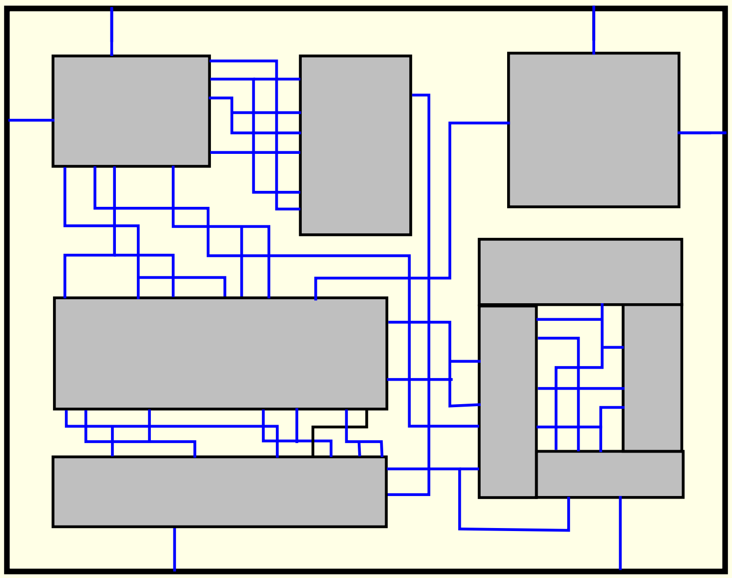
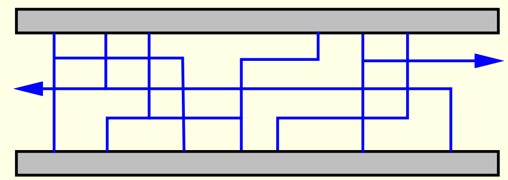
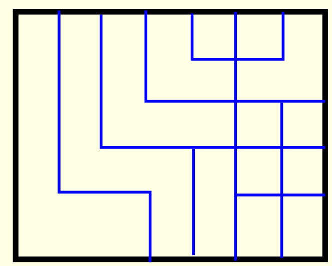
Channel & Switchbox Routing



Detailed routing



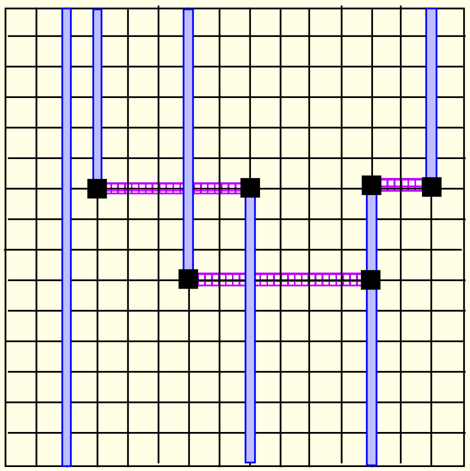
channel routing



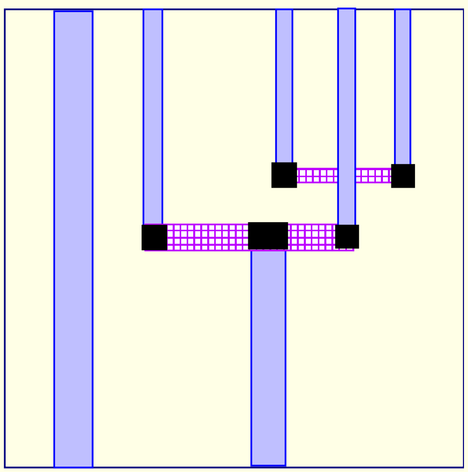
switchbox routing

Routing Models

- **Grid-based model:**
  - A grid is super-imposed on the routing region.
  - Wires follow paths along the grid lines.
- **Gridless model:**
  - Any model that does not follow this "gridded" approach.



