Building low latency networking channel

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About me

- 5+ years with Rust
- 3 years in HFT
- JavaScript, Python, C, C++ … in background
- gh: dunnock
- t: maxsparr0w

Teaser

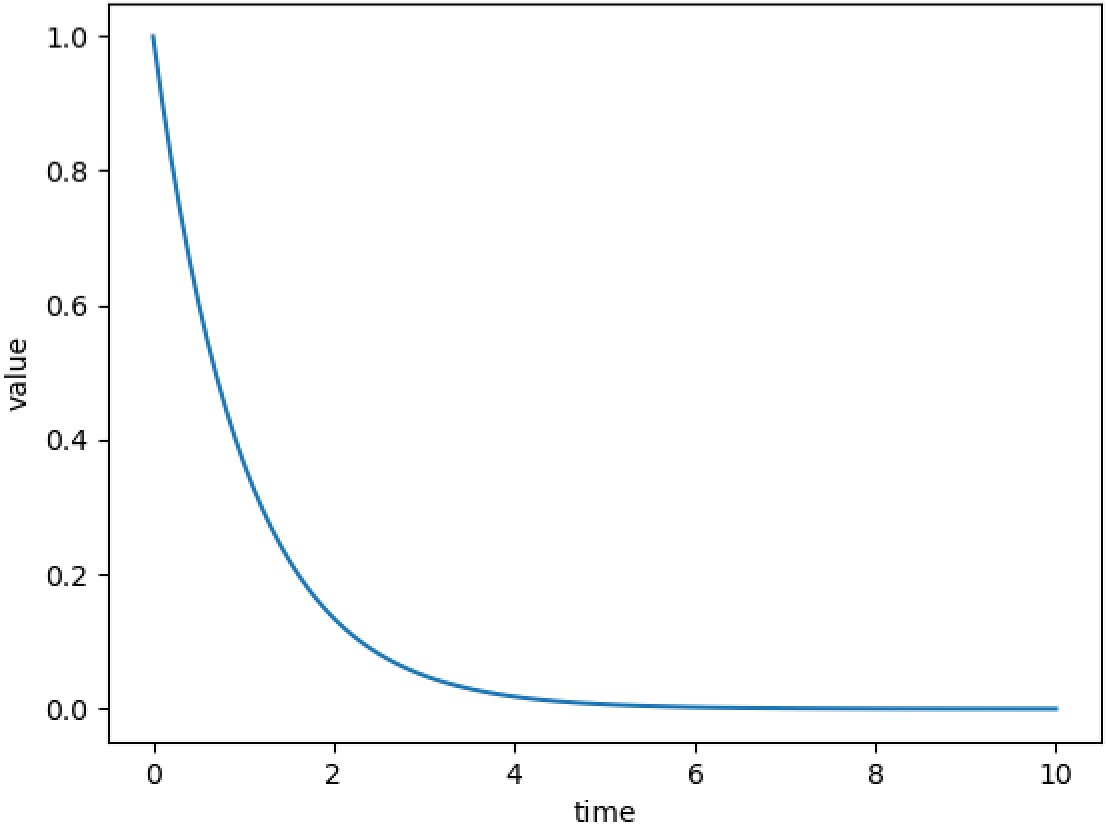
- What is low latency? 🏎️
- What problems are we trying to solve? 🐉
- Deep dive to microseconds level 🐠
- Discover CPU cache and system scheduler impact 🔬
- 🦀

Low latency refers to the short amount of time it takes for a signal or data to travel from one point to another in a system

Low latency	≠	High performance
↓time ↓dev		↑throughput

Rust is ideal choice for low latency, it handles technical risks without sacrificing performance and provides access to low level control over execution.

When low latency matters?



Low latency Applications

- HFT
- IoT
- Video Streaming
- Other realtime applications

Nothing comes for free

> except zero cost abstractions

Assumptions

- Sequence is less important than time
- Allowance for losing messages
- Maximum control over execution

Network protocol

Choosing network protocol

- UDP is convenient protocol with minimum required guarantees
- TCP guarantees sequence and delivery which might cost ~100us-1ms

UDP contraints

- Event must fit MTU = 1500b
- UDP multicast requires specialized hardware, not free in the cloud

