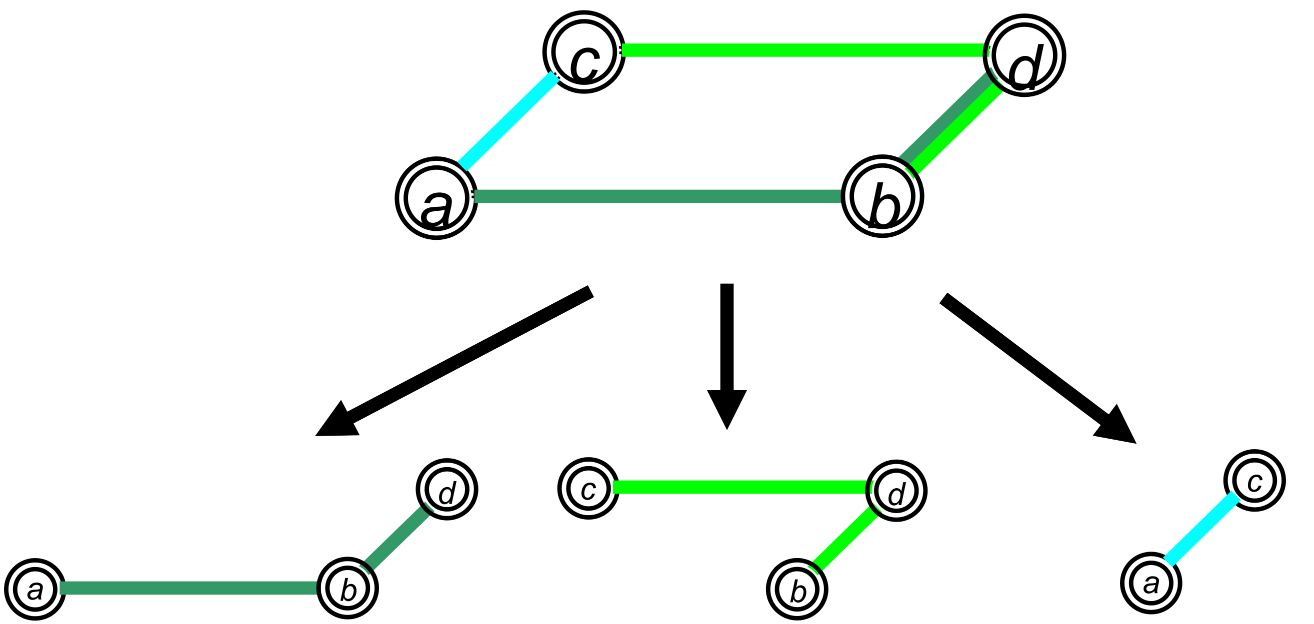
Refinement Stage

- Apply when iterative historical routing gets stuck
  - Recall that $cost_e = b_e + h_e \times p_e + vc_e$
  - $h_e \times p_e$ dominates edge cost when e tends to be congested
- Another evaluation way
  - If passing e induces overflow → $cost_e$=1
  - Otherwise → $cost_e$=0
- Rip-up & reroute 2-pin nets in decreasing order of total overflow
  - Monotonic routing
  - Adaptive multi-source multi-sink maze routing, if necessary

