Monotonic Parallel and Orthogonal Netlists for Single-Layer BGA packages

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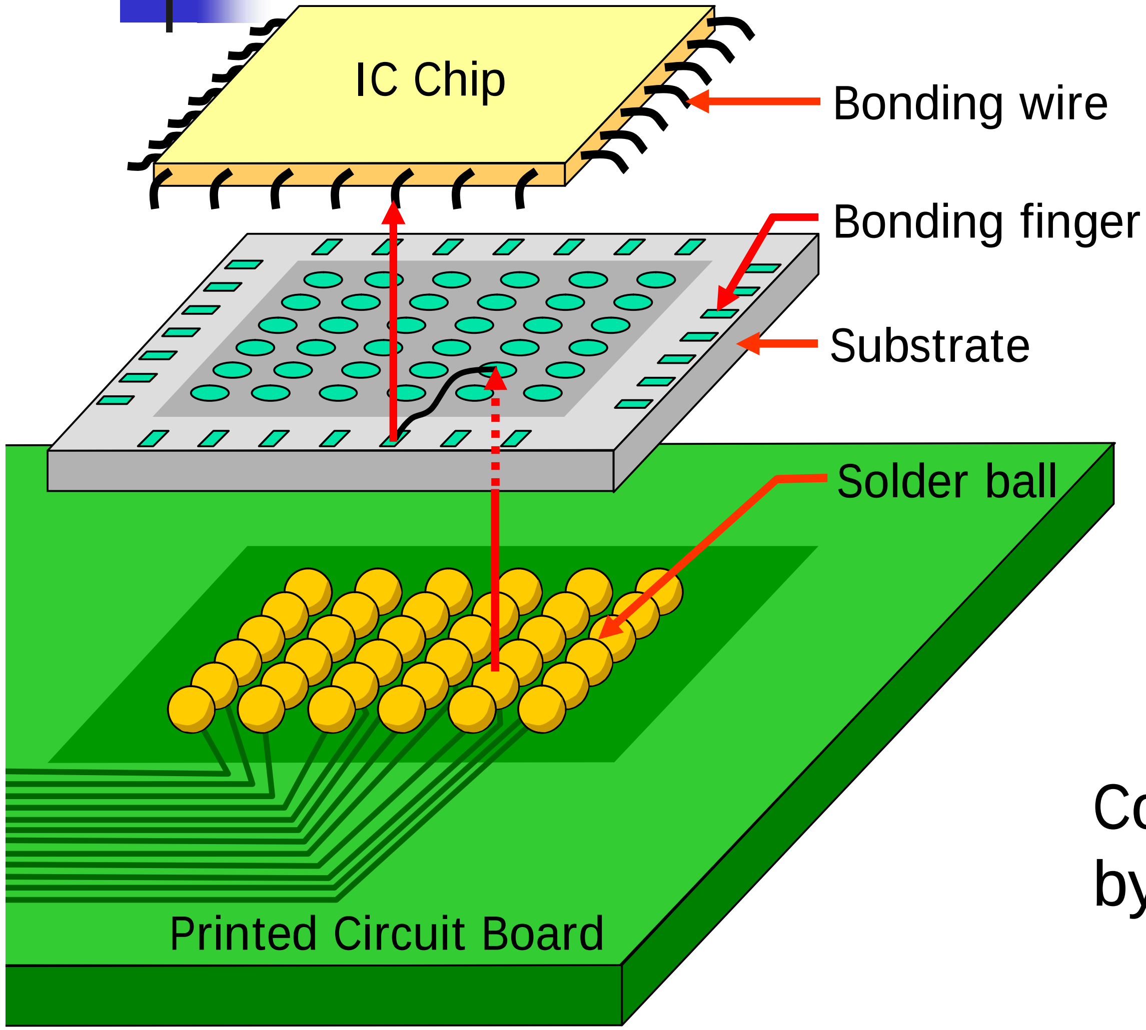
A Model of BGA package



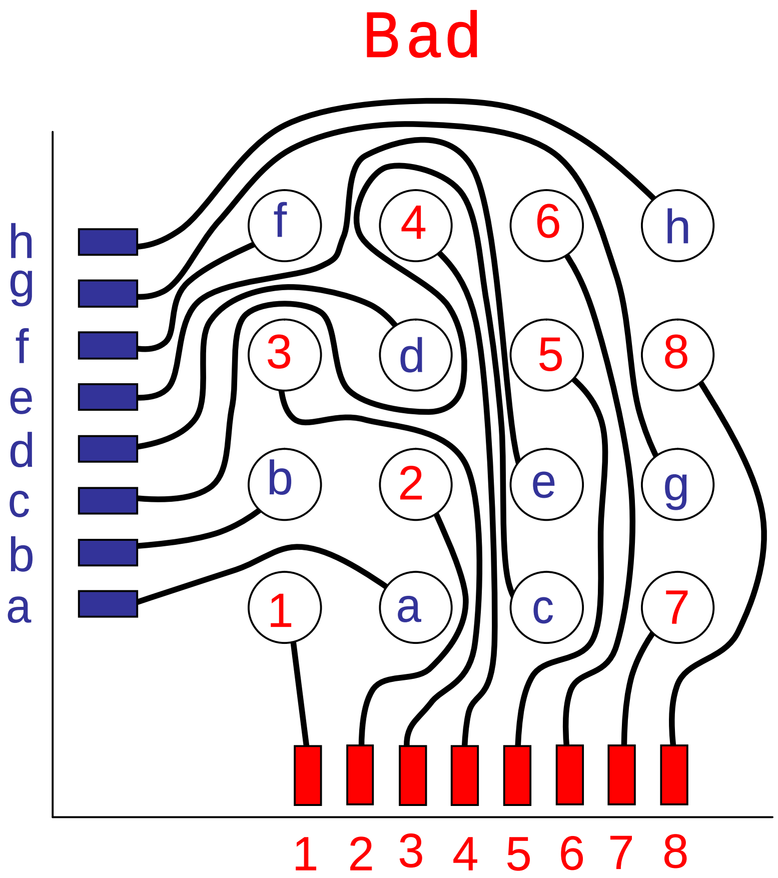
Bonding finger :
Connected to I/O pin of IC chip

