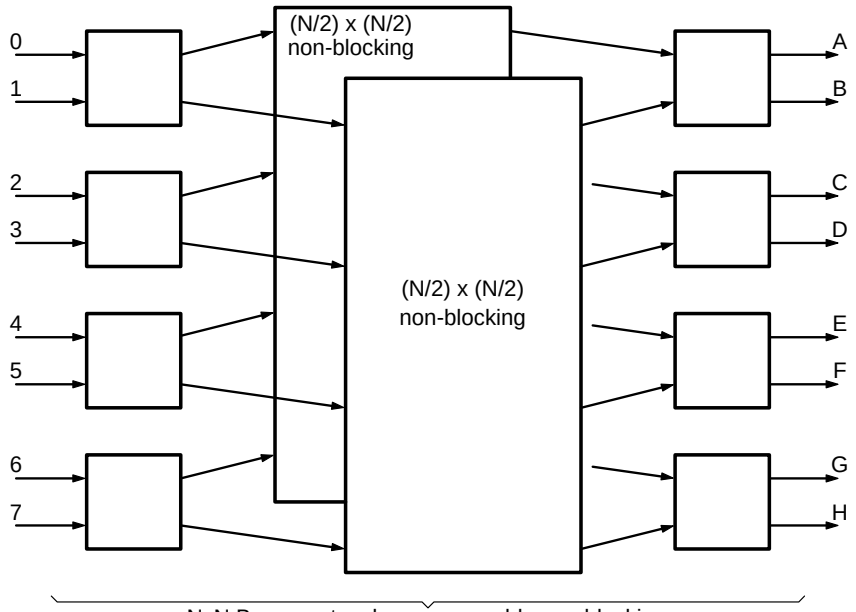
5.2 Switching Fabric Topologies

- Benes Fabrics – recursive construction
  - rearrangeably non-blocking (probably the lowest cost such)
  - proof under circuit switching with 2×2 switches
- Banyan Fabrics – one half of a Benes
  - internal blocking for non-uniform traffic patterns
- Clos Networks – generalization of Benes
  - rearrangeably or strictly non-blocking, depending on midle-stage width
- Fat Trees – like folded, bidirectional Clos
- Others
  - meshes, tori, hypercubes, etc.

