National University of Computer & Emerging Sciences

CS 3001 - COMPUTER NETWORKS

Lecture 11

Chapter 3

29th September, 2022

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Office Hours: 02:30 pm till 06:00 pm (Every Tuesday & Thursday)

Chapter 3 outline

3.1 transport-layer services

3.2 multiplexing and demultiplexing

3.3 connectionless transport: UDP

3.4 principles of reliable data transfer

3.5 connection-oriented transport: TCP

- segment structure
- reliable data transfer
- flow control
- connection management

3.6 principles of congestion control

3.7 TCP congestion control

Port

- Port is a transport layer address / identifier to choose among the multiple processes running among the same host

- 16 bit integers ranging between 0 & 65,535

- The client side program chooses a port number randomly (ephemeral port number)

- The server side ports are not random but well known and pre assigned

- IANA (Internet Assigned Number Authority) had divided port numbers into three ranges:

  - Well Known: 0 to 1023. Assigned & controlled by IANA. (Example HTTP uses Port # 80, FTP uses port # 21. List of well known ports given in RFC 1700 & updated via RFC 3232)
  - Registered: 1024 to 49,151. Not assigned / controlled by IANA, but registered with them to avoid duplication.
  - Dynamic (or Private): 49,152 to 65,535. Neither controlled, nor registered. Can be used by any process. (Ephemeral Ports.)

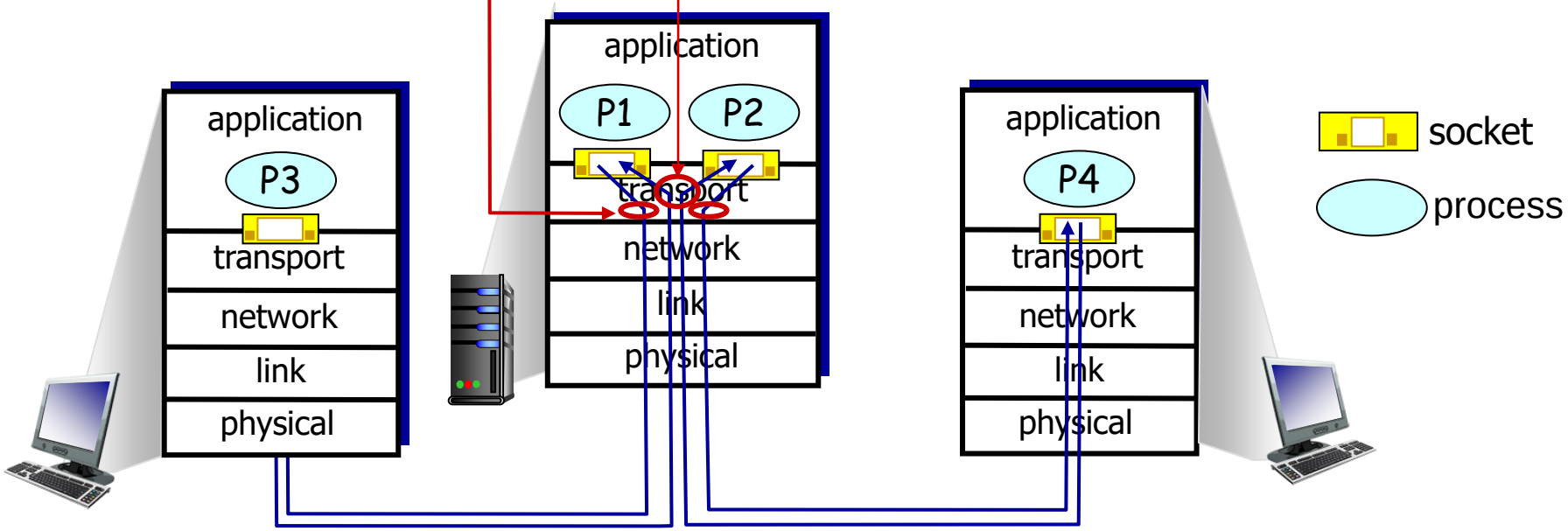
Multiplexing/demultiplexing

multiplexing at sender:

handle data from multiple sockets, add transport header (later used for demultiplexing)

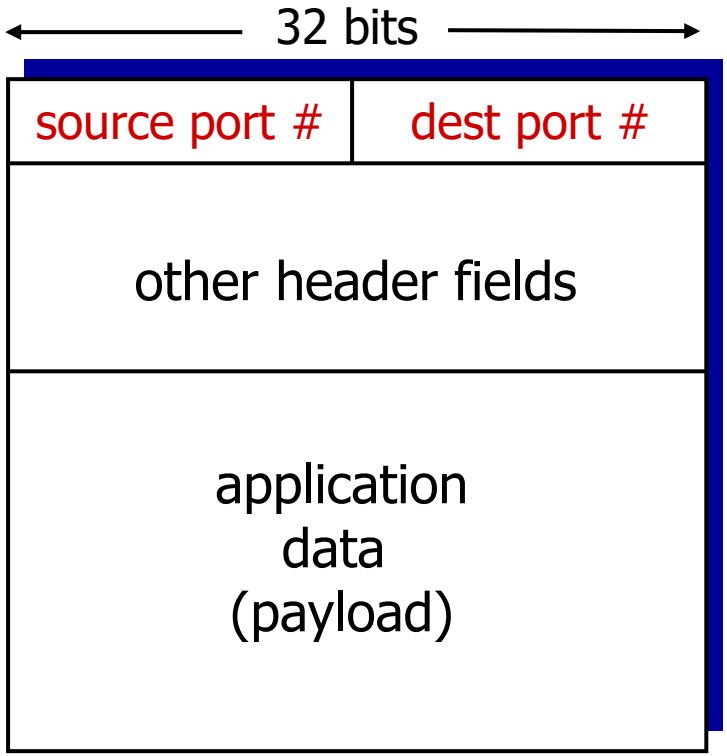
demultiplexing at receiver:

use header info to deliver received segments to correct socket



How demultiplexing works

- host receives IP datagrams
  - each datagram has source IP address, destination IP address
  - each datagram carries one transport-layer segment
  - each segment has source, destination port number
- host uses *IP addresses & port numbers* to direct segment to appropriate socket



TCP/UDP segment format

Connectionless demultiplexing

- *recall:* created socket has host-local port #:

```
DatagramSocket mySocket1
= new DatagramSocket(12534);
```

- *recall:* when creating datagram to send into UDP socket, must specify
  - destination IP address
  - destination port #

(thus UDP socket identified by 2-tuple:
- *dest IP address*
- *dest port number)*

- when host receives UDP segment:
  - checks destination port # in segment
  - directs UDP segment to socket with that port #

