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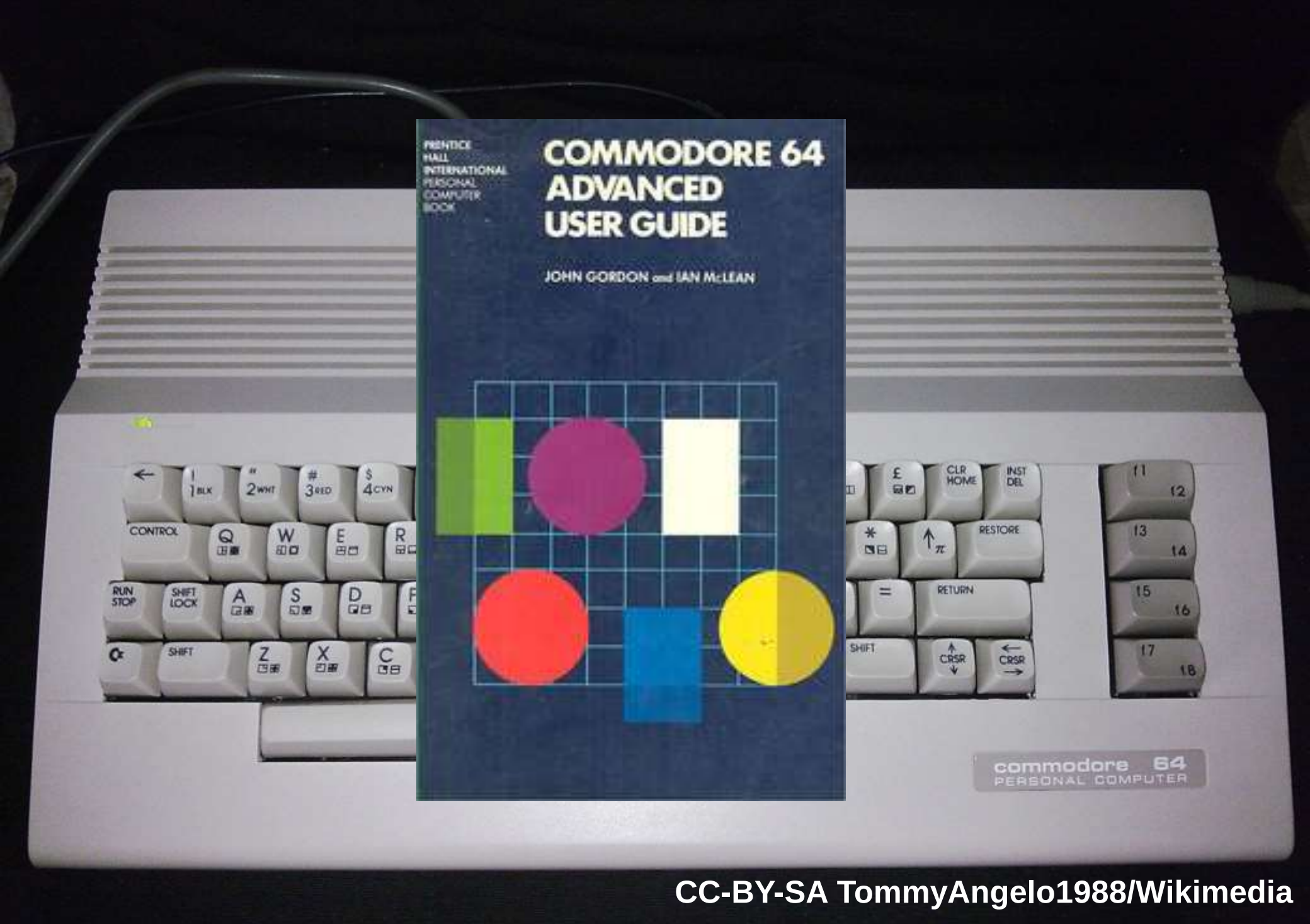
Grease

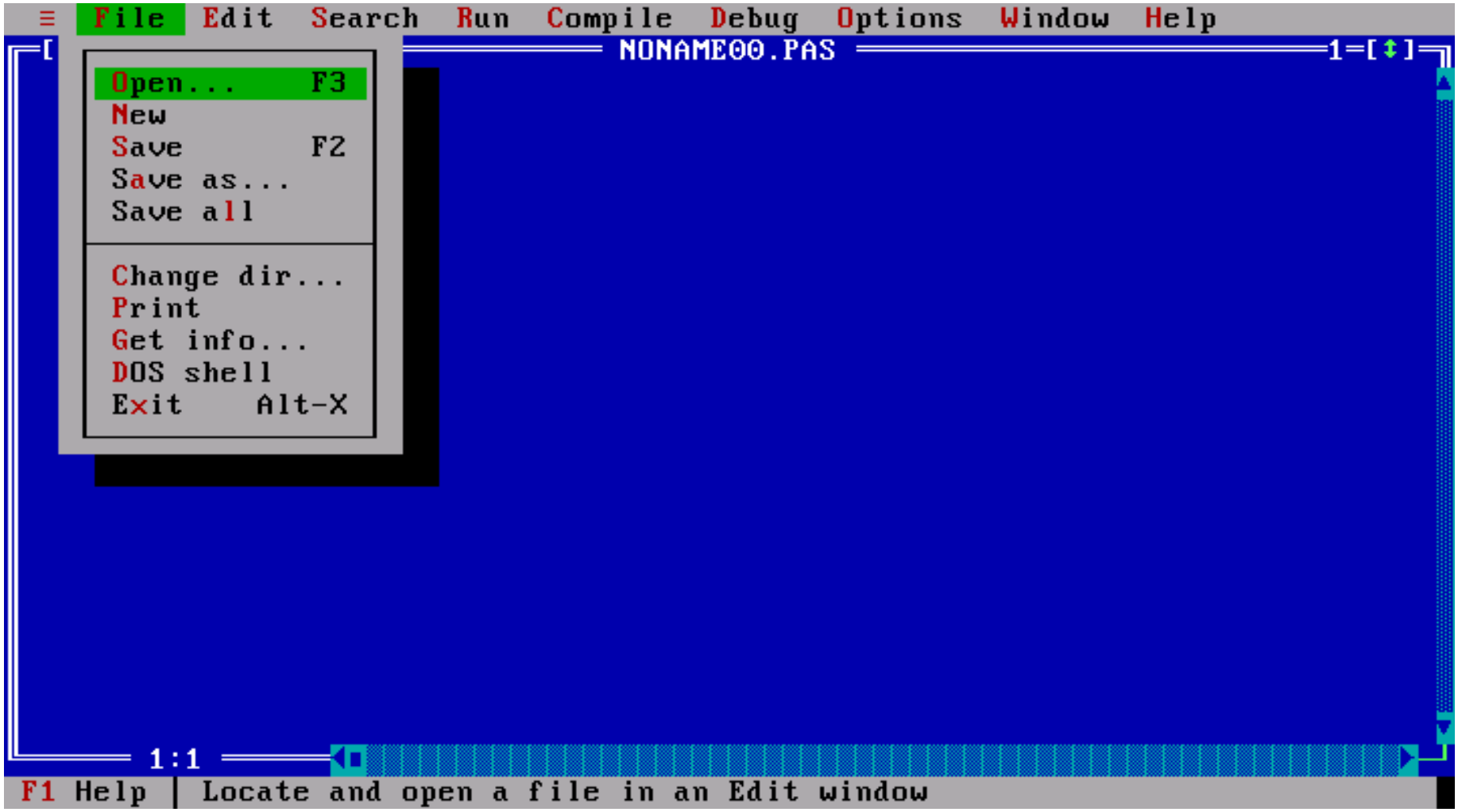
A Message-Passing Approach to Protocol Stacks in Rust

Jonathan Pallant

Cambridge Consultants

My Journey in Software Engineering

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Open... F3
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DOS shell
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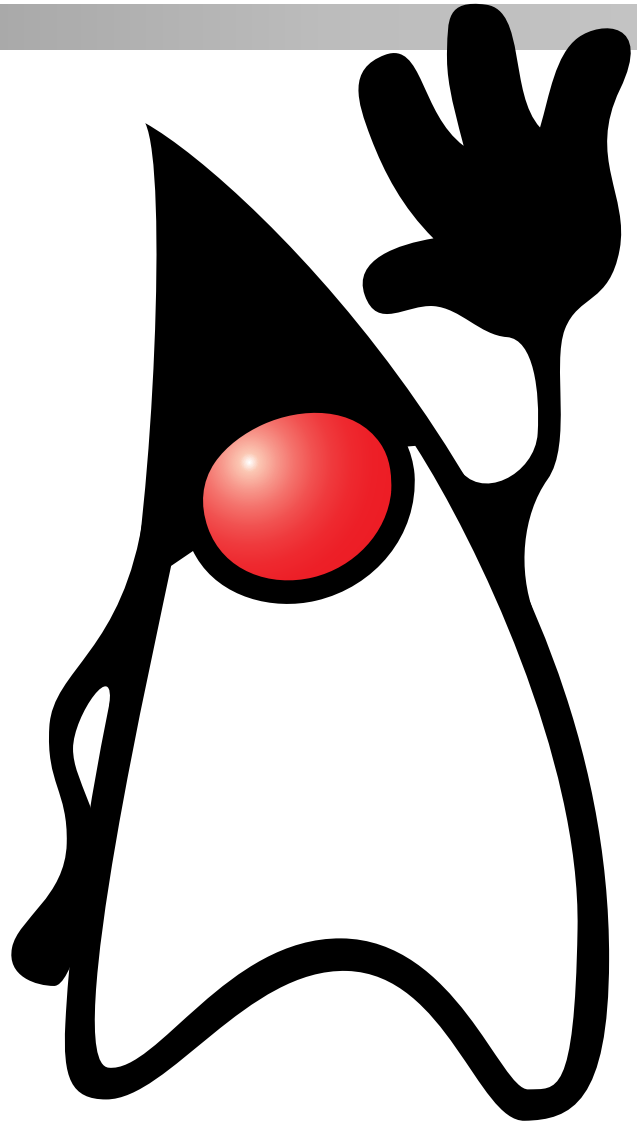
F1 Help | Locate and open a file in an Edit window