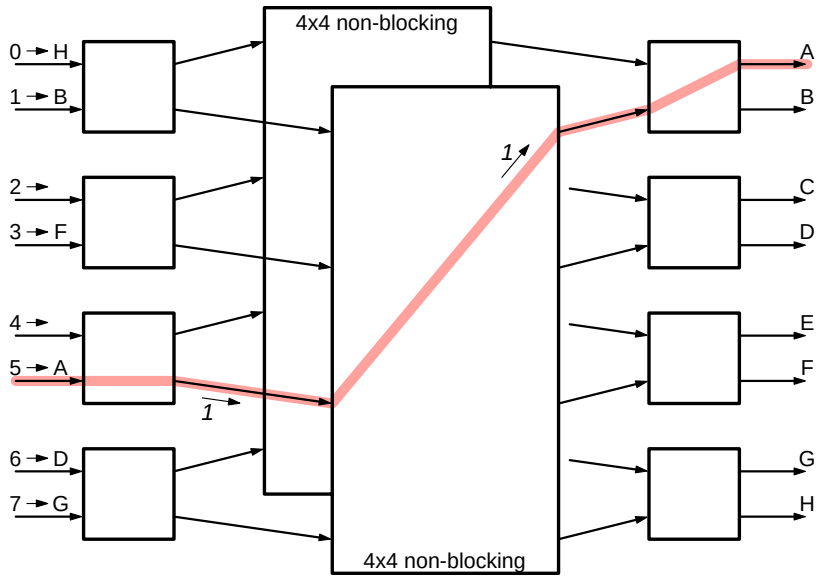
1

Benes Network: Recursive Definition

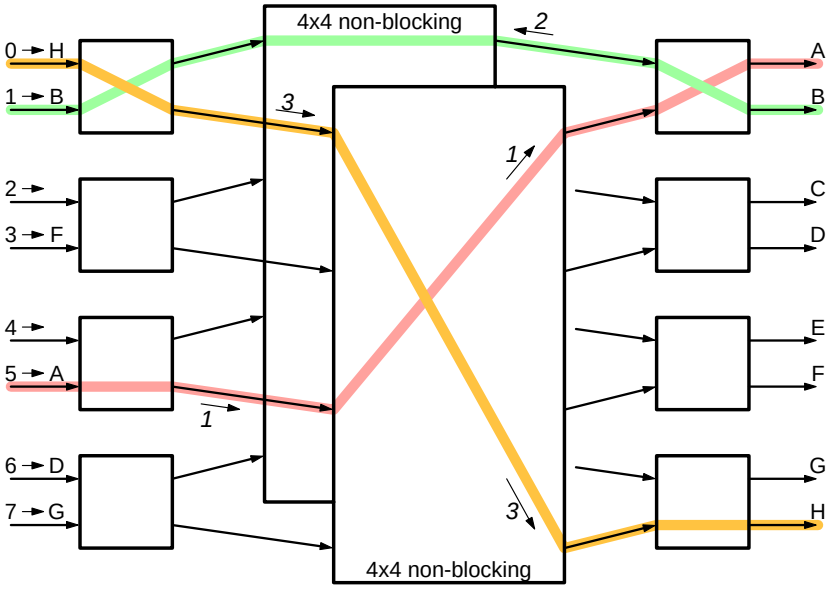


NxN Benes network: rearrangeably non-blocking

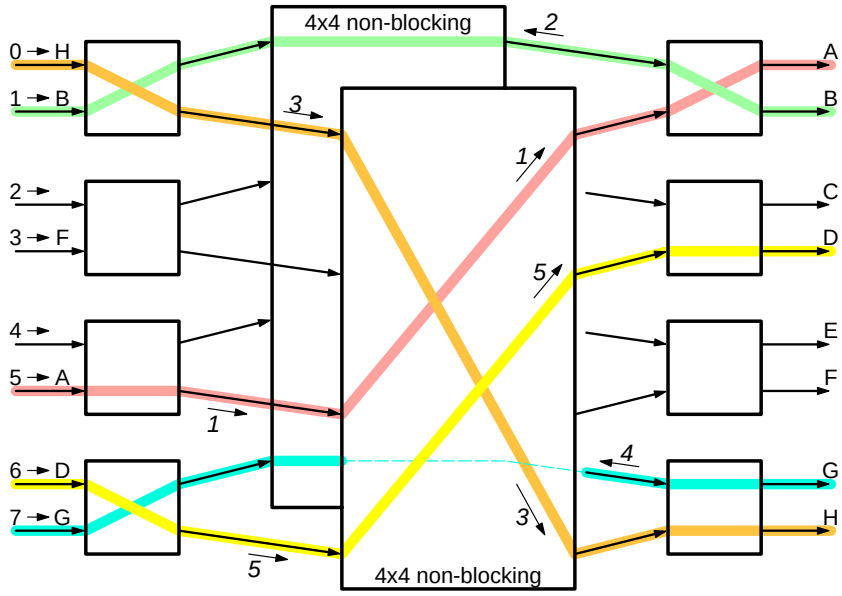
2



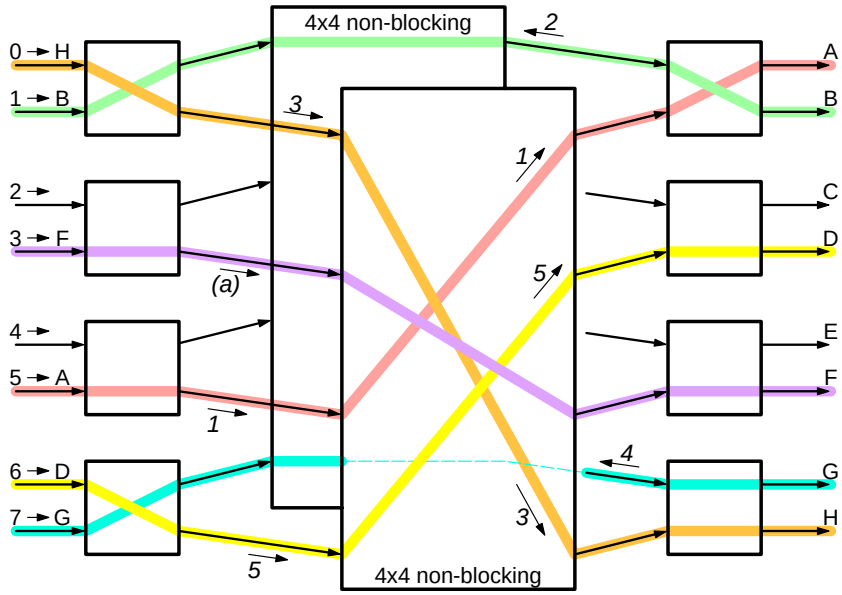
• Circuit Connections: Start from an input, use one of the subnets



• Continue from the brother port of the output, then the brother of the input

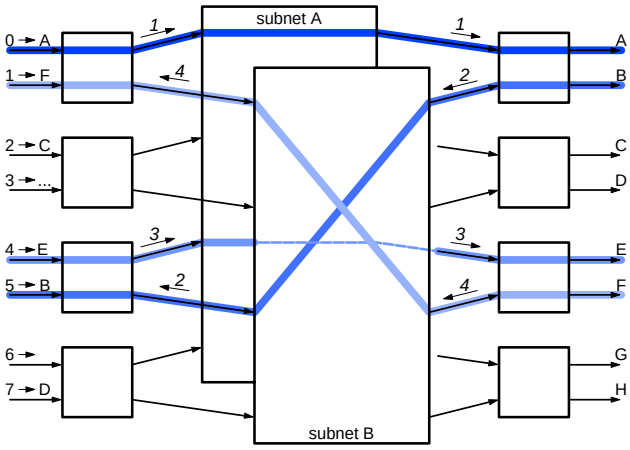


