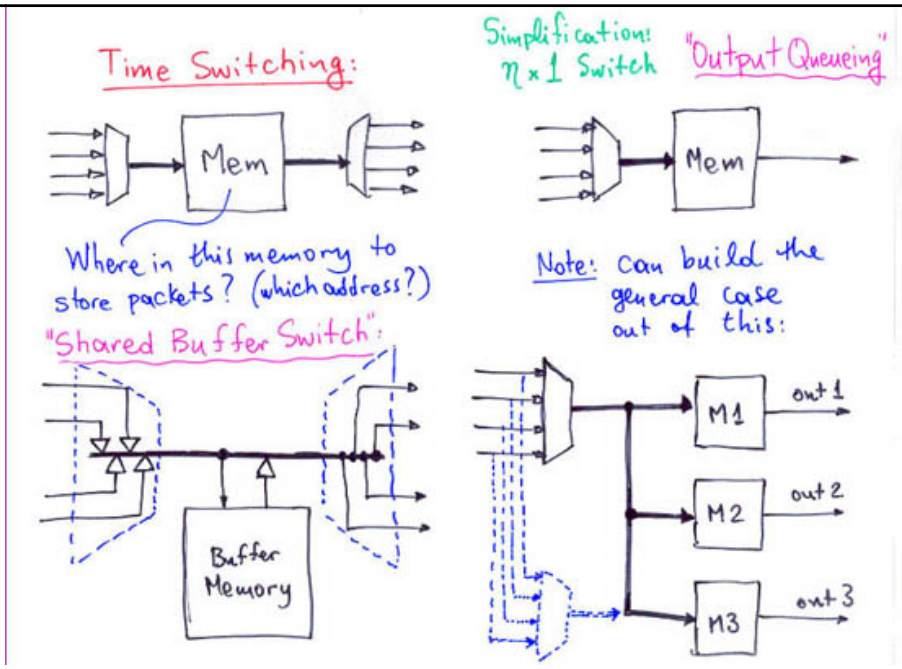
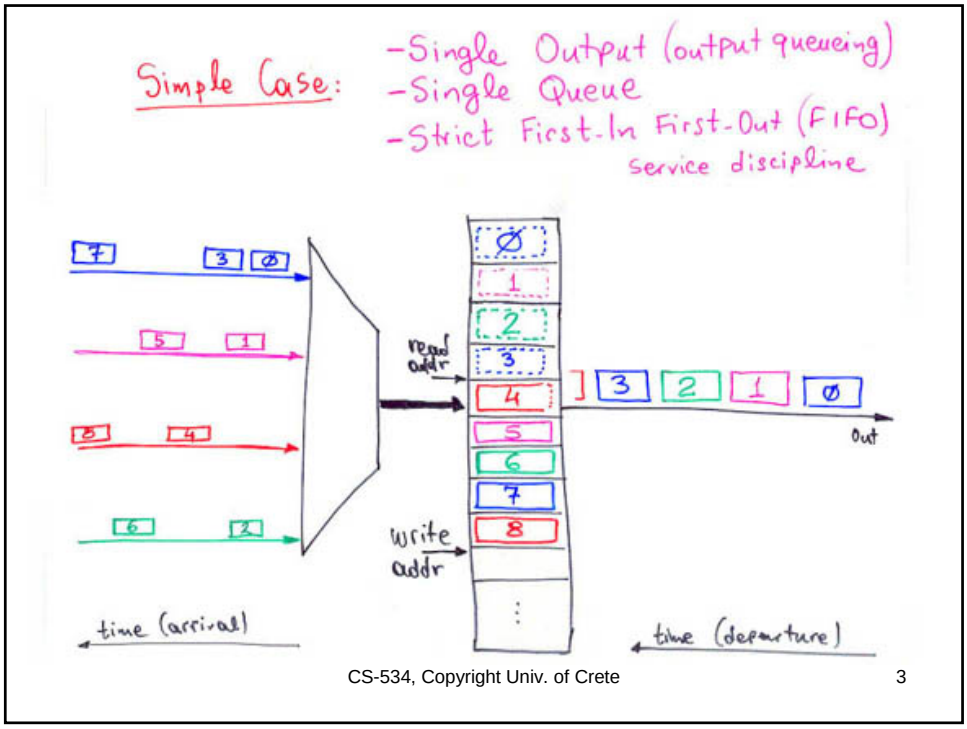
3.1 The need for multiple queues within a same buffer memory: Multi-Queue Data Strucutres

- Buffers memories for time switching: what data structures?
- Single queue feeding multiple destinations/classes
  ⇒ Head-of-Line (HOL) Blocking ⇒ poor performance
- Multiple Queues in one buffer:
  - Partitioned Space (underutilized) ⇒ circular queues
  - Shared Space (efficient) ⇒ linked-list queues




