e sched -A @3:823 --name guest -e sched
```

trace-cmd agent



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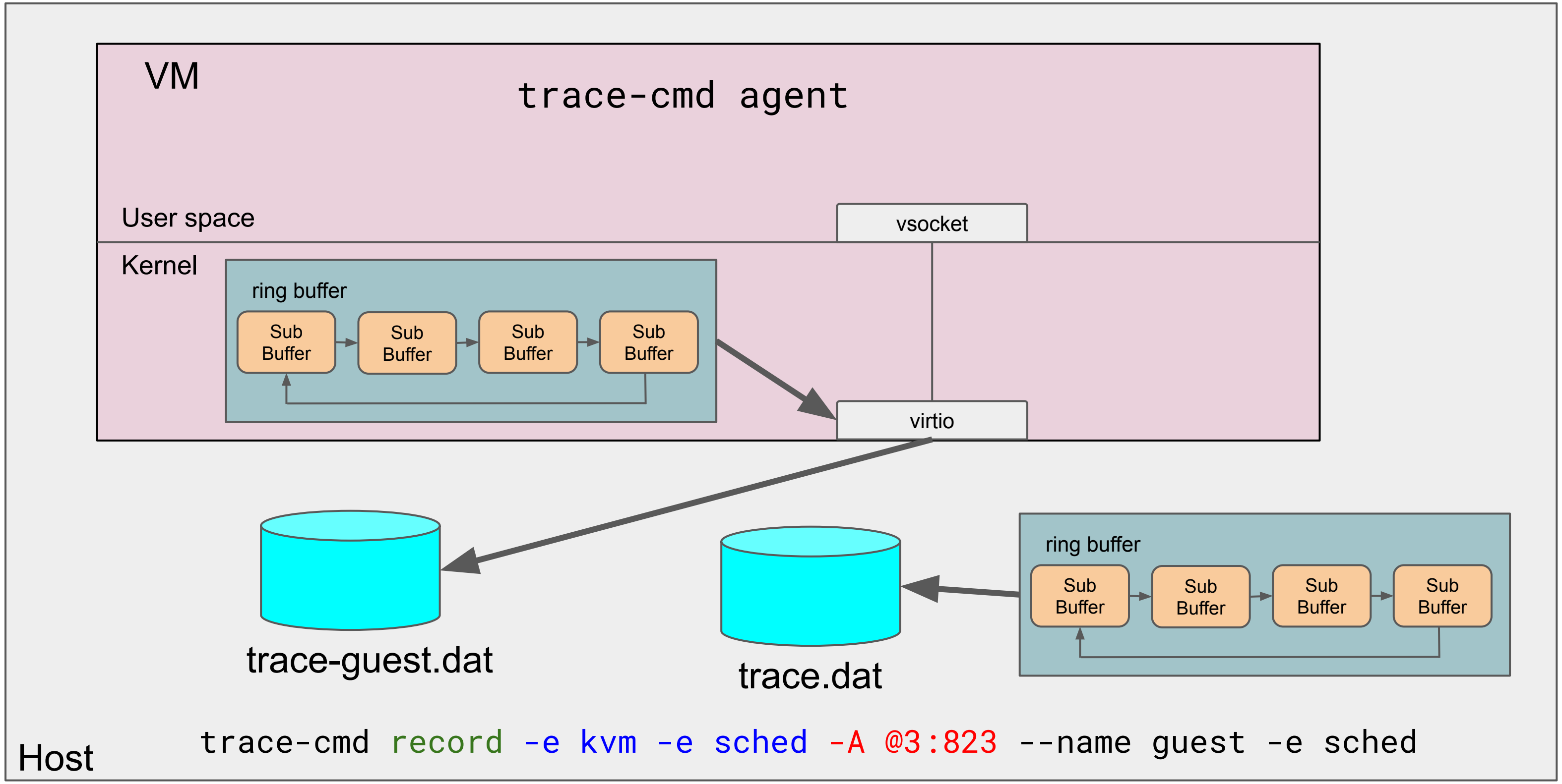

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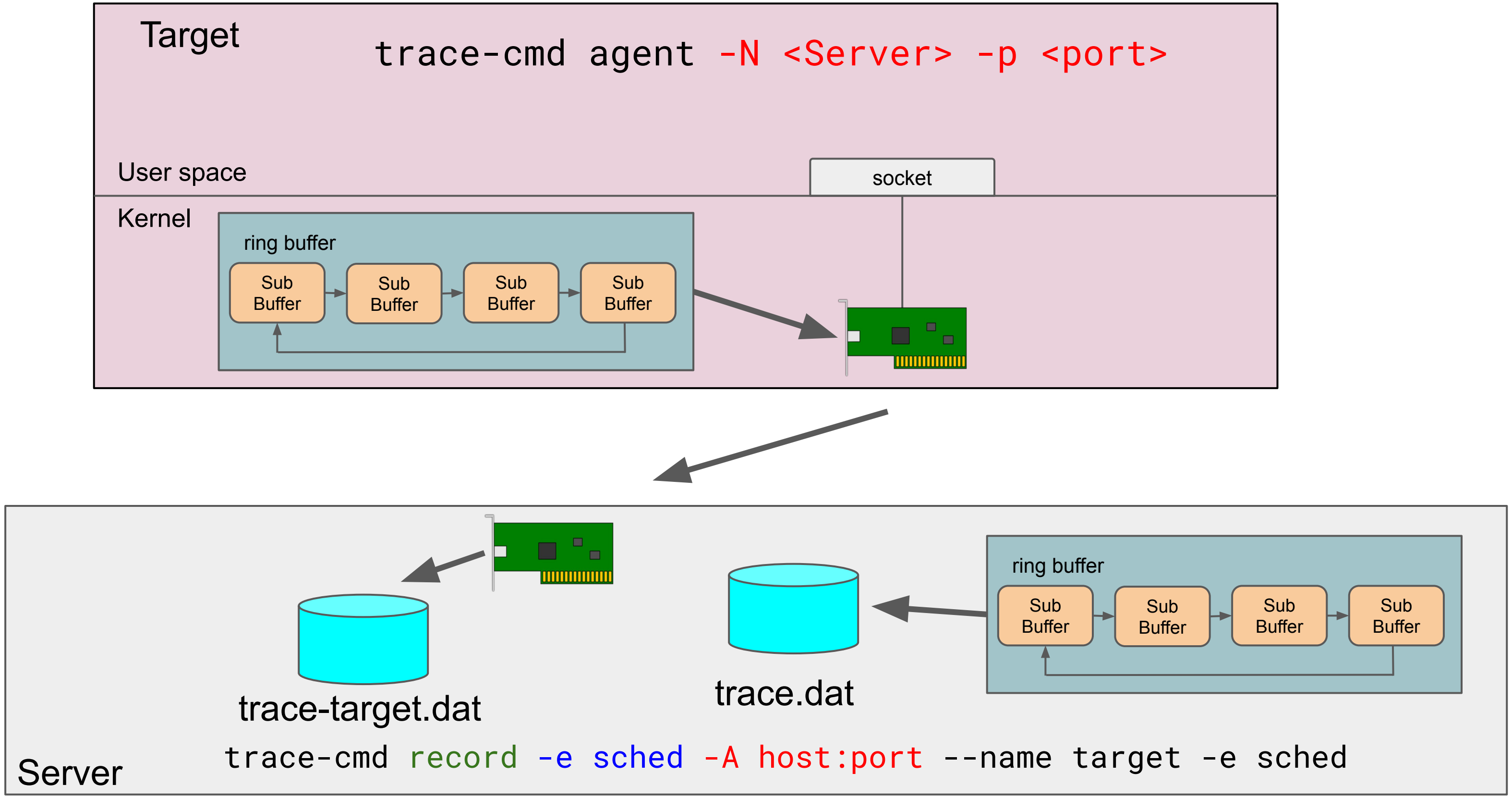
trace-cmd agent over network



```
trace-cmd agent -N <Server> -p <port>
```

```
trace-cmd record -e sched -A host:port --name target -e sched
```

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    - Anyone on the server can control the board
- Allows remote enabling of tracing
- Still has synchronization between events
    - P2P time synchronization protocol

Thank you!