Detailed Routing

Detailed Routing

- Find actual geometric layout of each net within assigned routing regions.
- No layouts of two different nets should intersect on the same layer.
- Problem is solved incrementally, one region at a time in a predefined order.

Global Routing

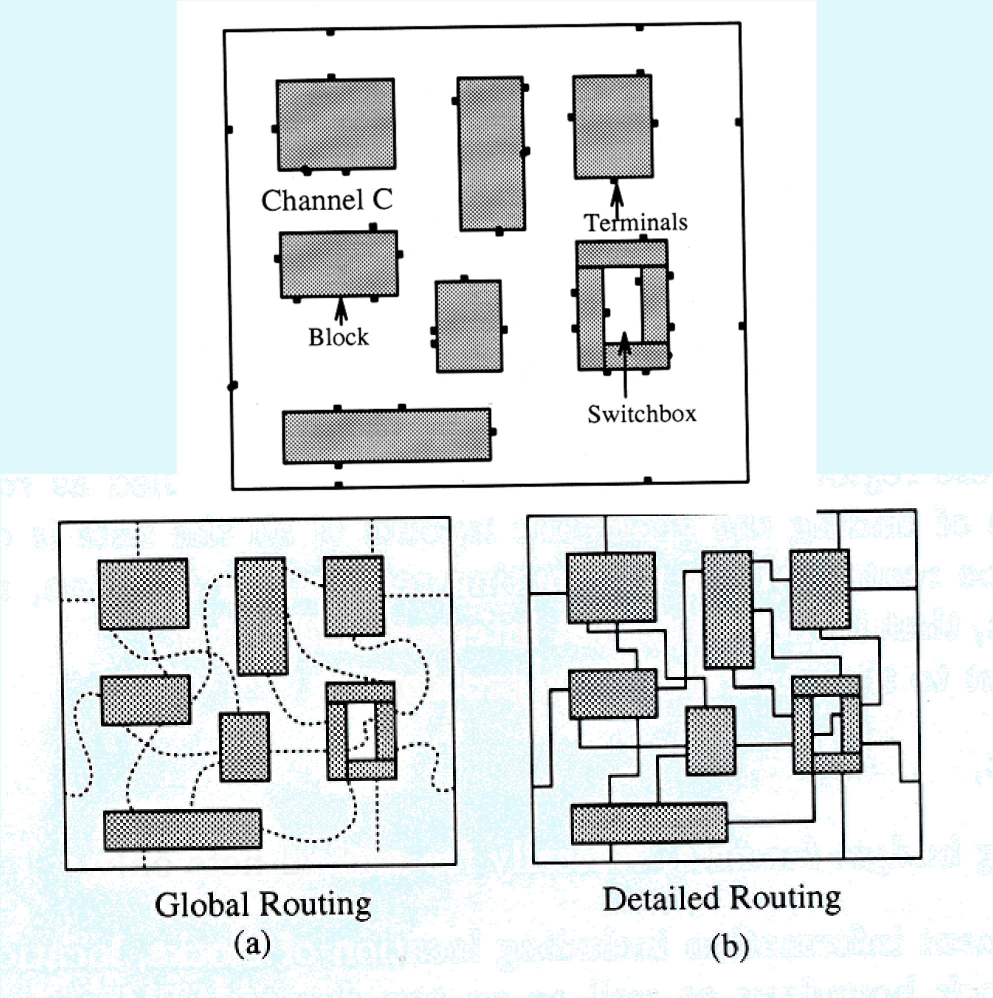
↓

Detailed Routing

↓

Compaction

A Routing Example

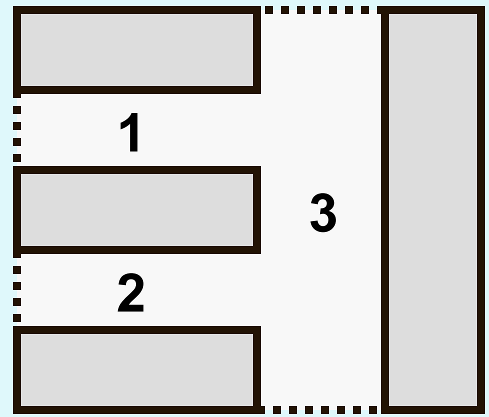


After Global Routing

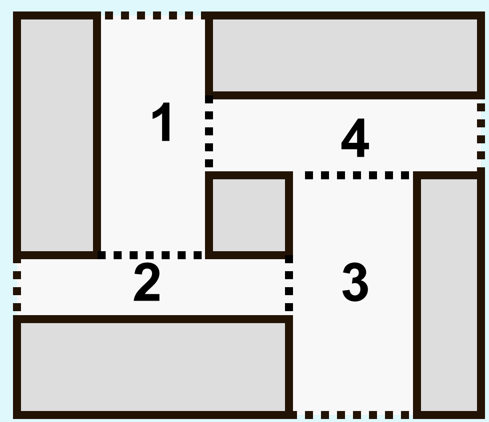
- The two-stage routing method is a powerful technique for routing in VLSI circuits.
- During the global routing stage
  - The routing region is partitioned into a collection of rectangular regions.
  - To interconnect each net, a sequence of sub-regions to be used is determined.
  - All nets crossing a given boundary of a routing region are called *floating terminals*.
  - Once the sub-region is routed, these floating terminals become fixed terminals for subsequent regions.

Order of Routing Regions

- Slicing placement topology
- Nets can be routed by considering channels 1, 2 and 3 in order.



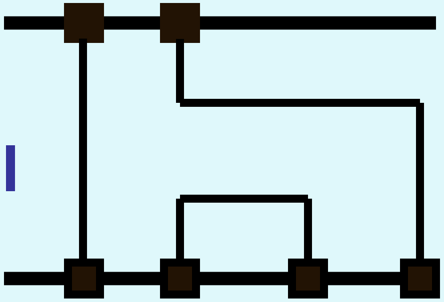
- Non-slicing placement topology.
- Channels with cyclic constraints.
- Some of the routing regions are to be considered as switchboxes.

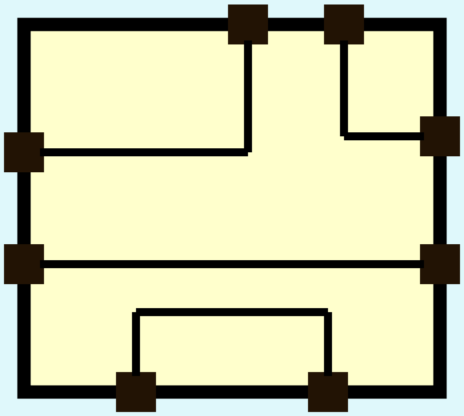


Channels and Switchboxes

- There are normally two kinds of rectilinear regions.
  - **Channels**: routing regions having two parallel rows of fixed terminals.
  - **Switchboxes**: generalizations of channels that allow fixed terminals on all four sides of the region.

Channel





Switchbox

Routing Considerations

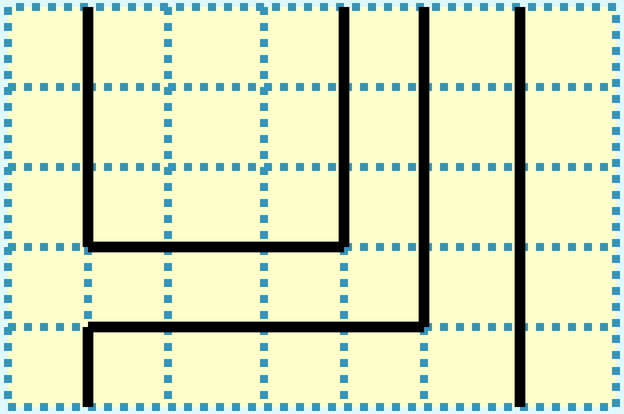
- **Number of terminals**
  - Majority of nets are two-terminal ones.
  - For some nets like clock and power, number of terminals can be very large.
  - Each multi-terminal net can be decomposed into several two-terminal nets.
- **Net width**
  - Power and ground nets have greater width.
  - Signal nets have less width.