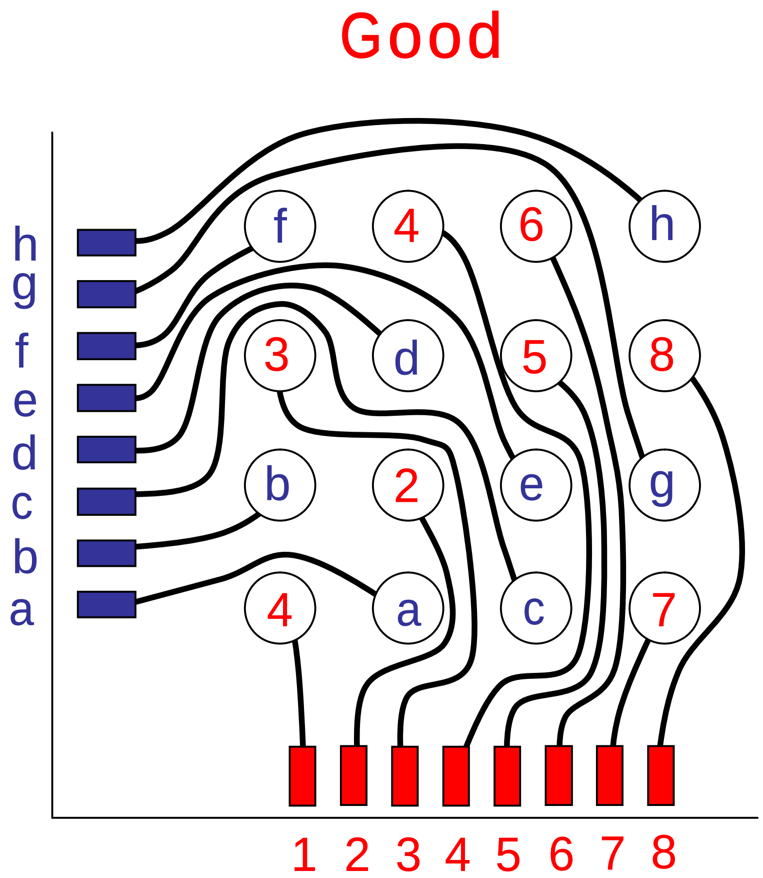
Solder ball :
I/O pin of the package

Connect finger and ball
by the wires in the substrate

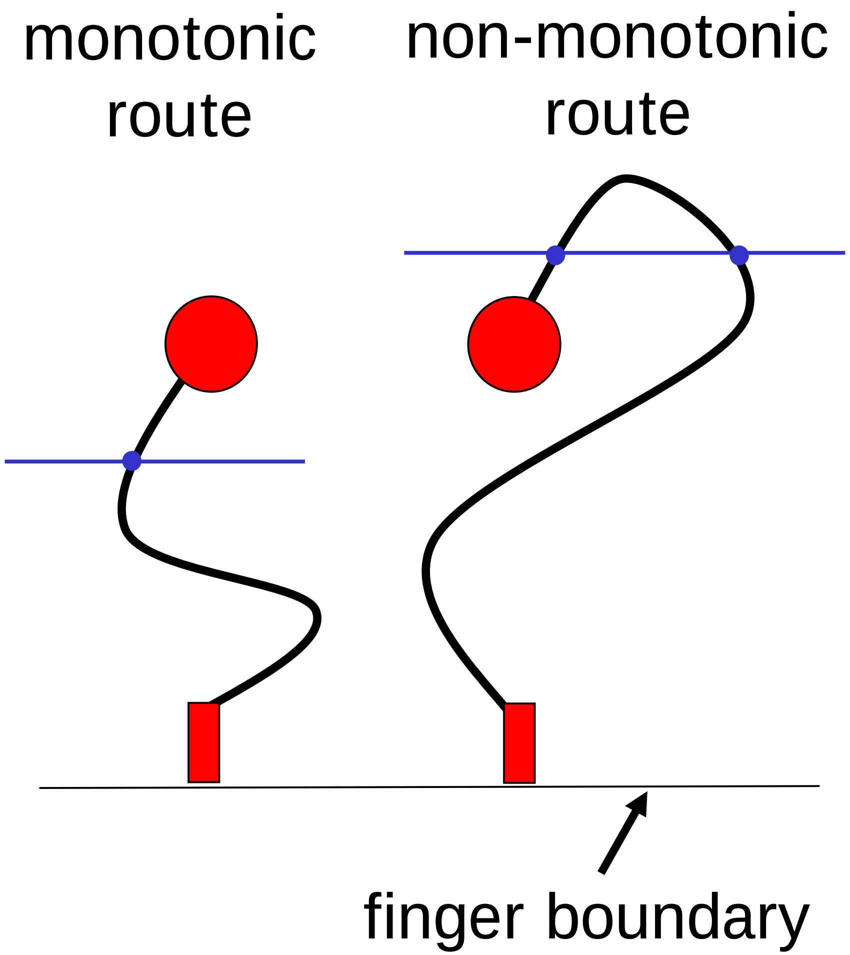
Example of Routing

Connect finger and ball with same labels
Routing layer : one



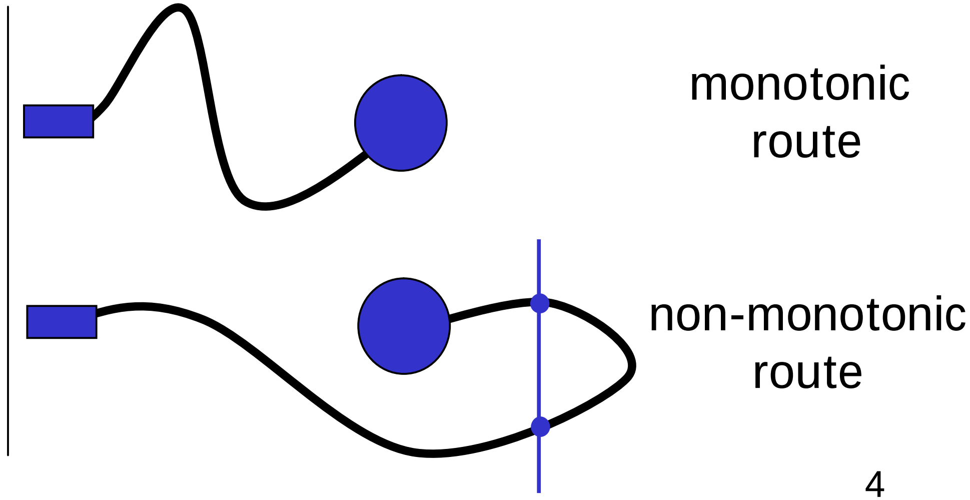


Monotonic and non-monotonic



monotonic route

The route from a finger to a ball intersects any straight lines
(parallel with the finger boundary)
at most once



Background

Netlist
- a set of connection requirements
- some properties

Design rule
- space between wires
- wire length of critical net
- etc . . .

manual routing

By using some properties,
a satisfactory routing pattern
can be obtained

It takes much time

automatic routing

EVENFANOUT for single layer
(1995, Yu and Dai)

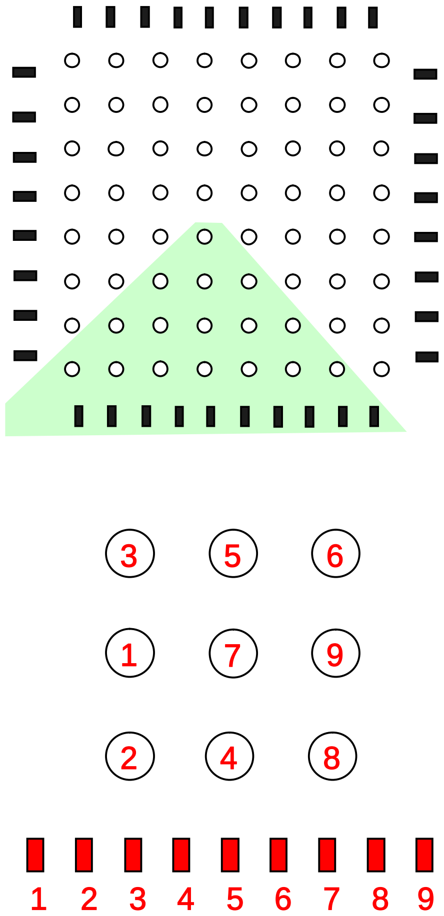
Via Assignment for 2-layers
(2005, Kubo and Takahashi)

Satisfactory routing pattern
- Most of routes are monotonic

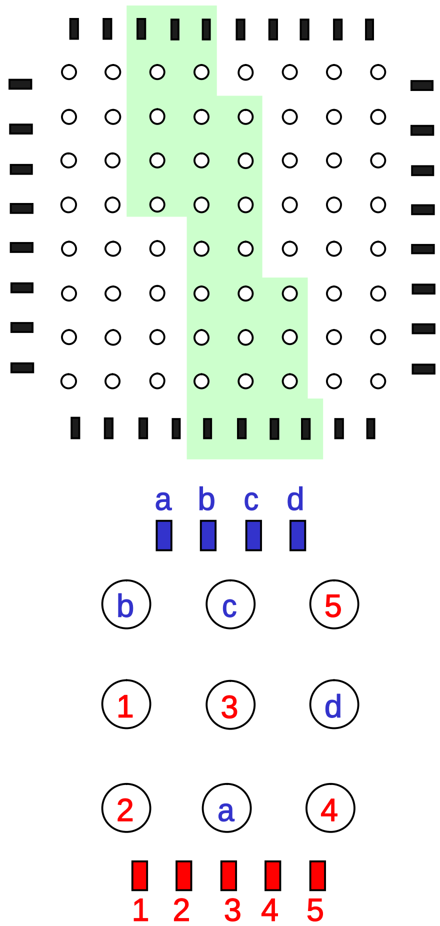
As the first step,
by only monotonic routes

Netlists

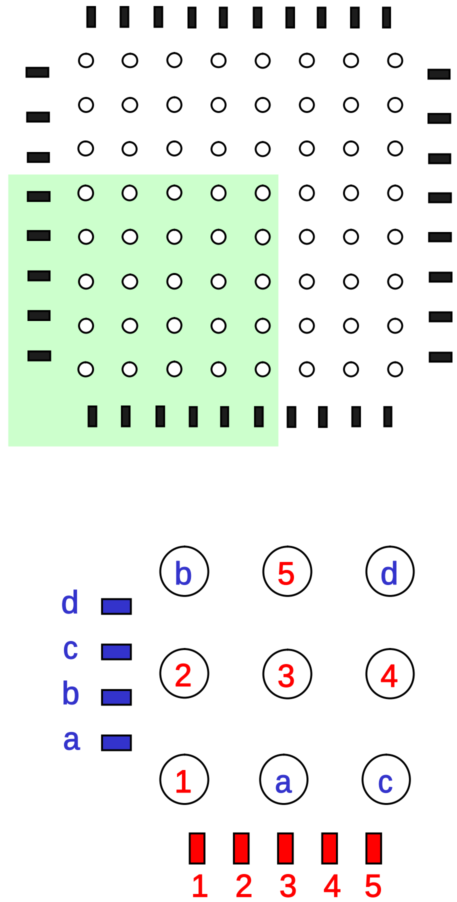
Single Netlist



Parallel Netlist



Orthogonal Netlist



Problem

Input

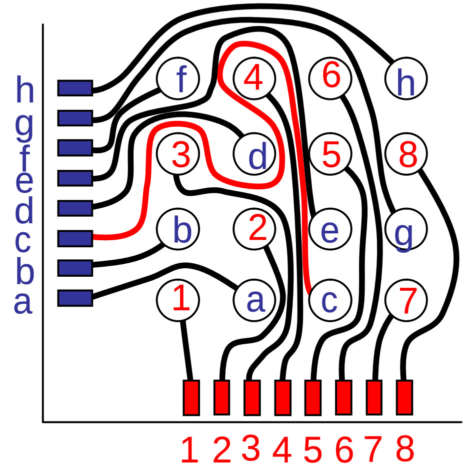
Connection requirements between a finger and a ball (Netlist)

Goal

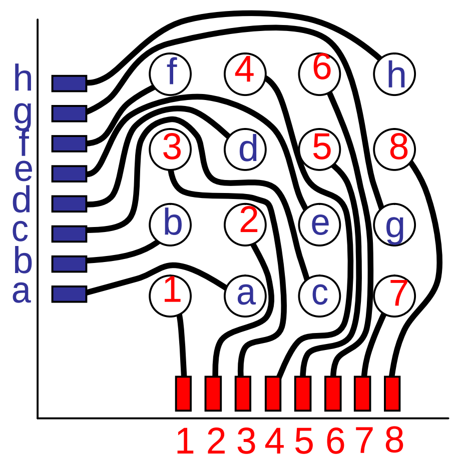
To realize all nets by only monotonic routes without intersecting

