Threads are an illusion

A guide to thinking about Program Design with Boost.Asio

When we hear “concurrency”...

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but threads are an illusion

When we hear “concurrency”...

... we usually think threads

but threads are an ~~illusion~~ abstraction

Threads are an abstraction

- A state machine, implemented using
  - stack frame +
  - thread locals +
  - registers +
  - sequence of instructions +
  - a program counter
- Threads are a *general purpose* abstraction

If we know our problem domain...

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... we can do better

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... we can do better

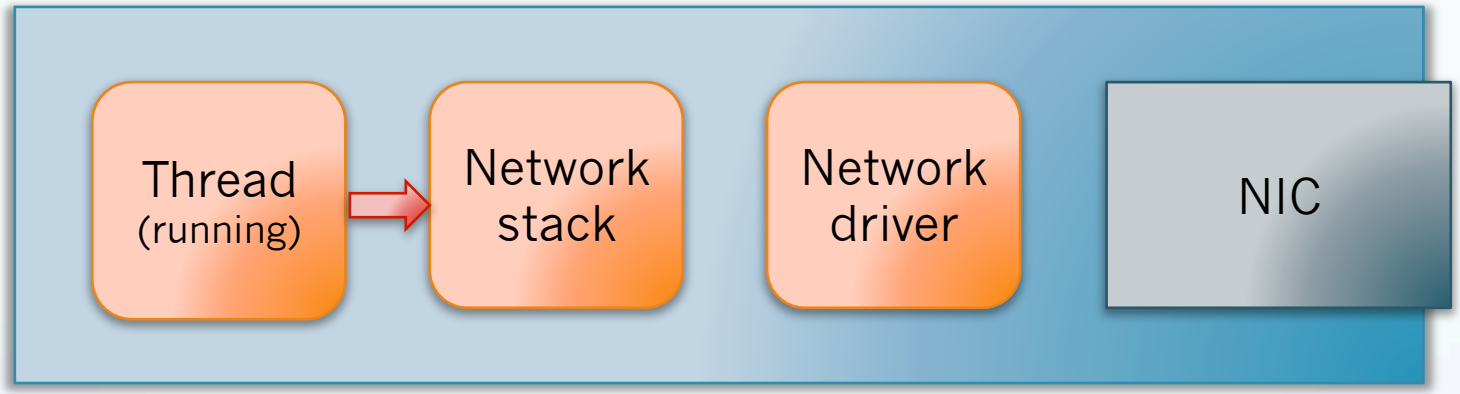
Networking is a domain where it is easy to do better

Thread per connection

```
array<unsigned char, 1024> data;
while (!ec)
{
  size_t n = my_socket.read_some(buffer(data), ec);
  // Do something with data ...
}
```

Thread per connection

Thread: `size_t n = my_socket.read_some(buffer(data), ec);`



Thread per connection

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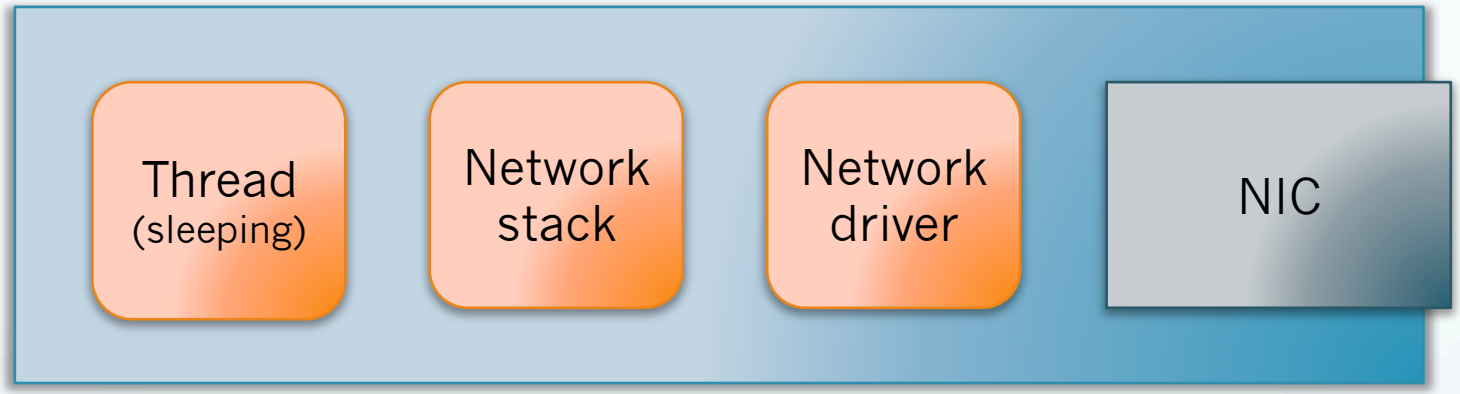

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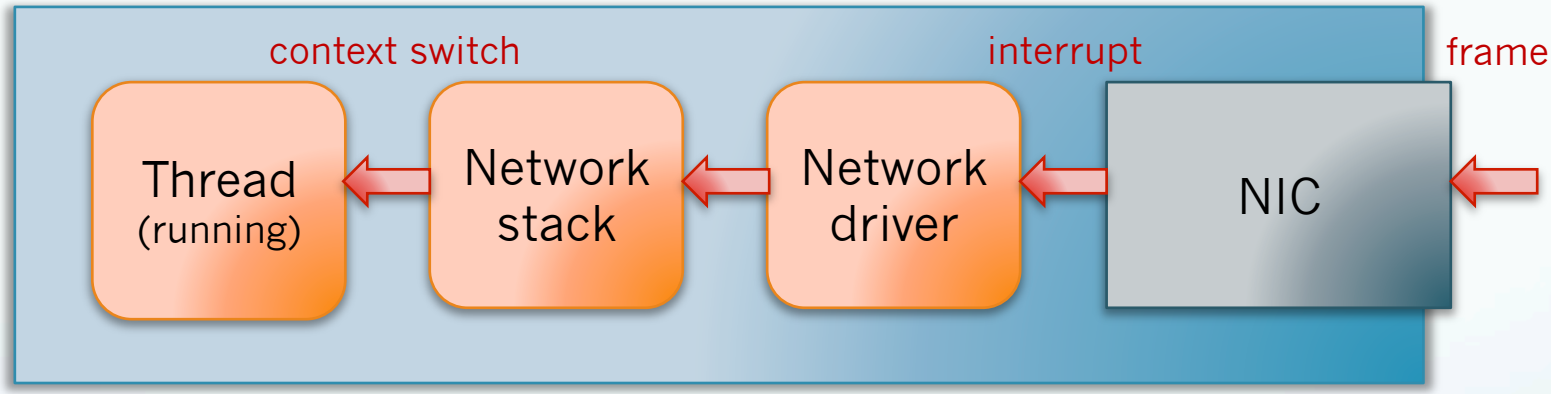

What if connections > number of CPUs?