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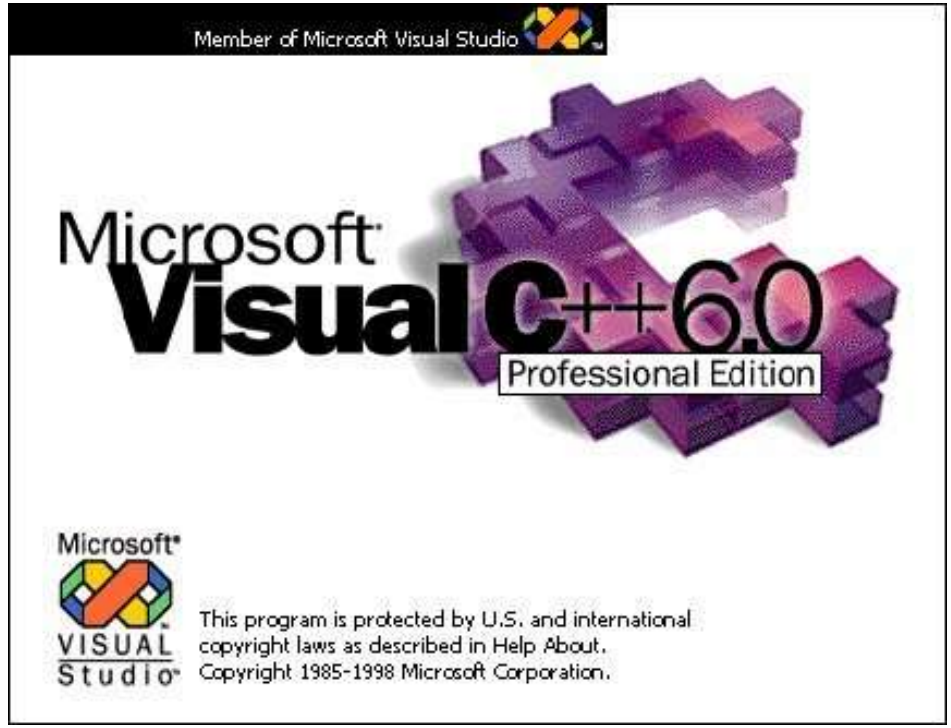
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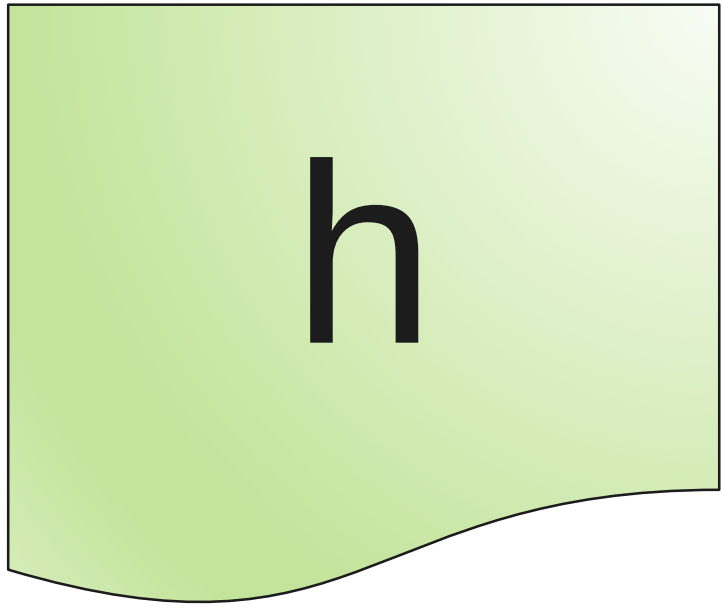
At this point…

- I know 11 languages (to some extent)
- I am a programmer, but
- I do not know how to write software.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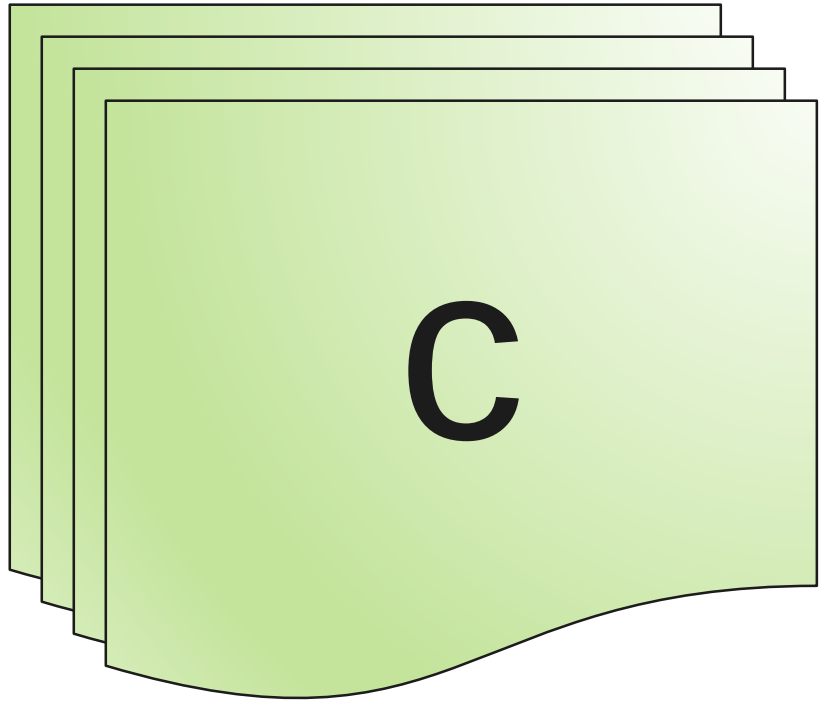
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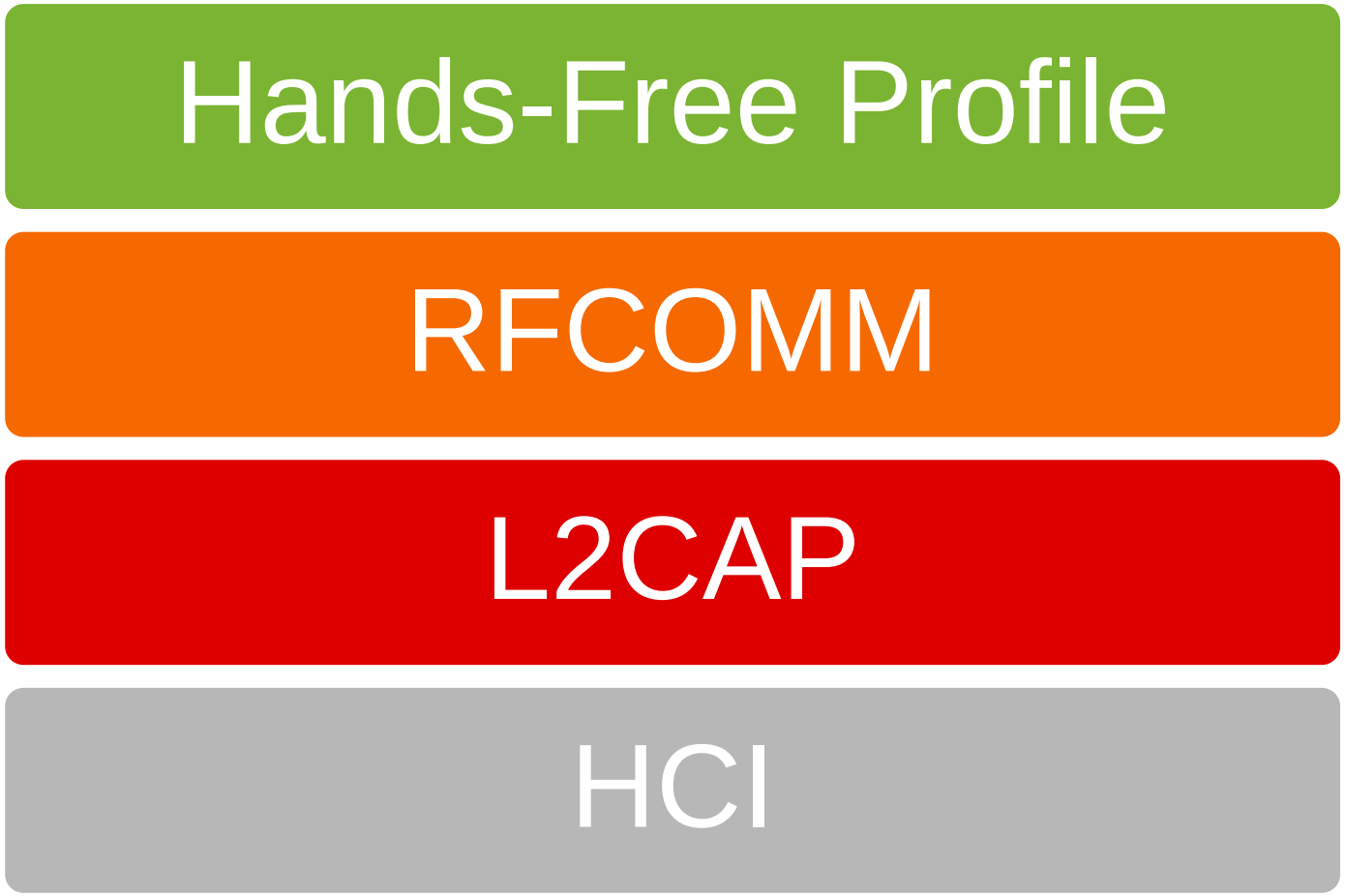
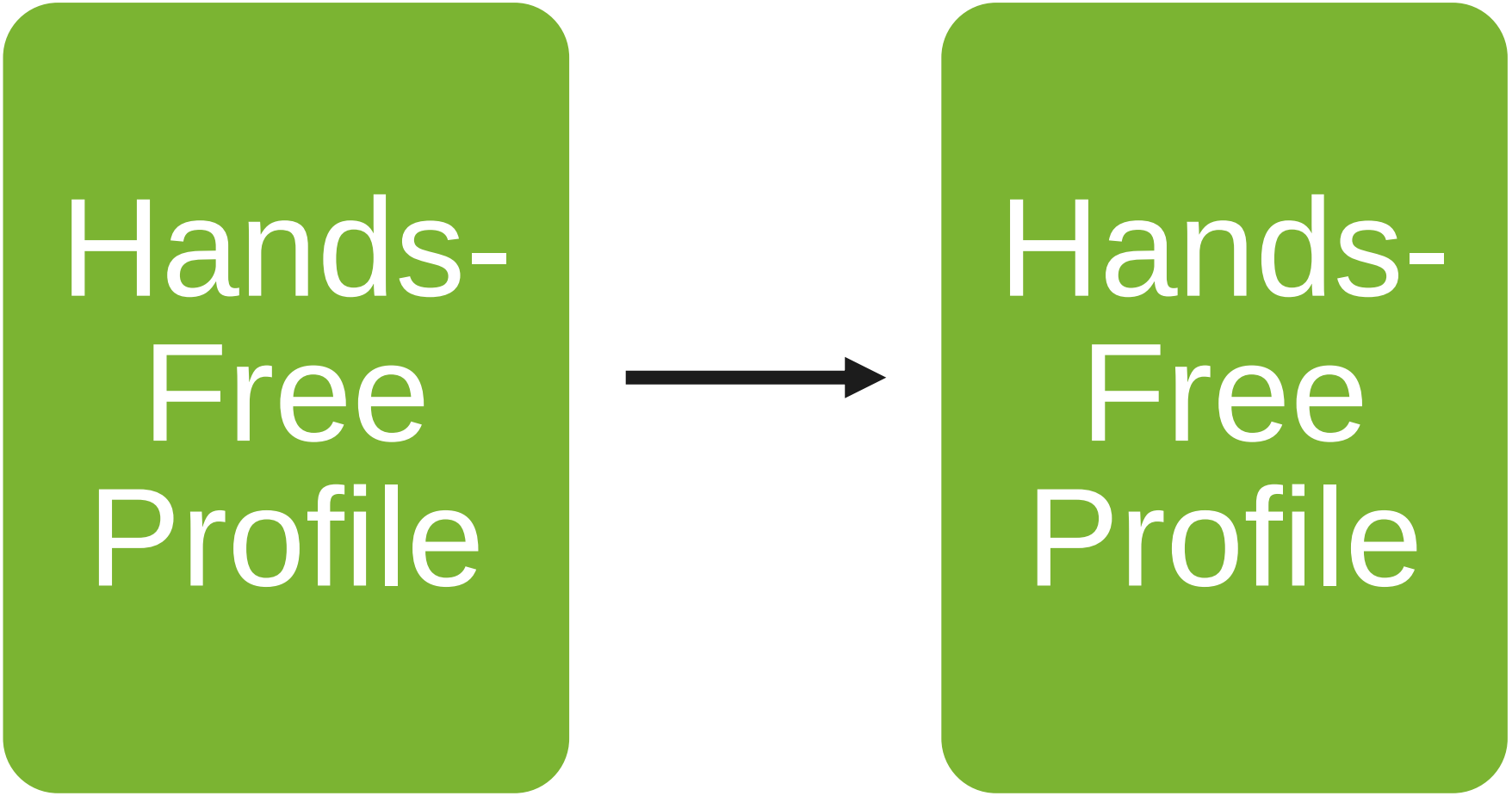
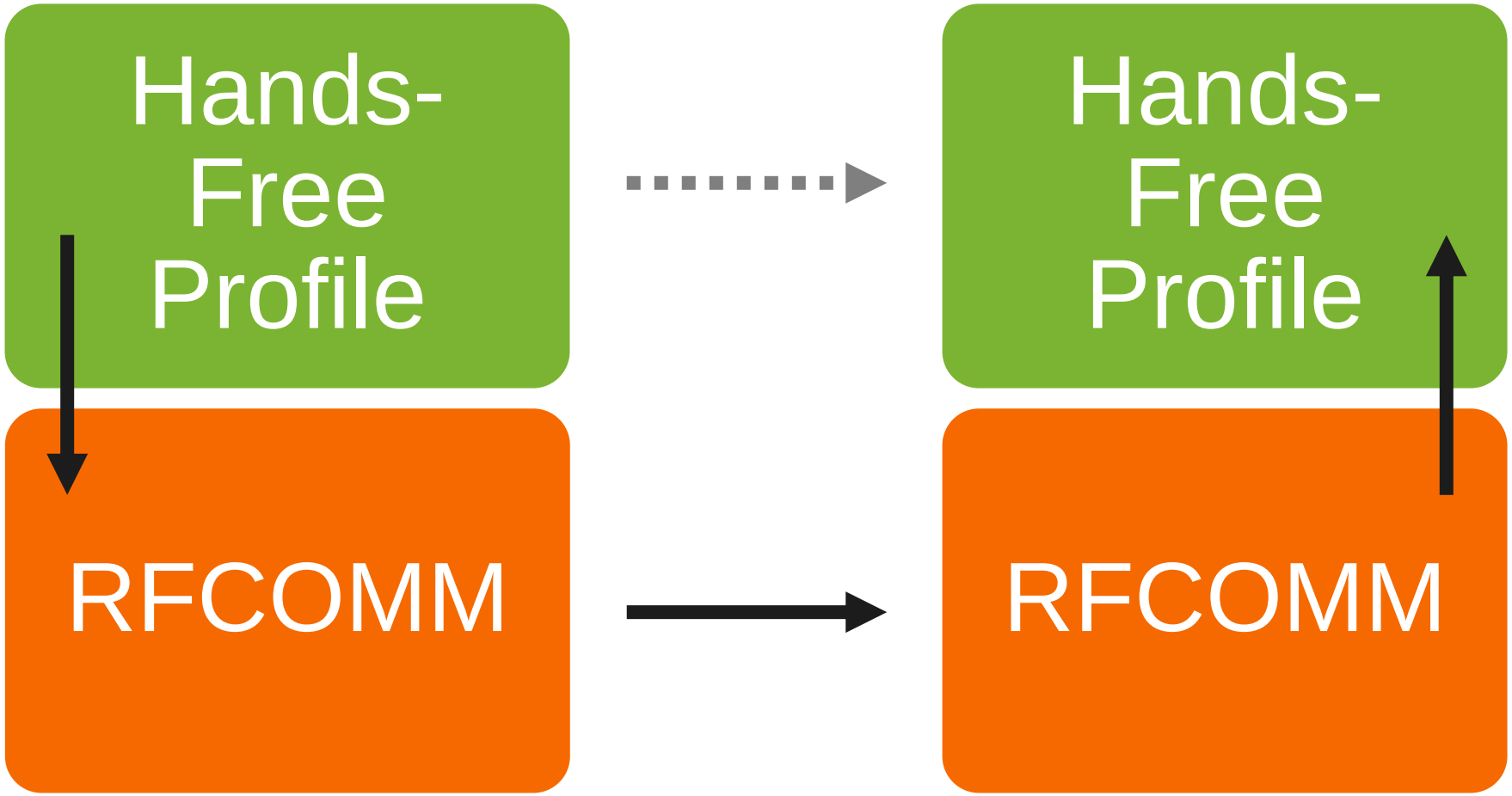
Protocol Stacks