Simple Case:
-Single Output (output queueing)
-Single Queue
-Strict First-In First-Out (FIFO) service discipline
read addr
write addr
Out
time (arrival)
time (departure)
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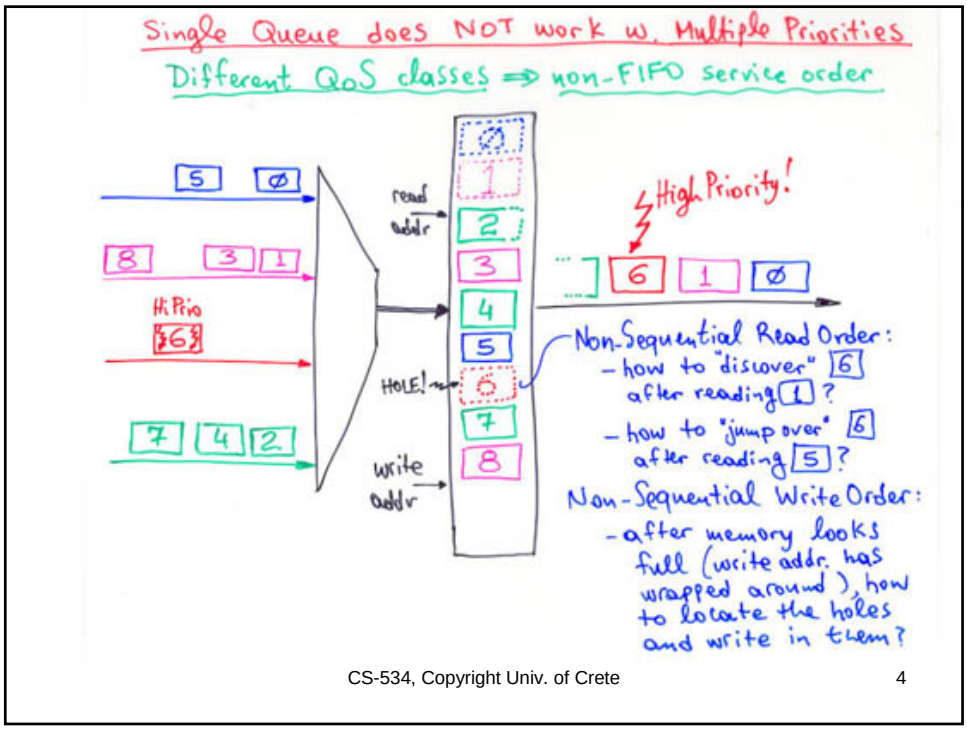
Single Queue does NOT work w. Multiple Priorities
Different QoS classes ⇒ non-FIFO service order
High Priority!
HiPrio
HOLE!
read addr
write addr
Non-Sequential Read Order:
- how to "discover" 6 after reading 1 ?
- how to "jump over" 6 after reading 5 ?
Non-Sequential Write Order:
- after memory looks full (write addr. has wrapped around), how to locate the holes and write in them?
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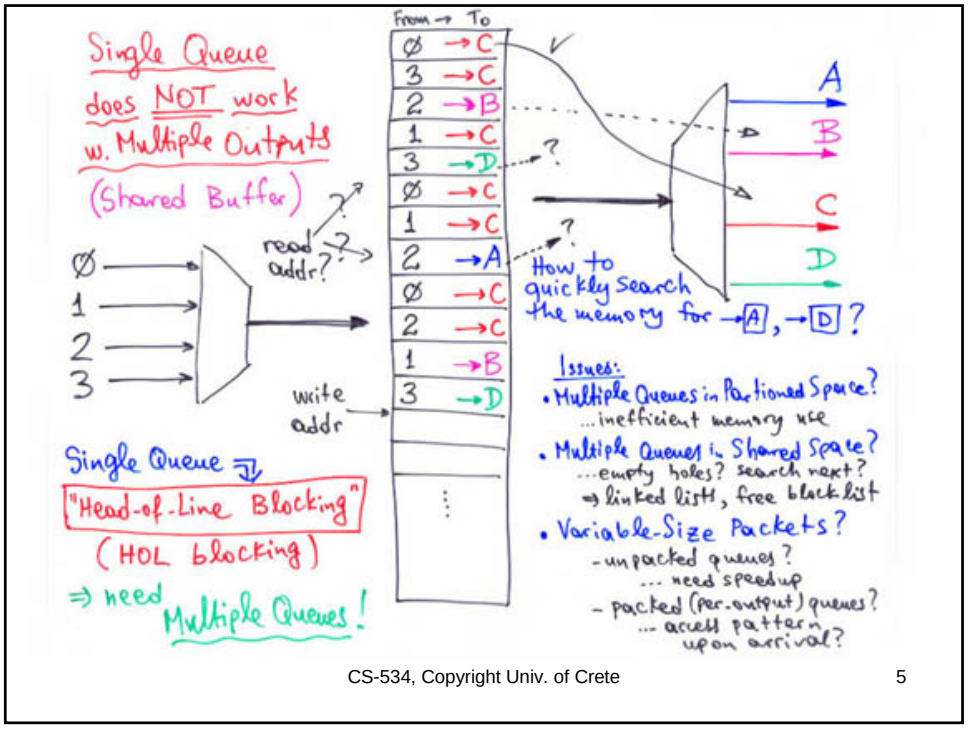
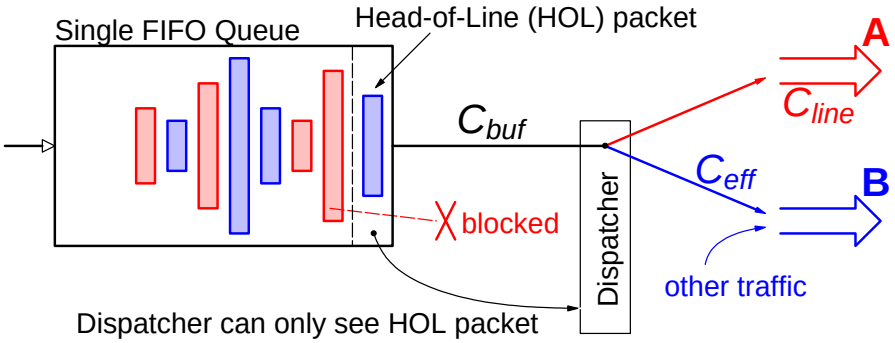


