Layer Optimization: Handling Loss
CS 118
Computer Network Fundamentals
Peter Reiher

Intralayer examples

- Integrity
- Time

Integrity

- Error
  - Detect accidental alteration
- Loss
  - Detect missing packet(s)
- Reordering (related mechanism)

Detect or correct?

- If we can correct, there’s no problem
- Here we focus on integrity failure
  - Based on detecting uncorrectable errors

can only detect, not correct

What do errors look like?

- Errors in destination address
  - The message ends up elsewhere
- Errors in source address
  - The message affects the wrong FSM
- Errors in contents
  - Impacts other layers (up to the user)

other layers, the AT NLP

It's important to know when you see an error

Making errors visible

- Consistency checks
  - Portion of a message has a valid range
  - Value is outside that range (invalid values)

  sets a valid range for consistency within that range

- Redundancy checks
  - Add redundancy in a message
  - If error only alters one of the redundant values, the other indicates an error

  redundancy to see if error alters one of the redundant values

Consistency checks

- Some values of some fields for some layers aren't allowed
- Examples:
  - Padding field in TCP header must be all zeros
  - Can't have unroutable IP address in Internet
  - IPv4 IHL field can't be less than 5

Redundancy checks

- Mathematical constraints
  - Treat contents as numbers
  - Use only values that satisfy an equation
    - Matching: $A = B$
    - Parity: $(\sum a_i)\ mod\ 2 = p$
    - Checksums
    - Cyclic Redundancy Check (CRC)

Example – IPv4 checksum

- 16-bit ones complement sum
  - Consider IPv4 header as set of 16 bit numbers
  - Add the numbers and hold the carry
  - Add the carry back in (carry-wraparound)

- Easy to implement in SW or HW

- IPv6 doesn’t have header checksum

only IPv4 has header checksum

TCP checksum

- Independent of IPv4 checksum
- Taken over entire packet (except a few IP header fields)
- Basic method like IPv4 checksum
- Somewhat different computation method if running over IPv6
  - Interlayer dependency in this optimization . . .

Loss

- Detecting when a message should have arrived but did not
  - Message completely lost
    - Never sent
    - Never arrives
  - Message source/destination error
    - Message arrives but cannot reach the intended receiver (or relay) FSM

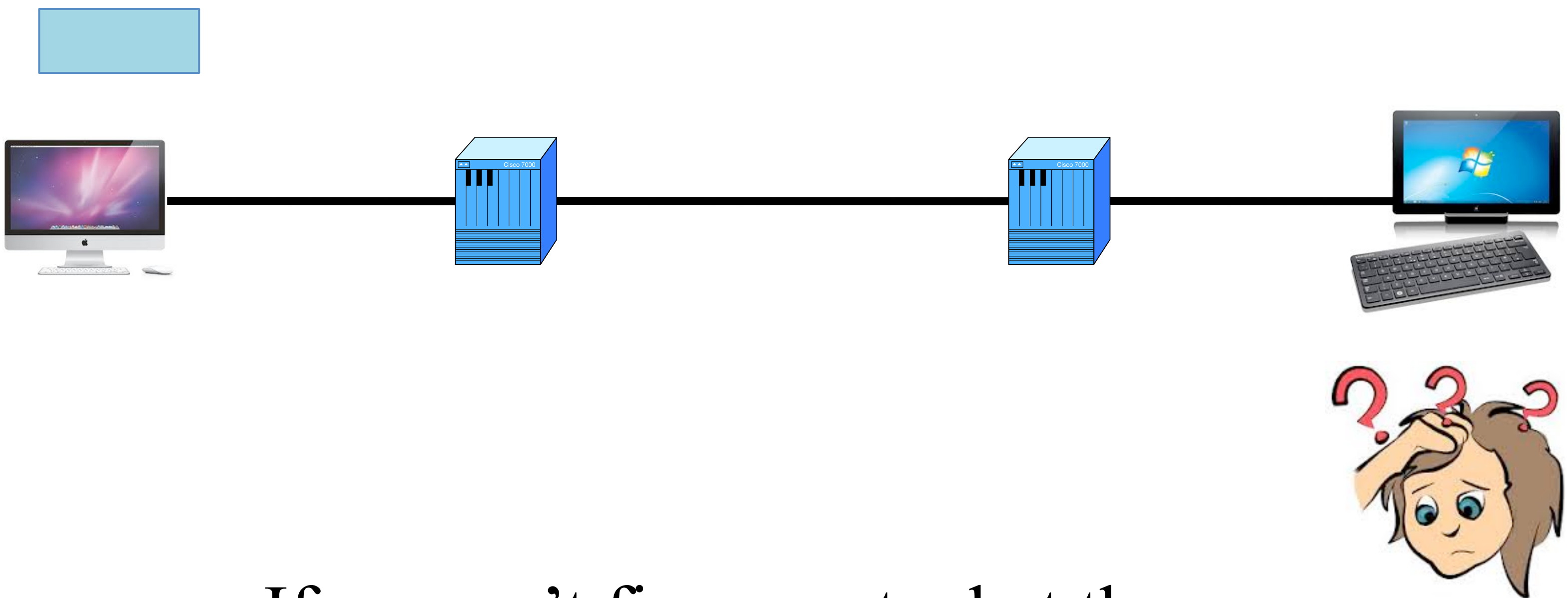
One way to lose a message

Timeout

Different Ways to Lose a Message
timeout
error detection / correction
flow control
congestion control

