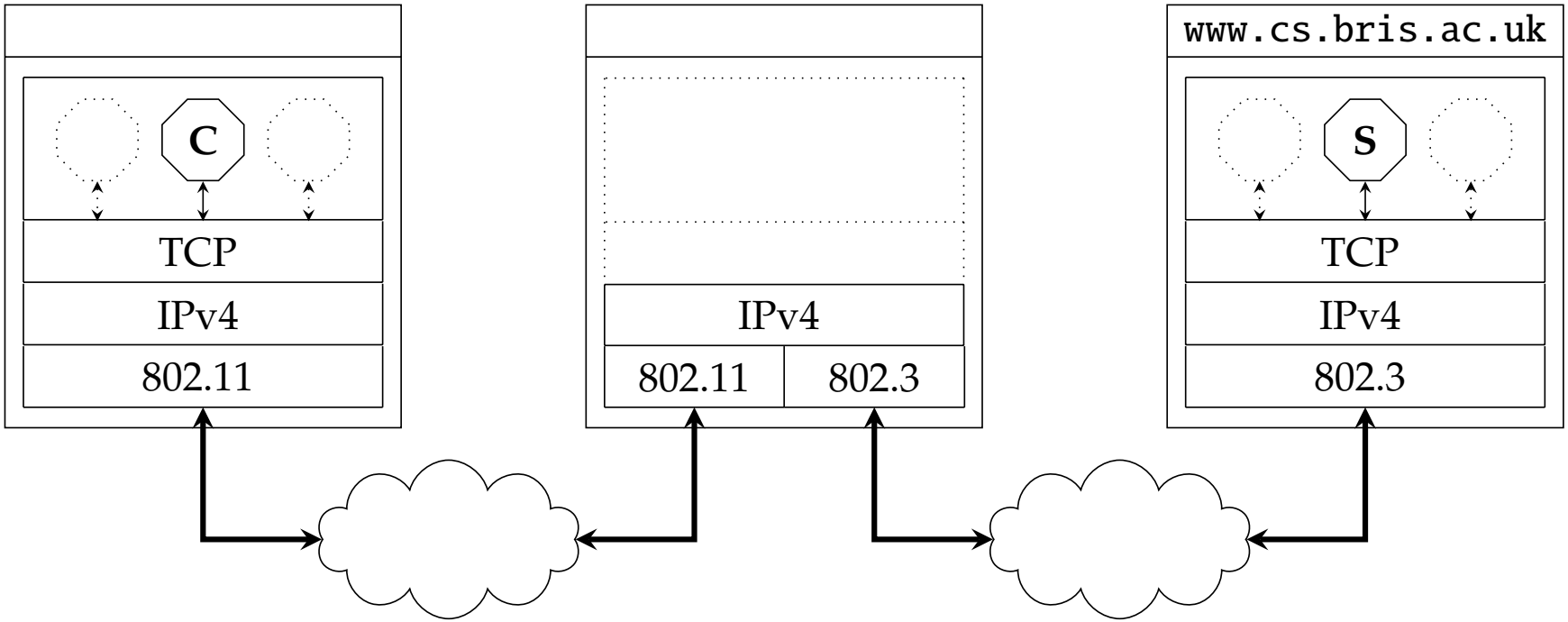

- Goal: investigate the **transport layer** e.g.,
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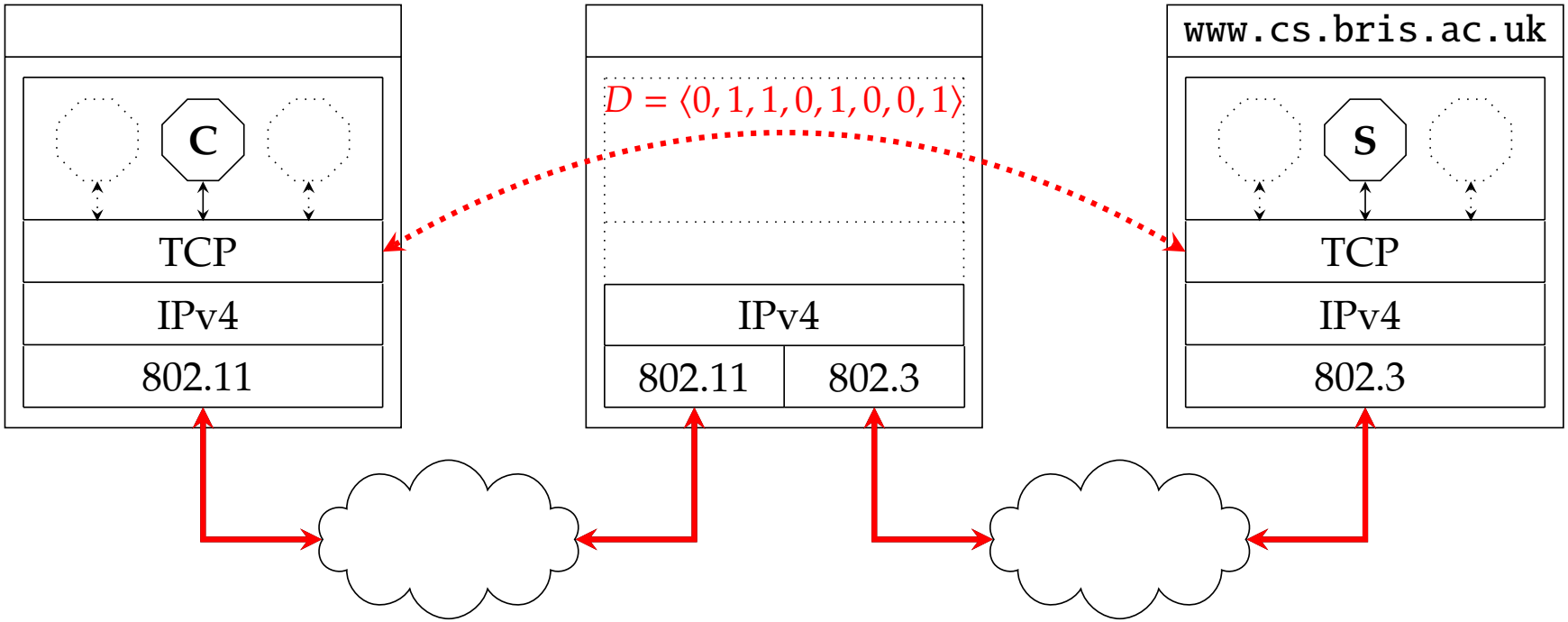

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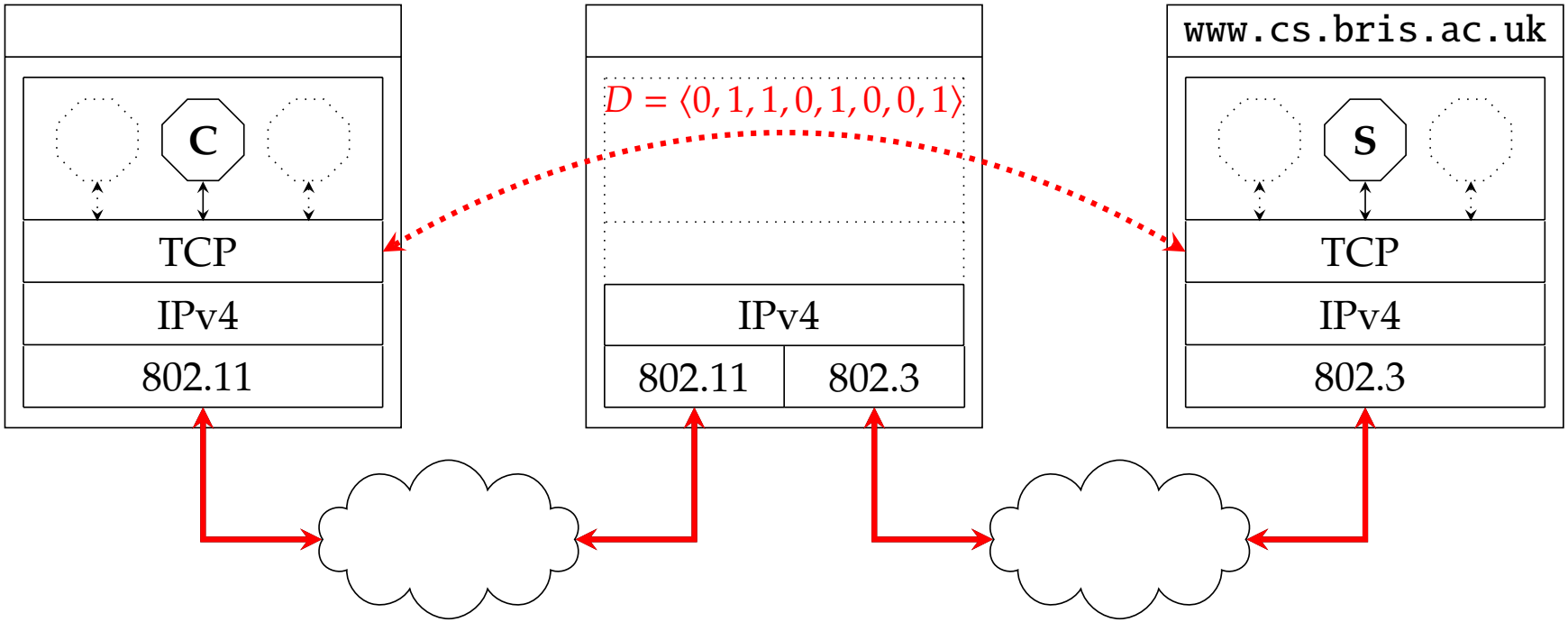

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- Note that:
  - the transport layer need *only* be implemented by in hosts; routers *only* deal with network (and lower) layers,
  - this implies the transport layer offers an abstraction of the network itself, i.e., a **service model** (or API) ...

- Question: *which* service model should we opt for?
- Answer: it depends ...

Definition (datagram model)

For instance, **User Datagram Protocol (UDP)** [6] is

1. datagram (or message) oriented,
2. connection-less, unreliable,
3. allows unrestricted transmission,
4. limited length segment,
5. relatively simple, relatively efficient,
6. (mainly) used for stateless applications (e.g., DNS).

Definition (stream model)

For instance, **Transport Control Protocol (TCP)** [7] is

1. stream oriented,
2. connection-based, reliable,
3. applies flow and congestion control,
4. arbitrary length segment,
5. relatively complex, relatively inefficient,
6. (mainly) used for stateful applications (e.g., HTTP).

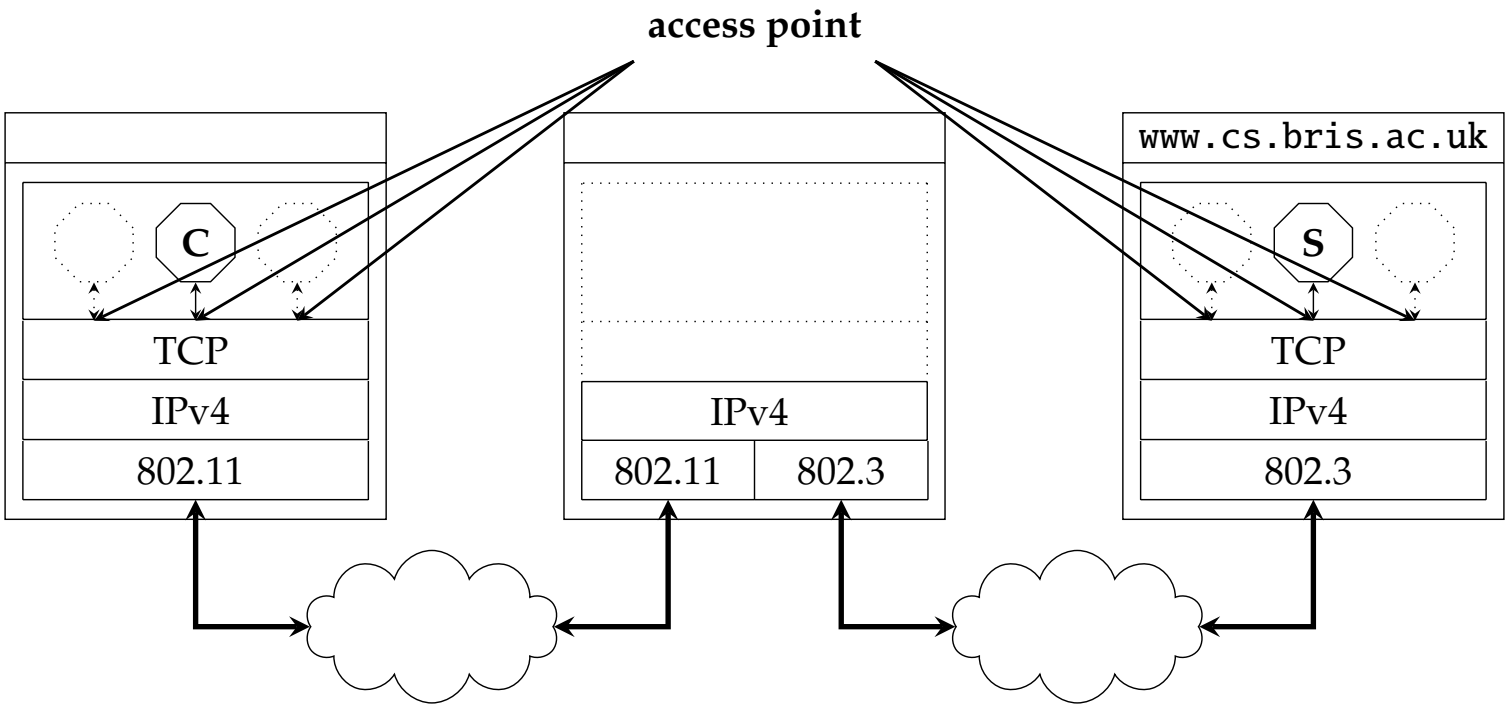
st. $\text{TCP} \gg \text{UDP} \simeq \text{IP} + \epsilon$.

Definition (**ports and sockets**)

Each transport layer **access point** is identified by a (local) **port number**; the tuple

(IP address, protocol, port number),

which is called a **socket**, therefore (globally) identifies the communication end-point (i.e., the application).



Definition (**ports and sockets**)

Note that

- a **socket pair** canonically identifies one connection,
- a **well-known port** is statically (pre-)allocated for specific (often system) applications (e.g., server instances),
- an **ephemeral port** is dynamically allocated for applications (e.g., client instances).

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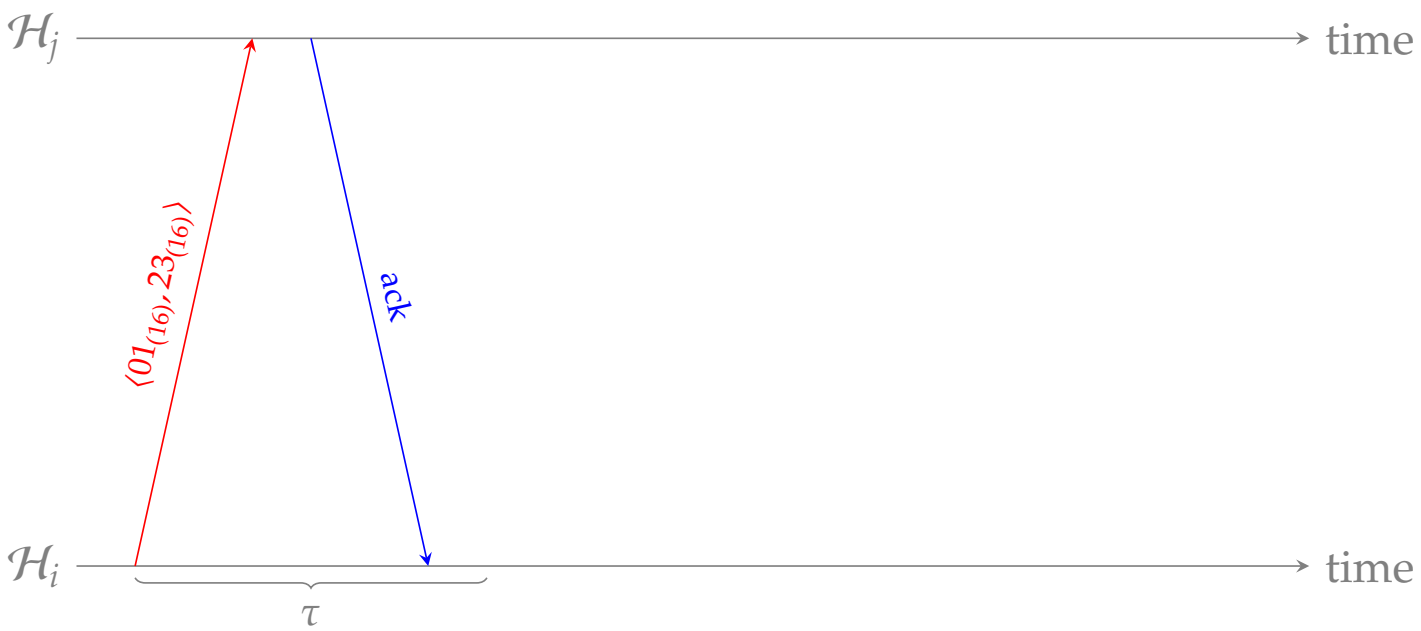