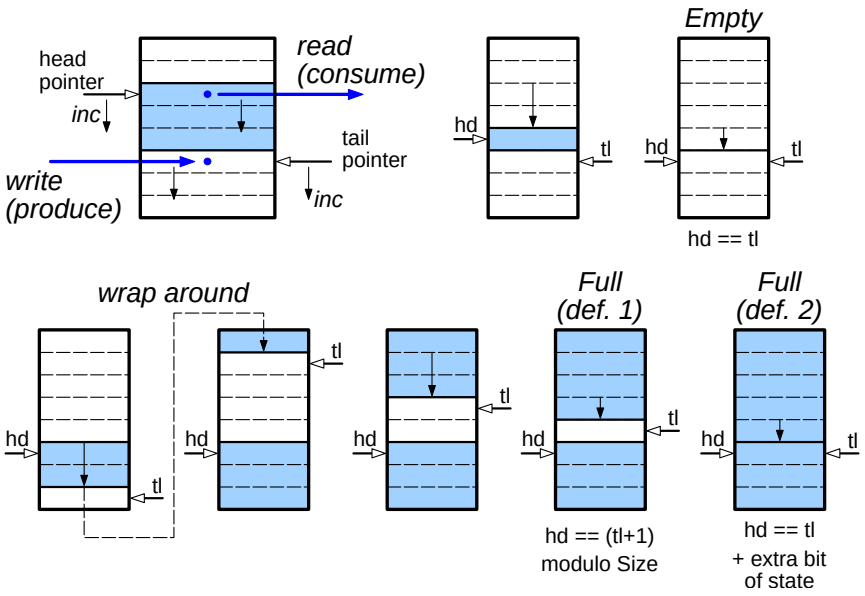
Shared Queue ⇒ Head-of-Line (HOL) Blocking



- Queue shared among multiple destinations/classes (A and B)
- $C_{line} < C_{buf}$ or $C_{eff} < C_{buf}$ due to other traffic

⇒ HOL packet can block packets behind it to other dest./classes

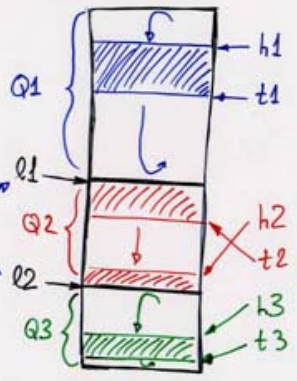
Reminder: Circular Array Implementation of FIFO Queu



B.2 Multiple FIFO Queues with Statically Partitioned Space

for each of them:

- One RAM for all queues; Two counters/pointers per queue.
- Limits between queue areas (partitions) can be "hardwired", or "configurable" off-line (when queues are empty); limit registers needed in the latter case
- Underutilization of memory space (one queue may overflow, while space exists on others)
- Variable-size packets OK.