- Keep “threading” output and input switches, till closing or no-connection



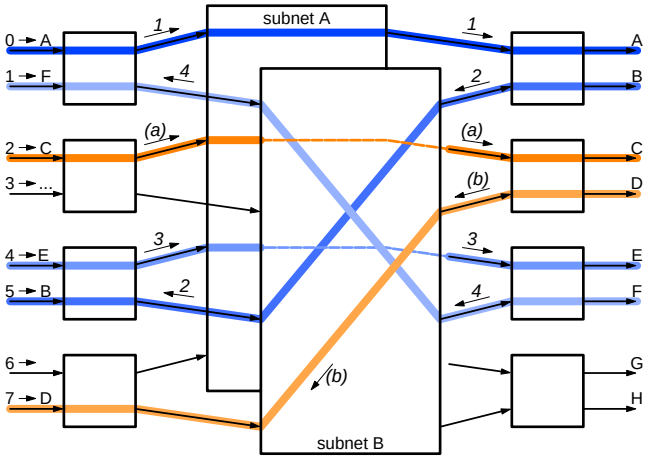
- Start a new “thread” (a) from an unconnected input, till completing all conn.

(A) Thread termination on input side (1 of 2)



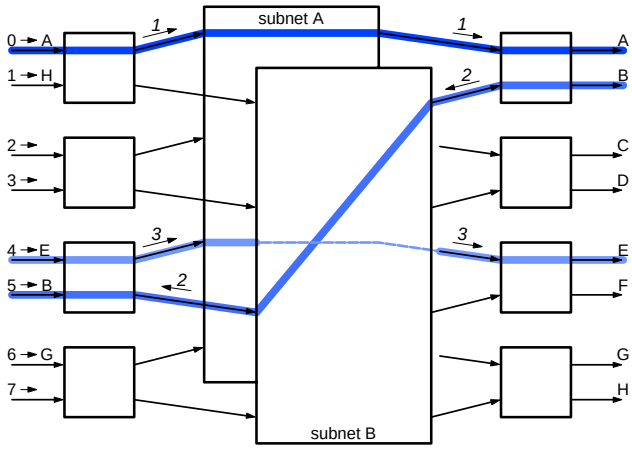
- Threads always start on the input side
- If a thread terminates on the input side:
  - all touched output switches are completely connected
  - concerning touched input switches:
    (1) if thread closes, all are complete, …