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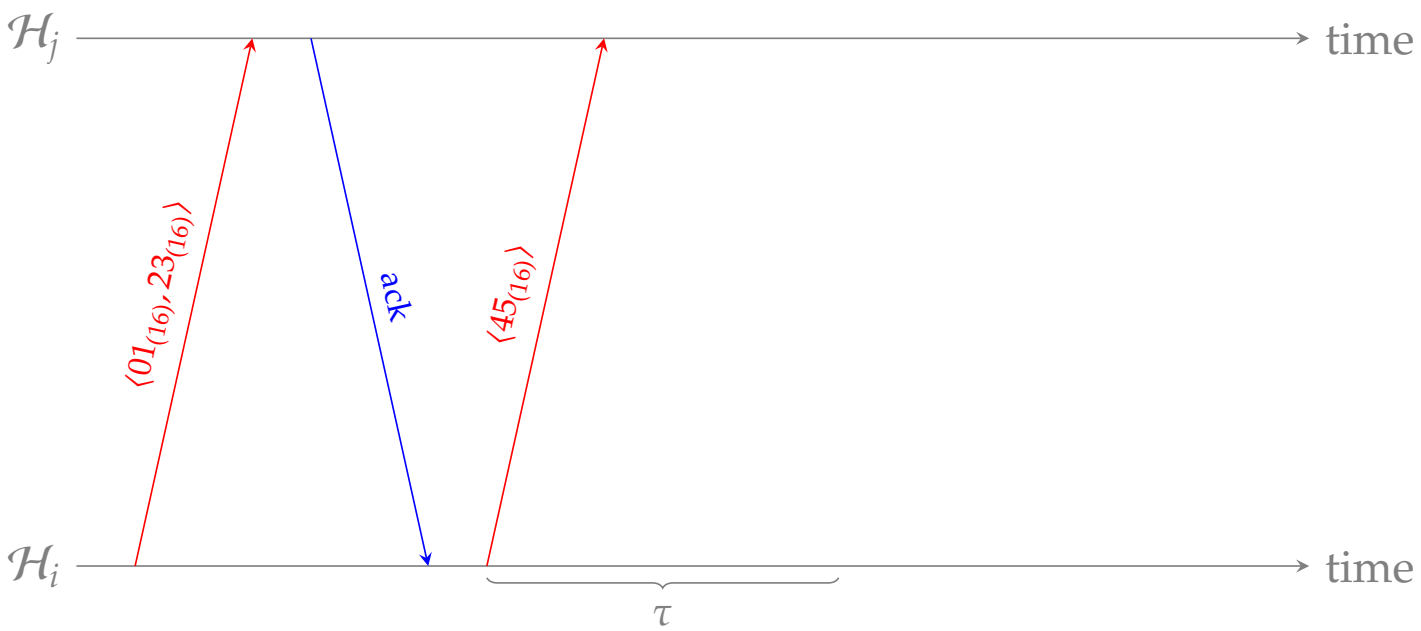

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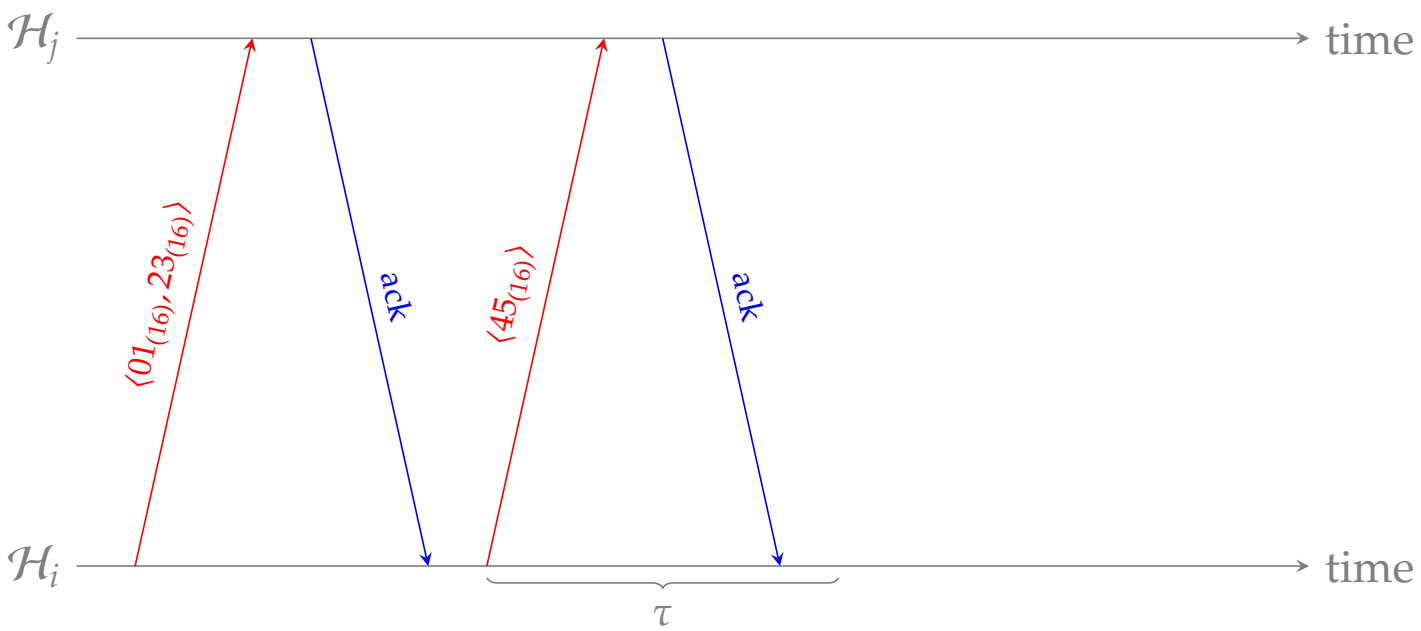

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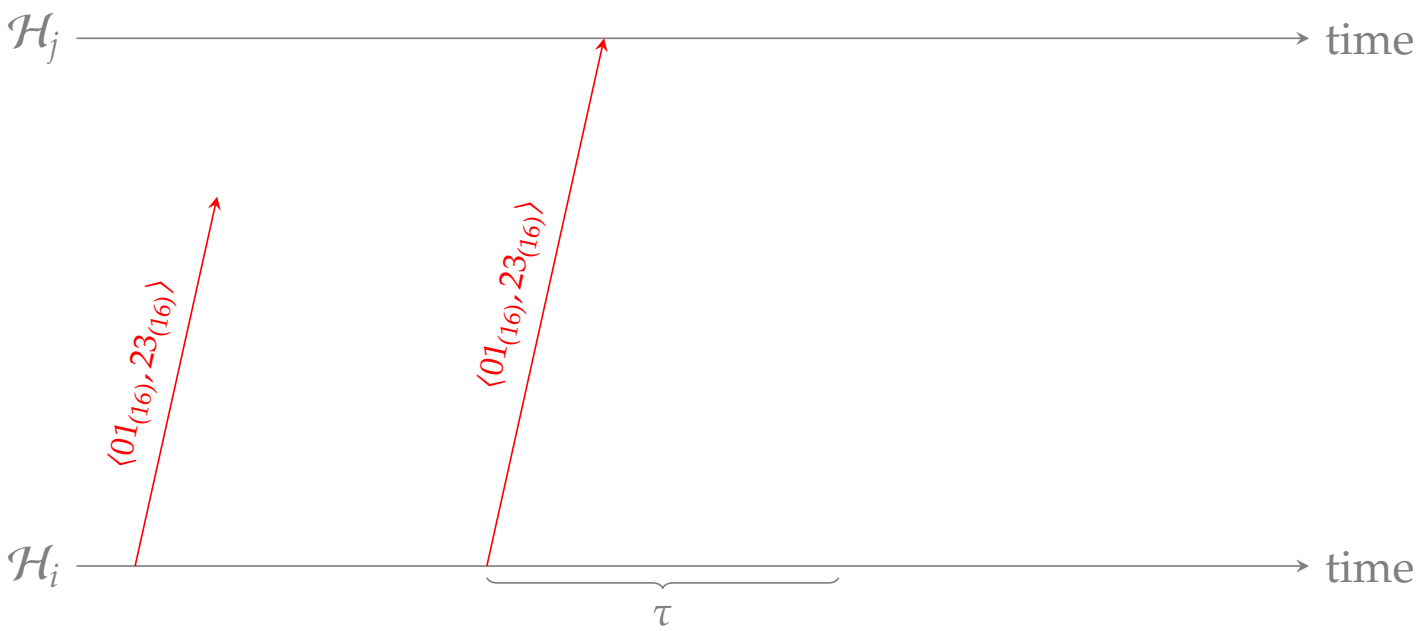

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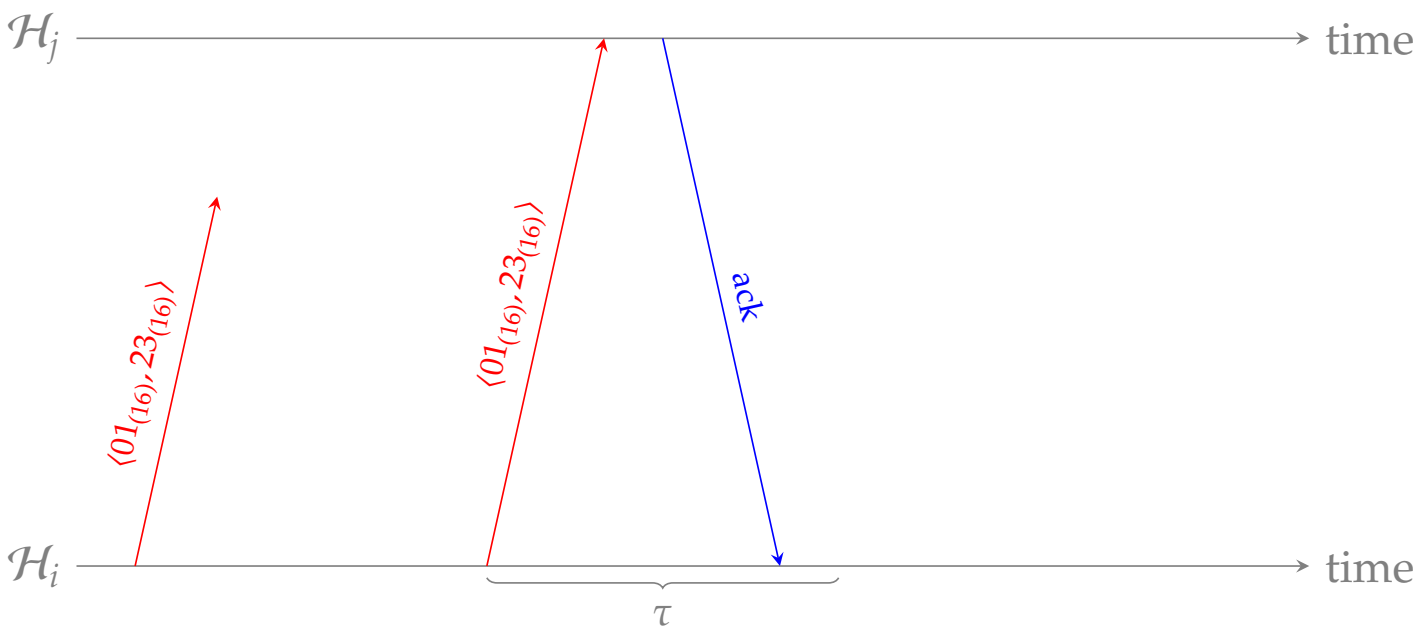

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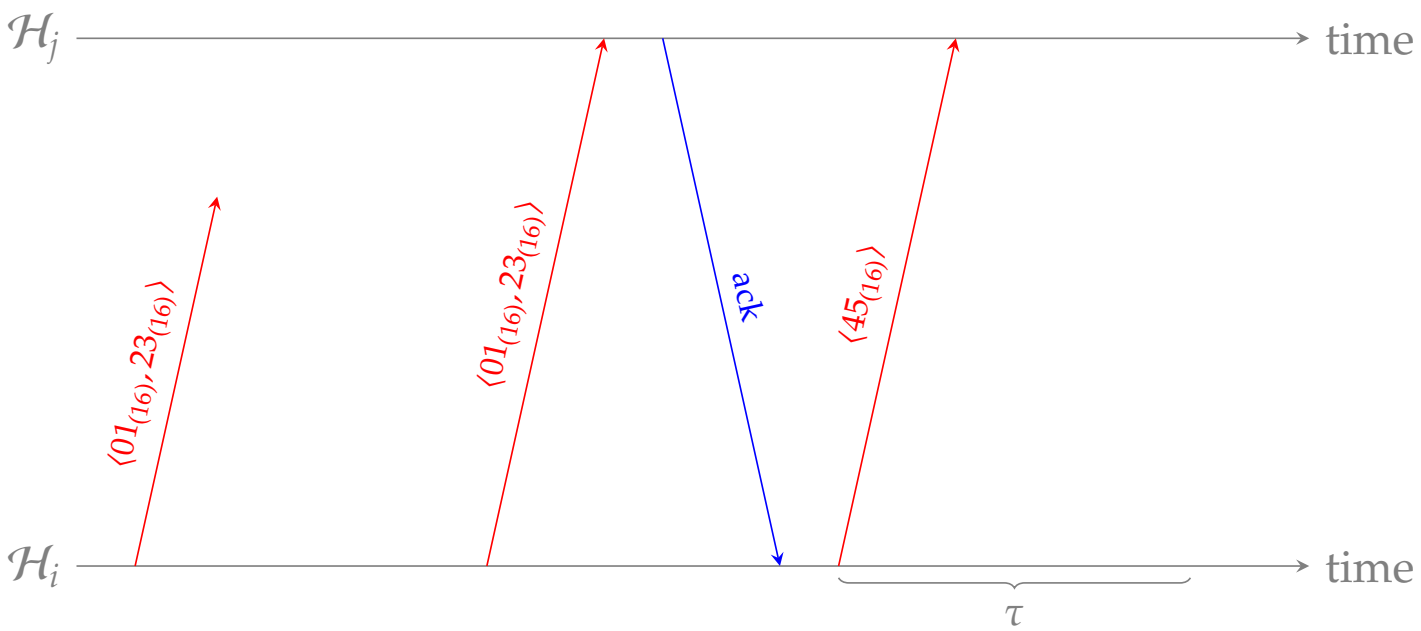

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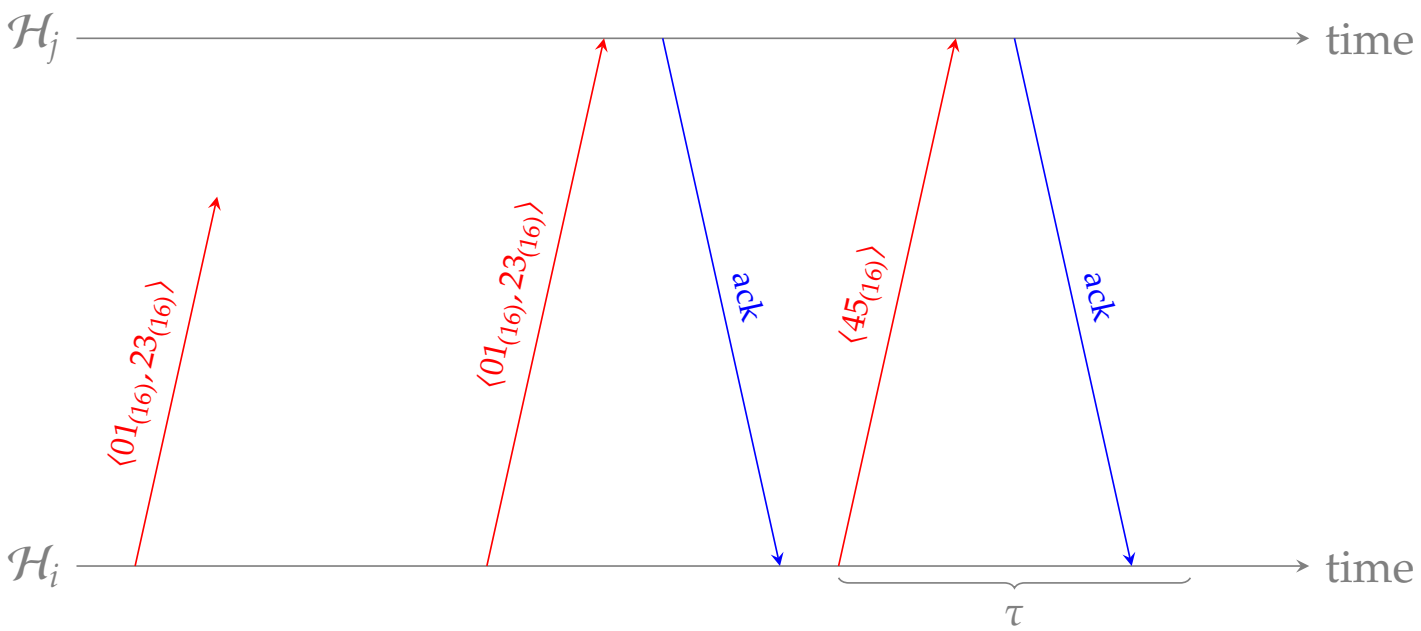

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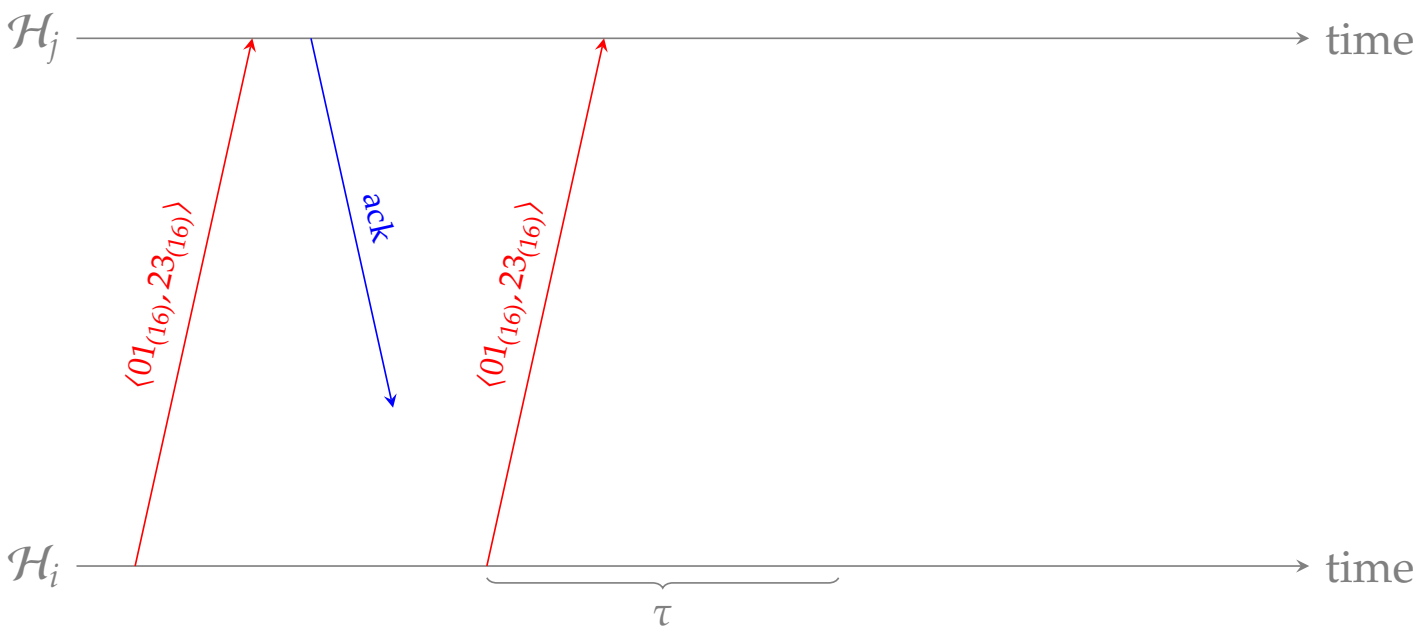

