3 types of 3-layer models

- Three-layer: HVH, VHY
- Two-layer: HV (horizontal-vertical), VH
- One-layer: grid-based

To particular layer(s):
- Certain type of segments are restricted

Reserved layer model:
- Any layer

Unreserved layer model:
- Any net segment is allowed to be placed

Models for Multi-Layer Routing

Routing Considerations

- Net types (critical vs. non-critical nets)
- Number of layers (two vs. three; more layers)
- Boundary layers (regular vs. irregular)
- Via restrictions (stacked vs. conventional via)
- Net widths (power and ground vs. signal nets)
- Number of terminals (two-terminal vs. multi-terminal nets)

Order of Routing Regions and L-Channels

- Any model that does not follow this "gridless" approach:
  - Gridless model

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

Routing Models
A routing problem and its VCG.

Vertical Constraint Graph (VCG)

Horizontal Constraint Graph (HCG)

Channel Routing Problem

Terminology for Channel Routing Problems
Basic Left-Edge Algorithm

```
12 end
11 if \( f \neq \phi \) then
10 \( \text{watermark} \rightarrow \{ f \} \)
9 else
8 \( \text{watermark} \rightarrow \{ \} \)
7 \( \text{watermark} \rightarrow \phi \)
6 \( \text{watermark} \rightarrow \{ \} \)
5 \( \text{watermark} \rightarrow \{ \} \)
4 \( \text{watermark} \rightarrow \{ \} \)
3 \( \text{watermark} \rightarrow \{ \} \)
2 \( \text{watermark} \rightarrow \{ \} \)
1 \( \text{begin} \)
```

Algorithm: Basic Left-Edge Algorithm

```
2-1 Channel Routing: Basic Left-Edge Algorithm

\[ \text{tracks (no vertical constraint)} \]

Optimal: Produces a routing solution with the minimum # of
tracks that can accommodate the net is assigned to the net.

For a net's tracks are scanned from top to bottom and the first
tracks that can accommodate the net is assigned to the net.

- Intervals (nets) are routed one-by-one according to the order.
- Intervals are sorted according to their left-end coordinates.
- Intervals are routed from left to right according to their left-end coordinates.
- Tracks are not added.
- HY-layer model is used.
- No vertical constraint.
- Mean within large artifacts: D.W. 74.
- Hashing is used.

Where used: Gray, Virgil routing by optimizing channel assign.

Example
- Optimal routing for additional views.

- Dagga router.

- Dagga rings:

  - Drawback of left-edge: the entire net is on a single track.

  - Daggas are used to place parts of nets on different tracks to minimize crosstalk.

  - Daggas are used to reduce crosstalk conflicts.

  - Drawbacks of left-edge: cannot handle the cases with crosstalk conflicts.

- Example of a Dagga channel router from [1976].

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**Dagga Channel Router**

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**Constrained Left-Edge Example**

---

```
12 end
11 begin
10 \{y\} \rightarrow N \rightarrow \{y\} \rightarrow L
9 select \{y\} \rightarrow L
8 \{y\} \rightarrow L
7 do while \{y\} \rightarrow L
6 \{y\} \rightarrow L
5 + \rightarrow L
4 \{y\} \rightarrow L
3 \{y\} \rightarrow L
2 \{y\} \rightarrow L
1 begin
1 end