A netlist has at least one monotonic routing pattern ⟺ netlist is monotonic

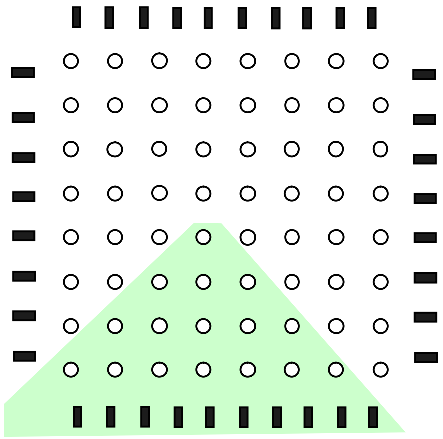
non-monotonic routing pattern



monotonic routing pattern



Single Netlist

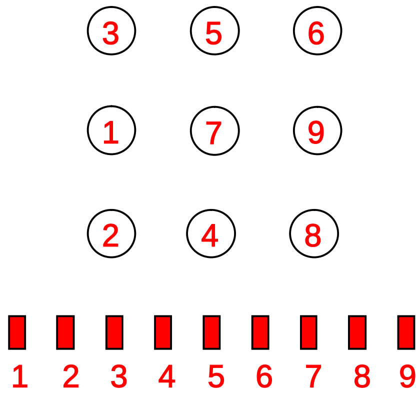


Input

Connection requirements between a bottom finger and a ball (Single Netlist)

Goal

Realize it by only monotonic routes



A single netlist is monotonic :

The necessary and sufficient condition is known

<Monotonic Single Netlists>

Necessary and Sufficient Condition

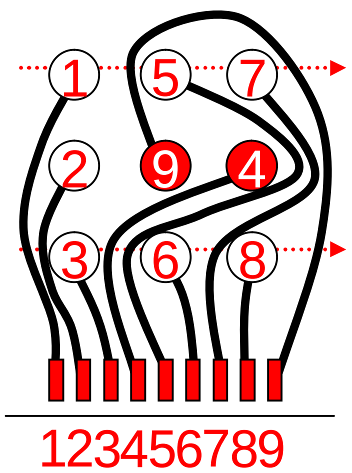
Fingers are in increasing order from left to right

A single netlist is monotonic

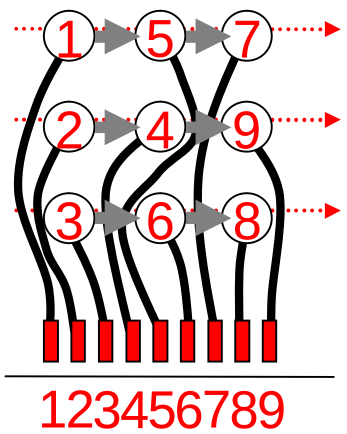
⟺ nets on each row are in increasing order

(1995, Yu and Dai)

non-monotonic netlist

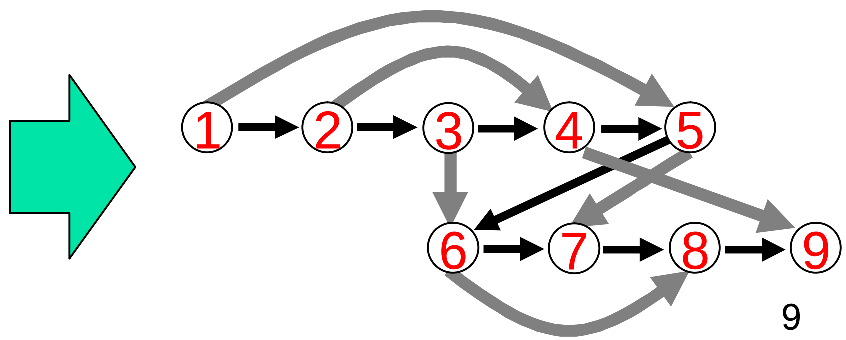


monotonic netlist



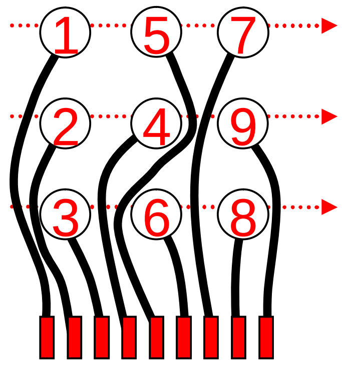
Order graph :

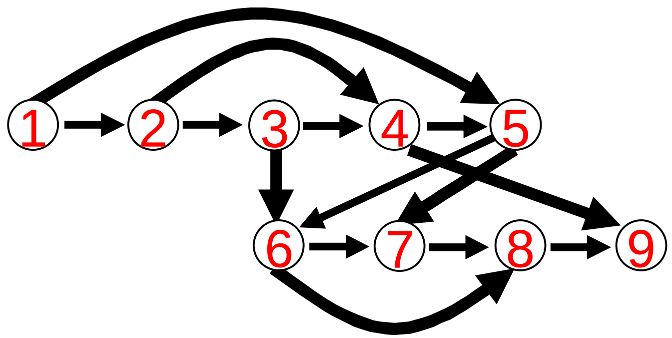
- ◆ Each vertex corresponds to each net
- ◆ Edges represent order constraints



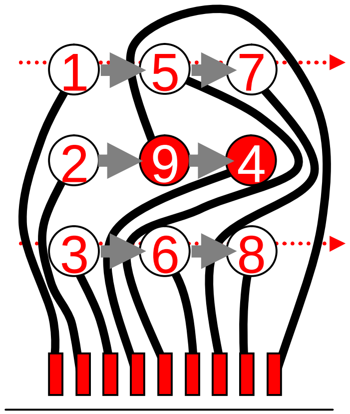
<Monotonic Single Netlists>

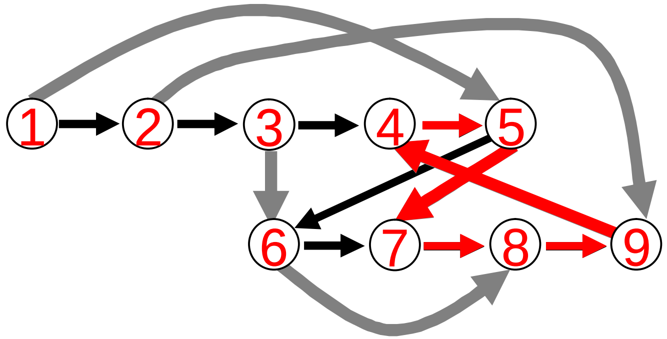
Necessary and Sufficient Condition





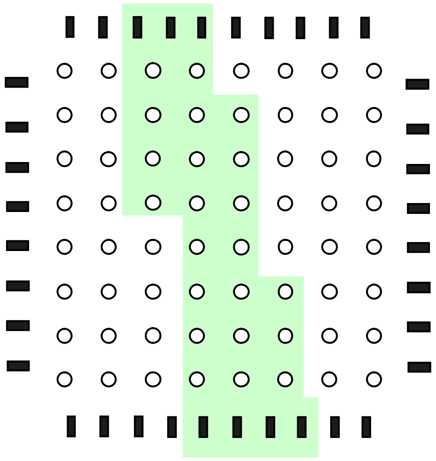
monotonic netlist ⇔ acyclic





non-monotonic netlist ⇔ cyclic

Parallel Netlists

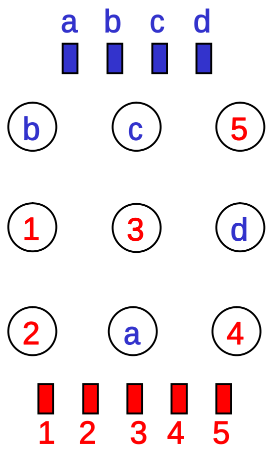


Input

Connection requirements between a bottom finger and a ball, or a top finger and a ball (Parallel Netlist)

Goal

Realize it by only monotonic routes

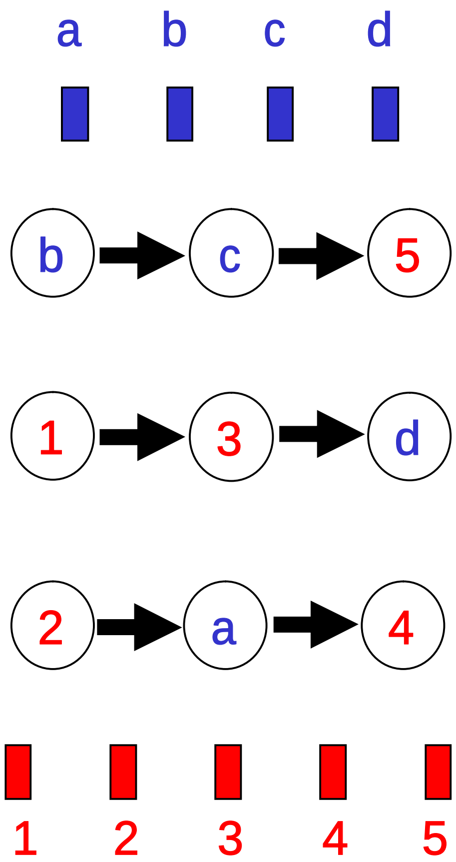


Contribution

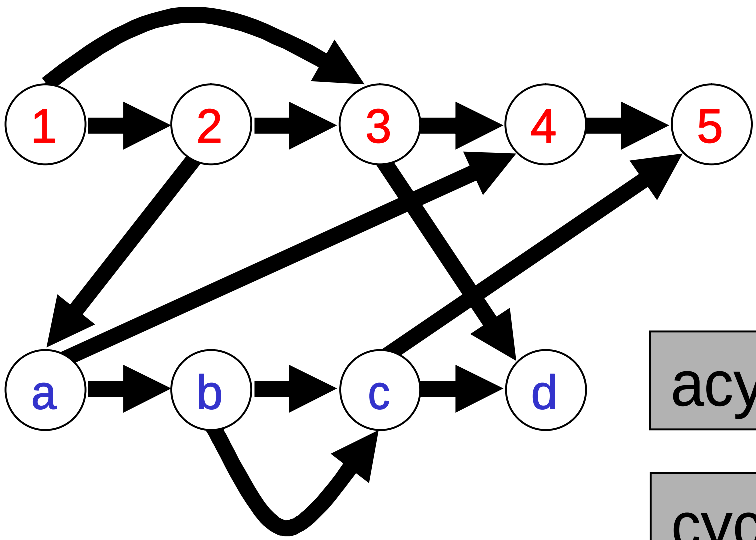
- The necessary and sufficient condition
- A routing method based on the condition