Hands-Free Profile
RFCOMM
L2CAP
HCI


Hands-Free Profile
Hands-Free Profile


Hands-
Free
Profile
Hands-
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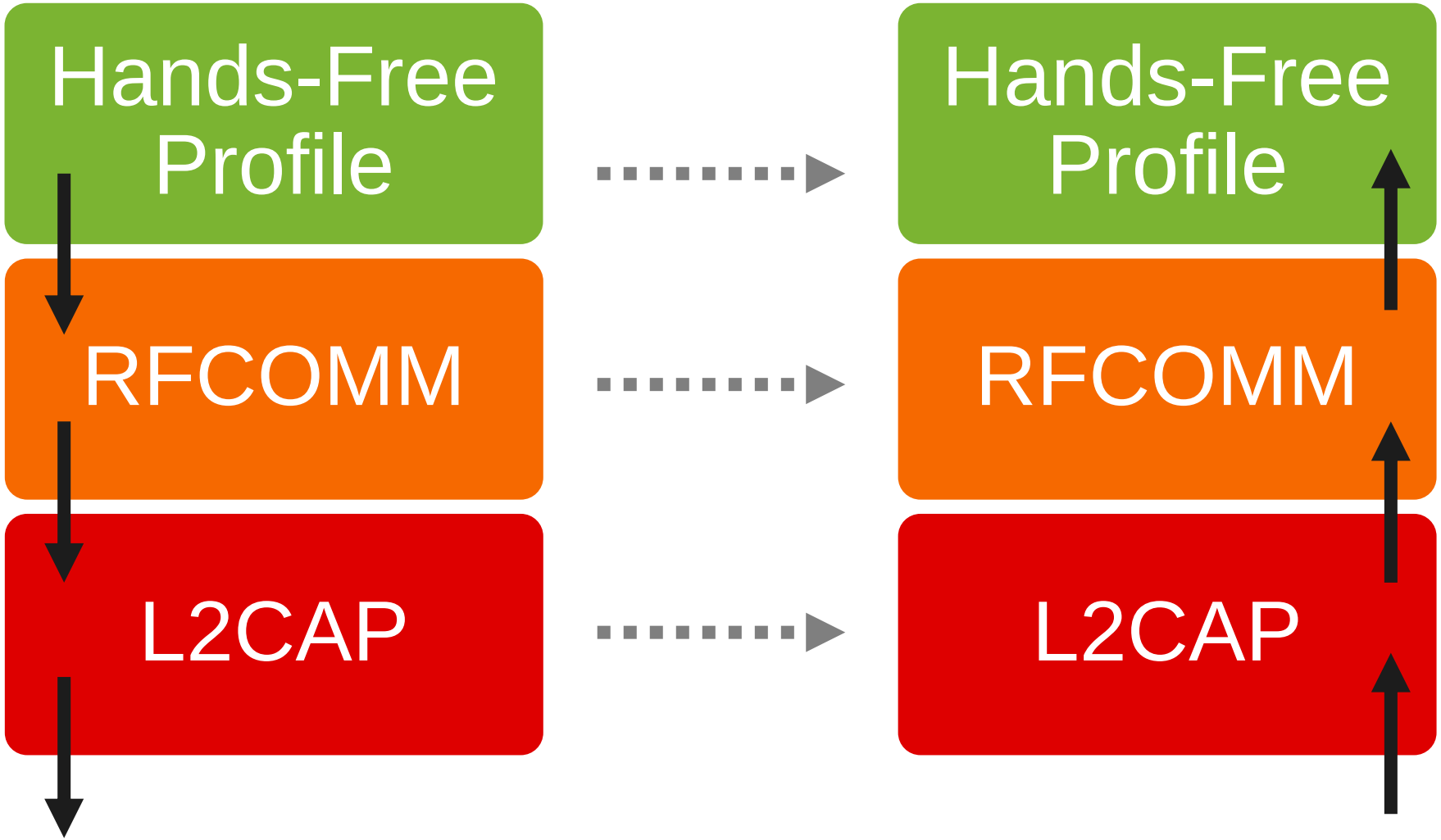
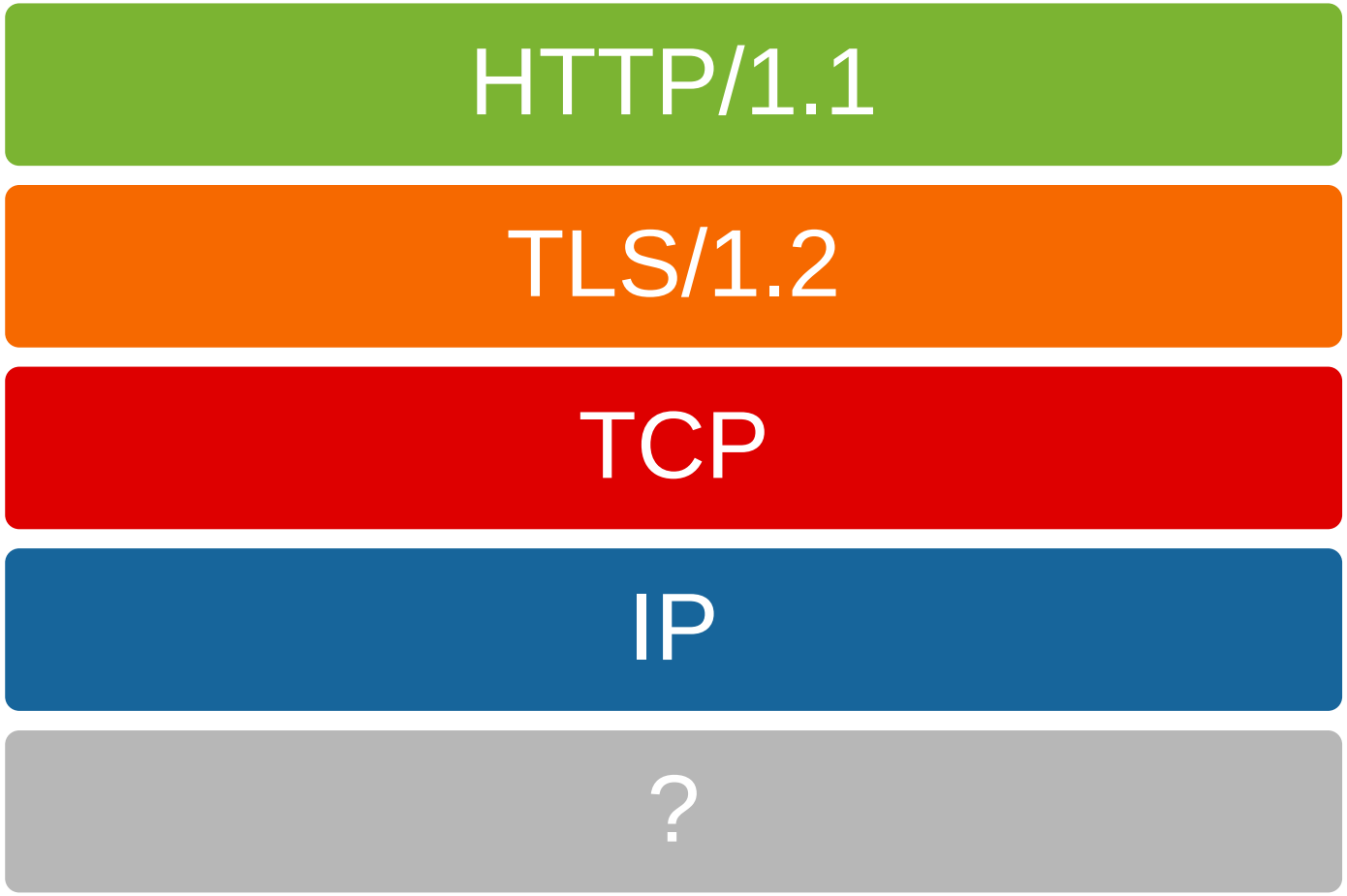
Profile
RFCOMM
RFCOMM


Hands-Free Profile
RFCOMM
L2CAP
Hands-Free Profile
RFCOMM
L2CAP


HTTP/1.1
TLS/1.2
TCP
IP
?