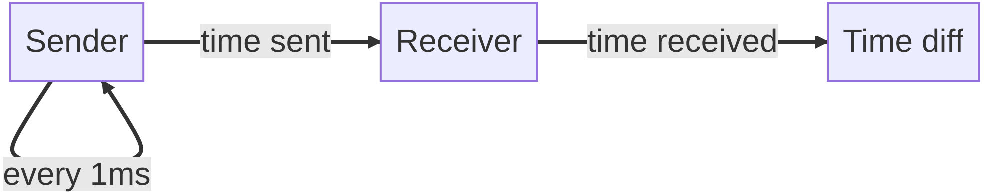
Implementation

Traditional event-loop

```rust
let channel: std::net::UdpSocket;
loop {
    match channel.recv(&mut buf) /* .await */ {
        Ok(len) => handle_message(&buf[..len]),
        Err(err) => handle_error(err),
    }
}
```

bincode

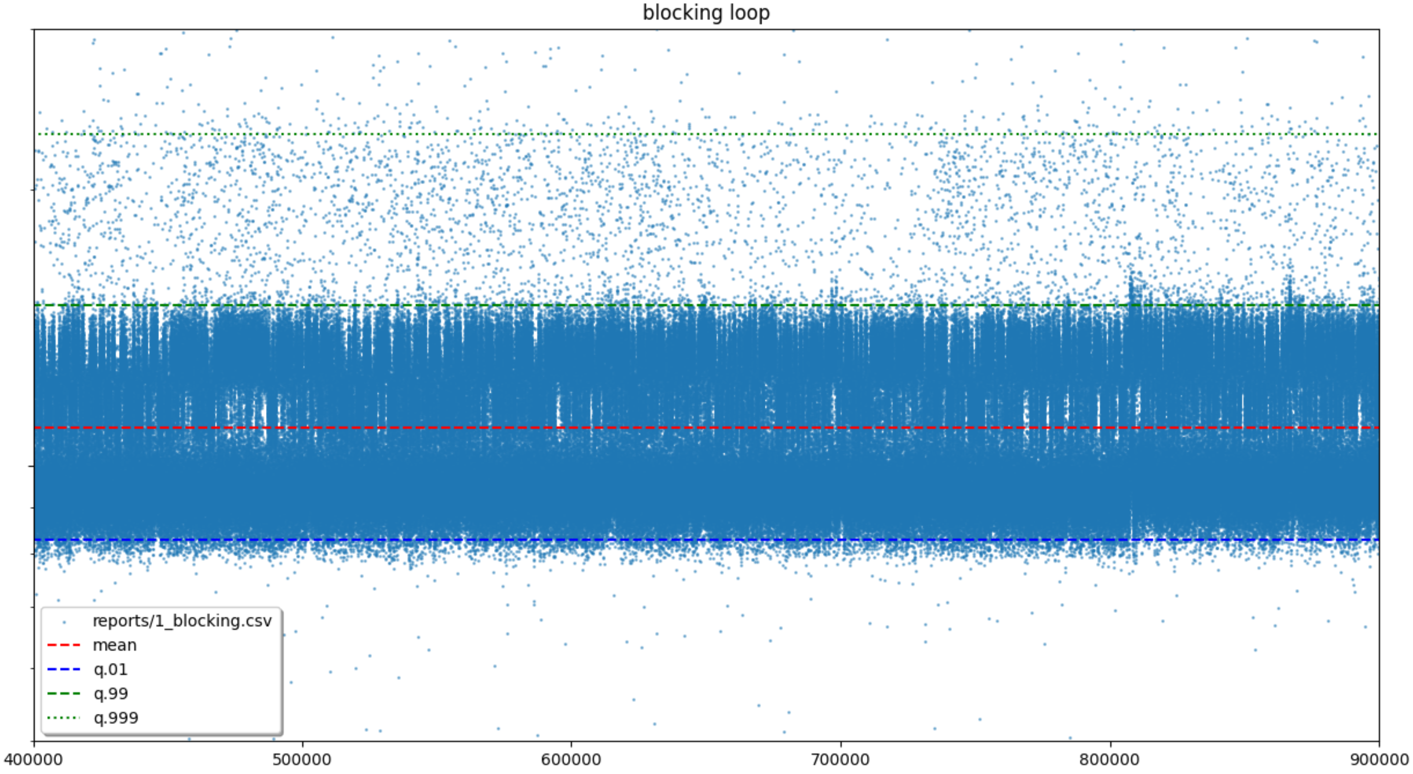
Measurement method



```
$ bin/receive -c ${PRIVATE_IP}:3000 -n 100000 > 1_blocking.csv &

$ bin/send -c ${PRIVATE_IP}:3000 -s ${PRIVATE_IP}:3001 -t 1000 -n 1000000
```