Another way to lose a message

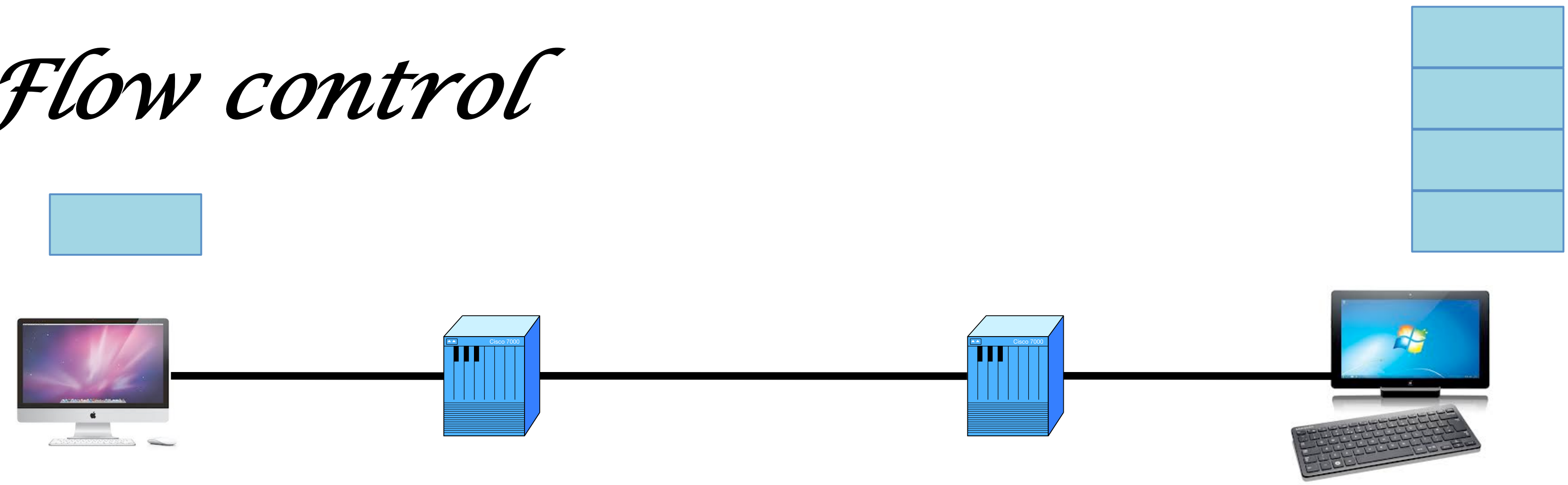
Error Detection/Correction



If we can't figure out what the message is, it's as good as lost

A third way to lose a message

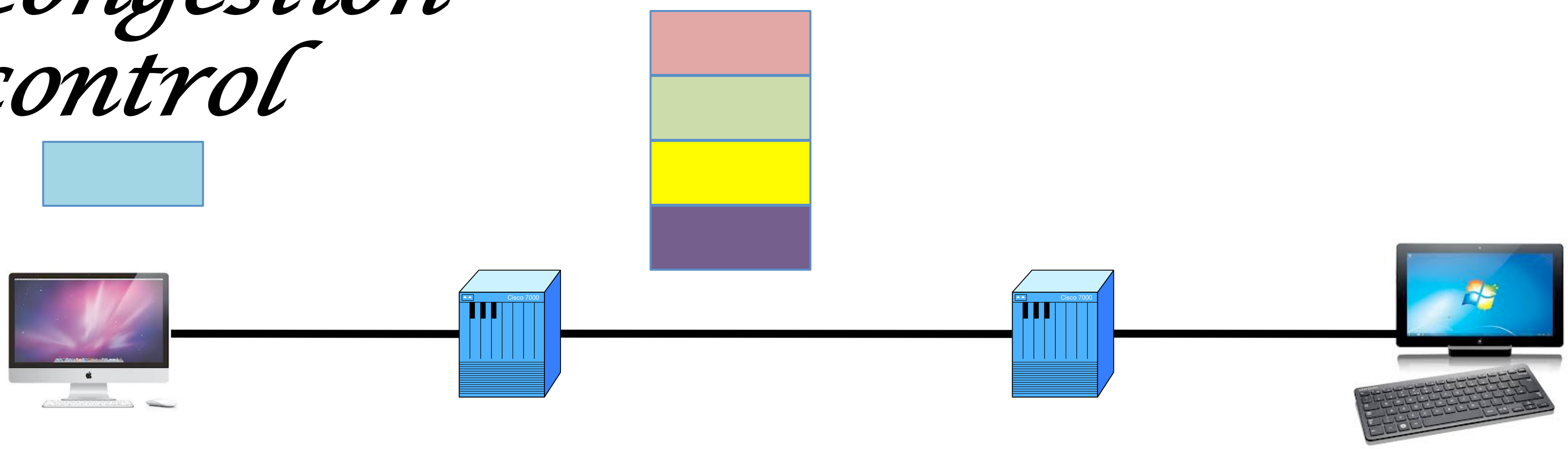
Flow control



If the receiver is too busy and has nowhere to put it, he'll have to drop it

A fourth way to lose a message

Congestion control



If the network is too congested, it may be dropped

Even if the receiver isn't overloaded

Detecting loss

- We've talked about this before
  - Need to keep track of time
  - So let's say we do…

The key issue: what time?

- Different possible times:
  - Time expected
  - Latest time we want to wait
  - Time since last message sent
  - Time since last message received
- Let's say we know (or pick) one
  - Still need to know the value to use

Estimating time

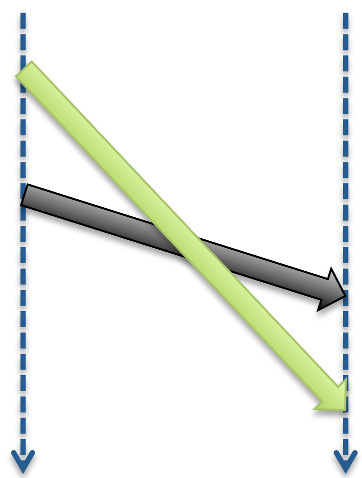
- Based on a network property
  - Number of hops (diameter)
  - Longest transmission time