<Monotonic Parallel Netlists>

Necessary and Sufficient Condition



Nets on each row are in increasing order without distinguishing bottom and top nets

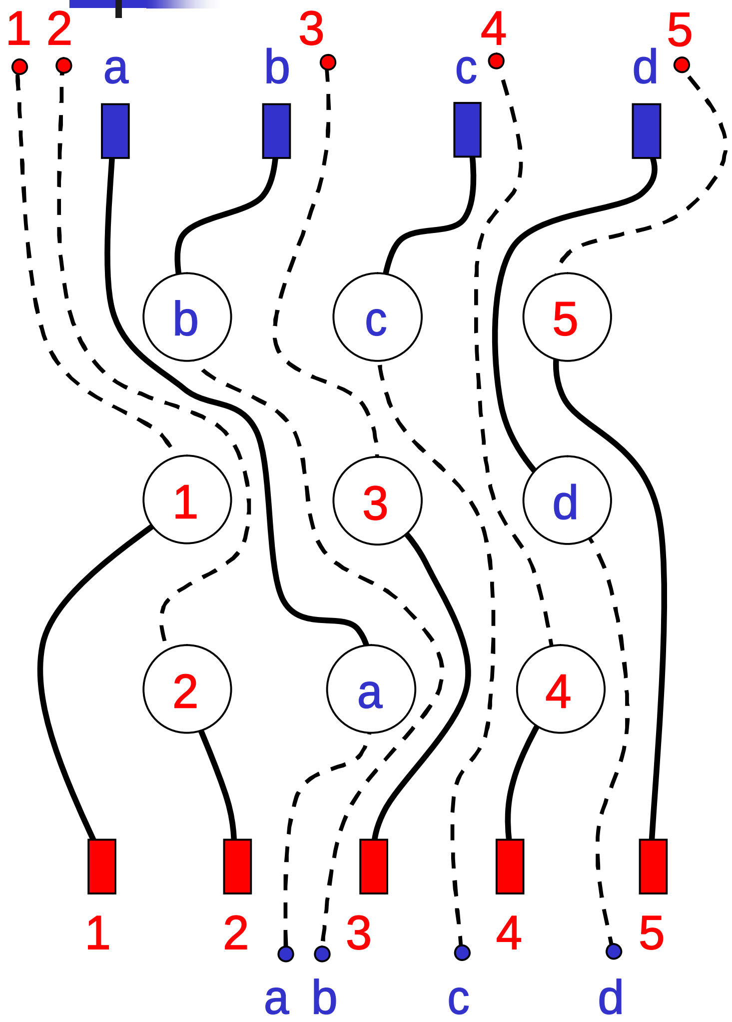


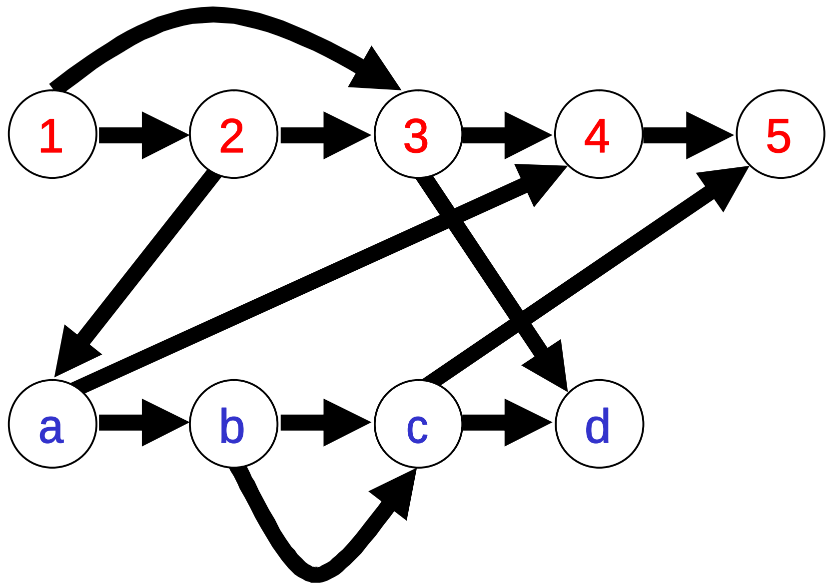
acyclic ⟺ monotonic

cyclic ⟺ non-monotonic

<Monotonic Parallel Netlists>

A Routing Method

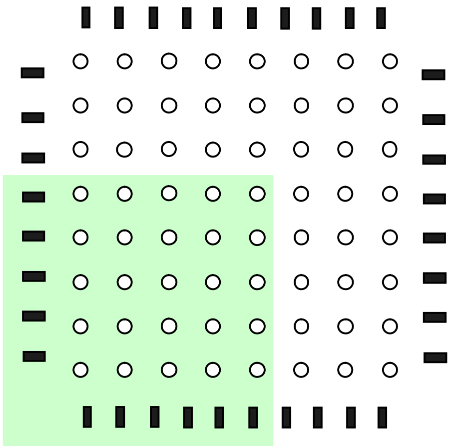




Order :

1 → 2 → a → b → 3
→ c → 4 → d → 5

Orthogonal Netlists

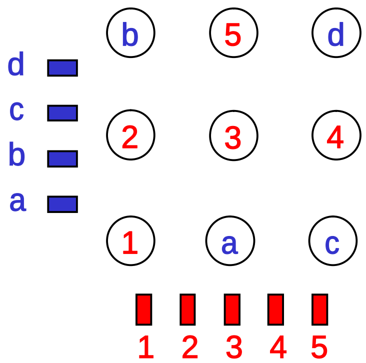


Input

Connection requirements between a bottom finger and a ball, or a left finger and a ball (Orthogonal Netlist)

Goal

Realize it by only monotonic routes



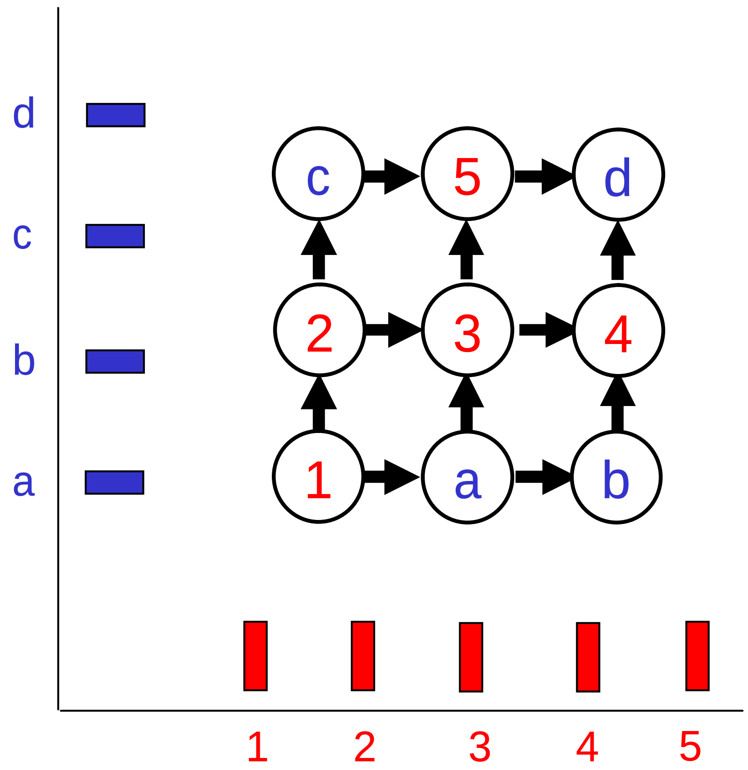
Contribution

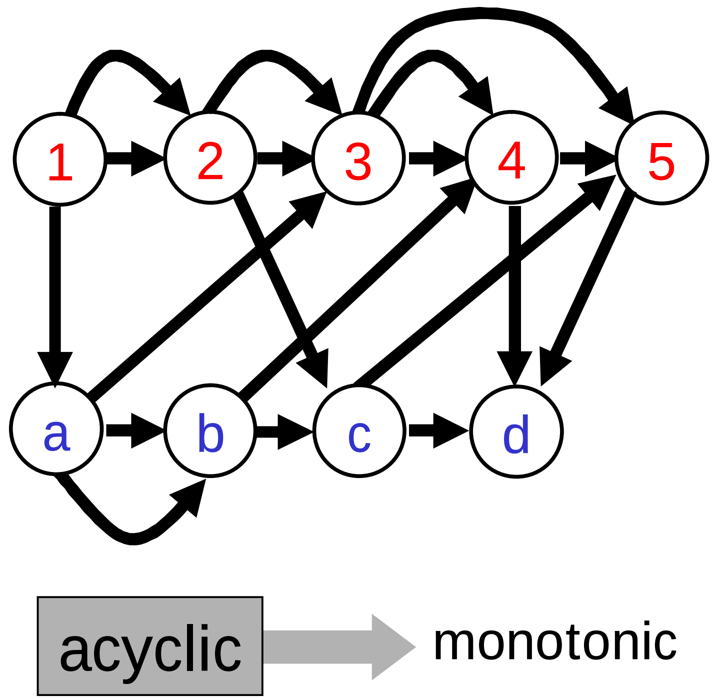
- A sufficient condition
- A necessary condition
- A routing method based on the necessary condition

