LMgr: A Low-Memory Global Router with Dynamic Topology Update and Bending-Aware Optimum Path Search

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Outline

- Introduction
- Problem formulation
- Existing problems and our solutions
- A new global router → LMgr
- Experimental Results
- Conclusion

Introduction

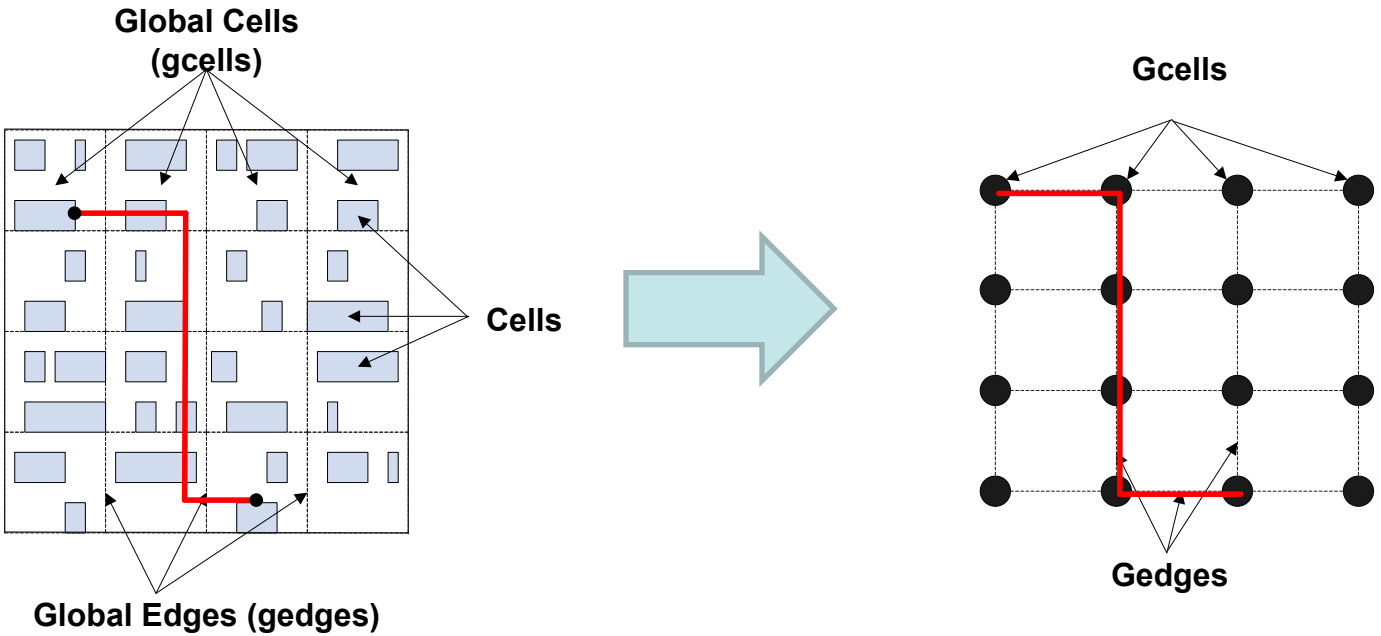
- **Fundamental research problem**
  - **Performance dominance**
  - **Impacts on timing and power closure**
  - **Bottleneck on design efficiency**

- **ISPD 2007-2008 global routing contest [ISPD08]**
  - **Bookshelf-format benchmark suite from real VLSI design**
  - **Lots of related research works have been proposed**

- **State-of-the-art approaches**
  - **Integer linear programming [Cho07, Shojaei11]**
  - **Iterative rip-up and rerouting [Chang08, chen09]**

Problem Formulation

- **Huge complexity of routing problem**
  - **Global routing + detail routing**
  - **Decomposition & inter-gcell routing**



