ECE 8823 A / CS 8803 - ICN

Interconnection Networks

Spring 2017

http://tusharkrishna.ece.gatech.edu/teaching/icn_s17/

Lecture 5: Deadlocks - I

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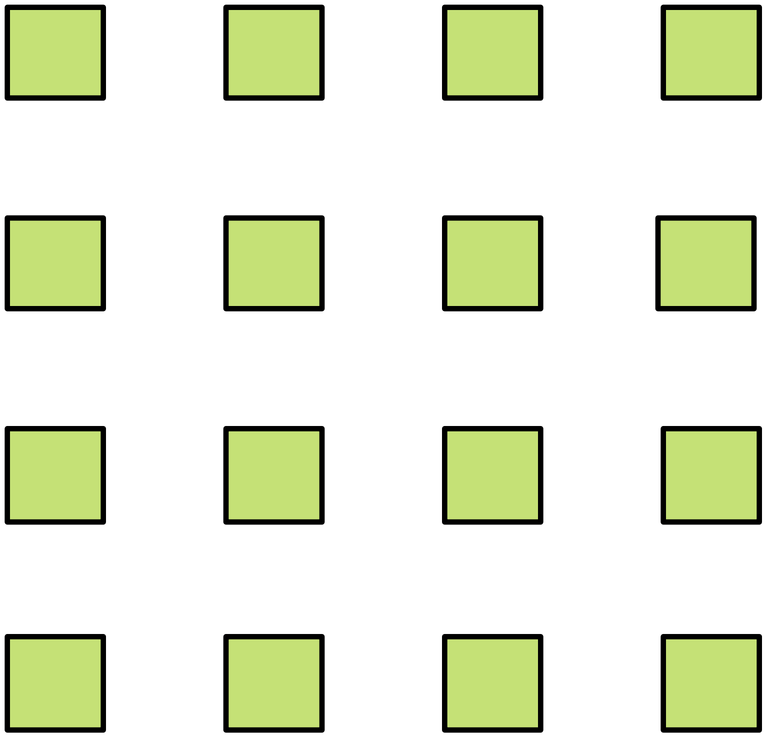
Announcement: Lab 2



16-router NoC
Each router connected to one CPU + one Directory
(--num-cpus=16,
 --num-dirs=16)
Just like Mesh_XY.py

DO NOT CONNECT 4 CPU/DIR to ONE ROUTER LIKE THE PAPER

Link Weights:
1 for X-direction links
2 for Y-direction links

Taxonomy of Routing Algorithms

- **Classification I: path length**
  - **Minimal**: shortest paths
    - Example: Greedy over Ring, XY over Mesh
  - **Non-minimal**: non-shortest paths
    - Example: Random and Adaptive over Ring/Mesh

Taxonomy of Routing Algorithms

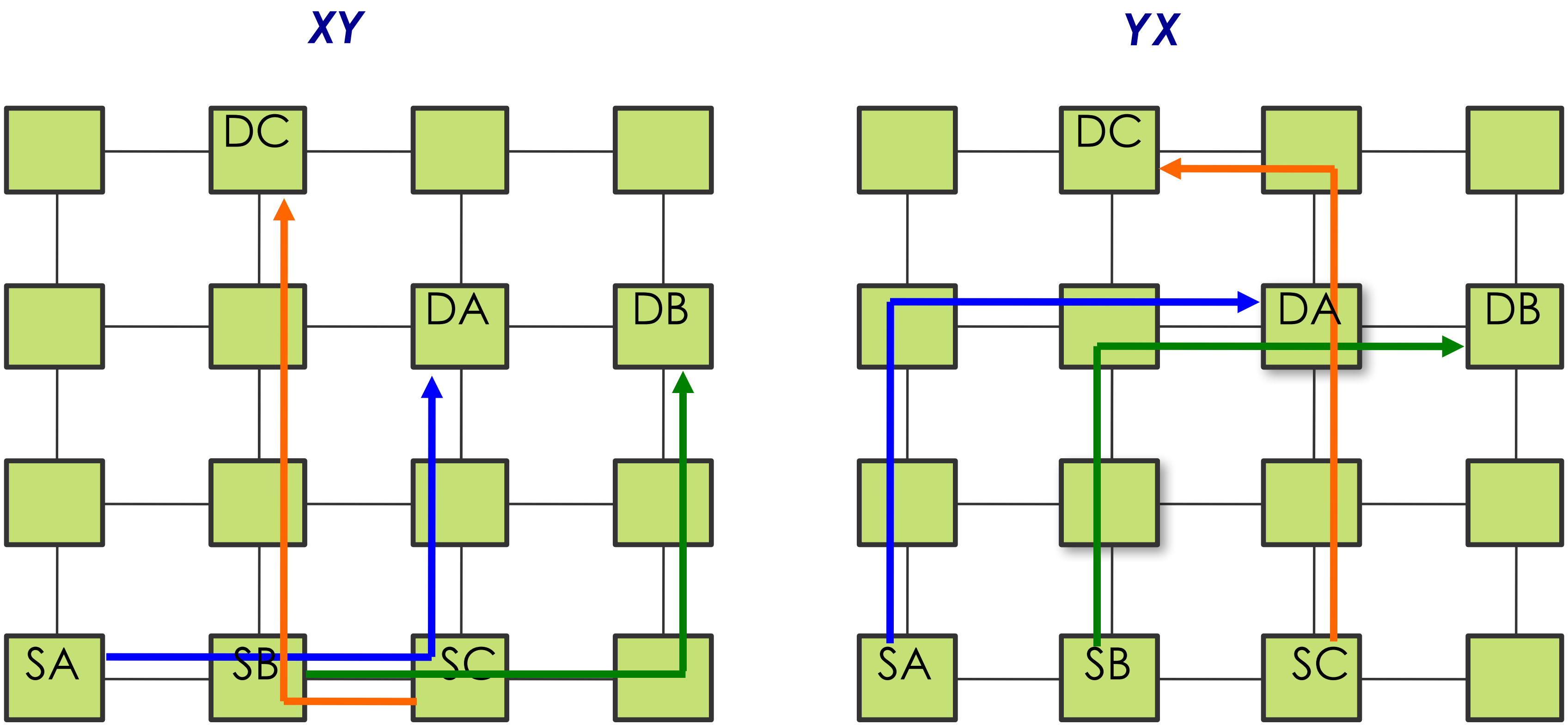
- **Classification II: path diversity** (how to select between the set of all possible paths R_{xy} from the source x to the dest y)
  - **Deterministic:** always choose the same route between x and y, even if $|R_{xy}| > 1$
    - **Example:** Greedy over Ring, XY over Mesh
    - + Easy to Implement
    - - Inefficient use of bandwidth
  - **Oblivious:** choose any of the routes in R_{xy} without considering any information about current network state (i.e., congestion)
    - **Example:** Random over Ring, O1Turn over Mesh
    - + More path diversity
    - - Can lead to deadlocks (this lecture)
  - **Adaptive:** choose one of the routes in R_{xy} depending on the current network state (i.e., congestion)
    - **Example:** Adaptive over Ring/Mesh
    - + Best use of available bandwidth
    - - Need to track congestion, can lead to deadlocks

Taxonomy of Routing Algorithms

- **Classification III – implementation**
  - **Source Routing**
  - **Node-Table Routing**
  - **Combinational Circuits**

  - *To be discussed when we discuss router microarchitecture!*

Recap: O1TURN Routing Algorithm

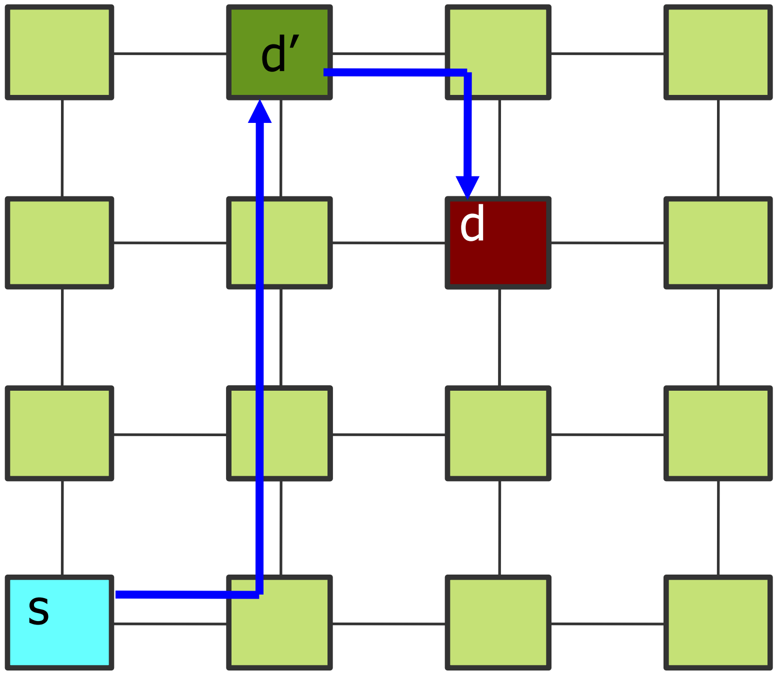


Randomly send over XY or YX

Minimal and Oblivious

Recap: Valiant's Routing Algorithm

- To route from s to d
  - Randomly choose intermediate node d'
  - Route* from s to d' (Phase I), and d' to d (Phase II)
- Pros
  - Randomizes any traffic pattern
    - All patterns appear uniform random
  - Balances network-load
    - Higher throughput
- Cons
  - Non-minimal
    - Higher latency and energy
  - Destroys locality