Thread 1: `size_t n = my_socket.read_some(buffer(data), ec);`

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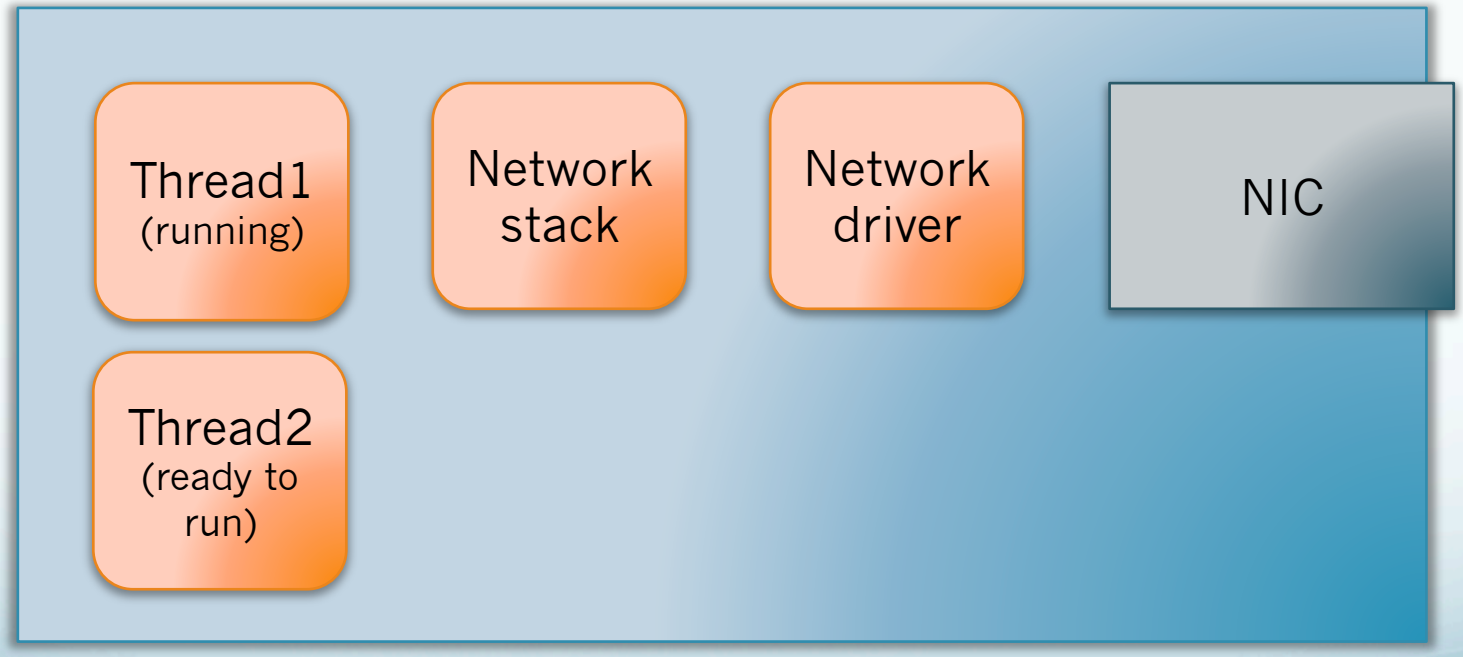

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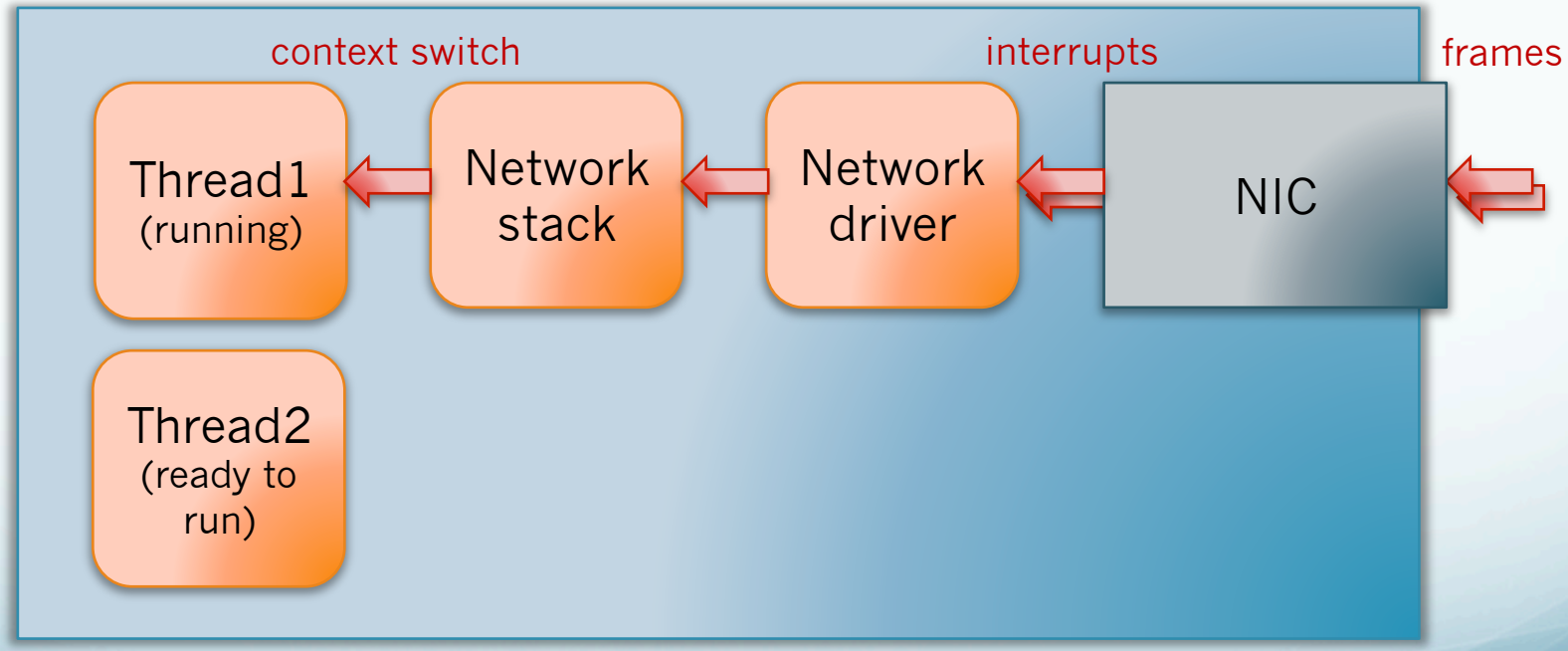

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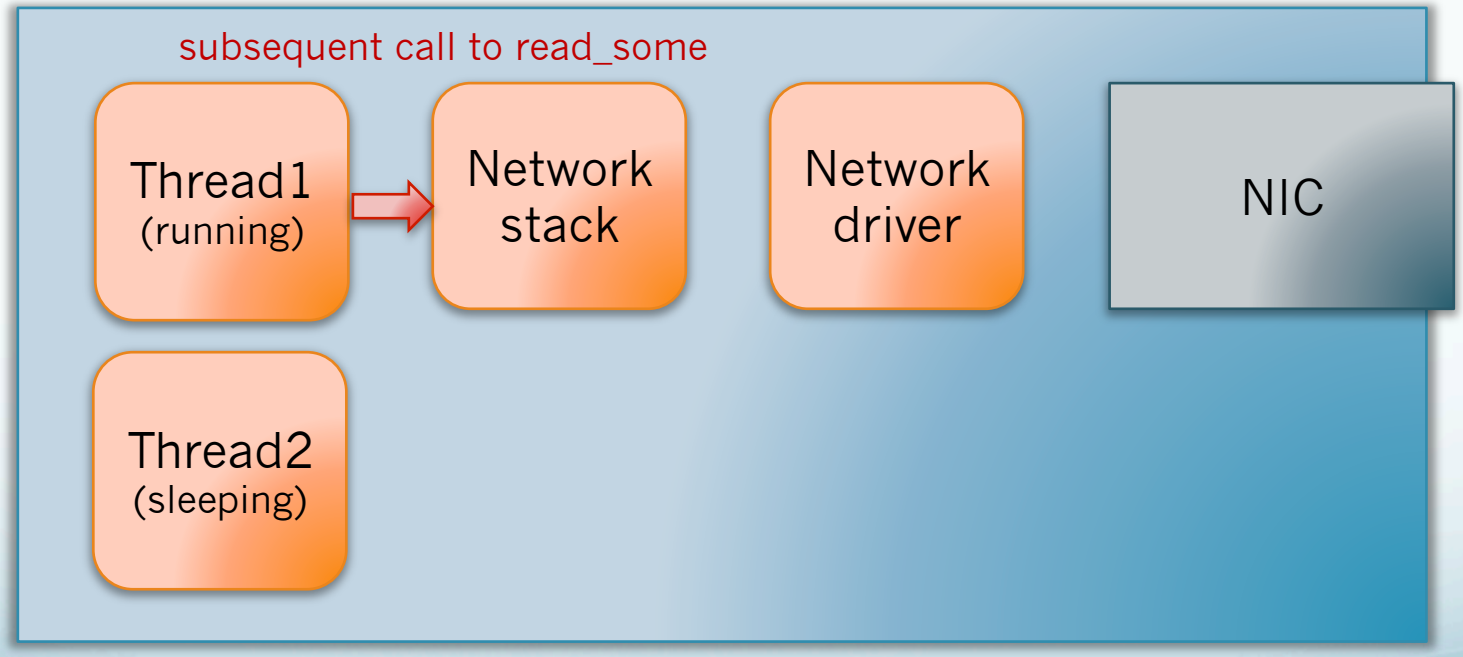