Obj → min. congestion and wirelength

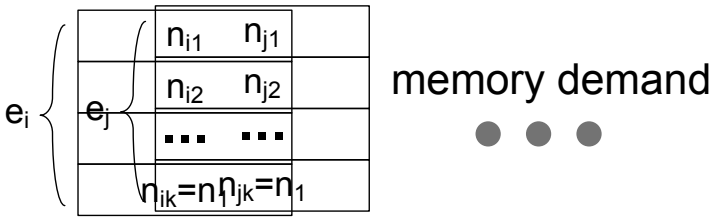
Existing Problems

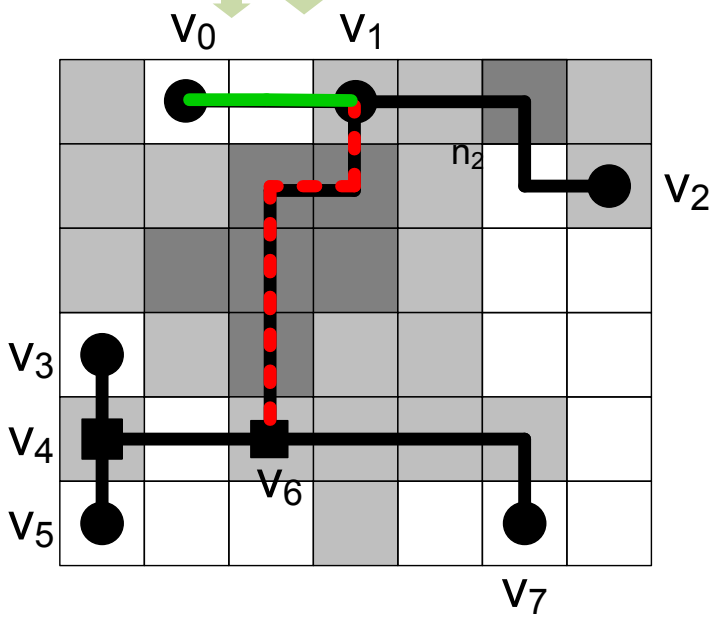
- **Memory overhead**
  - **Cause → avoiding of overlap**
  - ***Our solution → low-memory routing by graph coloring***
- **Topology corruption**
  - **Cause → subnet rip-up and rerouting**
  - ***Our solution → dynamic topology update***
- **Suboptimality of Lee's Maze routing method**
  - **Cause → vertex expansion based method**
  - ***Our solution → bending-aware optimum maze routing***

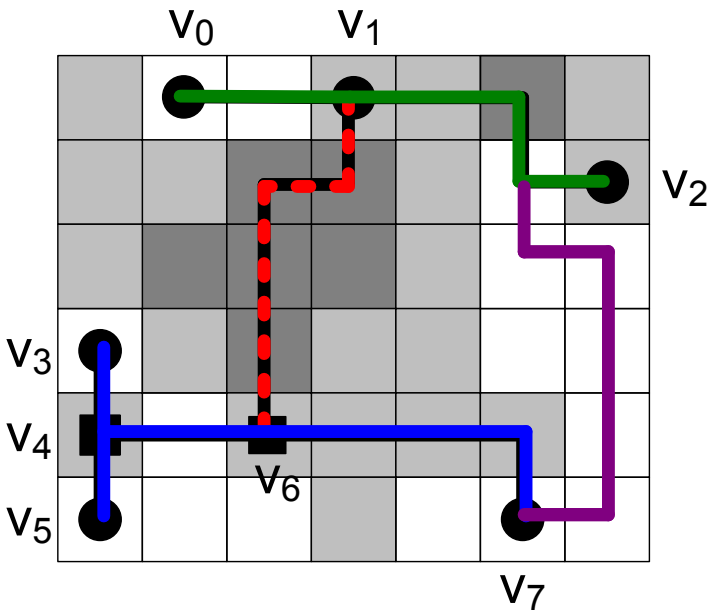
Memory Overhead

- **Observation from experiment**
  - **Routers are consuming huge memory**
- **Why low memory?**
  - **Cache miss, page fault and thrashing → efficiency**
  - **Easier for multi-threading**
  - **Negligible penalty on quality and efficiency**
- **Cause of memory demand**
  - **Avoid routing overlap**
  - **Recording list of nets using each edge**