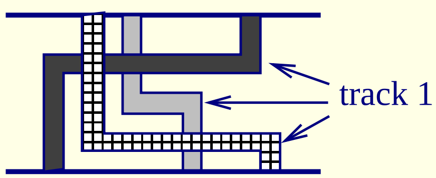
grid−based



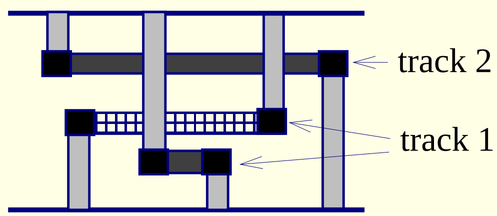
gridless

Models for Multi-Layer Routing

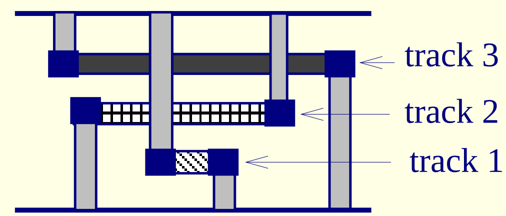
- **Unreserved layer model:** Any net segment is allowed to be placed in any layer.
- **Reserved layer model:** Certain type of segments are restricted to particular layer(s).
  - Two-layer: HV (horizontal-Vertical), VH
  - Three-layer: HVH, VHV



unreserved layer model



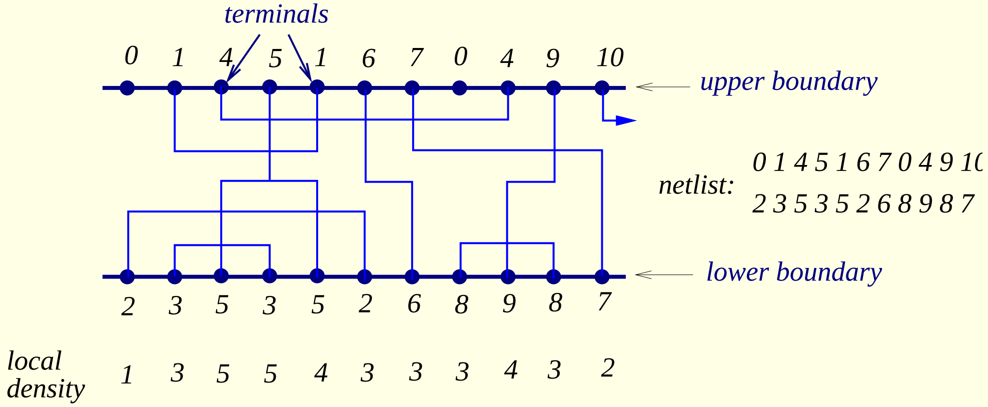
HVH model

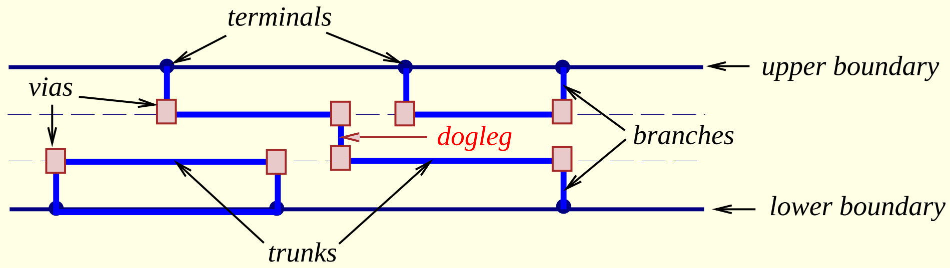


VHV model

3 types of 3−layer models

Terminology for Channel Routing Problems





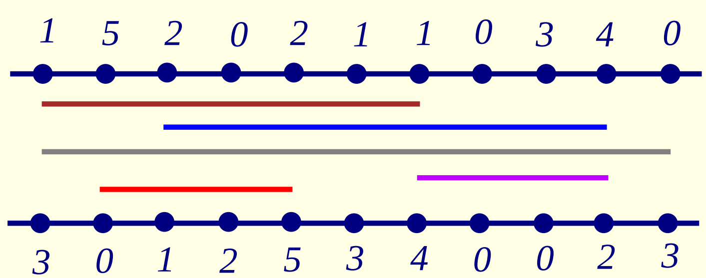
- Local density at column i: total # of nets that crosses column i.
- Channel density: maximum local density; # of horizontal tracks required $\geq$ channel density.