(A) Thread termination on input side (2 of 2)



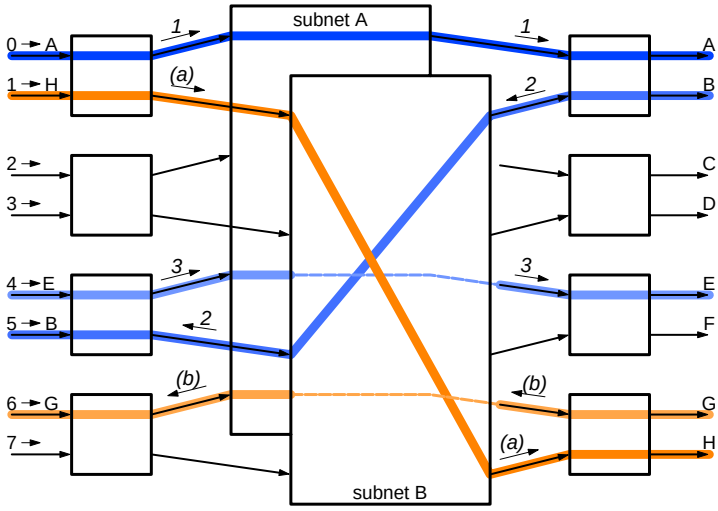
- Threads always start on the input side
- If a thread terminates on the input side:
  - all touched output switches are completely connected
  - concerning touched input switches:
    (1) if thread closes (4), all are complete,
    (2) if thread terminates on half-used input (b): all touched input switches are complete, except the first one, which is half-covered by this thread

(B) Thread termination on output side



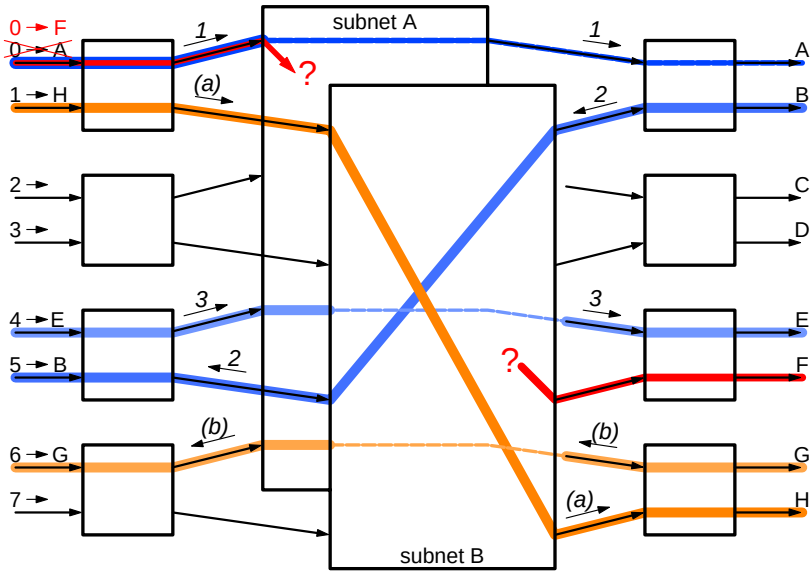
- Threads always start on the input side
- If a thread terminates on the output side:
  - all touched output switches are completely connected
  - the first touched input switch is half-covered