Improvement on Memory







Previous method

Our method

O(N) Memory

N = size of net

Zero Memory

Improvement on Efficiency

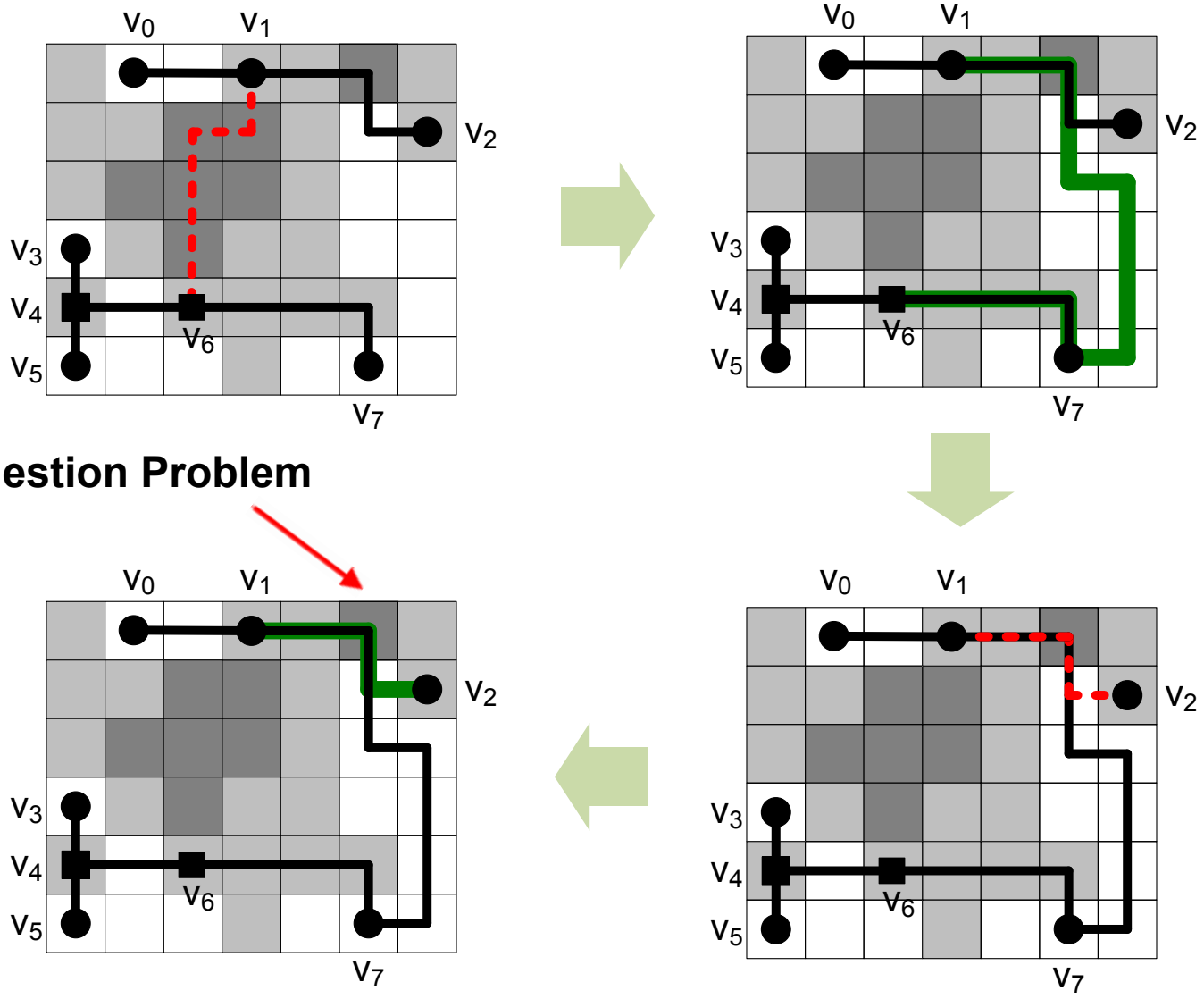
- **Pre-routing time cost**
  - **Previous methods → 0**
  - **Our method → O(N), due to net traversal**
  - **Negligible due to $O(N^2)$ routing time cost**