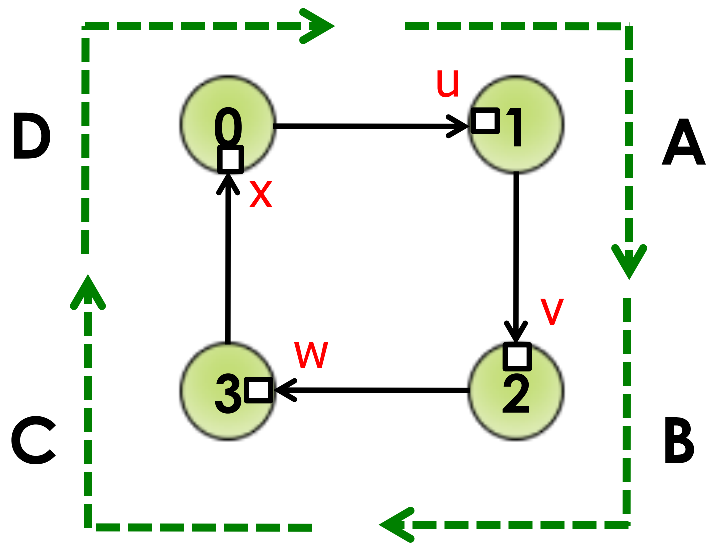


Non-Minimal and *Oblivious

can also be Adaptive

Deadlock

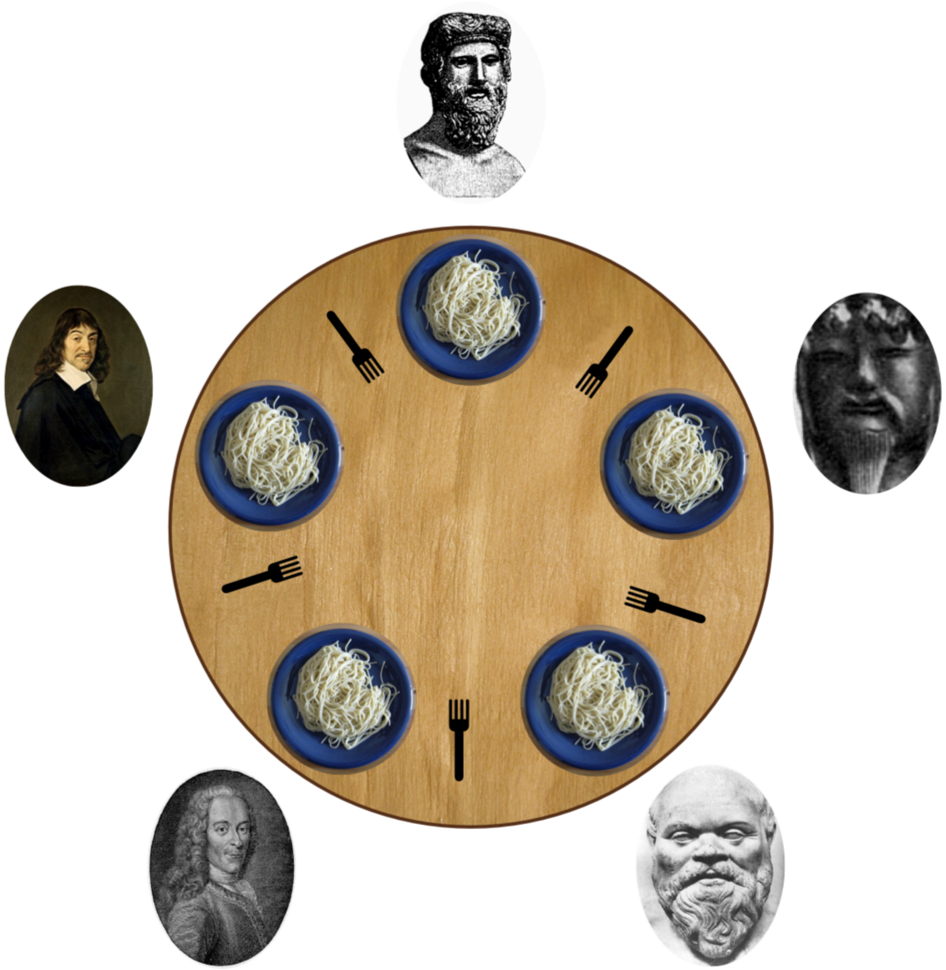
- A condition in which a set of **agents** wait indefinitely trying to acquire a set of **resources**



Note: holding buffer u == holding Channel 01 as no other packet can use channel 01 till buffer u becomes free

- Packet A holds buffer u (in 1) and wants buffer v (in 2)
- Packet B holds buffer v (in 2) and wants buffer w (in 3)
- Packet C holds buffer w (in 3) and wants buffer x (in 0)
- Packet D holds buffer x (in 0) and wants buffer u (in 1)

Classic Example: Dining Philosopher's Problem

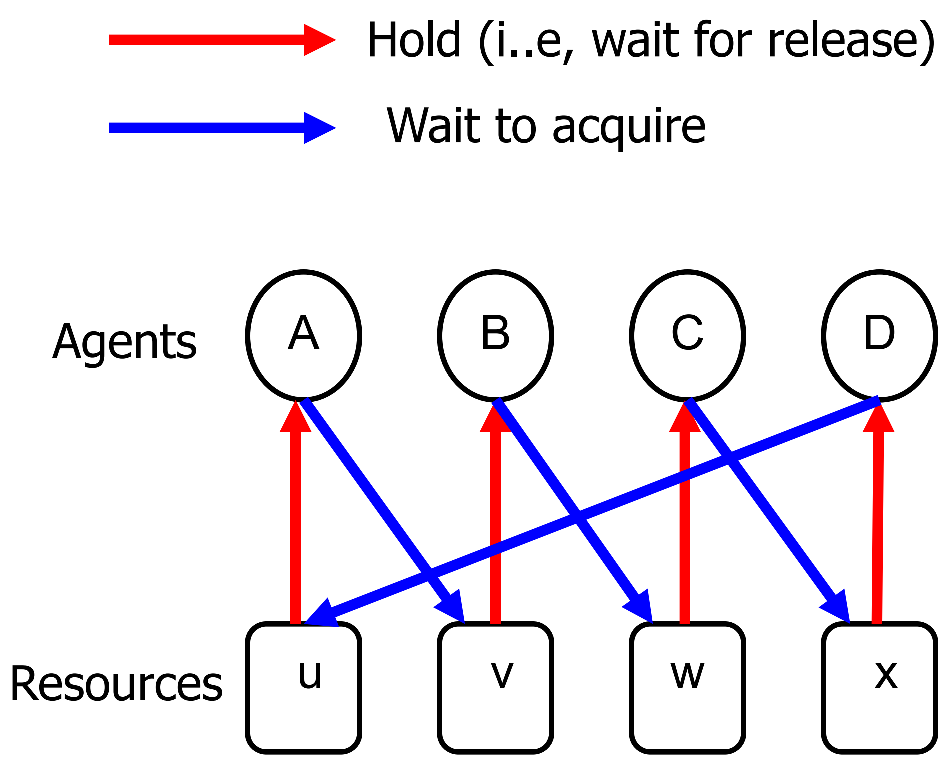


Agents:
Philosophers

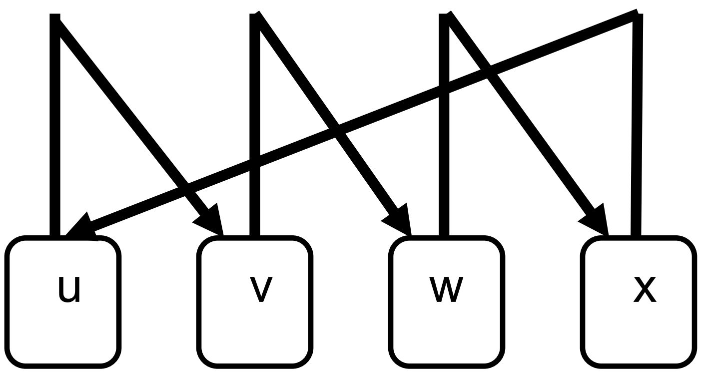
Resources:
Forks

Resource Dependence

Resource A is ***dependent*** on resource B if it is possible for A to be *held-by* an agent X and it is also possible for X to *wait-for* B



Resource Dependence Graph



Deadlock Condition

- Agents hold and do not release a resource while waiting for access to another
- A cycle exists between waiting agents such that there exists a set of agents A_0, .. A_{n-1}, where agent A_i holds resource R_i, while waiting on resource $R_{(i+i \bmod n)}$, for i = 0, …, n-1
- To avoid deadlock – resource dependence graph should not have any cycles