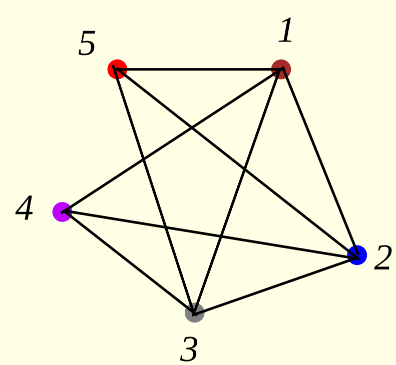
Channel Routing Problem

- **Assignments of horizontal segments of nets to tracks.**
- **Assignments of vertical segments to connect.**
  - horizontal segments of the same net in different tracks, and
  - the terminals of the net to horizontal segments of the net.
- **Horizontal and vertical constraints must not be violated.**
  - Horizontal constraints between two nets: The horizontal span of two nets overlaps each other.
  - Vertical constraints between two nets: There exists a column such that the terminal on top of the column belongs to one net and the terminal on bottom of the column belongs to the other net.
- **Objective: Channel height is minimized** (i.e., channel area is minimized).

Horizontal Constraint Graph (HCG)

- HCG $G = (V, E)$ is **undirected** graph where
  - $V = \{v_i | v_i$ represents a net $n_i\}$
  - $E = \{(v_i, v_j) |$ a horizontal constraint exists between n_i and $n_j\}$.
- For graph G: vertices $\Leftrightarrow$ nets; edge $(i, j) \Leftrightarrow$ net i overlaps net j.

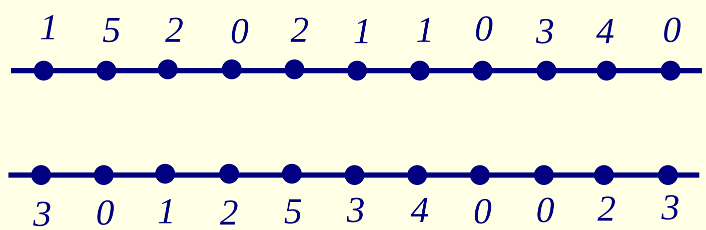


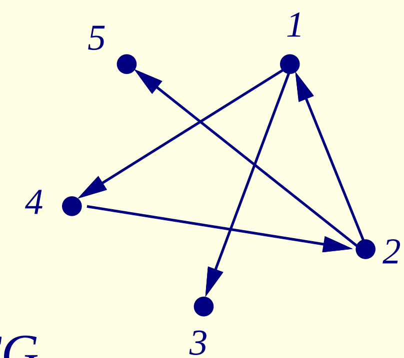


A routing problem and its HCG.

Vertical Constraint Graph (VCG)

- VCG $G = (V, E)$ is **directed** graph where
  - $V = \{v_i | v_i$ represents a net $n_i\}$
  - $E = \{(v_i, v_j) |$ a vertical constraint exists between n_i and $n_j\}$.
- For graph G: vertices $\Leftrightarrow$ nets; edge $i \rightarrow j \Leftrightarrow$ net i must be above net j.





A routing problem and its VCG.

2-L Channel Routing: Basic Left-Edge Algorithm

- Hashimoto & Stevens, "Wire routing by optimizing channel assignment within large apertures," DAC-71.
- **No vertical constraint.**
- HV-layer model is used.
- **Doglegs are not allowed.**
- Treat each net as an interval.
- Intervals are sorted according to their left-end x-coordinates.
- Intervals (nets) are routed one-by-one according to the order.
- For a net, tracks are scanned from top to bottom, and the first track that can accommodate the net is assigned to the net.
- Optimality: produces a routing solution with the minimum # of tracks (if no vertical constraint).