- **Routing time cost → $O(N^2)$**
  - **Need to search over all grids around the net**
  - **Other methods → $k \times N^2$ ($k >> 1$)**
    - **Hash table operation cost**
    - **Other data structure will induce higher complexity**
  - **Our method → exactly N^2**
    - **One operation → color checking**

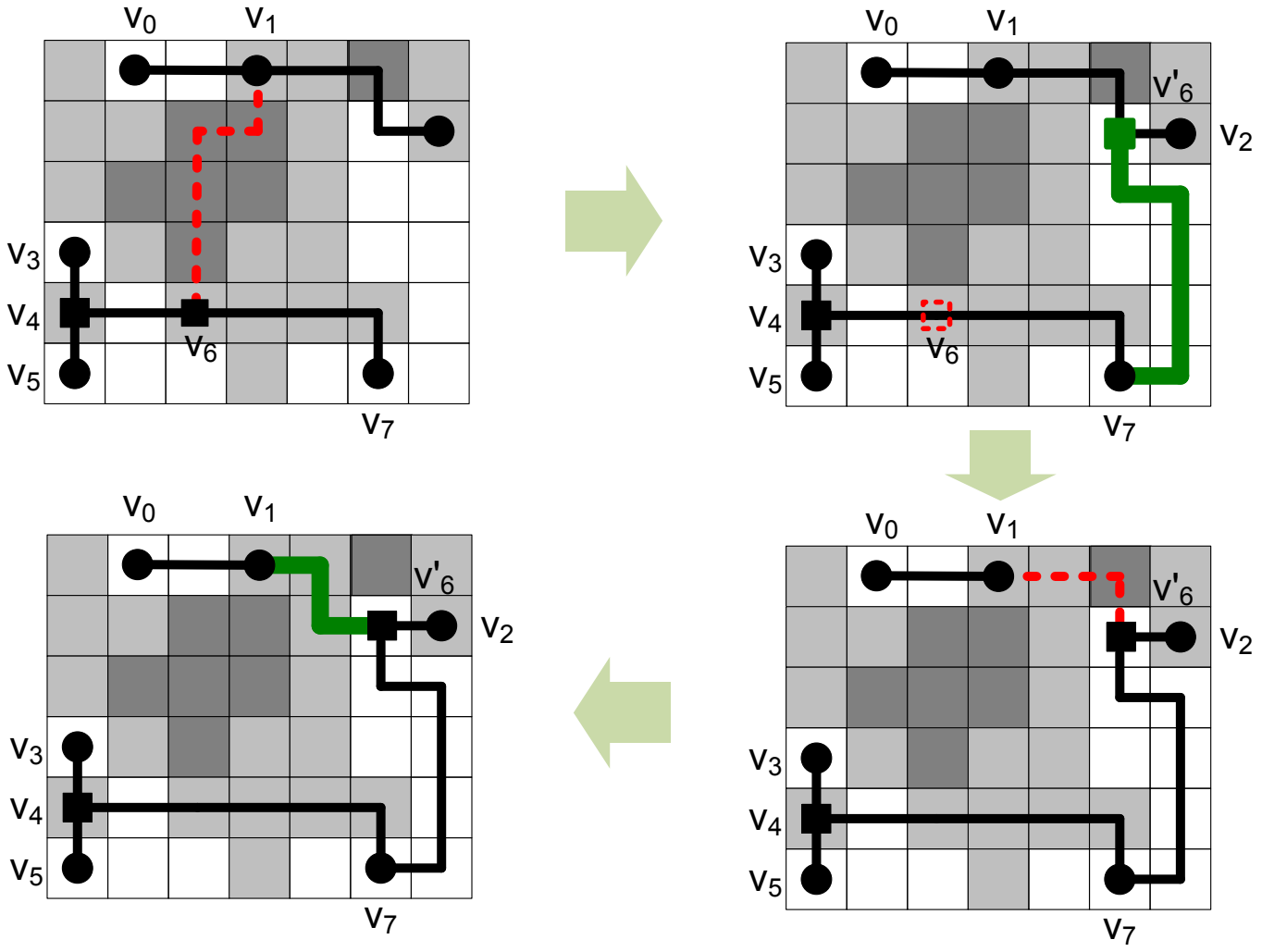
Topology Corruption

- Steiner tree topology
  - Widely used in modern routers
- Topology corruption
  - Due to rerouting of congested subnets
- Previous solutions
  - BFS to rebuild the topology
  - Usually at the end of iteration
  - Impede congestion reduction