 Algorithm: Constrained Left-Edge Algorithm
```
Same idea can be extended to three-layer channel routing (Chan

Track assignment:

The two steps are carried out to minimize vertical constraints and

Mapping of nets:

Zone representation of horizontal segments:

Algorithm consists of two major steps:

Constraint cycles:

Do not allow "unstrapped" doglegs and cannot handle vertical

Nets are assigned to minimize the effect of vertical constraint

TCAD, Jan, 1986.

V-CorA algorithm considers both HCG and VCG.

TCAD, Jan, 1986.

V-CorA Kunn, "Efficient Algorithms for Channel Routing,

Yoshimura-Kunn (YK) Algorithm

Modified Letter-Edge Algorithm is applied to each subnet.

Routing sequence: Specifies the starting position and the direction of route.

Routing can be picked on the same track.

Range: Determine the # of consecutive 2-terminal subnets of the same net

Two parameters are used to control routing:

- Each multi-terminal net is broken into a set of 2-terminal nets.

Dogleg Channel Router
Algorithm for Merging Nets

Minimizing the Longest Path

- Merge 2 nodes so as to minimize the increase of the longest path
- Merge 2 nodes so as to minimize the increase of the longest path
- Heuristic rule to select nets to merge sequentially
Second Approach Based on Matching

Algorithm for the Implementation

Implementation
The matching corresponding to any matching on $G'$ is feasible.

Feasibility Condition

1. Extract the set of nodes with in-degree 0, $\overline{\tilde{G}} = \{N, E\}$.
2. Apply an augmenting to $C_0$ and obtain $C_0'$. Compute a new matching in $(N', E_2 - E')$.
3. If $C_0' = \emptyset$, then the matching is feasible.
4. Else apply an Augmenting to $C_0'$ and obtain $C_0''$. Compute a new matching in $(N', E_2 - E')$.

Feasible Matching

Matching $E_2$ has no cycle in $\tilde{G}$.

Feasible Matching

Simultaneous matching can produce cyclic conflicts.

Cyclic Conflicts

How to modify a matching with cyclic conflicts to get a feasible matching:

$E_2$ becomes empty: $E_2 = (a, h)$.
The YK channel router does not allow unrestricted doglegging.

Restrained doglegging: All a dogleg can be position where there is no pin belonging to that net.

Unrestrained doglegging: All a dogleg even at a position where

**Overview of Greedy Router**

Greedy Channel Router

YK splits a net into subnets.

Solution exists!

YK channel router will fail!
Greedy Heuristics

A: Make Minimal Feasible Top/Bottom Connections
B: Collapse Split Nets

1. G: Extend to next column.
2. E: Video the channel when necessary.
3. D: Raise/raise nets/lowe/pulling nets.
4. C: Move split nets closer to one another.
5. B: Collapse split nets.

At each column, the greedy rule is to maximize the utility of the wiring product.
**Hierarchical Channel Router**

Previous hierarchy:
- Terminal positions for the new $2 \times n$ are defined by the routing in
- Nets are routed one at a time in the $2 \times n$ grid.
- Grid is partitioned into $2 \times n$ grids.

Boundary capacities:
- Capacity of each vertical boundary is the sum of corresponding
- Each column in these subgrids is considered as a separate
- A routing problem in $m \times n$ grid is reduced to $2 \times n$ grid.
- Uses a divide-and-conquer approach.

---

**Greedy Routing Example**

---

**Parameters to Greedy Router**

- $k$ also controls the # of Vias: Typically, $k = 1.0$
- $m$ controls the number of Vias: Use a larger $m$ for fewer Vias.
- Usually start low as the density increases.
- Determines # of time a multiplex net changes tracks.
- Steady-state constraint: The window size in terms of # of columns.
- Minimum-fog-Heuristic: $m_{\text{fog}}$
- Initial-channel-width: $i_{\text{ch}}$

---

**Heuristics:** $C, D, E, \text{ and } F$
Comparison of Two-Layer Channel Routers

Example of Hierarchical Channel Router

Routing Capacity Considerations

Example of Benchmark Example: Detectors, Difficult
Regular channel routing

over-the-cell nets

N−complete (cell minimum channel capacity)
Regular routing:
Non−complete
Select vertical channels

Regular over-the-cell routing

for circle graph

use Supowit’s MIS algorithm

Select over-the-cell nets

Jogging Schemes

Greedy Switchbox Router
No late project accepted

Due date: 3pm for demo & report, Jan. 12, 1999 (Thursday).

Hand-in (1) a written report and/or (2) programs of implement.

Individual (preferred) or 2-person project.

Read: my choice/choose a problem by yourself.

Research-oriented project (a general problem on crosstalk analysis)
Work:
Paper survey: stress on comparison, extensions, and runtime
Algorithm implementation

Options:

Final Project
- Crossbar estimation: Cost function
- Global routing
- Minimize the total cost of the crossbar
- Given an upper bound on channel density, minimize total cost
- Given an upper bound on crossbar of each net, minimize channel
- Minimize the minimum crossbar
- May be a more or less complex model with consideration of crossbar
- Trade-offs
- Design an optimal routing algorithm with consideration of channel density

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The Clock Routing Problem (CRP)