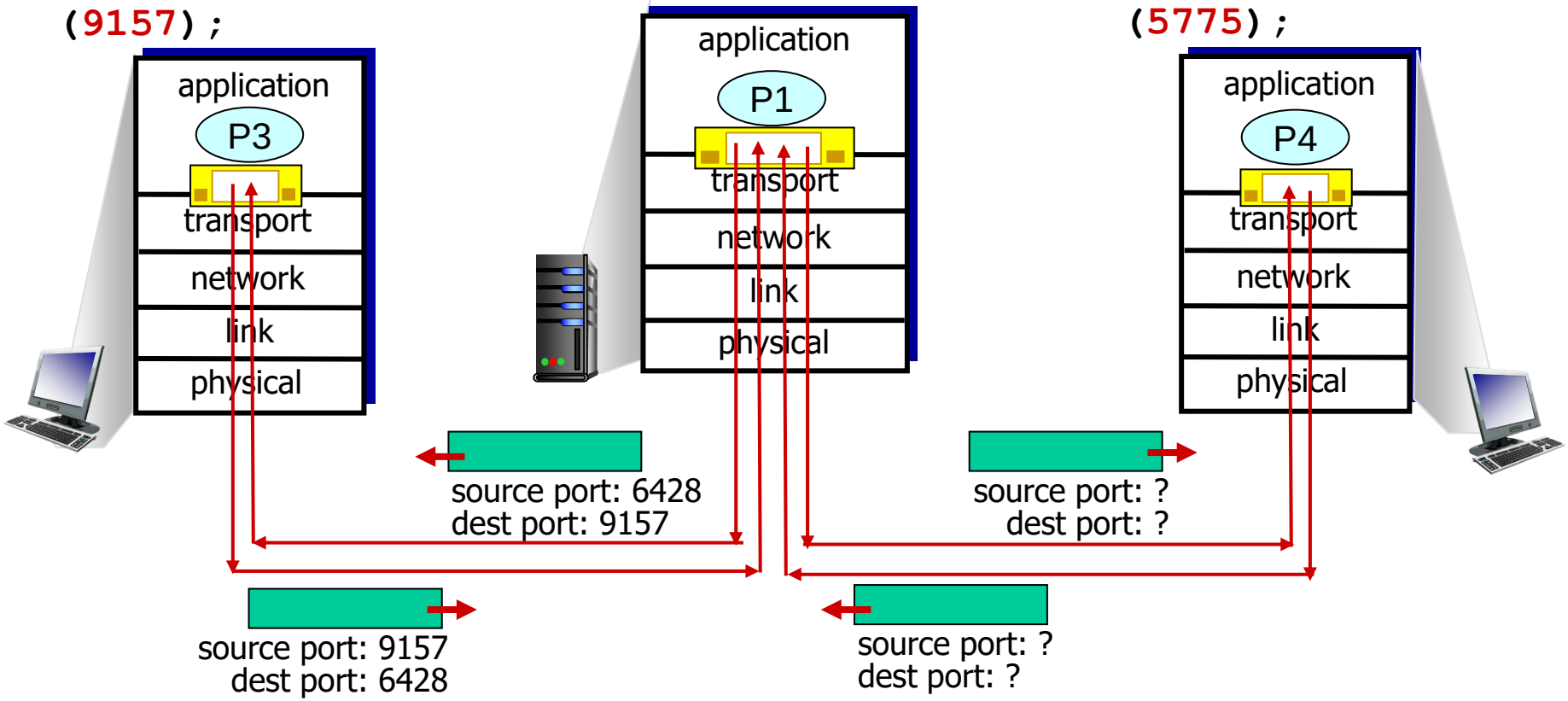
IP datagrams with *same dest. port #,* but different source IP addresses and/or source port numbers will be directed to *same socket* at dest

Connectionless demux: example

```
DatagramSocket
 mySocket2 = new
 DatagramSocket
 (9157);
```

```
DatagramSocket
 serverSocket = new
 DatagramSocket
 (6428);
```

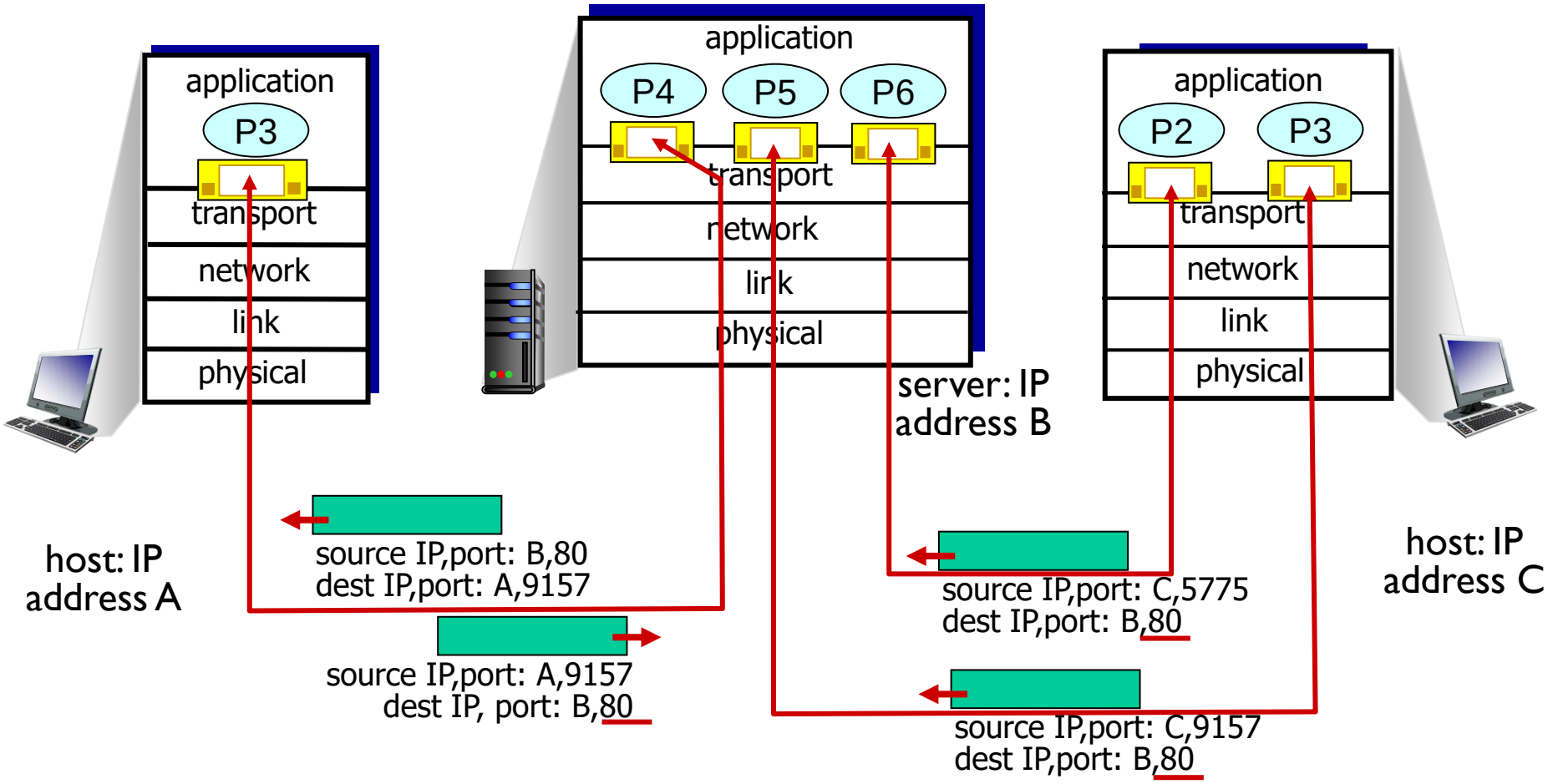
```
DatagramSocket
 mySocket1 = new
 DatagramSocket
 (5775);
```