Dealing with Deadlocks

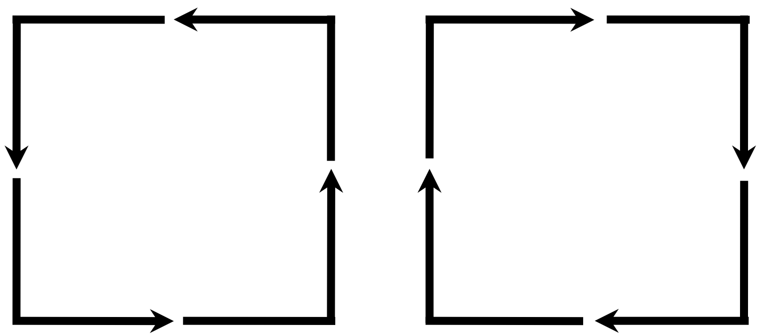
- **Avoidance**
  - Guarantee that the network will never deadlock
  - Almost all modern networks use deadlock avoidance

- **Recovery**
  - Detect deadlock and correct

Deadlock Avoidance

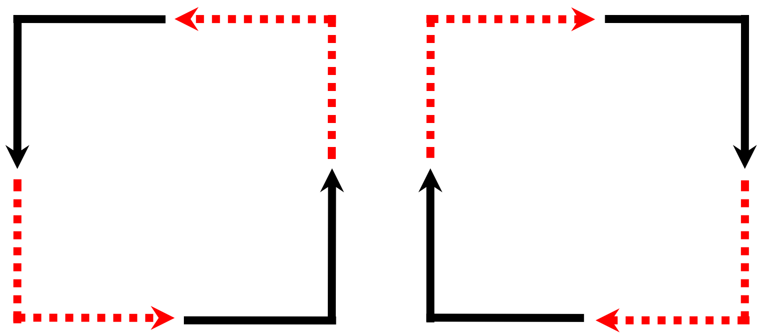
- Eliminate cycles in Resource Dependency Graph
  - Resource Ordering
    - Enforce a partial/total order on the resources, and insist that an agent acquire the resources in ascending order
    - Deadlock avoided since a cycle must contain at least one agent holding a higher numbered resource waiting for a lower-numbered resource which is not allowed by the ordering allocation
  - Implementation
    - Restrict certain routes so that a higher numbered resource cannot wait for a lower numbered resource
    - Partition the buffers at each node such that they belong to different resource classes. A packet only any route can only acquire buffers in ascending order of resource class

Turn Model (Glass and Ni 1994) for Mesh

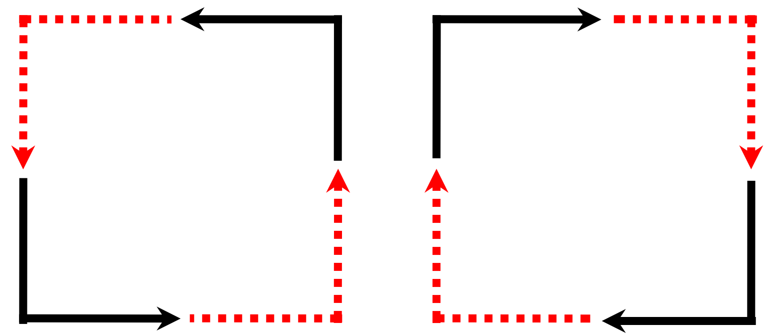


- Deadlocks may occur if the turns taken form a cycle
  - Removing some turns can make the routing algorithm deadlock free

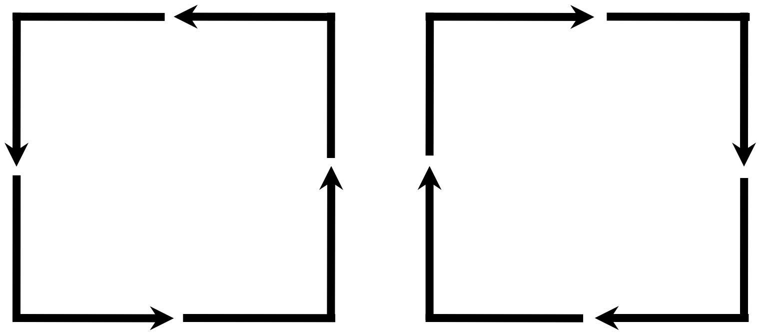
Dimension Ordered Routing



XY Model

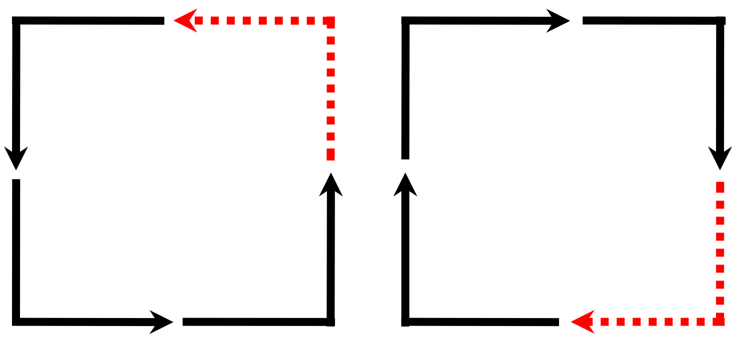


YX Model

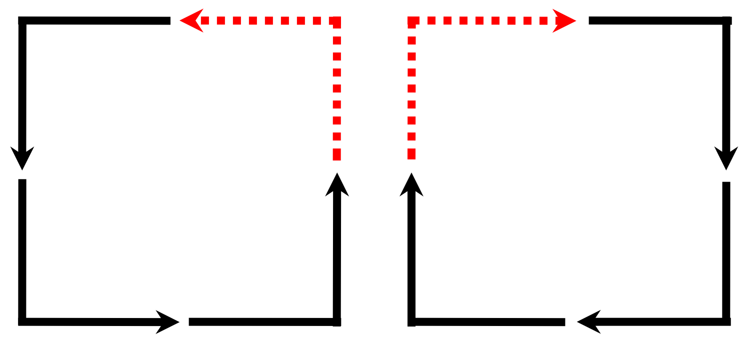


O1Turn **Deadlock!**

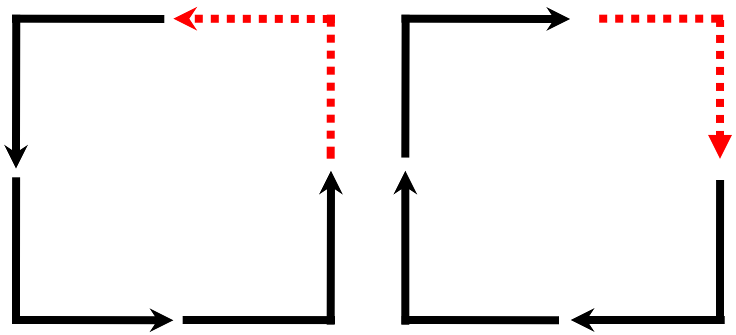
Deadlock-free Oblivious/Adaptive Routing Algorithms