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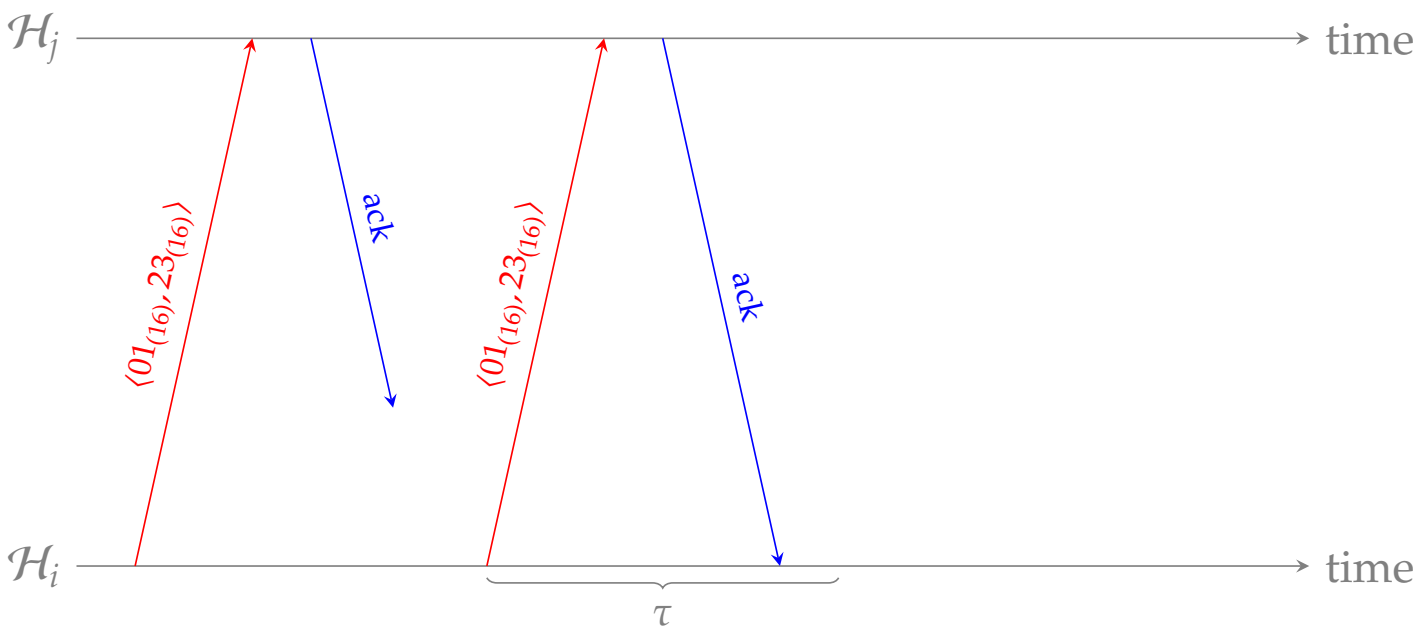

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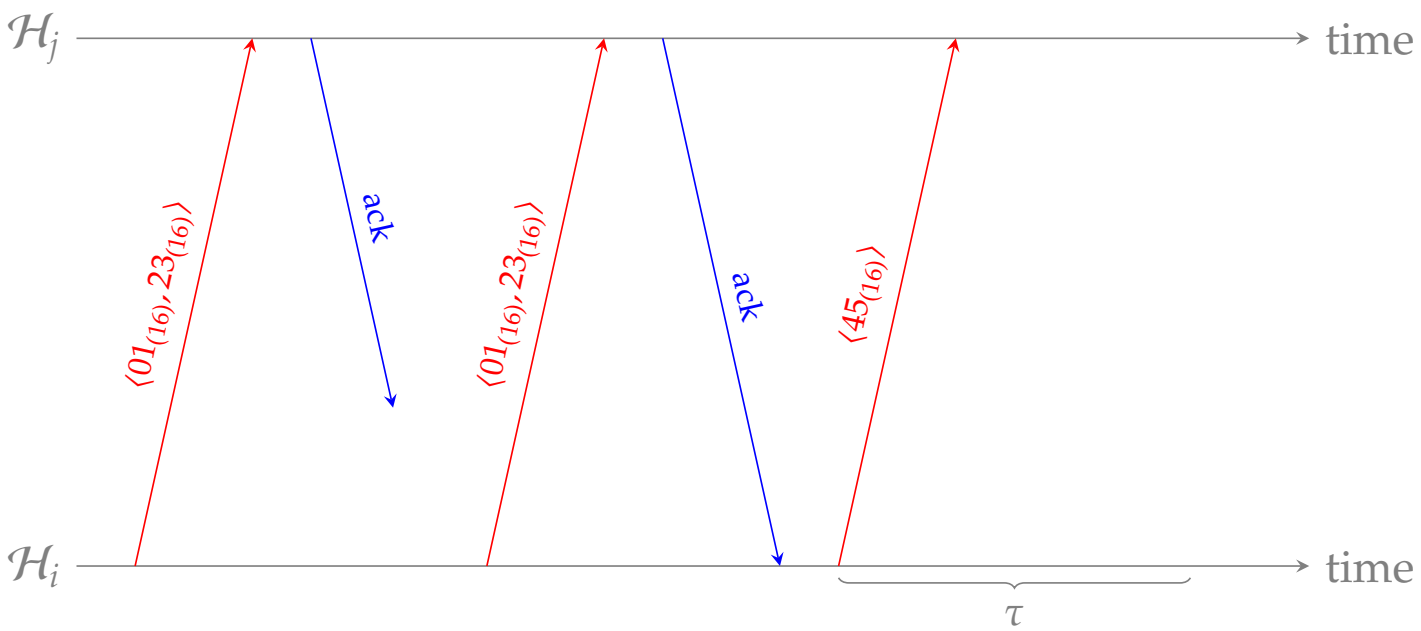

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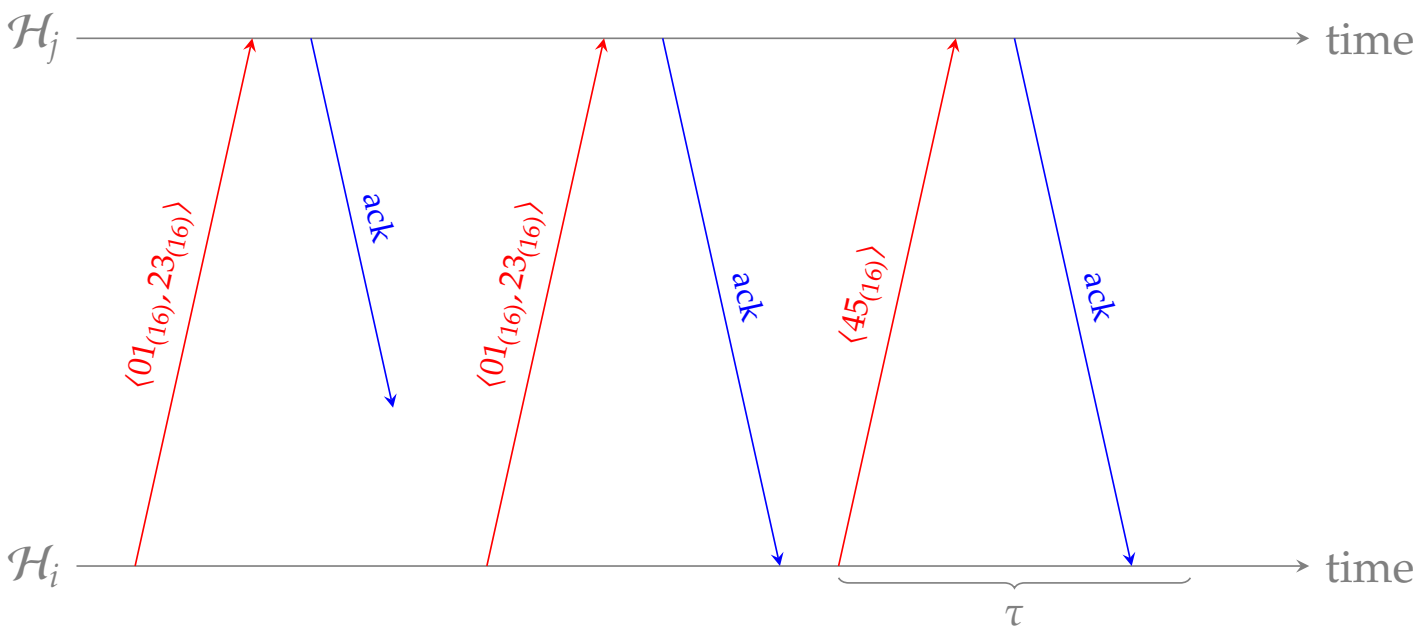

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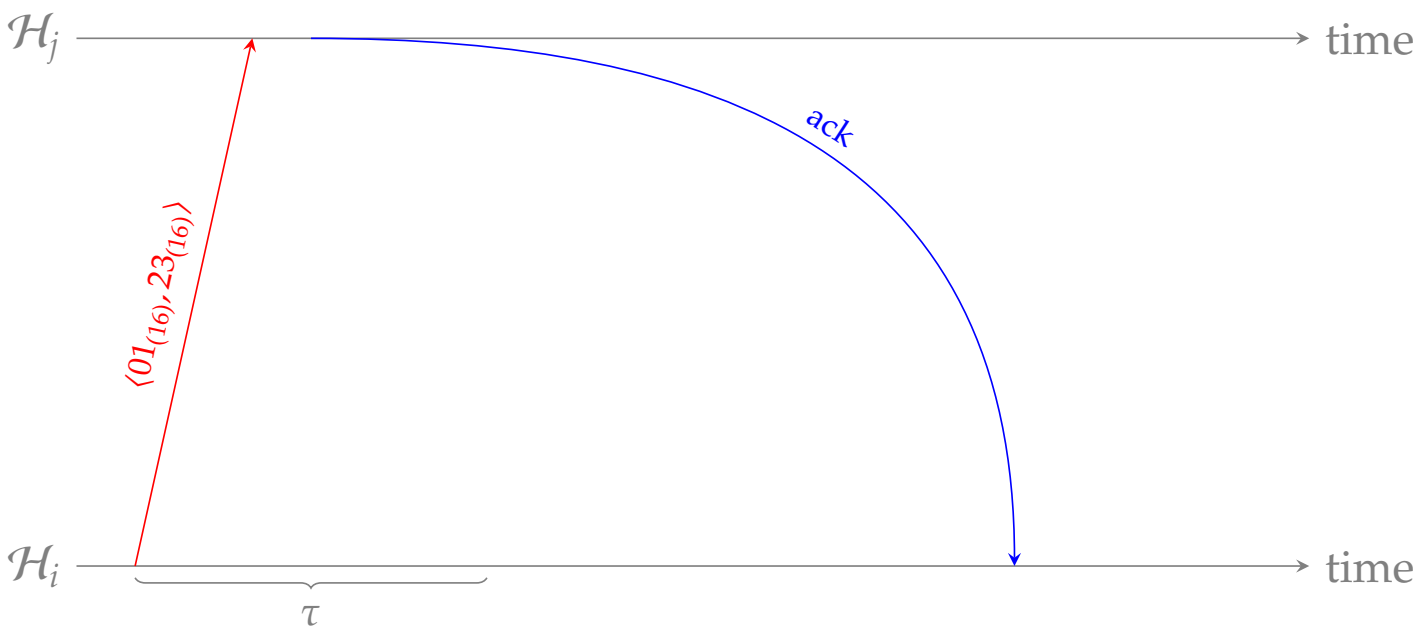

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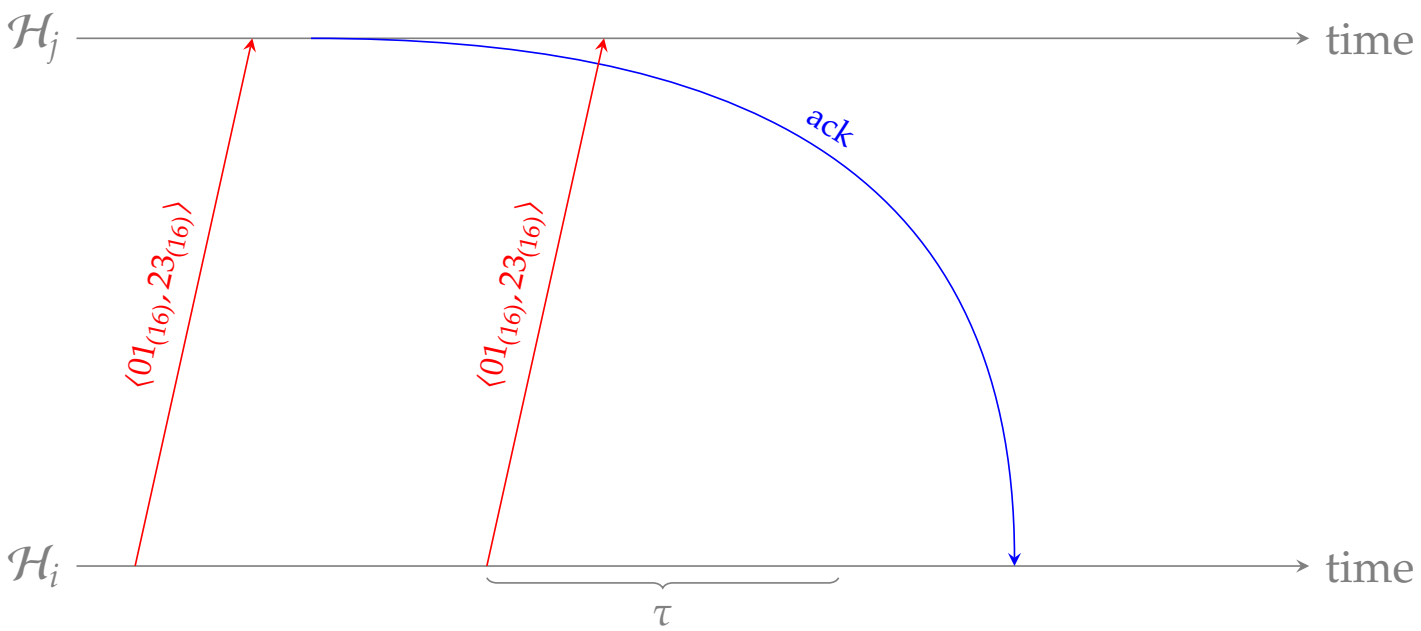

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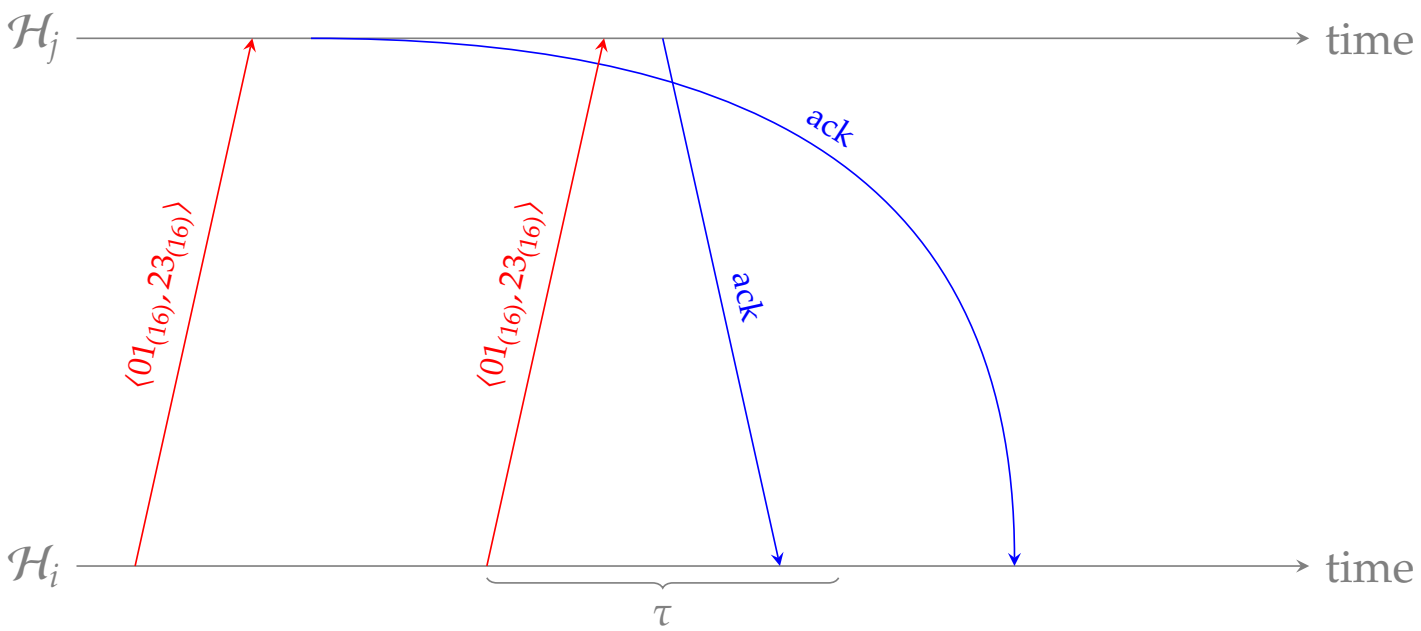