Topology Corruption – Previous Methods

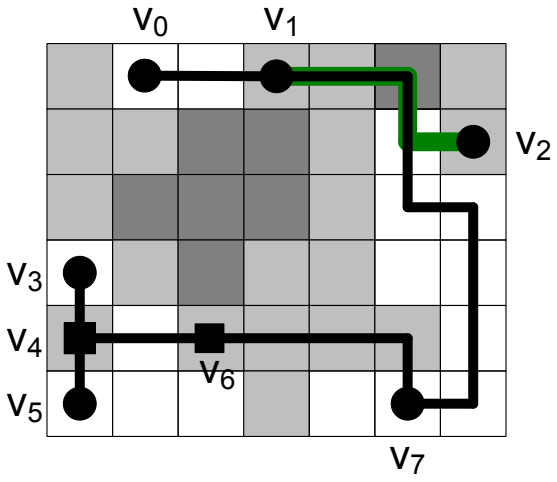


Our Solution – Dynamic Topology Update

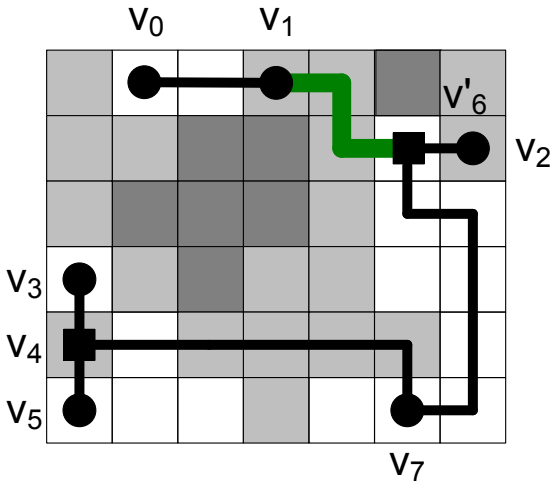


Comparison

Previous Methods



Our Method



Improved routing congestion

O(N) overhead on runtime
(negligible)

Bending-Aware Cost Function

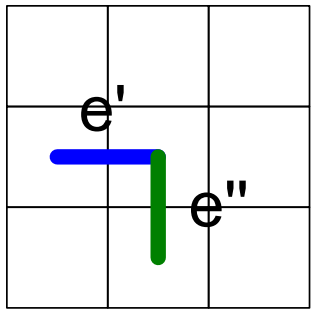
routing cost on $e_{i,j}$

$$c_{i,j} = c_{i,j}^{cong} + c_{i,j}^{len}$$

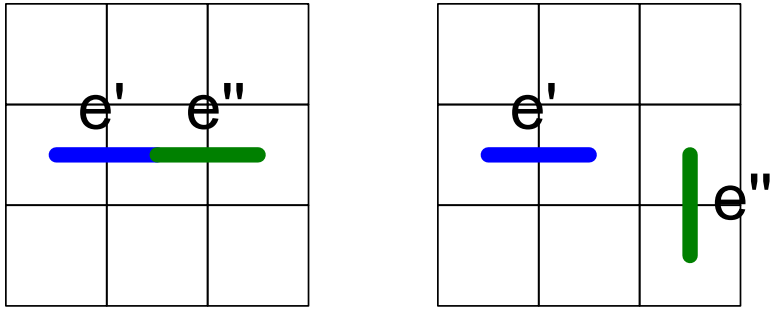
total cost of solution r_i

$$C_i = \sum_{e_{u,v} \in r_i} c_{u,v} + c_{bnd} \left(\sum_{e',e'' \in r_i} IsBend(e',e'') \right)$$