Connection-oriented demux

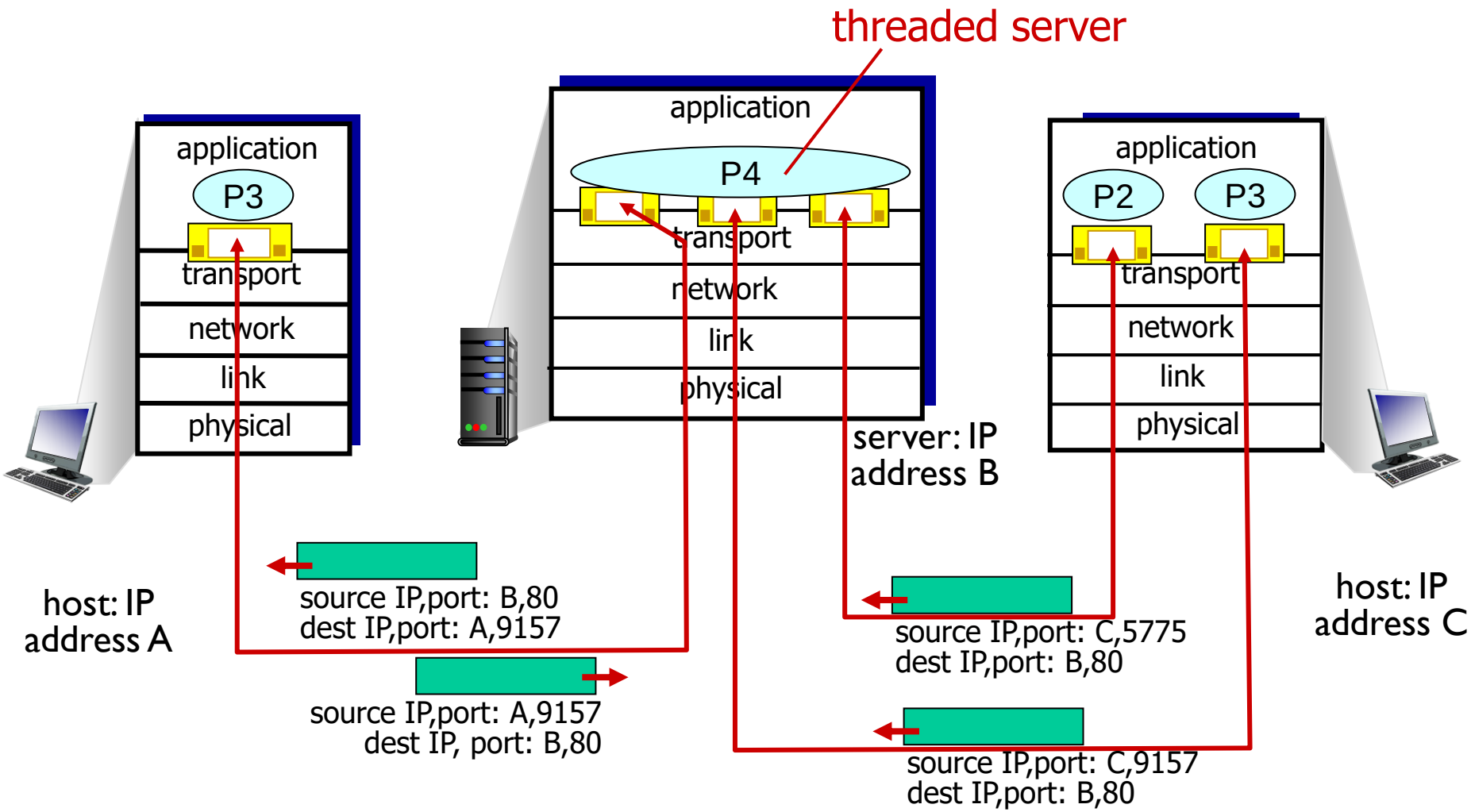
- TCP socket identified by 4-tuple:
  - source IP address
  - source port number
  - dest IP address
  - dest port number
- demux: receiver uses all four values to direct segment to appropriate socket
- server host may support many simultaneous TCP sockets:
  - each socket identified by its own 4-tuple
- web servers have different sockets for each connecting client
  - non-persistent HTTP will have different socket for each request

Connection-oriented demux: example



three segments, all destined to IP address: B, dest port: 80 are demultiplexed to *different* sockets

Connection-oriented demux: example



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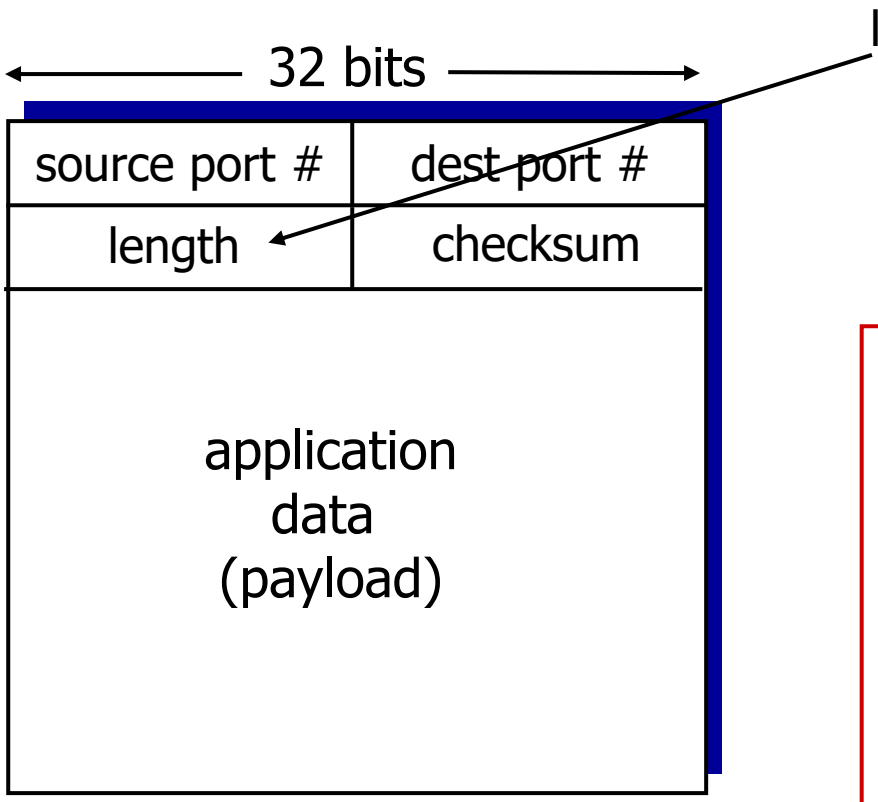
UDP: User Datagram Protocol [RFC 768]

- "no frills," "bare bones" Internet transport protocol
- "best effort" service, UDP segments may be:
  - lost
  - delivered out-of-order to app
- *connectionless:*
  - no handshaking between UDP sender, receiver
  - each UDP segment handled independently of others

- UDP use:
  - streaming multimedia apps (loss tolerant, rate sensitive)
  - DNS
  - SNMP
- reliable transfer over UDP:
  - add reliability at application layer
  - application-specific error recovery!