<Monotonic Orthogonal Netlist>

A Sufficient Condition

Nets on each row and column are in increasing order without distinguishing bottom and left nets

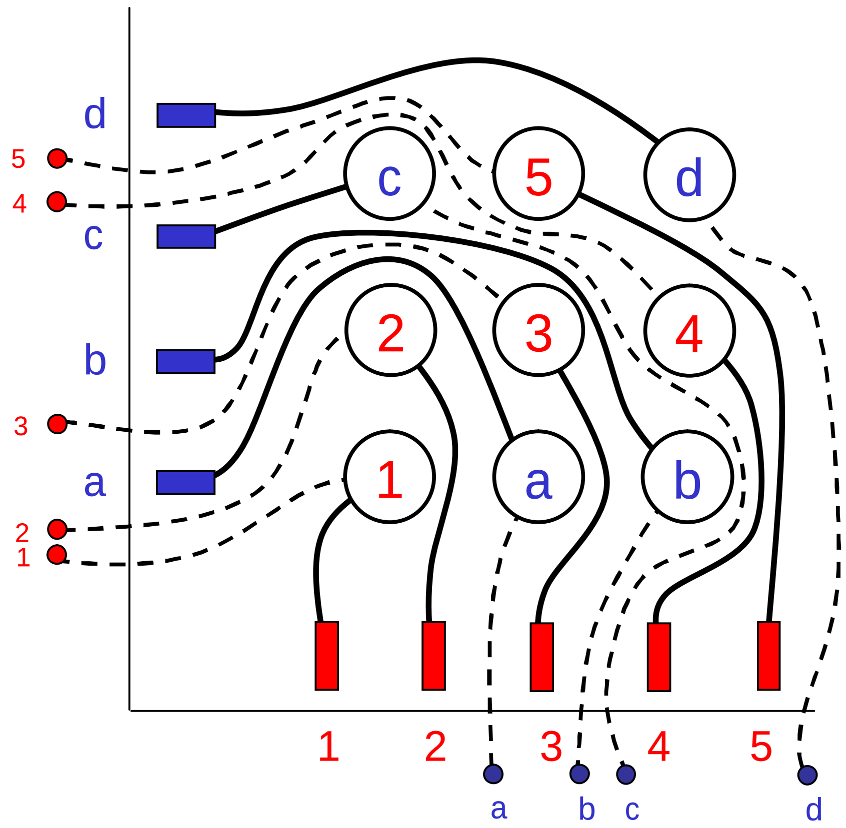


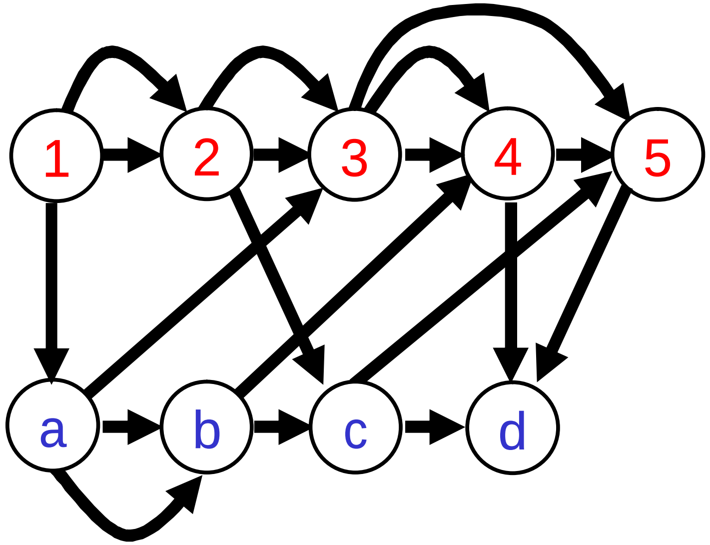


<Monotonic Orthogonal Netlists>

A Routing Method for netlists satisfying the sufficient condition

By connecting nets one by one as lower-left as possible

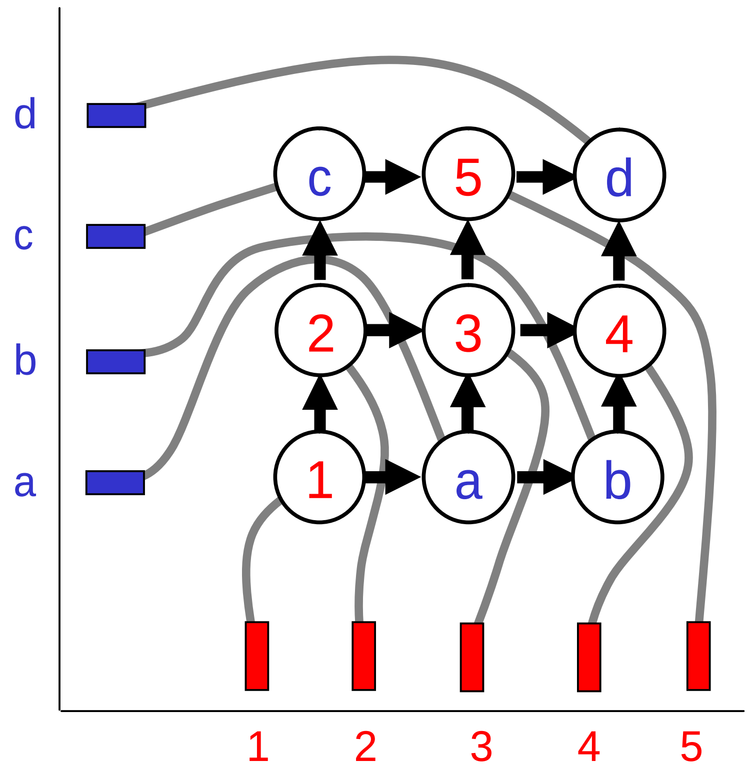




Order：

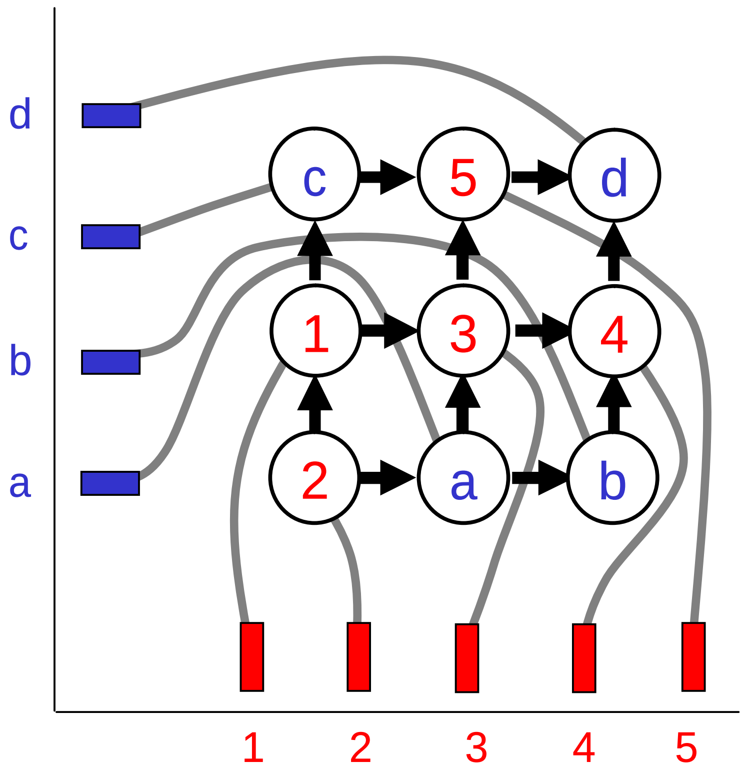
1 → 2 → a → 3 → b → c → 4 → 5 → d

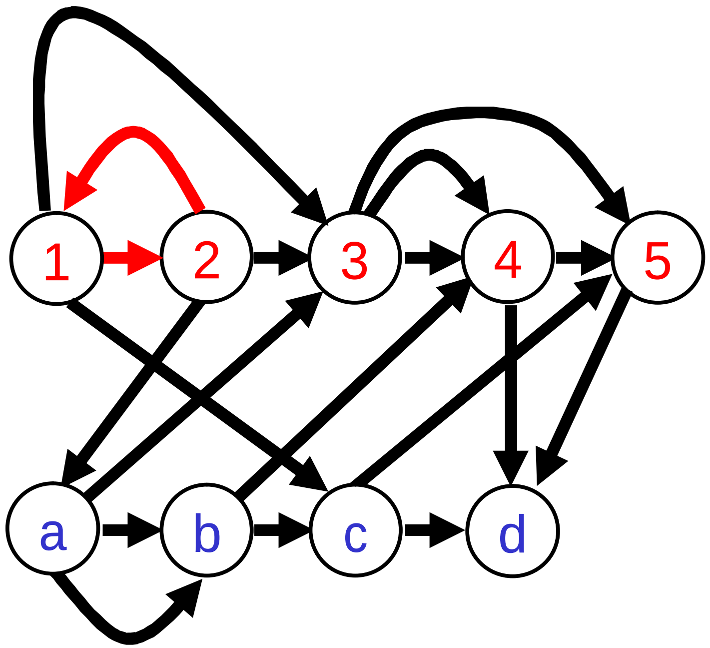
Other Monotonic Orthogonal Netlists



<Monotonic Orthogonal Netlists>

Other Monotonic Orthogonal Netlists





Our sufficient condition is not a necessary condition

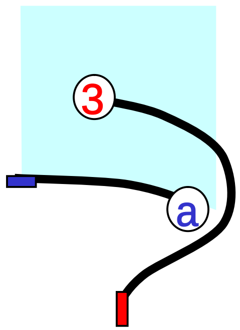
<Monotonic Orthogonal Netlist>

A Necessary Condition

Order Graph G_N

In any monotonic routing pattern,

- left net → wires passing above it
- bottom net → wires passing to the right of it



