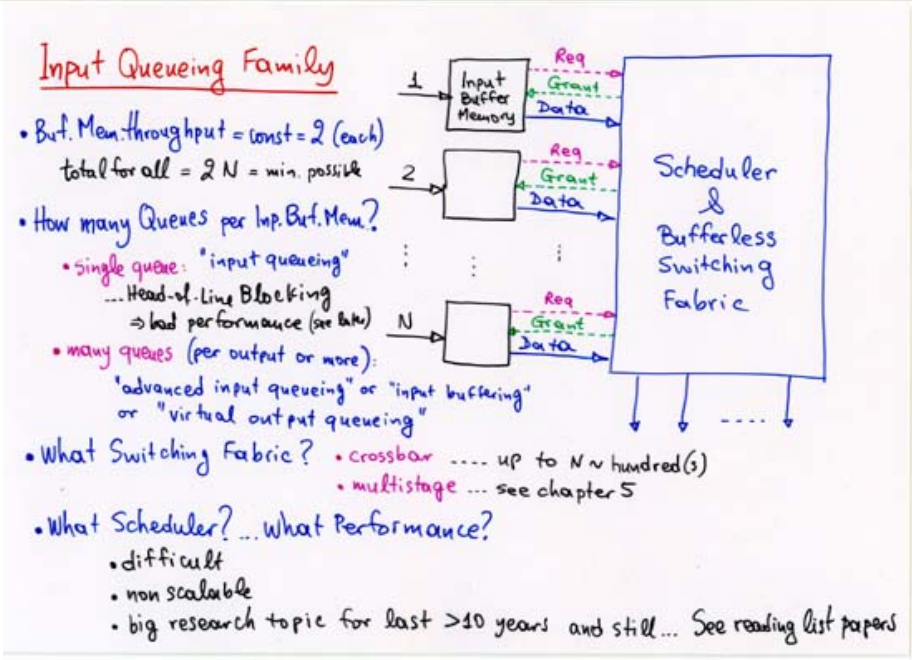
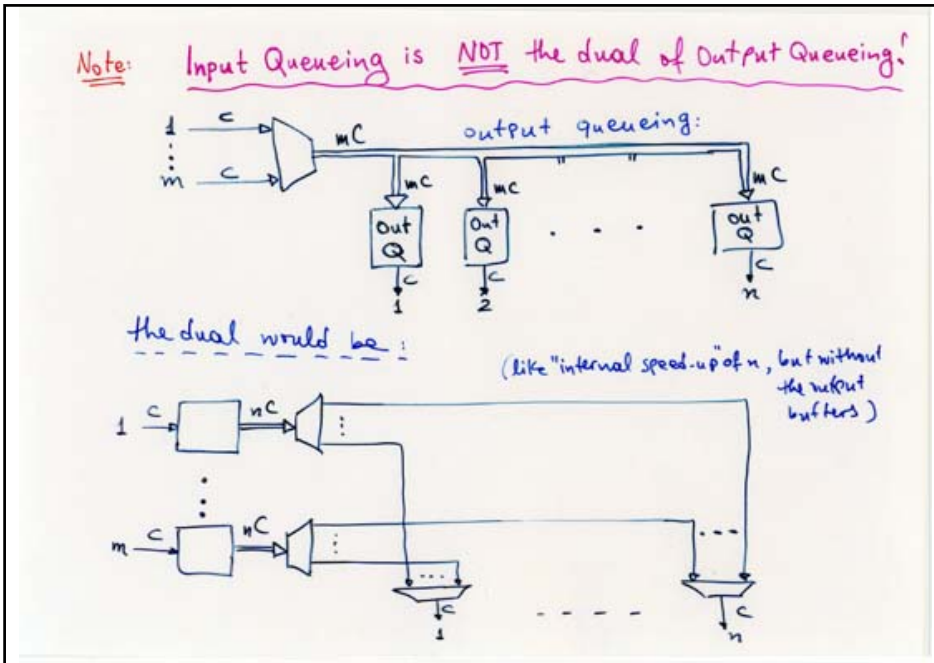
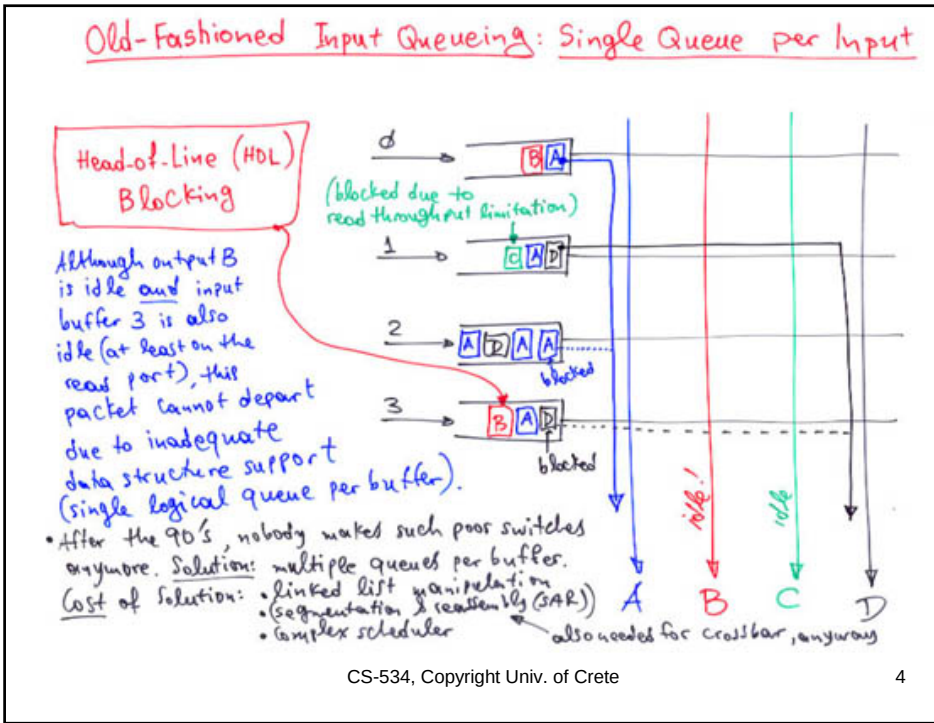