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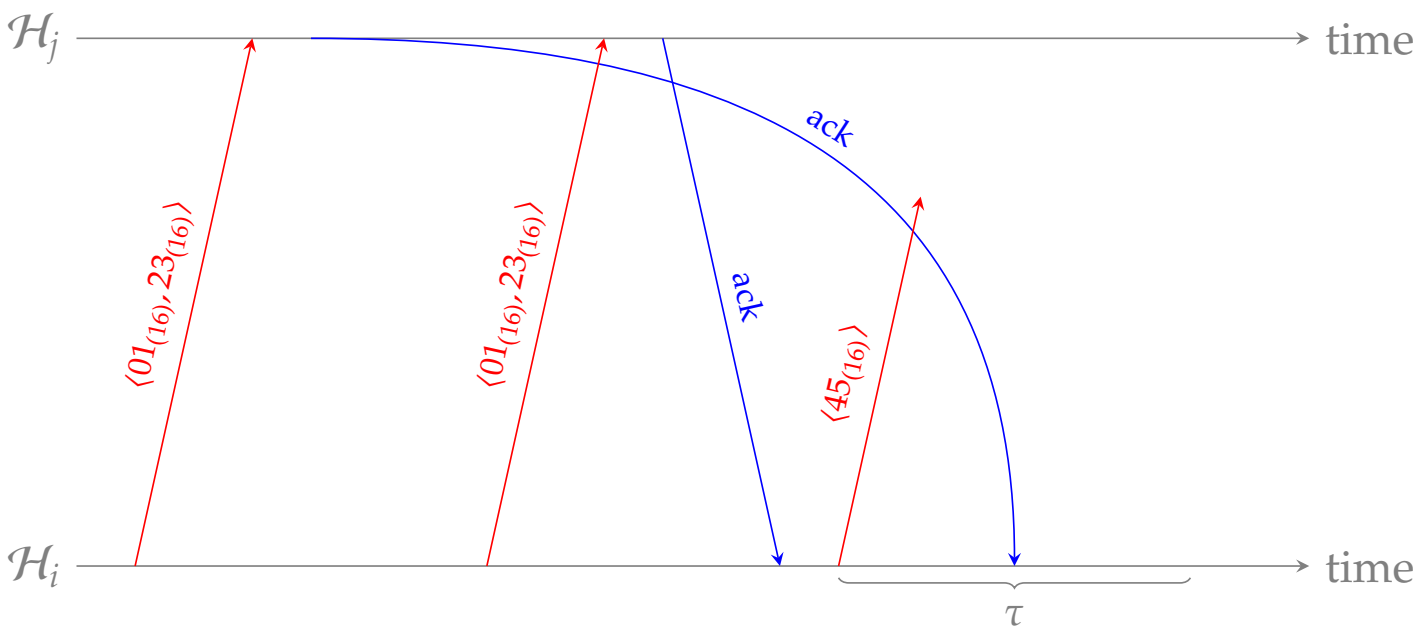

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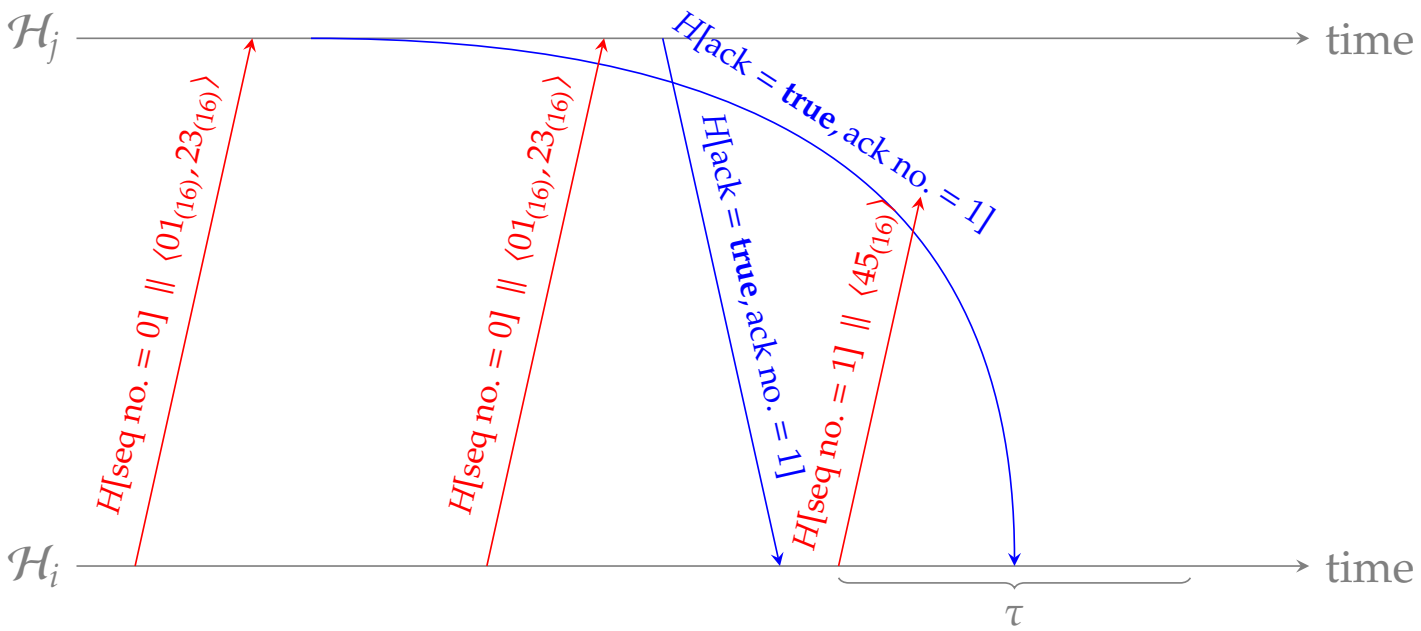
e.g., using the **stop-and-wait protocol** (plus **sequence numbers**).



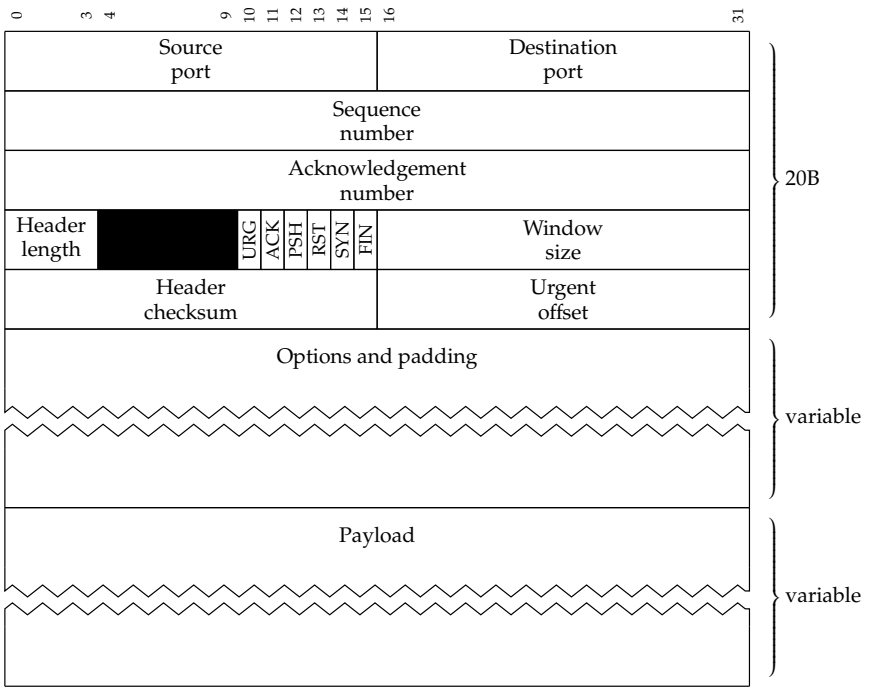
TCP (1)

- Normal TCP-based communication occurs in three phases, namely
  1. **connection establishment**
     - 1.1 exchange signalling parameters,
     - 1.2 allocate resources,
     - 1.3 synchronise ready to communicate
  2. full-duplex (i.e., 2-way), unicast (i.e., with precisely two end-points) communication via the established connection, then eventually
  3. **connection termination**
     - 3.1 complete pending communication,
     - 3.2 release resources

  plus various auxiliary actions, e.g., **connection reset**.

TCP (2)

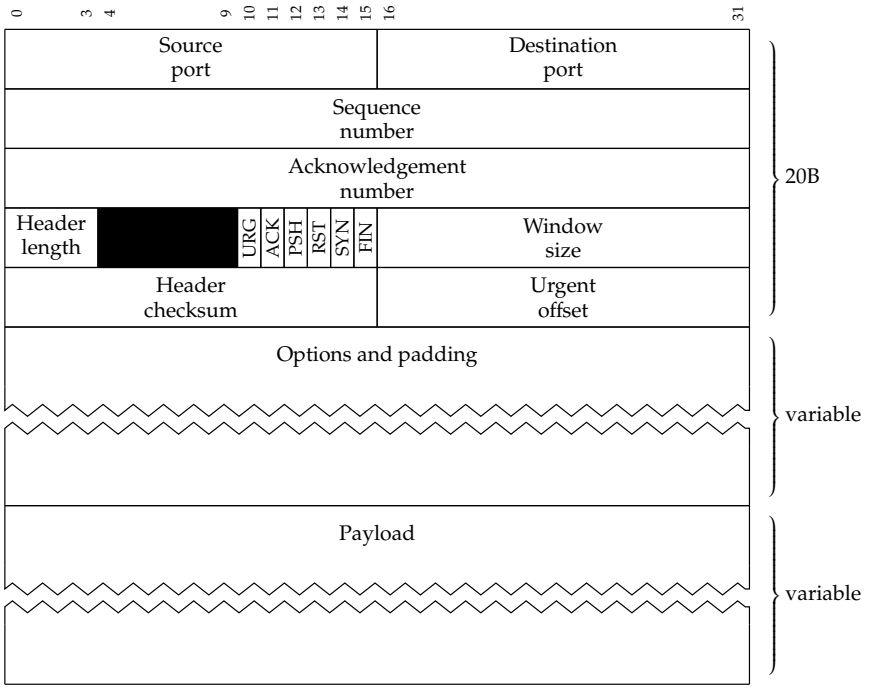
Data Structure (**TCP segment** [7, Section 3.1])



The data structure includes:

- A 16-bit source port.
- A 16-bit destination port.
- A 32-bit sequence number.
- A 32-bit acknowledgement number.

Data Structure (**TCP segment** [7, Section 3.1])



The data structure includes:

- A set of flags, including
  - 1-bit **URGent (URG)** flag, which marks the urgent pointer field as significant.
  - 1-bit **ACKnowledgement (ACK)** flag, which marks the acknowledgement field as significant.
  - 1-bit **PuSH (PSH)** flag, which means "transmit *now*: don't buffer".
  - 1-bit **ReSeT (RST)** flag, used for connection control.
  - 1-bit **SYNchronise (SYN)** flag, used for connection control.
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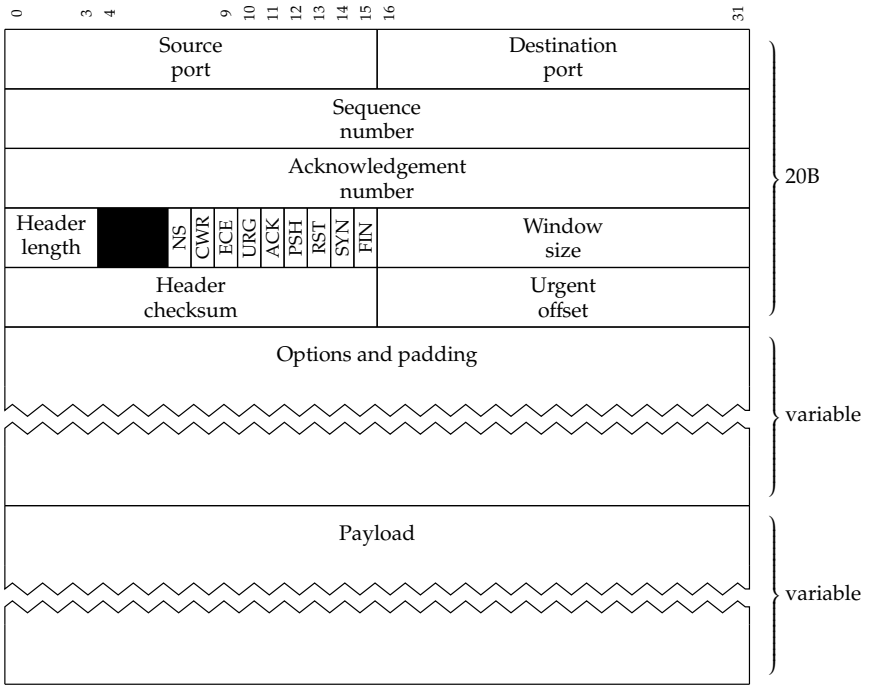
Data Structure (**TCP segment** [7, Section 3.1]+[8, Section 6]+[9, Section 9])



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  plus some extras for **Explicit Congestion Notification (ECN)**.

TCP (2)

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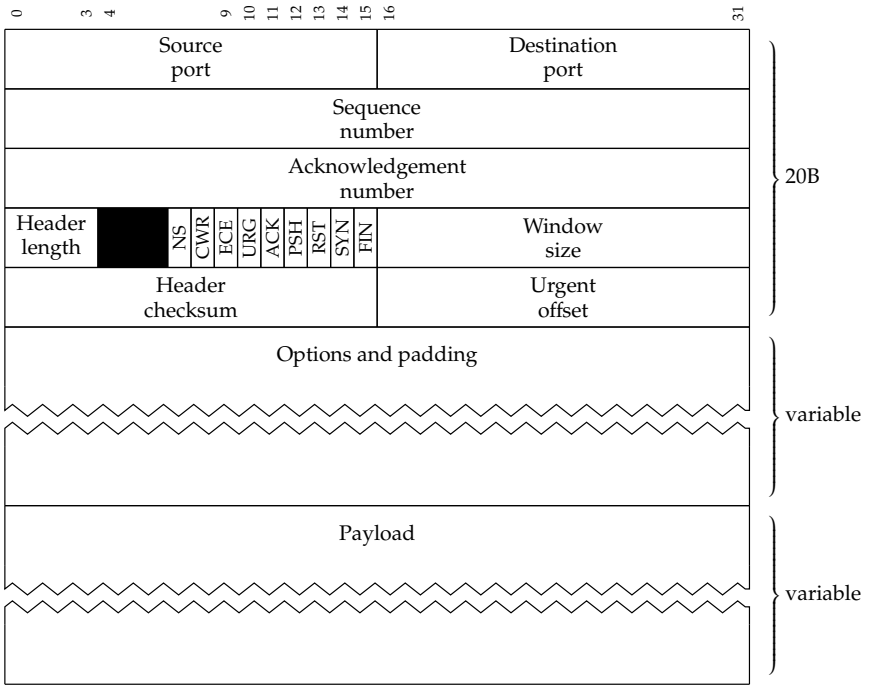
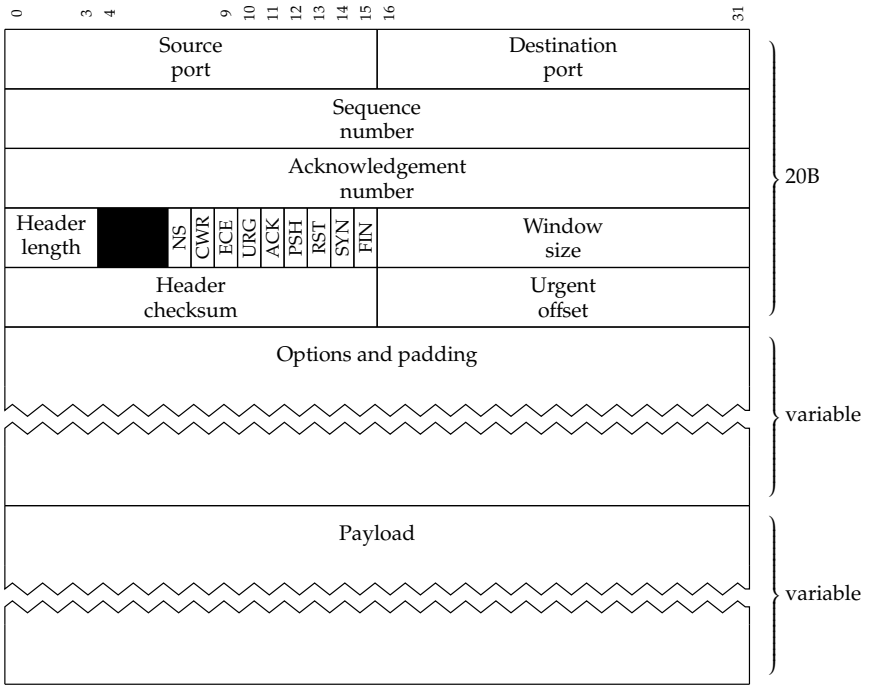


The data structure includes:

- A window size, used for flow control.
- A 16-bit checksum (on whole segment) used to detect errors
- An urgent offset, used for flow control.

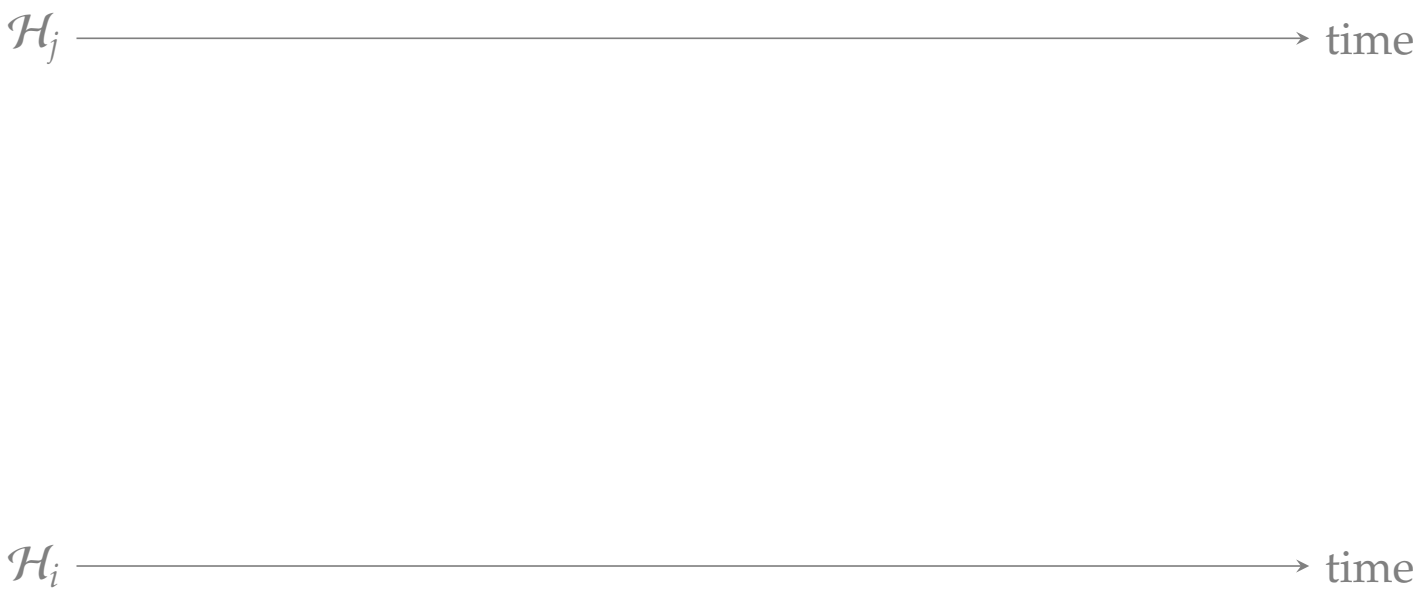
Data Structure (**TCP segment** [7, Section 3.1]+[8, Section 6]+[9, Section 9])



The data structure includes:

- A set of options (allowing protocol extensibility).
- Any padding required to ensure the header is a multiple of 32 bits.
- The payload.