We proved that for a netlist,

G_N is cyclic ⇒ The netlist is non-monotonic

<Monotonic Orthogonal Netlists>

Order Graph G_N

In any monotonic routing pattern,

- left net → wires passing above it
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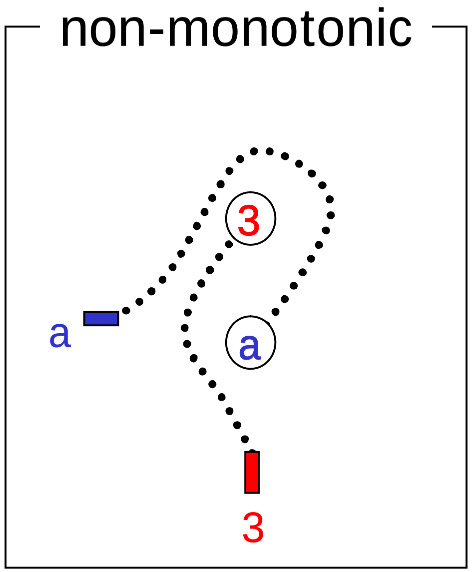
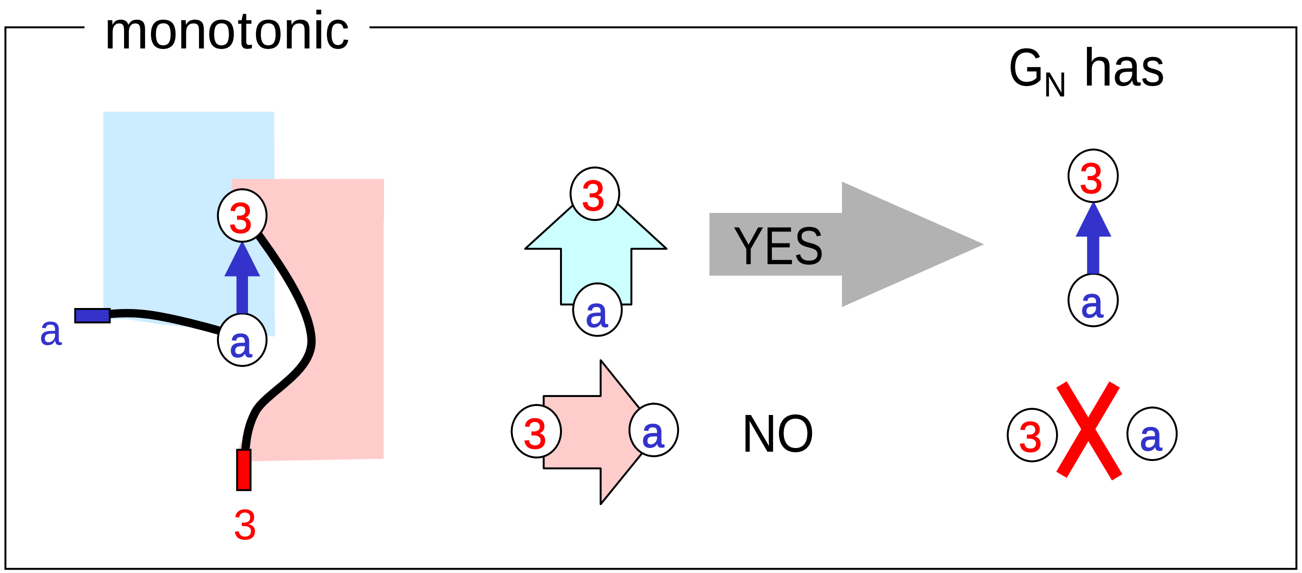
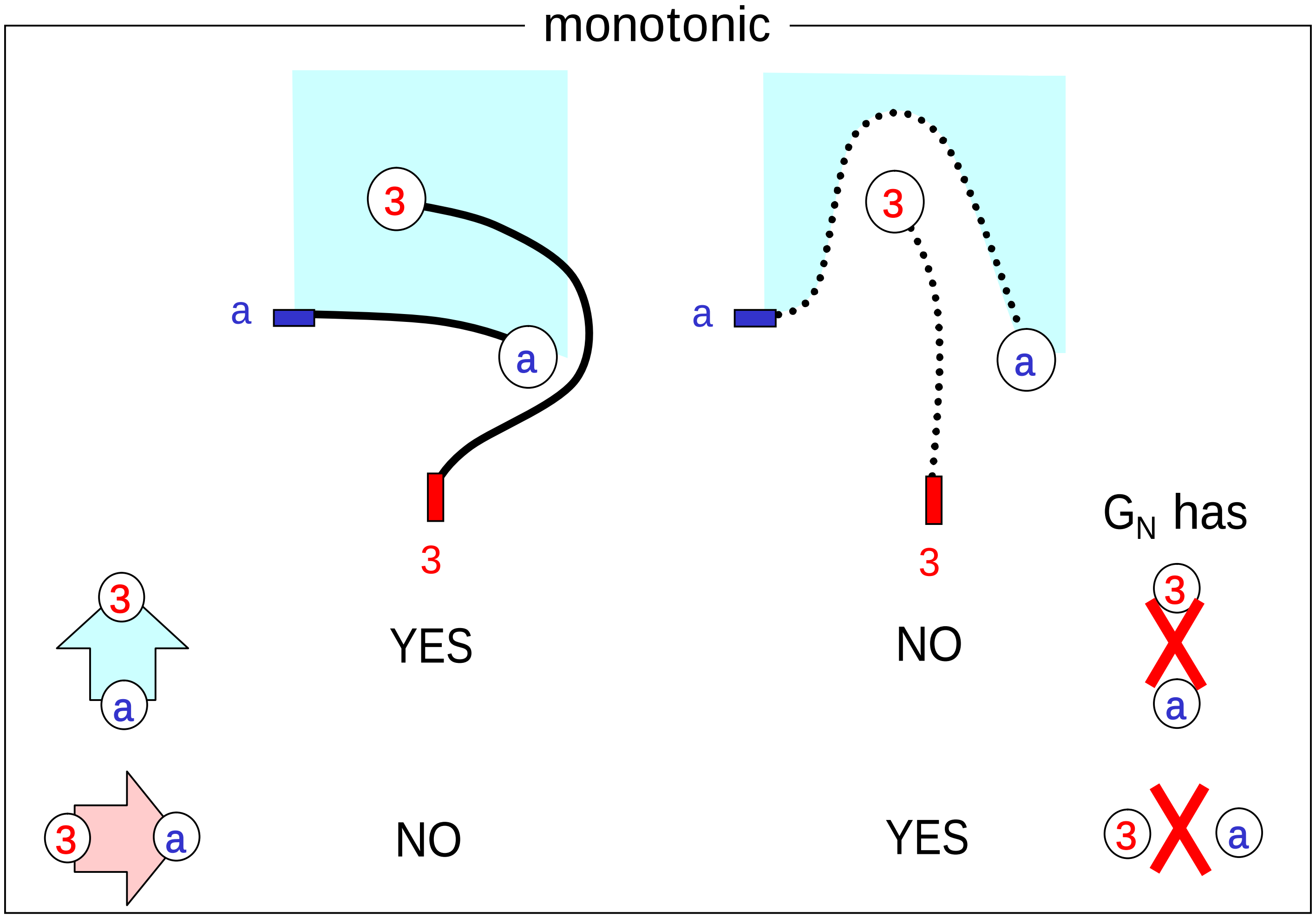