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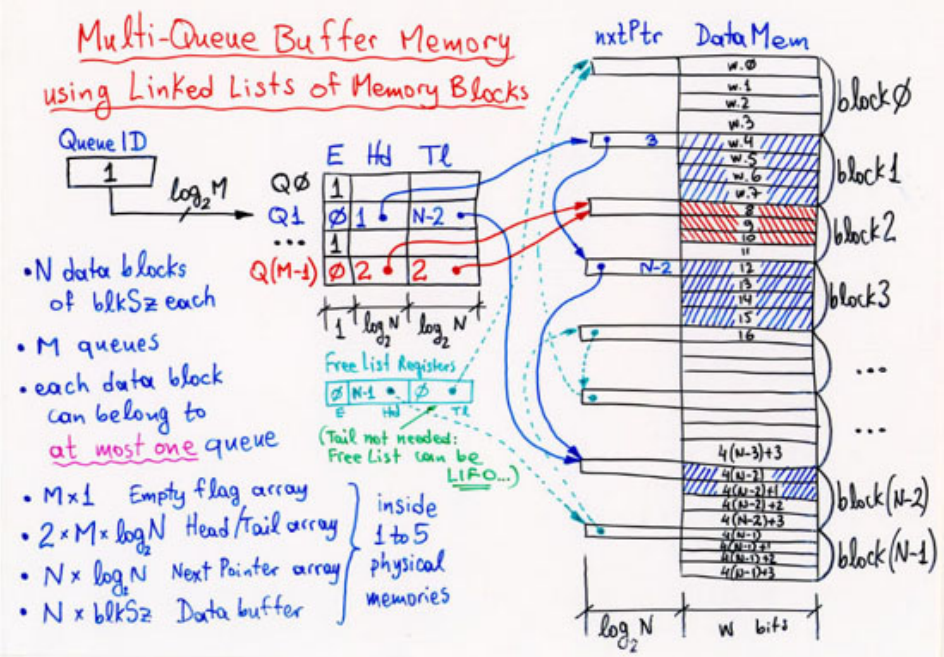
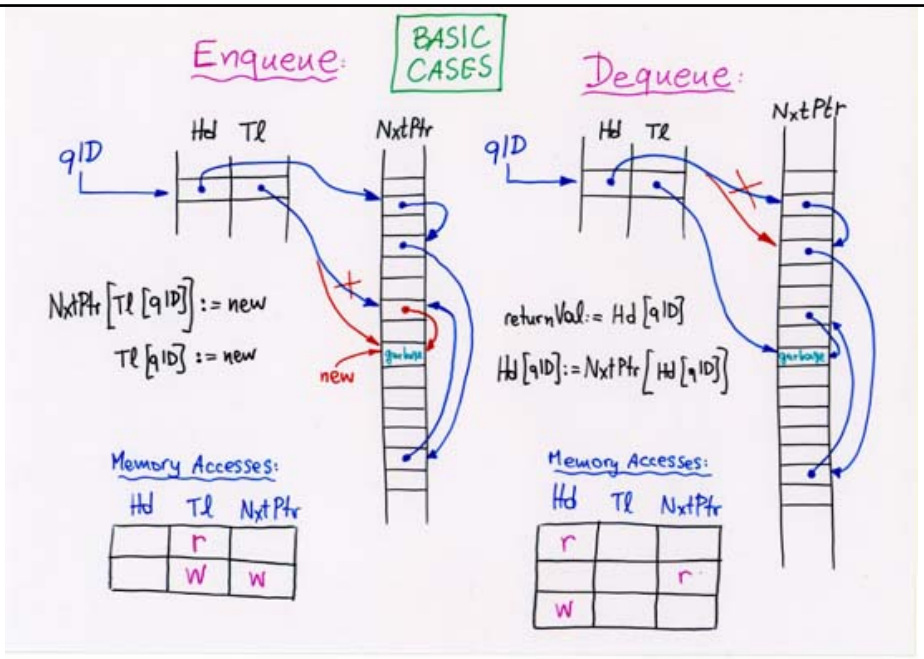
12.6

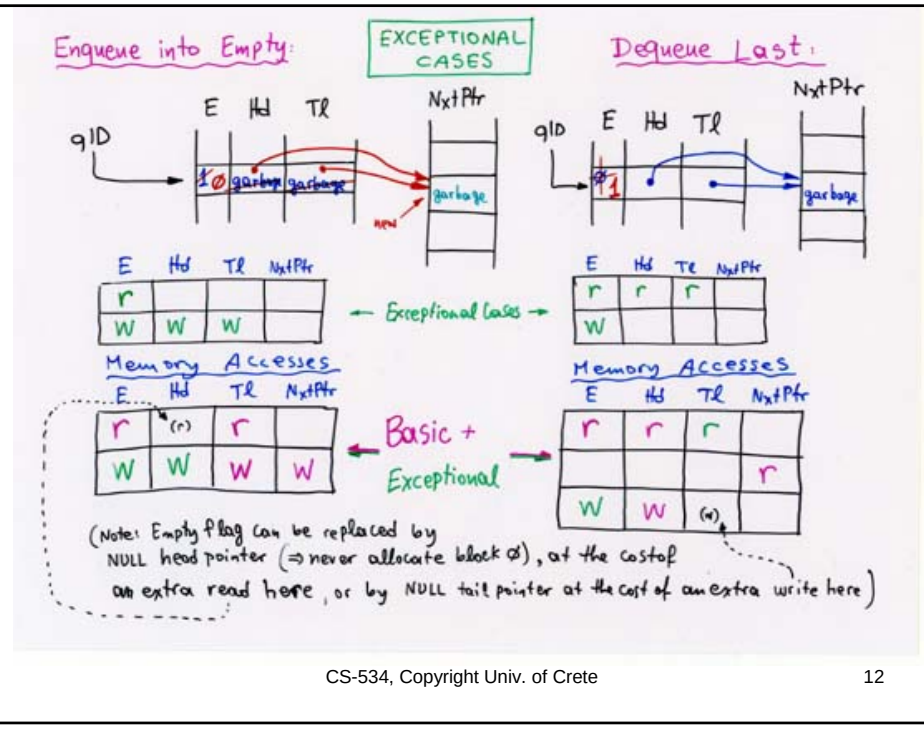
Multiple Queues Sharing a Buffer Memory Space