Measurement results

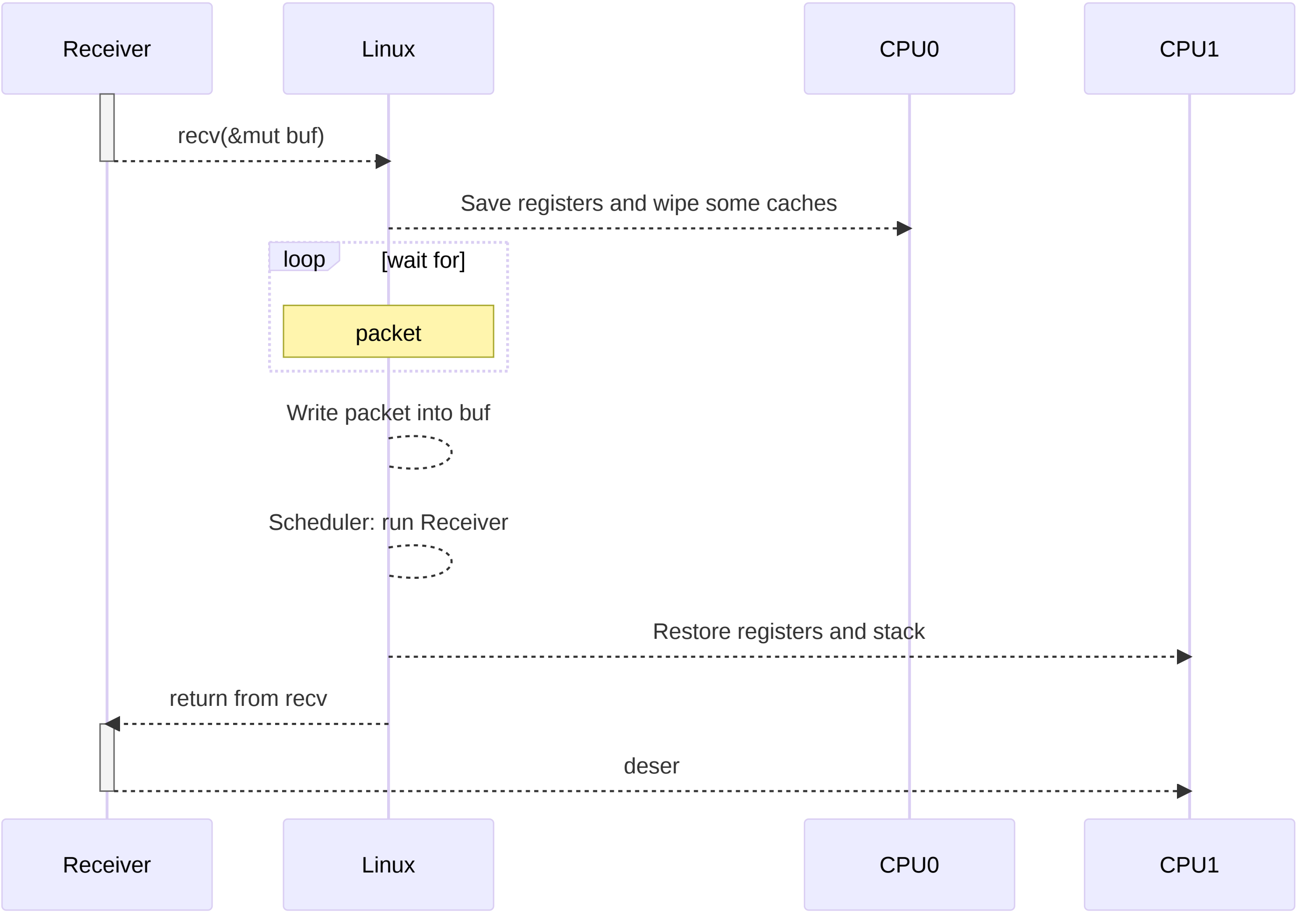


Profile

```
$ perf stat bin/receive -c ${PRIVATE_IP}:3000 -n 100000

            339.31 msec task-clock                #    0.003 CPUs utilized
            100329      context-switches          #  295.683 K/sec
                 2      cpu-migrations            #    5.894 /sec
               787      page-faults               #    2.319 K/sec
```