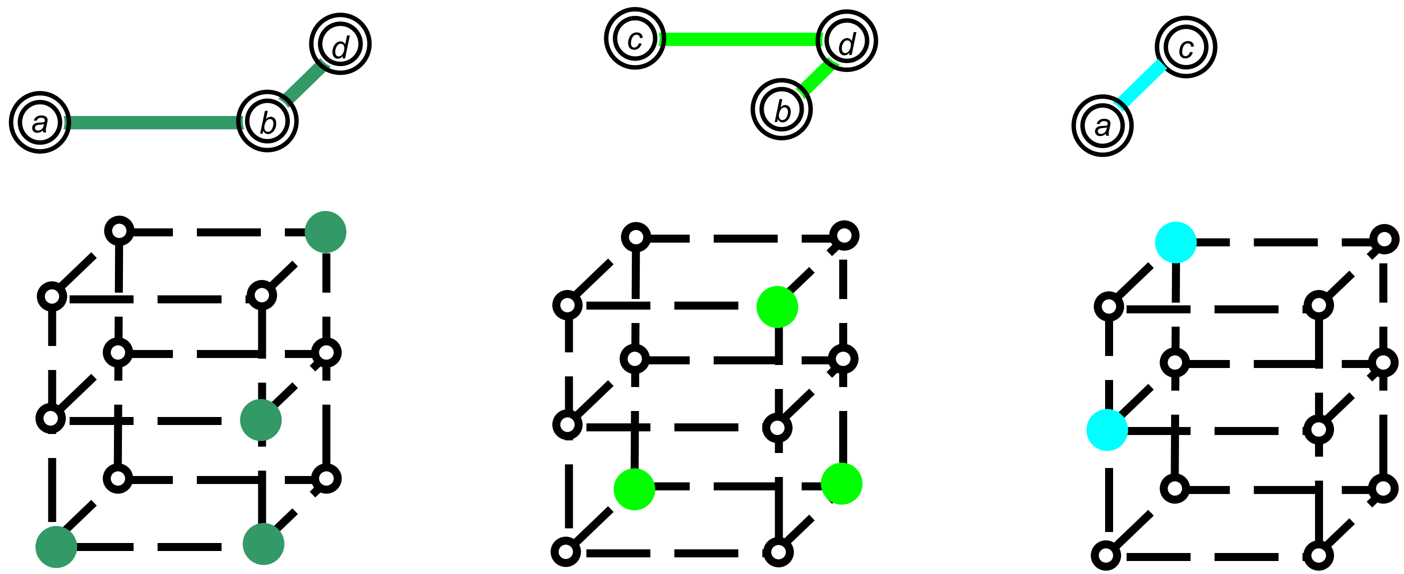
Layer Assignment Stage

- Input: 2D global routing solution $S(G^1,N^1)$



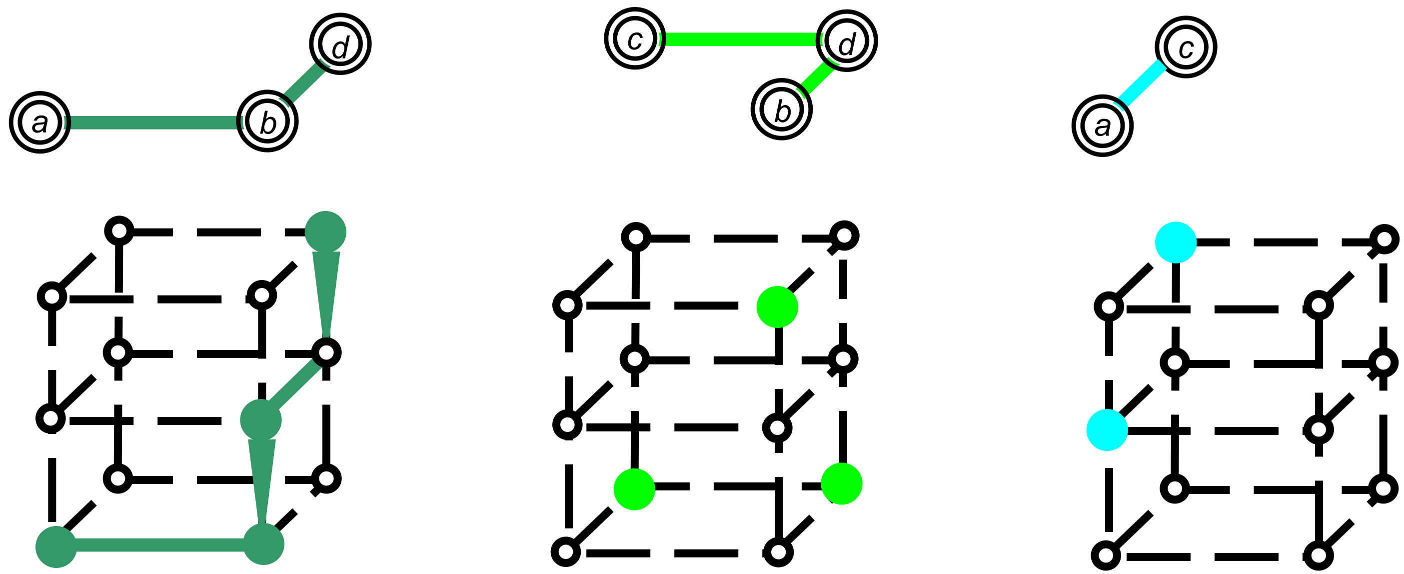
Layer Assignment Stage (cont'd)

- Output: 3D (k-layer) global routing solution $S(G^k,N^k)$



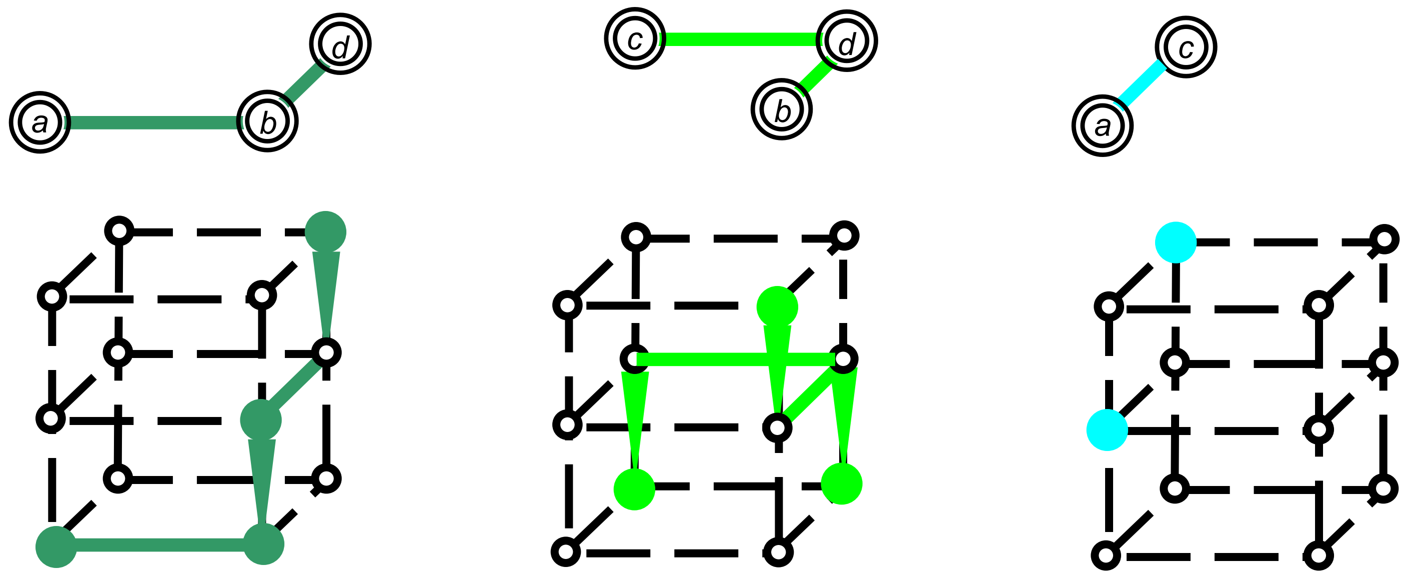
Layer Assignment Stage (cont'd)

- Output: 3D (k-layer) global routing solution $S(G^k,N^k)$



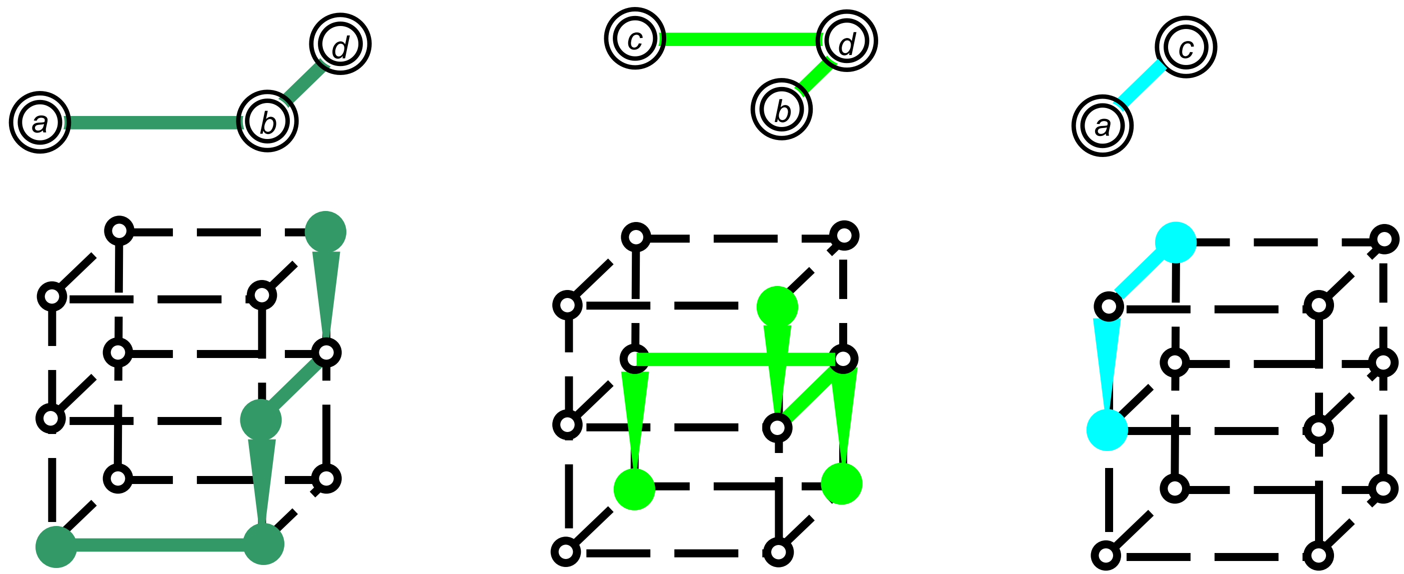
Layer Assignment Stage (cont'd)