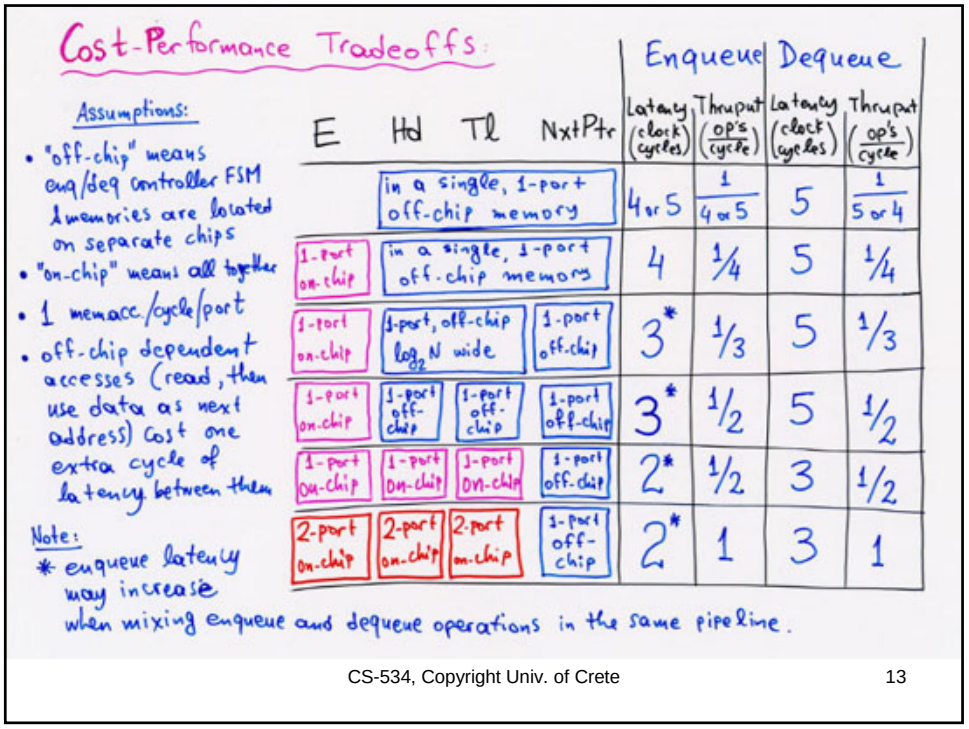
- Often need many queues where most have low occupancy (or empty) but few have high occupancy
- Departures create holes ⇒ empty space is fragmented
  ⇒ neighboring packets physically non-contiguous
  ⇒ linked-list data structure

  Reference: Y. Tamir, G. Frazier: "High Performance Multi-Queue Buffers for VLSI Communication Switches", ISCA 1988
- "*malloc( )*" works on fixed-size blocks
  - block size is a tradeoff between fragmentation cost (for very large blocks) and memory address rate (for very small blocks): see exercise set 4
  - … unless multiple packet fragments in a same block – ex. 6.1




Enqueue:
BASIC CASES
Dequeue:
qID
Hd Tl
NxtPtr
NxtPtr[Tl[qID]] := new
Tl[qID] := new
new
garbage
returnVal := Hd[qID]
Hd[qID] := NxtPtr[Hd[qID]]
Memory Accesses:
Hd Tl NxtPtr
r
w
w
Memory Accesses:
Hd Tl NxtPtr
r
r
w

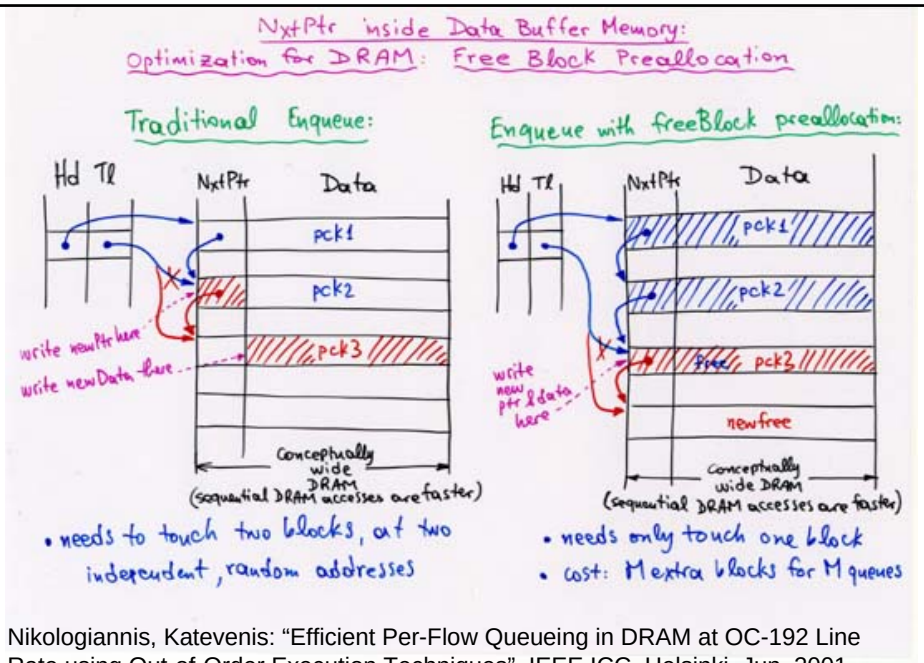

Enqueue into Empty:
EXCEPTIONAL CASES
Dequeue Last:
qID
E Hd Tl
NxtPtr
garbage
new
E Hd Tl NxtPtr
r
w w w
← Exceptional cases →
E Hd Tl NxtPtr
r r r
w
Memory Accesses
E Hd Tl NxtPtr
r (r) r
w w w w
Basic +
Exceptional
Memory Accesses
E Hd Tl NxtPtr
r r r
r
w w (w)
(Note: Empty flag can be replaced by NULL head pointer (⇒ never allocate block ∅), at the costof an extra read here, or by NULL tail pointer at the cost of an extra write here)