Contd.

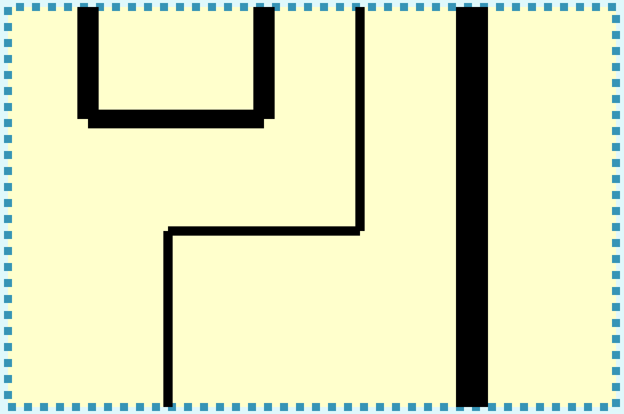
- Via restrictions
  - Regular: only between adjacent layers.
  - Stacked: passing through more than two layers.
- Boundary type
  - Regular: straight border of routing region
  - Irregular
- Number of layers
  - Modern fabrication technology allows at least five layers of routing.
- Net types
  - Critical: power, ground, clock nets
  - Non-critical: signal nets

Routing Models

- **Grid-based model**
  - A grid is super-imposed on the routing region.
  - Wires follow paths along the grid lines.



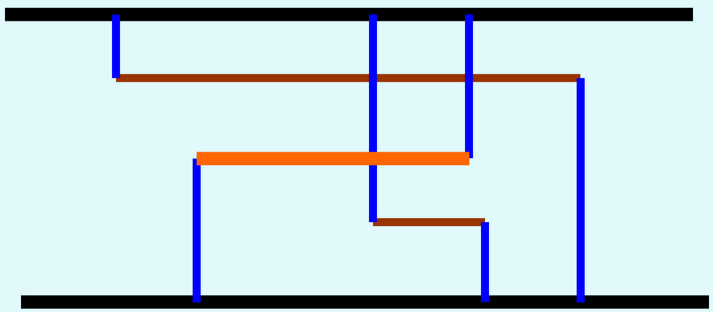
- **Gridless model**
  - Does not follow the gridded approach.



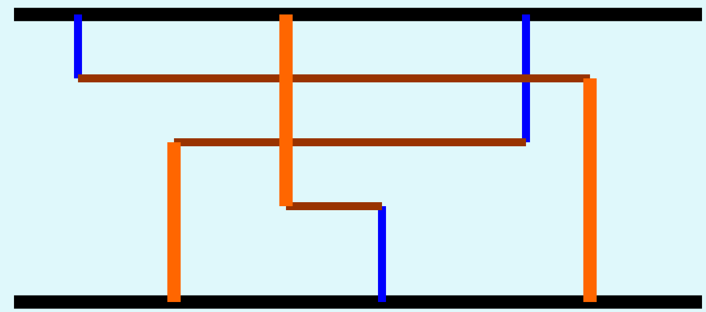
Models for Multi-Layer Routing

- Unreserved layer model
  - Any net segment is allowed to be placed in any layer.
- Reserved layer model
  - Certain types of segments are restricted to particular layer(s).
    - Two-layer (HV, VH)
    - Three-layer (VHV, HVH)

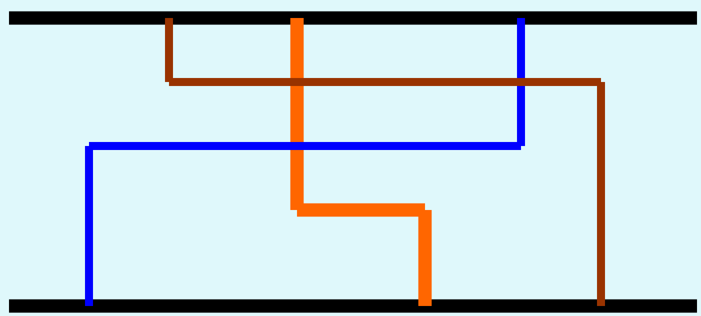
Illustration



HVH Model



VHV Model

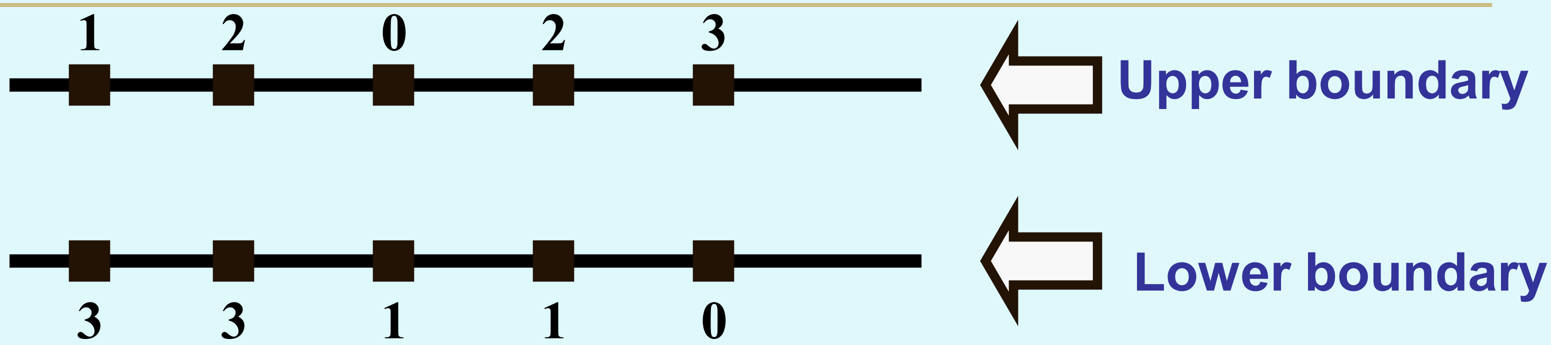


Unreserved Layer Model

Channel Routing

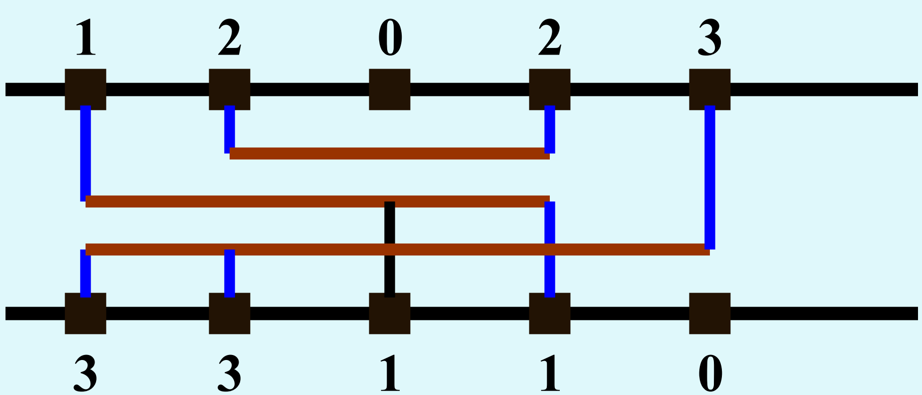
- In channel routing, interconnections are made within a rectangular region having no obstructions.
  - A majority of modern-day ASIC's use channel routers.
  - Algorithms are efficient and simple.
  - Guarantees 100% completion if channel width is adjustable.
- Some terminologies:
  - **Track**: horizontal row available for routing.
  - **Trunk**: horizontal wire segment.
  - **Branch**: vertical wire segment connecting trunks to terminals.
  - **Via**: connection between a branch and a trunk.