- Output: 3D (k-layer) global routing solution $S(G^k, N^k)$



Layer Assignment Stage (cont'd)

- Output: 3D (k-layer) global routing solution $S(G^k,N^k)$



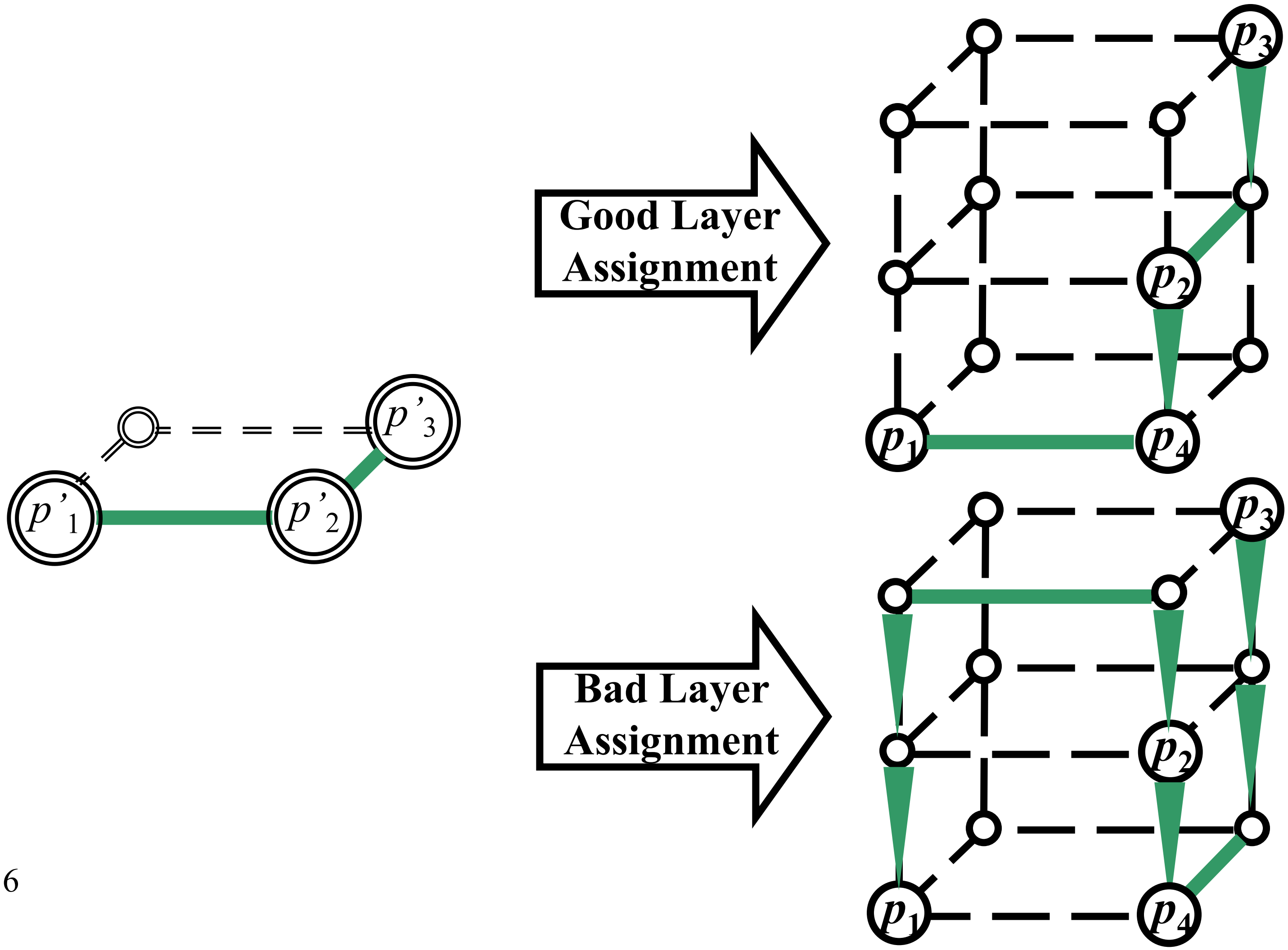
Layer Assignment Stage (cont'd)

- Congestion constraints
  - Total overflow constraint
    $TO(S(G^k,N^k))=TO(S(G^1,N^1))$
  - Maximum overflow constraint
    $MO(S(G^k,N^k))= \left\lceil MO(S(G^1,N^1))/k \right\rceil$ (w/o preferred routing directions)
    or $= \left\lceil MO(S(G^1,N^1))/(k/2) \right\rceil$ (with preferred routing directions)
- Objective: via count minimization

Layer Assignment Algorithms

- 2-layer design
  - Allow horizontal wires on one layer and vertical wire on the other layer
  - Solution can be transformed by directly adding a via for each bend on the routing path
- *k*-layer design ($k > 2$)
  - A layer assignment method is adopted
    - Two components
      - Net order determination
      - Single-net layer assignment considering congestion constraints

Single-net Layer Assignment



Net Order Determination

- For each net T_i^1, compute $Score(T_i^1)$
- Sort nets according to scores

$$Score(T_i^1) = \underbrace{\boxed{\alpha / Length(T_i^1)}}_{1} + \underbrace{\boxed{\beta \times PinNum(T_i^1)}}_{2} + \underbrace{\boxed{\gamma \times AvgDensity(T_i^1)}}_{3}$$