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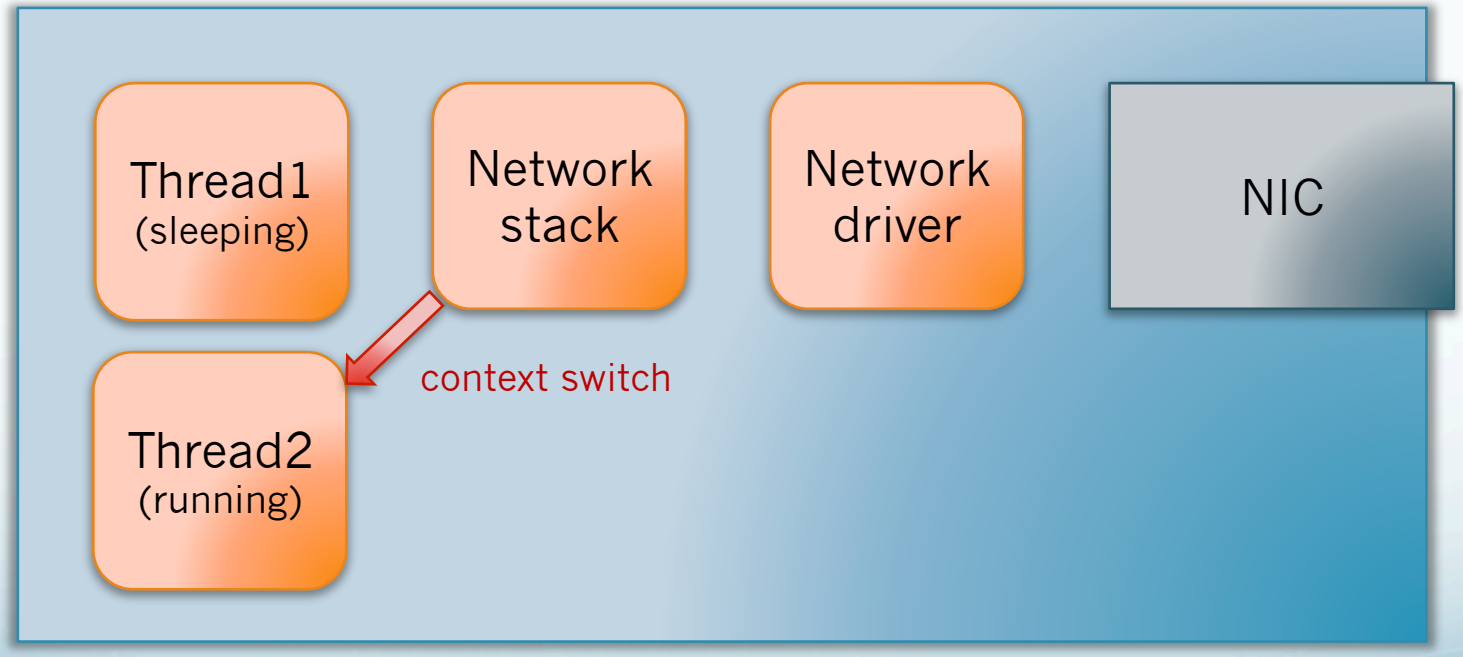


What if connections > number of CPUs?

- Really a queuing problem
- Cost of running each task includes a context switch
- General problem is N ready connections > #CPUs
- Both throughput and latency are impacted

We could amortise costs

- Process network events in a batch
- One context switch per batch

Recall that threads are:

- A *state machine*, implemented using
  - stack frame +
  - thread locals +
  - registers +
  - sequence of instructions +
  - a program counter
- There are other ways of representing state machines...

Single-threaded asynchronous I/O

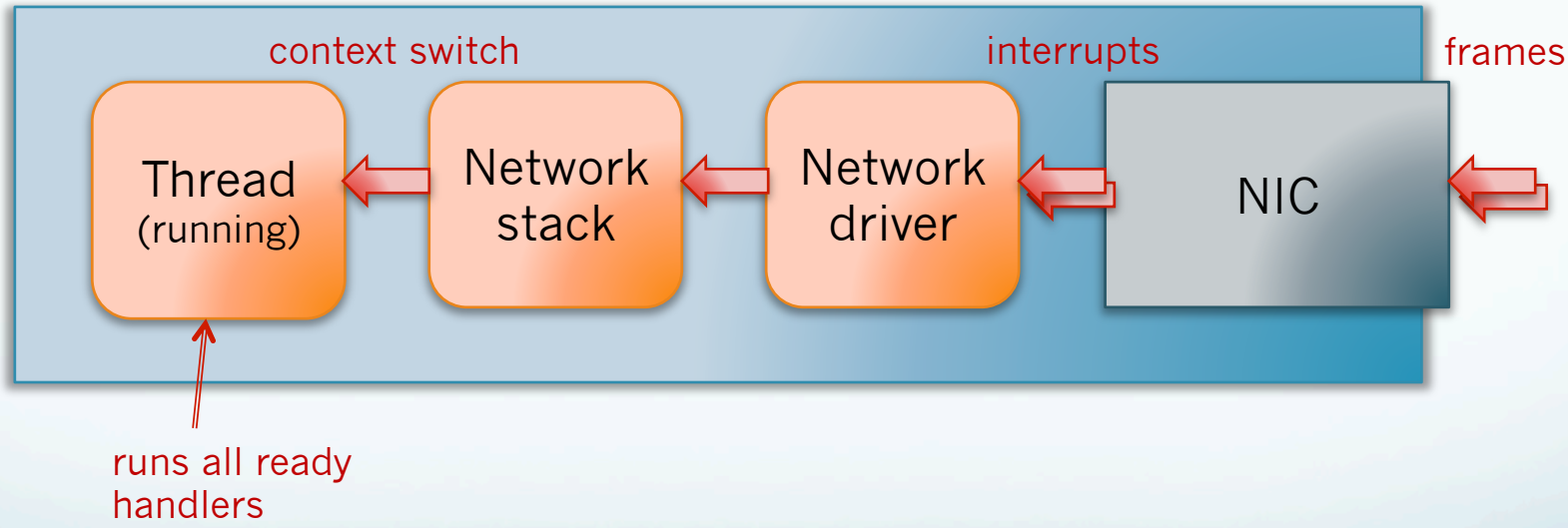
```
class session
{
  tcp::socket socket_;
  array<unsigned char, 1024> data_;
  ...
  void do_read()
  {
    socket_.async_read_some(buffer(data_),
        [this](std::error_code ec, std::size_t n)
        {
          // Do something with data ...
          do_read();
        });
  }
};

...

io_service.run();
```