West-First Turn Model

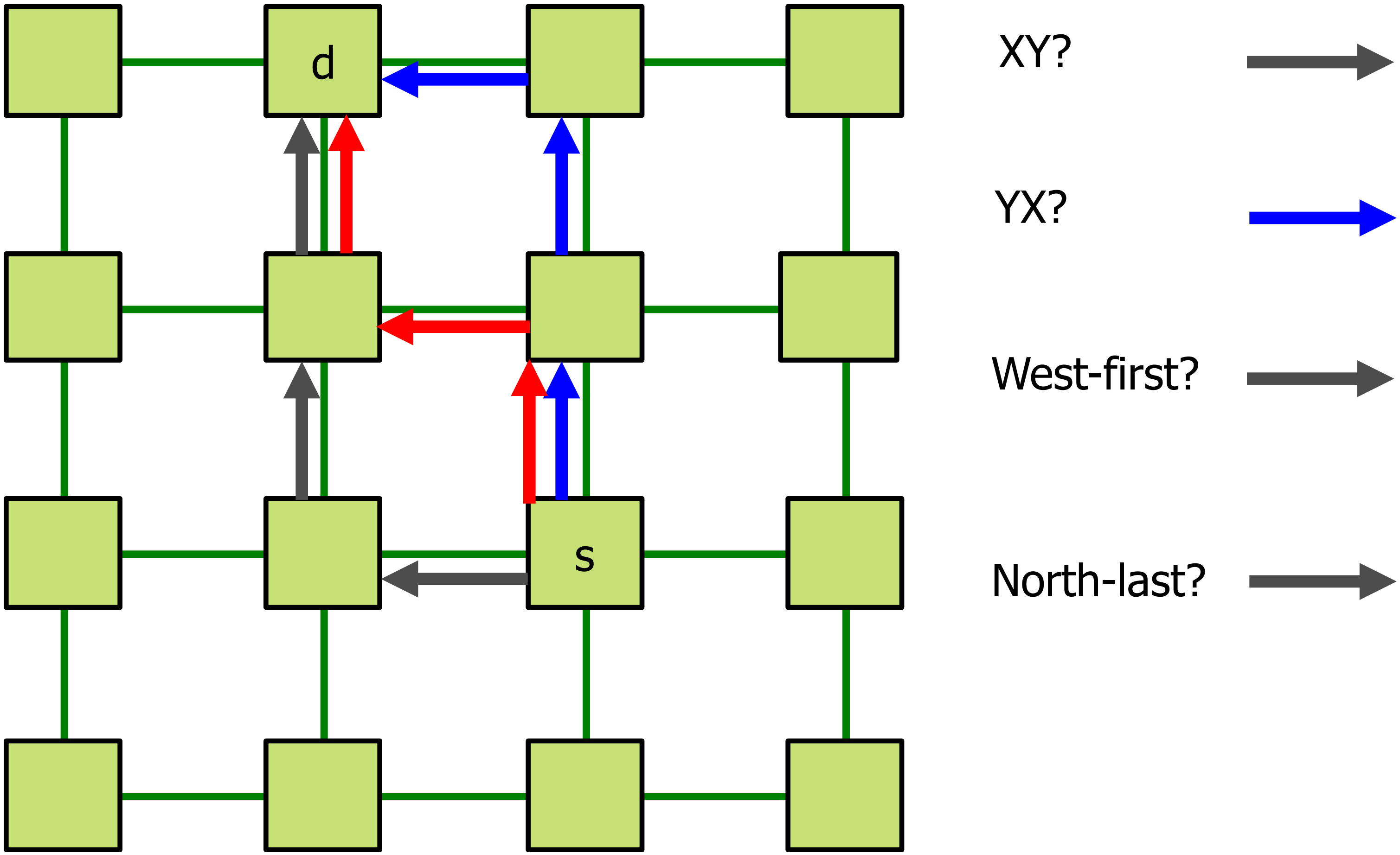


North-Last Turn Model

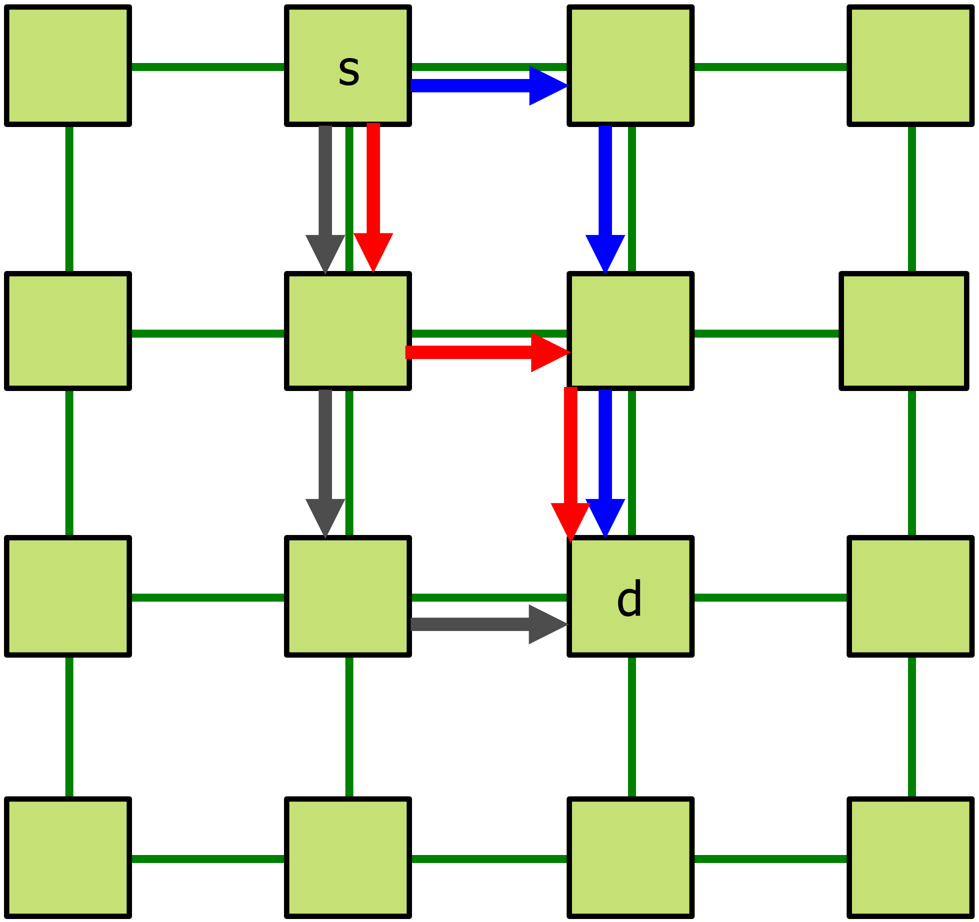


Negative-First Turn Model

Example 1



Example 2



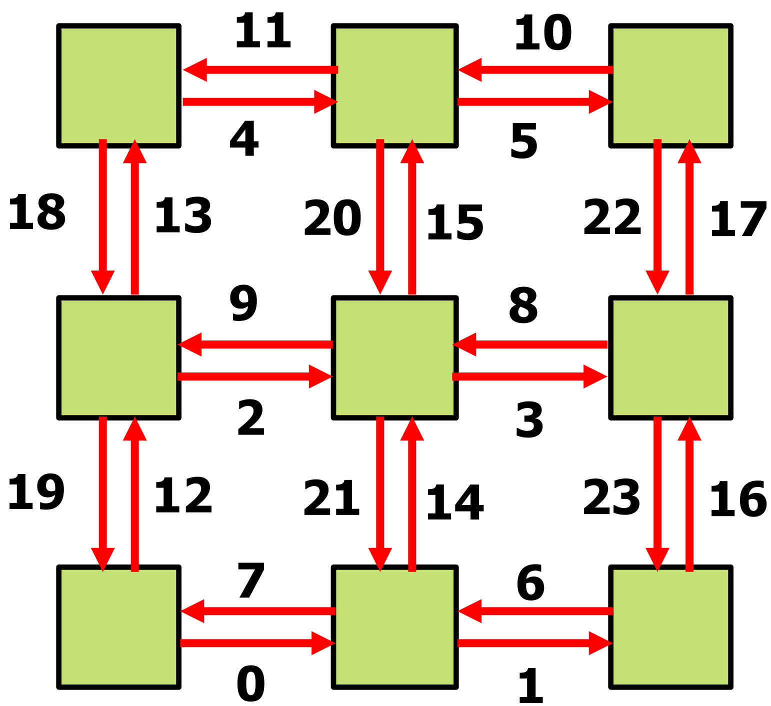
XY?

YX?

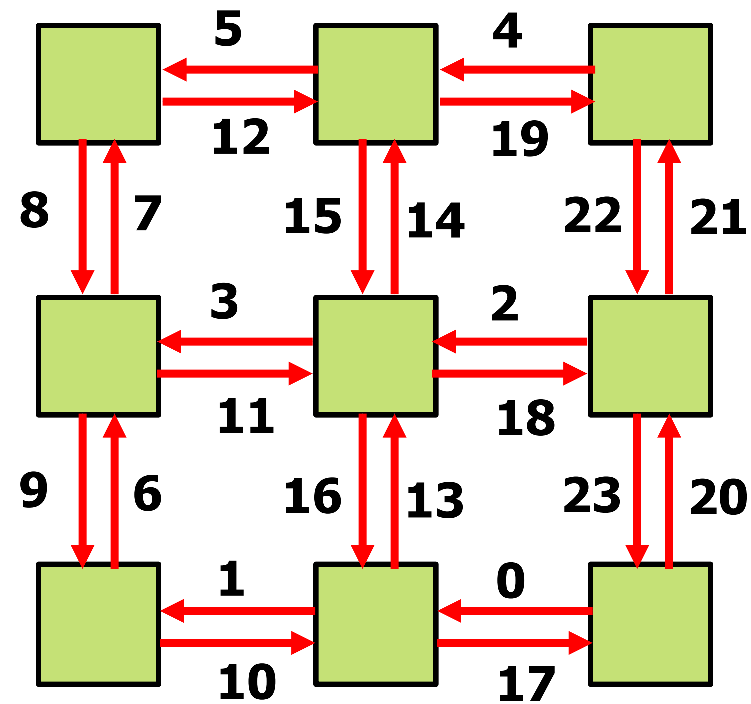
West-first?

North-last?