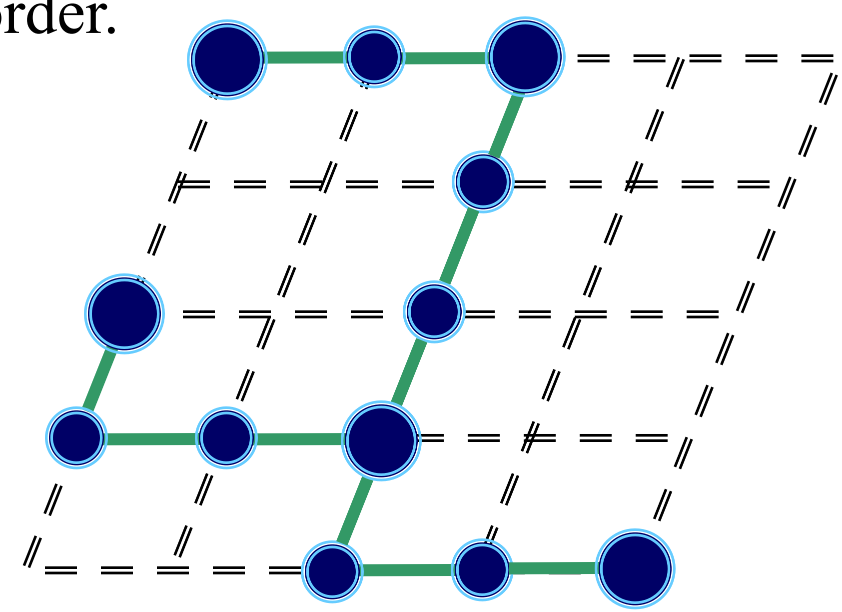
1 $Length(T_i^1)\uparrow \Rightarrow \begin{cases} \text{cost of } T_i^k \uparrow \\ \#\text{ solutions } T_i^k \uparrow \end{cases}$ $\quad Score(T_i^1) \propto 1 / Length(T_i^1)$

2 $PinNum(T_i^1)\uparrow \Rightarrow \#\text{ solutions } T_i^k \downarrow$ $\quad Score(T_i^1) \propto PinNum(T_i^1)$

3 $AvgDensity(T_i^1)\downarrow \Rightarrow$ Need of resource $\downarrow$ $\quad Score(T_i^1) \propto AvgDensity(T_i^1)$

Single-Net Layer Assignment

- Optimal congestion-constrained single-net layer assignment for via count minimization
- For each net, layer assignment assigns each edge one at a time.
- The layer assignment order is the reverse order of DFS traversal order.



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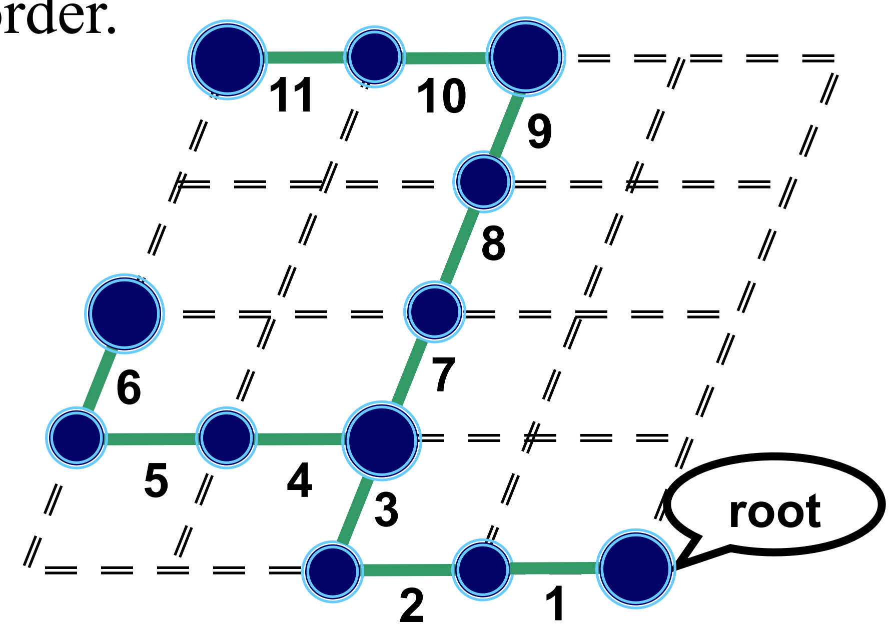

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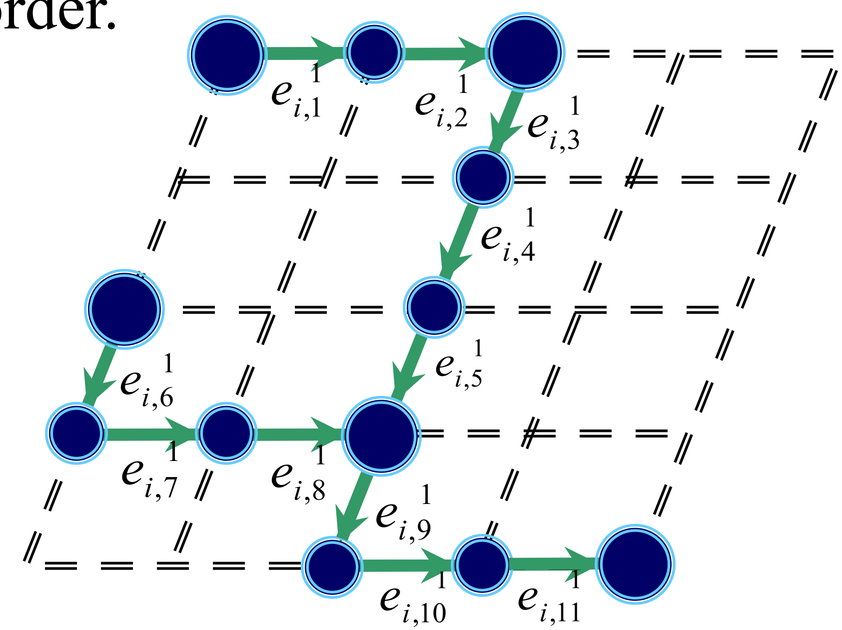