Channel Routing Problem :: Terminologies



Net list:: TOP = [1 2 0 2 3]

BOT = [3 3 1 1 0]



Problem Formulation

- The channel is defined by a rectangular region with two rows of terminals along its top and bottom sides.
  - Each terminal is assigned a number between 0 and N.
  - Terminals having the same label i belong to the same net i.
  - A ‘0’ indicates no connection.
- The netlist is usually represented by two vectors TOP and BOT.
  - TOP(k) and BOT(k) represents the labels on the grid points on the top and bottom sides of the channel in column k, respectively.

Contd.

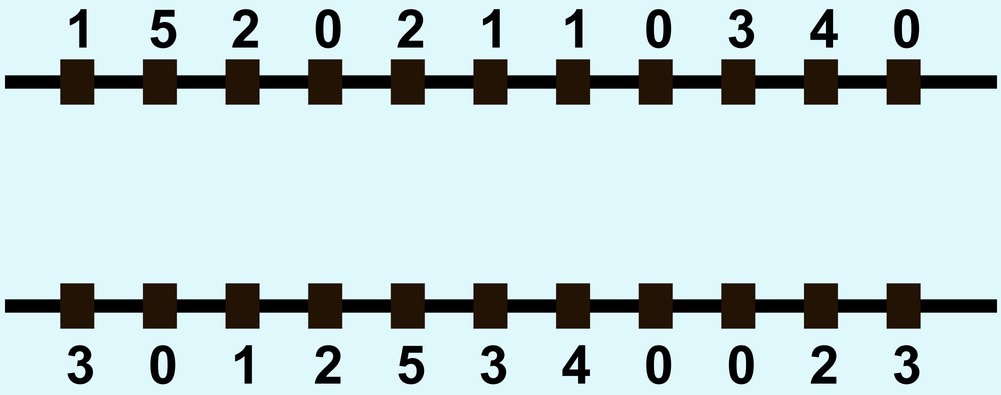
- The task of the channel router is to:
  - Assign horizontal segments of nets to tracks.
  - Assign vertical segments to connect
    - Horizontal segments of the same net in different tracks.
    - The terminals of the net to horizontal segments of the net.
- Channel height should be minimized.
- Horizontal and vertical constraints must not be violated.

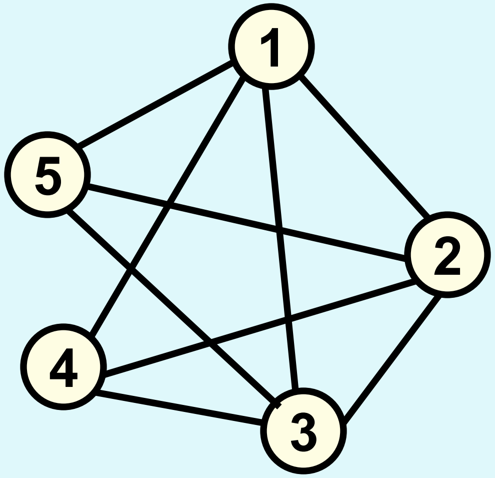
Contd.

- **Horizontal constraints between two nets:**
  - The horizontal span of two nets overlaps each other.
  - The nets must be assigned to separate tracks.
- **Vertical constraints between two nets:**
  - There exists a column such that the terminal i on top of the column belongs to one net, and the terminal j on bottom of the column belongs to the other net.
  - Net i must be assigned a track above that for net j.

Horizontal Constraint Graph (HCG)

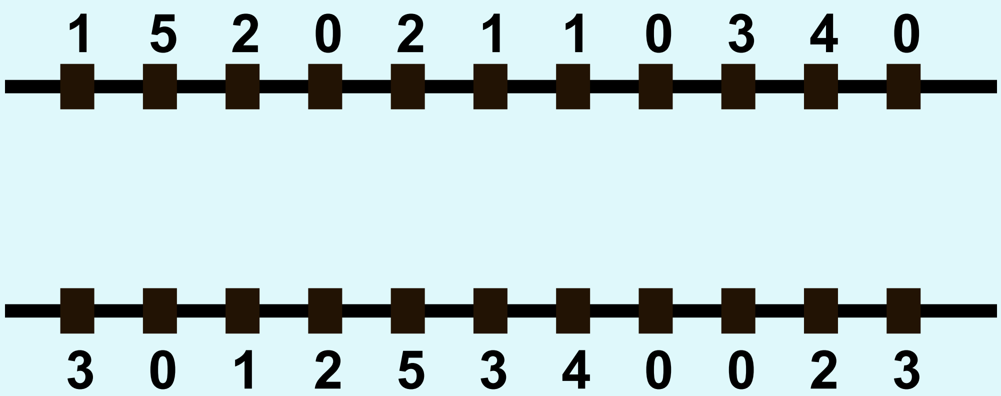
- It is a graph where vertices represent nets, and edges represent horizontal constraints.

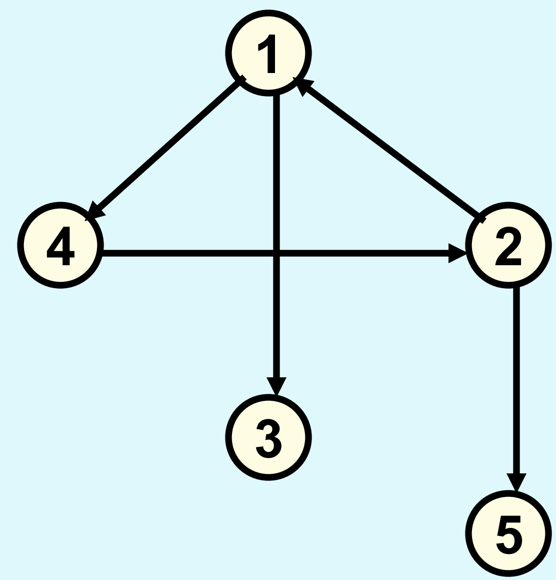




Vertical Constraint Graph (VCG)

- It is a directed graph where vertices represent nets, and edges represent vertical constraints.





Two-layer Channel Routing

- Left-Edge Algorithms (LEA)
  - Basic Left-Edge Algorithm
  - Left-Edge Algorithm with Vertical Constraints
  - Dogleg Router
- Constraint-Graph Based Algorithm
  - Net Merge Channel Router
  - Gridless Channel Router
- Greedy Channel Router
- Hierarchical Channel Router