  - Longest time held per relay * # relays
- Based on past measurements
  - How do we measure time?
  - How do we aggregate measurements?

Measuring time

- Need a timer
  - Can't wrap-around too quickly
  - Good resolution (time of smallest increment)
- Need to timestamp messages
  - Measure differences

Reordering

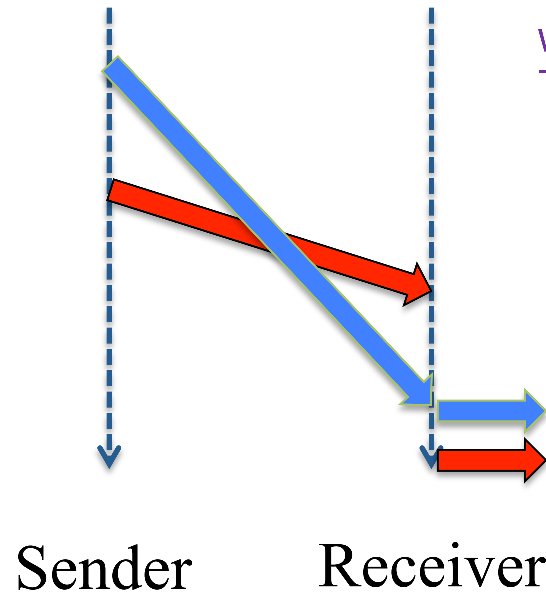
- Messages arrive without loss
  – But out of order



Fixing reordering

- Hold onto messages
  - Keep the ones that come too early
  - Process once sequence gaps are filled

way to fix reordering
This is important



RED arrives before BLUE

Wait for BLUE

Deliver BLUE first

Then deliver RED second

What’s hard about reordering?

- Need more state – a reordering buffer takes up space
- How much space?
  - Enough to store maximum displacement
- Where?
  - At the receiver, where things arrive too early
- Do you just wait for late messages?
- Or request a resend?
  - If so, how aggressively?