Single-threaded asynchronous I/O

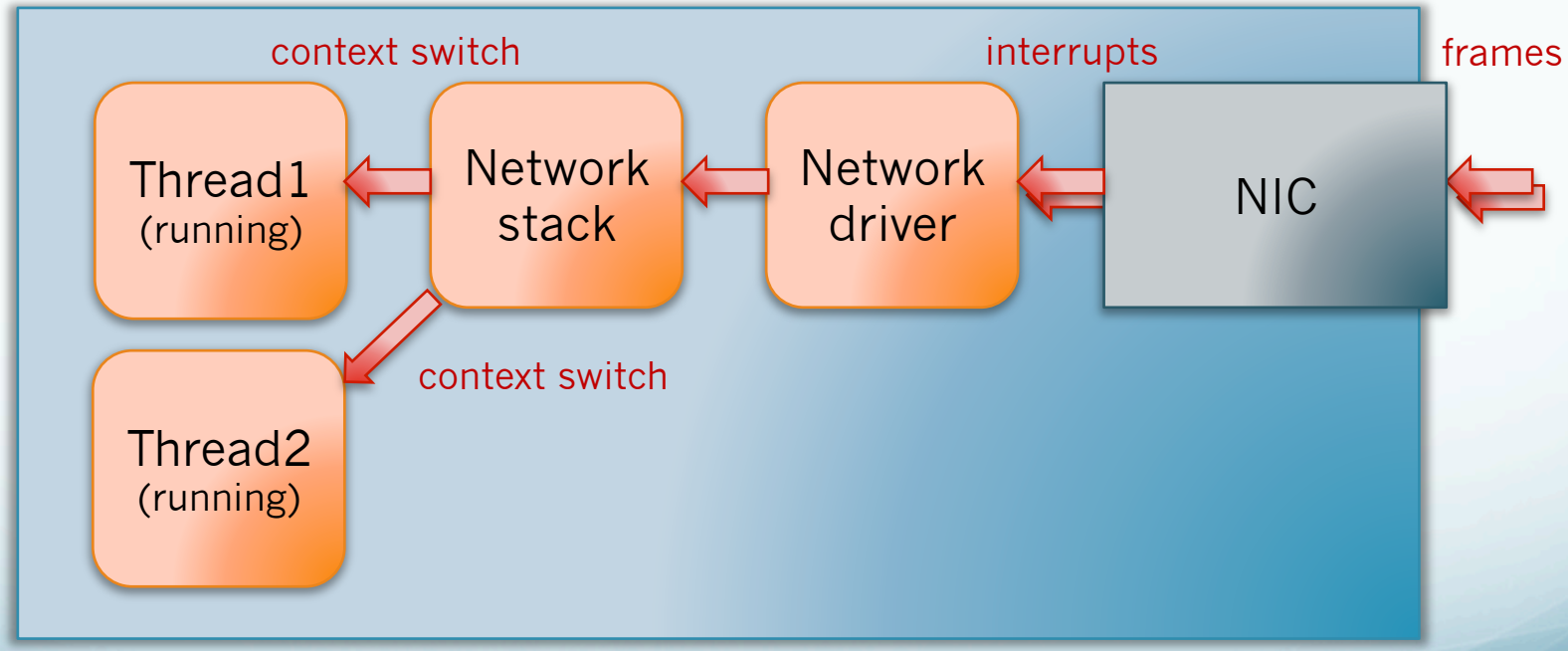
Thread: `io_service.run();`



What if connections ≤ number of CPUs?

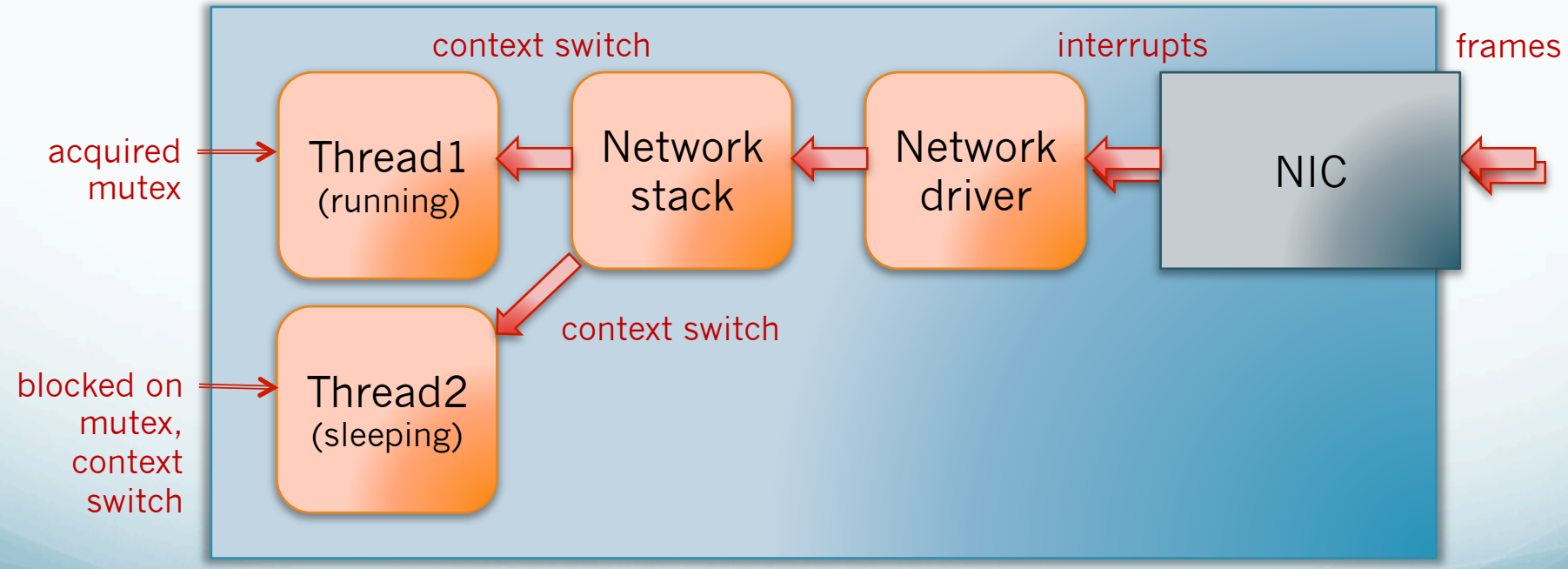
Thread 1: `size_t n = my_socket.read_some(buffer(data), ec);`

Thread 2: `size_t n = my_socket.read_some(buffer(data), ec);`



What if connections ≤ number of CPUs?

- Consider shared resources
  - Are connections truly independent or must they access or manipulate shared data



With single-threaded asynchronous I/O...

```
class session
{
  tcp::socket socket_;
  array<unsigned char, 1024> data_;
  ...
  void do_read()
  {
    socket_.async_read_some(buffer(data_),
        [this](std::error_code ec, std::size_t n)
        {
          // Do something with data ...
          do_read();
        });
  }
};

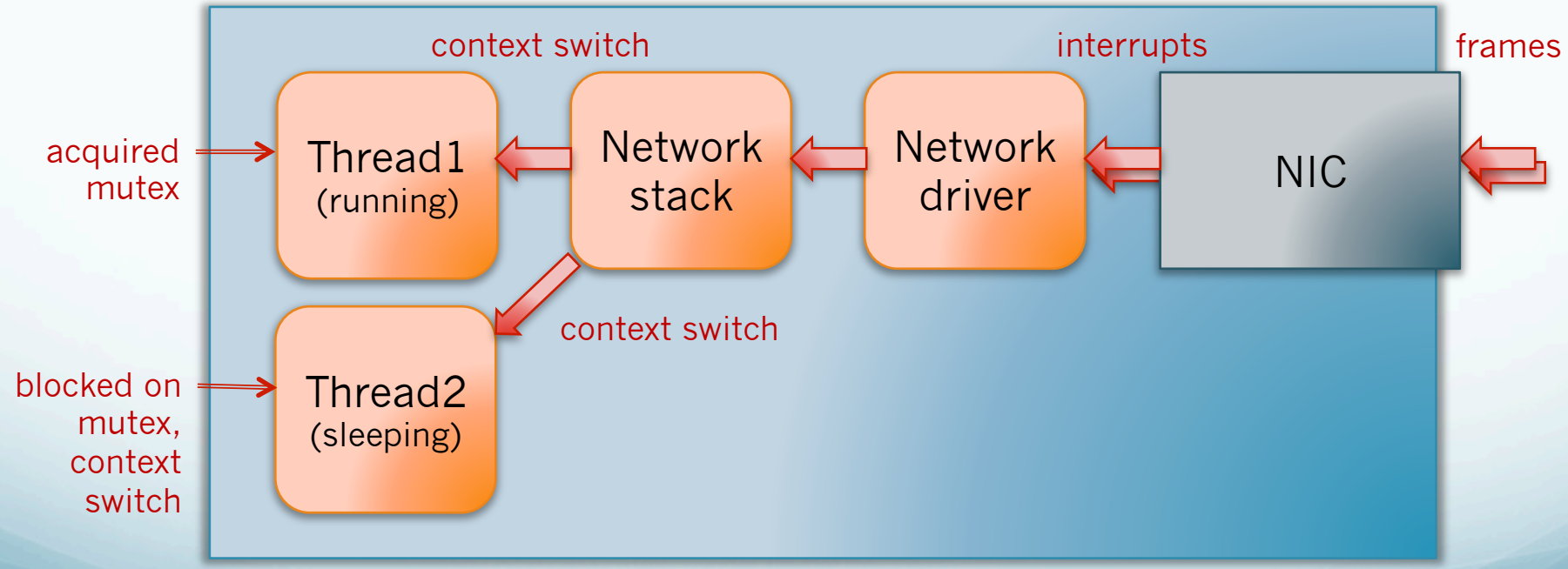
...

io_service.run();
```

Only one context switch per batch of events

What if connections ≤ number of CPUs?