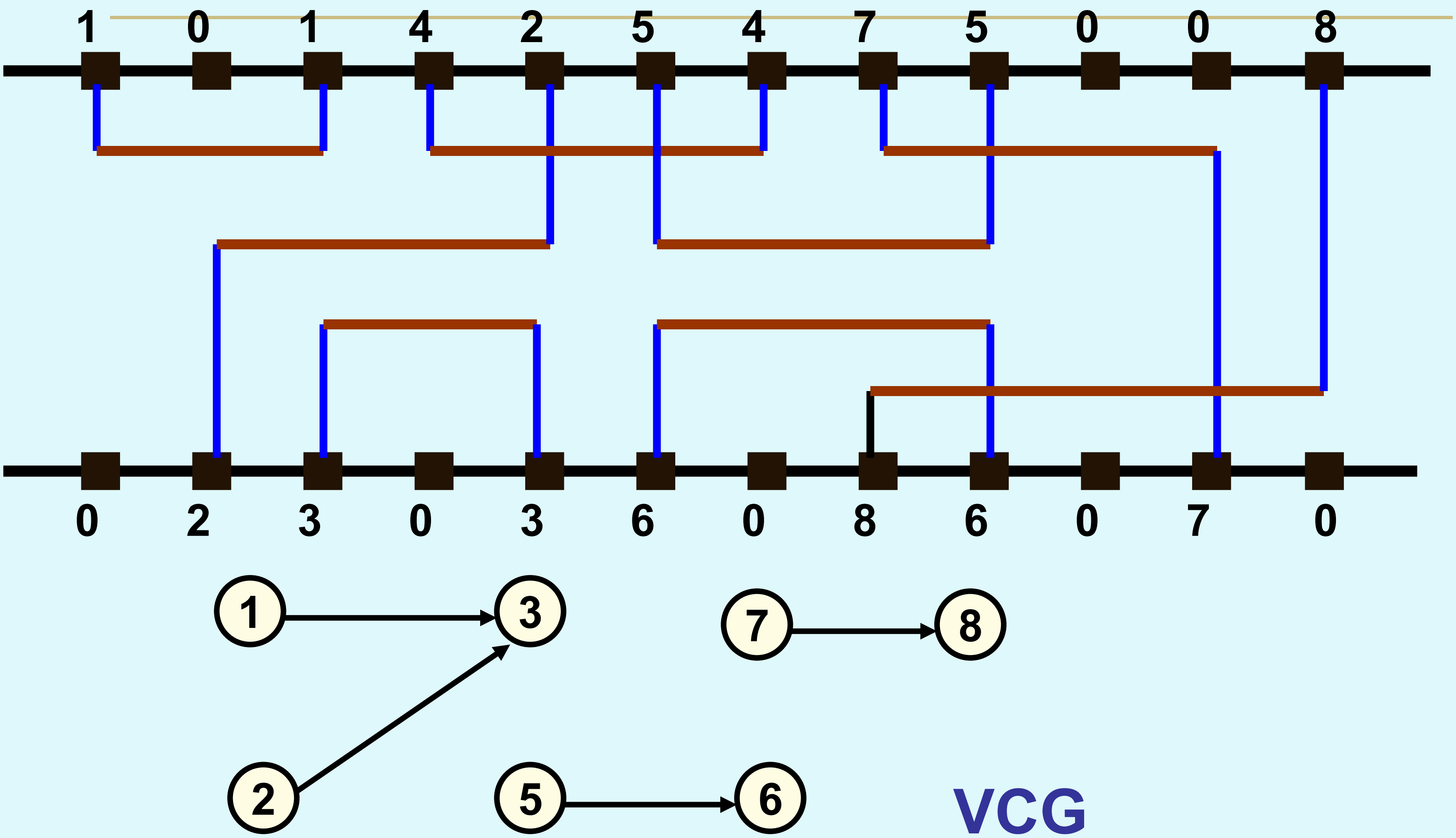
Basic Left Edge Algorithm

- **Assumptions:**
  - Only two-terminal nets.
  - No vertical constraints.
  - HV layer model.
  - Doglegs are not allowed.
- **Basic Steps:**
  - Sort the nets according to the x-coordinate of the leftmost terminal of the net.
  - Route the nets one-by-one according to the order.
  - For a net, scan the tracks from top to bottom, and assign it to the first track that can accommodate it.
- In the absence of vertical constraints, the algorithm produces a minimum-track solution.

Contd.

- **Extension to Left-Edge Algorithm**
  - Vertical constraints may exist, but there are no directed cycles in the VCG.
  - Select a net for routing if
    - The x-coordinate of the leftmost terminal is the least.
    - There is no edge incident on the vertex corresponding to that net in the VCG.
  - After routing a net, the corresponding vertex and the incident edges are deleted from the VCG.
  - Other considerations same as the basic left-edge algorithm.

Illustration



VCG

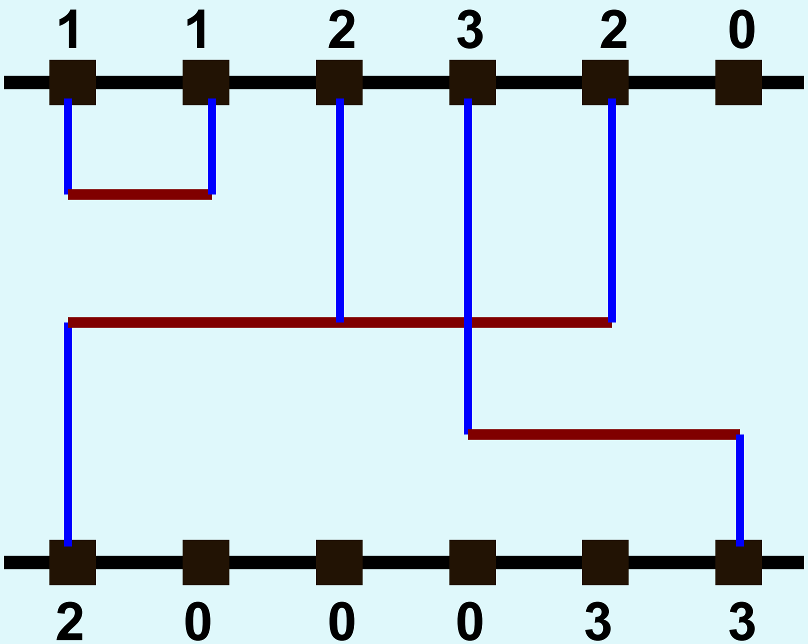
Dogleg Router

- <u>Drawback of LEA</u>
  - The entire net is on a single track.
  - Sometimes leads to routing with more tracks than necessary.
- Doglegs are used to place parts of the same net on different tracks.
  - A dogleg is a vertical segment that connects two trunks located in two different tracks.
  - May lead to a reduction in channel height.

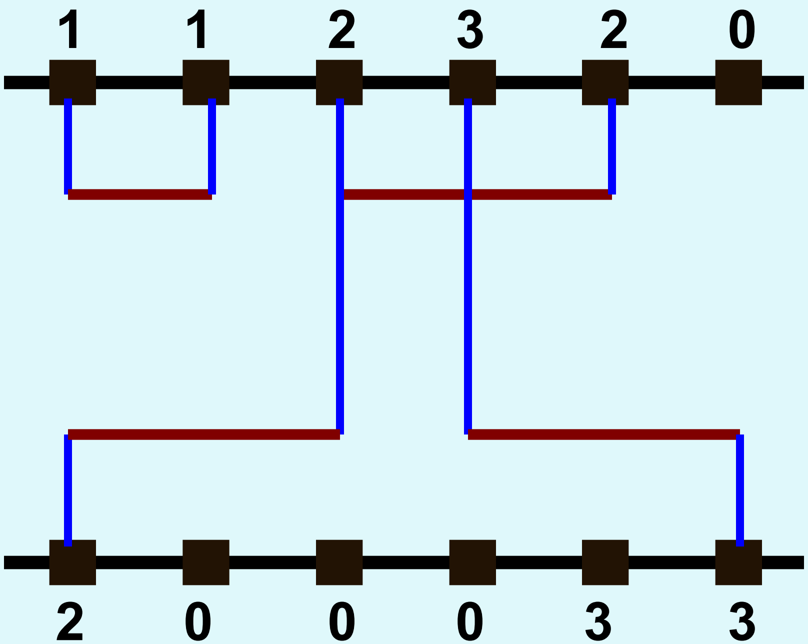
Contd.

- Dogleg router allows multi-terminal nets and vertical constraints.
  - Multi-terminal nets can be broken into a series of two-terminal nets.
- Cannot handle cyclic vertical constraints.

