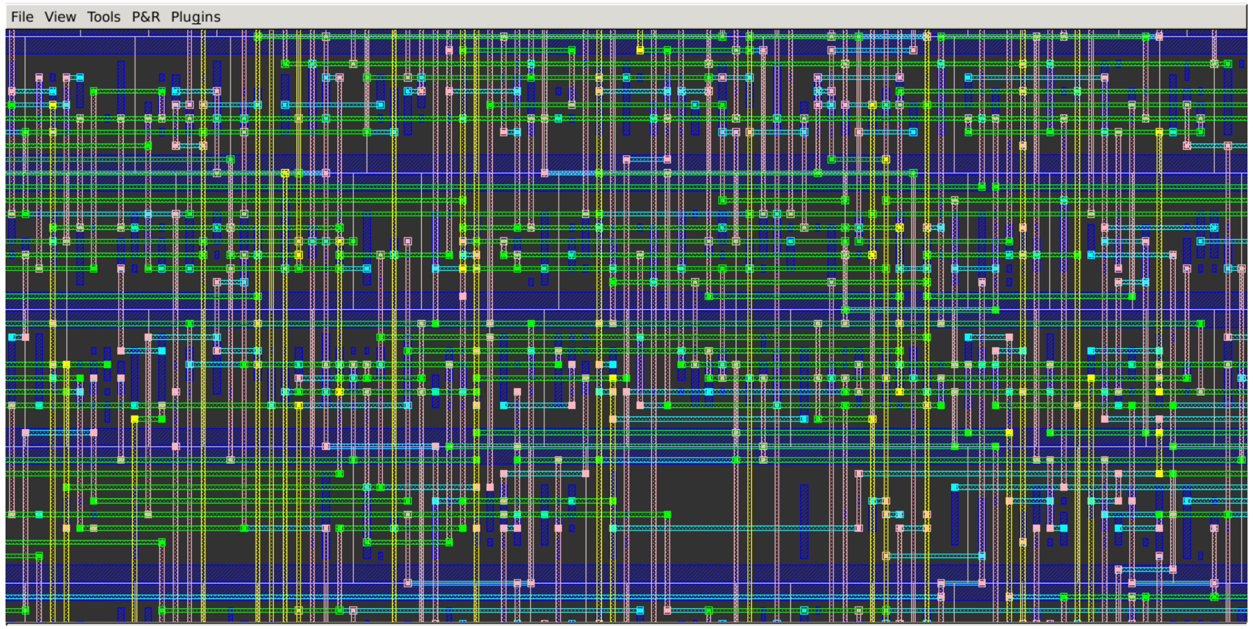
Routing

VLSI CAD

Compiled by Oleg Venger

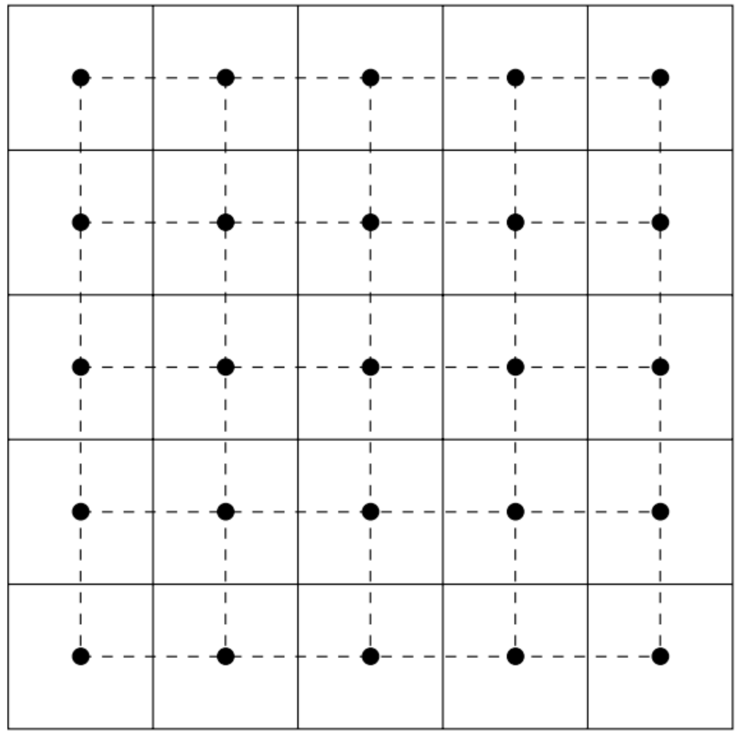
Routing problem

- The goal of routing is to produce complete wire layouts for all nets in a given placed netlist
- Because of the complexity it is solved in two steps:
  - Global routing defines approximate solution on a coarse grid
  - Detailed routing then finds the exact routes for all nets