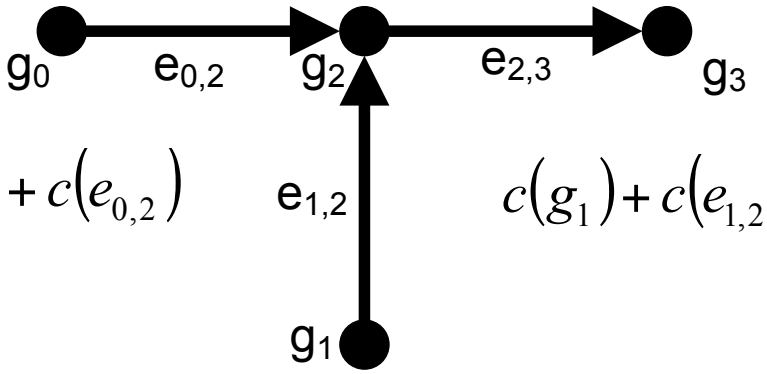
$IsBend(e',e'') = 1$



$IsBend(e',e'') = 0$



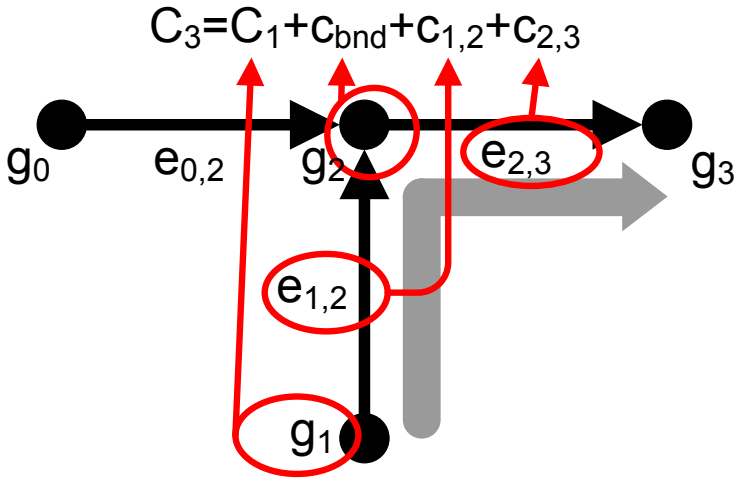
Sub-Optimalitay of Lee's Algorithm [Lee61]



$$c(g_1)+c(e_{1,2})<c(g_0)+c(e_{0,2})$$

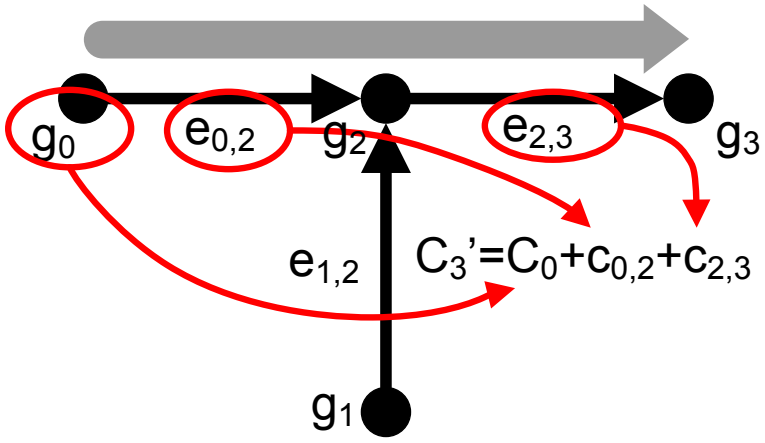
$$c(g_1)+c(e_{1,2})+c_{bnd}>c(g_0)+c(e_{0,2})$$

Actual solution for g_3 [Lee61]