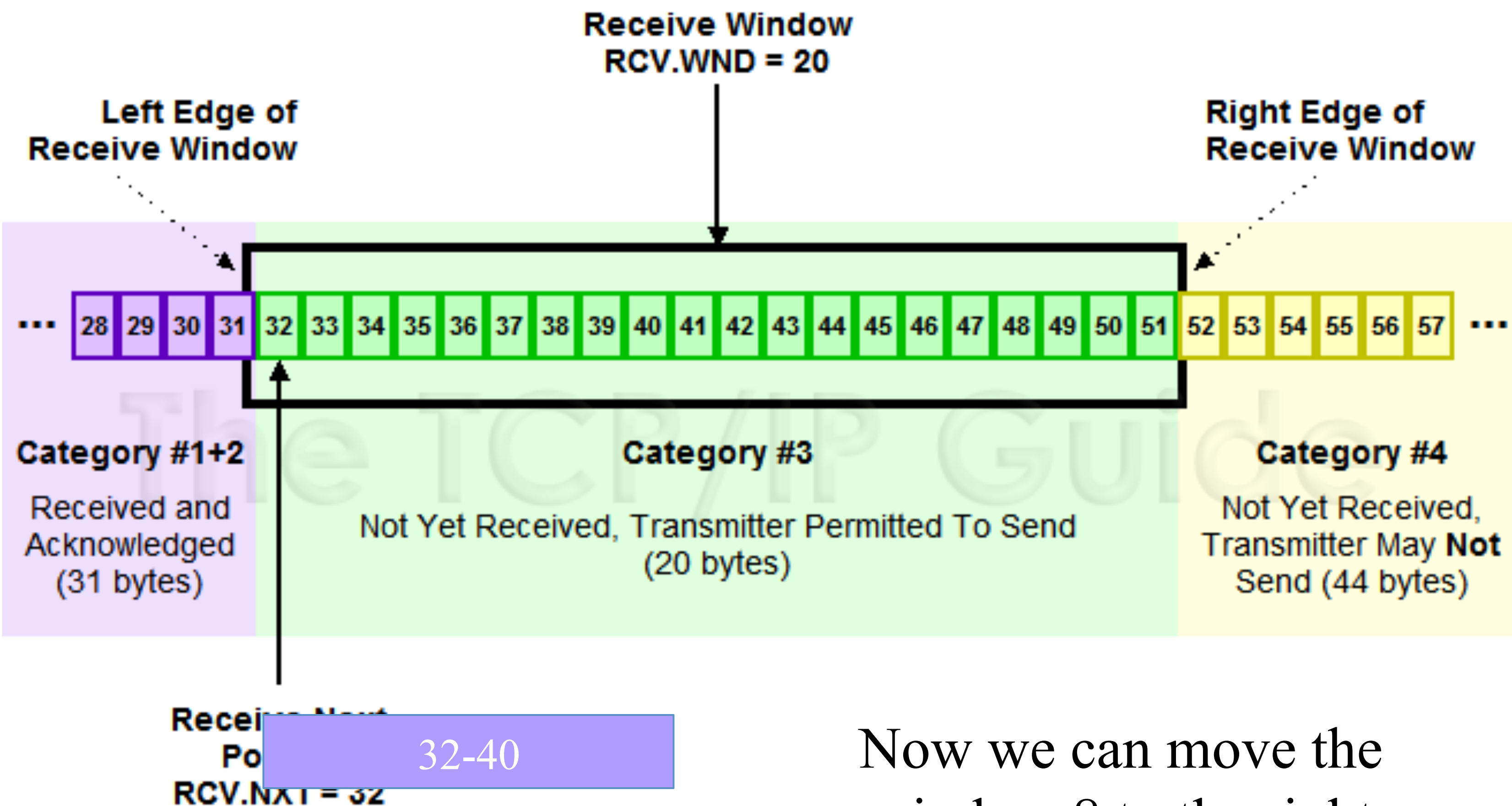
TCP receive window

- TCP segments have a sequence number
  - Number indicates byte offset of each segment
- TCP receive window enables reordering
  - Make it large to handle large displacements
  - Left side = smallest offset not yet here
  - Right side = largest offset that can be held