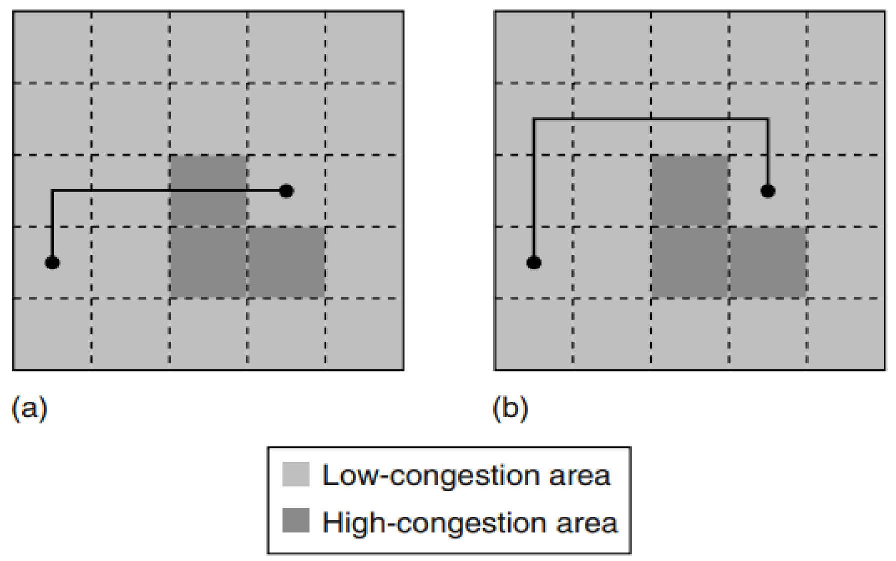
Tile-based graph model for global routing

- Routing is done on metal layers on top of cells
  - Each layer is used for either horizontal or vertical routing
- Layout is partitioned into rectangular regions and grid graph G is formed such that:
  - There is a vertex in each tile
  - Edges exist between neighbor tiles
- Each net terminal is assumed to lie at the center of tile that contains the terminal
- Each edge has associated capacity: maximum number of routing tracks that can pass along the edge



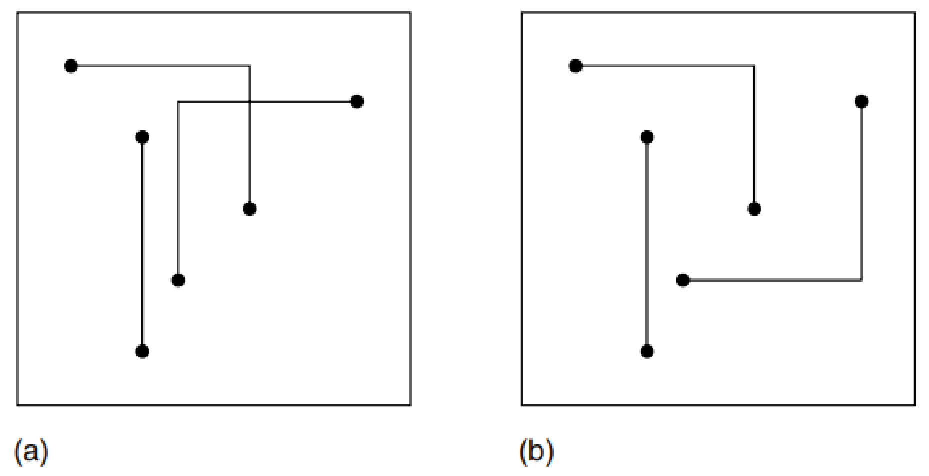
Routing optimization objectives

- Total wirelength
  - Reduced total wirelength is good for delay and power consumption
- Congestion
  - Edge is congested if total number of tracks assigned to it exceeds the edge capacity
  - Congested hotspots make detailed routing much harder
  - Even spread of congestion throughout routing region usually leads to better detailed routing
- Bend count
  - Each bend indicates the need for layer change and via
  - Vias have negative effects on delay, routing area and manufacturing yields



Routing optimization objectives

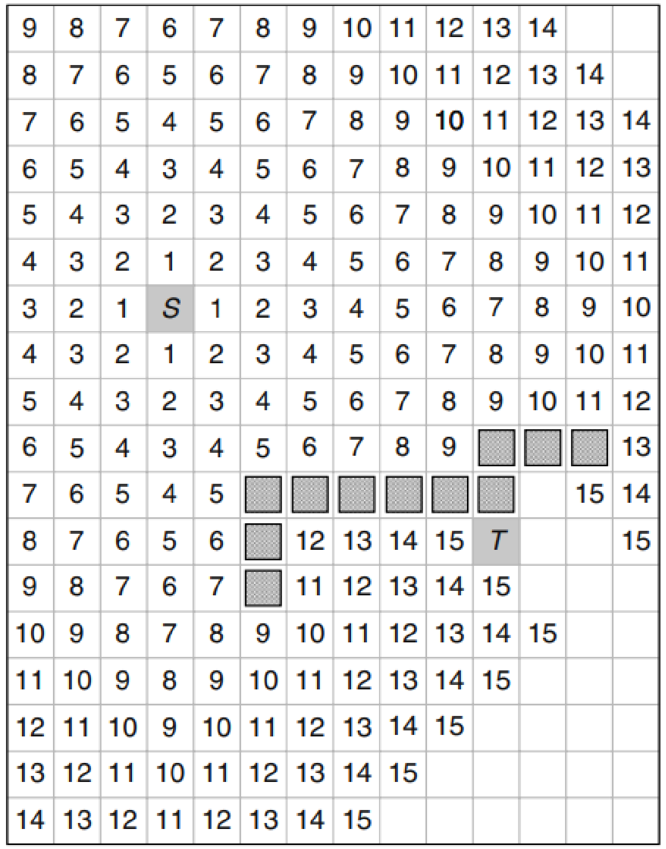
- Timing
  - Certain timing bounds are imposed on critical connections
- Coupling
  - Coupling capacitance between two wires is proportional to the amount of parallel overlap between them, and inversely proportional to the distance between them.
  - Coupling capacitance negatively affects timing



(a) Layout with coupling owing to long parallel wires and (b) layout with no coupling.