Sub-optimum

Another solution for g_3



Optimum

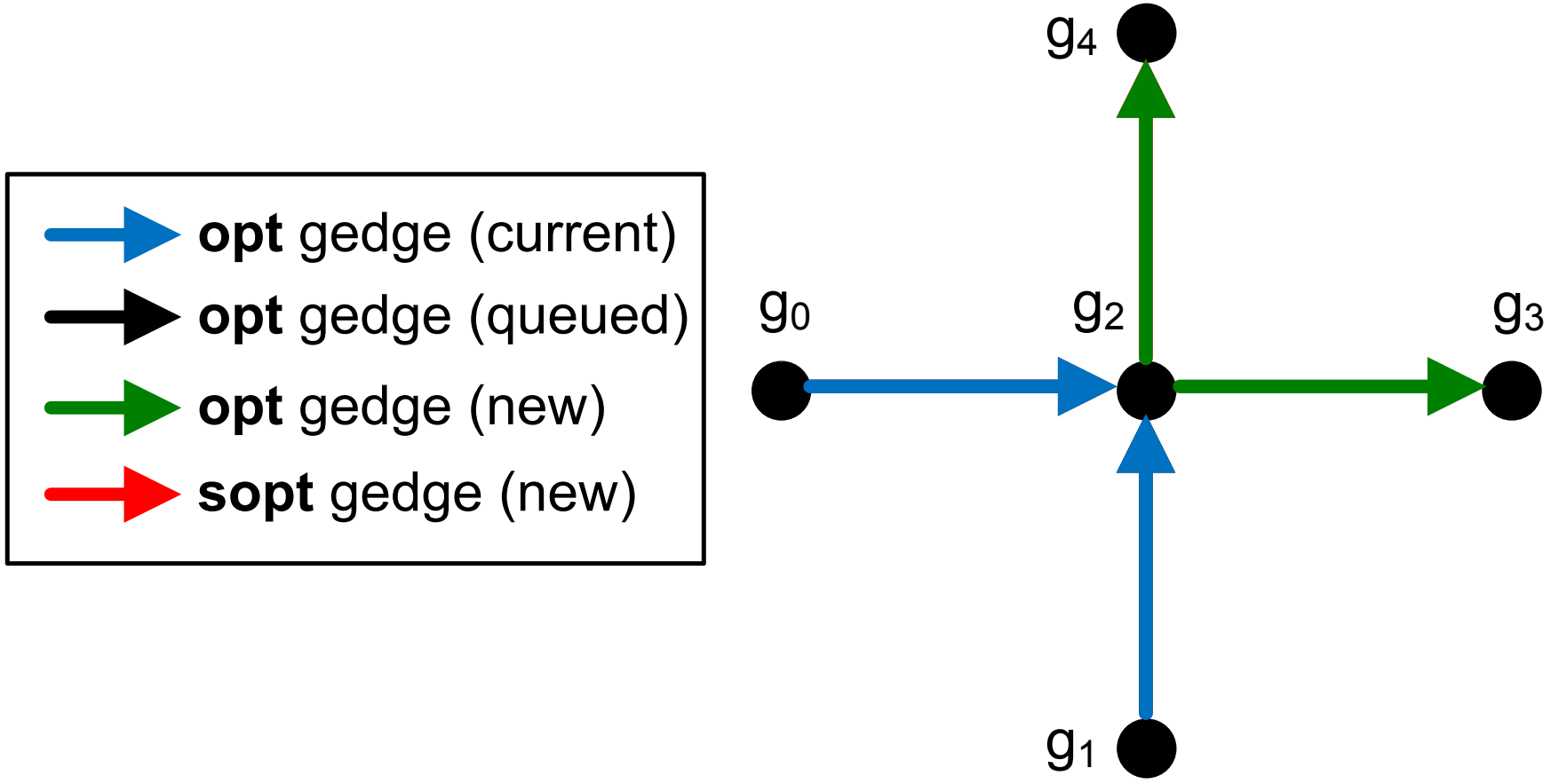
Our Optimum Solution

- Edge expansion based maze search
  - Instead of traditional grid expansion
  - All gedges are directed

- Edges classified into three sets
  - opt → Optimum solution obtained
  - sopt → SubOptimum solution obtained
  - nopt → No solution obtained