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TELECOMMUNICATION
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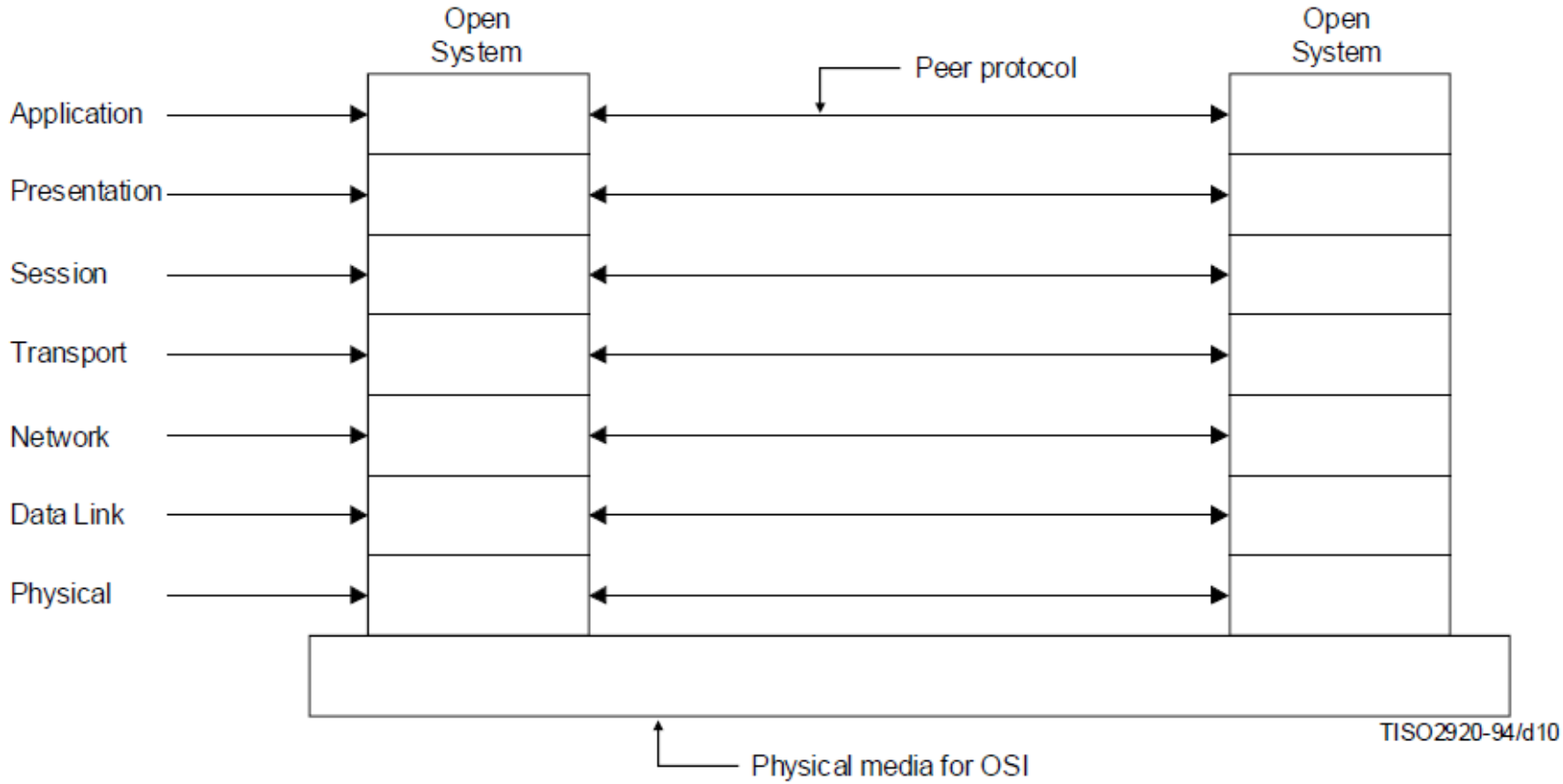
DATA NETWORKS AND OPEN SYSTEM COMMUNICATIONS

OPEN SYSTEMS INTERCONNECTION – MODEL AND NOTATION

INFORMATION TECHNOLOGY – OPEN SYSTEMS INTERCONNECTION – BASIC REFERENCE MODEL: THE BASIC MODEL


Open System
Peer protocol
Open System
Application
Presentation
Session
Transport
Network
Data Link
Physical
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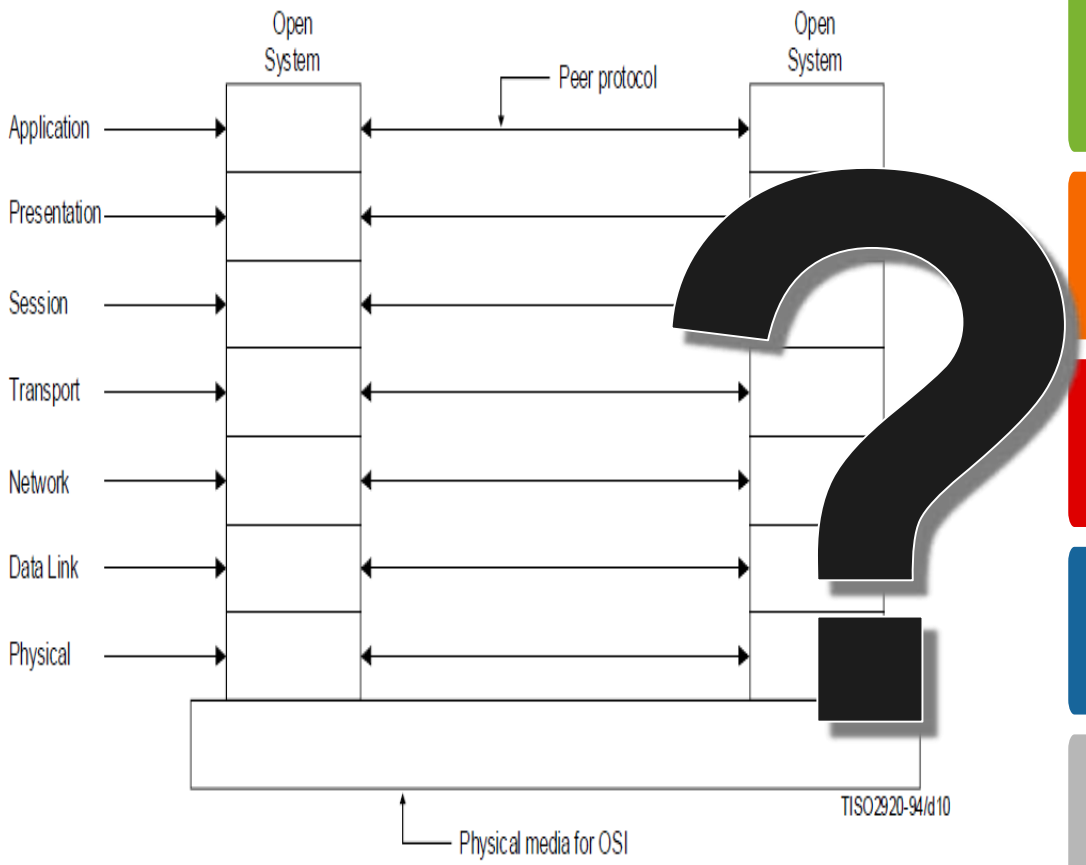
Physical media for OSI



HTTP

TLS

TCP

IP

?