Maze routing

- Given a planar rectangular grid graph, two terminals S and T, obstacles modeled as blocked vertices it finds the shortest path between S and T
- Finds the shortest possible path if the path exists
- Two phases:
  - (a) wavefront expansion
  - (b) backtracking
- Modifications:
  - Start from pin that is located closer to the boundary
  - Expand from both terminals simultaneously
  - Define artificial bounding box on the search region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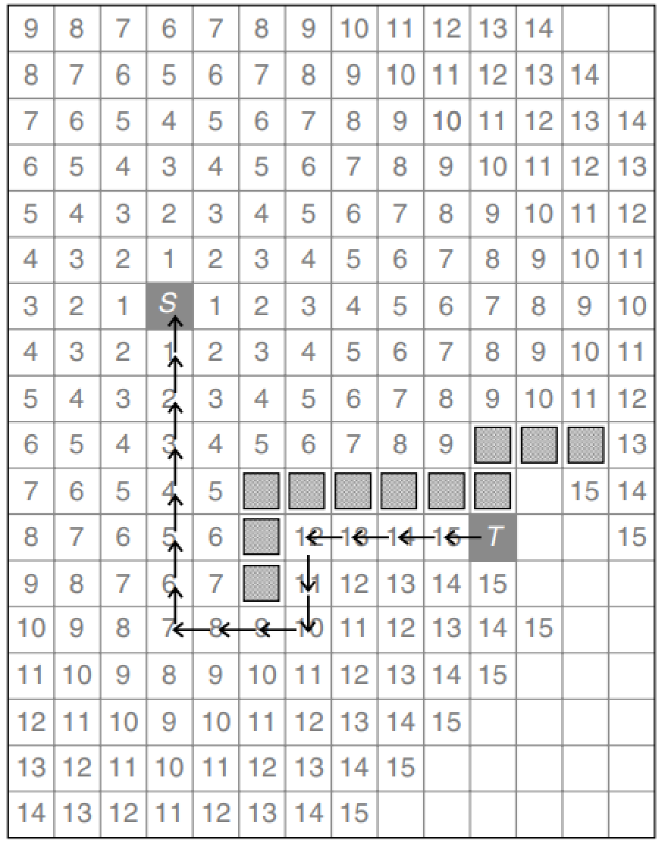
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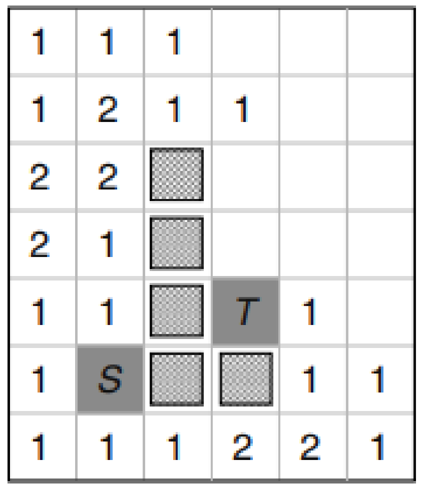
Aker’s labeling scheme

- The following sequence is used to label the cells during wavefront expansion phase: 1, 1, 2, 2, 1, 1, 2, 2, . ..
- In this case the predecessor of each cell *C* is labeled different from the successor of cell *C*.
- During backtracking, the same sequence is used to construct the path from target to source
- This reduces the memory requirements of the algorithm



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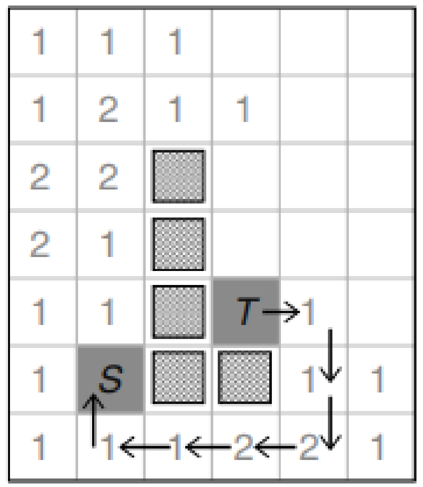