Context switching



Let’s pin our receiver to CPU Core

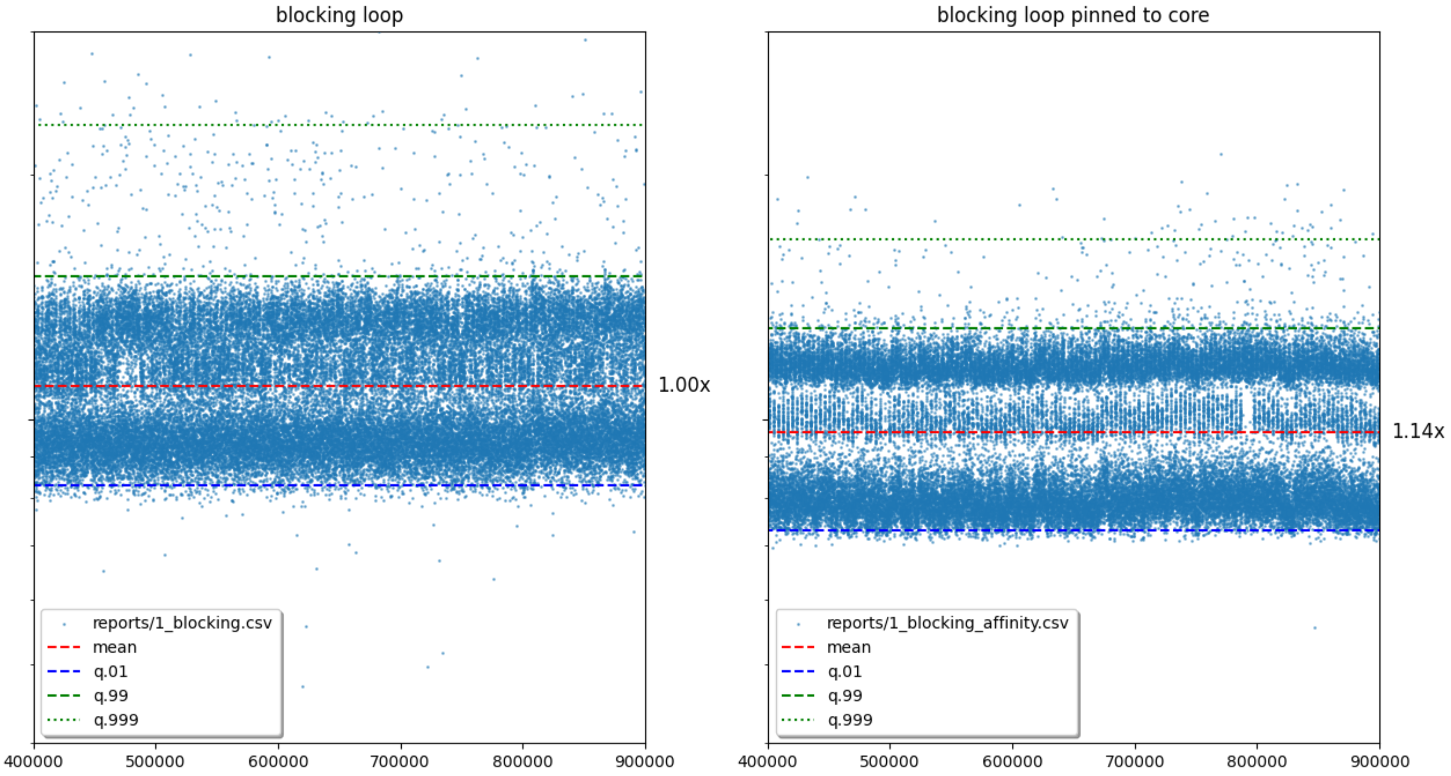
```rust
let channel: std::net::UdpSocket;
core_affinity::set_for_current(core_id);
loop {
    match channel.recv(&mut buf) /* .await */ {
        Ok(len) => handle_message(&buf[..len]),
        Err(err) => handle_error(err),
    }
}
```

core_affinity

libc::sched_setaffinity

> Use isolated cores via `isolcpus=1-7` kernel setting

Measure and compare



crossbeam_channel::array

```rust
pub(crate) fn recv(&self, deadline: Option<Instant>) -> Result<T, RecvTimeoutError> {
    ...
    loop {
        if self.start_recv(token) {
            return unsafe { self.read(token) };
        }
        if backoff.is_completed() {
            break;
        } else {
            backoff.snooze();
        }
    }
    ...
    // Block the current thread.
    let sel = cx.wait_until(deadline);
    ...
}
```