(C) Completing half-covered input switches

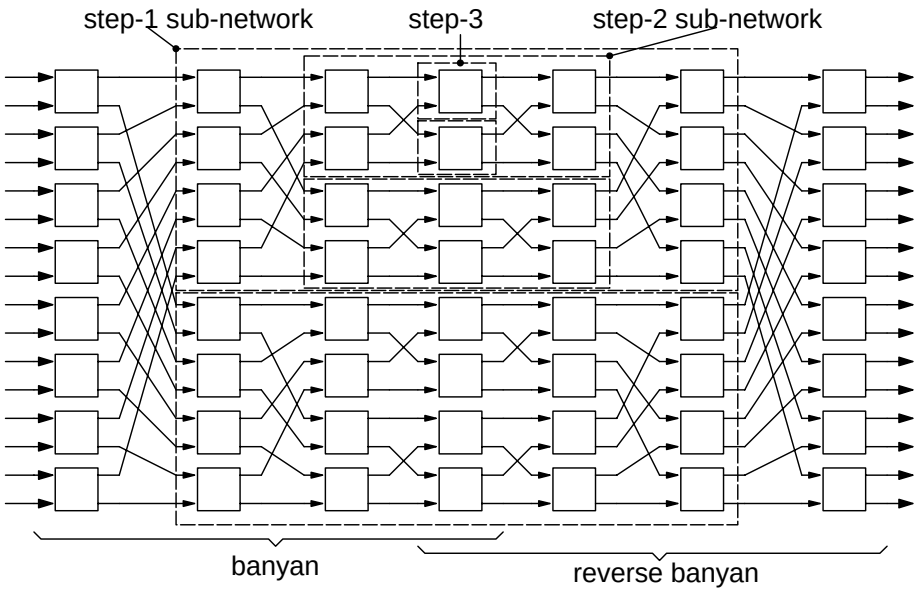


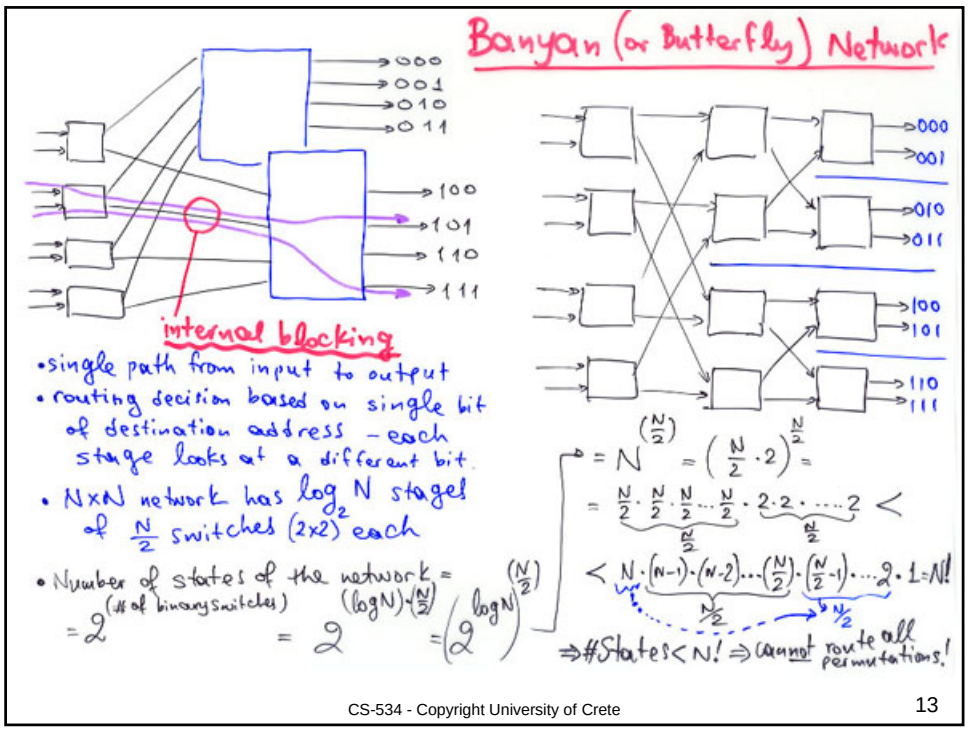
- New threads always start from a half-covered input switch, if there is one
  ⇒ all threads cover all out-sw's they touch, in-sw's are covered in sequence