Example



No dogleg
3 tracks

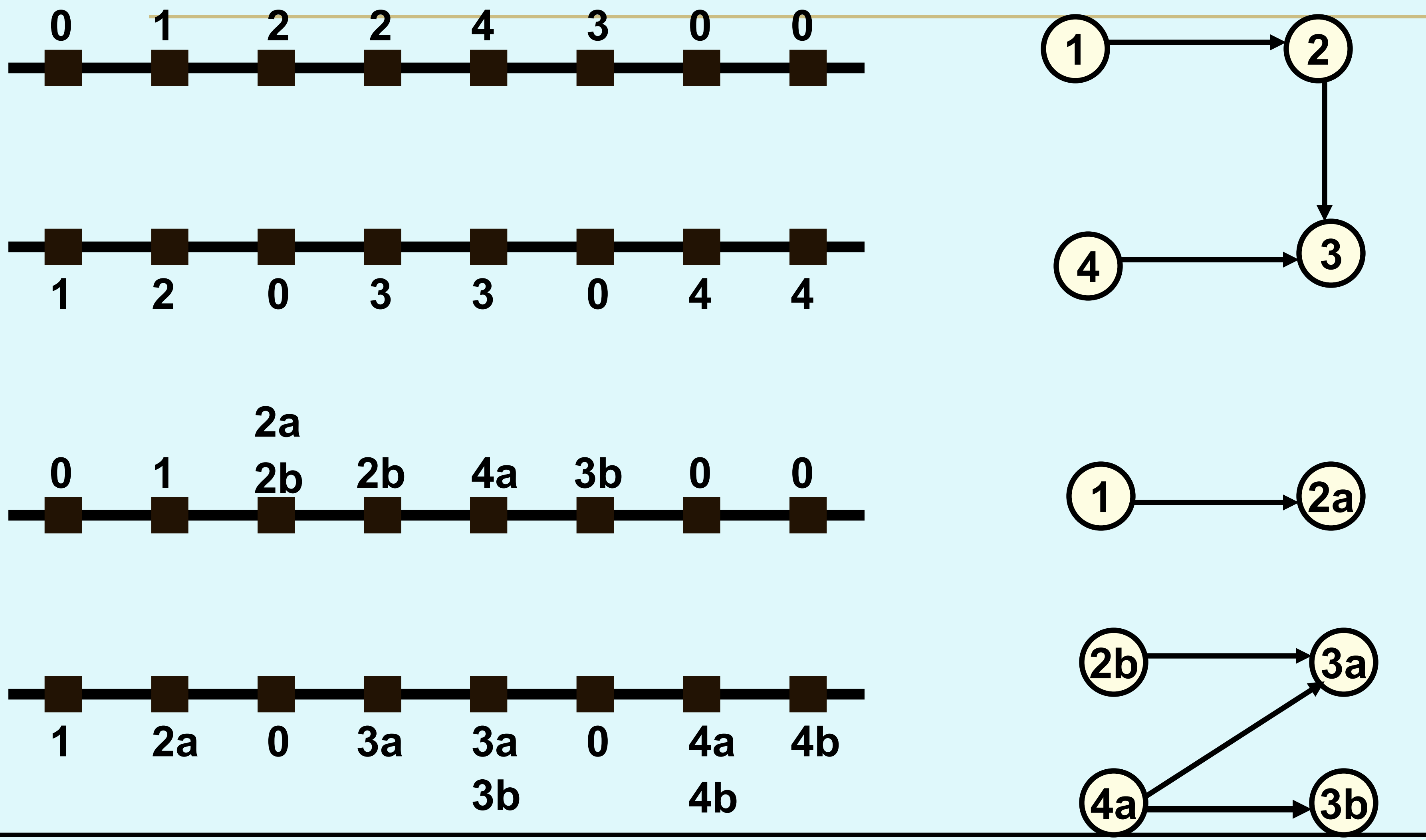


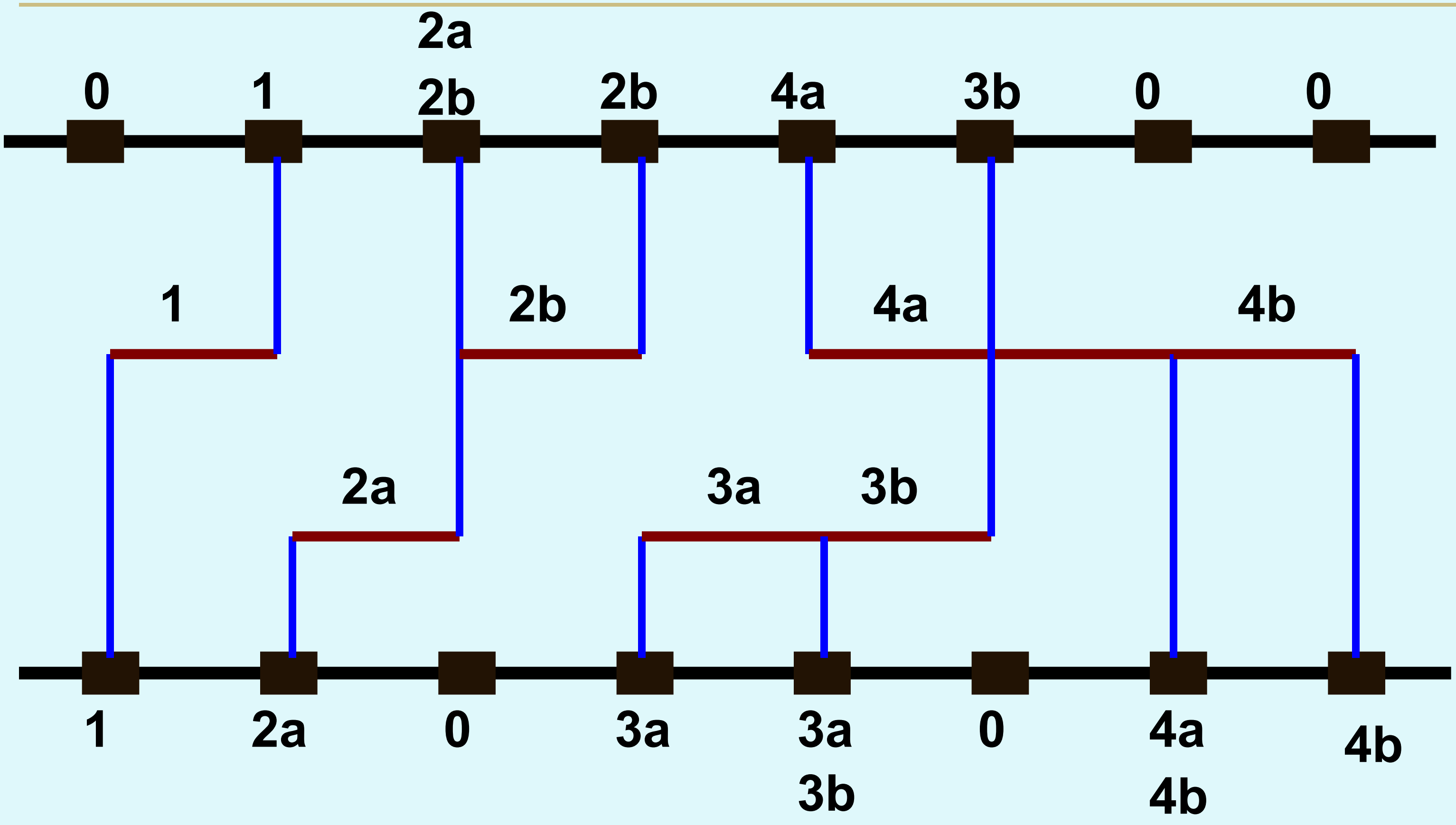
With dogleg
2 tracks

Dogleg Router: Algorithm

- **Step 1**:
  - If cycle exists in the VCG, return with failure.
- **Step 2**:
  - Split each multi-terminal net into a sequence of 2-terminal nets.
    - A net 2 .. 2 .. 2 will get broken as 2a .. 2a 2b .. 2b.
  - HCG and VCG gets modified accordingly.
- **Step 3**:
  - Apply the extended left-edge algorithm to the modified problem.