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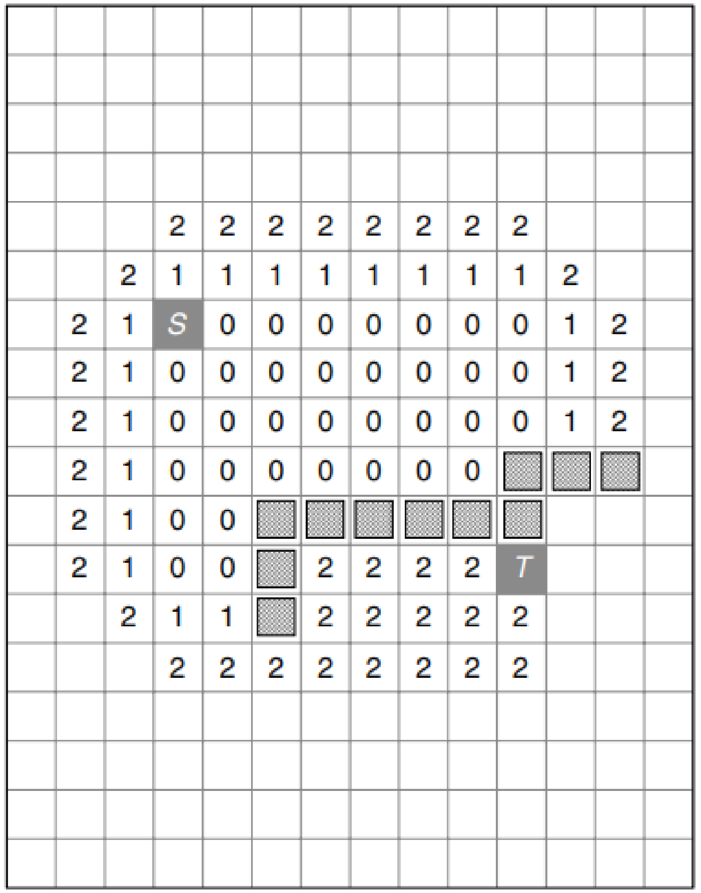
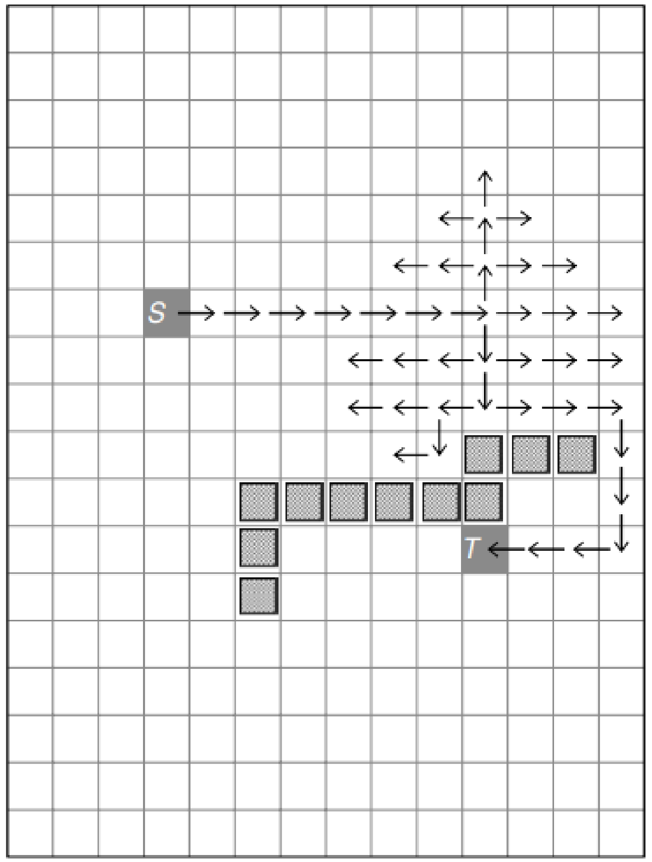
Hadlock’s minimum detour scheme



- Uses the detour numbers as the cell labels
- The cells with smaller detour numbers are expanded before the cells with higher detour numbers.
- Finds the shortest path if one exists

Soukup's fast maze

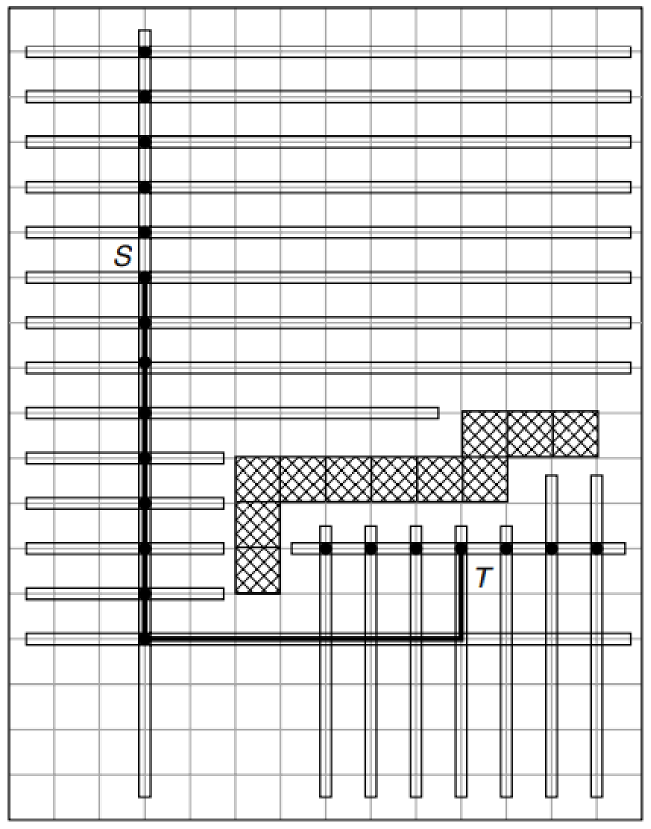


- Phase1: wavefront expansion is done toward the target without changing direction until an obstacle is reached
- phase2: the same wavefront expansion methodology as the original maze-routing algorithm is used to search around the obstacle
- Once a cell in the direction of the target is found, the first phase begins again for a directed search toward the target
- The path found is not guaranteed to be the shortest