UDP: segment header

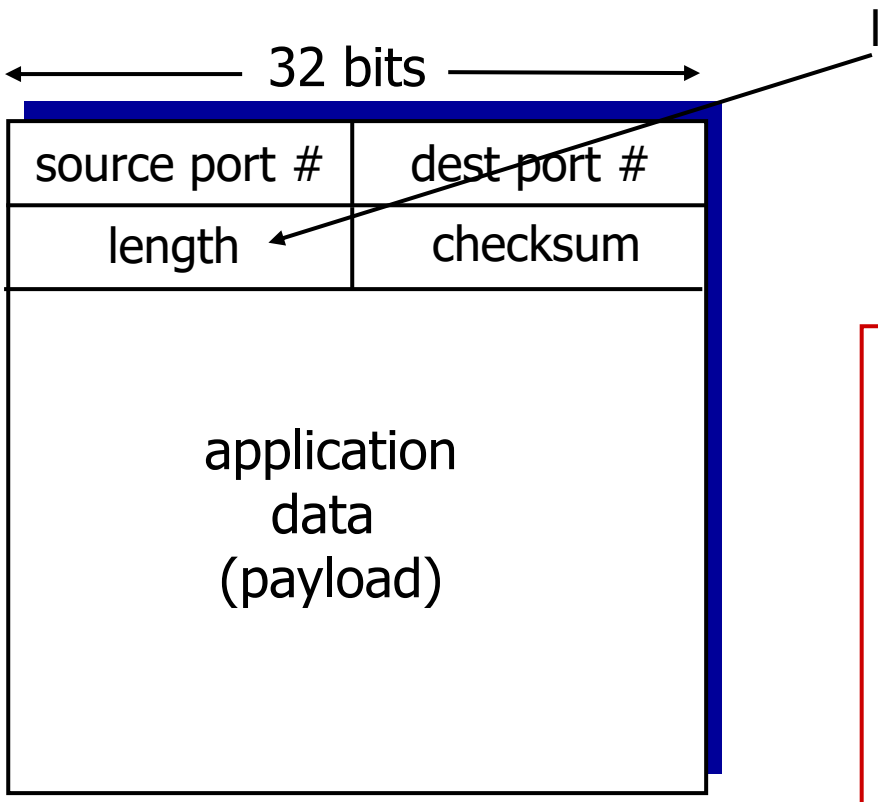


UDP segment format

why is there a UDP?

- no connection establishment (which can add delay)
- simple: no connection state at sender, receiver
- small header size
- no congestion control: UDP can blast away as fast as desired

UDP: segment header



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UDP checksum

Goal: detect "errors" (e.g., flipped bits) in transmitted segment

sender:

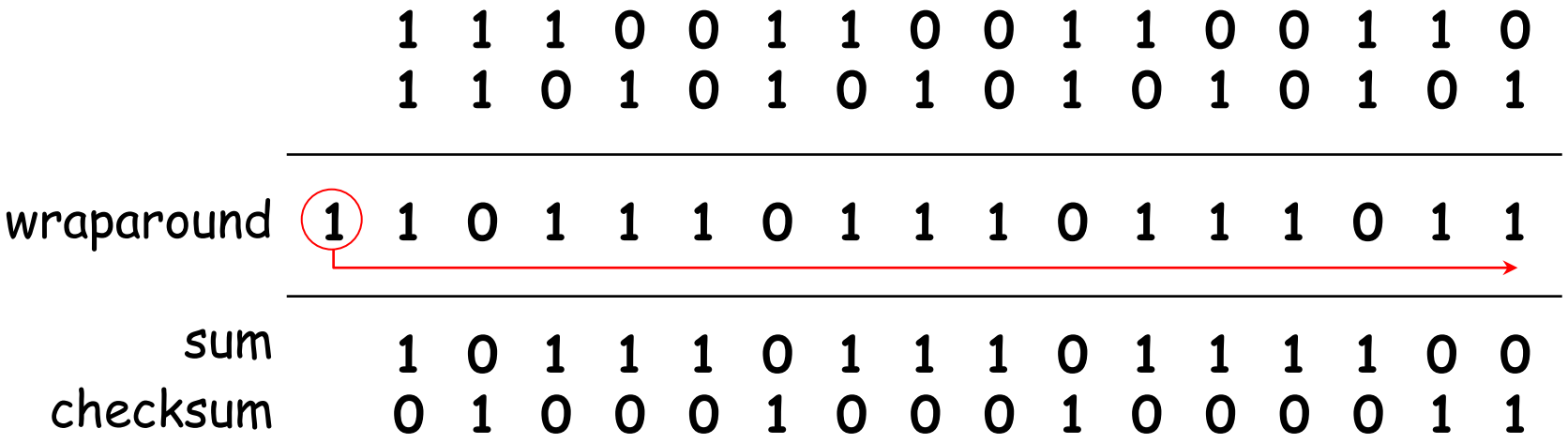
- treat segment contents, including header fields & data, as sequence of 16-bit integers (words)
- checksum: addition (one's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. *But maybe errors nonetheless?* More later ….

Internet checksum: example

example: add two 16-bit integers



Note: when adding numbers, a carryout from the most significant bit needs to be added to the result

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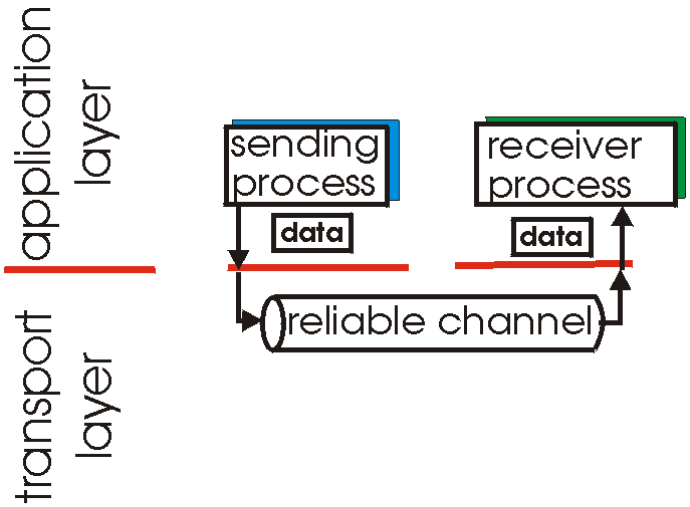
Principles of reliable data transfer

- important in application, transport, link layers
  - top-10 list of important networking topics!