TCP (5)



- Question: why have a sequence *and* ACK numbers?
- Answer: it allows optimisation of stop-and-wait via **ACK piggy-backing** st.
  - communication is reduced, i.e., it optimises use of bandwidth, *but*
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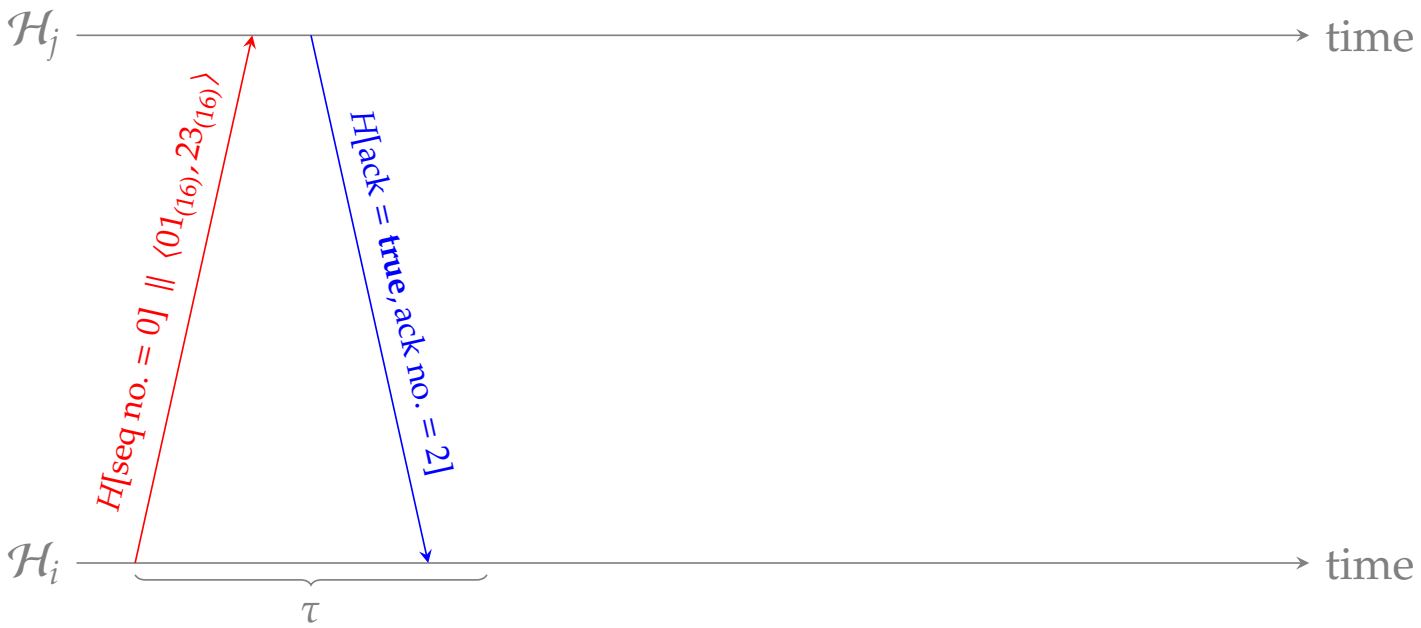

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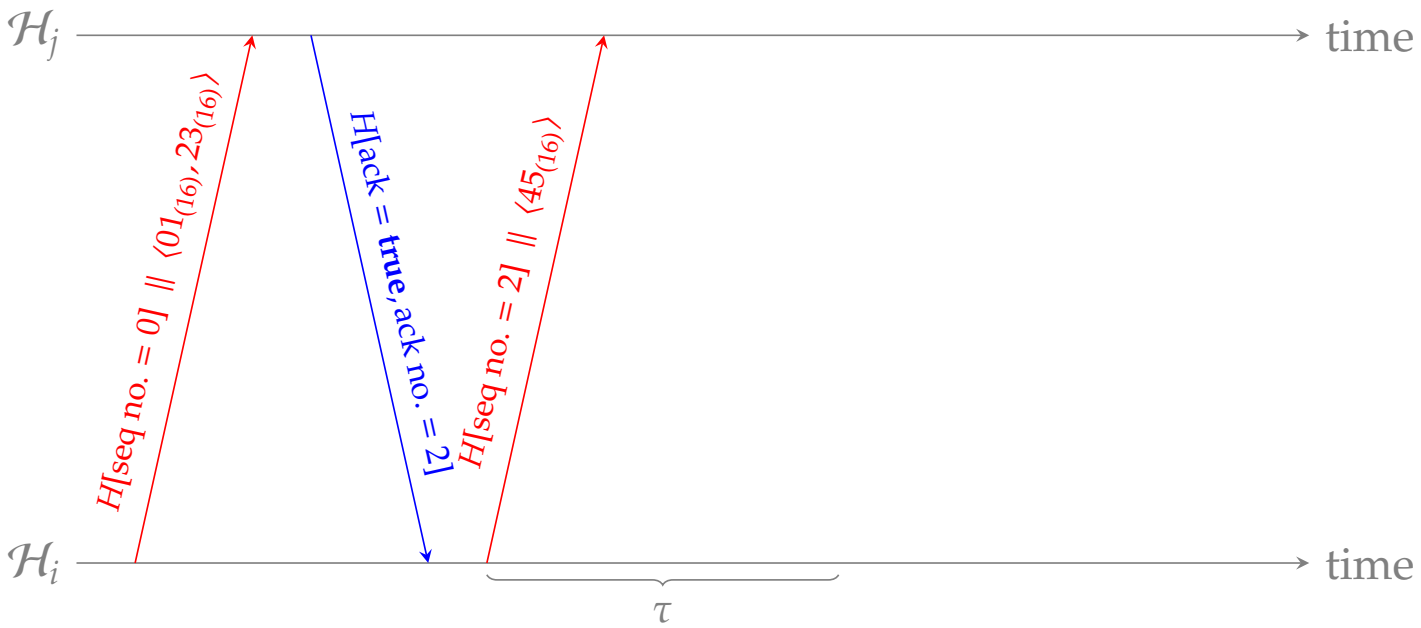

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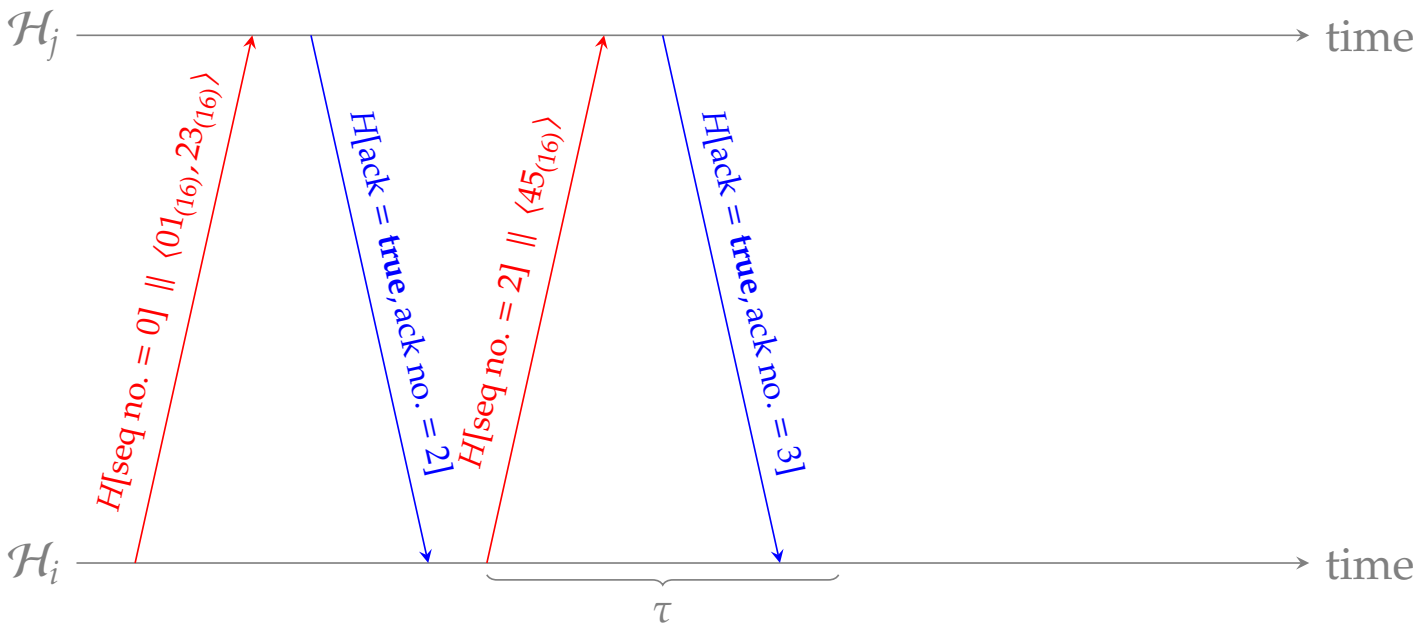

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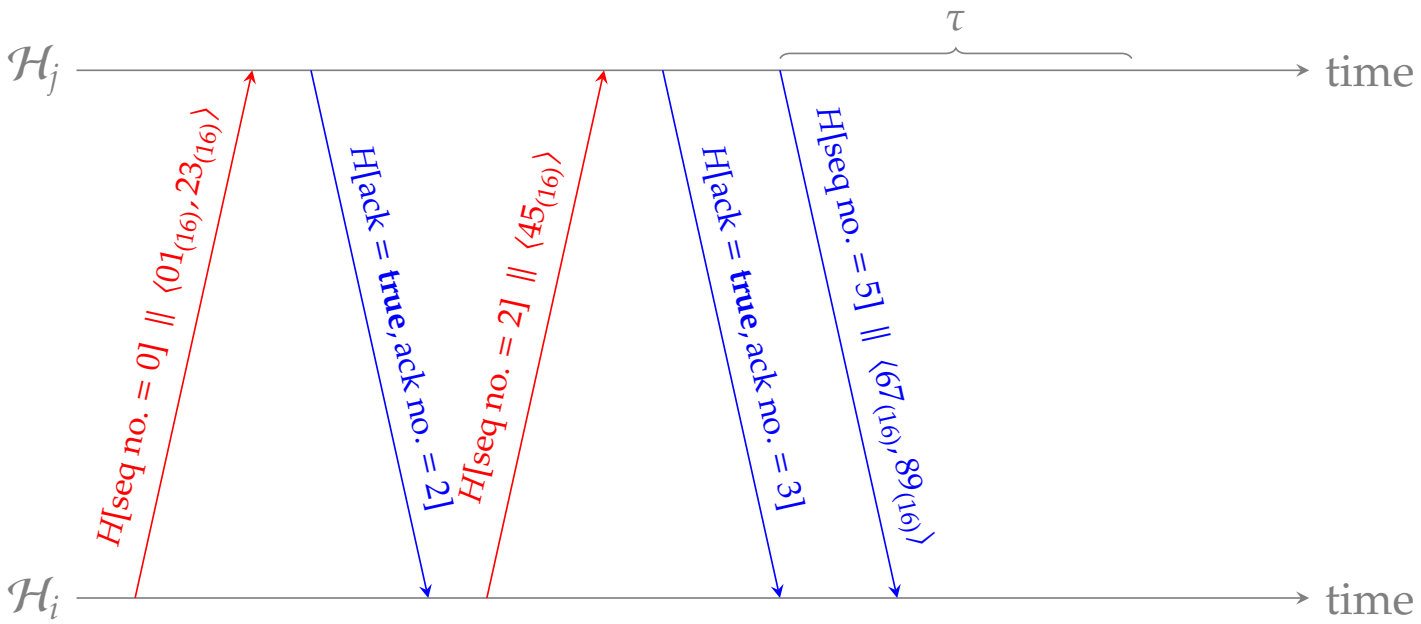

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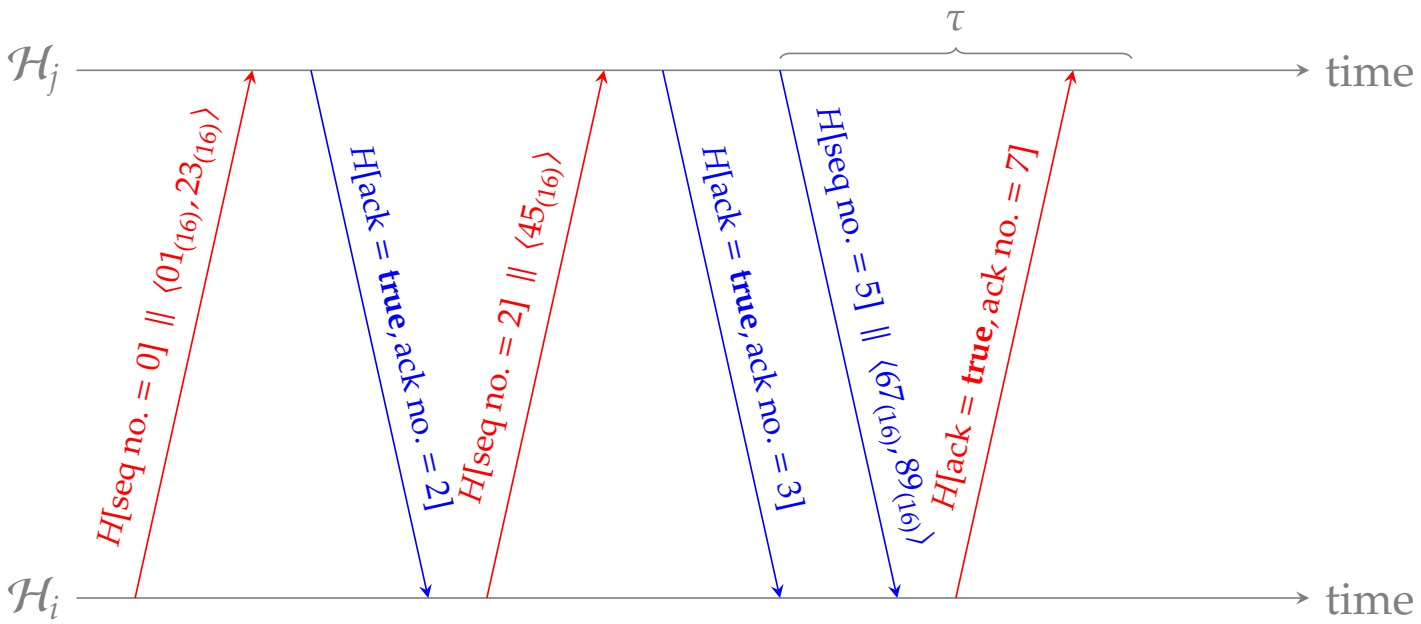

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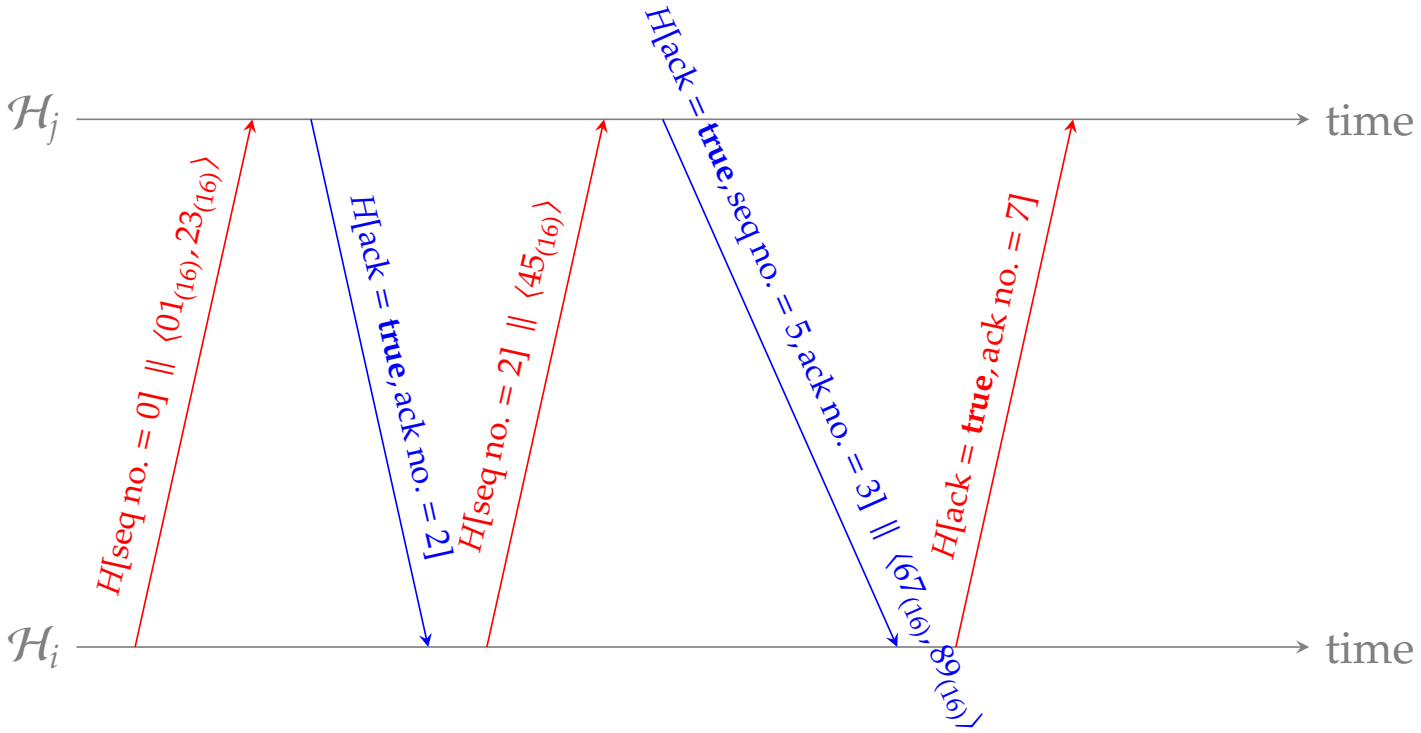