Illustration



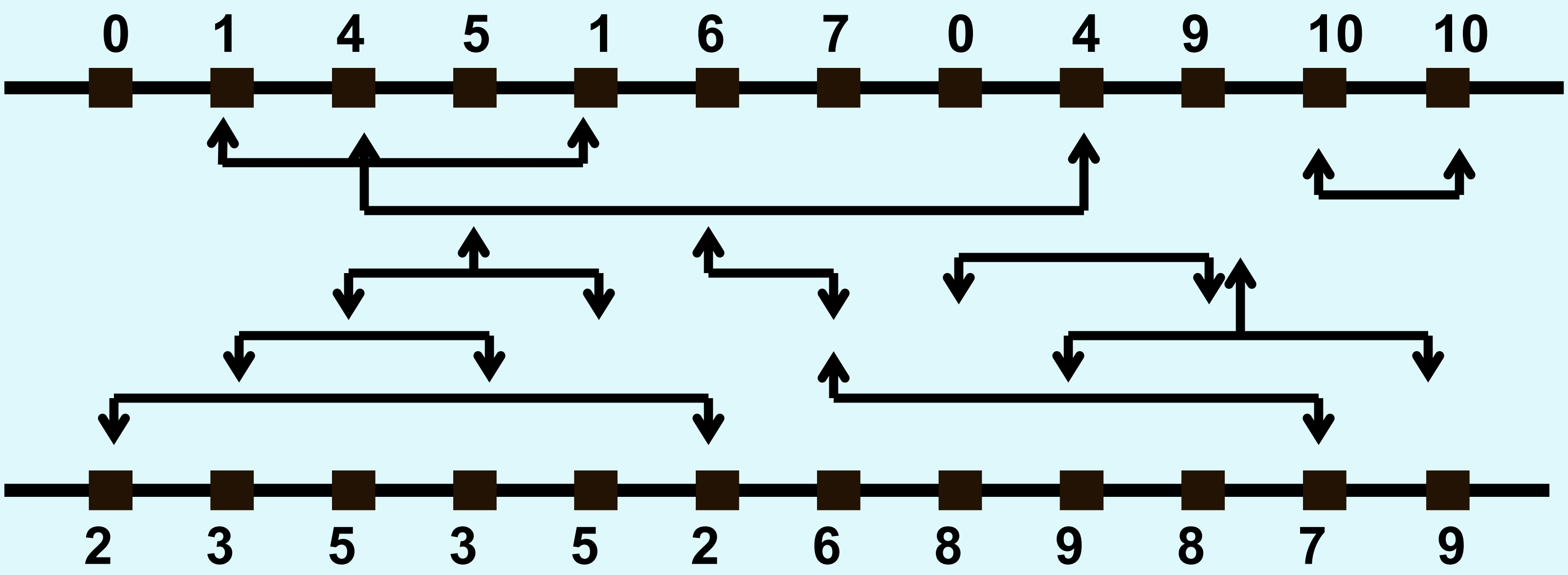

2a
0
1
2b
2b
4a
3b
0
0
1
2b
4a
4b
2a
3a
3b
1
2a
0
3a
3a
3b
0
4a
4b
4b

Net Merge Channel Router

- Due to Yoshimura and Kuh.
- Basic idea:
  - If there is a path of length *p* in the VCG, at least *p* horizontal tracks are required to route the channel.
  - Try to minimize the longest path in the VCG.
  - Merge nodes of VCG to achieve this goal.
- Does not allow doglegs or cycles in the VCG.
- How does it work?
  - Partition the routing channel into a number of regions called "zones".
  - Nets from adjacent zones are merged.
    - Merged nets are treated as a "composite net" and assigned to a single track.

Contd.

- <u>Key steps of the algorithm</u>:
    a) Zone representation
    b) Net merging
    c) Track assignment
- <u>An example</u>:



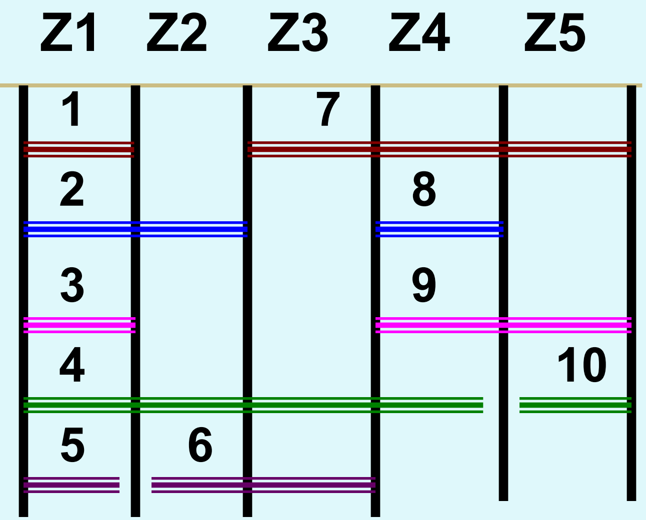
Step 1: Zone Representation

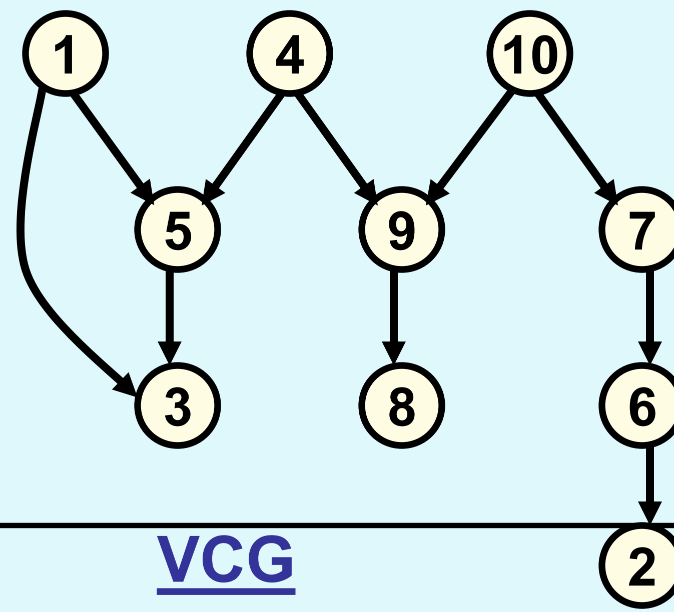
- Let *S(i)* denote the set of nets whose horizontal segments intersect column *i*.
- Take only those *S(i)* which are maximal, that is, not a proper subset of some other *S(j)*.
- Define a zone for each of the maximal sets.
- In terms of HCG / interval graph, a zone corresponds to a maximal clique in the graph.

Zone Table

Column	S(i)	Zone
1	{2}	
2	{1,2,3}	
3	{1,2,3,4,5}	1
4	{1,2,3,4,5}	
5	{1,2,4,5}	
6	{2,4,6}	2
7	{4,6,7}	3
8	{4,7,8}	
9	{4,7,8,9}	4
10	{7,8,9}	
11	{7,9,10}	5
12	{9,10}	

Zone Representation





VCG

Step 2: Net Merging

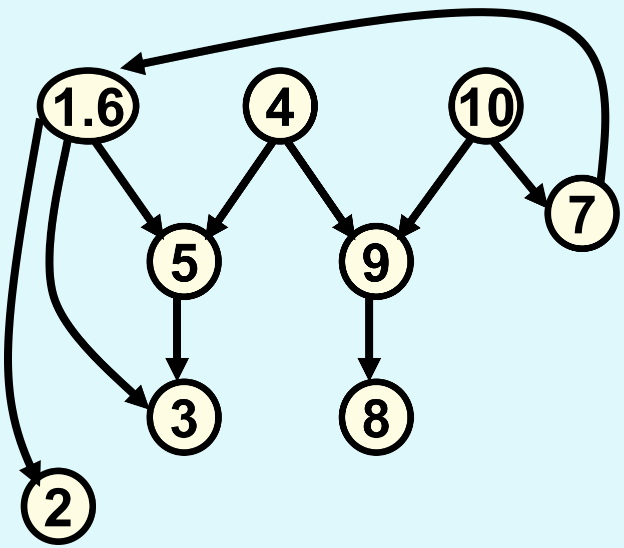
- Let N_i and N_j be two nets for which the following conditions are satisfied:
  - There is no edge between v_i and v_j in HCG.
  - There is no directed path between v_i and v_j in VCG.
- Nets N_i and N_j can then be *merged* to form a new composite net.
  - Modifies VCG by merging nodes v_i and v_j into a single node $v_{i.j}$.
  - Modifies HCG / zone representation by replacing nodes v_i and v_j by a net $v_{i\text{-}j}$, which occupies the consecutive zones including those of nets N_i and N_j.