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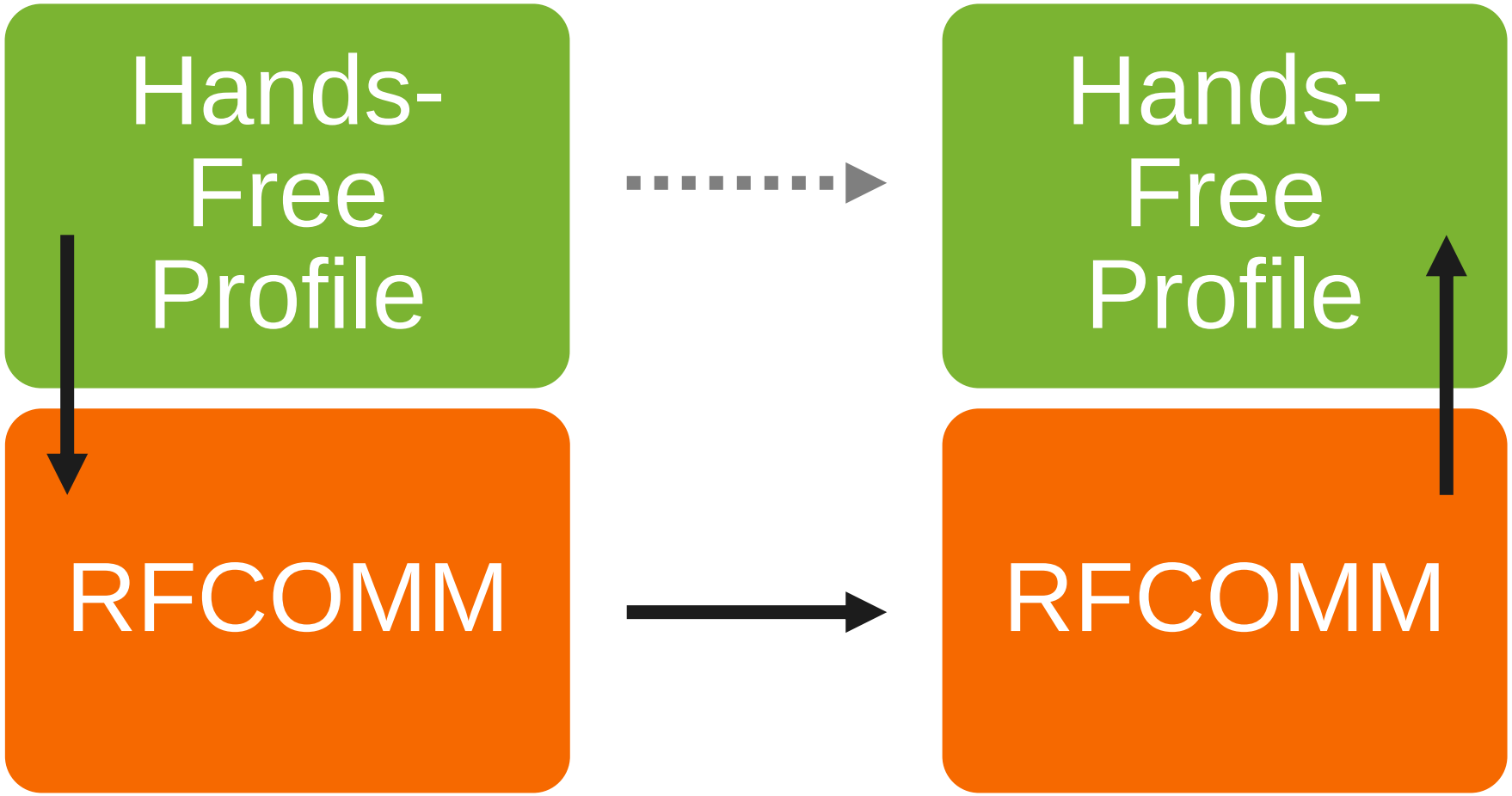
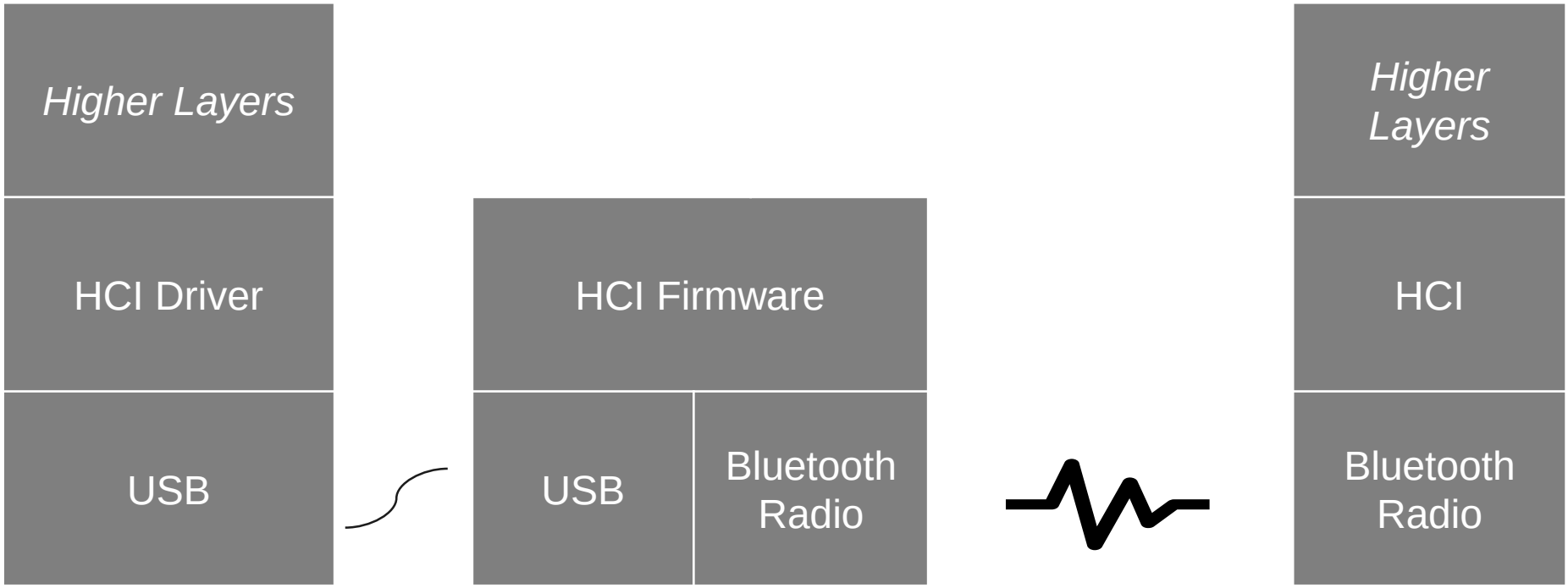
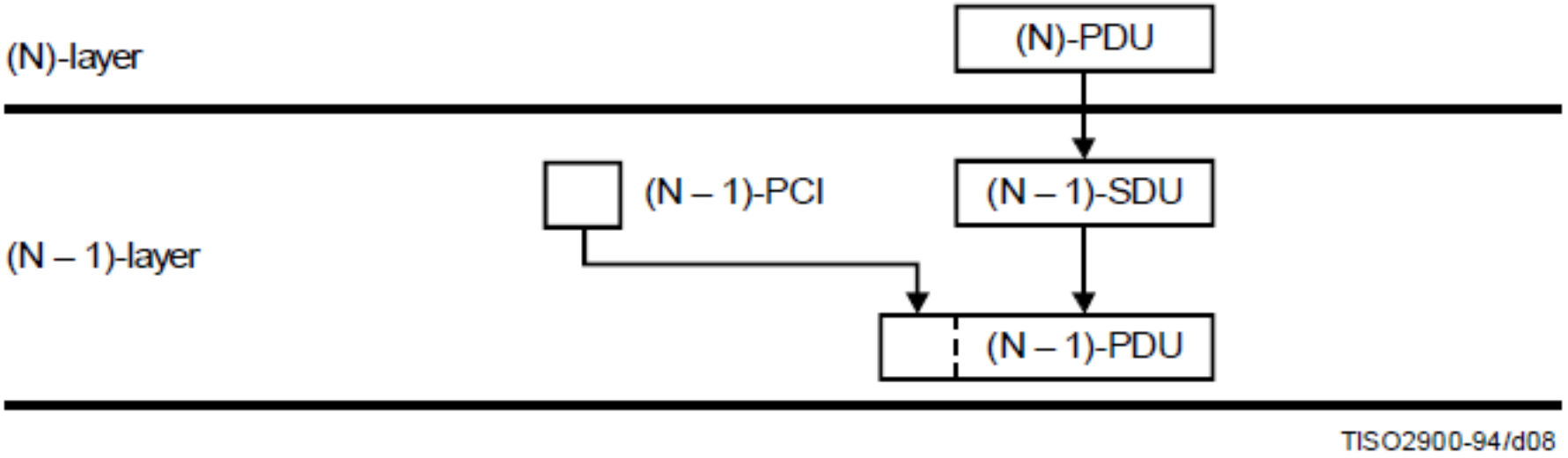
The Layered Model


Hands-
Free
Profile
Hands-
Free
Profile
RFCOMM
RFCOMM

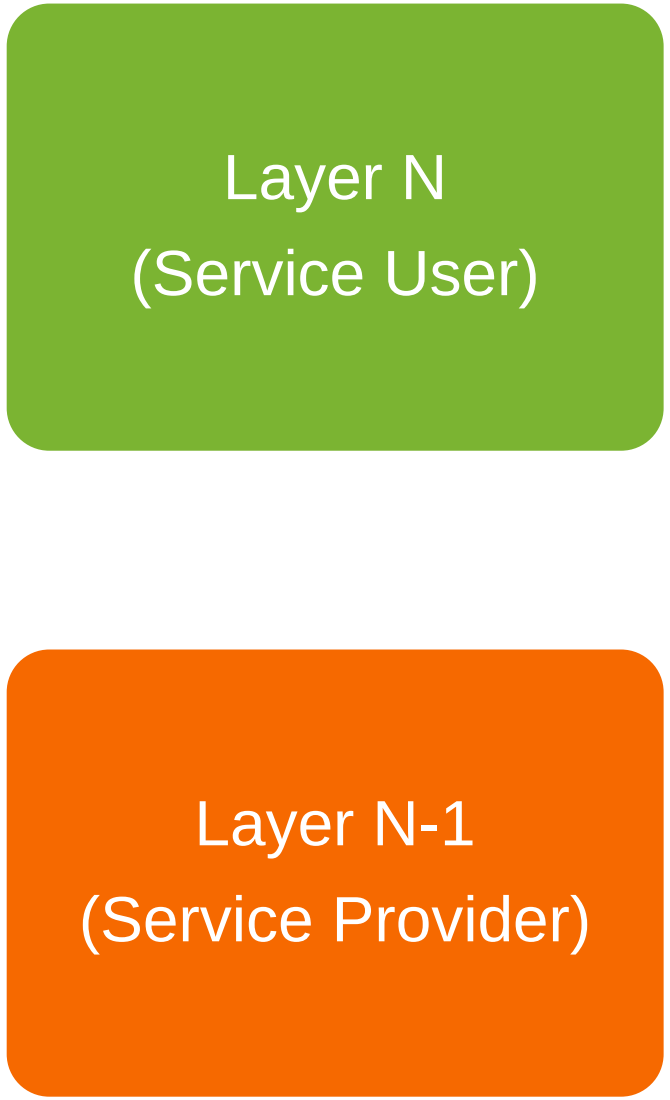

Higher Layers
HCI Driver
USB
HCI Firmware
USB
Bluetooth Radio
Higher Layers
HCI
Bluetooth Radio
PC
USB Bluetooth Module
Single-chip Bluetooth Module