Resource (channel) Ordering

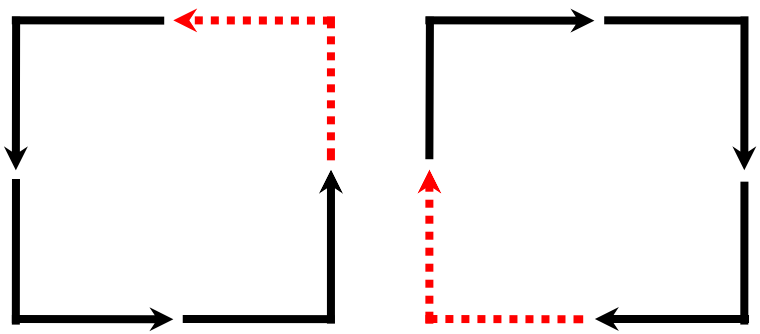


XY Model

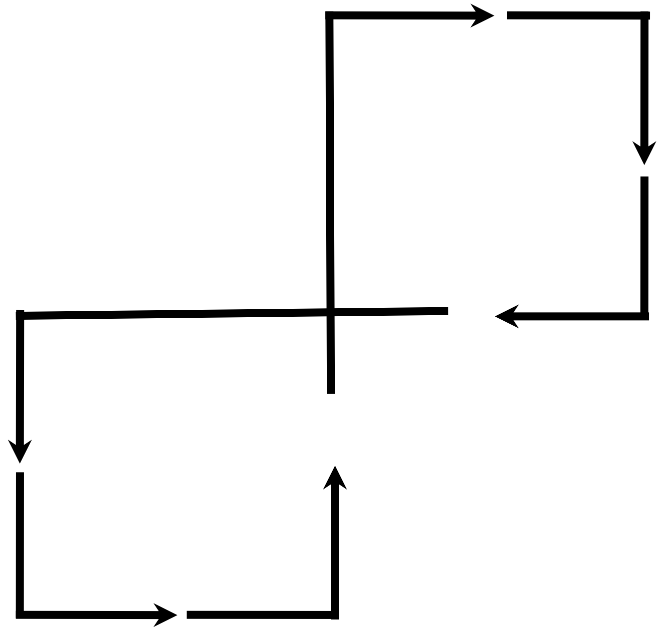


West-First Turn Model

Can we eliminate *any* 2 turns?



Six turn model

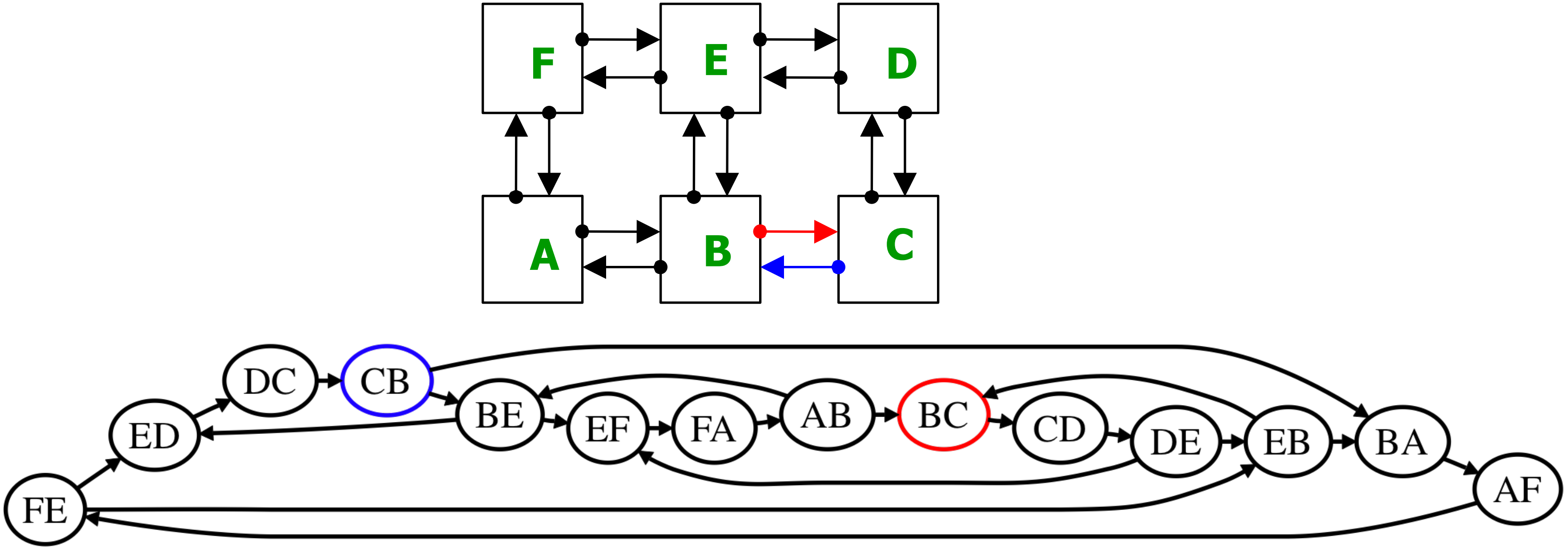


Deadlock!

Total Turn Models = 16
Deadlock Free = 12
Unique (non-symmetrical) = 3

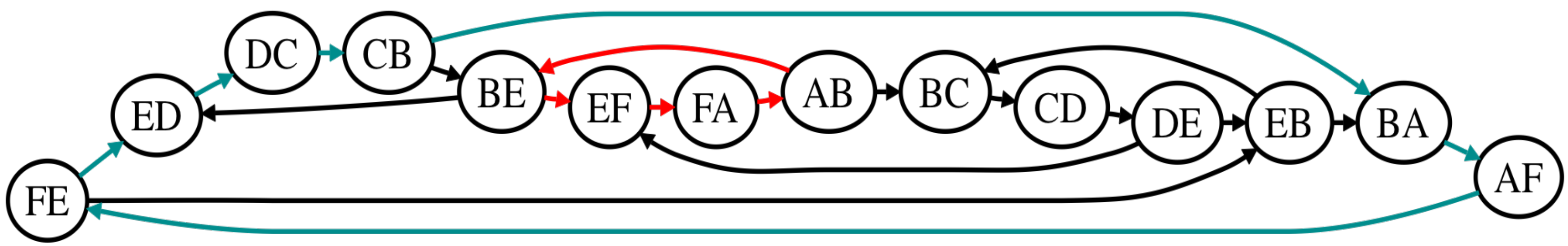
Channel Dependency Graph (CDG)

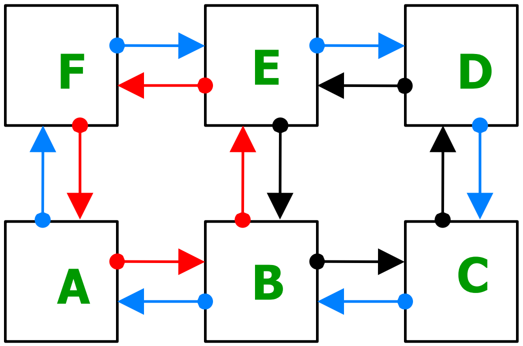
- Vertices represent network links (channels)
- Edges represent turns
  - *180º turns not allowed, e.g., AB → BA*



Cycles in the CDG

The channel dependency graph D derived from the network topology may contain many *cycles*

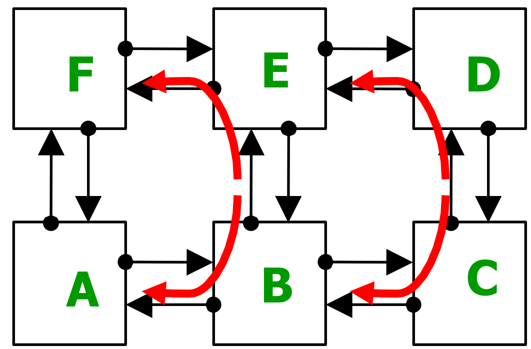




Flow routed through links AB, BE, EF
Flow routed through links EF, FA, AB
Deadlock!

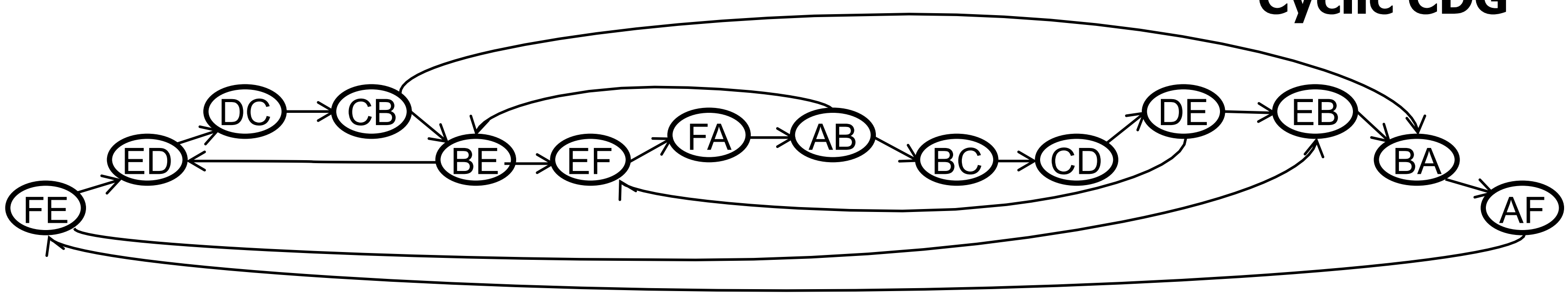
Edges in CDG = Turns in Network
➔ Disallow/Delete certain edges in CDG

Acyclic CDG

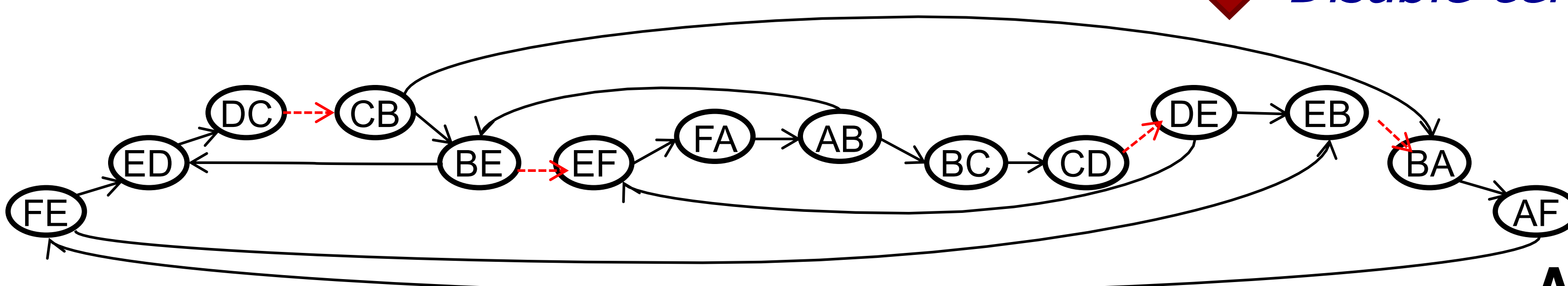


This is the
West-first turn model!