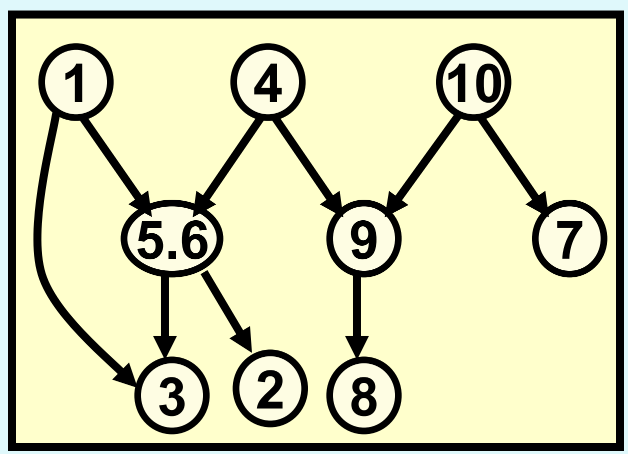
Contd.

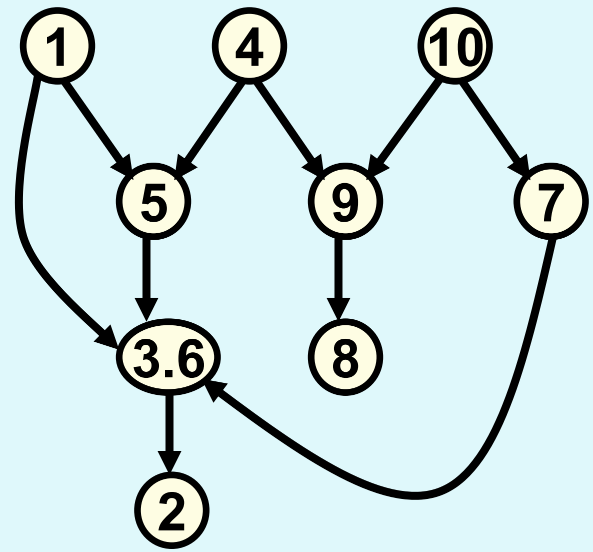
- **The process is iterative:**
  - Pairs of nodes are successively merged.
  - At every step of the iteration, in case of multiple choices, merge the net-pair that minimizes the length of the longest path in the VCG.
  - That is, the increase in length is minimum.
- **A result:**
  - If the original VCG has no cycles, then the updated VCG with merged nodes will not have cycles either.

Contd.

- **Iteration 1 of the example:**
  - **We can merge nets pairs (1,6), (3,6) or (5,6).**



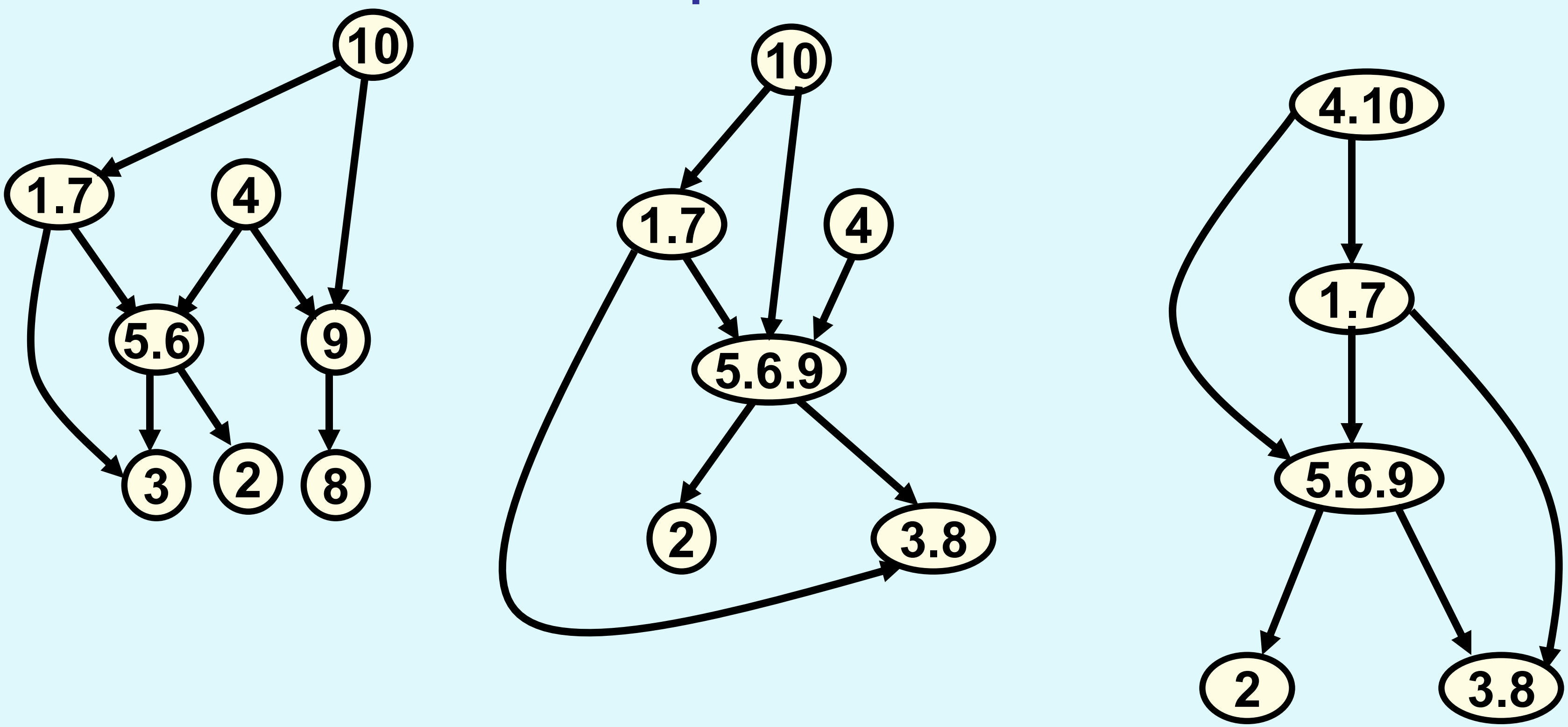




Best Choice

Contd.