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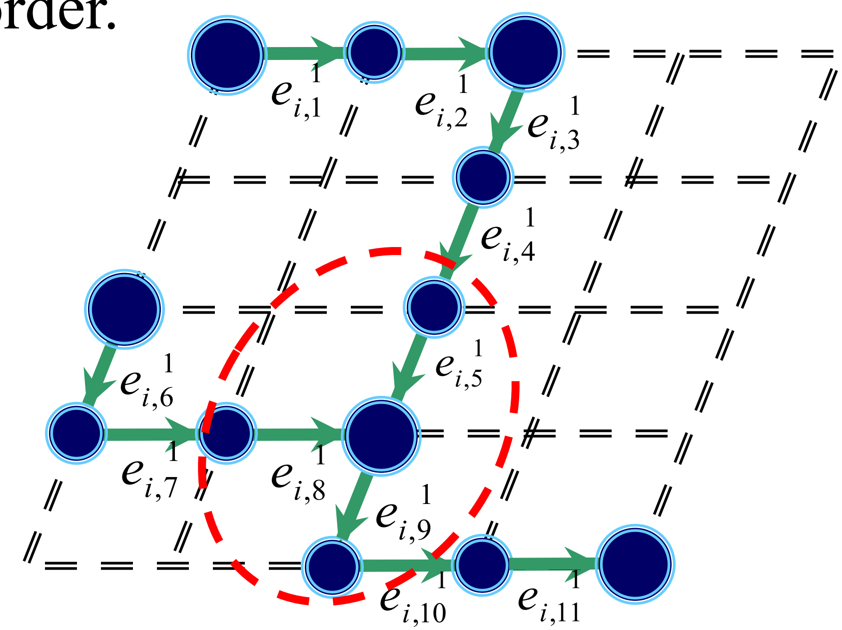
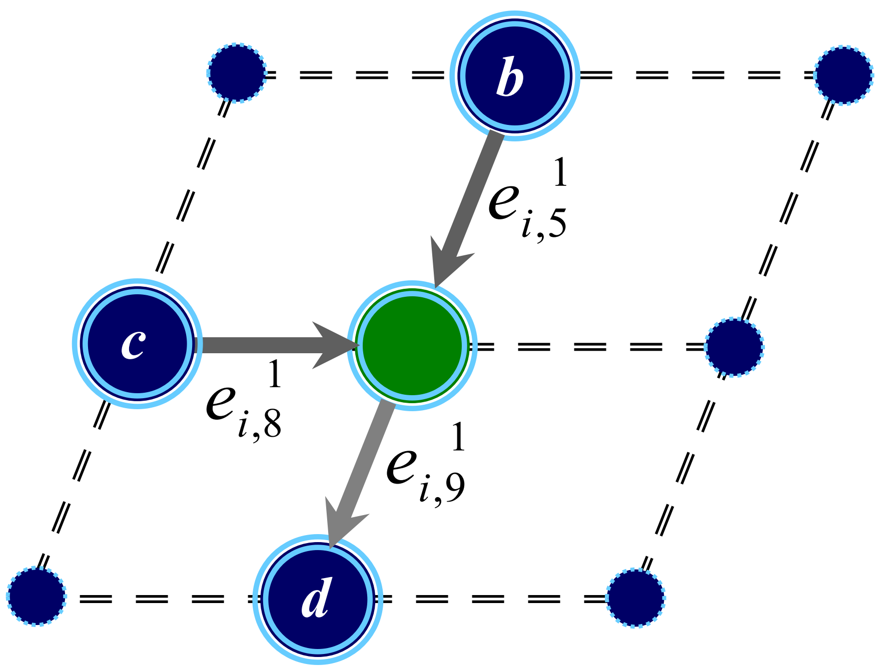
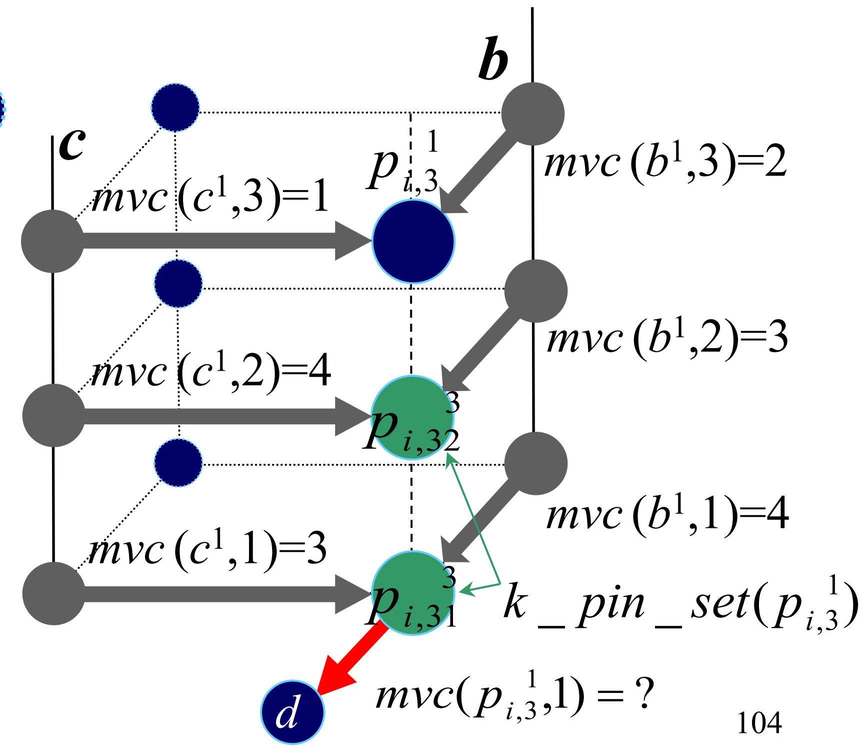


Single-Net Layer Assignment (cont'd)