Line-search algorithms

- Mikami-Tabuchi algorithm (a)
  - Start with expanding horizontal and vertical line segments for S and T
  - Repeat for each point at recently added segments until one of segments originated from S intersects with one originated from T

- Hightower algorithm (b)
  - Escape lines on the most recently created line segments identified based on blockages



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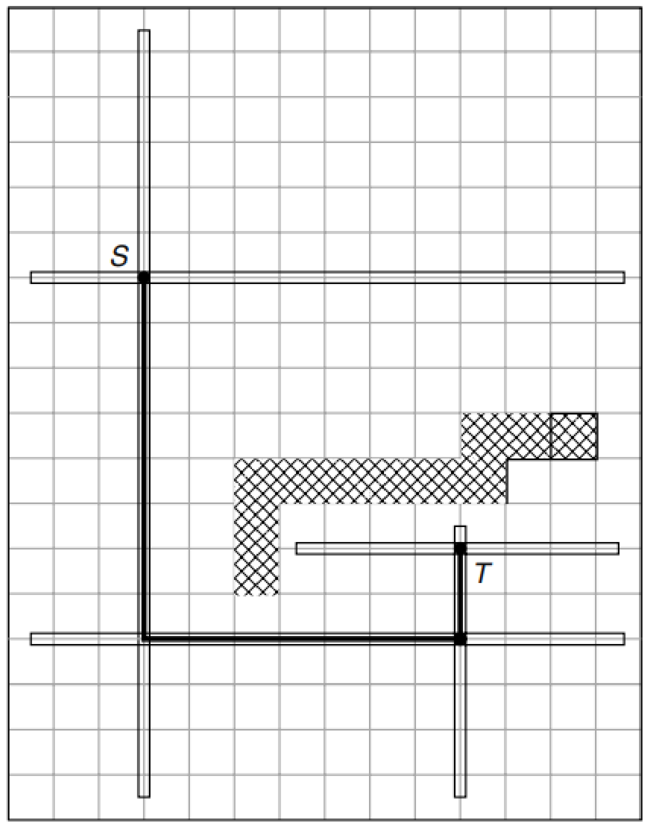

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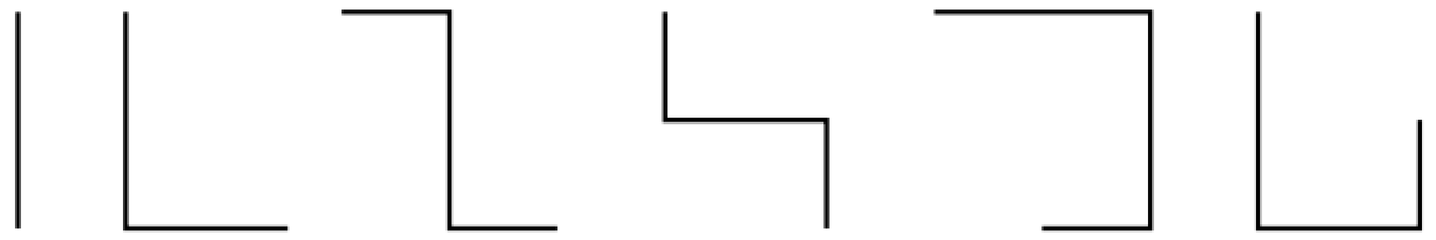
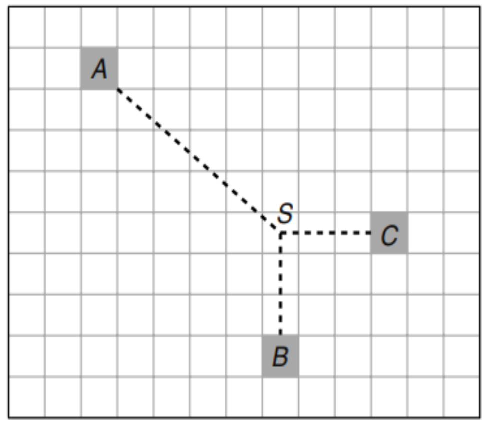
Pattern routing

- Solution space is restricted to routes with predefined patterns, such as I-, L-, Z-, and U-shaped patterns
- Can be effectively used in global routing to reduce the runtime requirements



Routing for multiple terminal net

- Finding the optimal route for a multiple terminal net is NP-complete problem
- Fortunately there are good heuristic algorithms that
  a. Generate Steiner topology T and
  b. Perform point-to-point routing between points of that topology T



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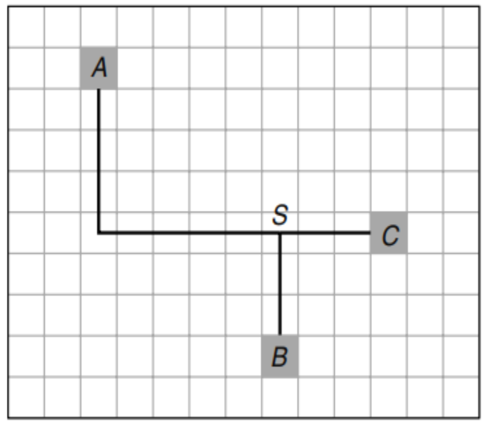