Receive window management

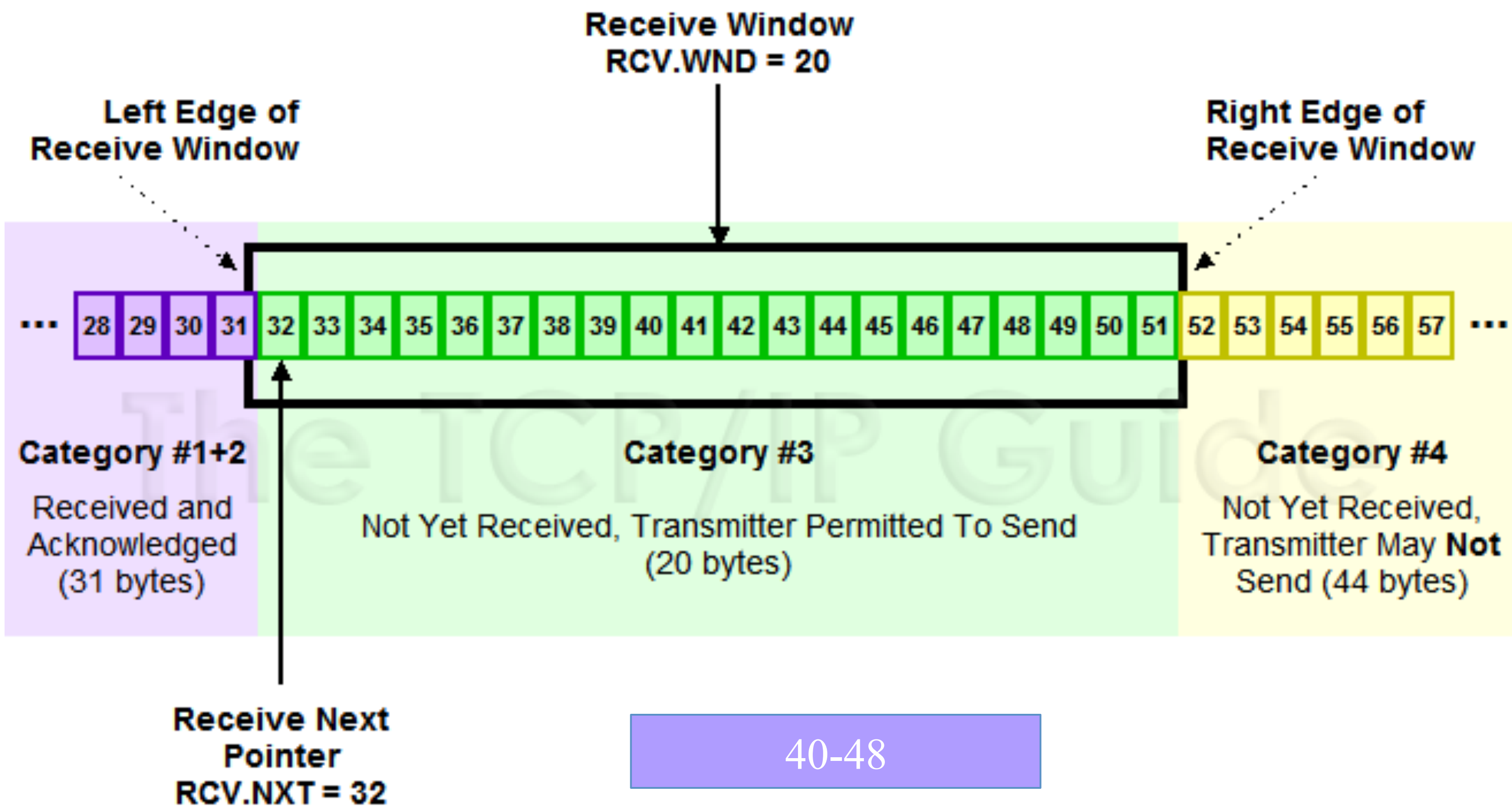
- Message arrives
  - Put it in the buffer if it fits
  - Buffer size = RCV.WND
- RCV.NXT (left side)
  - Move right to deliver info to the user (upper)
  - Stop and wait at the first gap
- RCV.NXT + RCV.WND (right side)
  - Moves right (allow higher offsets) whenever left side moves right

Receive window



Now we can move the window 8 to the right

Receive window with misordering



Can’t move the window yet

Hmm – what’s that about the sender?

- That figure shows how the receive buffer is tied to the send buffer
- The receive buffer is for reordering
  - So what’s the send buffer for?
  - Why (and how) are the two related?

Time

- Flow control
- Congestion Control
- Latency management

Flow control I

- Not overrunning the receiver
  - The receiver always can handle one message
  - Send that,
    wait for confirmation,
    send the next, …

- Why does the sender need to wait?
  - Message was lost
  - Message is waiting at the receiver
    - If receiver can handle messages as fast as the sender, not an issue
  - Solution: send one at a time
    - One message outstanding at any given time

    avoid waiting, send one message at a time

Stop and Go

- Assume a sequence number
  - One number per message
- Sender and receiver work in lockstep
  - Both “walk” the number space
  - Both have “inchworm” behavior