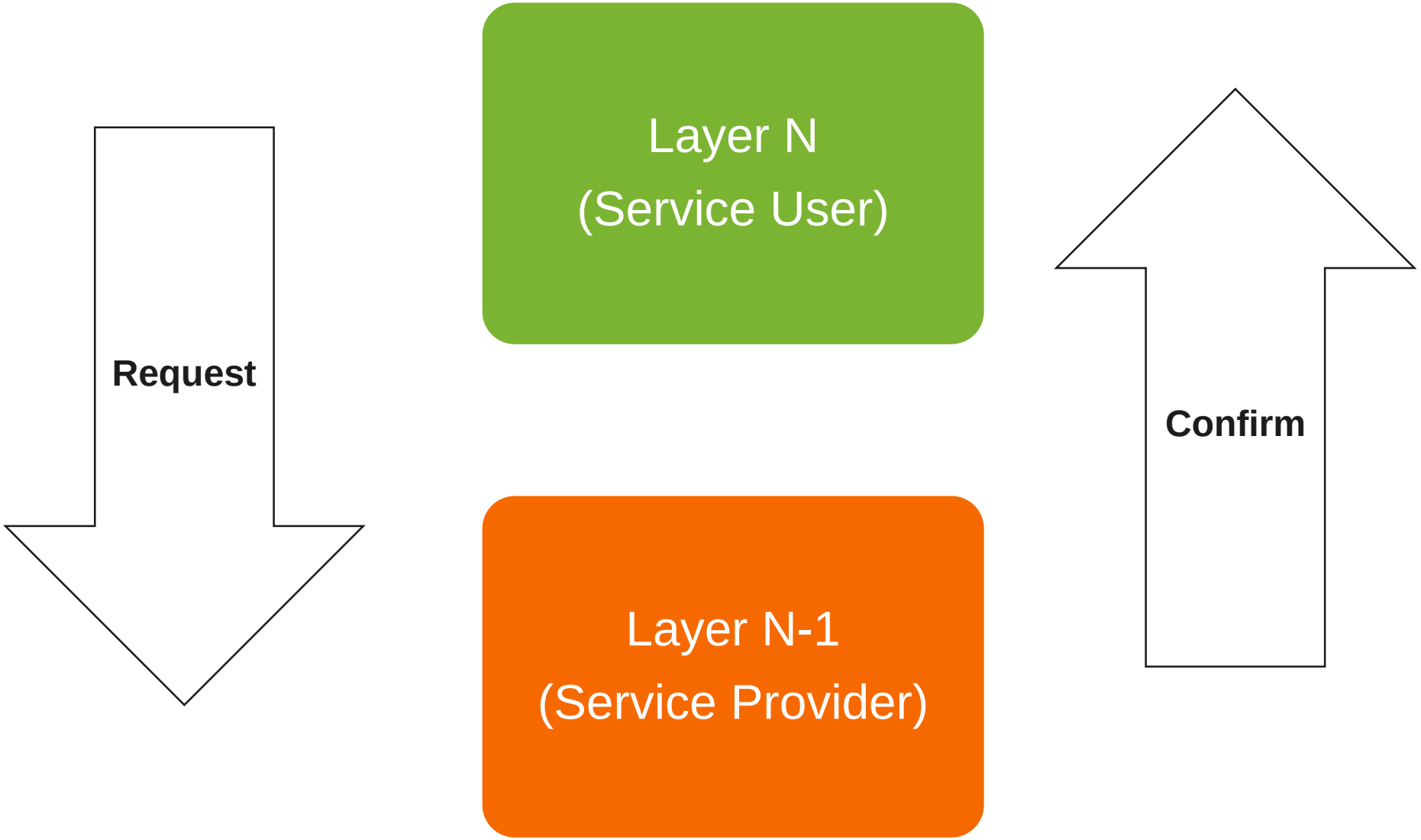


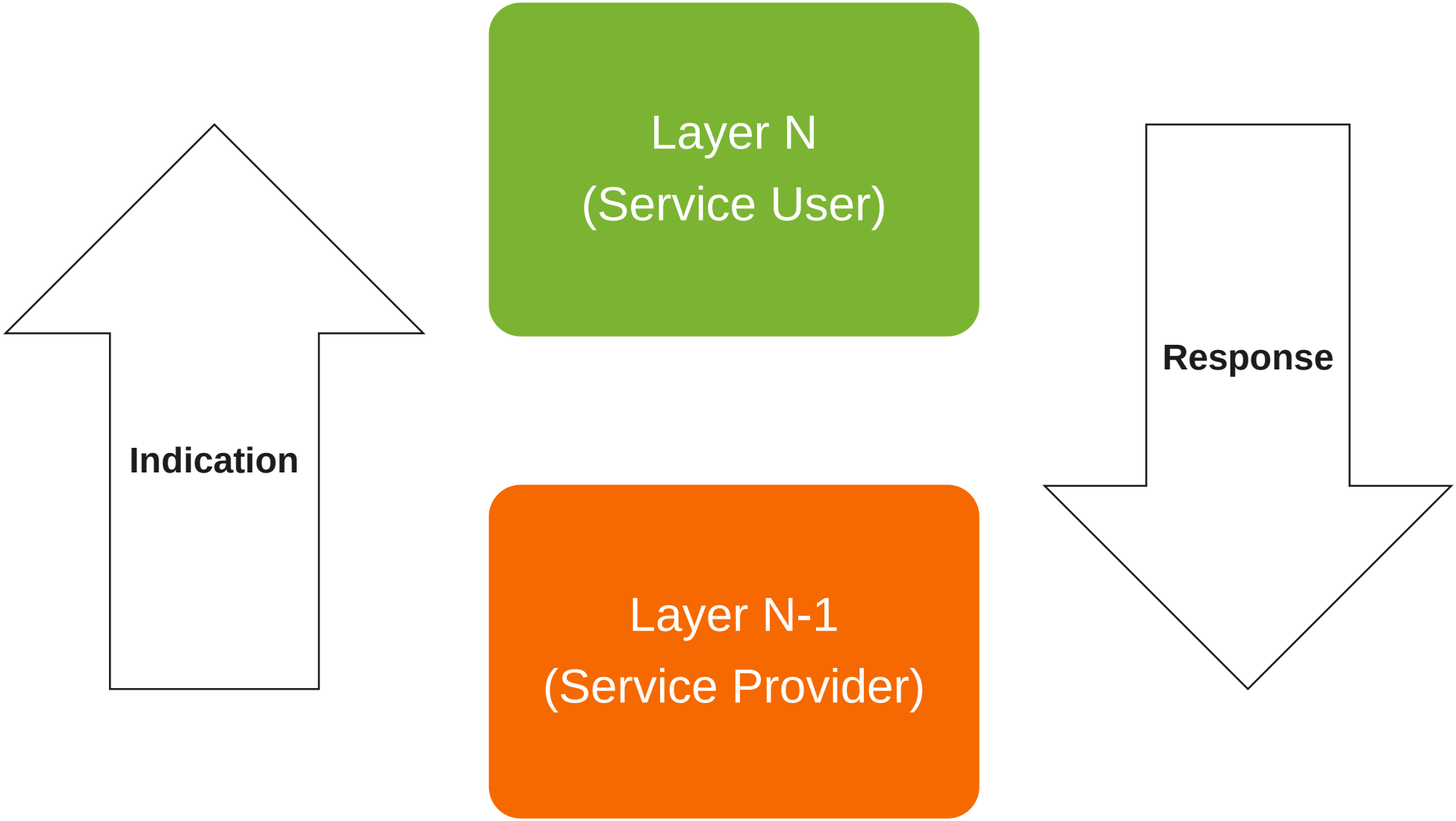
PCI Protocol-control-information
PDU Protocol-data-unit
SDU Service-data-unit

Hands-Free Profile

RFCOMM


Layer N
(Service User)
Layer N-1
(Service Provider)


Layer N
(Service User)
Request
Confirm
Layer N-1
(Service Provider)


Layer N
(Service User)
Indication
Response
Layer N-1
(Service Provider)

Naming Messages

- Good Names
  - FRAME_SEND_REQ / FRAME_SEND_CFM
  - FRAME_QUEUE_REQ / FRAME_QUEUE_CFM
  - FRAME_TX_IND
  - DATA_RECEIVED_IND
  - POSITION_REQUIRED_IND / POSITION_REQUIRED_RSP
  - IndDataReceived

- Clearly state the intention.
- Matched pairs of REQ/CFM.
- Appropriate case depends on language.

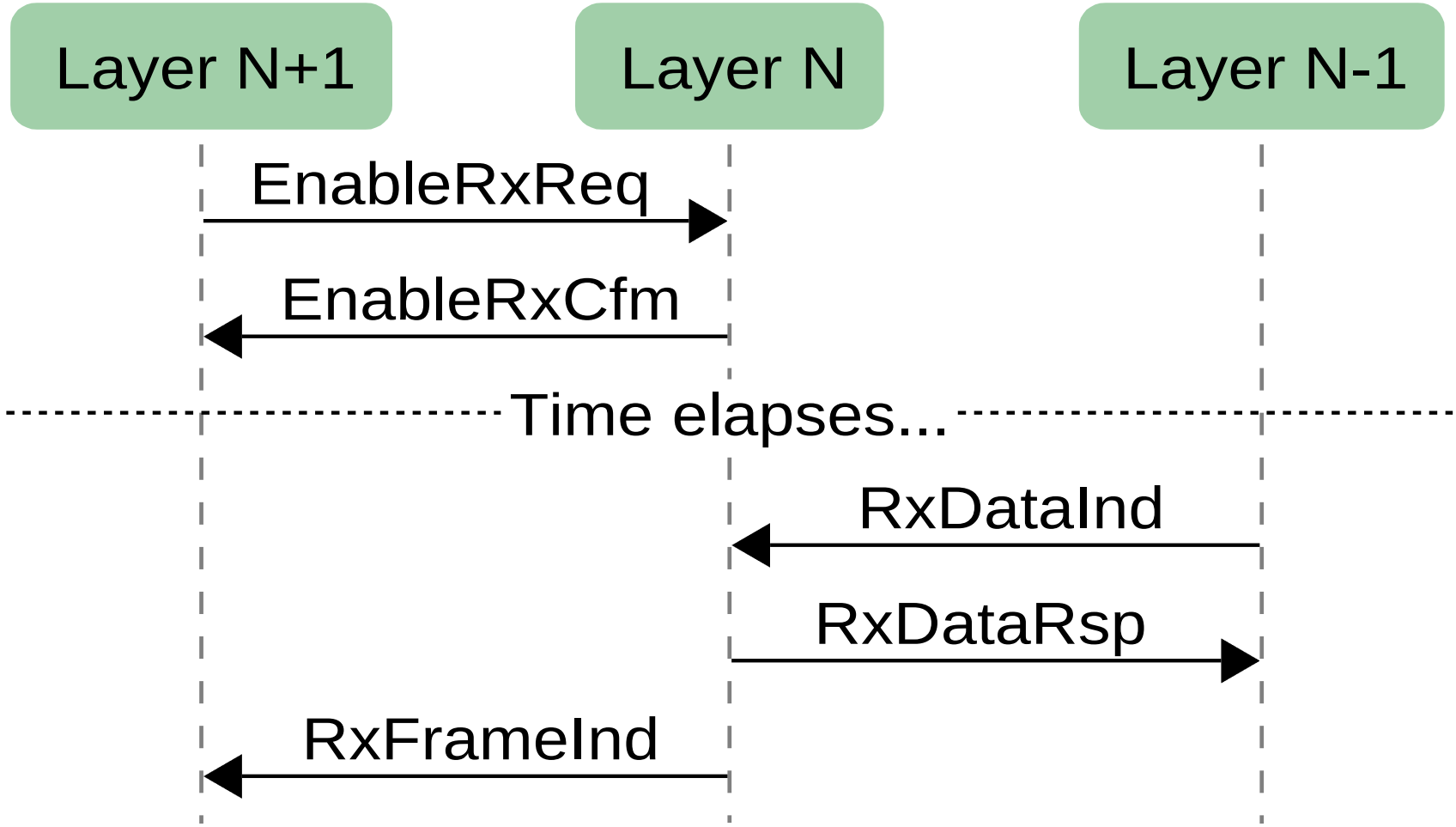
- Bad Names
  - SEND_DATA_REQ / DATA_SEND_CFM
  - DATA_RECEIVED

- Mismatched pair.
- Unclear message type.

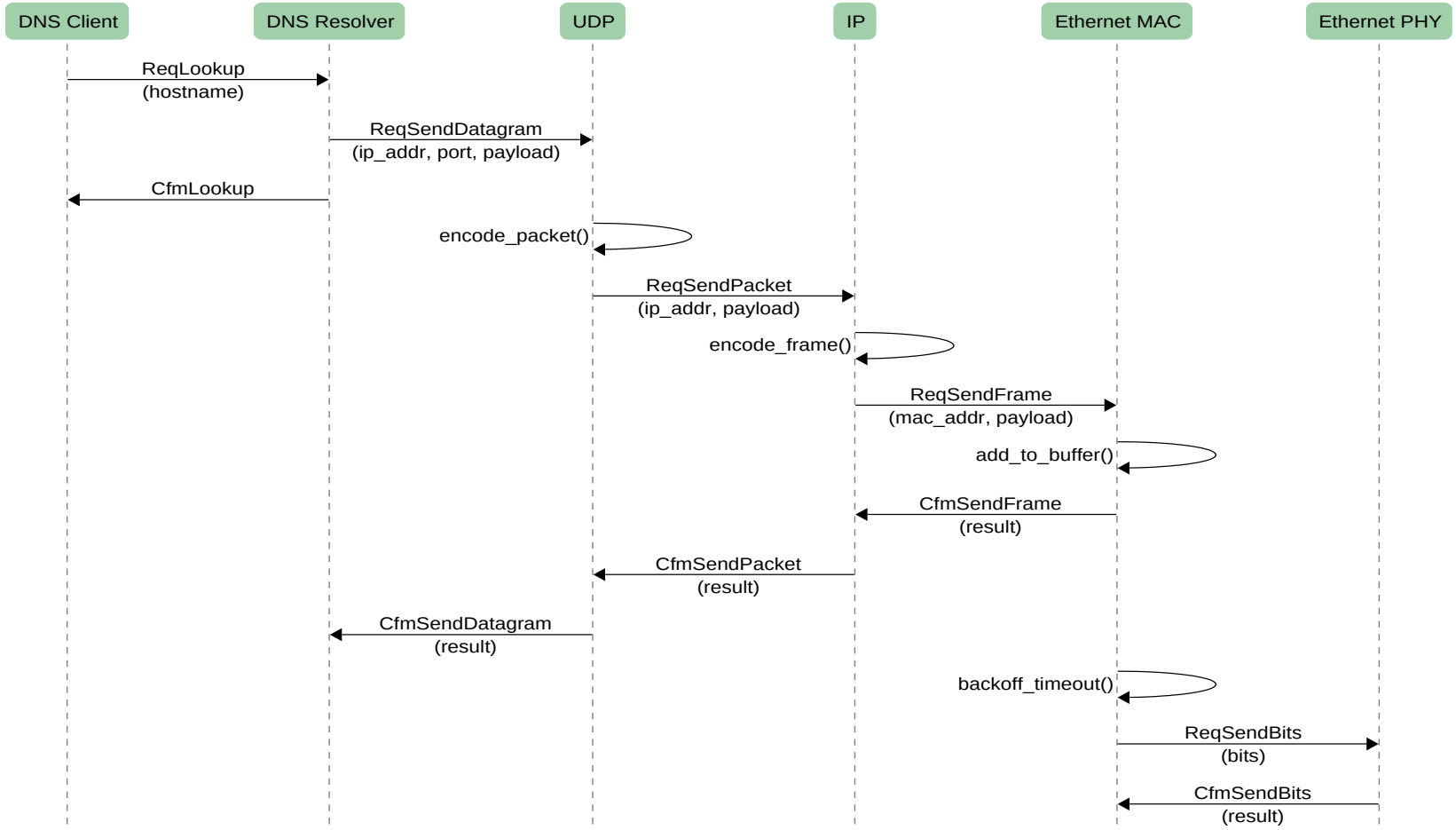
But why?