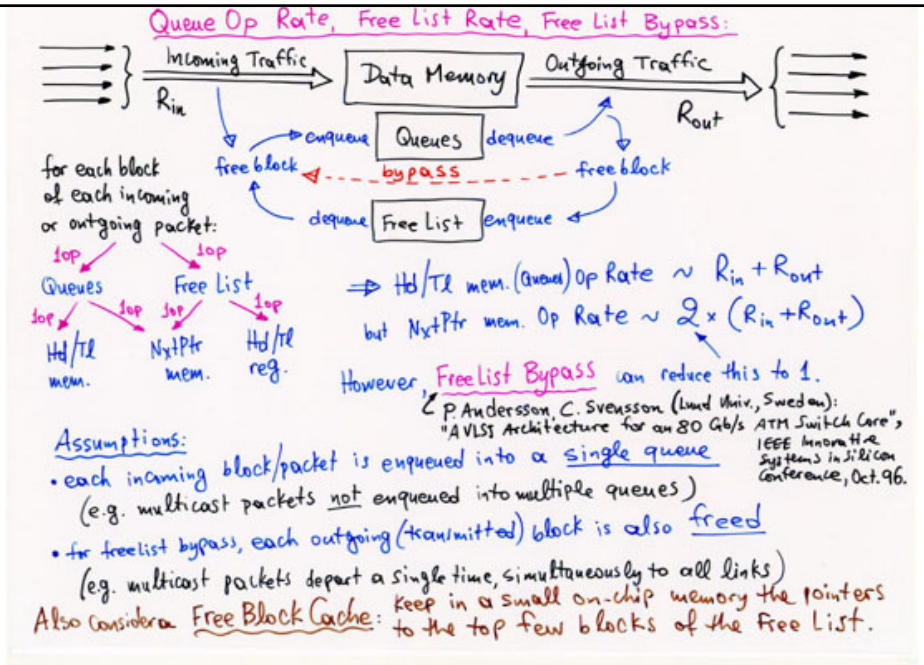
Notes on Enqueue/Dequeue Performance Table

- Table assumes we always need to perform both normal and exceptional accesses – see ex. 5.1
- Table assumes fall-through timing for off-chip SRAM: one-cycle latency per access, plus one extra cycle between dependent off-chip accesses – see ex. 5.2
- For peak throughput: overlap successive operations (latency of individual operations increases)

  For a highly pipelined implementation, refer to: Kornaros, Kozyrakis, Vatsolaki, Katevenis: ``Pipelined Multi-Queue Management in a VLSI ATM Switch Chip with Credit-Based Flow Control'', 17th Conf. on Advanced Research in VLSI, 1997



Nikologiannis, Katevenis: "Efficient Per-Flow Queueing in DRAM at OC-192 Line Rate using Out-of-Order Execution Techniques", IEEE ICC, Helsinki, Jun. 2001 15



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Dropping a Segment (= move to free list) or Moving a Segment to a Different Queue

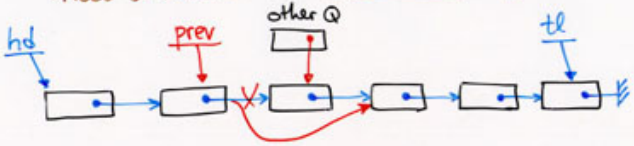
(1) From the Head of the Source Queue:

(a) dequeue from source queue,

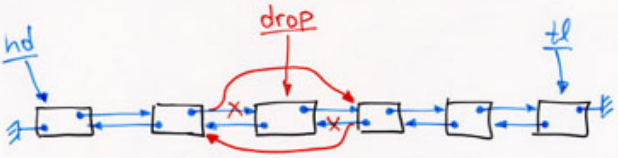
(b) enqueue into destination Q.

(2) From the "Middle" of the Source Queue

- Need a Pointer to the Previous Segment:



else • Need Doubly Linked List:



Dropping Entire Packet (multi-segment) or moving to other Queue:

(1) In O(pckSize) Time:

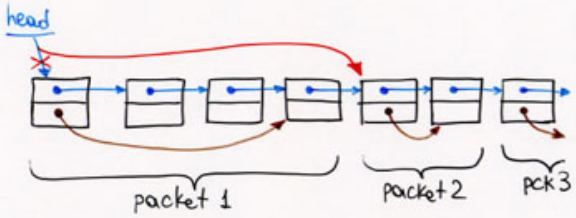
- Drop or move one segment at a time ...

⇒ takes time proportional to the size of the packet

Usually, this consumes the same resources (time, memory ports) as if the packet were transmitted to the output port

(2) In O(1) Time:

- Need two next-pointers per segment:

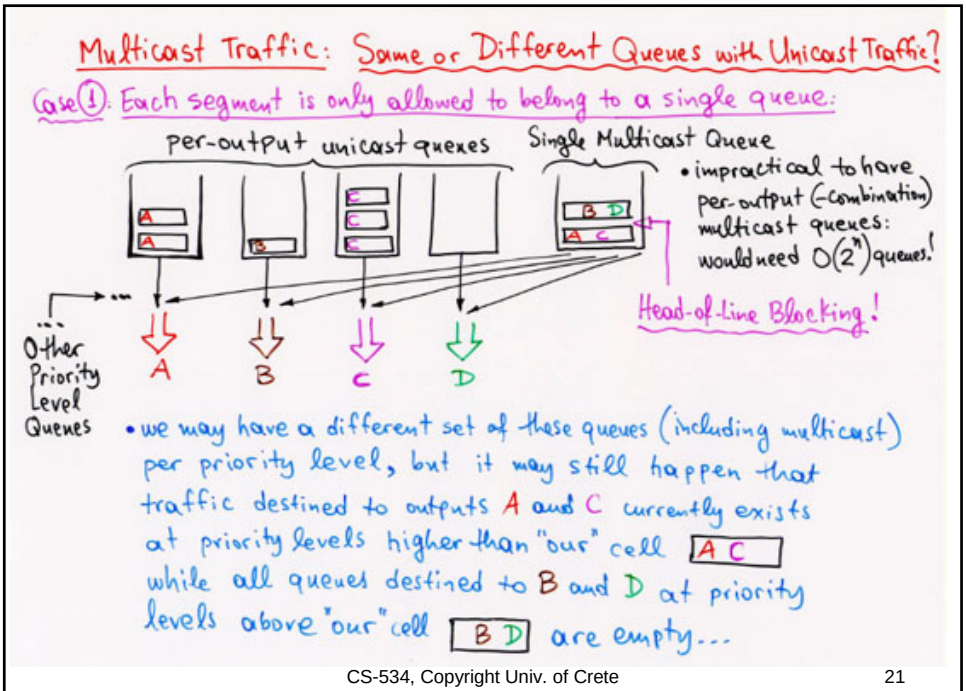


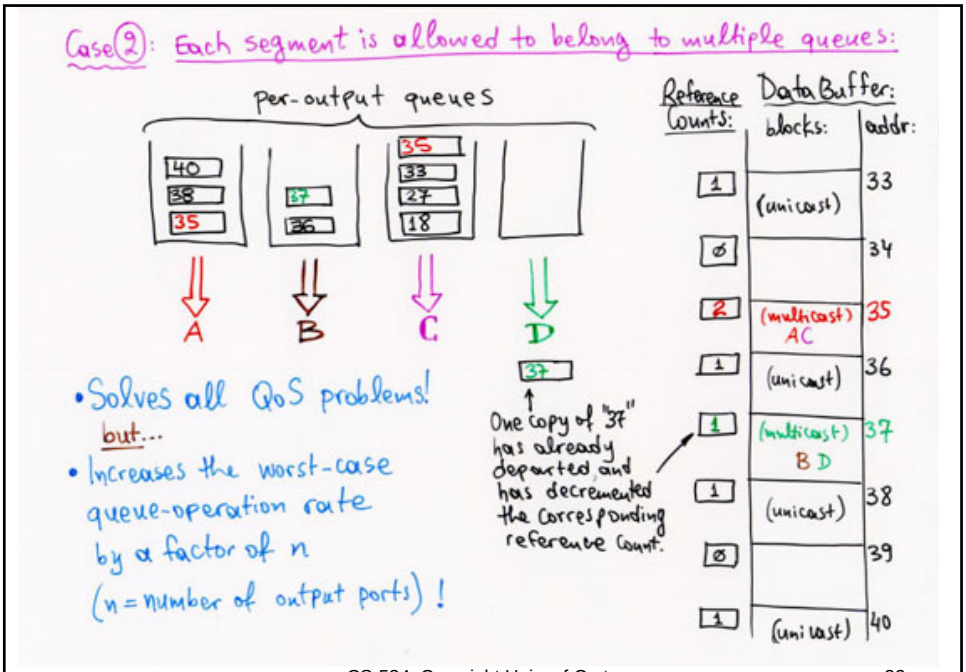
(the utilization of the second set of pointers is only: $\left(\frac{1}{\text{average number of segments per packet}}\right)$

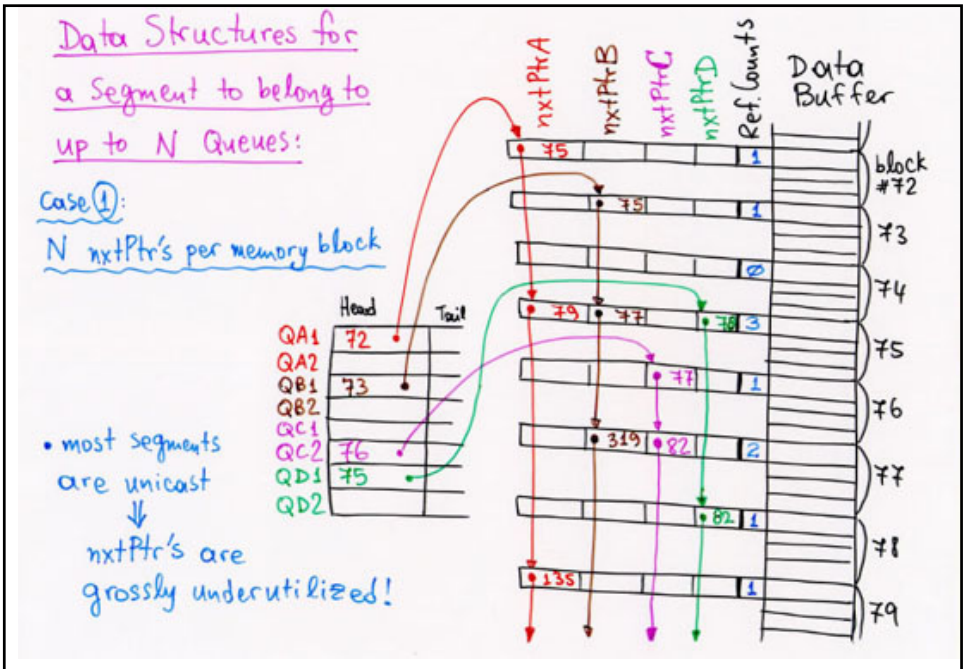
→ alternative: separate "packet descriptor" data structures, like for multicast segment descriptors — see below).