Basic Left-Edge Algorithm

Algorithm: Basic_Left-Edge($U, track[j]$)

U: set of unassigned intervals (nets) $I_1, \ldots, I_n$;

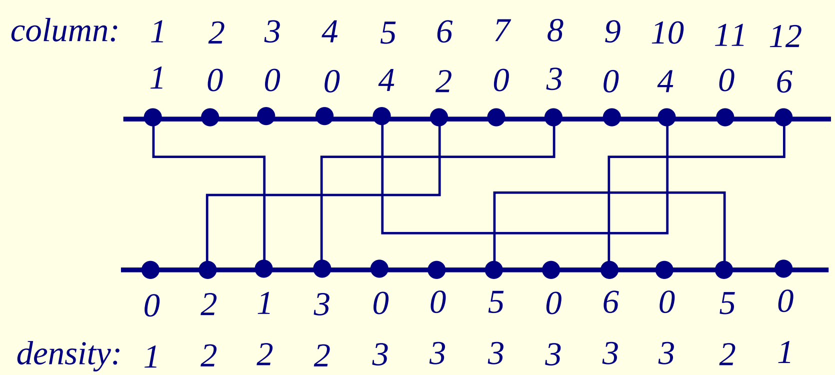
$I_j = [s_j, e_j]$: interval j with left-end x-coordinate s_j and right-end e_j;

$track[j]$: track to which net j is assigned.

begin
$U \leftarrow \{I_1, I_2, \ldots, I_n\}$;
$t \leftarrow 0$;
while ($U \neq \emptyset$) **do**
  $t \leftarrow t + 1$;
  $watermark \leftarrow 0$;
  while (there is an $I_j \in U$ s.t. $s_j > watermark$) **do**
    Pick the interval $I_j \in U$ with $s_j > watermark$,
    nearest $watermark$;
    $track[j] \leftarrow t$;
    $watermark \leftarrow e_j$;
    $U \leftarrow U - \{I_j\}$;
end

Basic Left-Edge Example

- $U = \{I_1, I_2, \ldots, I_6\}$; $I_1 = [1, 3]$, $I_2 = [2, 6]$, $I_3 = [4, 8]$, $I_4 = [5, 10]$, $I_5 = [7, 11]$, $I_6 = [9, 12]$.
- $t = 1$:
  - Route I_1: $watermark = 3$;
  - Route I_3: $watermark = 8$;
  - Route I_6: $watermark = 12$;
- $t = 2$:
  - Route I_2: $watermark = 6$;
  - Route I_5: $watermark = 11$;
- $t = 3$: Route I_4



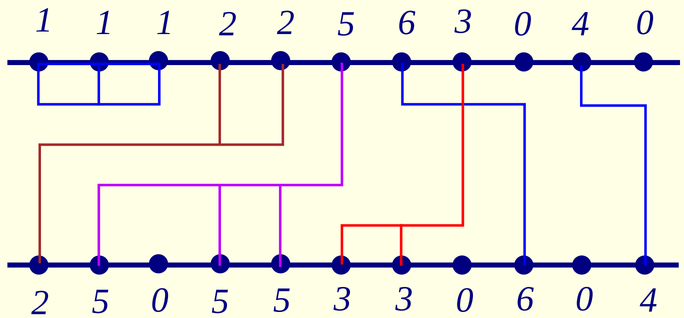
Constrained Left-Edge Algorithm

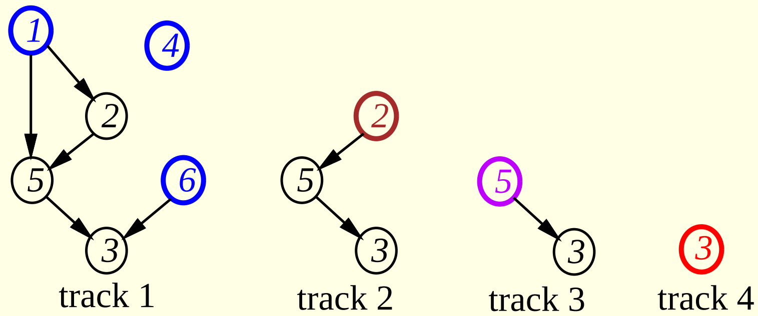
Algorithm: Constrained_Left-Edge($U, track[j]$)
U: set of unassigned intervals (nets) $I_1, \ldots, I_n$;
$I_j = [s_j, e_j]$: interval j with left-end x-coordinate s_j and right-end e_j;
$track[j]$: track to which net j is assigned.