crossbeam_utils::backoff

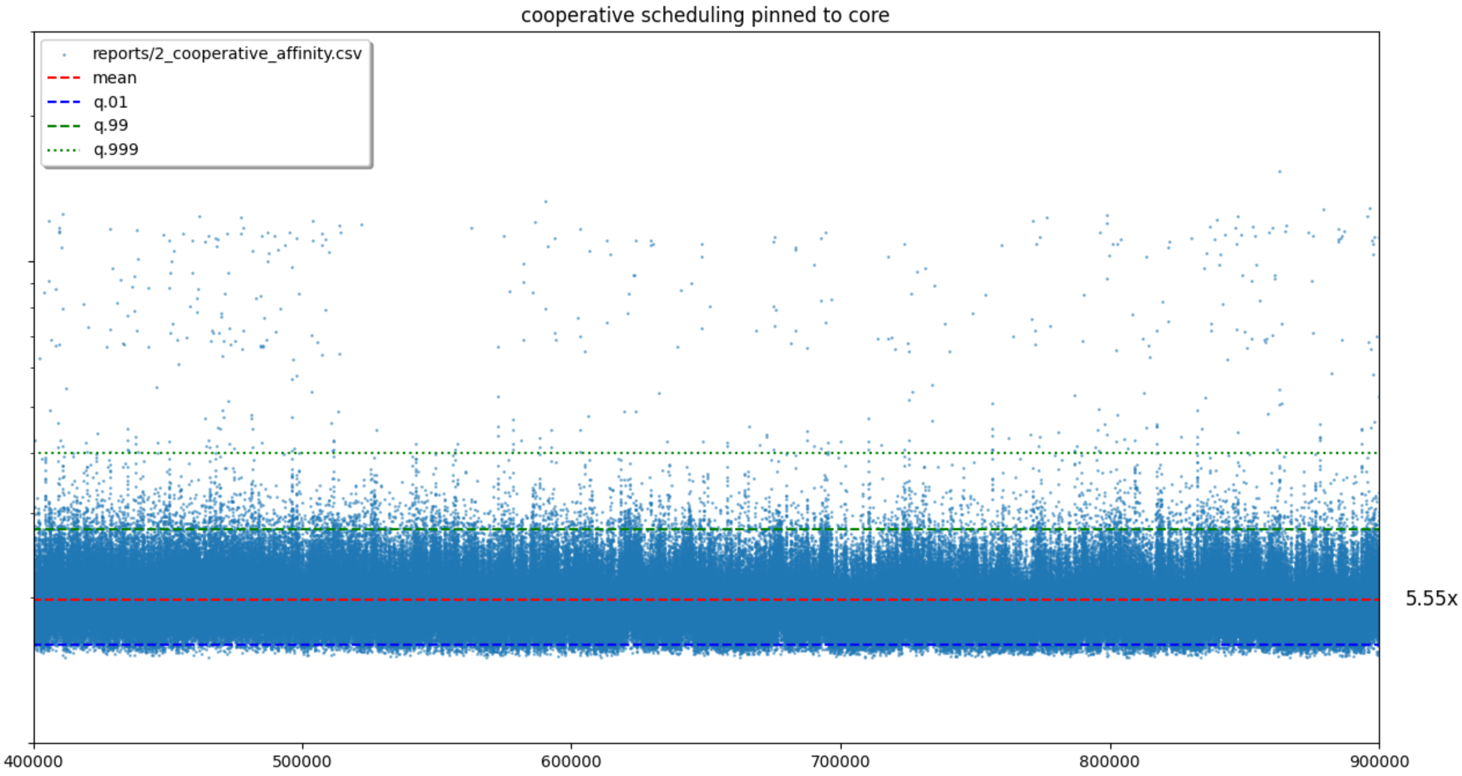
```rust
pub fn snooze(&self) {
    if self.step.get() <= 6 {
        for _ in 0..1 << self.step.get() {
            ::std::hint::spin_loop(); // Busy loop
        }
    } else {
        ::std::thread::yield_now(); // Cooperative scheduling
    }
    if self.step.get() <= 10 {
        self.step.set(self.step.get() + 1); // => backoff.is_completed()
    }
}
```