- Consider shared resources
  - Are connections implemented using multiple threads?



Single-threaded asynchronous I/O

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        {
          // Do something with data ...
          do_read();
        });
  }
};

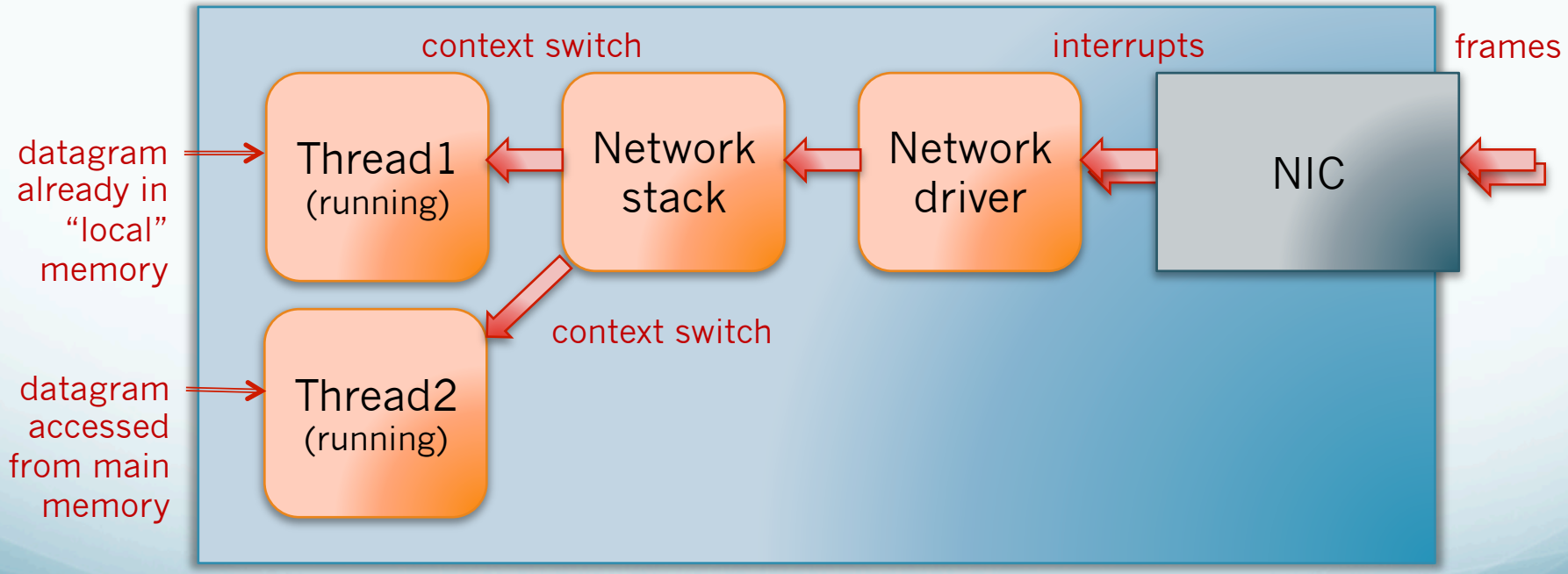
...

io_service.run();
```


No mutex required because all state machines run on the one "real" thread

What if connections ≤ number of CPUs?

- Consider interrupts:
  - NIC may be closer to one physical CPU than another
  - Pay attention to where your interrupts go



With single-threaded asynchronous I/O...

```
class session
{
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  ...
  void do_read()
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        [this](std::error_code ec, std::size_t n)
        {
          // Do something with data ...
          do_read();
        });
  }
};

...
pthread_np_setaffinity(...);
io_service.run();
```

All state machines run on a specific CPU

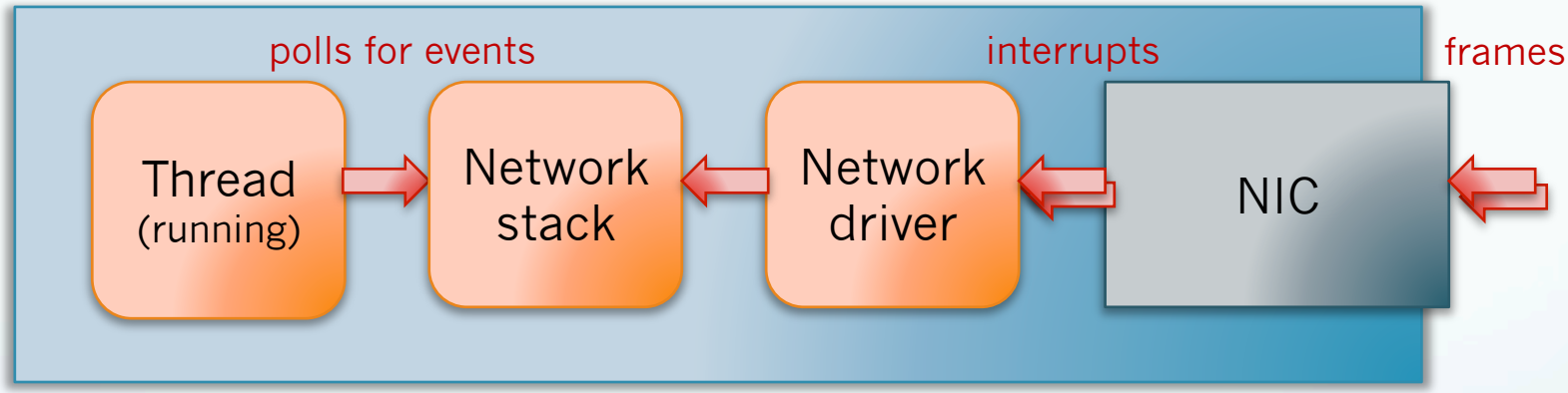
Bonus: no context switches!

```
class session
{
  tcp::socket socket_;
  array<unsigned char, 1024> data_;
  ...
  void do_read()
  {
    socket_.async_read_some(buffer(data_),
        [this](std::error_code ec, std::size_t n)
        {
          // Do something with data ...
          do_read();
        });
  }
};