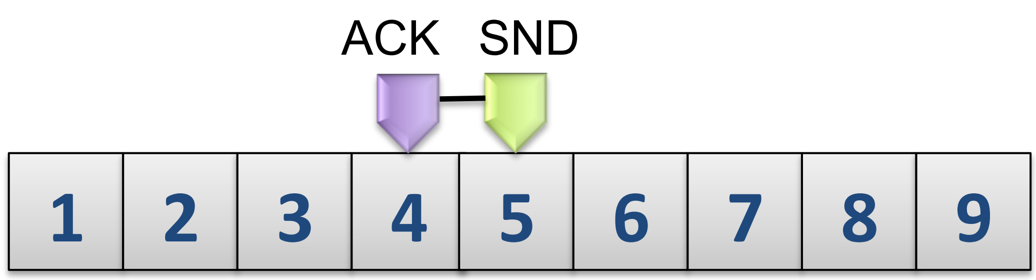
Let’s take a walk

- Messages are numbered

- Sender “walks” the line via receiver ACKs

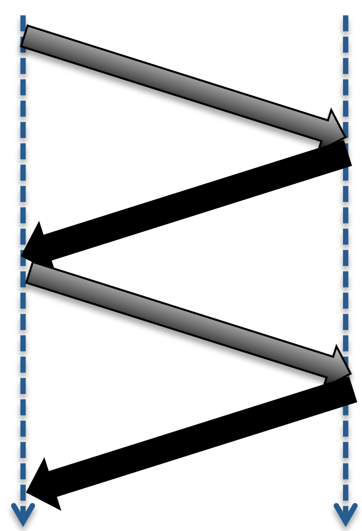
Limiting the walk

- Send and receiver ACK linked by a limit
  - $SND - ACK \leq N$ equation for linking send and receive
  - For stop-and-go, N=1



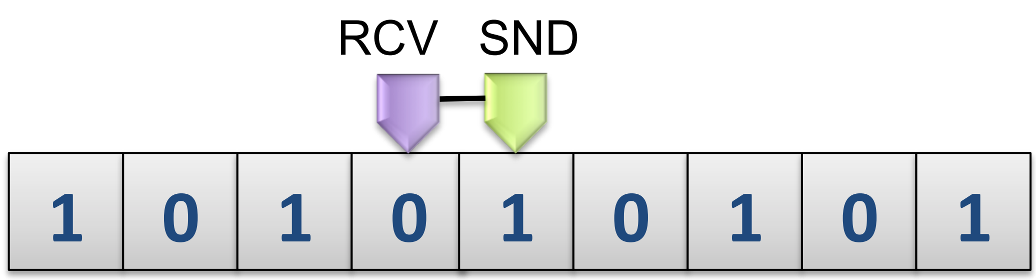
A look at the exchanges

- One message per round trip
  - ACK indicates *received* and *ready for next*



A look at the numbering

- If SND and ACK differ by at most 1, we don't need to number 1..999
  – OK to just number 0,1,0,1,0,1
  – Also known as "alternating bit" protocol



Why do anything else?

- Receiver might be faster than sender
  - In which case it could handle more messages
- Learning that receiver has handled a message takes time
  - At least time to get acknowledgement to sender
- During that time, channel is not in use, receiver is not busy, sender is not busy
  - Lots of wasted resources

What if we have more than 1 outstanding message?

- Messages could arrive out of order
  - As we've already discussed
- A message could arrive while receiver is busy handling an earlier message
  - Not possible with 1 message window Stop and Go
- If we allow multiple outstanding messages, we must handle both problems

Flow control II

- How to handle these problems?
- As discussed, use a buffer to handle misordered messages
  - The receive window indicates max misorder
  - Also max “outstanding” held messages
- Hmm – let’s use that buffer two ways!
  - If receiver is busy when message arrives, put it in the buffer
  - Even if it is the next message to be received
- So we can send more than one at a time…

Go Back N

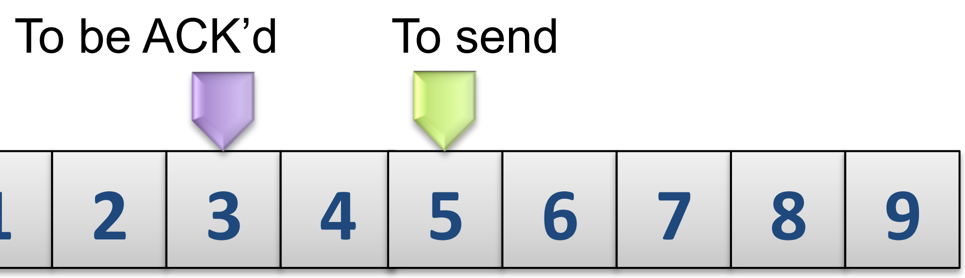
- Assume a sequence number
  - One number per message
- Sender and receiver work in lockstep
  - Both “walk” the number space
  - Both have “inchworm” behavior