begin
$U \leftarrow \{I_1, I_2, \ldots, I_n\}$;
$t \leftarrow 0$;
while ($U \neq \emptyset$) **do**
  $t \leftarrow t + 1$;
  $watermark \leftarrow 0$;
  while (there is an **unconstrained** $I_j \in U$ s.t. $s_j > watermark$) **do**
    Pick the interval $I_j \in U$ that is unconstrained,
    with $s_j > watermark$, nearest $watermark$;
    $track[j] \leftarrow t$;
    $watermark \leftarrow e_j$;
    $U \leftarrow U - \{I_j\}$;
end

Constrained Left-Edge Example

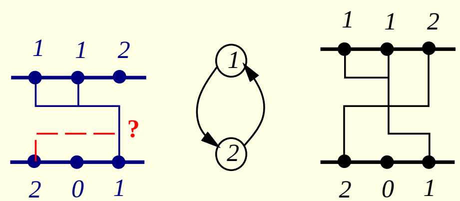
- $I_1 = [1, 3],\ I_2 = [1, 5],\ I_3 = [6, 8],\ I_4 = [10, 11],\ I_5 = [2, 6],\ I_6 = [7, 9]$.
- Track 1: Route I_1 (cannot route I_3); Route I_6; Route I_4.
- Track 2: Route I_2; cannot route I_3.
- Track 3: Route I_5.
- Track 4: Route I_3.



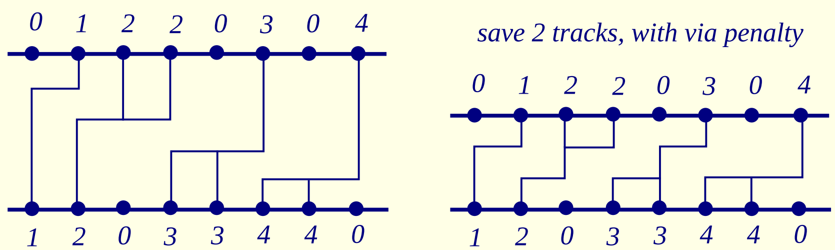


Dogleg Channel Router

- Deutch, "A dogleg channel router," 13rd DAC, 1976.
- **Drawback of Left-Edge: cannot handle the cases with constraint cycles.**
  - **Doglegs** are used to resolve constraint cycle.



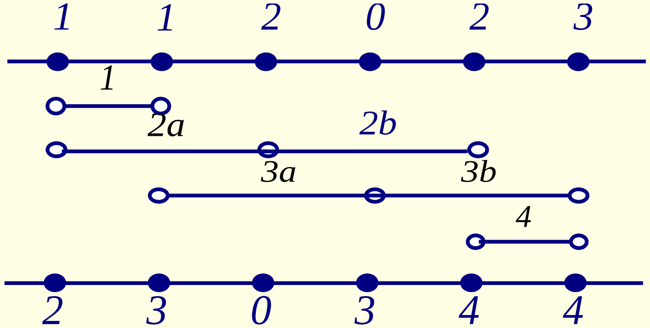
- **Drawback of Left-Edge: the entire net is on a single track.**
  - **Doglegs** are used to place parts of a net on different tracks to minimize channel height.
  - Might incur penalty for additional vias.

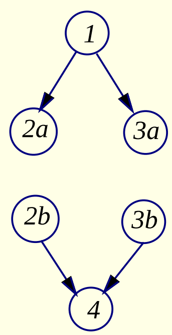


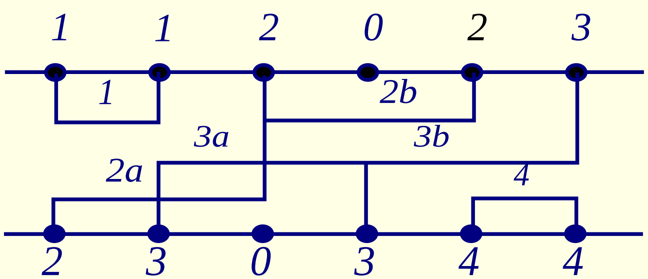
no dogleg *with dogleg*

Dogleg Channel Router

- Each multi-terminal net is broken into a set of 2-terminal nets.
- Two parameters are used to control routing:
  - Range: Determine the # of consecutive 2-terminal subnets of the same net that can be placed on the same track.
  - Routing sequence: Specifies the starting position and the direction of routing along the channel.
- Modified Left-Edge Algorithm is applied to each subnet.