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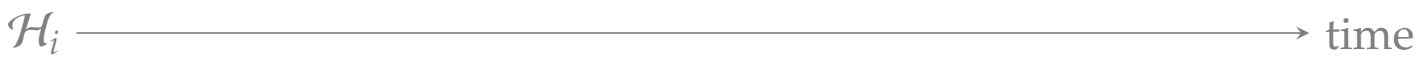

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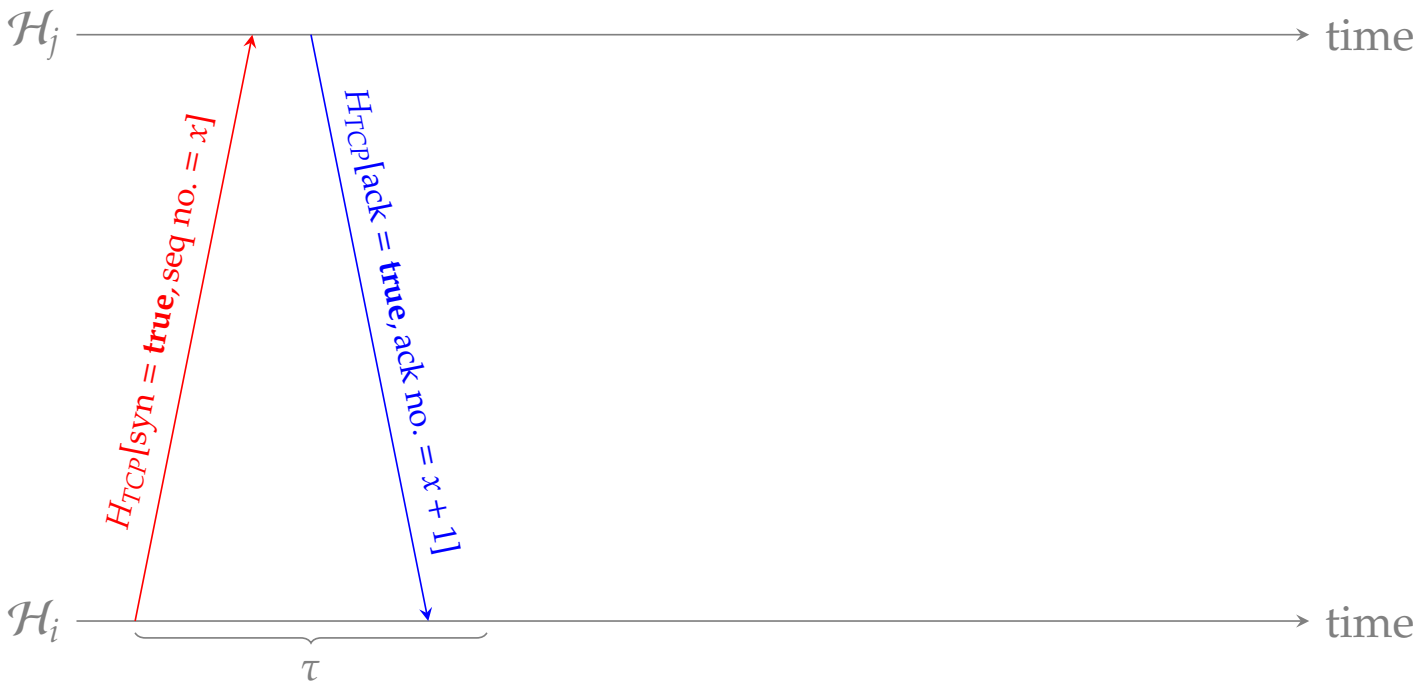

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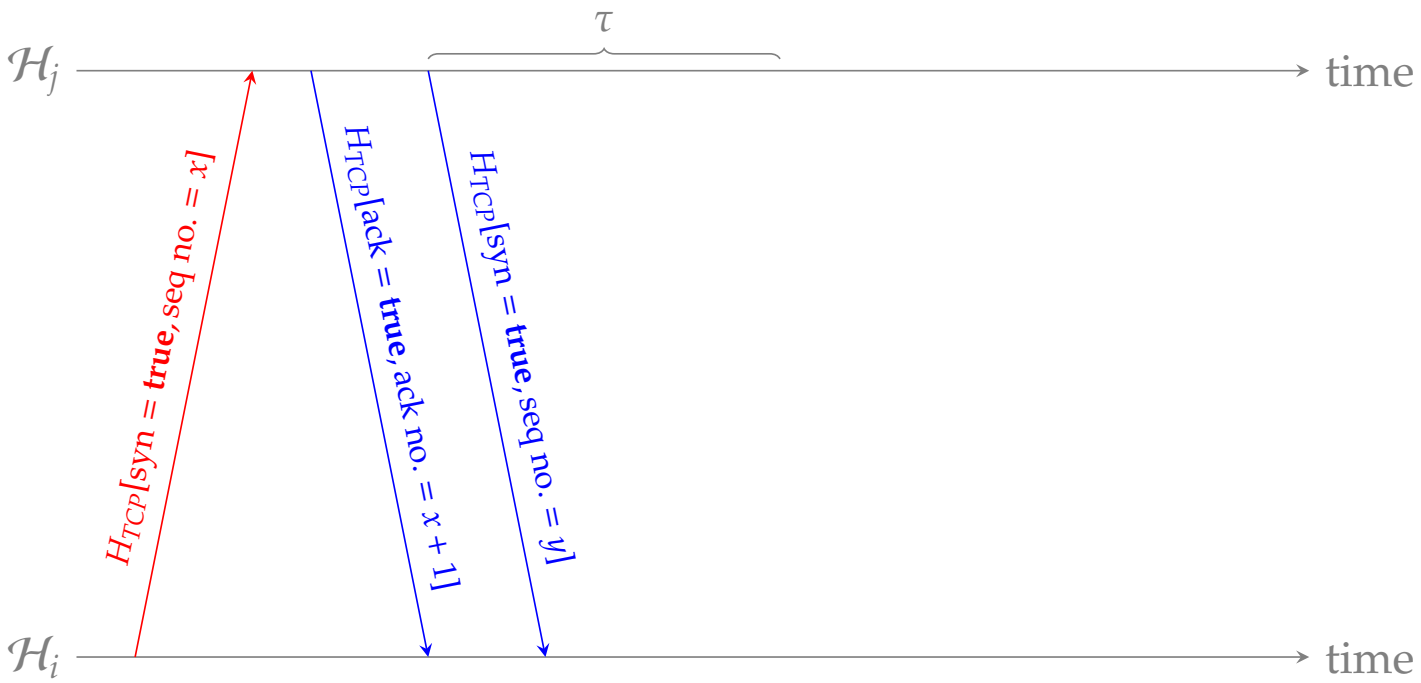

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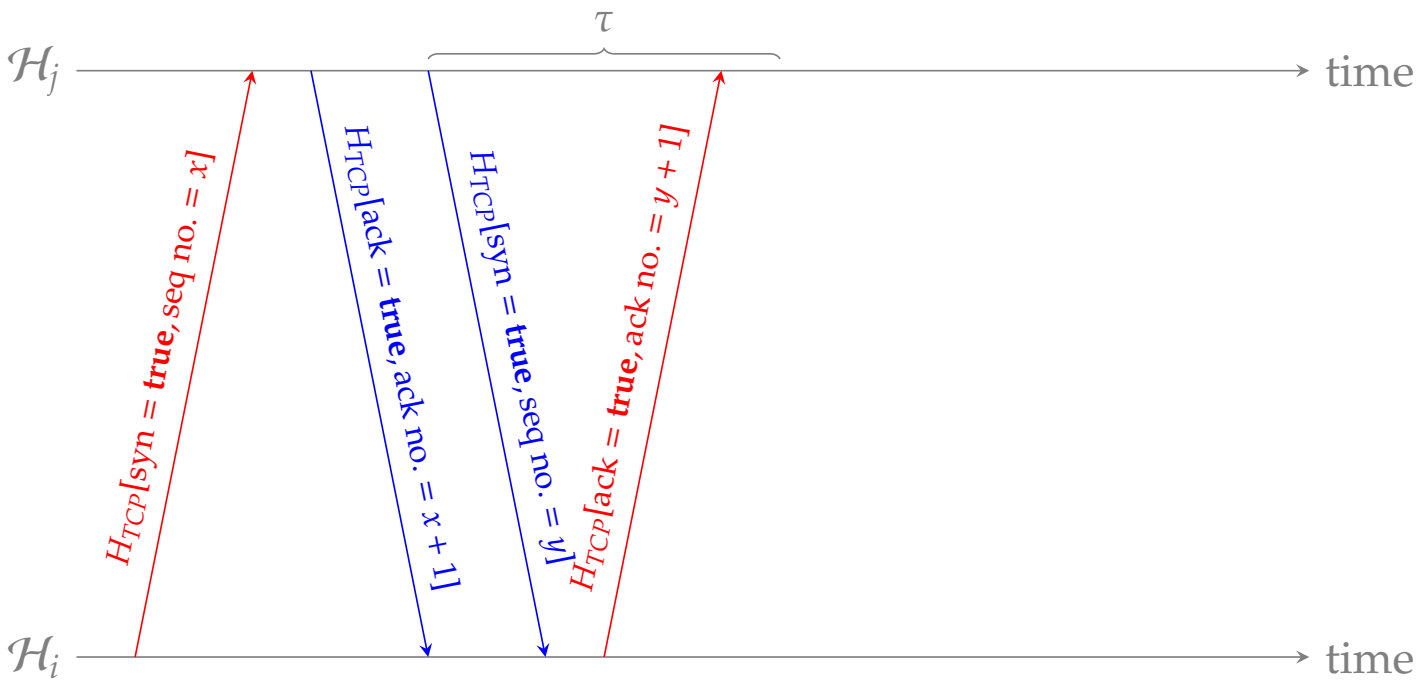

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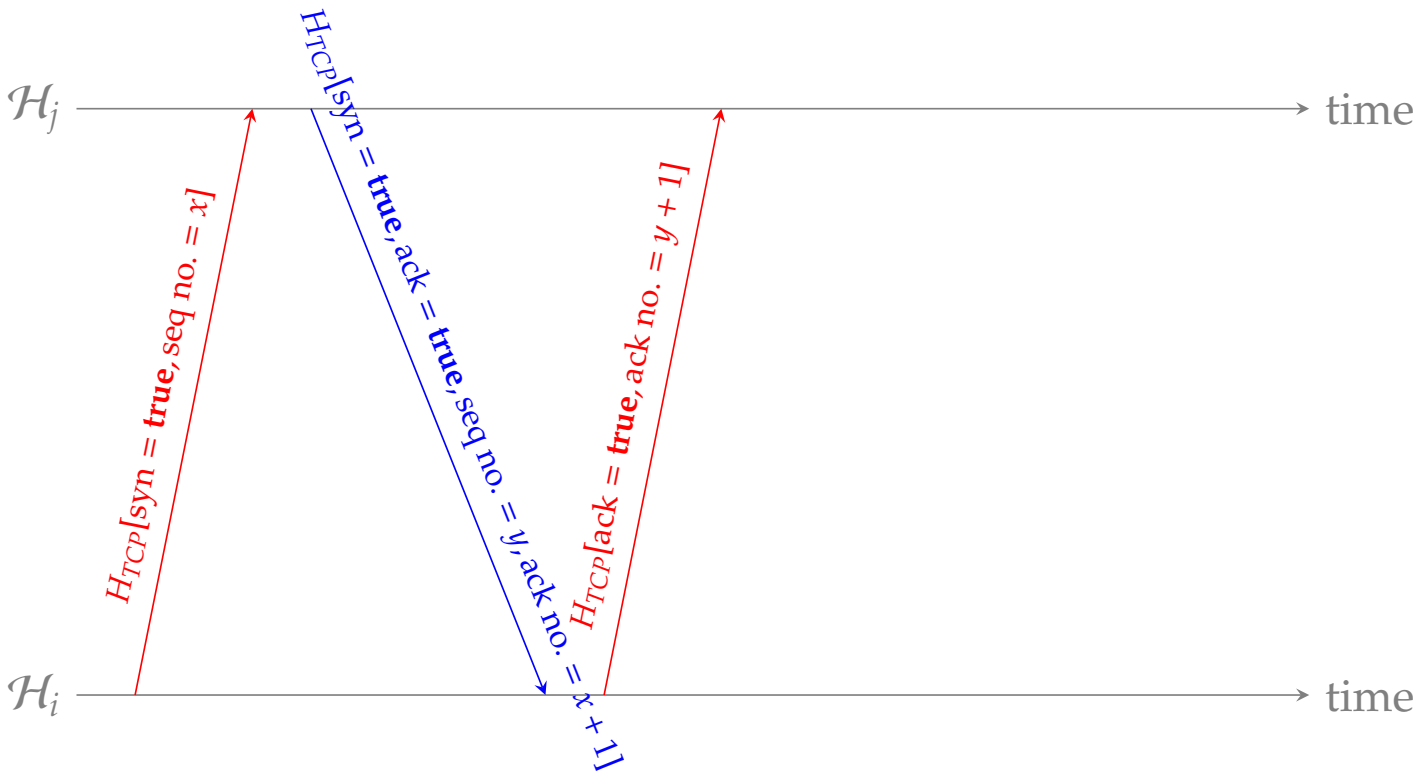

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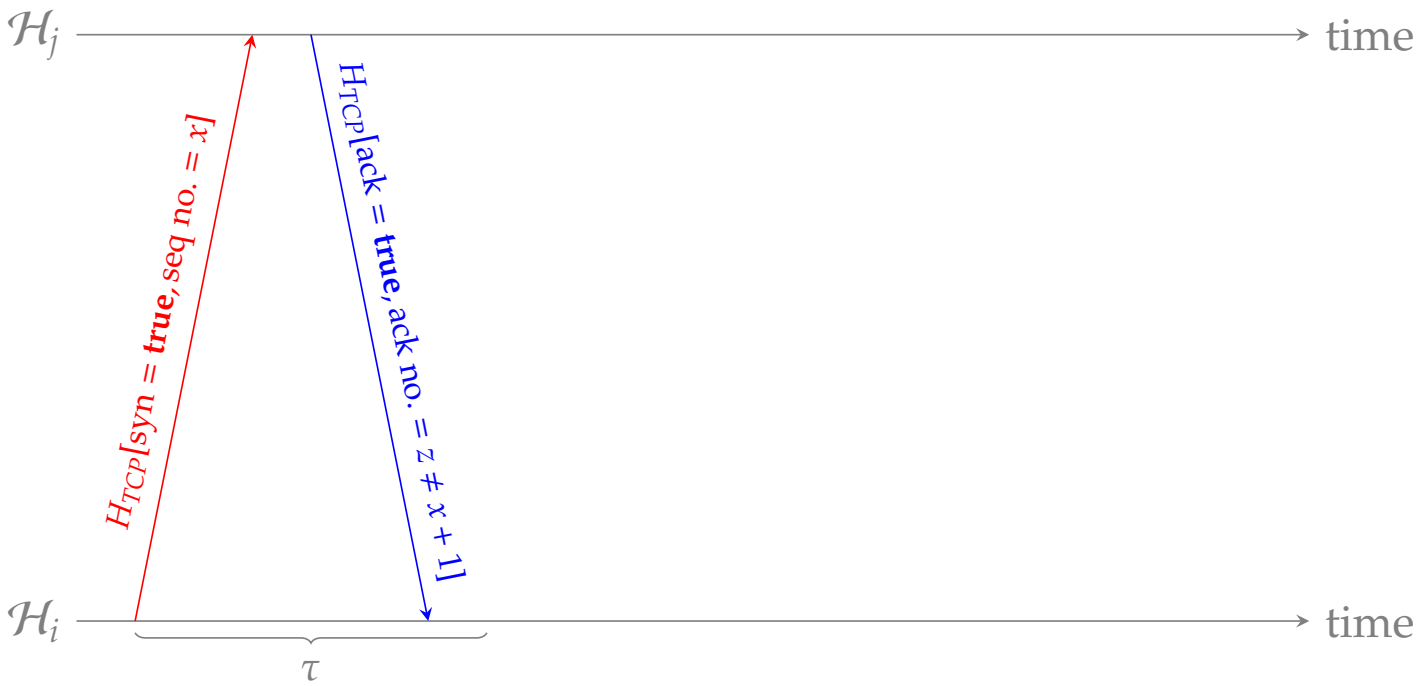

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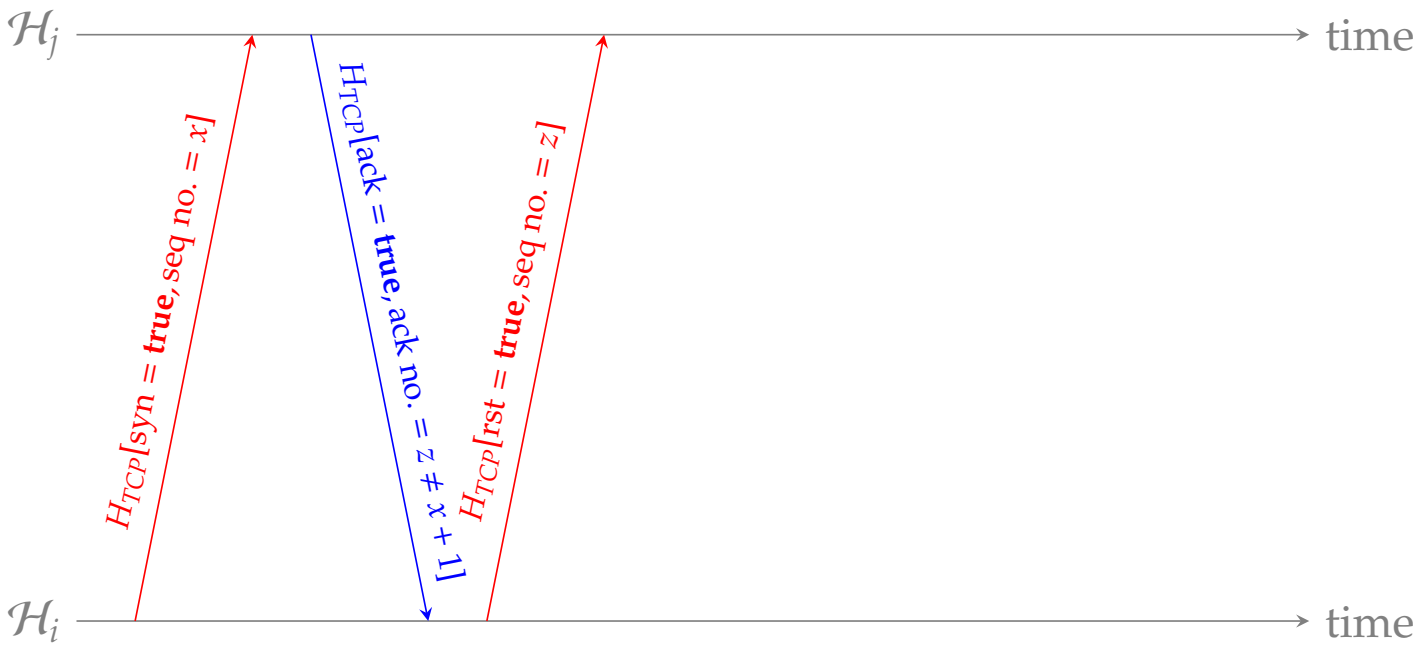