Benes Fabric: *Rearrangeably* Non-Blocking



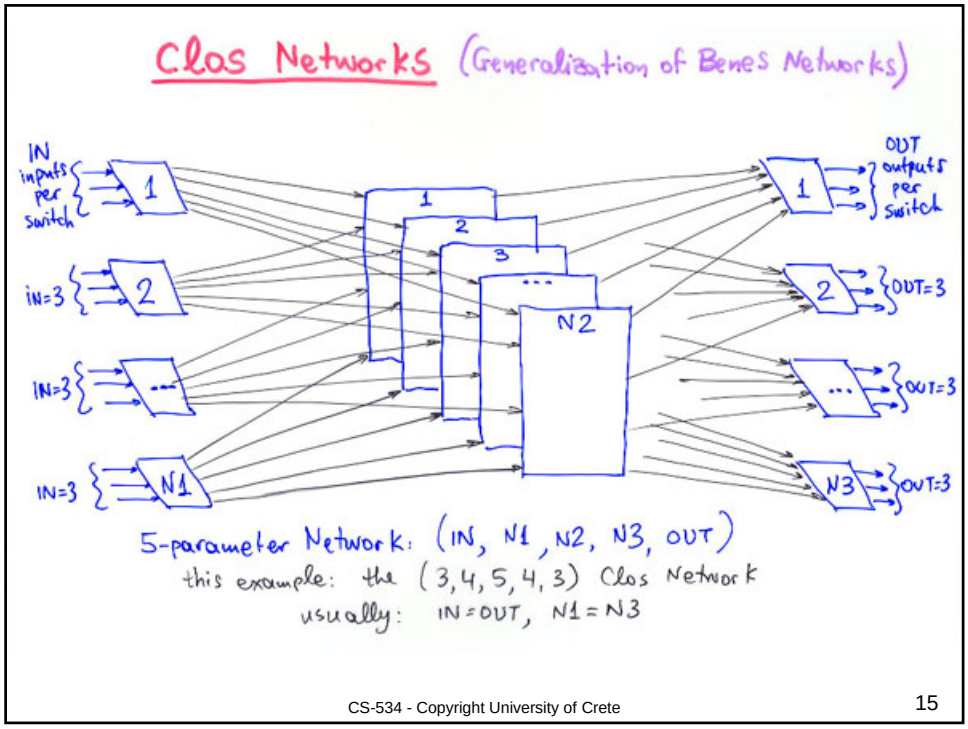
Recursive Construction of 16x16 Benes Network out of 2x2 Switches





Reminder of topics discussed in class, which need to be included in future-year slides

- Banyan fabric is like a set of binary trees with shared nodes.
- Dst/Src Address: in a banyan, a single field suffices for both, if each stage replaces one “consumed” destination-address bit with one corresponding source-address bit.
- Number of states of a fabric made of 2×2 switch elements, internal blocking, and cost-minimality of non-blocking fabrics:
  - banyan has *(½ · N · log_2N)* switches, and its number of states is less than *(N!)*, hence it cannot route all permutations – has internal blocking
  - Benes has *(N · (log_2N - ½))* switches, its number of states is more than *(N!)*, it can route all permutations, and it is internally non-blocking
  - the minimum-cost non-blocking fabric made of 2×2 switches must have at least *(log_2(N!))* switches, hence it must have a cost in-between the cost of the banyan and the cost of the Benes.
- Clos Networks: *N2* parameter is like “internal speedup”…
- Fat Trees – Benes/Clos: bidirectional vs. unidirectional links:
  - bidirectional links needed to carry flow control (backpressure) info. …