(a) provided service

- characteristics of unreliable channel will determine complexity of reliable data transfer protocol (rdt)

Principles of reliable data transfer

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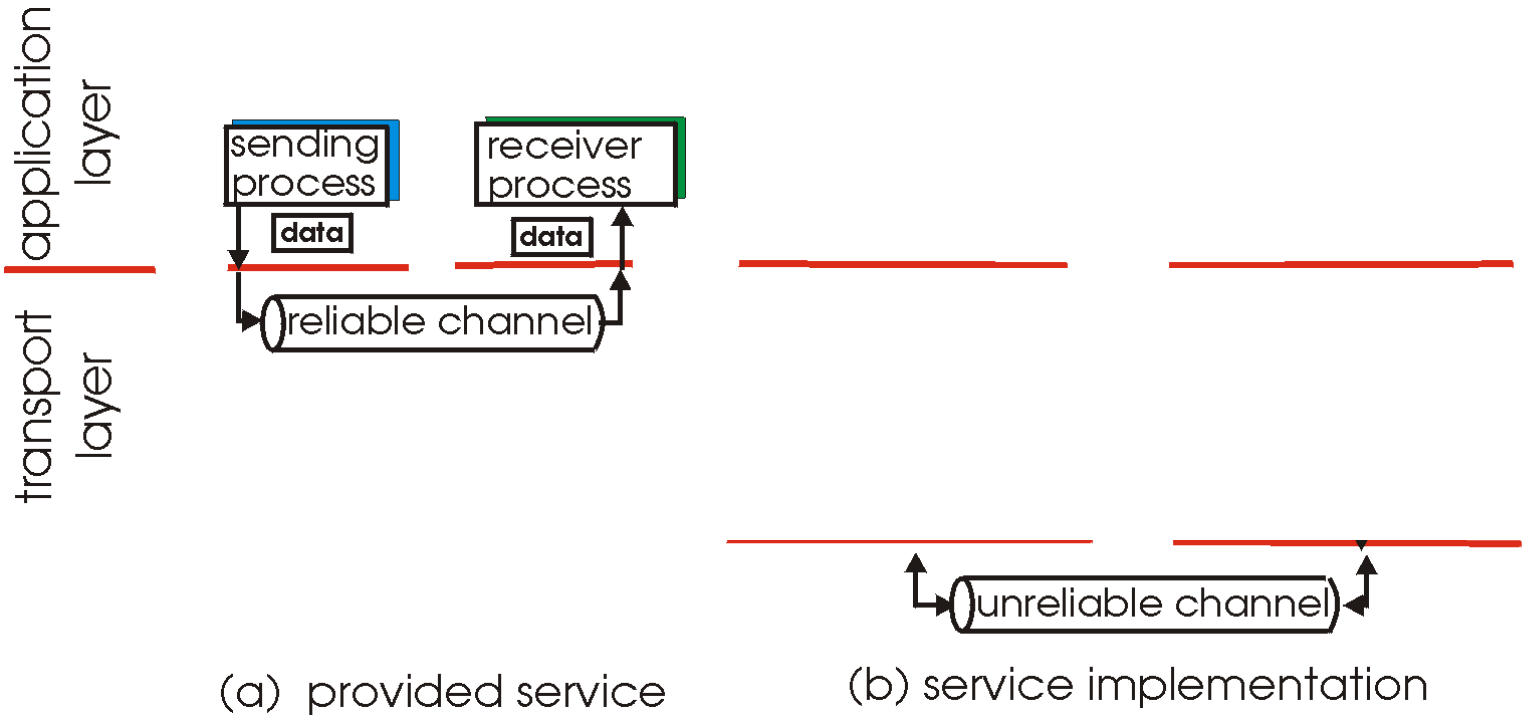

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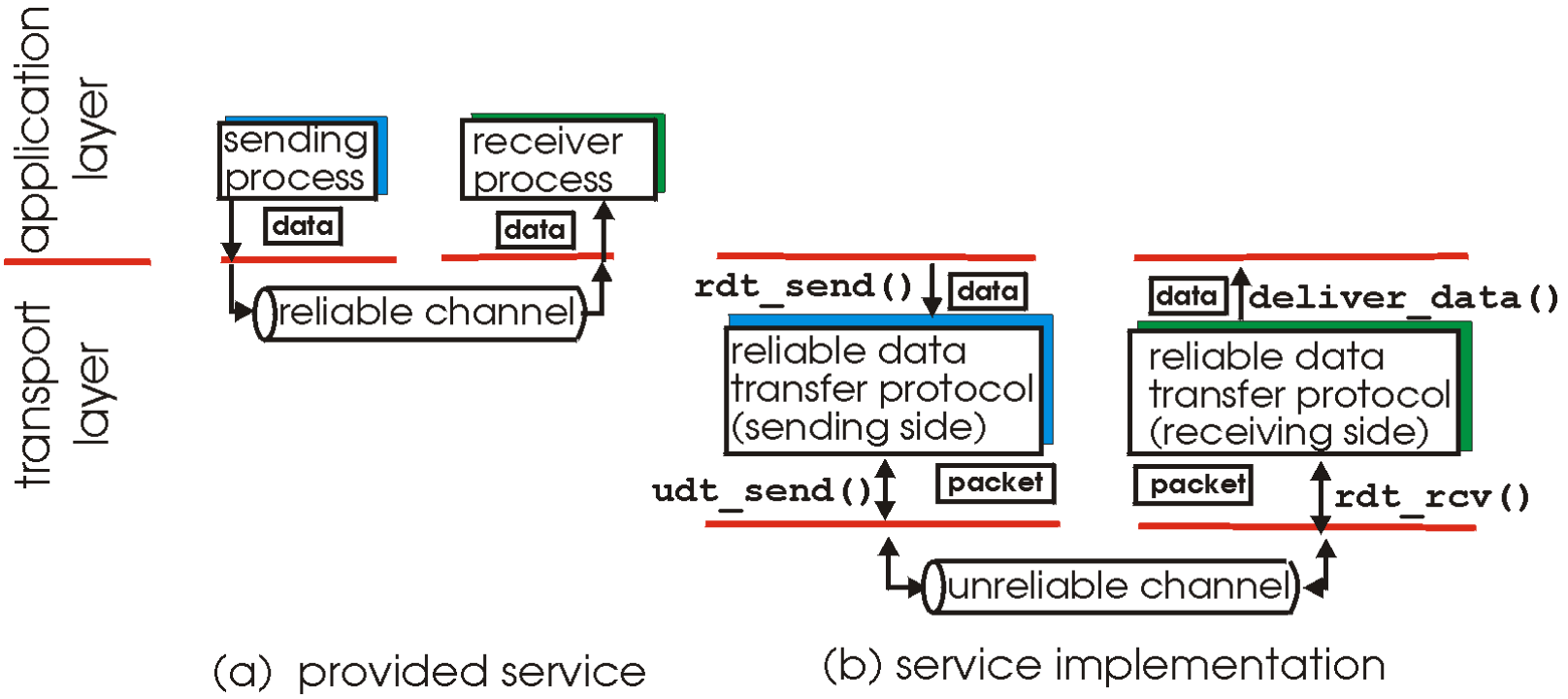
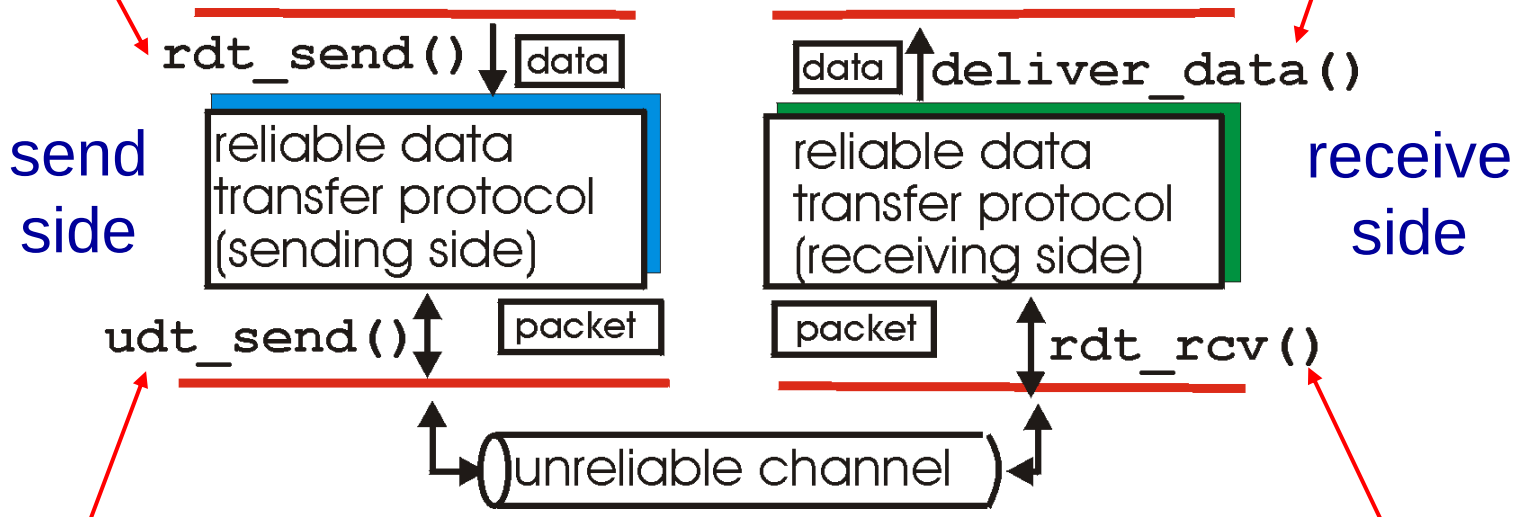