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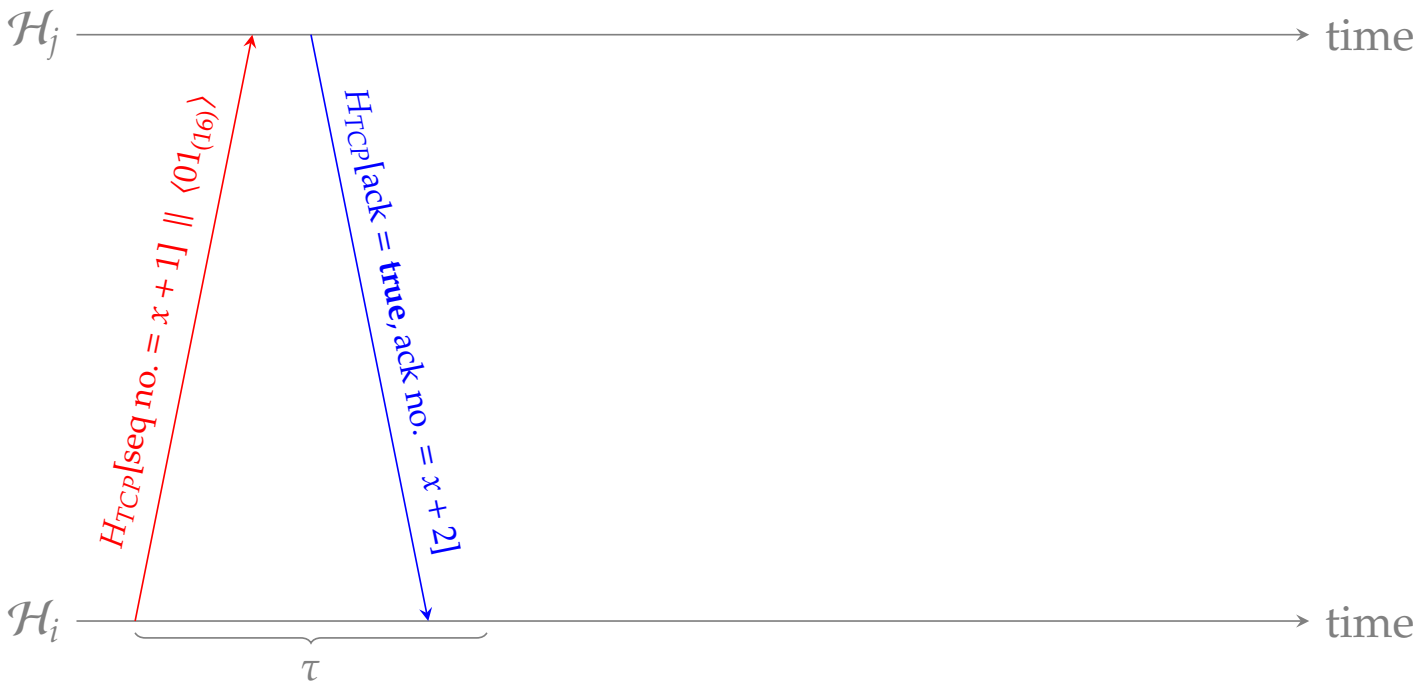

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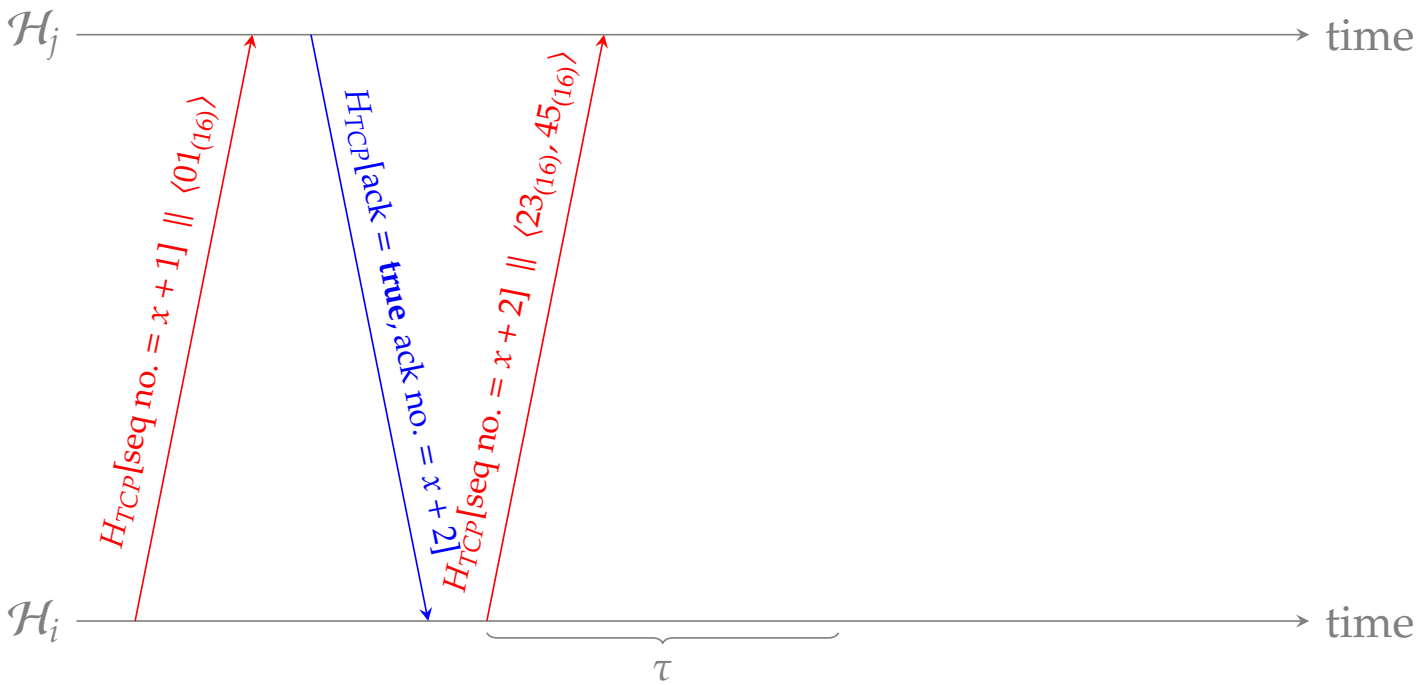

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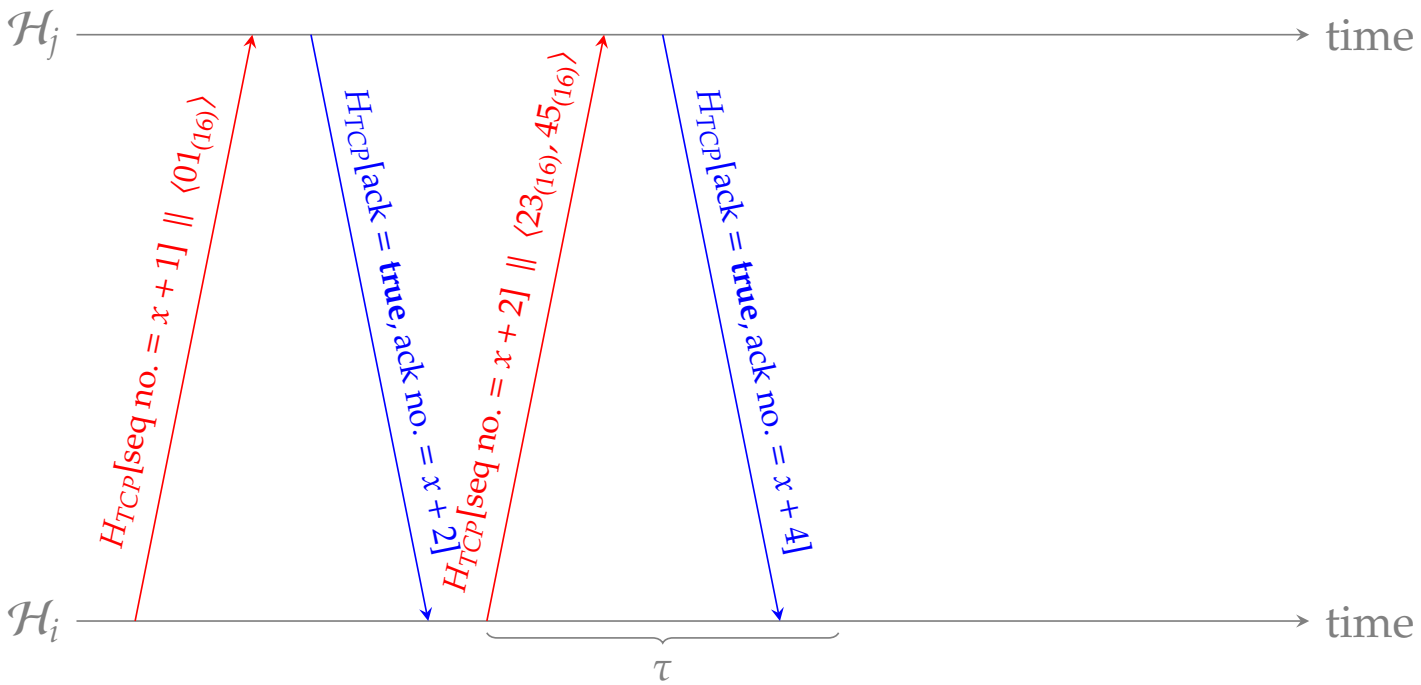

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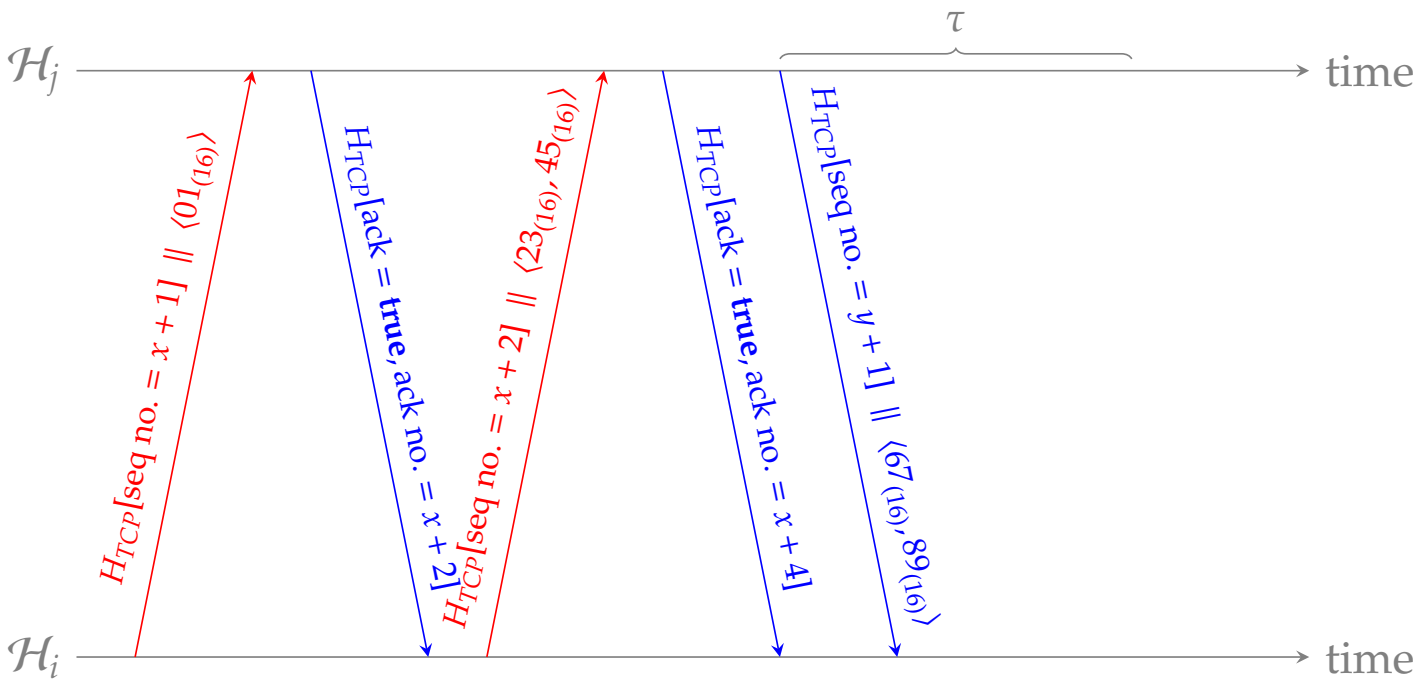

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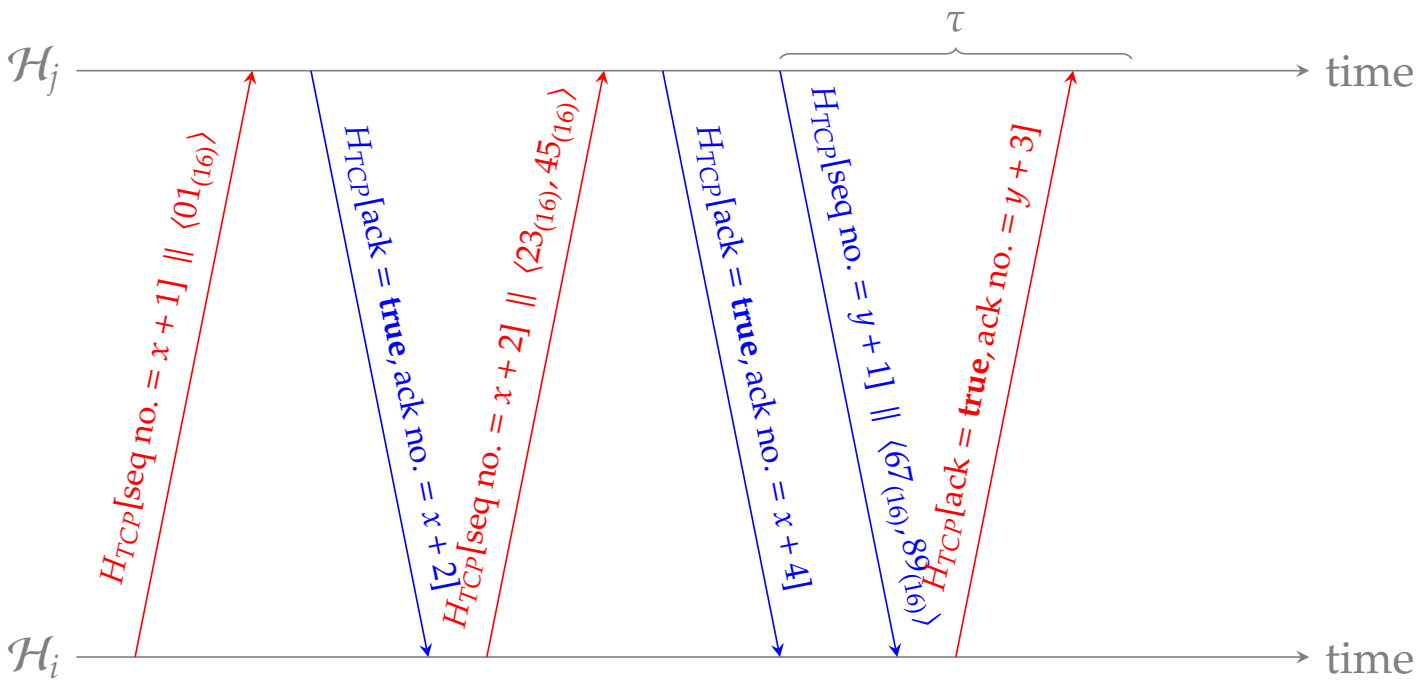

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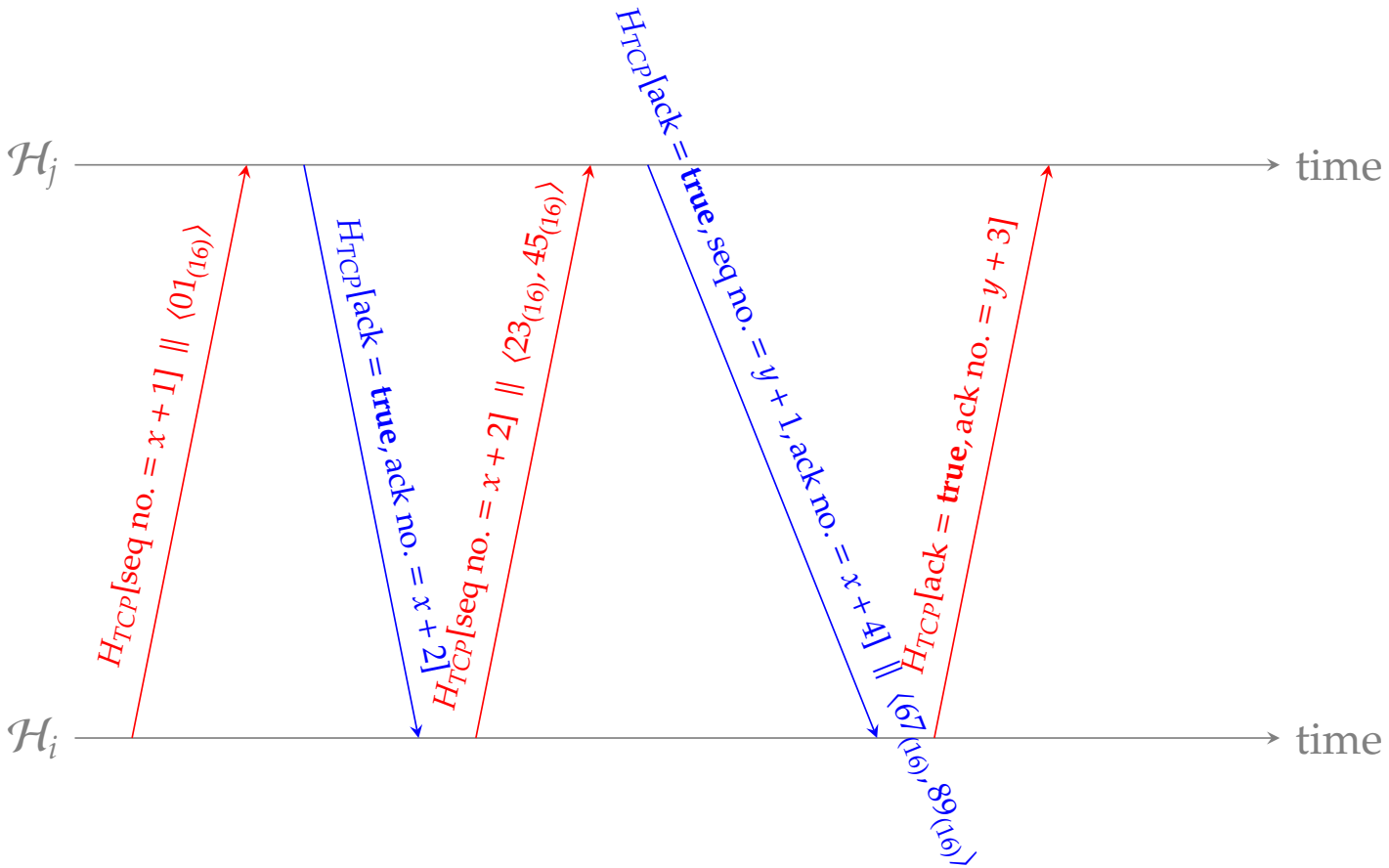