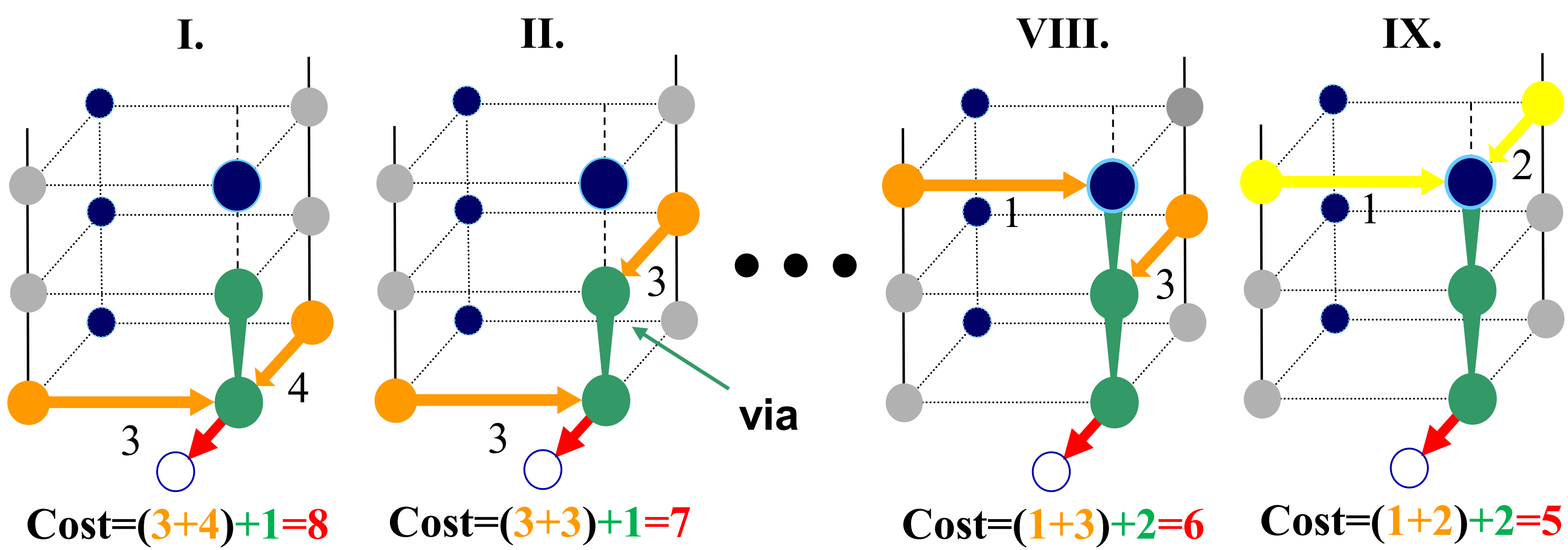
- $mvc(v,l)$: The minimum via count of a subtree rooted at v when the edge between v and its parent is assigned to layer l.





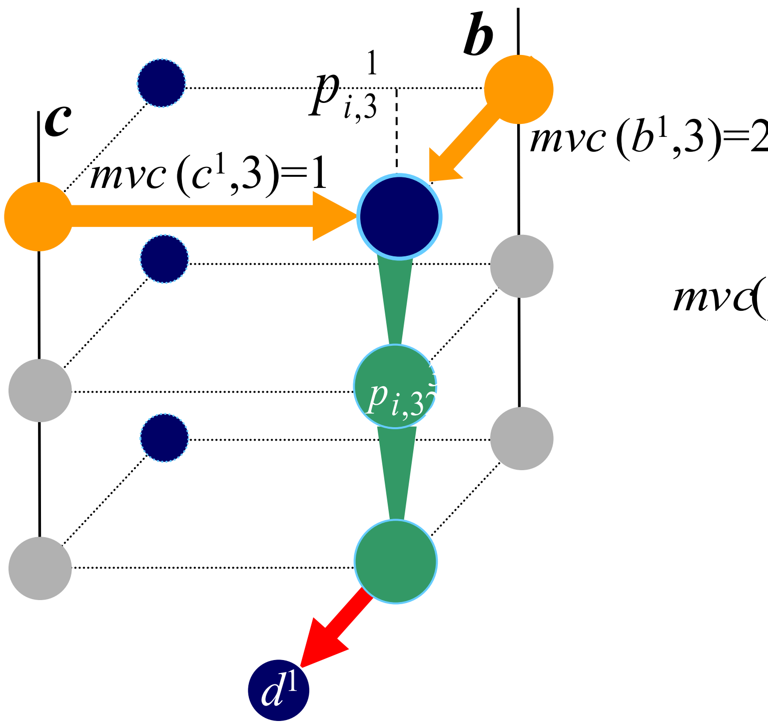
Single-Net Layer Assignment (cont'd)

- Enumerate all possible layer assignment results of children.

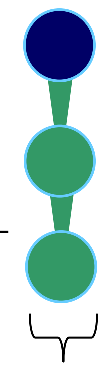


Single-Net Layer Assignment (cont'd)

- The minimum among all combinations is the answer



$$mvc(p_3^1,1) = \overbrace{(mvc(c^1,3)+mvc(b^1,3))}^{\textbf{Cost from } ch\_v(p_{i,3}^1)} +$$



The via cost on $p_{i,3}^{1}$

=(1+2)+2

=5 vias

Single-Net Layer Assignment (cont'd)

- To take the maximum and total overflow constraints into account, an edge e^1 in G^1 can be assigned to an edge e in $k\_edge\_set(e^1)$ if after the assignment, the following two conditions are satisfied
  - $o(e) \leq \lceil MO(S(G^1, N^1))/k \rceil$ (or $o(e) \leq \lceil MO(S(G^1, N^1))/(k/2) \rceil$)
  - $o(e^1) \geq \sum o(e^k)$, where e^k is in $k\_edge\_set(e^1)$
- If assigning the edge between v and its parent to layer l violates either of the two conditions, then $mvc(v,l)$ is set to ∞.

Extensions of NTHU-Route 2.0

- **Temperature-aware global routing**
  - Y.-T. Lee, Y.-J. Chang, and T.-C. Wang, "A Temperature-Aware Global Router," VLSI-DAT 2010.
- **Antenna-aware layer assignment**
  - T.-H. Lee and T.-C. Wang, "Simultaneous Antenna Avoidance and Via Optimization in Layer Assignment of Multi-layer Global Routing," ICCAD 2010.
- **Layer-directives-aware global routing**
  - Y.-J. Chang, T.-H. Lee and T.-C. Wang, "GLADE: A Modern Global Router Considering Layer Directives," ICCAD 2010.
  - T.-H. Lee, Y.-J. Chang and T.-C. Wang, "An Enhanced Global Router with Consideration of General Layer Directives," ISPD 2011.