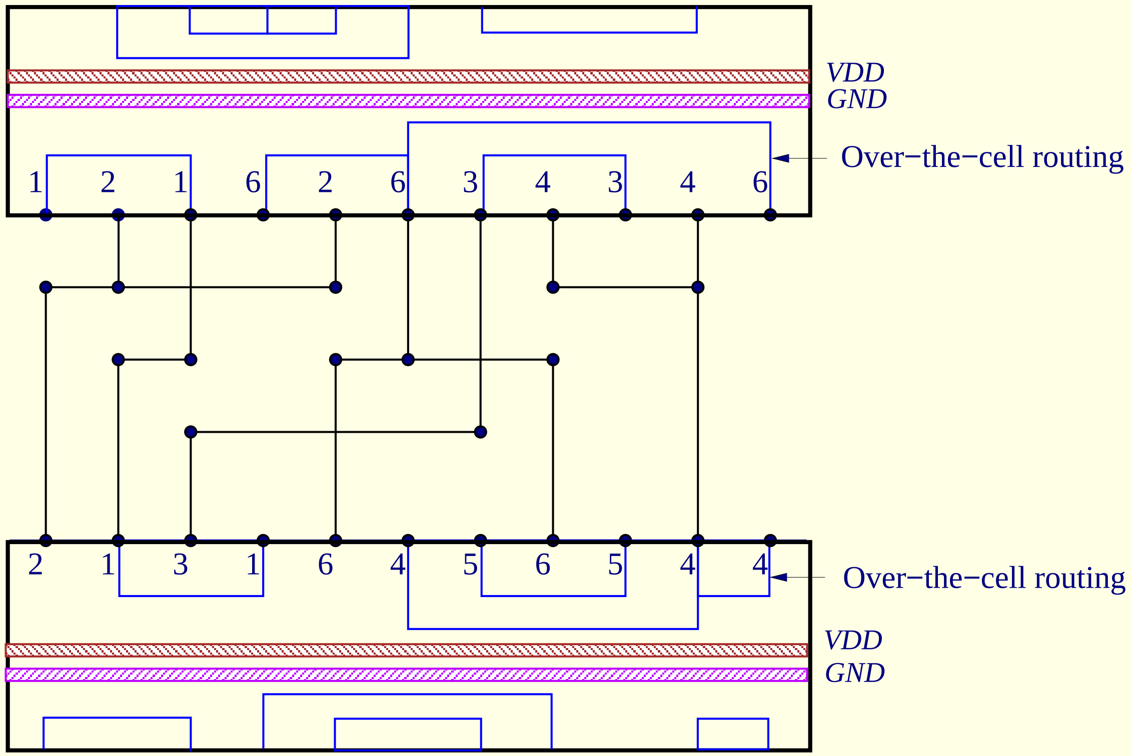






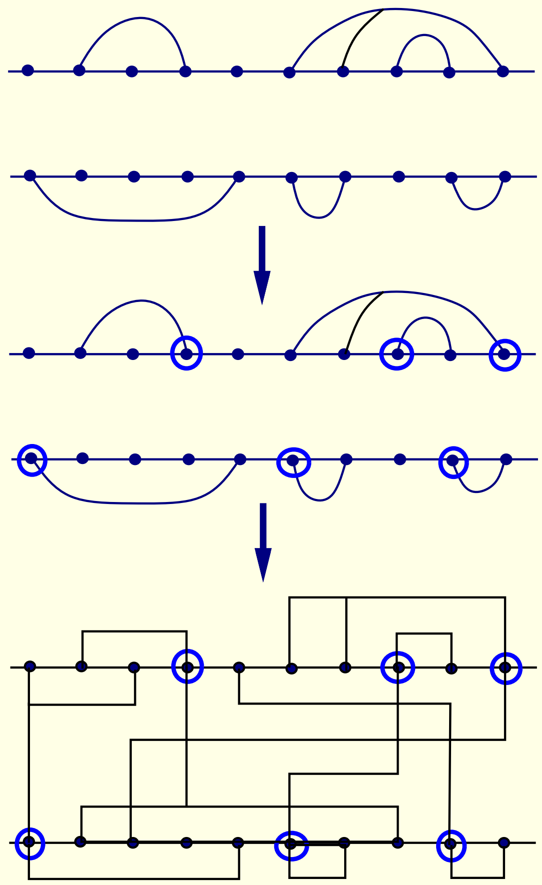
Over-the-Cell Routing

- Routing over the cell rows is possible due to the limited use of the 2nd (M2) metal layers within the cells.
- Divide the over-the-cell routing problem into 3 steps: (1) routing over the cell, (2) choosing the net segments, and (3) routing within the channel.
- Reference: Cong & Liu, "Over-the-cell channel routing," IEEE TCAD, Apr. 1990.



Over-the-Cell Channel Routing

- Cong & Liu, "Over-the-cell channel routing," IEEE TCAD, Apr. 1990.



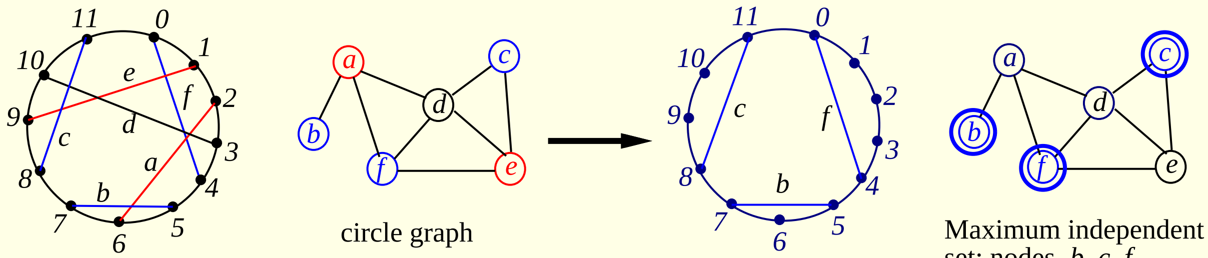
Select over−the−cell nets
use Supowit's Max. Independent
Set algorithm for circle graph
(solvable in $O(c^3)$ time,
c: # of columns)

Select terminals among
"equivalent" ones for regular