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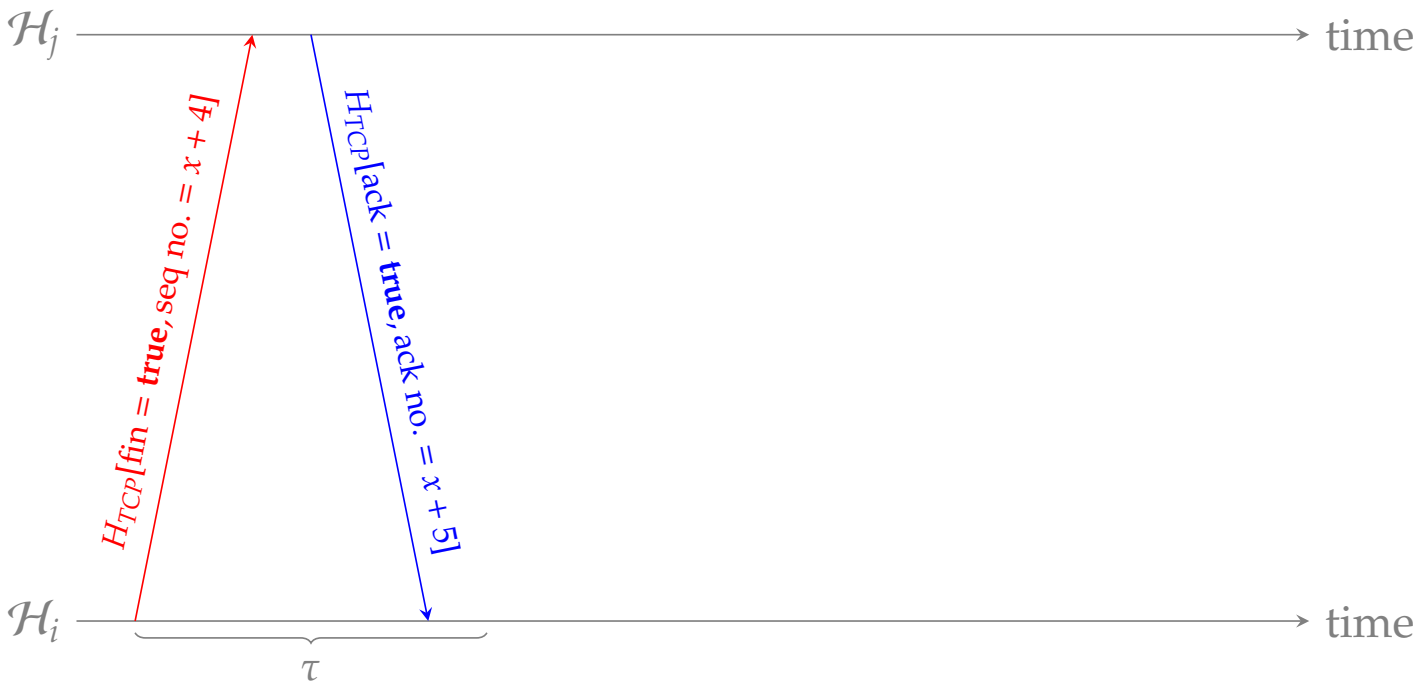

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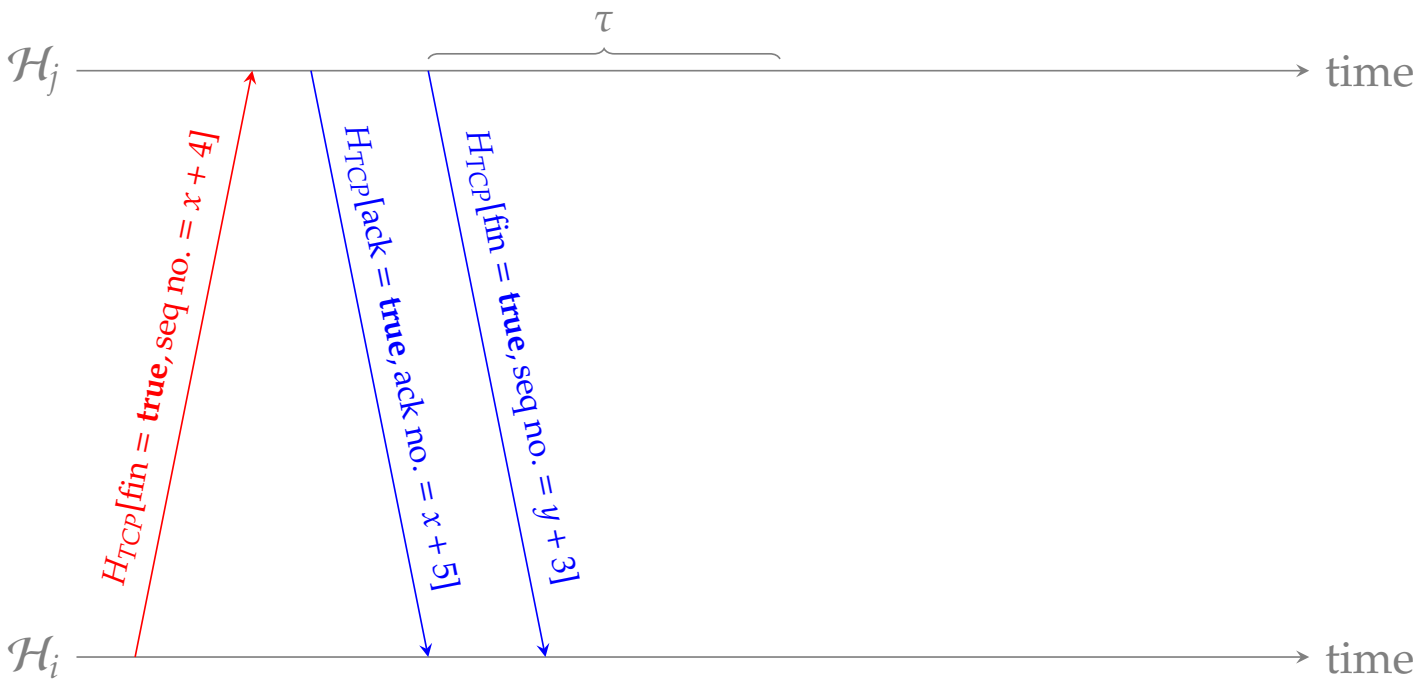

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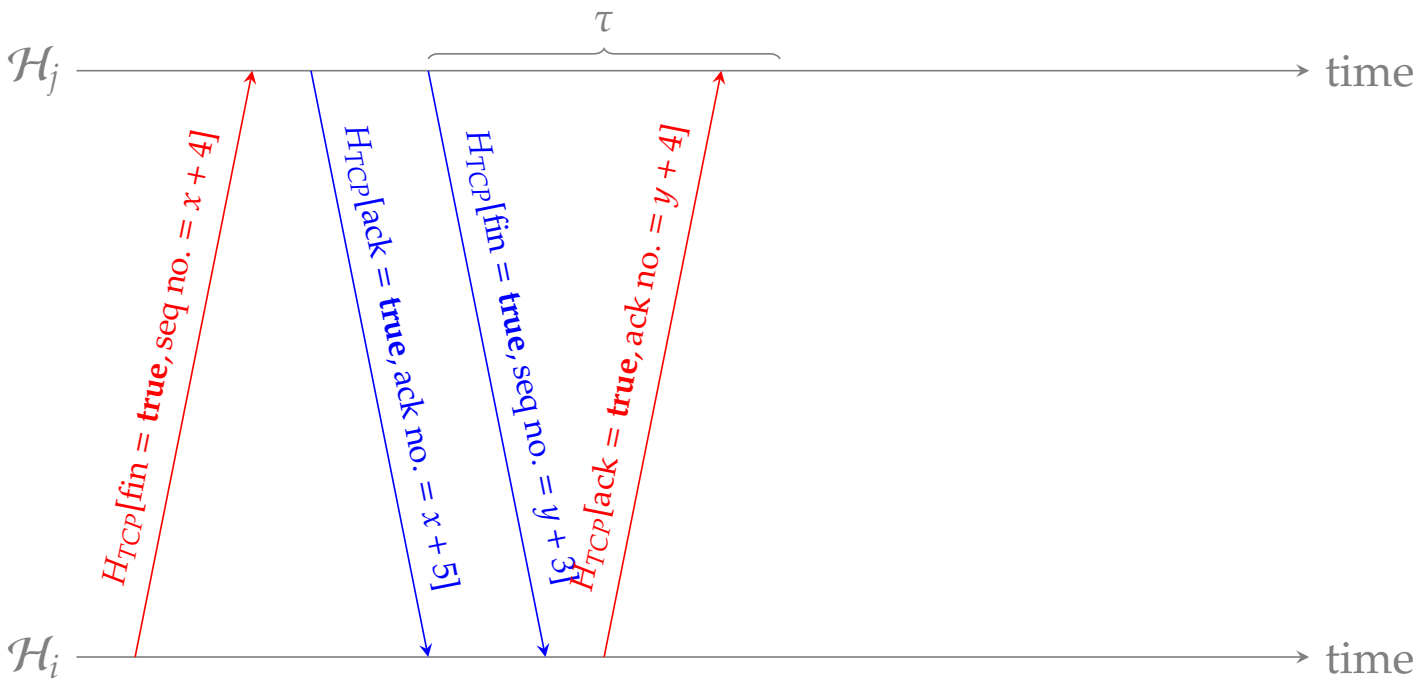

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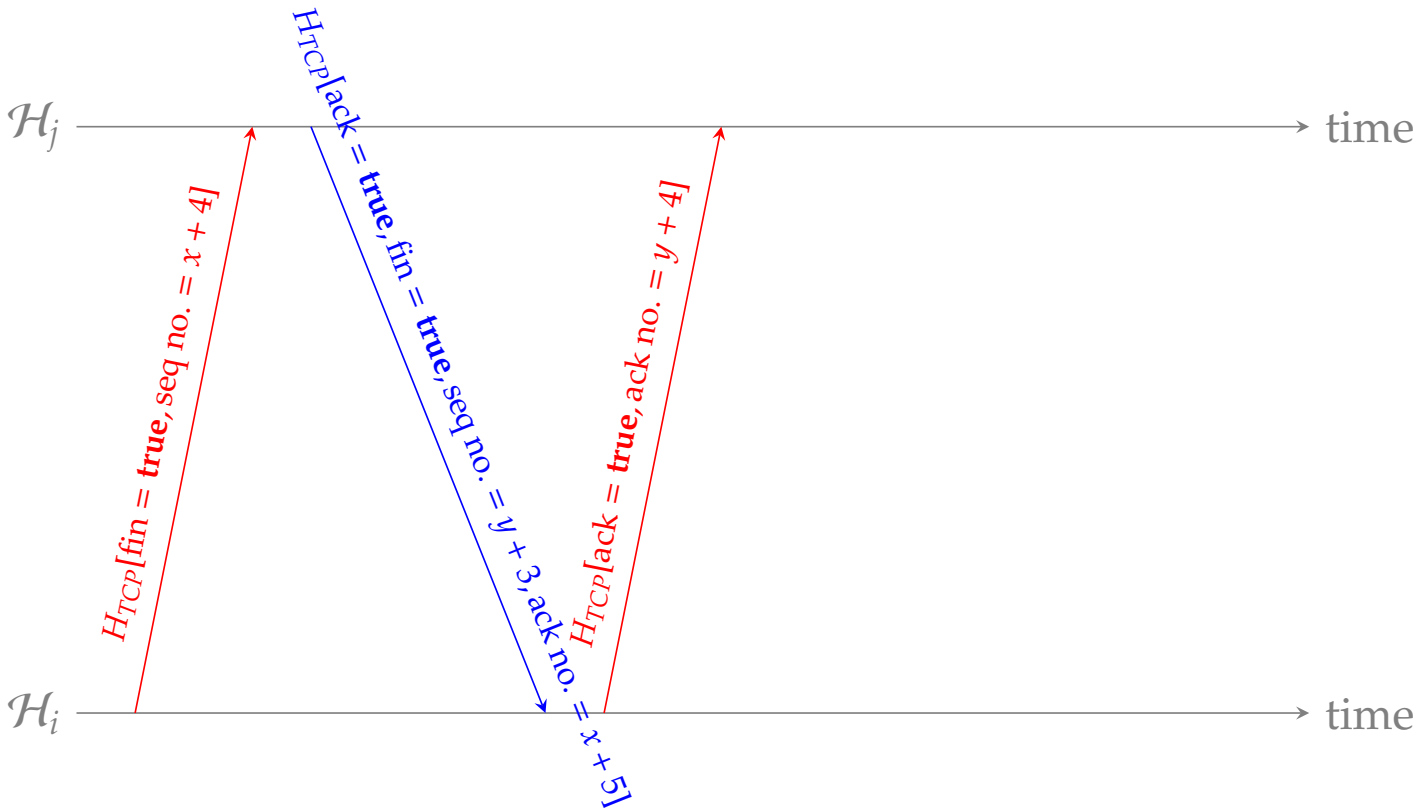
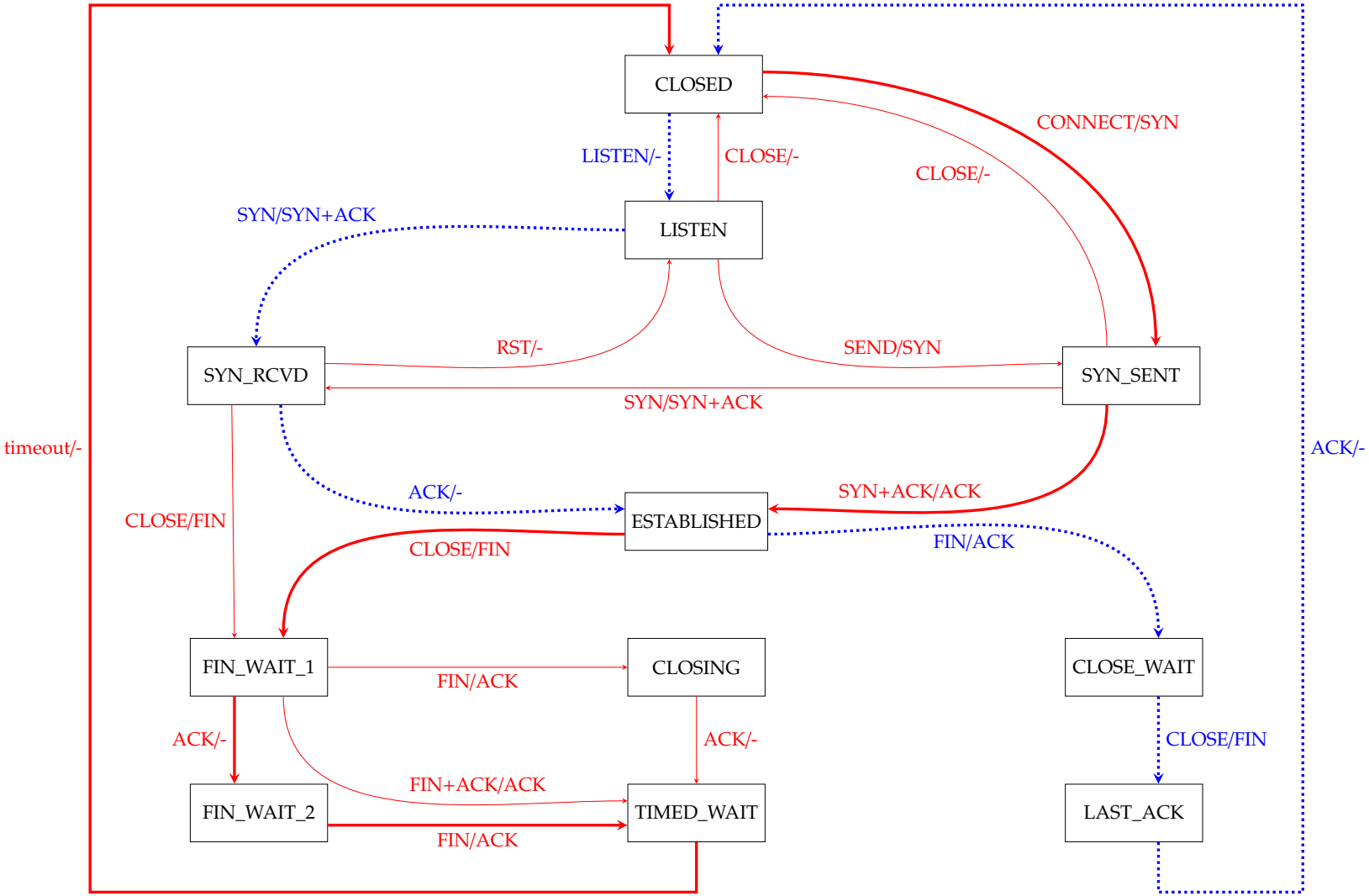


Algorithm (**TCP state machine**)



Continued in next lecture ...

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