...
pthread_np_setaffinity(...);
for (;;) io_service.poll();
```

Thread polls for network events and never blocks

Bonus: no context switches!



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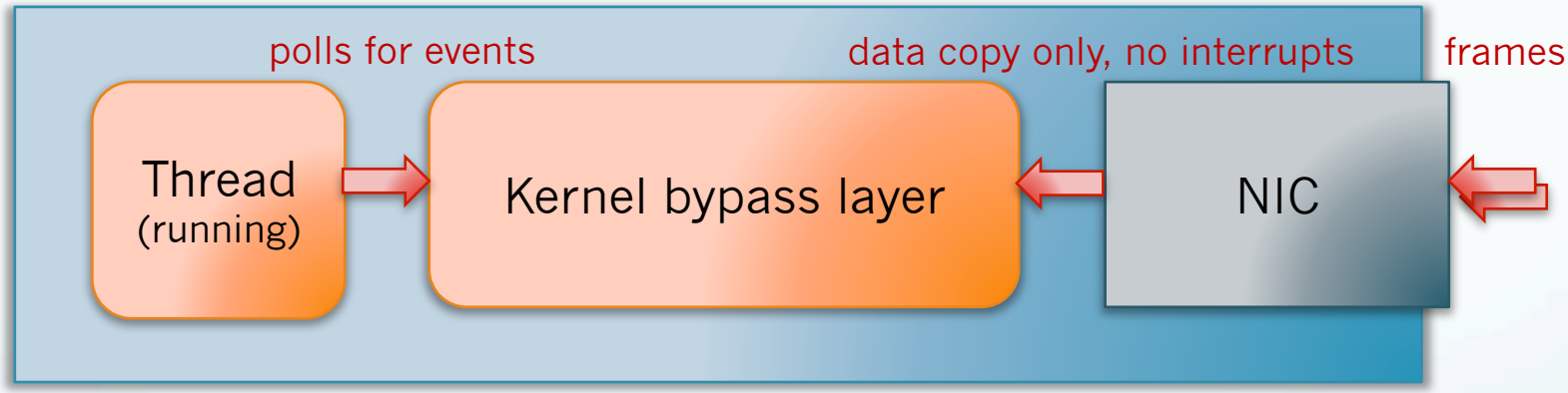


Design recommendations

Example Scenario

- TCP proxy:
  1. Client establishes connection to proxy
  2. Proxy establishes connection to server
  3. Proxy simultaneously:
     a. receives data from client and sends to server
     b. receives data from server and sends to client

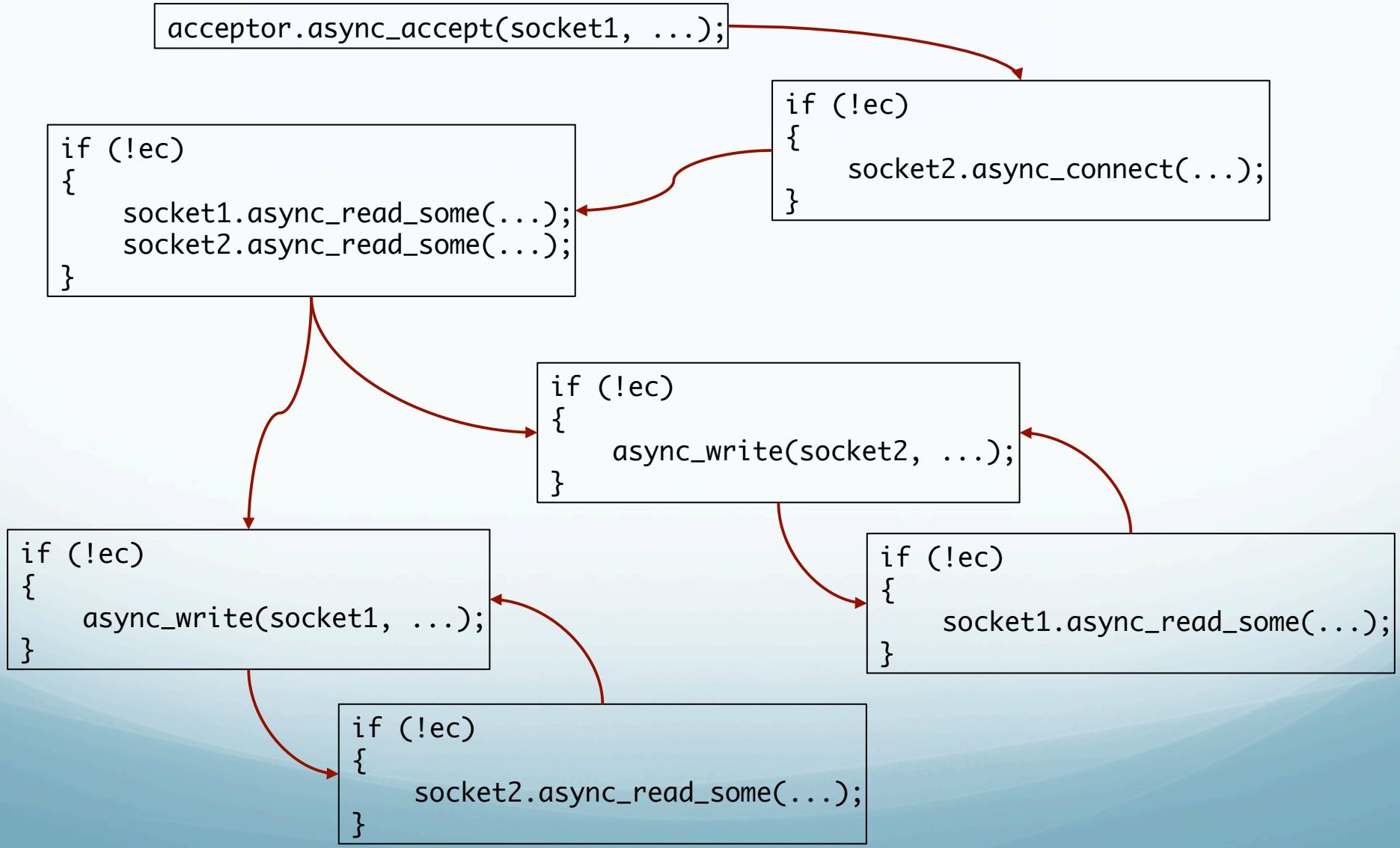
Recommendations

- Spectrum of approaches, in order of preference:
  1. Single-threaded
     1.1. Use threads for long-running tasks
  2. Multiple io_services, one thread each
  3. One io_service, many threads

1. Single-threaded

- Preferred starting point
- Keep handlers short and non-blocking

1. Single-threaded



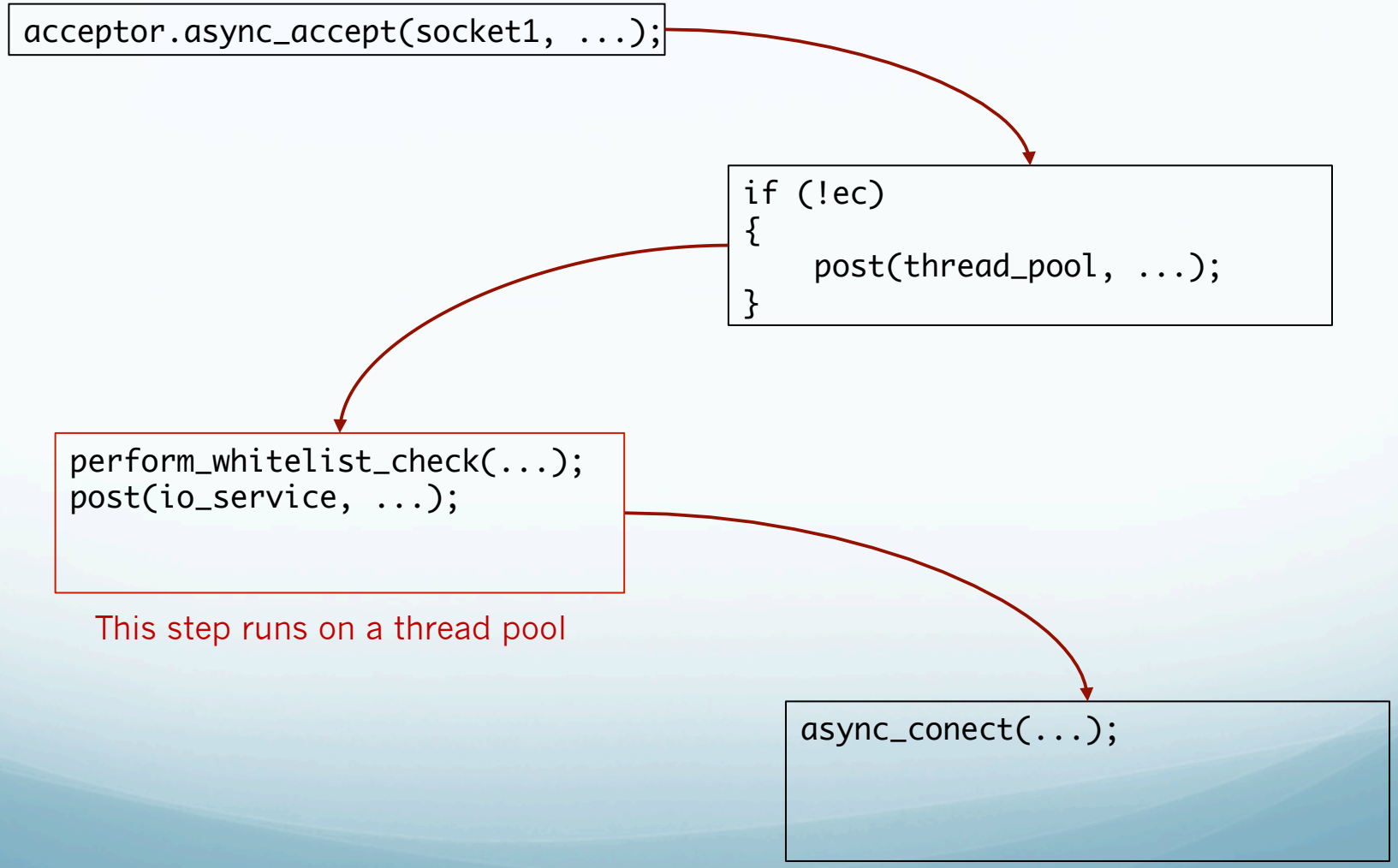