Cyclic CDG

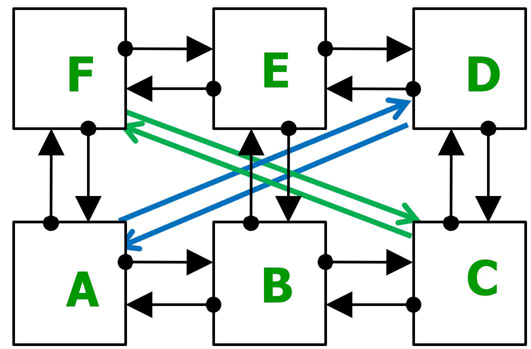


Disable certain edges



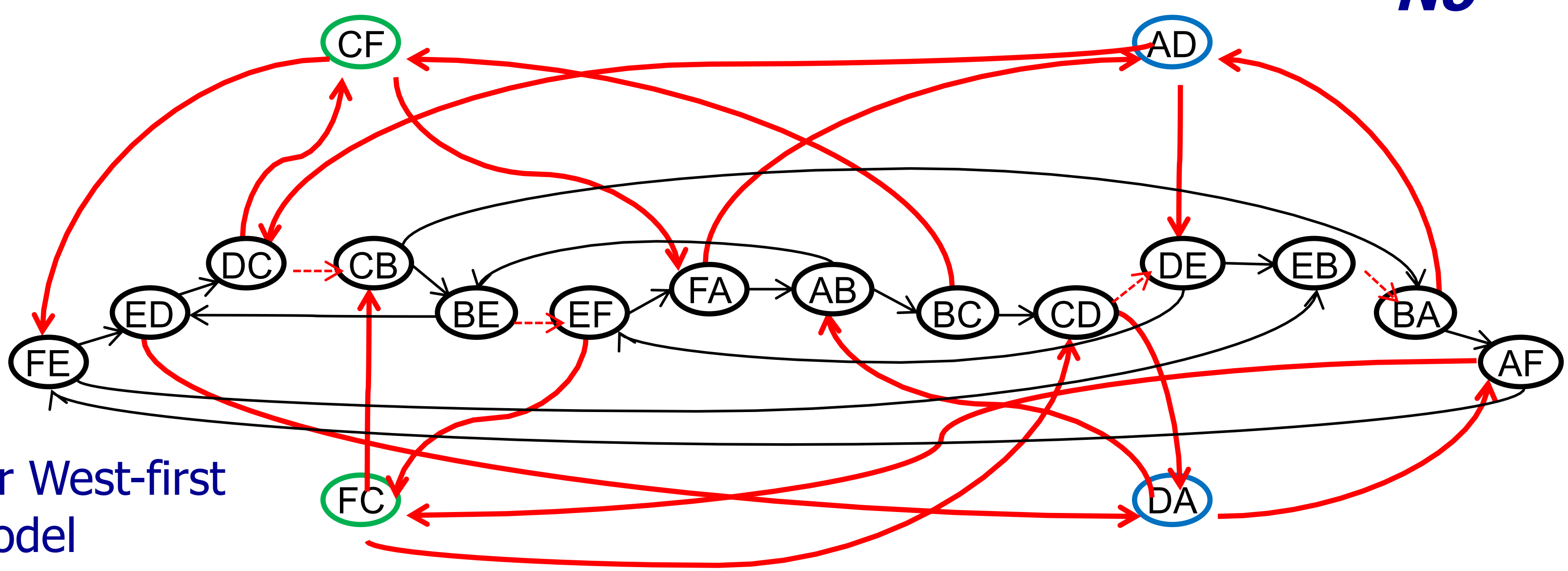
Acyclic CDG

CDG for arbitrary topology



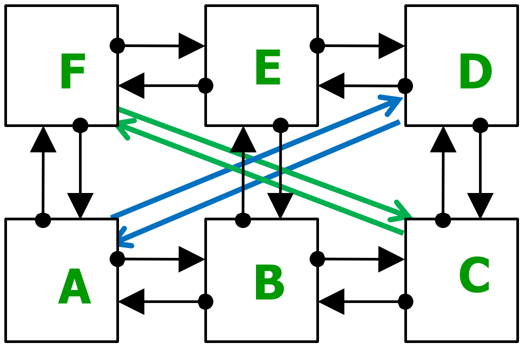
Deadlock free?

No

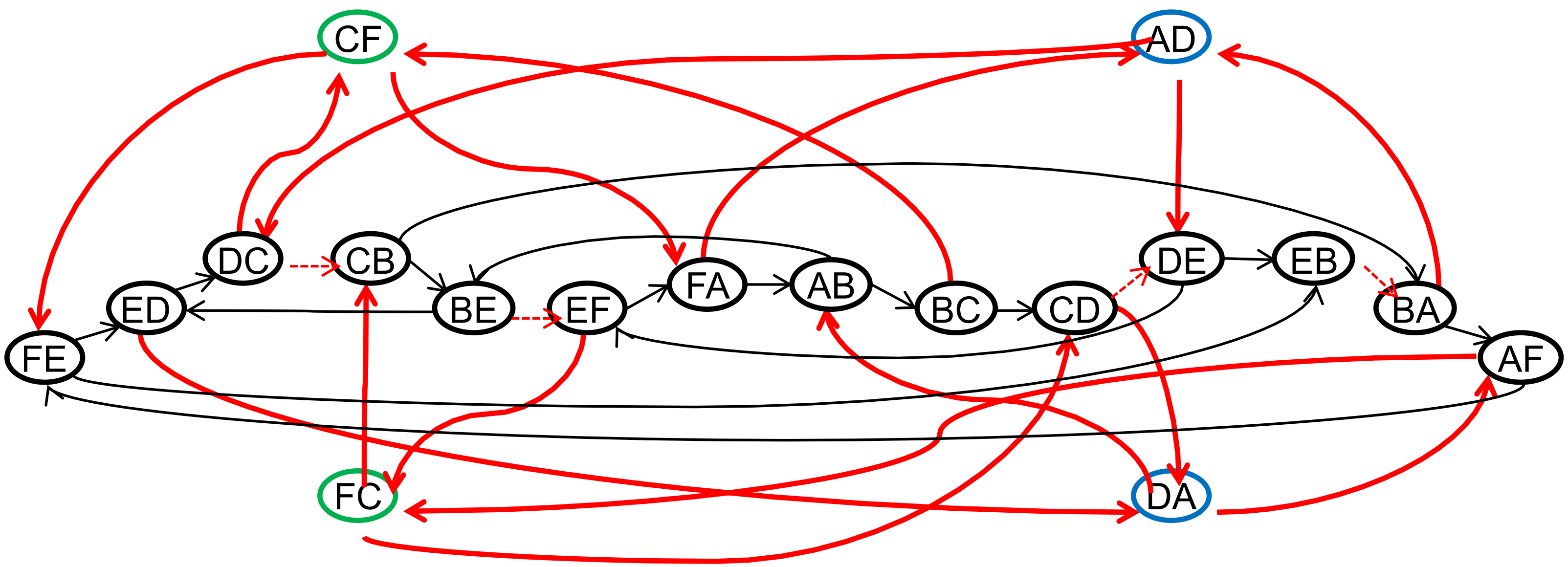


CDG for West-first turn model

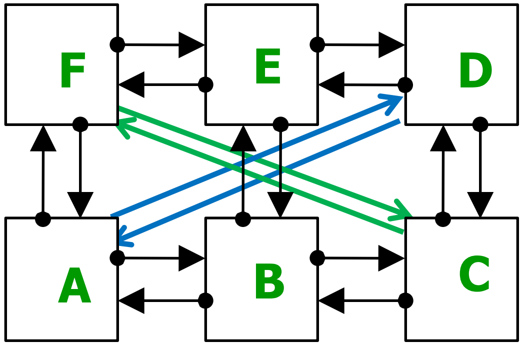
Deadlock-free Routing Algorithm



Suppose: Diagonal links should be traversed last (i.e., no edge from blue/green channel to black)