Clos Networks (Generalization of Benes Networks)
IN inputs per switch
IN=3
IN=3
IN=3
1
2
...
N1
1
2
3
...
N2
OUT outputs per switch
1
2
...
N3
OUT=3
OUT=3
OUT=3
5-parameter Network: (IN, N1, N2, N3, OUT)
this example: the (3,4,5,4,3) Clos Network
usually: IN=OUT, N1=N3
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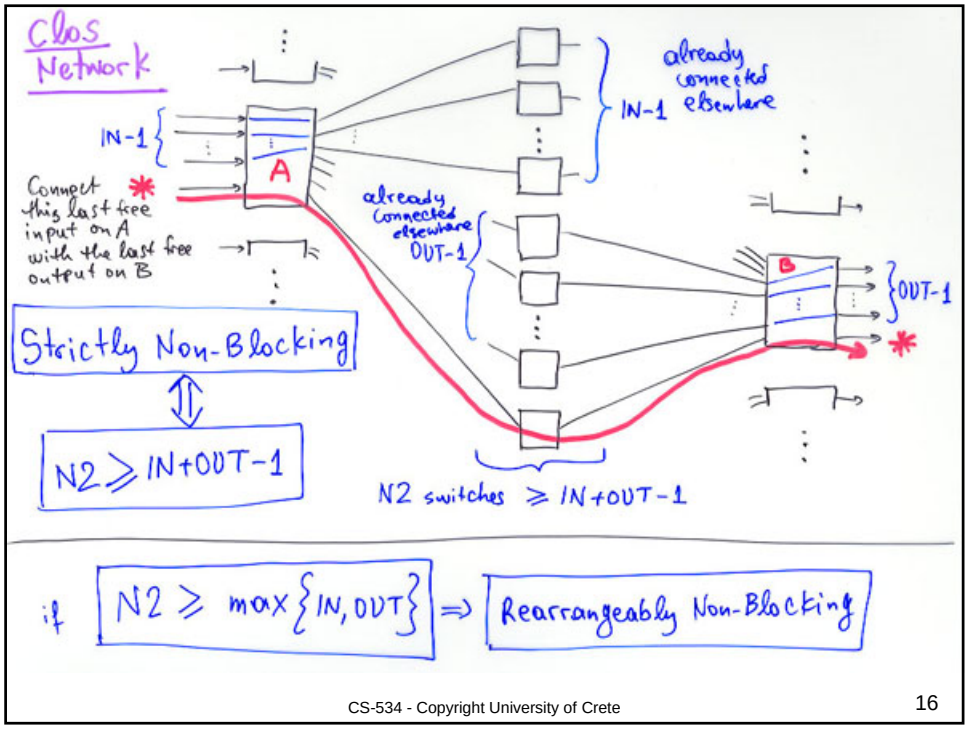
Clos Network
IN-1
A
Connect this last free input on A with the last free output on B
already connected elsewhere
IN-1
already connected elsewhere
OUT-1
B
OUT-1
Strictly Non-Blocking
N2 ≥ IN+OUT-1
N2 switches ≥ IN+OUT-1
if N2 ≥ max{IN, OUT} ⇒ Rearrangeably Non-Blocking