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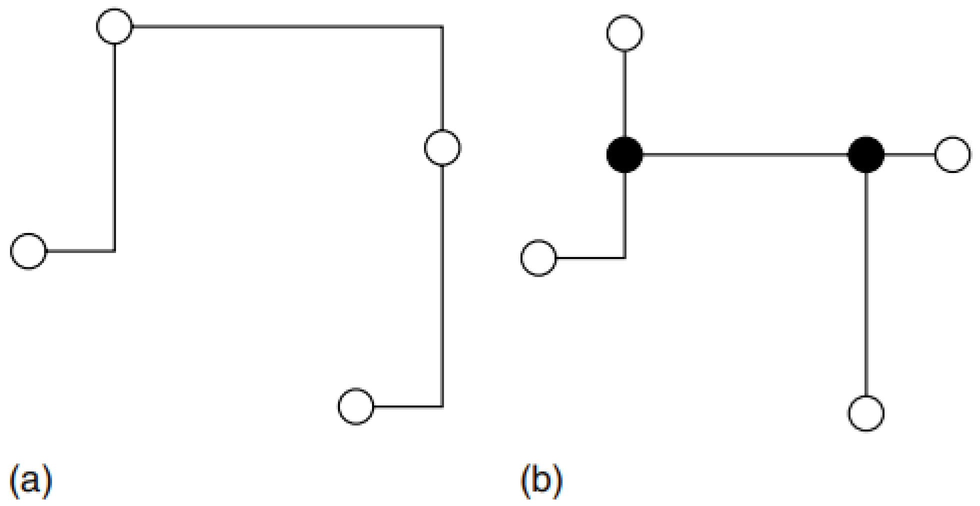
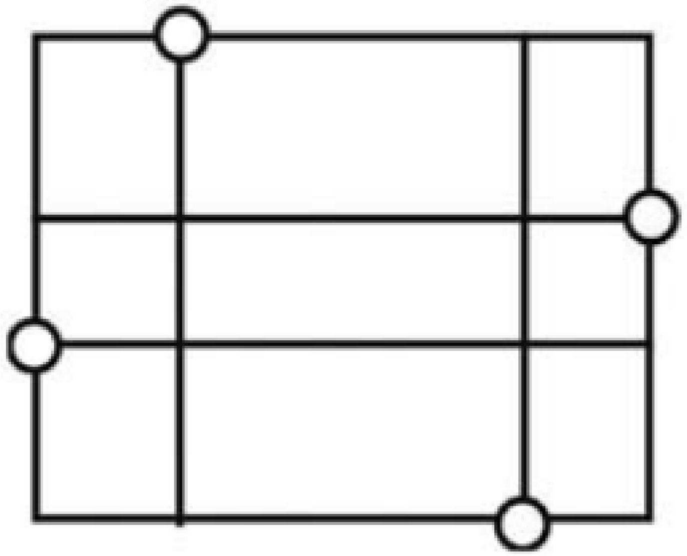
Steiner minimal tree (SMT) problem

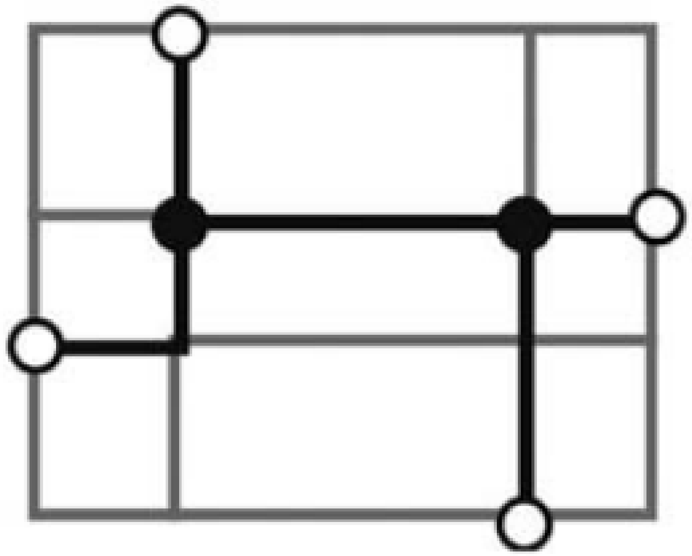
- Given a set P of n points determine a set S of Steiner points such that the MST cost over $P \cup S$ is minimized.
- The cost between pair of pins is modeled by Manhattan distance:
  - $|x_1 - x_2| + |y_1 - y_2|$
- It was shown (Hwang, 1976) that the MST over P is a good approximation to the SMT with cost ratio $\leq \frac{3}{2}$



Hanan’s theorem

- There exists an SMT with Steiner points chosen from the Hanan grid, i.e., intersection points of all horizontal and vertical lines drawn through the points.