Queueing for Multicast Traffic

- Multicast traffic is expected to become very important in the future –but so has it been for many years in the past…
- Supporting multicast traffic usually increases complexity and cost
- Queueing for Multicast Traffic:
  - Each segment (block) allowed in only one queue ⇒ HOL blocking
  - Each segment allowed in multiple queues ⇒ need many nxtPtr's
  - Enqueue throughput and nxtPtr space: static vs. dynamic sharing
- References:
  - F. Chiussi, Y. Xia, V. Kumar: "Performance of Shared-Memory Switches under Multicast Bursty Traffic", IEEE Jour. Sel. Areas in Communications (JSAC), vol. 15, no. 3, April 1997, pp. 473-487.
  - D. Stiliadis: "Efficient Multicast Algorithms for High-Speed Routers", Proc. IEEE Workshop on High Performance Switching and Routing (HPSR 2003), Torino, Italy, June 2003, pp. 117-122.




Case (2): Each segment is allowed to belong to multiple queues:
per-output queues
A
B
C
D
Reference Counts:
Data Buffer:
blocks:
addr:
(unicast)
(multicast) AC
(unicast)
(multicast) B D
(unicast)
(unicast)
One copy of "37" has already departed and has decremented the corresponding reference count.
• Solves all QoS problems!
but...
• Increases the worst-case queue-operation rate by a factor of n (n = number of output ports)!


Data Structures for a Segment to belong to up to N Queues:
Case (1):
N nxtPtr's per memory block
nxtPtrA
nxtPtrB
nxtPtrC
nxtPtrD
Ref. Counts
Data Buffer
Head
Tail
QA1
QA2
QB1
QB2
QC1
QC2
QD1
QD2
• most segments are unicast
nxtPtr's are grossly underutilized!

Case (2): Decouple Linked List Nodes from Data Buffer Addresses

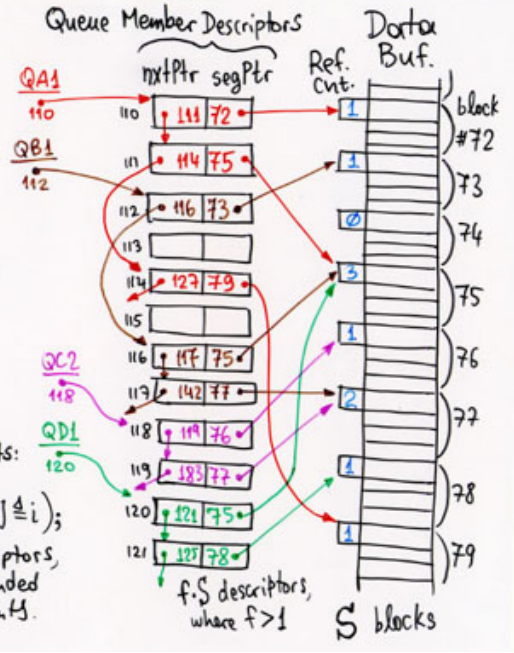
- twice the cost per nxtPtr (need a segPtr as well now)

but...

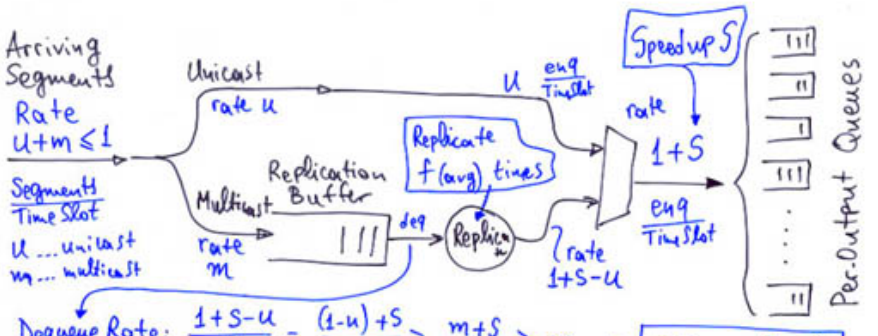
- much fewer than N·S descriptors (based on average ratio of unicast-to-multicast segments, and average fan-out of multicast segments - e.g. f=2)

Optimization:
Partition the address space of queue member descriptors into two parts:

- Ø to S-1: unicast-only segments, no segPtr needed (segPtr[i] ≙ i);
- S to fS-1: full queue member descriptors, with nxtPtr and segPtr, intended for use by multicast segments.



Enqueue Operation Rate for multicast segments onto multiple per-output queues



Dequeue Rate: $\frac{1+S-u}{f} = \frac{(1-u)+S}{f} \geq \frac{m+S}{f} \geq m \Rightarrow S \geq m\cdot(f-1)$

for the replication buffer not to overflow

References:

- F. Chiussi, Y. Xia, V. Kumar: IEEE JSAC, April 1997, pp. 473-487
- D. Stiliadis: HPSR 2003, pp. 117-122