sched_yield

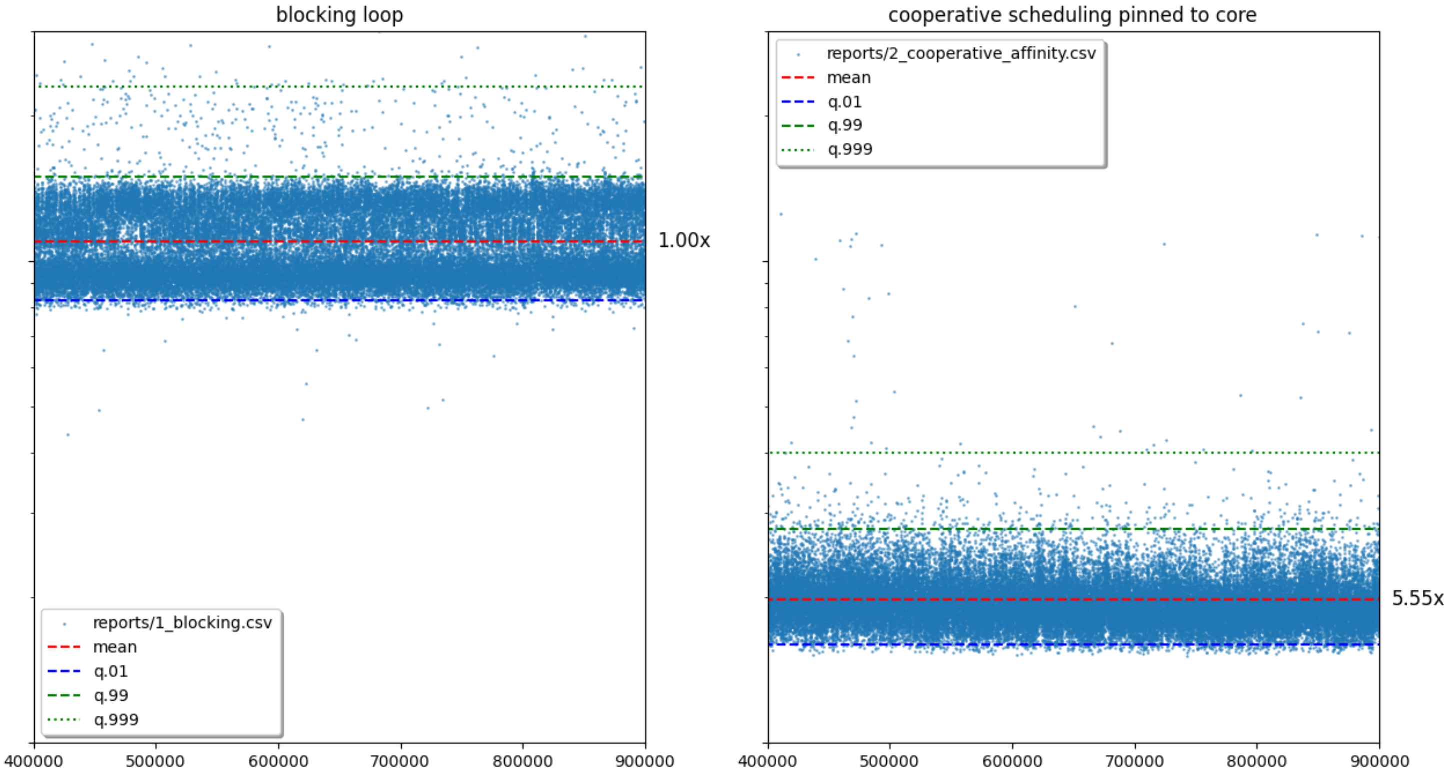
Use cooperative scheduling

```rust
let sock: std::net::UdpSocket;
core_affinity::set_for_current(core_id);
sock.set_nonblocking(true);
loop {
    match sock.recv(&mut buf) {
        Ok(len) => handle_message(&buf[..len]),
        Err(err) if err.kind() == ErrorKind::WouldBlock ||
            err.kind() == ErrorKind::TimedOut => { }
        Err(err) => handle_error(err),
    }
    std::thread::yield_now();
}
```