1.1. Use threads for long running tasks

- Networking state machine stays in network thread
  - i.e. networking is still single-threaded
- Pass work to background thread
- Pass result back to network thread

Modified example scenario

- TCP proxy:
  1. Client establishes connection to proxy
  2. Proxy checks client IP against whitelist database
  3. Proxy establishes connection to server
  4. Proxy simultaneously:
     a. receives data from client and sends to server
     b. receives data from server and sends to client

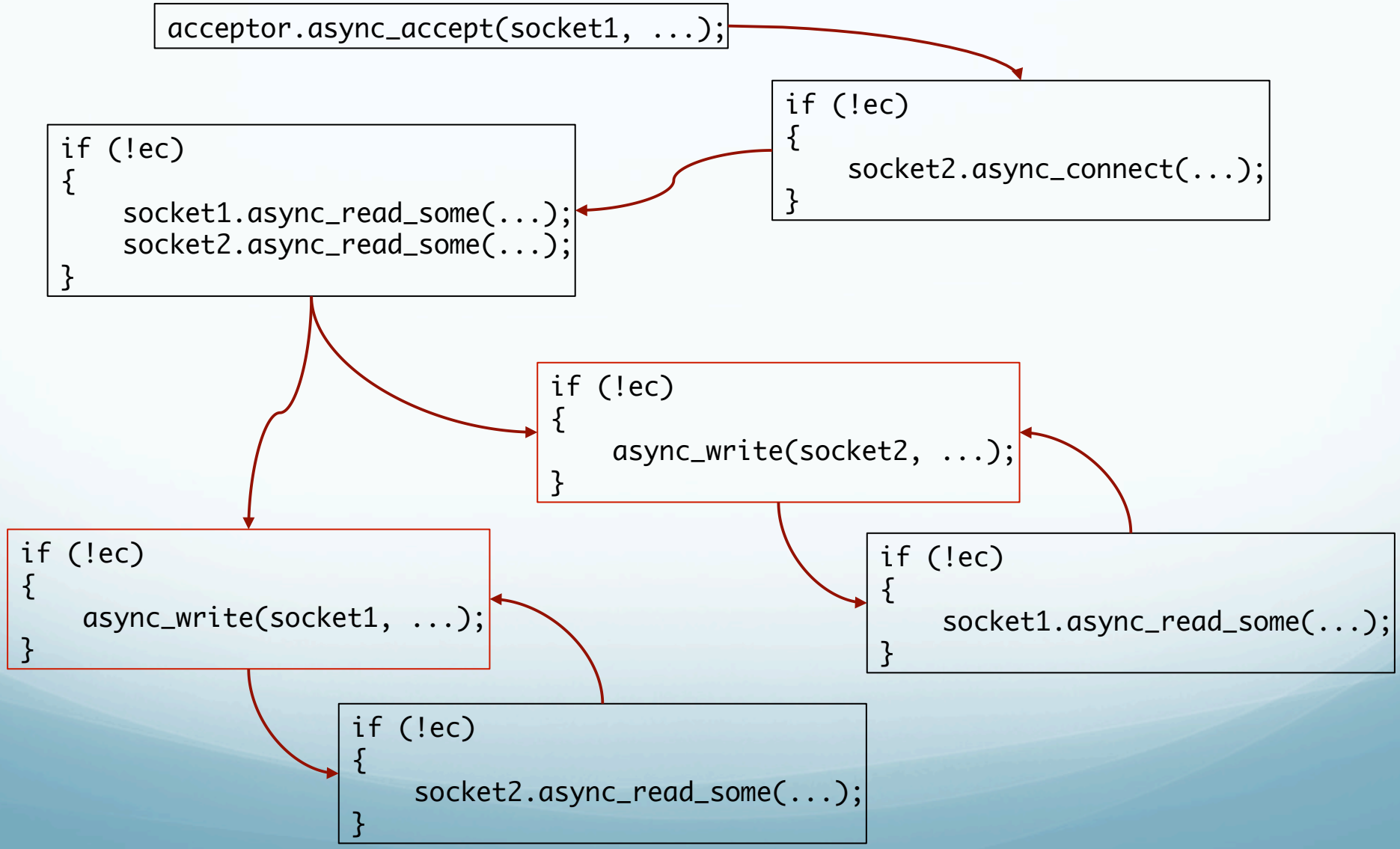
1.1. Use threads for long running tasks



2. Multiple io_services, one thread each

- Networking state machine stays in each object's “home” thread
- Keep handlers short and non-blocking
- Objects communicate via “message passing”

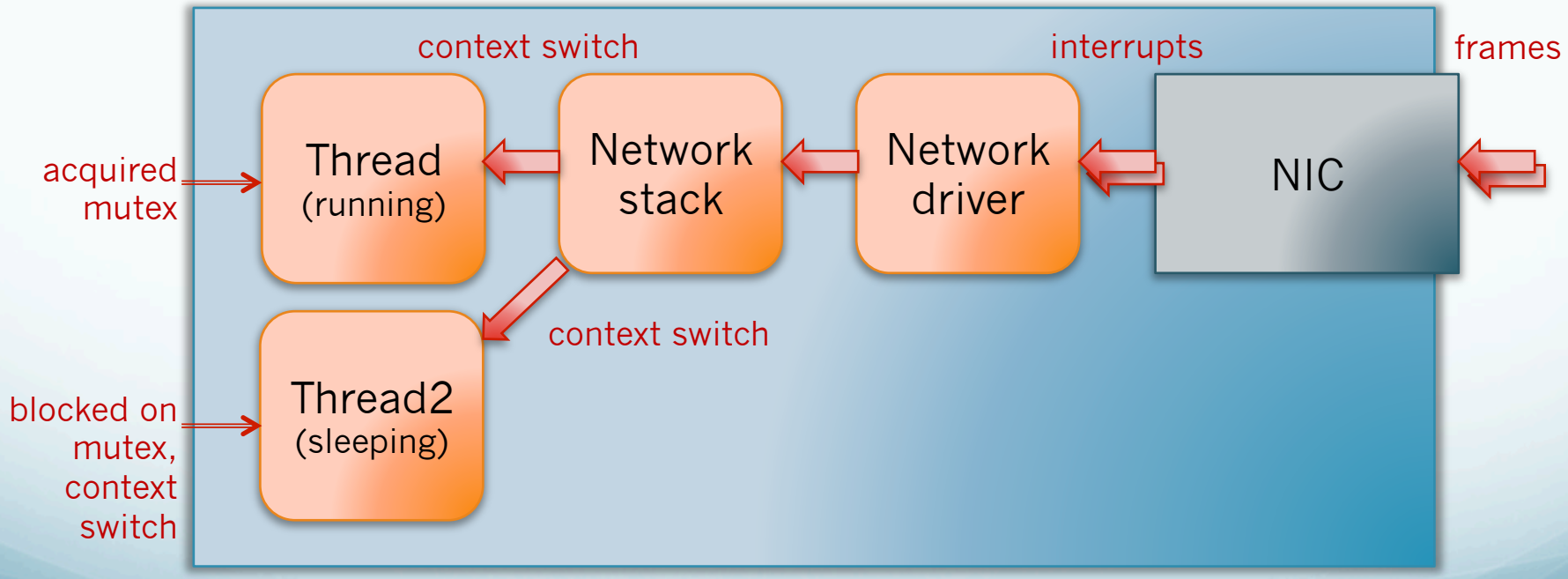
2. Multiple io_services, one thread each



Multithreaded asynchronous I/O