Iterated 1-Steiner heuristic

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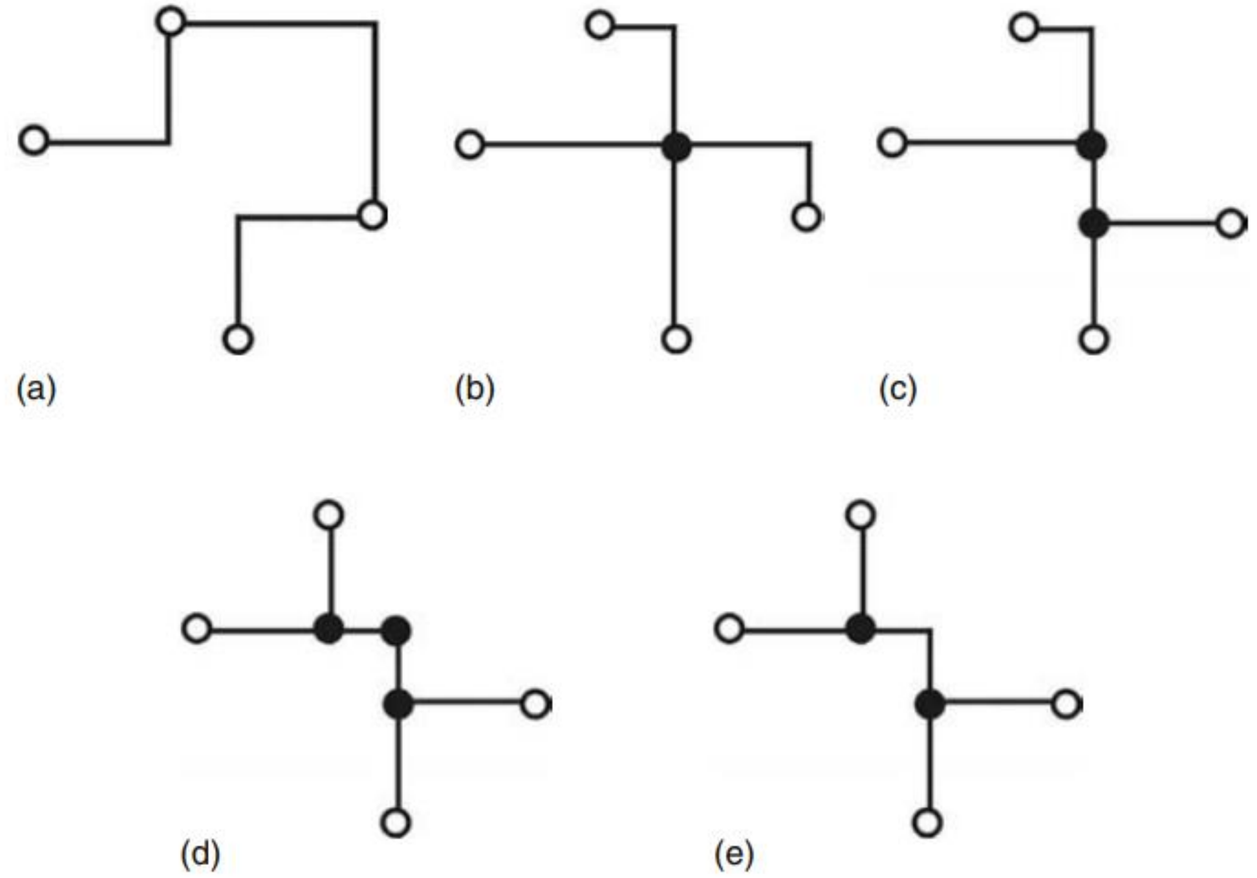
**Iterated 1-Steiner (I1S) heuristic**
**Input**: Set $P$ of $n$ points
**Output**: Rectilinear Steiner tree spanning $P$
$S = \emptyset$
**While** Candidate_Set $= \{x \in H(P \cup S) \mid \Delta MST(P \cup S, \{x\}) > 0\} \neq \emptyset$ **Do**
    **Find** $x \in$ Candidate_Set which maximizes $\Delta MST(P \cup S, \{x\})$
    $S = S \cup \{x\}$
    **Remove** points in $S$ which have degree $\leq 2$ in $MST(P \cup S)$
**Output** MST$(P \cup S)$
```

Example



Analysis

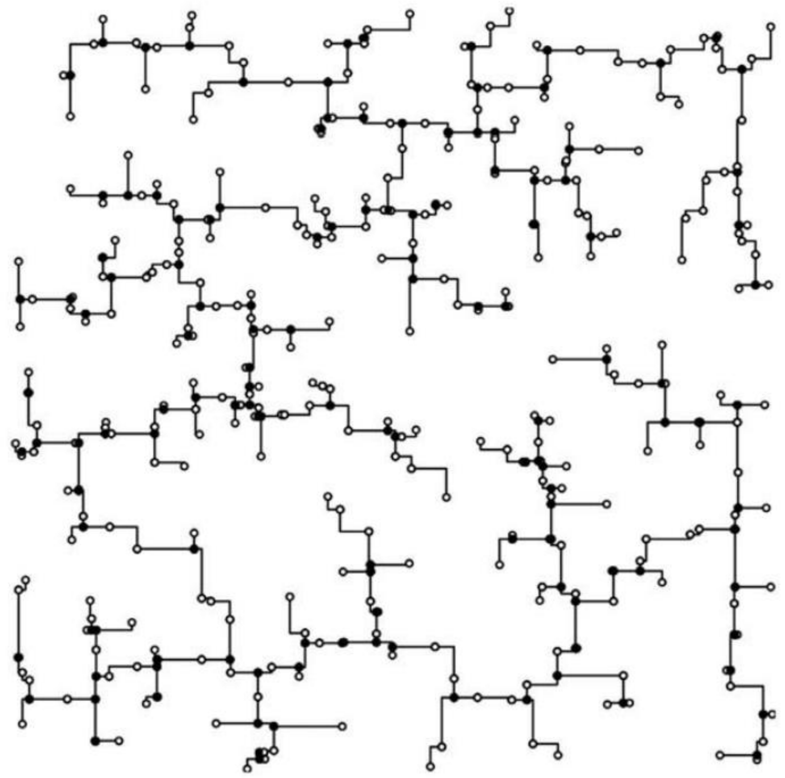
- Need to construct MST for each of $O(n^2)$ members of the Steiner candidate set (i.e., Hanan grid points)
- Each MST computation can be performed in $O(\mathrm{n}\log(n))$
- $O(n^3\log(n))$ time method to find a single 1-Steiner point.
- In practice, the number of iterations performed by I1S averages less than *n*/2 for uniformly distributed random pointsets.
- I1S heuristic is provably optimal for four or less points

Directions to improve SMT runtime and quality

- Pre-filtering of candidate Steiner points
- Incremental/dynamic MST updating schemes
- Local Steiner tree restructuring along the way

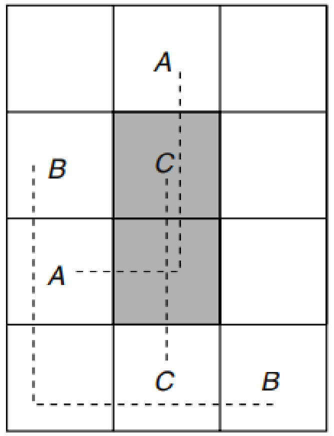
Performance of iterated 1-Steiner

- On average, solution cost is within 0.5% of optimal.
- Produce optimal solutions on 90 percent of all random eight-point instances (and on more than half of all random 15-point instances)
- For n = 30 points, on average only about 0.3 percent away from optimal, and yields optimal solutions in about one quarter of the cases


Sample solution on random set of 300 points

Routing multiple nets

- Routing for one net may impact the routing of other nets because common resources are being used. Order of routing matters.



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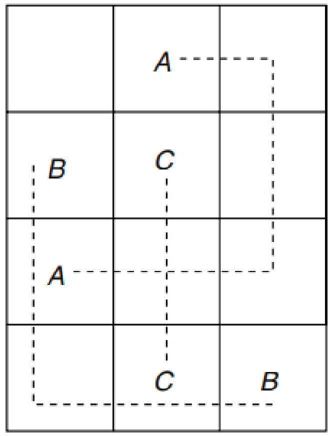

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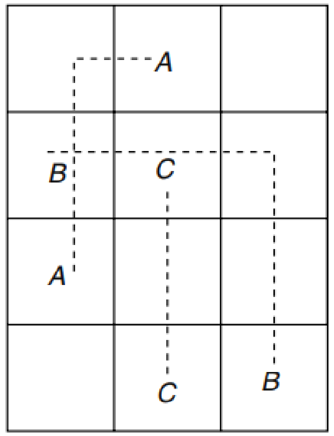