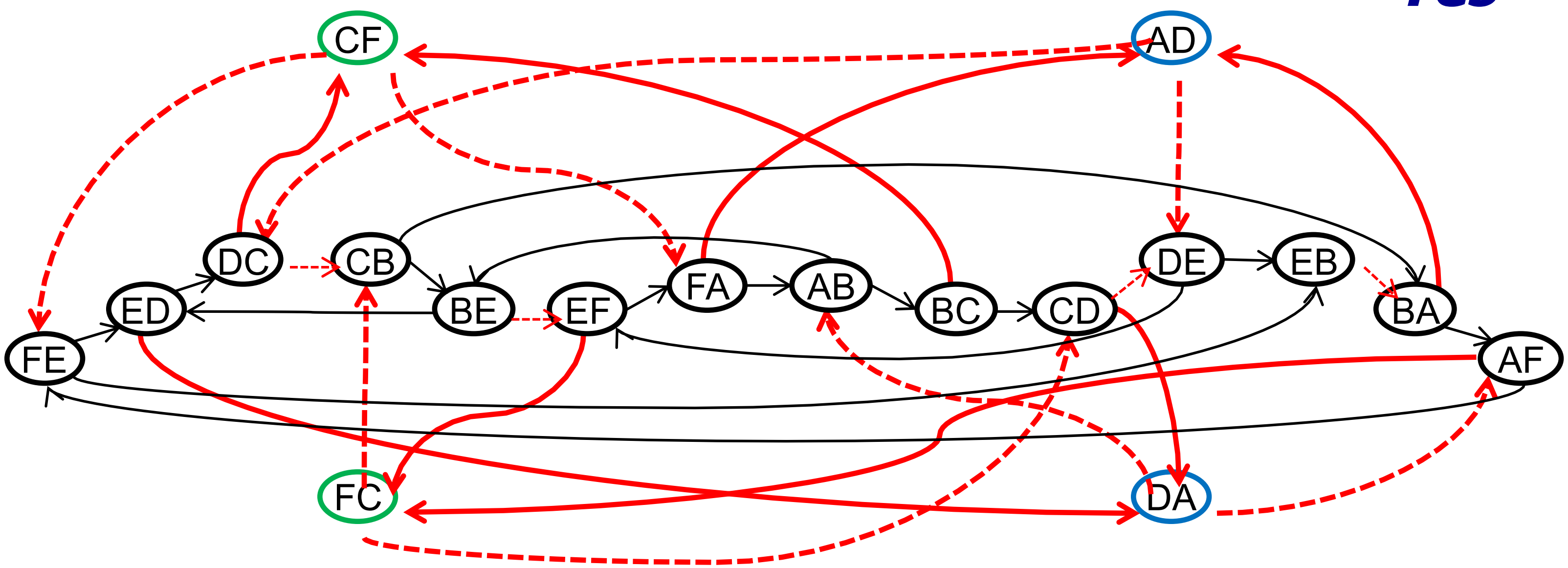
Deadlock-free Routing Algorithm



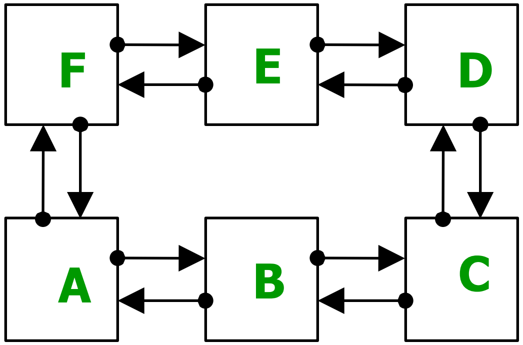
Suppose: Diagonal links should be traversed last (i.e., no edge from blue/green channel to black)

Deadlock free?

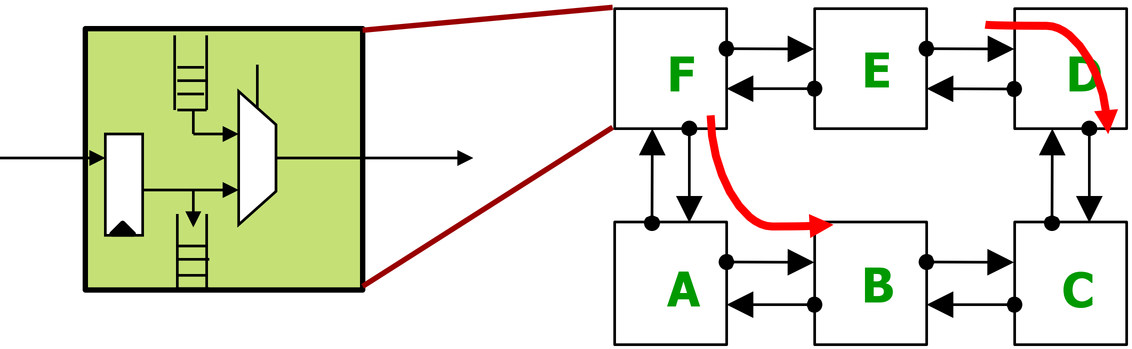
Yes



What about a Ring?



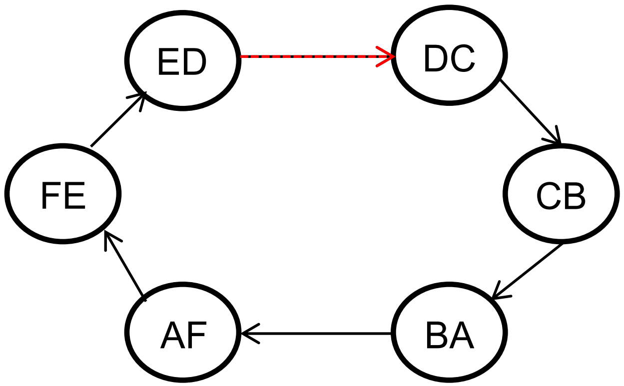
Acyclic CDG for a Ring



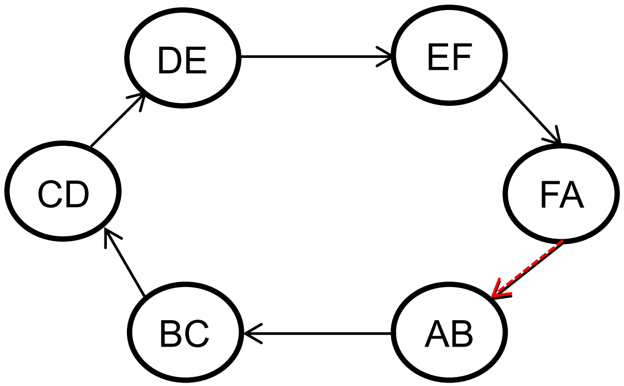
Route from E to C disabled
(E to D) and (D to C) allowed