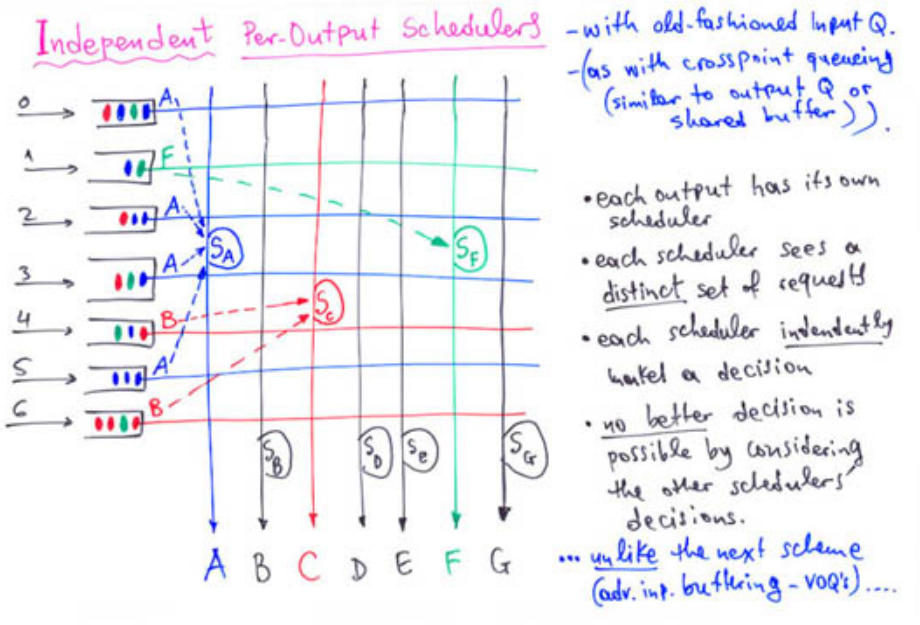
4.2 Input Queueing
(a) the Single-Queue per Input Case