- characteristics of unreliable channel will determine complexity of reliable data transfer protocol (rdt)

Reliable data transfer: getting started

`rdt_send()`: called from above, (e.g., by app.). Passed data to deliver to receiver upper layer

`deliver_data()`: called by **rdt** to deliver data to upper



`udt_send()`: called by rdt, to transfer packet over unreliable channel to receiver

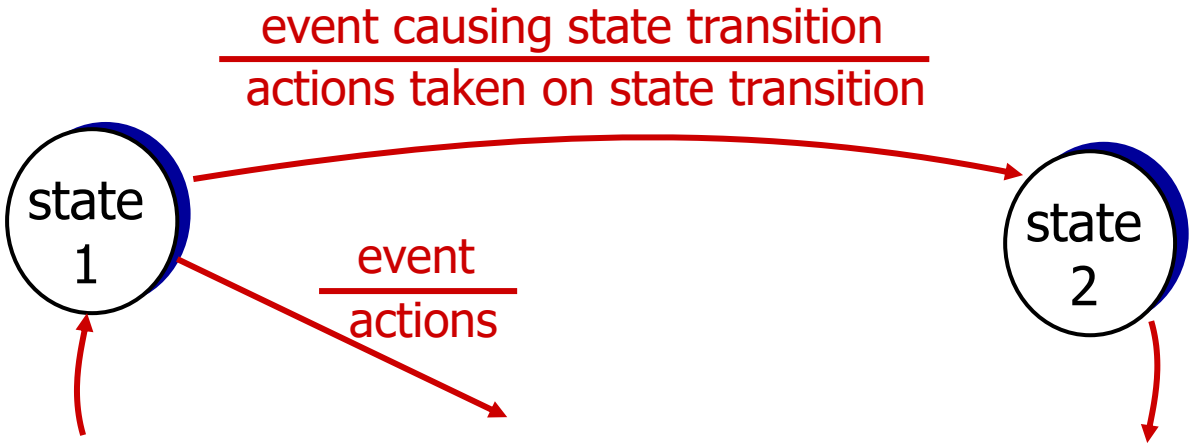
`rdt_rcv()`: called when packet arrives on rcv-side of channel

Reliable data transfer: getting started

we'll:

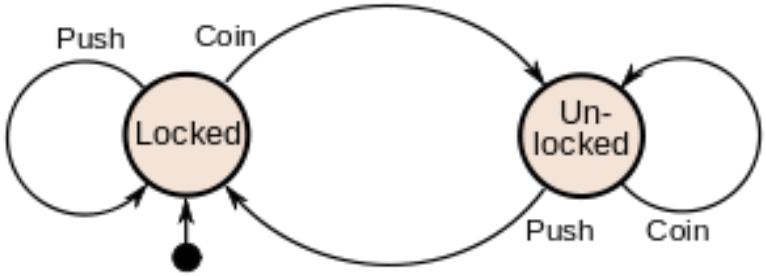
- incrementally develop sender, receiver sides of reliable data transfer protocol (rdt)
- consider only unidirectional data transfer
  - but control info will flow on both directions!
- use finite state machines (FSM) to specify sender, receiver

state: when in this "state" next state uniquely determined by next event



Finite State Machine (FSM)

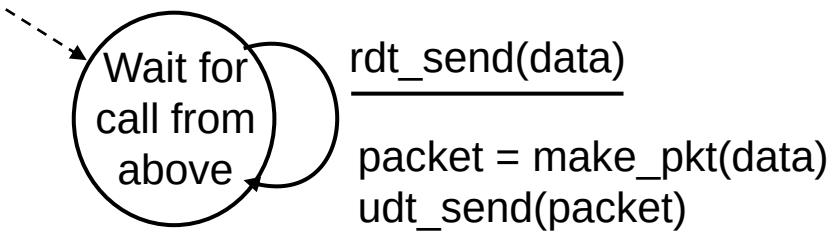
- Or simply a State Machine
- It is a mathematical model of computation.
- It is an abstract machine that can be in exactly one of a finite number of states at any given time.
- The FSM can change from one state to another in response to some event / input
- The change from one state to another is called a transition
- An FSM is defined by:
  - a list of its states
  - its initial state
  - and the event / input that trigger each transition
  - & the resultant actions that happen in response to the event
- Examples are vending machines, elevators, traffic signals, turnstile