- Large systems are *large.*
- A consistent set of rules of crucial.
  - Signposting so you don’t get lost.
  - Avoids misunderstanding.
  - This works in practice!

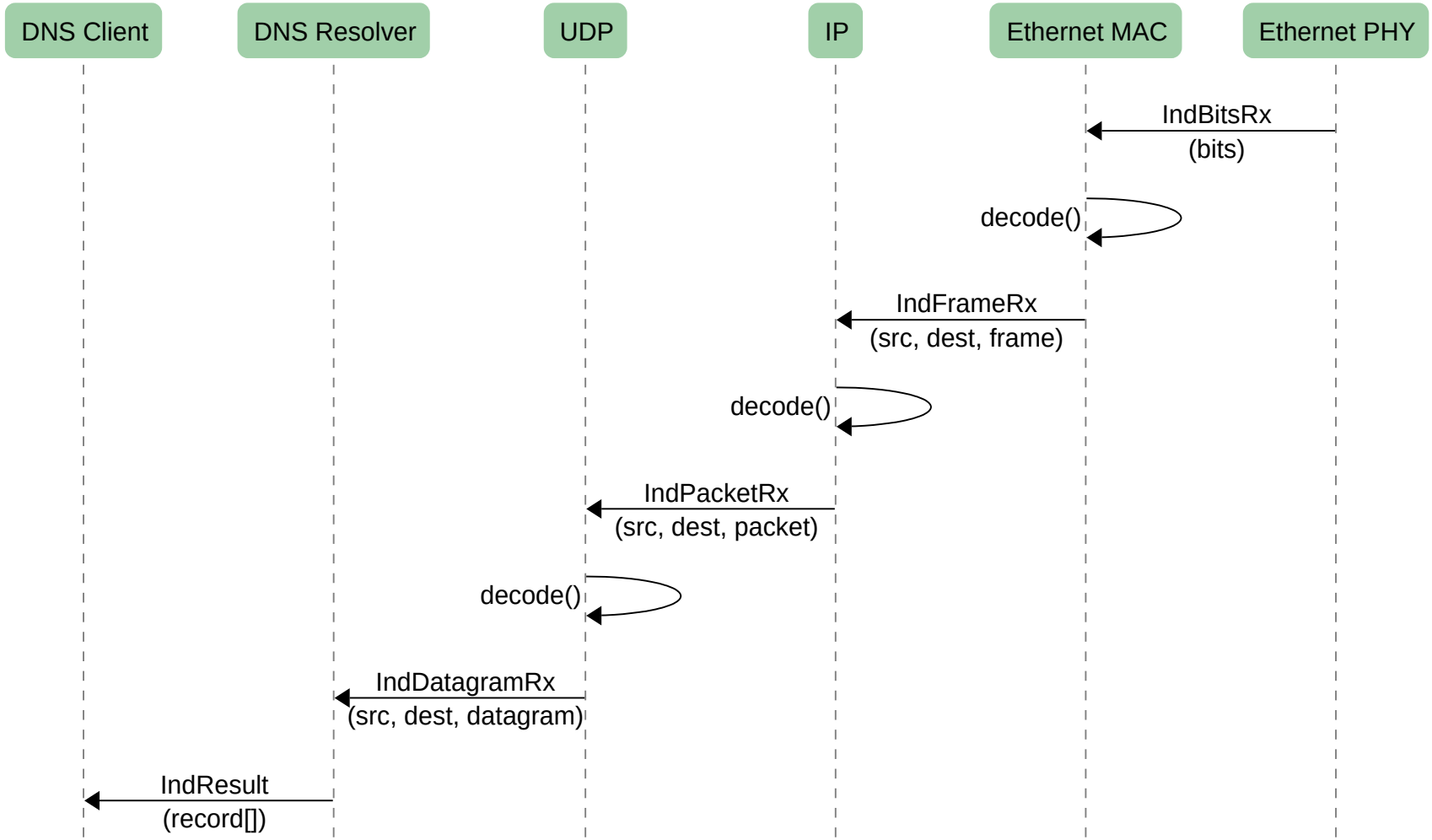
Message Sequence Charts



DNS Example, Part 1



DNS Example, Part 2



You can use this model to
make good software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Function-call

- Single threaded

Message-passing

- Multi-threaded

Function-call

- Single threaded

Message-passing

- Multi-threaded

Function Calling stacks

- Many (most?) stacks and OS APIs are based around function calling:
  - Berkeley sockets API, for example
  - Callback functions for asynchronicity
  - Which thread does the callback function execute in?
  - Can take ‘short-cuts’ and poke around in the memory of another module.

```
// One method per message
result_t foo_tx_data_req(const uint8_t* p);

// One function for all requests
result_t foo_req(const foo_req_t* p);
```

```
// One method per message
result_t bar_tx_frame_req(addr_t addr, ...);

// One function for all requests
result_t bar_req(const bar_req_t* p);
```

Function-call

- Single threaded

Message-passing

- Multi-threaded

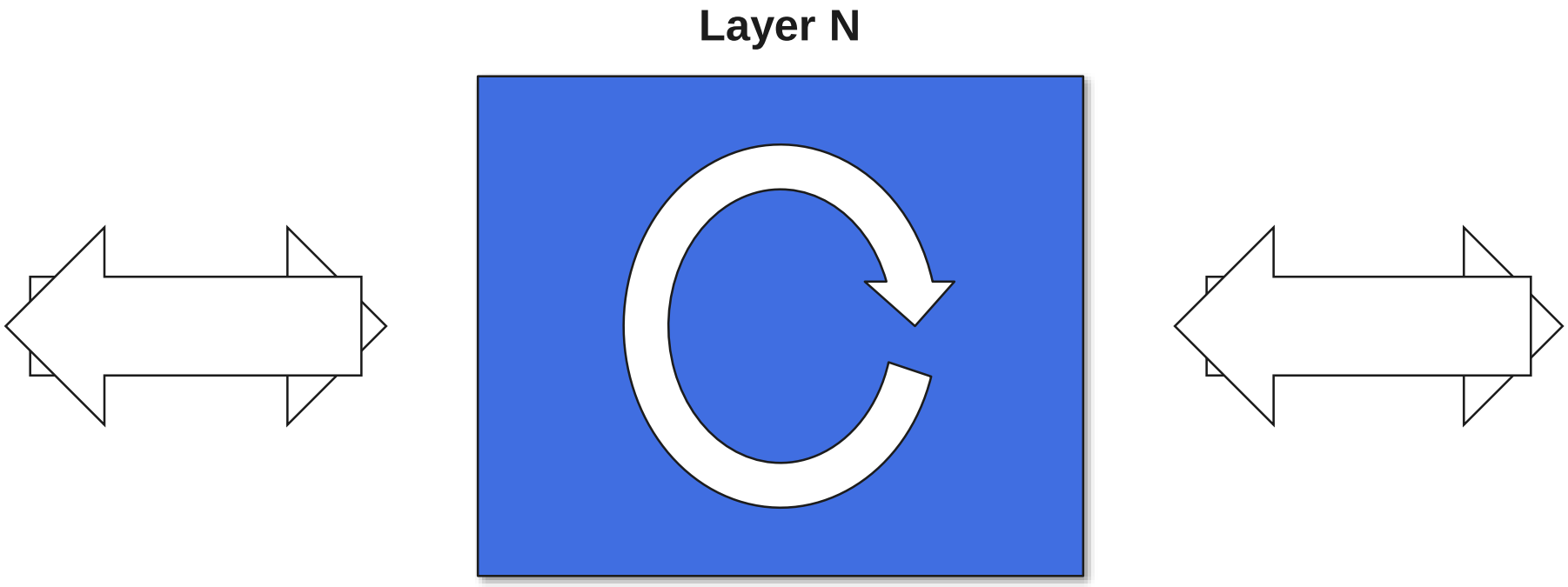
Message Passing

- Message passing is more work, but has benefits:
  - API is enforced, and well defined
  - Can't (easily) poke around with another task's variables
  - Unit testing is clean
    - No fighting the linker to provide stubs, fakes and mocks
  - Can hook the message passing system to provide debugging
    - He said, she said…

Every Layer is a Task

- Tasks are:
  - 1 Thread (or maybe more…)
  - 1 Queue (or maybe more…)

- The (primary) thread pends on the (primary) queue and performs actions based on the events received, before going to sleep again.


Layer N

Context

- If you allow more than one request to be in-flight at a time then, when a Confirmation is received, the service-user needs to be able to work out which Request it is a reply to.
  - You might need to handle multiple simultaneous connections
  - Requests might take an indeterminate amount of time.

- We use a *Context* field for this.
  - Each layer should use an unambiguous (to that layer) value
    - A pointer/reference
    - A unique integer from an incrementing thread-local value

Context

- The *Confirmation* reflects back the *Context* in the *Request.* Perhaps also used in a later *Indication*.
  - Service-user may have some sort of Hash Table to allow fast lookups.
- Context values generated in a given layer do not (generally) go up – they go down.
- Always decided by the Service-User
  - Service Providers must not rely on uniqueness
  - Example/test/~~production~~ code might always set it to zero!
- For brevity, context values were omitted from the previous diagrams (along with error codes).

Typical C implementation

```
typedef struct message_t
{
    inter_id_t inter_id;
    prim_id_t prim_id;
    address_t return_address;
    size_t size;
} message_t;

typedef enum http_prim_id_t
{
    HTTP_REGISTER_URL_REQ,
    HTTP_REGISTER_URL_CFM,
    ...
    HTTP_LAST_PRIM // Not a prim
} http_prim_id_t;
```

```
typedef struct http_bind_req_t
{
    message_t hdr;
    ip_address_t addr;
    http_bind_context_t ctx;
} http_bind_req_t;

http_register_url_req_t* p_req = message_alloc(
    sizeof(http_register_url_req_t),
    INTER_ID_HTTP,
    HTTP_REGISTER_URL_REQ);
p_req->addr.port = 8000;
p_req->addr.ip[0] = 0x00;
…
message_send(OS_QID_HTTP, p_req);
```

Standard C problems…

- Memory management
- Structure initialisation
- Tagged enumerations

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There must be a better way!