Measurement results



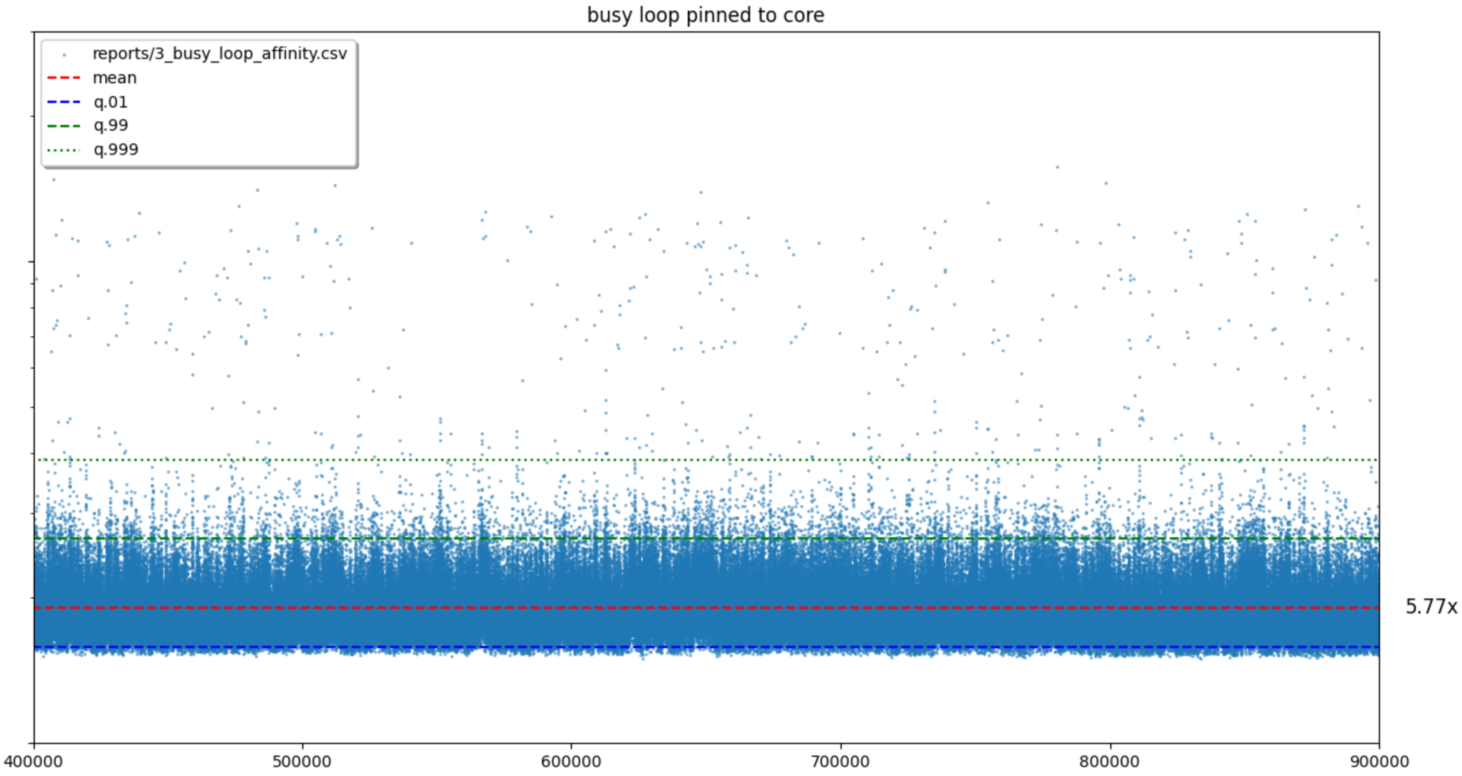
Compare with blocking



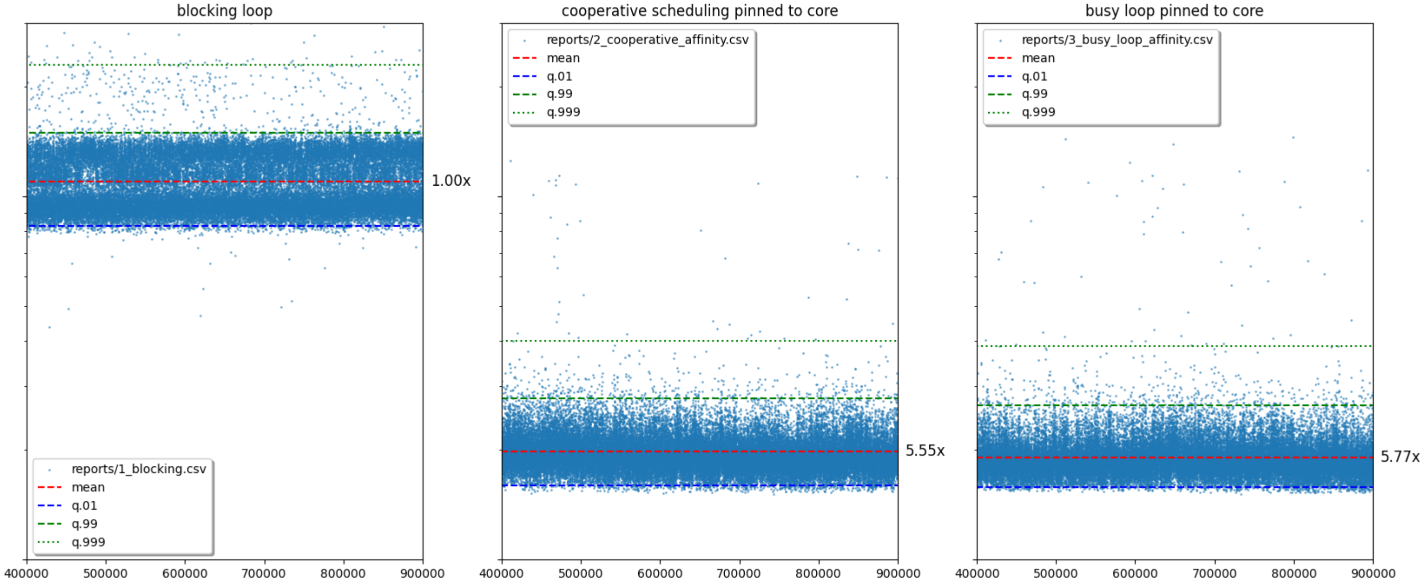
Busy loop

```
let sock: std::net::UdpSocket;
sock.set_nonblocking(true);
loop {
    match channel.recv(&mut buf) {
        Ok(len) => handle_message(&buf[..len]),
        Err(err) if err.kind() == ErrorKind::WouldBlock ||
            err.kind() == ErrorKind::TimedOut => { }
        Err(err) => handle_error(err),
    }
    std::hint::spin_loop();
}
```

Measurement results



Compare measurement results



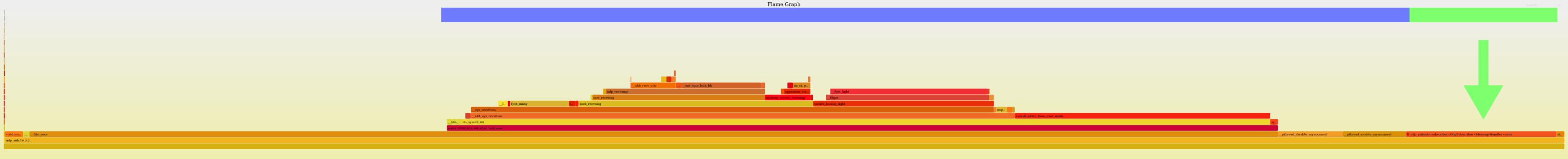
Profiling summary

```
$ perf stat taskset -c 1-4 bin/receive -c ${PRIVATE_IP}:3000 -n 100000 --non-blocking --core 1

         106103.94 msec task-clock                #    1.000 CPUs utilized
               253      context-switches          #    2.384 /sec
                 2      cpu-migrations            #    0.019 /sec
               789      page-faults               #    7.436 /sec
```

PREVIOUS RESULT:

```
            339.31 msec task-clock                #    0.003 CPUs utilized
            100329      context-switches          #  295.683 K/sec
                 2      cpu-migrations            #    5.894 /sec
               787      page-faults               #    2.319 K/sec
```


Flame Graph
__skb_recv_udp
_..
_raw_spin_lock_bh
aa_sk_p..
udp_recvmsg
apparmor_soc..
__fget_light
inet_recvmsg
security_socket_recvmsg
__fdget
__f..
fput_many
i..
sock_recvmsg
sockfd_lookup_light
__sys_recvfrom
imp..
__x64_sys_recvfrom
syscall_enter_from_user_mode
__x64_..
do_syscall_64
sy..
entry_SYSCALL_64_after_hwframe
<std::ne..
_..
__libc_recv
__pthread_disable_asynccancel
__pthread_enable_asynccancel
ll_udp_pubsub::subscriber::UdpSubscriber<MessageHandler>::run
st..
udp_sub:10.0.2.

ll-udp-pubsub

- Generic statically linked message type via serde
- Publisher maintains list of subscriptions
- Subscriptions expire after 60 seconds
- Subscriber actively maintains subscriptions

Want to know more?

- What Every Programmer Should Know About Memory | Ulrich Drepper | Red Hat Inc
- How GPU Computing works | Stephen Jones | nVidia
- Q & A