- Successive iteration steps:



Step 3: Track Assignment

- Each node in the final graph is assigned a separate track.
- Actually we apply the left-edge algorithm to assign horizontal tracks to the merged nets.
  - The list of nets sorted on their left edges, subject to the vertical constraint, is:

    [4-10, 1-7, 5-6-9, 2, 3-8]

Track 1: Nets 4 and 10

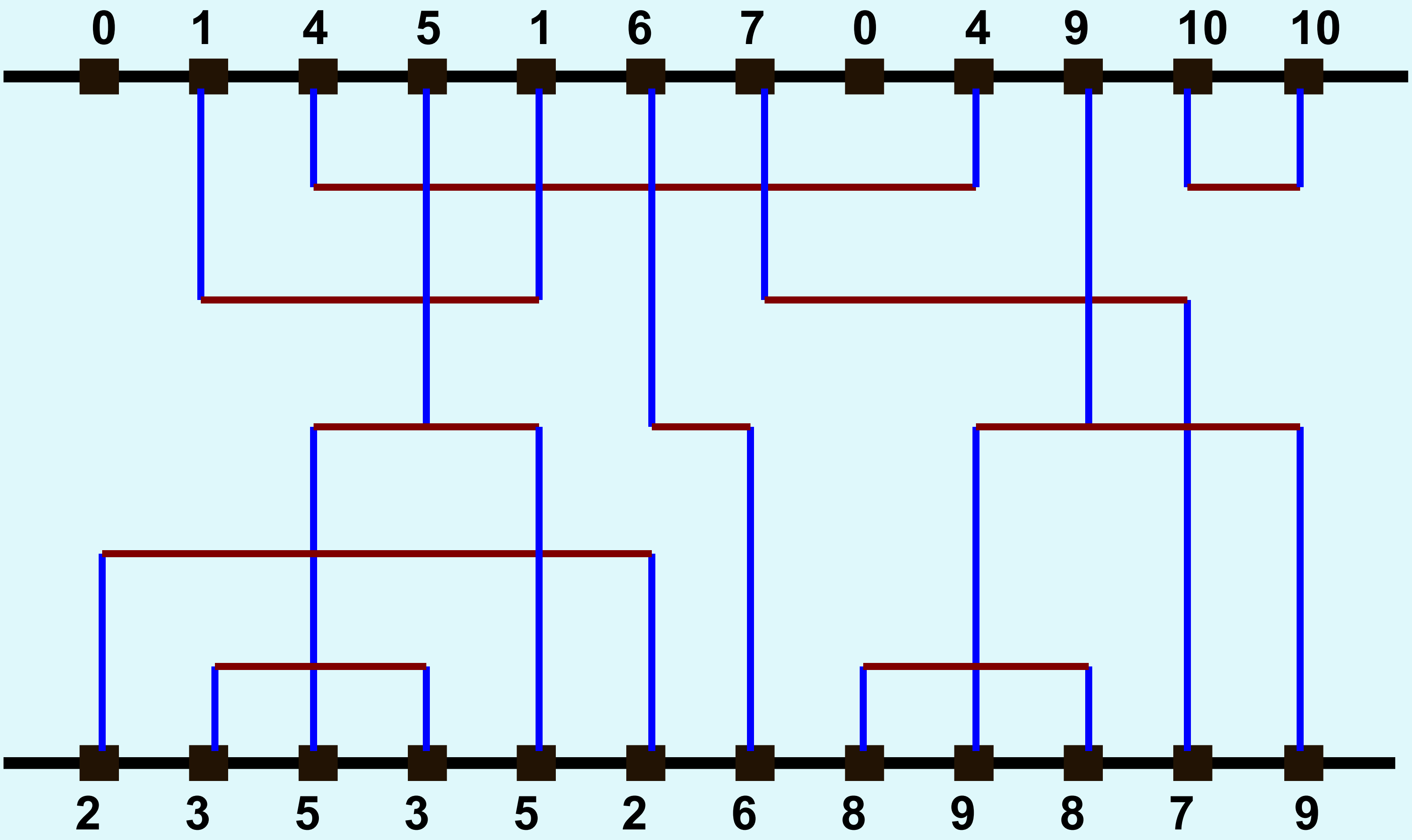
Track 2: Nets 1 and 7

Track 3: Nets 5, 6 and 9

Track 4: Net 2

Track 5: Nets 3 and 8

The Final Solution



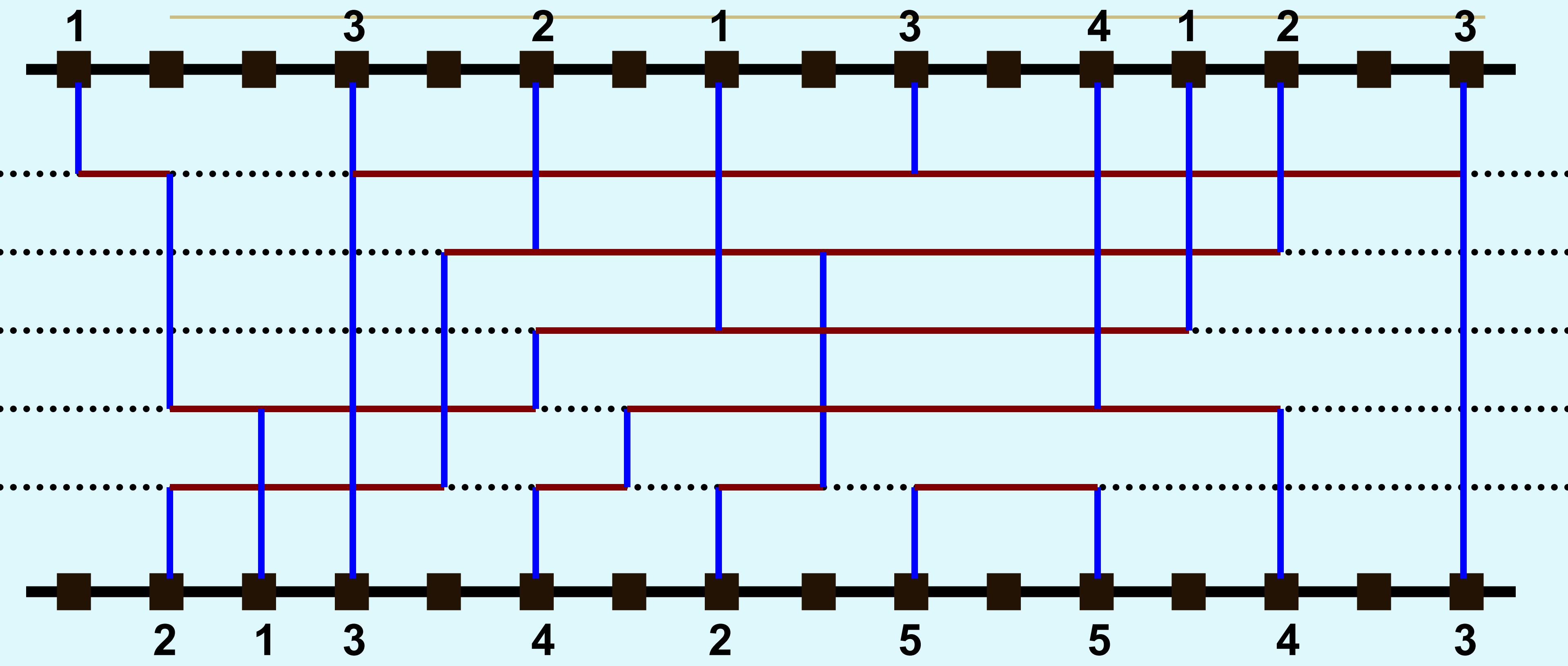
Greedy Channel Router

- The routing algorithms discussed so far route the channel one net at a time.
  - Based on left-edge algorithm or some of its variation.
- The Greedy Channel Router algorithm routes the channel column by column starting from the left.
  - Apply a sequence of greedy but intelligent heuristic at each column.
  - Objective is to maximize the number of tracks available in the next column.
- Can handle problems with cycles in VCG.
  - May need additional columns at the end of the channel.

Contd.

- Some of the heuristics used:
  - Place all segments column by column, starting from the leftmost column.
  - Connect any terminal to the trunk segment of the corresponding net.
  - Collapse any split net using a vertical segment.
  - Try to reduce the distance between two tracks of same net.
  - Try to move the nets closer to the boundary which contains the next terminal of that net.
  - Add additional tracks if needed.

Channel Routed using a Greedy Router



Summary

- The detailed routing problem is solved by routing the channels and switchboxes.
- Routing results may differ based on the routing model used.
  - Grid-based.
  - Based on assigning layer of different net segments.
- The objectives for routing a channel is to minimize channel density, the length of routing nets, and the number of via's.
- The main objective of channel routing is to minimize the total routing area.
- The objective of switchbox routing is to determine the routability.