(c)

Assume that horizontal and vertical edge capacity = 1 and not more than 2 bends is allowed

a) A–B–C leads to a solution with two overcongested tiles

b) C–B–A leads to a solution where A is detoured to avoid congestion

c) C–A–B leads to the congestion-free solution with optimal routing for each net

Routing multiple nets

- Sequential routing route nets in a specific order
  - More critical nets are routed first
  - Route nets with less routing alternatives before other nets. In practice this means short nets first
- Nets are first routed allowing congestion, and then the nets in the overcongested regions are ripped up and rerouted in the later iterations
- Rip-up-and-reroute strategy is typically a combination of progressive and iterative schemas

Progressive rip-up-and-reroute

```
1. For pass = 1 to $k$
2. For each net $n$
3. For each connection $r$ in $n$
    a. Remove $r$
    b. Reroute $r$
```

- Pros:
  - Simplicity of design
- Issues:
  - Detouring. The case when the length of the routed connection is much longer than the length of a connection if congestion is not considered.
  - Net ordering
  - Divergence. Commonly happens when a design is infeasible

Iterative improvement scheme

```
1. Route nets
2. Identify areas where the design constraints are violated
3. Identify nets/connections $r$ to
   a. Remove $r$
   b. Reroute $r$
```

- Select one violated design constraint and then attempt to resolve it by rip-up and reroute without introducing new violations.
- Issues:
  - Insufficient rip-up
  - Net ordering
  - Oscillations

References

- Handbook of Algorithms for Physical Design Automation, Chapter 23, Muhammet Mustafa Ozdal and Martin D.F. Wong, Global Routing Formulation and Maze Routing
- Handbook of Algorithms for Physical Design Automation, Chapter 24, Minimum Steiner Tree Construction, Gabriel Robins and Alexander Zelikovsky
- Handbook of Algorithms for Physical Design Automation, Chapter 31, Jeffrey S. Salowe, Rip-up and reroute