- Crossbar Switch with one Buffer Memory per Input Line
- Throughput per Buffer Memory = 1 (incoming) + 1 (outgoing)
- *Not* the Dual of Output Queueing
  - Output-queueing throughput per buffer memory = *N+1*
  - Output queueing does *not* contain a crossbar:
    a crossbar allows each output to be fed by at most *one* input;
    output queueing allows each output to be fed by *any* (even all) inputs
- Crossbar Scheduling is an issue
  - Single queue per input ⇒ independent schedulers per-output (easy)
  - Multiple queues per input (next section) ⇒ difficult…



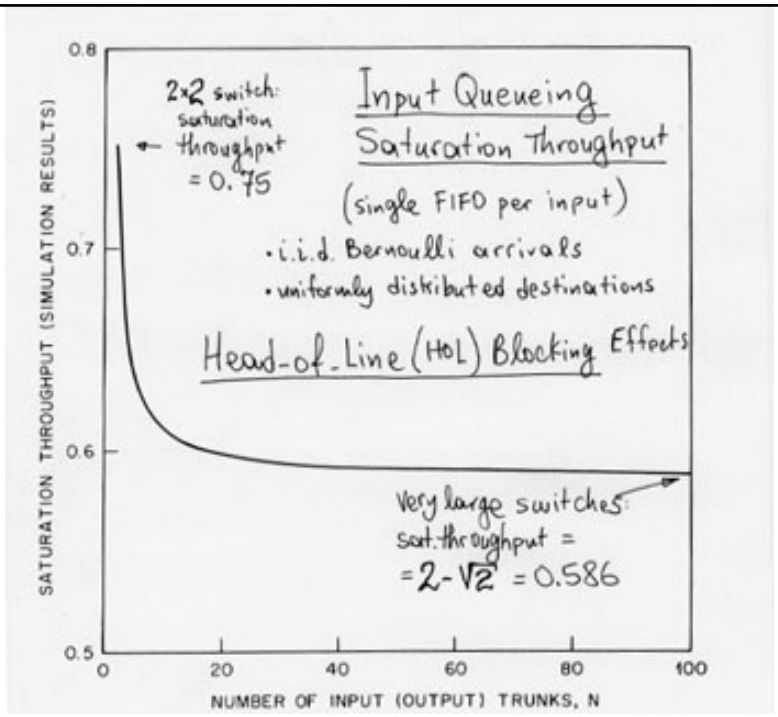

Note: Input Queueing is NOT the dual of Output Queueing!
output queueing:
Out Q
the dual would be:
(like "internal speed-up" of n, but without the output buffers)


Old-Fashioned Input Queueing: Single Queue per Input
Head-of-Line (HOL) Blocking
(blocked due to read throughput limitation)
blocked
idle
idle
A
B
C
D
Although output B is idle and input buffer 3 is also idle (at least on the read port), this packet cannot depart due to inadequate data structure support (single logical queue per buffer).
• After the 90's, nobody makes such poor switches anymore. Solution: multiple queues per buffer.
Cost of Solution:
• linked list manipulation
• (segmentation & reassembly (SAR))
• complex scheduler
also needed for crossbar, anyway