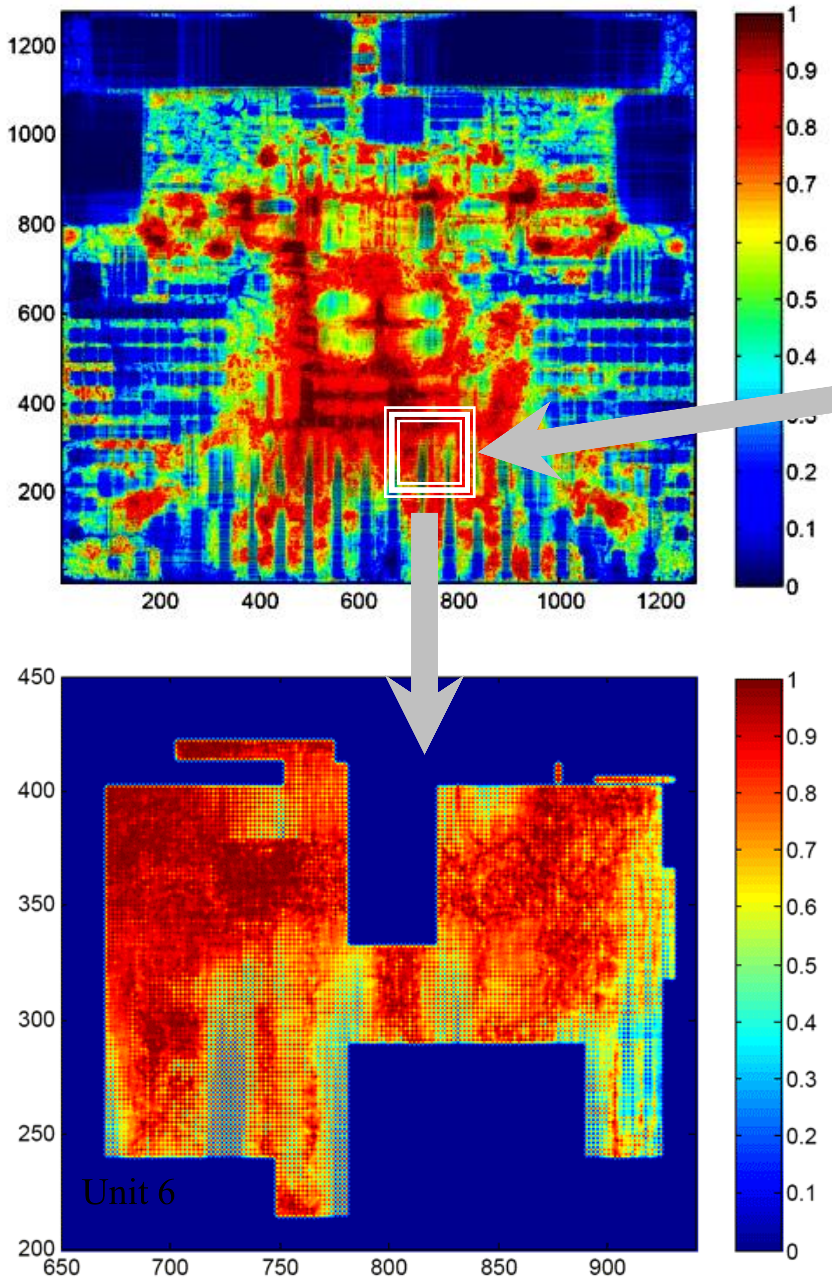
Extensions of NTHU-Route 2.0

- Thermal becomes an even more important problem in modern VLSI designs than before
  - J. Black proposed a model to formulate Mean Time to Failure (MTF) of an interconnect due to electromigration

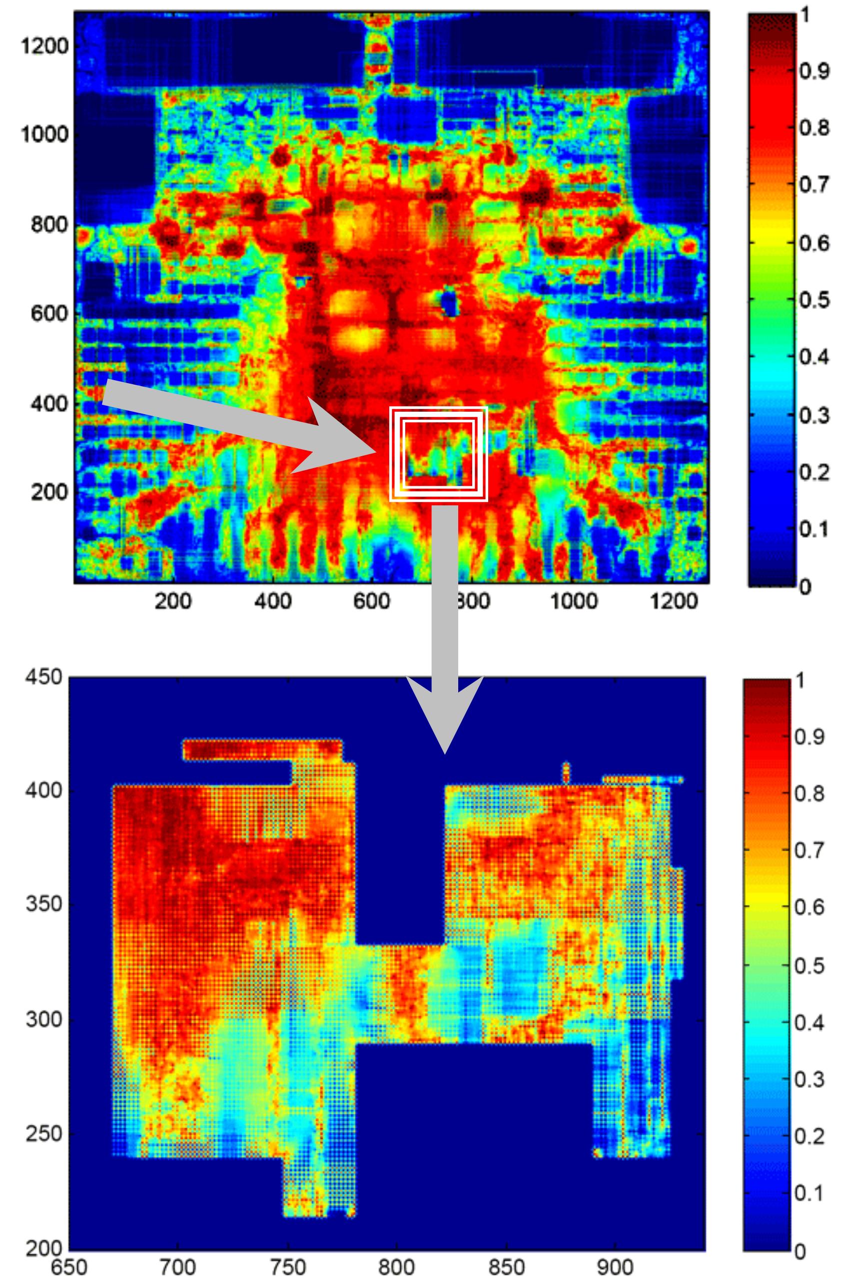
$$\mathrm{MTF} = M\, j^{-2} \mathrm{e}^{\frac{Q}{kT}}$$