Introducing Rust

- Rust is a systems programming language that runs blazingly fast, prevents segfaults, and guarantees thread safety.
  - www.rust-lang.org
- Out of Mozilla
- Used in Firefox today on Win/Mac/Linux/Android…
- The Servo HTML5 rendering engine (replacing Gecko) is their use-case

Why should I care?

- Fast like C with excellent C inter-op
- Segmentation faults are impossible*
- Null-pointer dereferences are impossible*
- Buffer overflows are impossible*
- First class build system / documentation generator / code formatting
- Rich, expressive type system
- But unlike C++, the types are sane (e.g. std::string)

Introducing Grease!

- A Message-Passing Approach to Protocol Stacks in Rust
- A proof of concept is available from https://github.com/cambridgeconsultants/grease

Queues in Rust

- Standard library offers ‘mpsc’ channels
  - Multiple Provider Single Consumer
- Could easily substitute in another channel with the same API, e.g. to use an RTOS
  - Would love someone to do this!
- Wrapped into two types:
  - MessageSender – many per channel
  - MessageReceiver – one per channel

Tasks

- Standard library offers a threading API
- Could easily substitute in another threading library with the same API, e.g. to use an RTOS
- Messages can contain smart containers (like Vec) so tasks must be in the same address space

Grease, Mk1

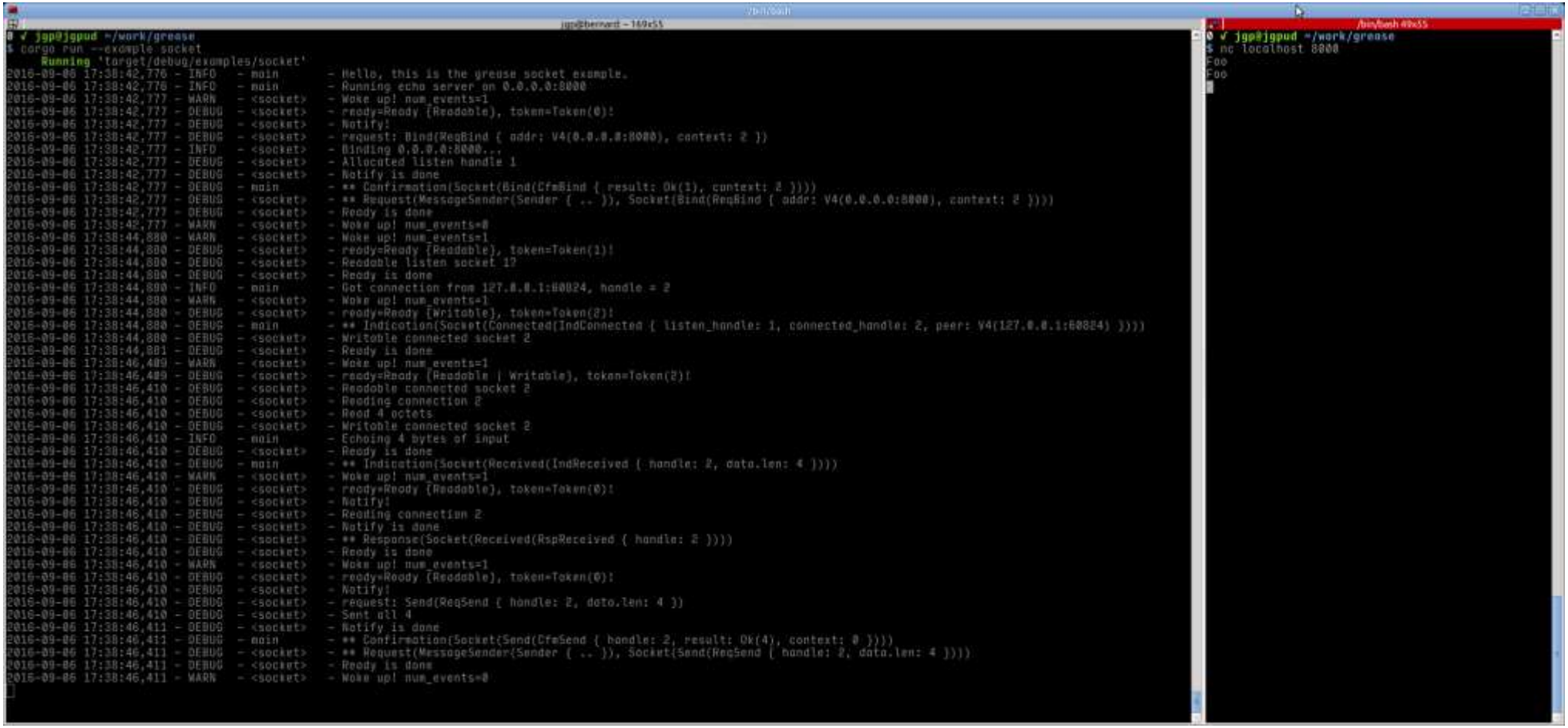
```
pub enum Message {
    Request(MessageSender, Request),
    Confirmation(Confirmation),
    Indication(Indication),
    Response(Response),
}
```

Grease, Mk2

```
pub trait ServiceProvider<REQ, CFM, IND, RSP> {
    /// Call this to send a request to this provider.
    fn send_request(&self, req: REQ, reply_to: &ServiceUser<CFM, IND>);

    /// Call this to send a response to this provider.
    fn send_response(&self, rsp: RSP);

    /// Call this to clone this object so another task can use it.
    fn clone(&self) -> ServiceProviderHandle<REQ, CFM, IND, RSP>;
}
```

Grease, Mk2

```
pub trait ServiceUser<CFM, IND> {
    /// Call this to send a confirmation back to the service user.
    fn send_confirm(&self, cfm: CFM);

    /// Call this to send an indication to the service user.
    fn send_indication(&self, ind: IND);

    /// Call this so we can store this user reference in two places.
    fn clone(&self) -> ServiceUserHandle<CFM, IND>;
}
```


jgp@jgpud ~/work/grease
$ cargo run --example socket
Running 'target/debug/examples/socket'
2016-09-06 17:38:42,776 - INFO - main - Hello, this is the grease socket example.
2016-09-06 17:38:42,776 - INFO - main - Running echo server on 0.0.0.0:8000
2016-09-06 17:38:42,777 - WARN - <socket> - Woke up! num_events=1
2016-09-06 17:38:42,777 - DEBUG - <socket> - ready=Ready {Readable}, token=Token(0)!
2016-09-06 17:38:42,777 - DEBUG - <socket> - Notify!
2016-09-06 17:38:42,777 - DEBUG - <socket> - request: Bind(ReqBind { addr: V4(0.0.0.0:8000), context: 2 })
2016-09-06 17:38:42,777 - INFO - <socket> - Binding 0.0.0.0:8000...
2016-09-06 17:38:42,777 - DEBUG - <socket> - Allocated listen handle 1
2016-09-06 17:38:42,777 - DEBUG - <socket> - Notify is done
2016-09-06 17:38:42,777 - DEBUG - main - ** Confirmation(Socket(Bind(CfmBind { result: Ok(1), context: 2 })))
2016-09-06 17:38:42,777 - DEBUG - <socket> - ** Request(MessageSender(Sender { .. }), Socket(Bind(ReqBind { addr: V4(0.0.0.0:8000), context: 2 })))
2016-09-06 17:38:42,777 - DEBUG - <socket> - Ready is done
2016-09-06 17:38:42,777 - WARN - <socket> - Woke up! num_events=0
2016-09-06 17:38:44,880 - WARN - <socket> - Woke up! num_events=1
2016-09-06 17:38:44,880 - DEBUG - <socket> - ready=Ready {Readable}, token=Token(1)!
2016-09-06 17:38:44,880 - DEBUG - <socket> - Readable listen socket 1?
2016-09-06 17:38:44,880 - DEBUG - <socket> - Ready is done
2016-09-06 17:38:44,880 - INFO - main - Got connection from 127.0.0.1:60824, handle = 2
2016-09-06 17:38:44,880 - WARN - <socket> - Woke up! num_events=1
2016-09-06 17:38:44,880 - DEBUG - <socket> - ready=Ready {Writable}, token=Token(2)!
2016-09-06 17:38:44,880 - DEBUG - main - ** Indication(Socket(Connected(IndConnected { listen_handle: 1, connected_handle: 2, peer: V4(127.0.0.1:60824) })))
2016-09-06 17:38:44,880 - DEBUG - <socket> - Writable connected socket 2
2016-09-06 17:38:44,881 - DEBUG - <socket> - Ready is done
2016-09-06 17:38:46,409 - WARN - <socket> - Woke up! num_events=1
2016-09-06 17:38:46,409 - DEBUG - <socket> - ready=Ready {Readable | Writable}, token=Token(2)!
2016-09-06 17:38:46,410 - DEBUG - <socket> - Readable connected socket 2
2016-09-06 17:38:46,410 - DEBUG - <socket> - Reading connection 2
2016-09-06 17:38:46,410 - DEBUG - <socket> - Read 4 octets
2016-09-06 17:38:46,410 - DEBUG - <socket> - Writable connected socket 2
2016-09-06 17:38:46,410 - INFO - main - Echoing 4 bytes of input
2016-09-06 17:38:46,410 - DEBUG - <socket> - Ready is done
2016-09-06 17:38:46,410 - DEBUG - main - ** Indication(Socket(Received(IndReceived { handle: 2, data.len: 4 })))
2016-09-06 17:38:46,410 - WARN - <socket> - Woke up! num_events=1
2016-09-06 17:38:46,410 - DEBUG - <socket> - ready=Ready {Readable}, token=Token(0)!
2016-09-06 17:38:46,410 - DEBUG - <socket> - Notify!
2016-09-06 17:38:46,410 - DEBUG - <socket> - Reading connection 2
2016-09-06 17:38:46,410 - DEBUG - <socket> - Notify is done
2016-09-06 17:38:46,410 - DEBUG - <socket> - ** Response(Socket(Received(RspReceived { handle: 2 })))
2016-09-06 17:38:46,410 - DEBUG - <socket> - Ready is done
2016-09-06 17:38:46,410 - WARN - <socket> - Woke up! num_events=1
2016-09-06 17:38:46,410 - DEBUG - <socket> - ready=Ready {Readable}, token=Token(0)!
2016-09-06 17:38:46,410 - DEBUG - <socket> - Notify!
2016-09-06 17:38:46,410 - DEBUG - <socket> - request: Send(ReqSend { handle: 2, data.len: 4 })
2016-09-06 17:38:46,410 - DEBUG - <socket> - Sent all 4
2016-09-06 17:38:46,411 - DEBUG - <socket> - Notify is done
2016-09-06 17:38:46,411 - DEBUG - main - ** Confirmation(Socket(Send(CfmSend { handle: 2, result: Ok(4), context: 0 })))
2016-09-06 17:38:46,411 - DEBUG - <socket> - ** Request(MessageSender(Sender { .. }), Socket(Send(ReqSend { handle: 2, data.len: 4 })))
2016-09-06 17:38:46,411 - DEBUG - <socket> - Ready is done
2016-09-06 17:38:46,411 - WARN - <socket> - Woke up! num_events=0
/bin/bash 49x55
$ nc localhost 8000
Foo
Foo

What next?

- Think about message-passing architectures in your next project
- Think about what Rust can do you for
- Think about what you can do for Rust
- Check out https://github.com/cambridgeconsultants/grease
- Check out https://cambridgeconsultants.com/careers

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