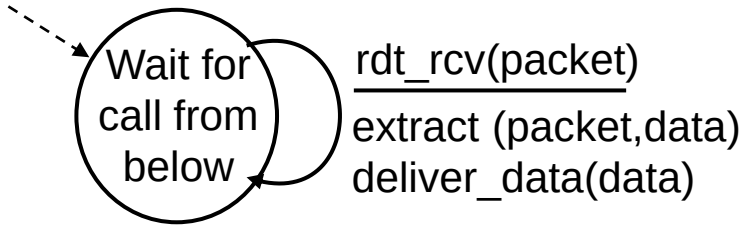
State Diagram of a Turnstile

rdt1.0: reliable transfer over a reliable channel

- underlying channel perfectly reliable
  - no bit errors
  - no loss of packets
- separate FSMs for sender, receiver:
  - sender sends data into underlying channel
  - receiver reads data from underlying channel



sender



receiver

rdt2.0: channel with bit errors

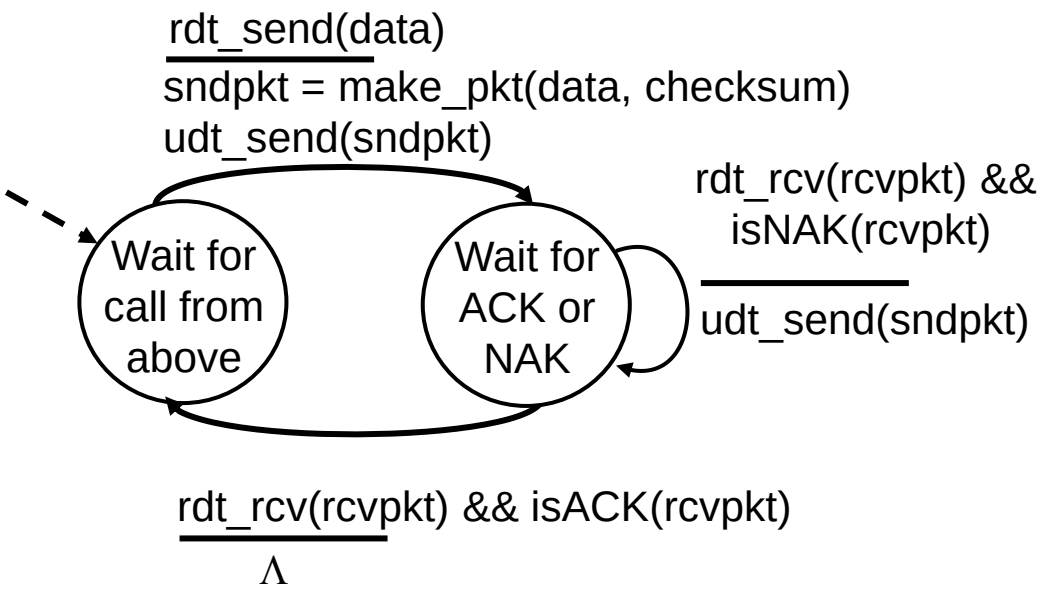
- underlying channel may flip bits in packet
  - checksum to detect bit errors
- *the* question: how to recover from errors:

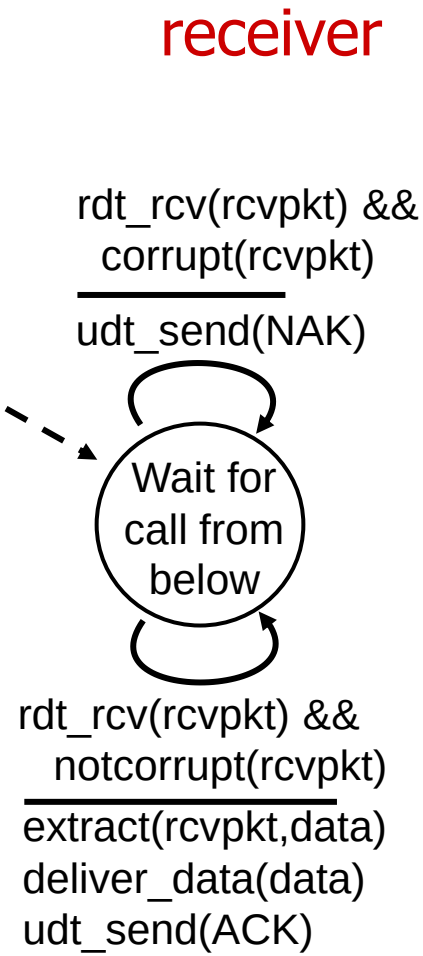
How do humans recover from "errors" during conversation?

rdt2.0: channel with bit errors

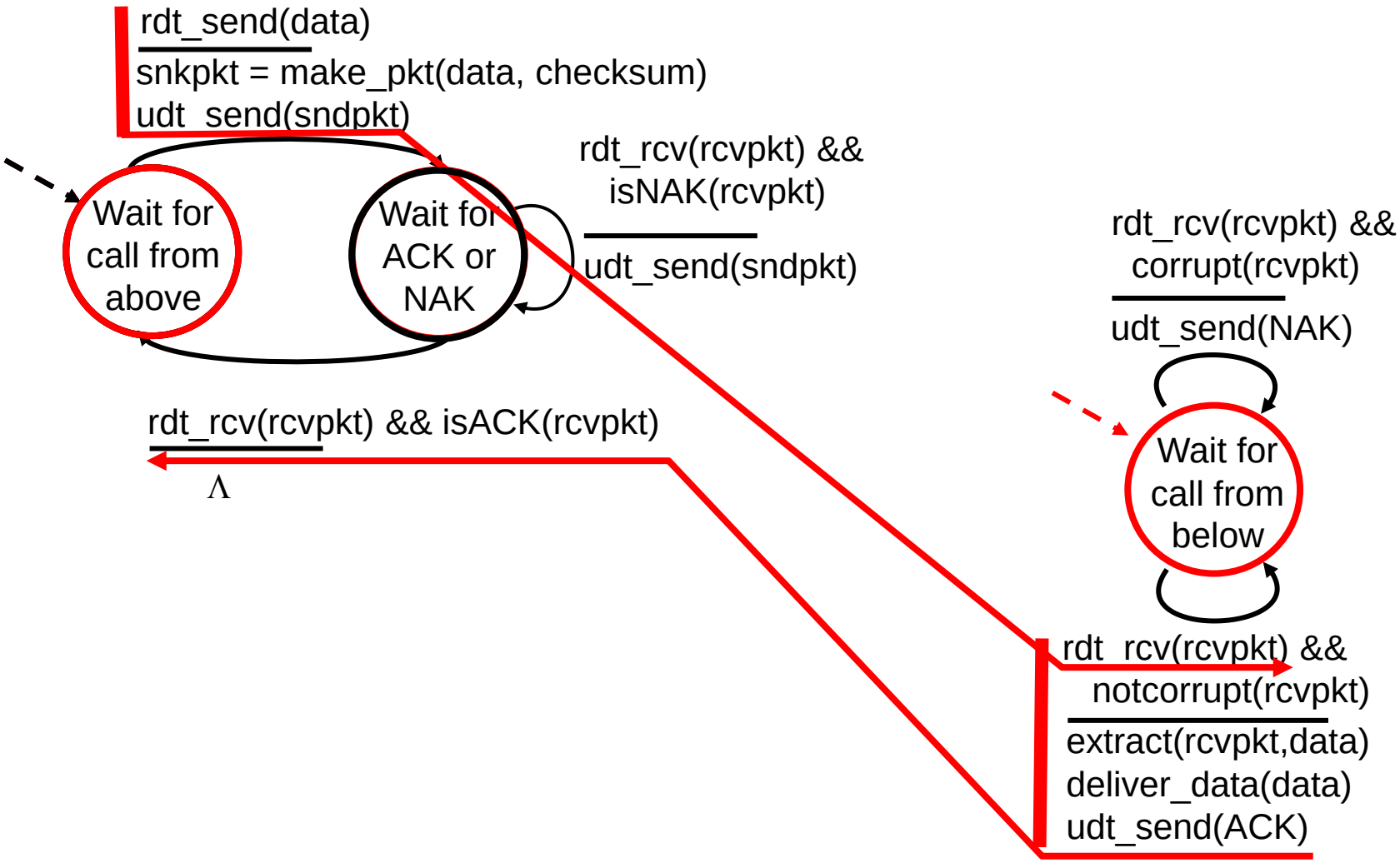
- underlying channel may flip bits in packet
  - checksum to detect bit errors
- *the* question: how to recover from errors:
  - *acknowledgements (ACKs):* receiver explicitly tells sender that pkt received OK
  - *negative acknowledgements (NAKs):* receiver explicitly tells sender that pkt had errors
  - sender retransmits pkt on receipt of NAK
- new mechanisms in `rdt2.0` (three new functionalities beyond `rdt1.0`):
  - error detection (e.g. checksum)
  - feedback: control msgs (ACK,NAK) from receiver to sender
  - retransmission: A packet arriving in error at receiver is retransmitted by the sender.