Just like stop-and go, but with N messages

Let’s take another walk

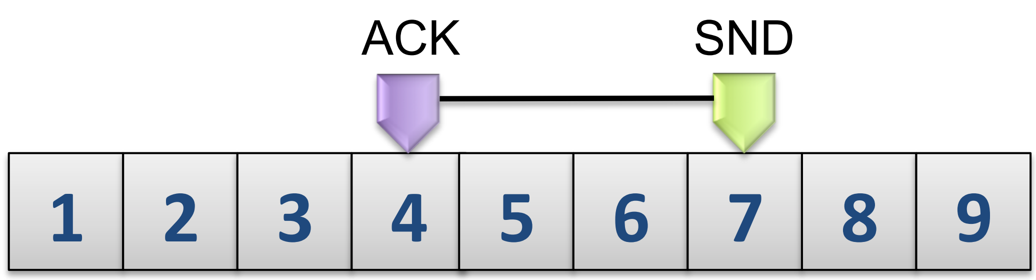
- Messages are numbered

- Sender “walks” the line via receiver ACKs



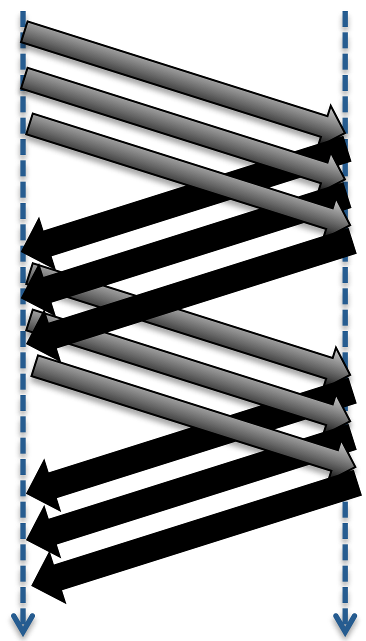
Limiting the walk

- Send and receiver ACK linked by a limit
  - $SND - ACK \leq N$
  - For Go-back-N, N>1



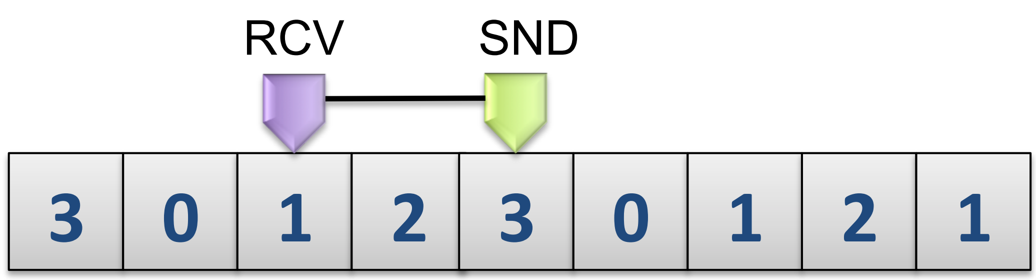
A look at the exchanges

- N messages per round trip
  - ACKs indicates *received* and *ready for next*



A look at the numbering

- If SND and ACK differ by at most N, we don't need to number 1..999
  - OK to just number 0,1,2,3,…,2N-1



Why 2N values?

- N outstanding values
  - Each RTT, the window can slide forward by N
  - Need to prevent overlap from one RTT to next

How big is N?

- How many messages before getting ACK?
  - Once you get the ACK for the first,
    you can send N+1
  - ACK provides a "clock" to the pipeline
    - Every ACK/N+1 pair acts like stop-and-go
    - Go-back-N is *like* N overlapping stop-and-go

N overlapping stop and go is a good analogy for stop and go

About the receive window

- What if the receiver isn't fast enough?
  - Info (message) has to go into the buffer as fast as it arrives (or we have other problems!)
  - If the FSM doesn't release the info to the upper layer as fast as it comes in, there's a delay