- **Temperature-aware global routing** [VLSI-DAT 2010]
  - Also minimize the amount of routed net segments located in hot spots
  - Enhancements
    - Temperature-aware L-shaped pattern routing in 2D routing
    - Two temperature-aware cost functions in 2D routing

Congestion map of NTHU-Route 2.0

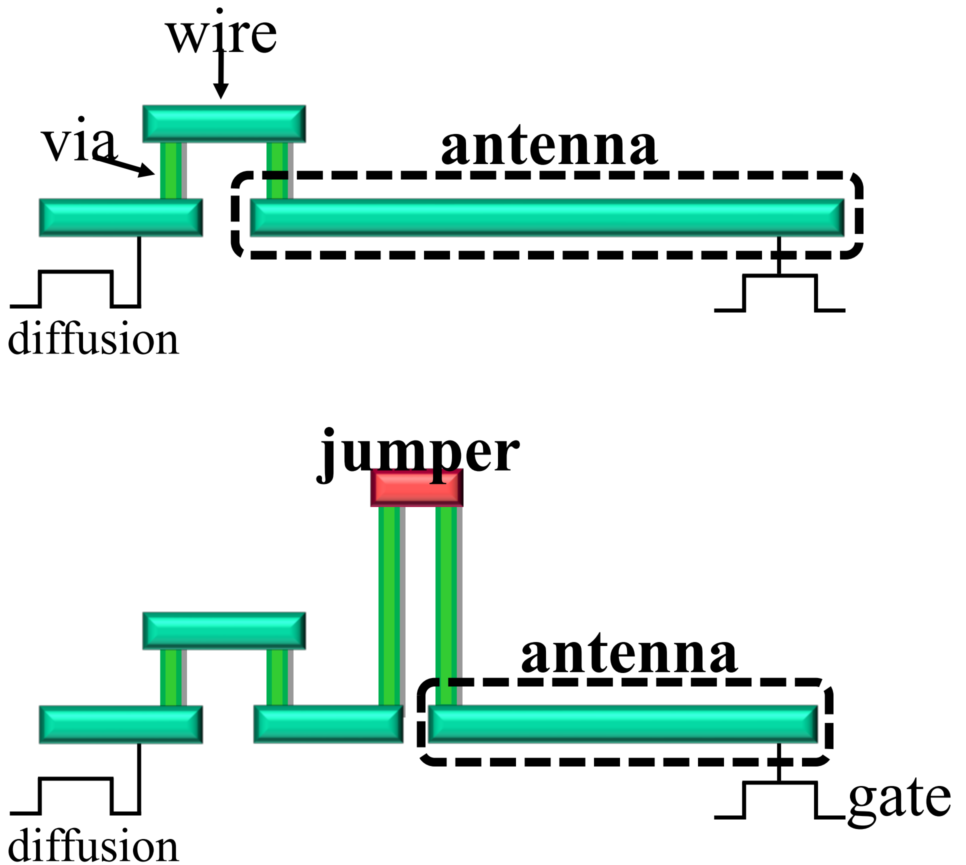


Congestion map of enhanced router



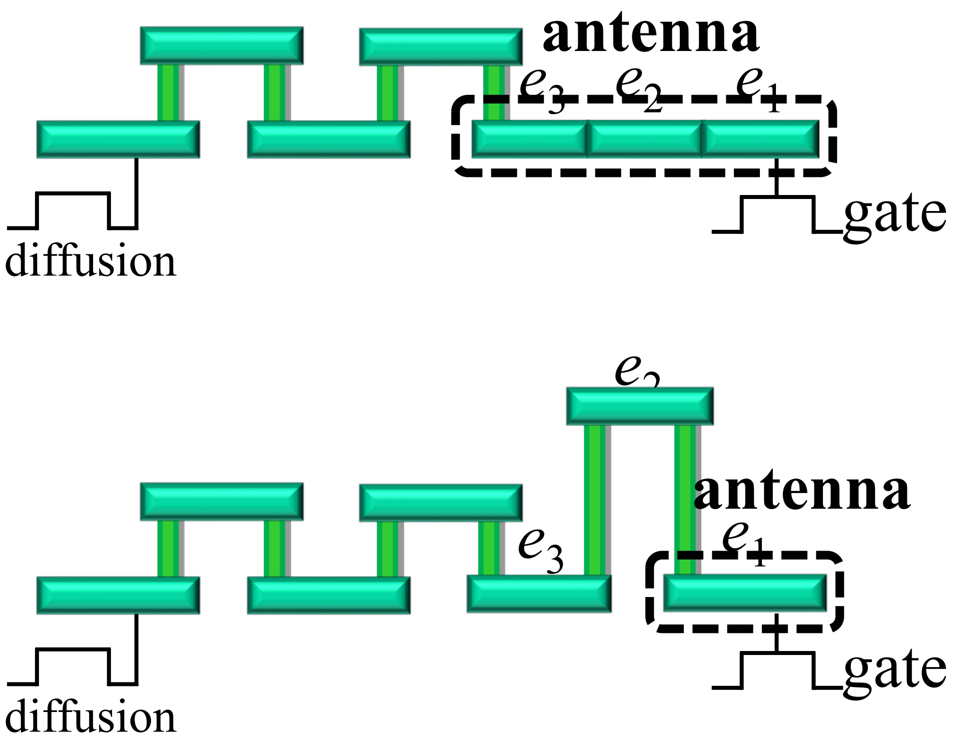
Extensions of NTHU-Route 2.0 (cont'd)

- Antenna effect



Extensions of NTHU-Route 2.0 (cont'd)

- **Antenna-aware layer assignment** [ICCAD 2010]
  - Also minimize the amount of antenna violations
  - Enhancements
    - Single-net layer assignment algorithm is modified to take both antenna avoidance and via count minimization into account for each net
    - A mini-cost max-flow based refinement procedure is proposed to further reduce the via count but without increasing the amount of antenna violations



Extensions of NTHU-Route 2.0 (cont'd)

- Layer directives
  - Specify target layer ranges often for timing-critical nets to meet the performance target in a modern physical design flow
- **Layer-directives-aware global routing** [ICCAD 2010, ISPD 2011]
  - Also minimizes the amount of layer directive violations
  - Enhancements
    - Pseudo layer assignment during 2D routing
    - Layer–directives-aware layer assignment