rdt2.0: FSM specification

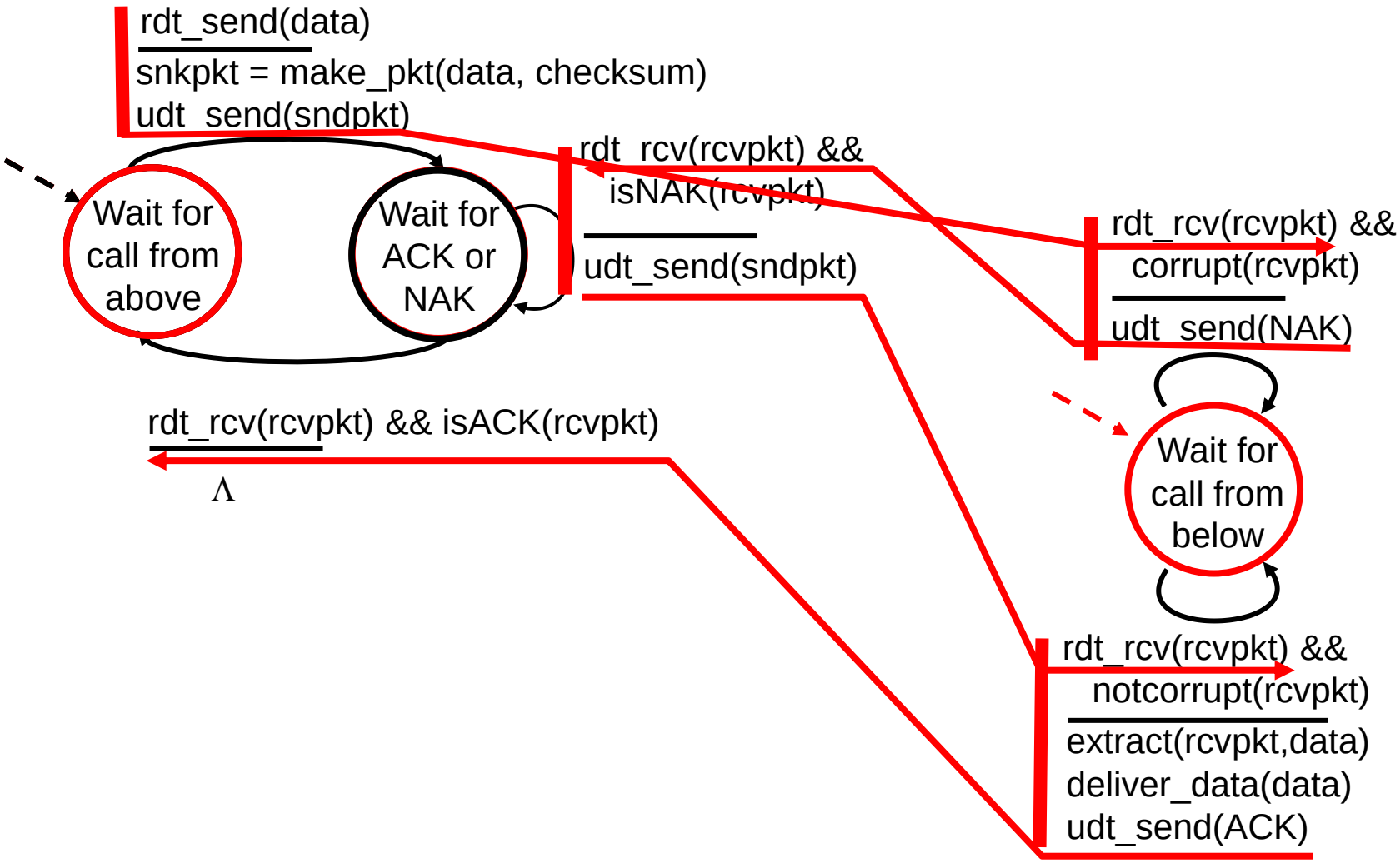




rdt2.0: operation with no errors



rdt2.0: error scenario



rdt2.0 has a fatal flaw!

what happens if ACK/NAK corrupted?

- sender doesn't know what happened at receiver!
- can't just retransmit: possible duplicate

handling duplicates:

- sender retransmits current pkt if ACK/NAK corrupted
- sender adds *sequence number* to each pkt
- receiver discards (doesn't deliver up) duplicate pkt

stop and wait

sender sends one packet, then waits for receiver response

Assignement # 2 (Chapter – 2)

- *2nd Assignment will be uploaded on Google Classroom after the lecture in the Stream Section, on 22nd September, 2022*
- *Due Date: ~~Tuesday, 4th Ocotober 2022~~ Deadline extended to 6th October, 2022(During the lecture)*
- *Hard copy of the handwritten assignment to be submitted directly to the Instructor during the lecture.*
- *Submit the Assignment allotted for your own section only*
- *Please read all the instructions carefully in the uploaded Assignment document, follow & submit accordingly*