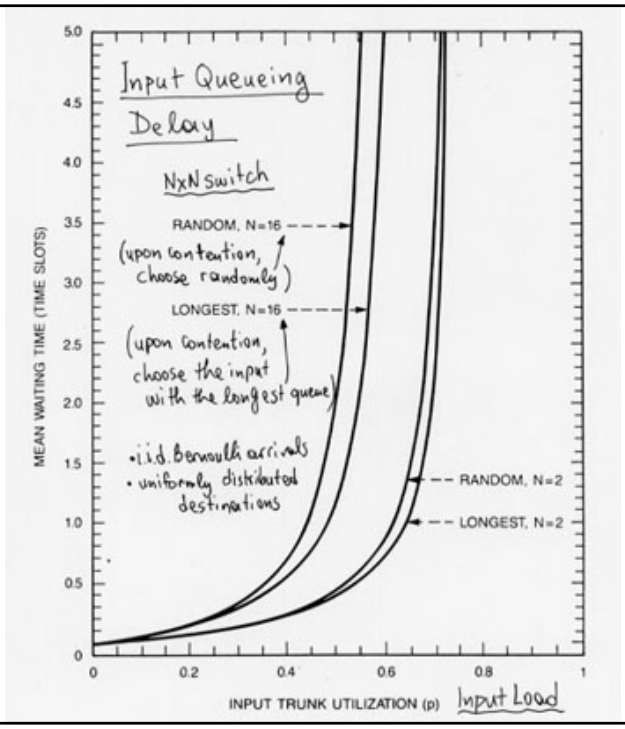


Throughput & Delay under Single-Queue Input Q'ing

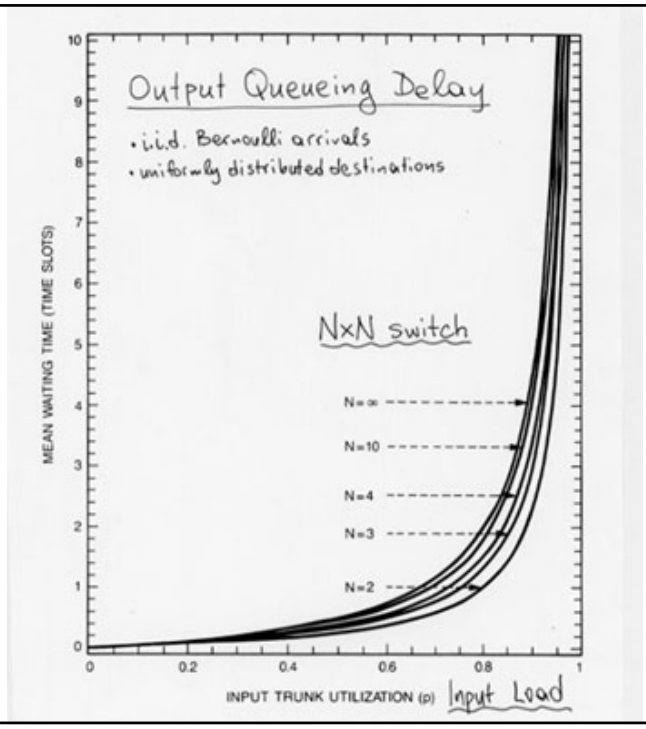
- *References:*
  - M. Hluchyj, M. Karol: "Queueing in High-Performance Packet Switching", IEEE Journal on Sel. Areas in Commun. (JSAC), Dec. 1988, pp. 1587-1597.
  - M. Karol, M. Hluchyj, S. Morgan: "Input versus Output Queueing on a Space-Division Packet Switch", IEEE Tr. on Communic., Dec. 1987, pp. 1347-1356.
  - J. Hui, E. Arthurs: "A Broadband Packet Switch for Integrated Transport", IEEE Journal on Sel. Areas in Commun. (JSAC), Oct. 1987, pp. 1264-1273.
- *Attention:* results for i.i.d. Bernoulli (non-bursty) arrivals, with uniformly-distributed destinations (no overloaded hot-spots), are only useful for gaining a rough, first insight into the behavior of systems, but are often not representative of the real behavior of systems under real traffic!...


Input Queueing
Saturation Throughput
(single FIFO per input)
• i.i.d. Bernoulli arrivals
• uniformly distributed destinations
2×2 switch: saturation throughput = 0.75
Head-of-Line (HOL) Blocking Effects
Very large switches: sat. throughput = $2-\sqrt{2}$ = 0.586
SATURATION THROUGHPUT (SIMULATION RESULTS)
NUMBER OF INPUT (OUTPUT) TRUNKS, N
0.8
0.7
0.6
0.5
0
20
40
60
80
100

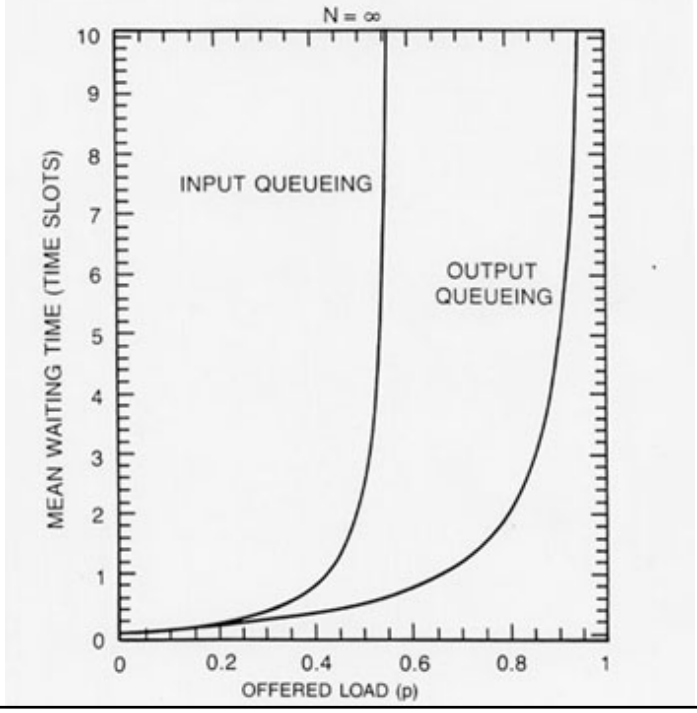
7


Input Queueing
Delay
N×N switch
RANDOM, N=16
(upon contention, choose randomly)
LONGEST, N=16
(upon contention, choose the input with the longest queue)
• i.i.d. Bernoulli arrivals
• uniformly distributed destinations
RANDOM, N=2
LONGEST, N=2
MEAN WAITING TIME (TIME SLOTS)
INPUT TRUNK UTILIZATION (p)
Input Load
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0.2
0.4
0.6
0.8
1

8


Output Queueing Delay
• i.i.d. Bernoulli arrivals
• uniformly distributed destinations
NxN switch
N=∞
N=10
N=4
N=3
N=2
MEAN WAITING TIME (TIME SLOTS)
INPUT TRUNK UTILIZATION (p)
Input Load
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7
8
9
10

9


N = ∞
INPUT QUEUEING
OUTPUT QUEUEING
MEAN WAITING TIME (TIME SLOTS)
OFFERED LOAD (p)
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7
8
9
10

10