Thread1: `io_service.run();`

Thread2: `io_service.run();`



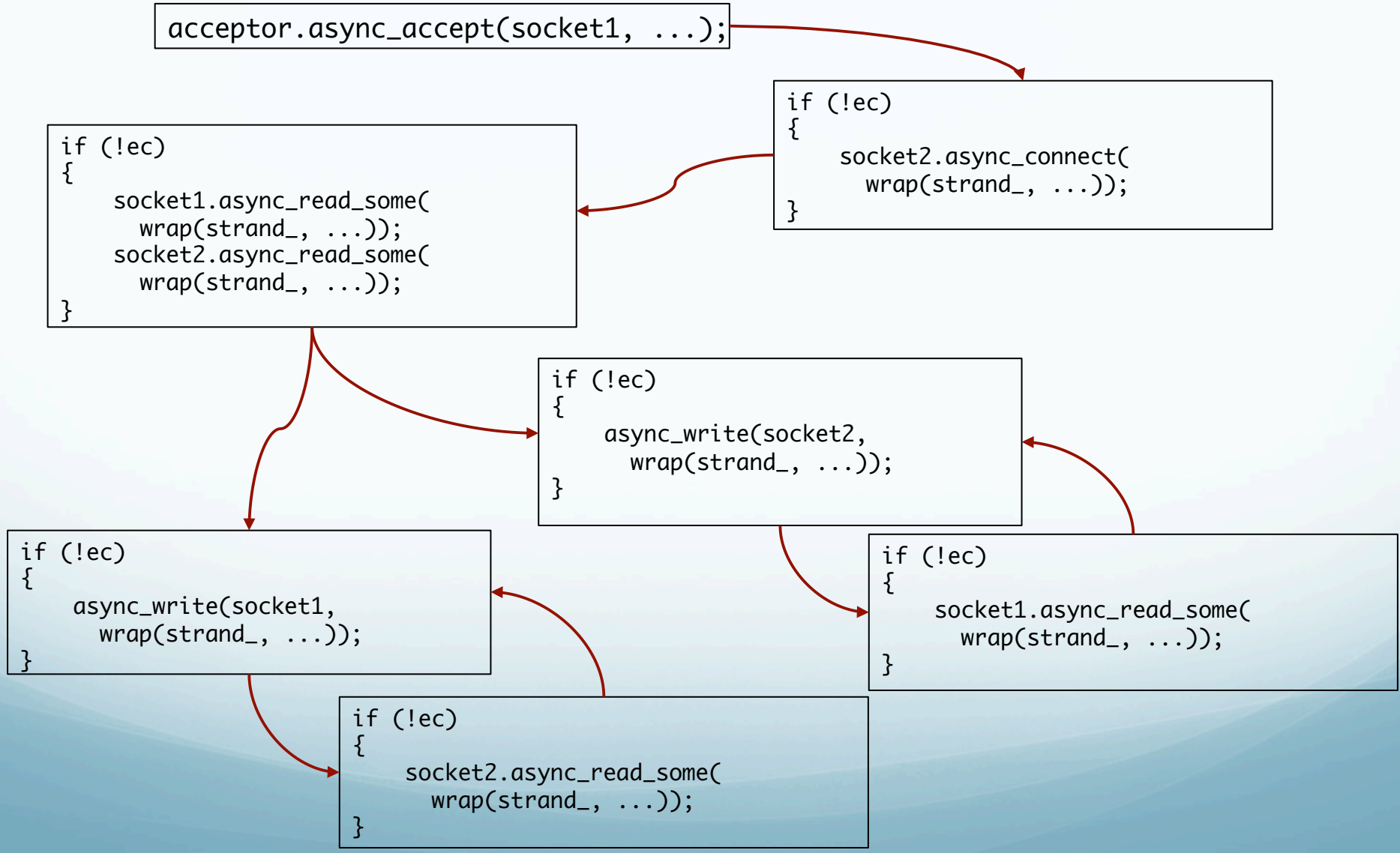
2. Multiple io_services, one thread each

- One io_service, multiple threads:
- Handlers can be called on any thread
- *Execute state machines in strands*
- Objects communicate via “message passing”

Strands

- Ensures:
  - non-concurrent execution of handlers
  - FIFO execution of handlers

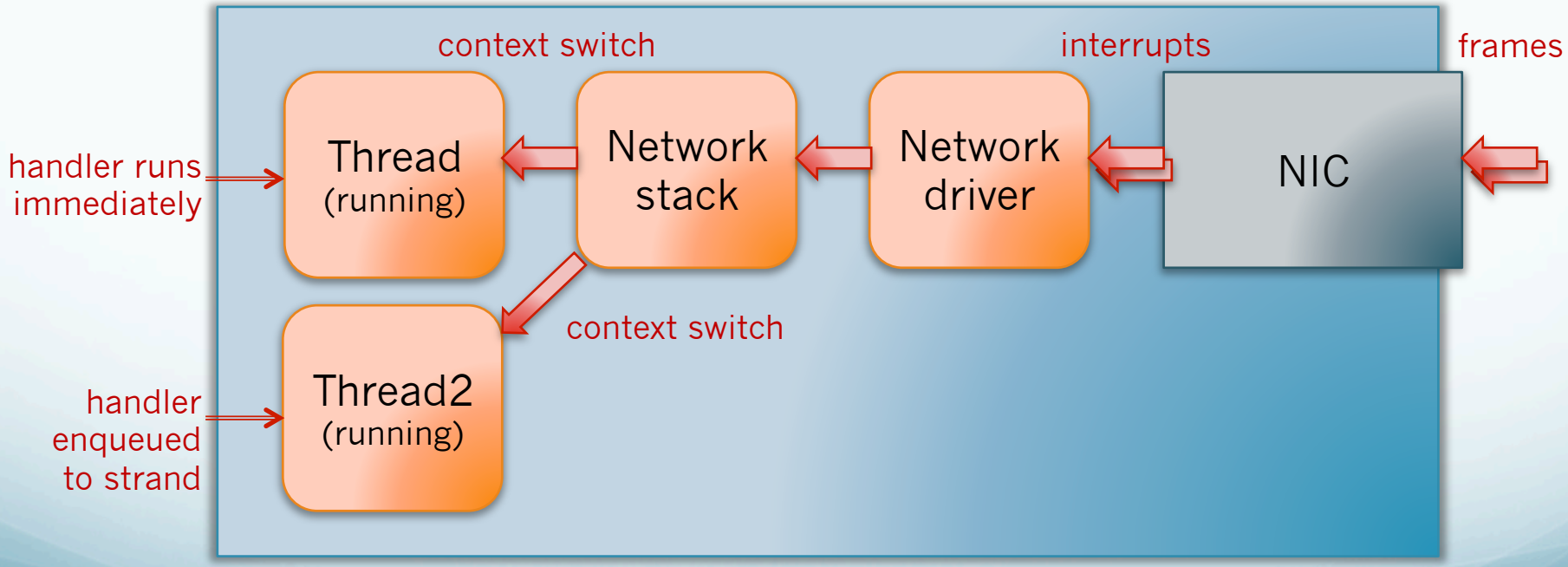
2. Multiple io_services, one thread each



Multithreaded asynchronous I/O

Thread1: `io_service.run();`

Thread2: `io_service.run();`



Recommendations

- Spectrum of approaches, in order of preference:
  1. Single-threaded
     1.1. Use threads for long-running tasks
  2. Multiple io_services, one thread each
  3. One io_service, many threads
- Whichever approach is used, pay attention to interrupts and CPU affinity
  - May provide an easy win, with no source changes

Questions?