channel routing
(Goal: minimize channel density
NP−complete!)

Plannar routing for
over−the−cell nets
+
Regular channel routing

Supowit's Algorithm

- Supowit, "Finding a maximum plannar subset of a set of nets in a channel," IEEE TCAD, 1987.
- Problem: Given a set of chords, find a maximum plannar subset of chords.
  - Label the vertices on the circle 0 to $2n-1$.
  - Compute $MIS(i,j)$: size of maximum independent set between vertices i and j, $i<j$.
  - Answer $= MIS(0, 2n-1)$.

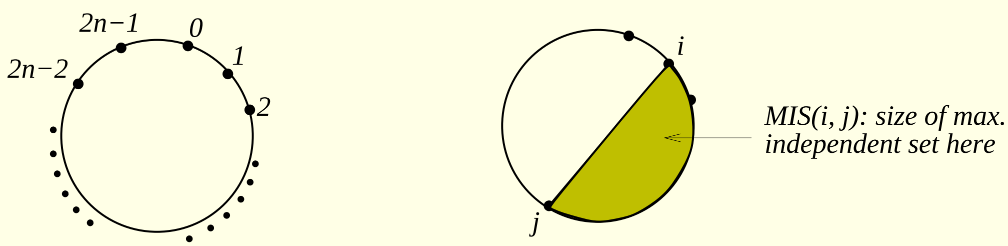


A set of chords.

circle graph

Maximum plannar subset of chords.

Maximum independent set: nodes *b, c, f*



vetrices on the circle

MIS(i, j), i < j

Dynamic Programming in Supowit's Algorithm

- Apply dynamic programming to compute $MIS(i, j)$.