Route from F to B disabled

Option 1

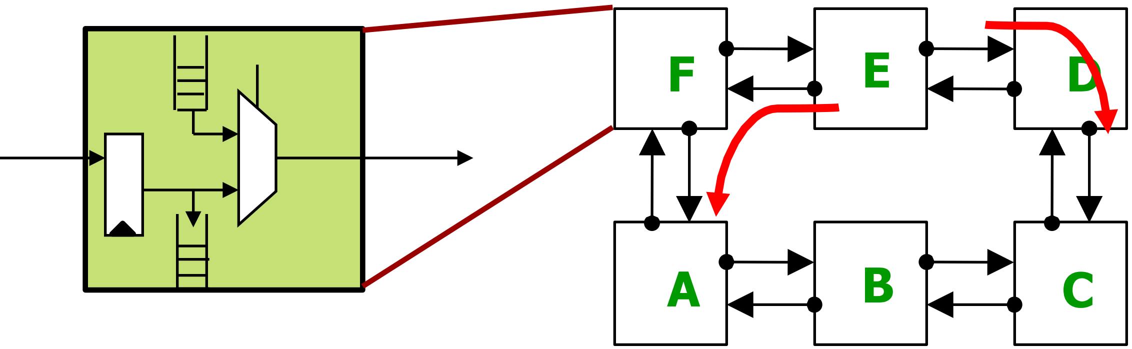


CDG



Problem? No route from E/F to B/C

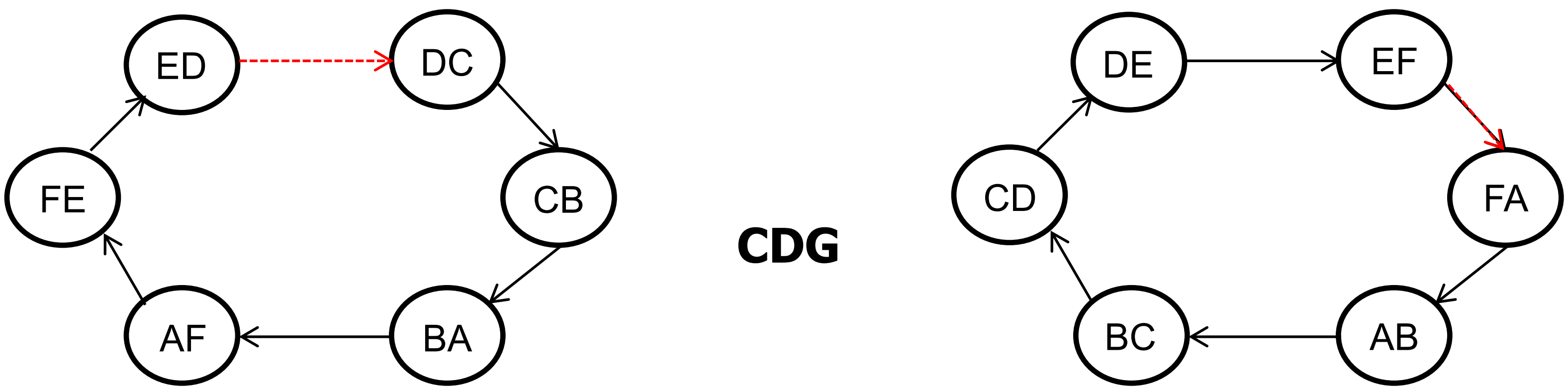
Acyclic CDG for a Ring



Route from E to C disabled
(E to D) and (D to C) allowed

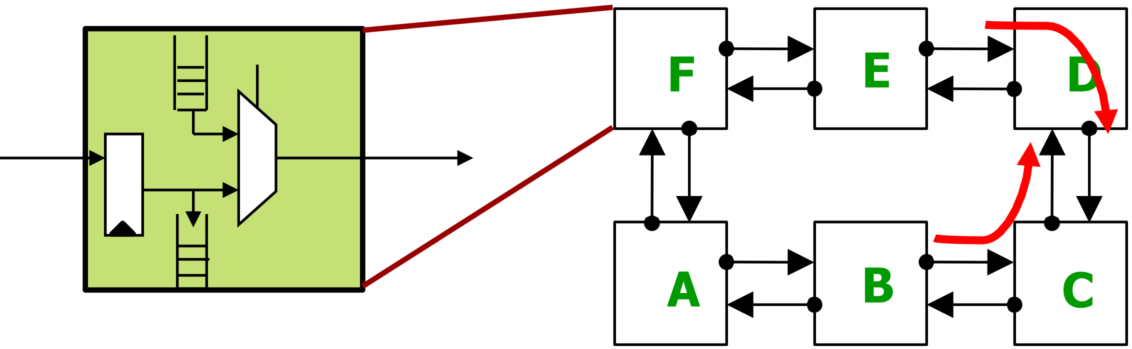
Route from E to A disabled

Option 2



Problem? No route from E to A/B/C

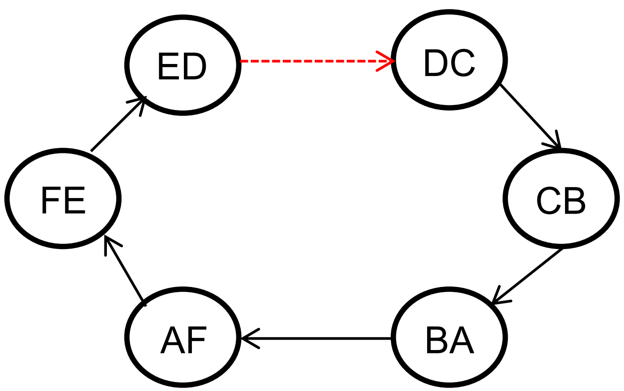
Acyclic CDG for a Ring



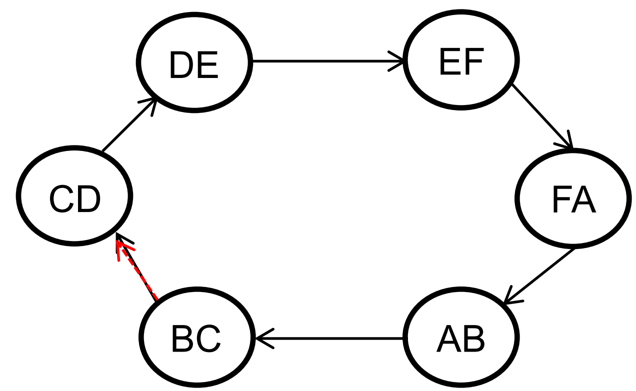
Route from E to C disabled
(E to D) and (D to C) allowed

Route from B to D disabled

Option 3



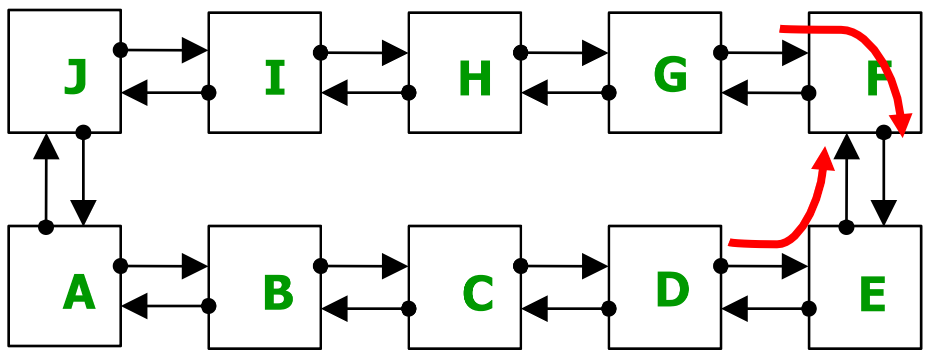
CDG



Acceptable CDG

Problem? E to C no longer minimal

Acyclic CDG for a Large Ring

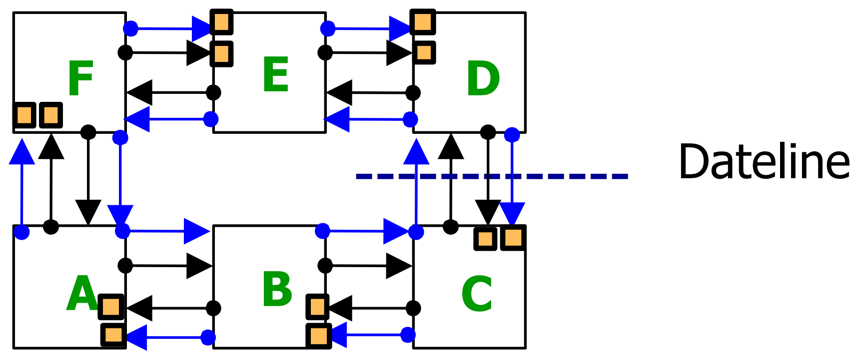


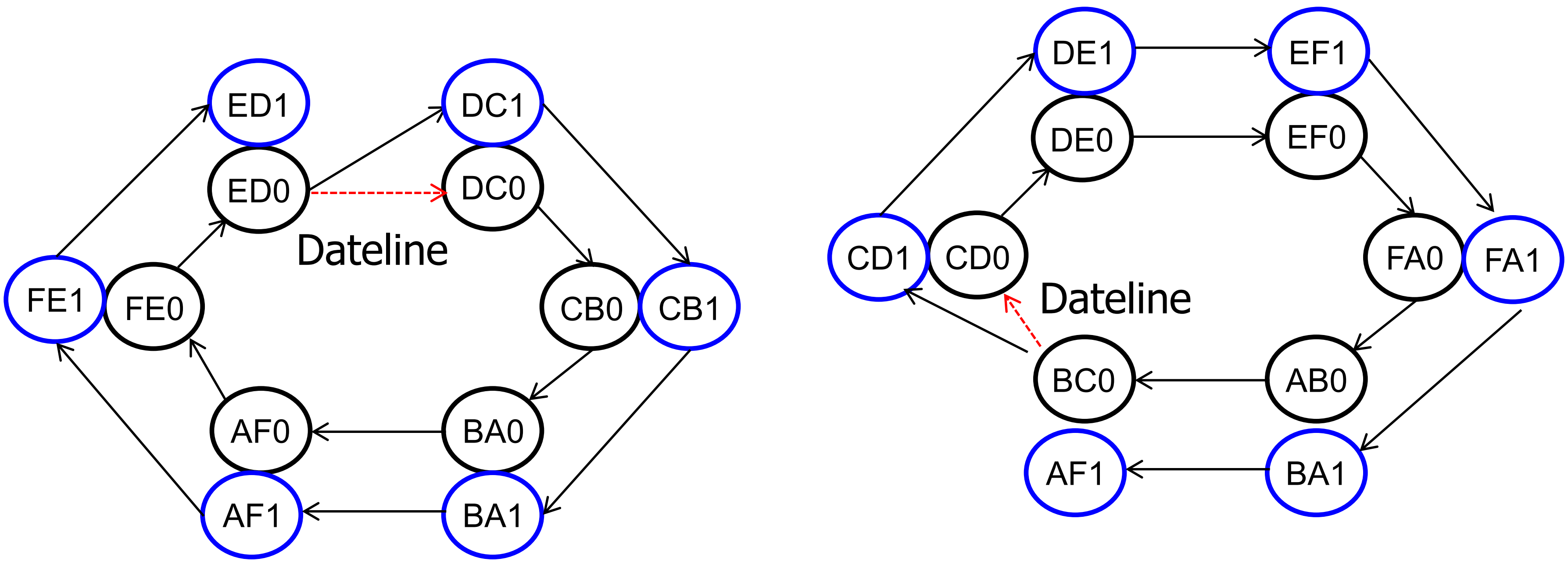
Problem?

G, H, I have to take non-minimal paths to reach E!

D, C, B have to take non-minimal paths to reach F

Suppose *two* channels





Need not be physical channels

Need at least 2 classes of buffers - called **"Virtual Channels"**

Start in VC in Class0
After Dateline, jump to VC in Class1