Recall receive rules

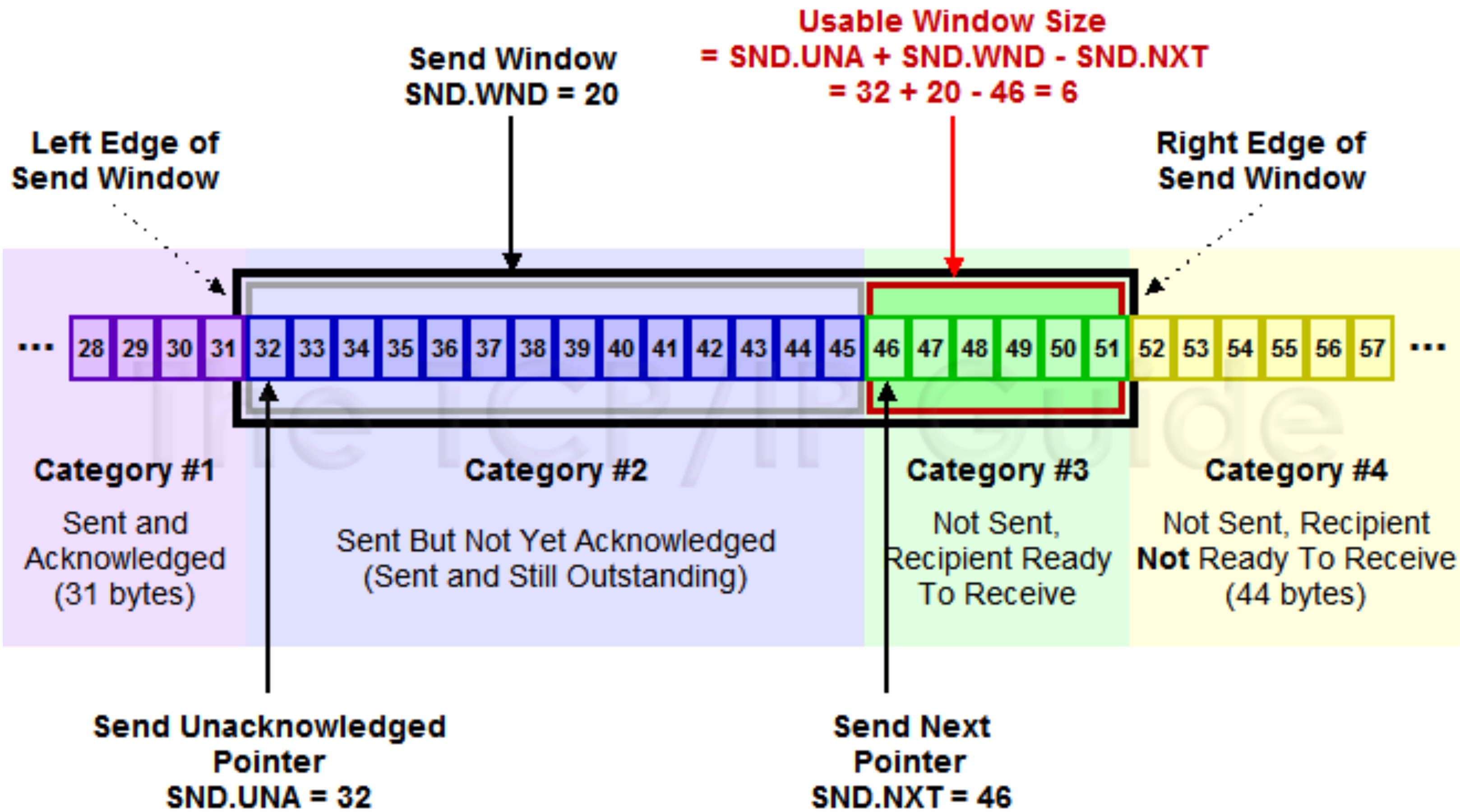
- Info (message) arrives
  - Place message in sequence
  - Move left side to the right until a gap
    - Pass that info to the next layer up
  - Right side moves to the right at the same time
- <u>If</u> the FSM is fast enough
  - The left side doesn't move immediately
    - Takes time – time to process the message

Left and right

- If left side doesn't move, right doesn't
  - I.e., receiver isn't ready for new offset info
- How do we coordinate with the sender?
  - Sender has a similar buffer
  - SND.WIN = RCV.WIN
    - If smaller, we could have sent messages that could have been held by receiver – wasted resources
    - If bigger, we won't be able to send it anyway (we can only fill the receive buffer!)

flow control - uses a window --> at sender, permitted to send out certain amount of data to the receiver; receiver checks what they have seen
- deal with misordered messages
- receiver is capable of holding a certain amount of data until his FSM is capable of catching up wit hthe different layers; ensure no overflow

Coordinating SND and RCV



guarantee that we can send you all the data we have

Combining loss + windowing

s

- Positive feedback (ACK)
  - Indicate what was received
- Negative feedback (NACK)
  - Indicate what is missing but expected
  - Always a gap after the last msg received

use NACK when we know something is missing

Use this info to coordinate retransmission

if negative ack, we can go ahead and do a retransmission

Loss / windowing variants

- Stop and Go   one at a time request for retransmit
  - On timeout, send retransmit request
  - Only one message to ever request
- Go back N   back up to lowest ACK every trip
  - On timeout, ACK lowest missing sequence number
  - Sender "backs up" to where ACK indicates
  - Every round trip, backs up to the lowest gap
- Selective ACK   ACK everything you send ; selective repeat
  - ACK everything you get, ask to fill in the holes
  - Sender fills in only the holes

    resend one packet at a time

Congestion control

- Receiver might be ready, but is the net?
  – Don’t want to overwhelm the network

control the congestion of data
when sender and receiver are both okay, but network is too busy

- We have some windows
  – Send = how much info *can* be outstanding
  – Recv = how much info *can* be reordered
- *Can* isn’t the same as *should*

How much SHOULD be outstanding?

Solution: congestion window

receive window stays fixed

- Receive window
  - Stays fixed (no benefit to adjusting)
  - As large as reordering max
  - As large as send pipelining too
- Send window
  - No larger than the reordering max
  - As large as is needed to keep up with the receiver
  - Not so large that messages are lost in the net
- OK, how big is that?

increase the send window to keep up with the receiver