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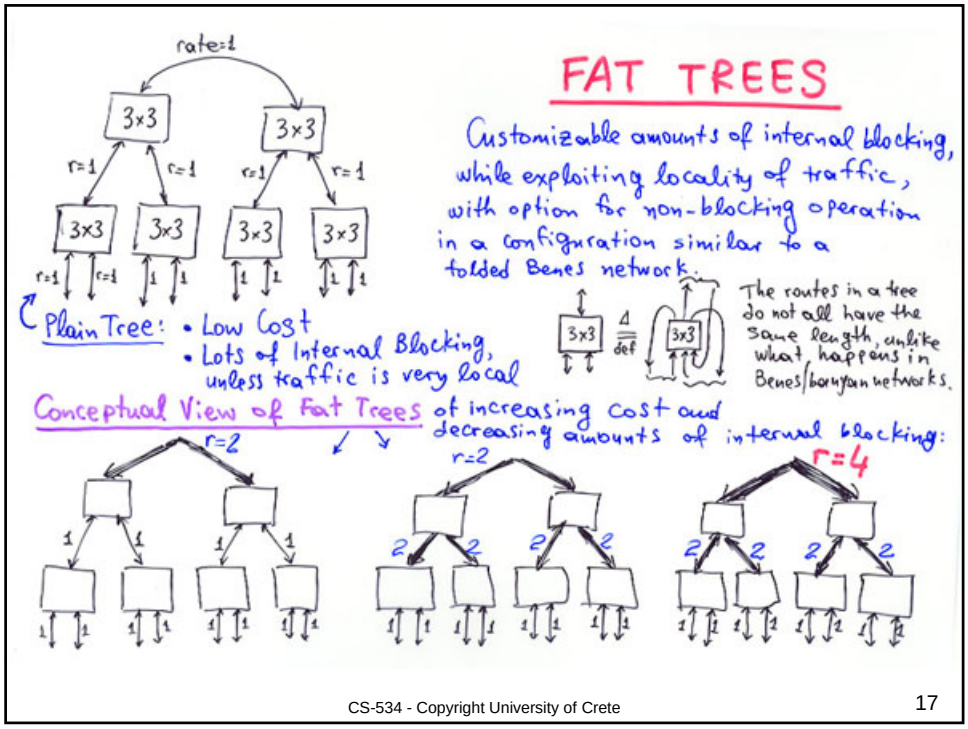
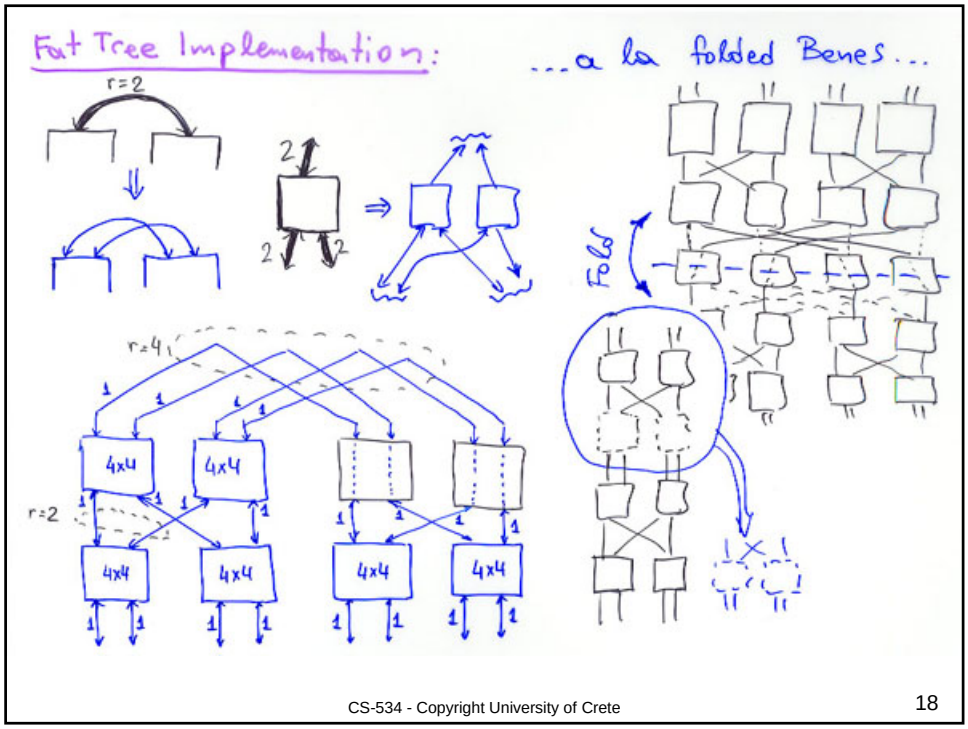

FAT TREES
Customizable amounts of internal blocking, while exploiting locality of traffic, with option for non-blocking operation in a configuration similar to a folded Benes network.
rate=1
3x3
r=1
Plain Tree:
• Low Cost
• Lots of Internal Blocking, unless traffic is very local
The routes in a tree do not all have the same length, unlike what happens in Benes/banyan networks.
Conceptual View of Fat Trees
of increasing cost and decreasing amounts of internal blocking:
r=2
r=4


Fat Tree Implementation:
...a la folded Benes...
r=2
r=4
4x4
fold