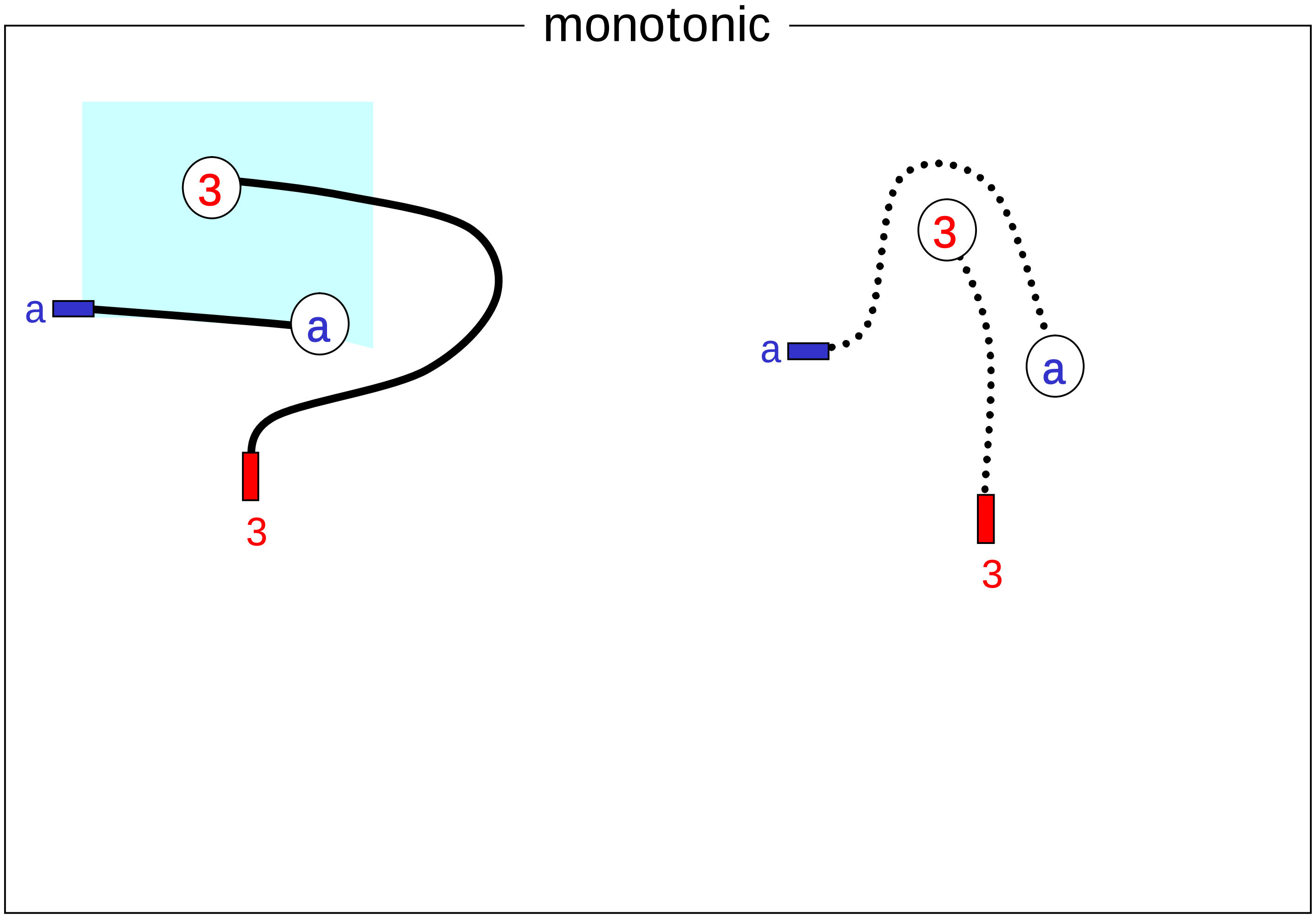


Constraints between two nets



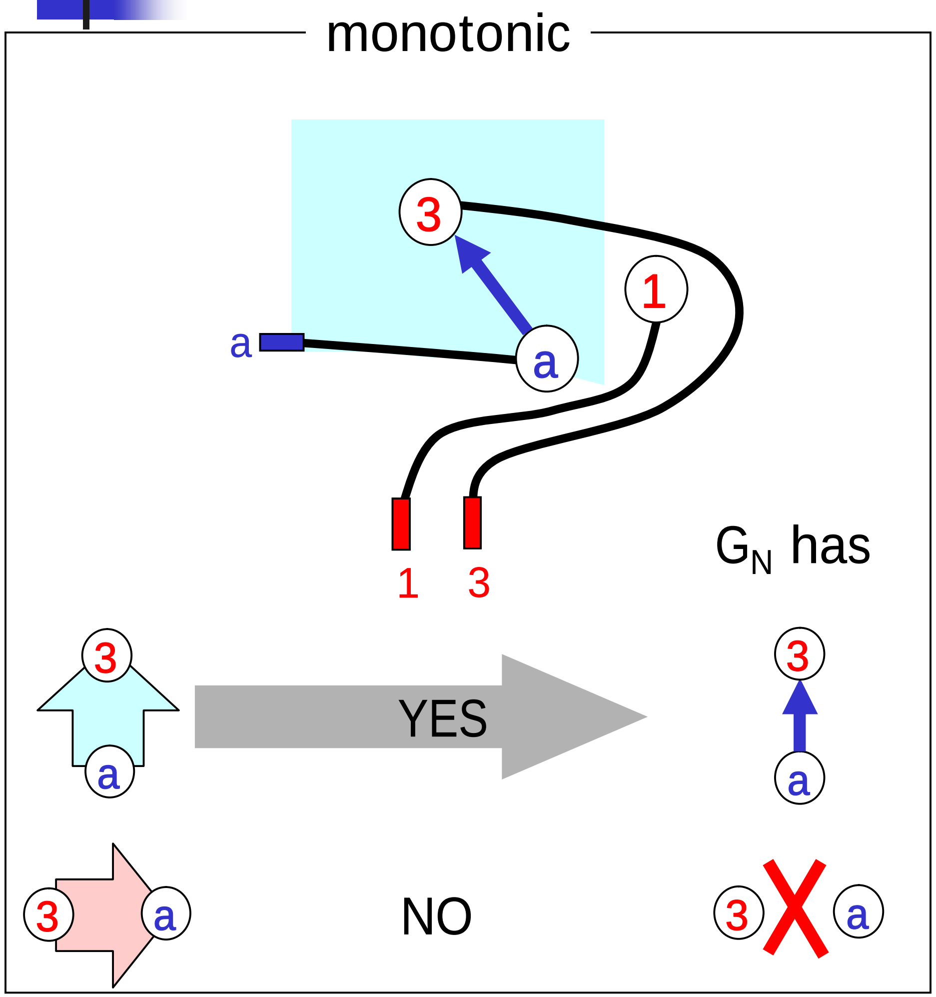
<Monotonic Orthogonal Netlist>

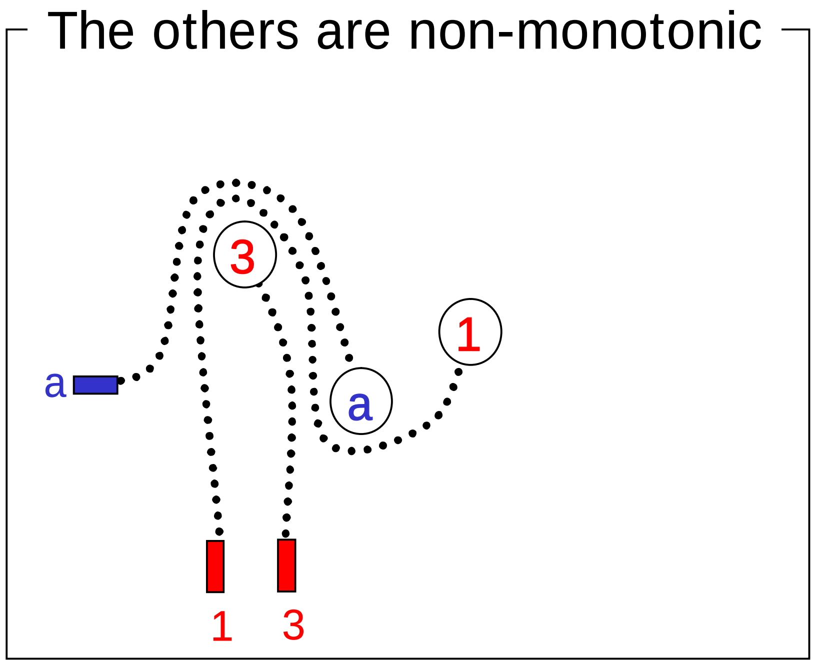
Constraints between three nets



<Monotonic Orthogonal Netlist>

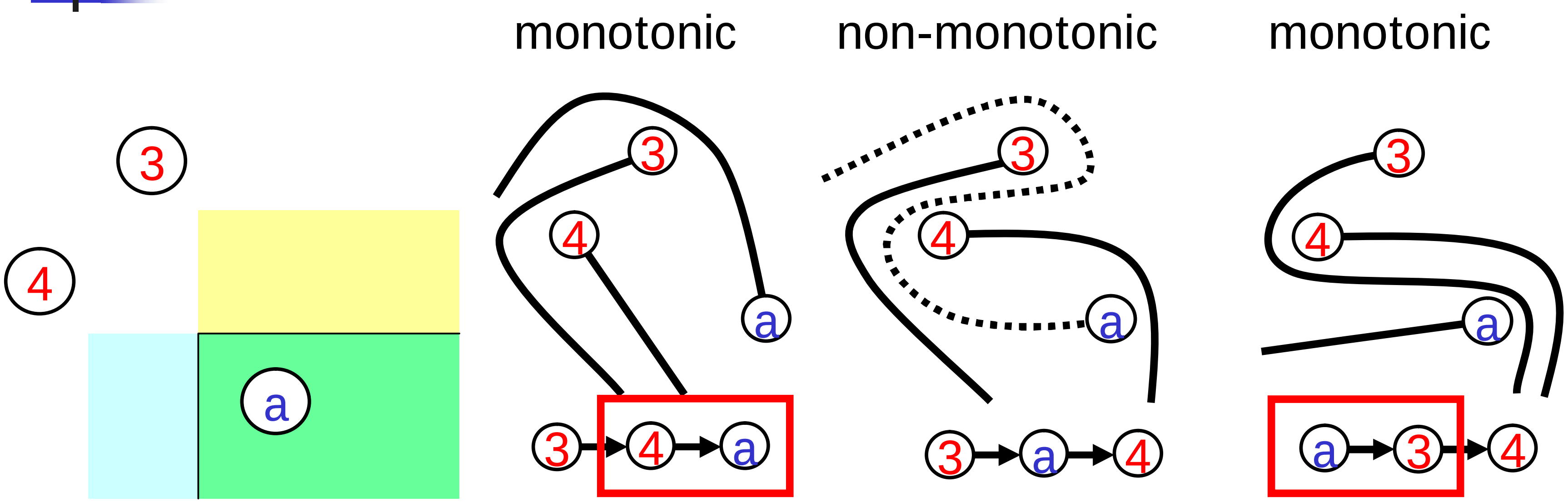
Constraints between three nets





<Monotonic Orthogonal Netlists>

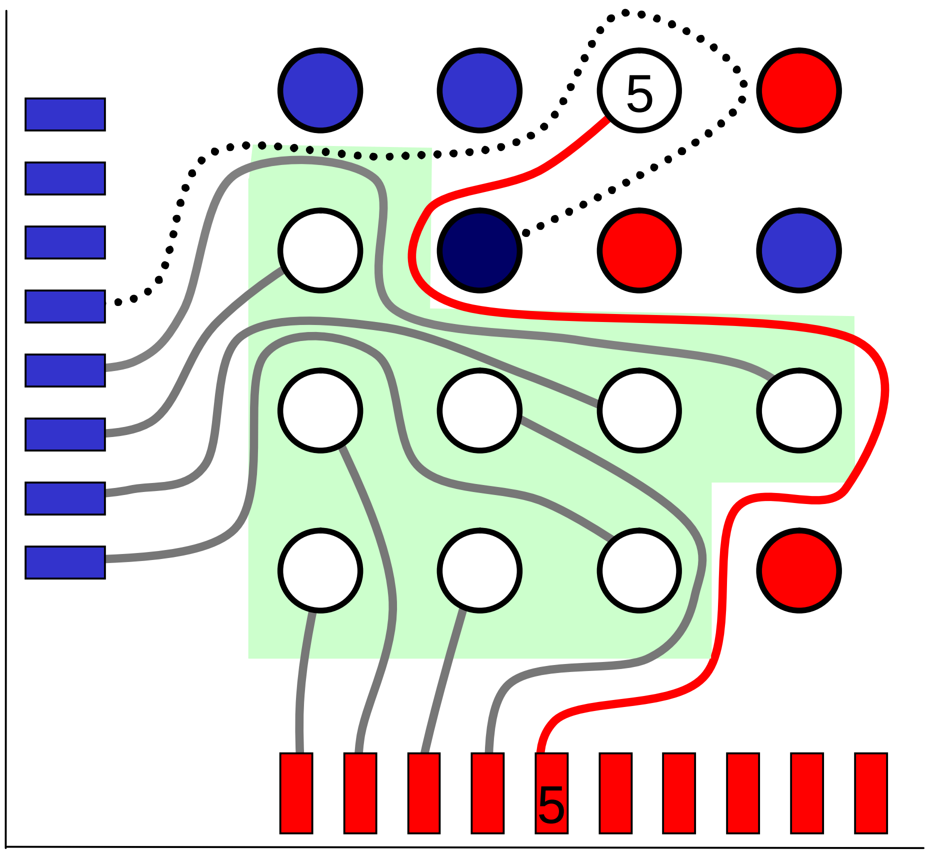
Alternative Constraints



Either a passes to the right of 3 and 4,
or 3 and 4 passes above a

<Monotonic Orthogonal Netlists>

Monotonic Routing



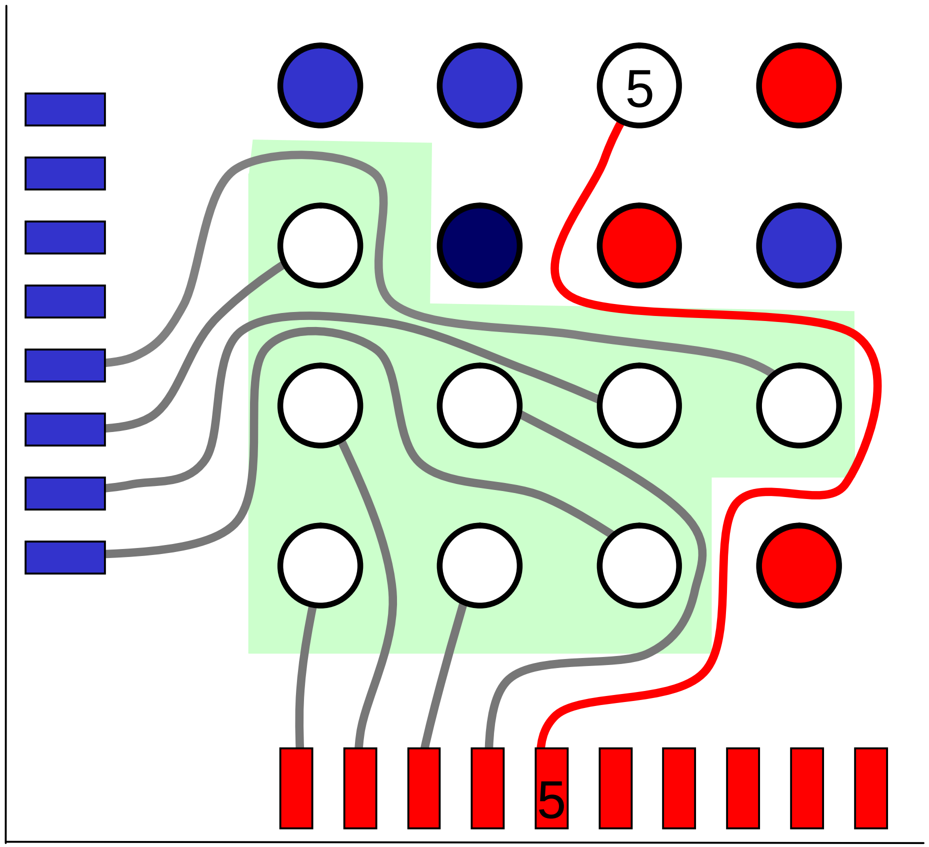
Routes of bottom nets passes as left as possible

Passes to the right of

- ◆ connected balls
- ◆ unconnected left net balls

in lower-left region of its ball

Monotonic Routing

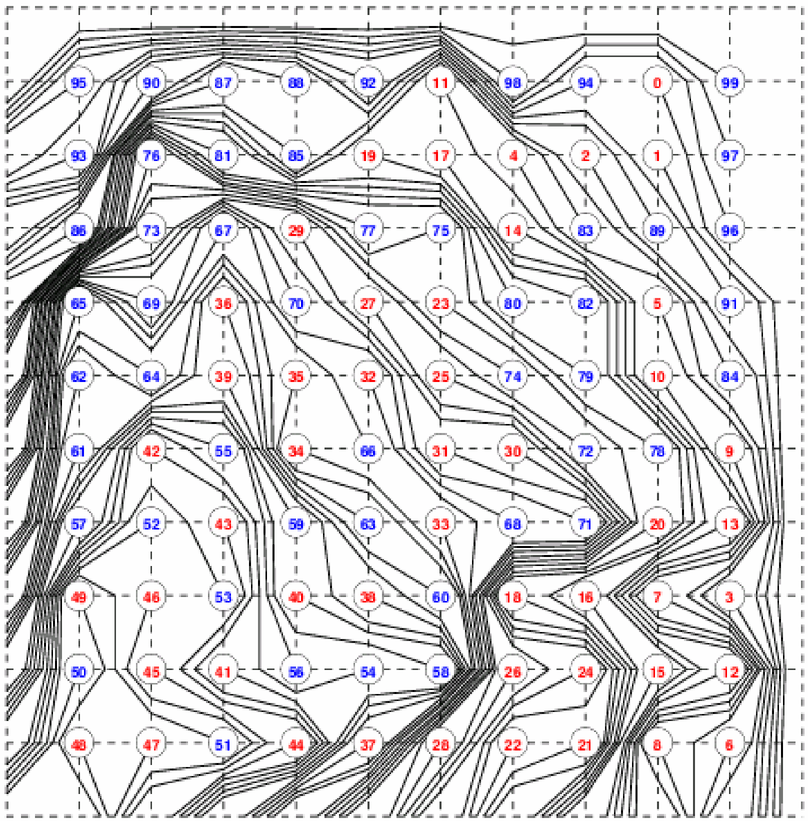


Routes of bottom nets passes as left as possible

Passes to the right of
- connected balls
- unconnected left net balls

in lower-left region of its ball

Experiments and Results



- According to routing order, combinations of alternative constraints change, and whether G_N is cyclic depends on it

Problems of 56 sizes from 5x5 to 60x60
In each size 100 patterns

Fault : Two instances in 44x44 and 45x45
(Because G_N became cyclic
due to the alternative edges
added in routing process)

Complete : the others
(even for 3000 nets, within 1 second)

Conclusion

Monotonic Parallel Netlist

- The necessary and sufficient condition
- A routing method based on it

Monotonic Orthogonal Netlist

- A necessary condition and a sufficient condition
- A routing method based on our necessary condition

Future Work

◆ Propose a routing method with consideration of wire congestion, since various monotonic routing patterns exist for a monotonic netlist

◆ Realize automation of package routing, by putting our methods into practice