- Priority queue storing optimized edges
  - Pop out min-cost edge for expansion

Our Optimum Solution



Overview of LMgr

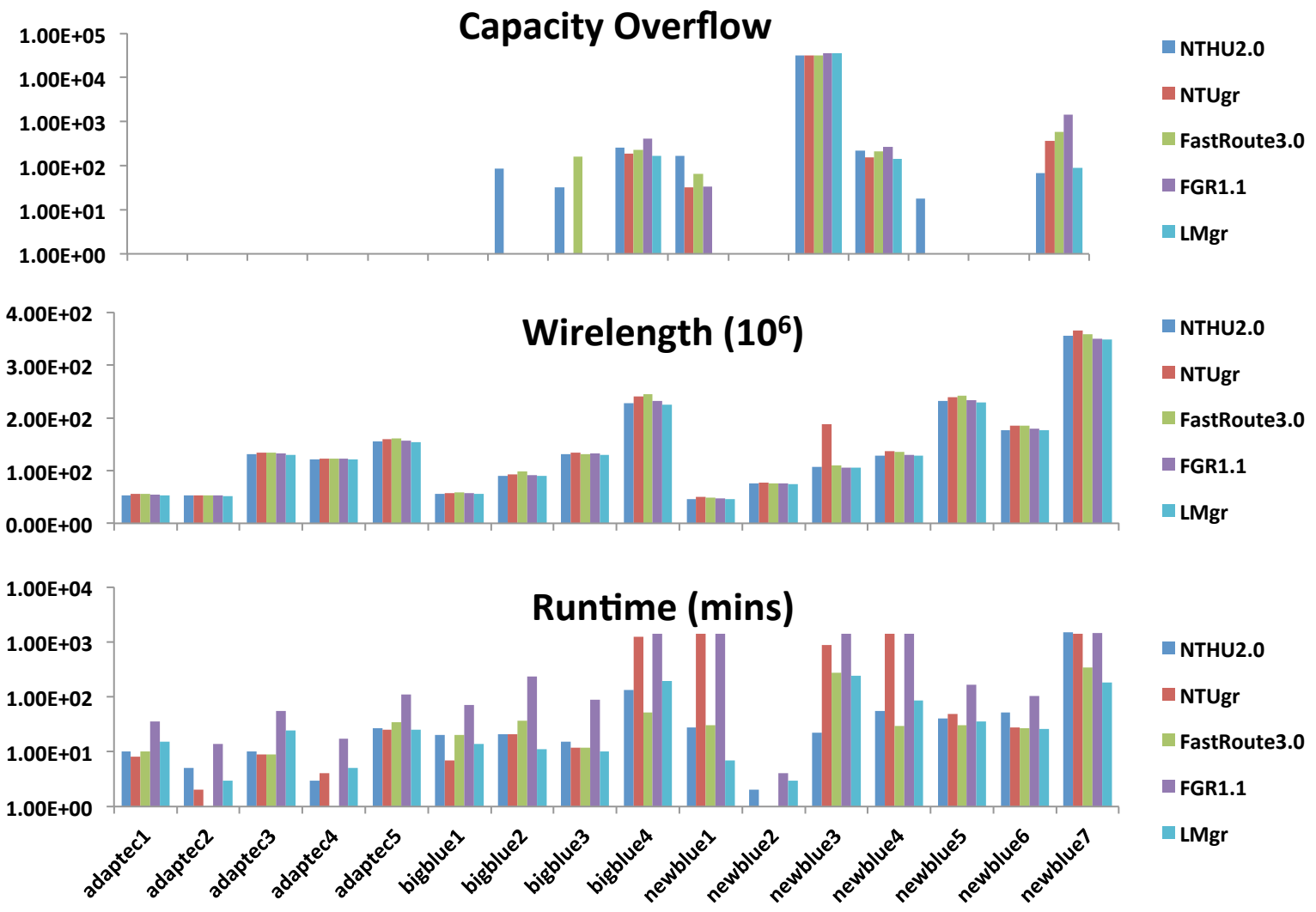
- 2D global routing (LMgr) + 3D layer assign [Dai09]
- RSMT topology generation by FLUTE [Chu08]
- Pattern-based initial routing
  - L-shape [Kastner02] & monotonic [Zhang08]
- Maze-based iterative rip-up & rerouting
  - (1) Congestion- and wirelength-driven
  - (2) Congestion-driven (most aggressive)
  - (3) Wirelength-driven (zero congestion penalty)

Experiments

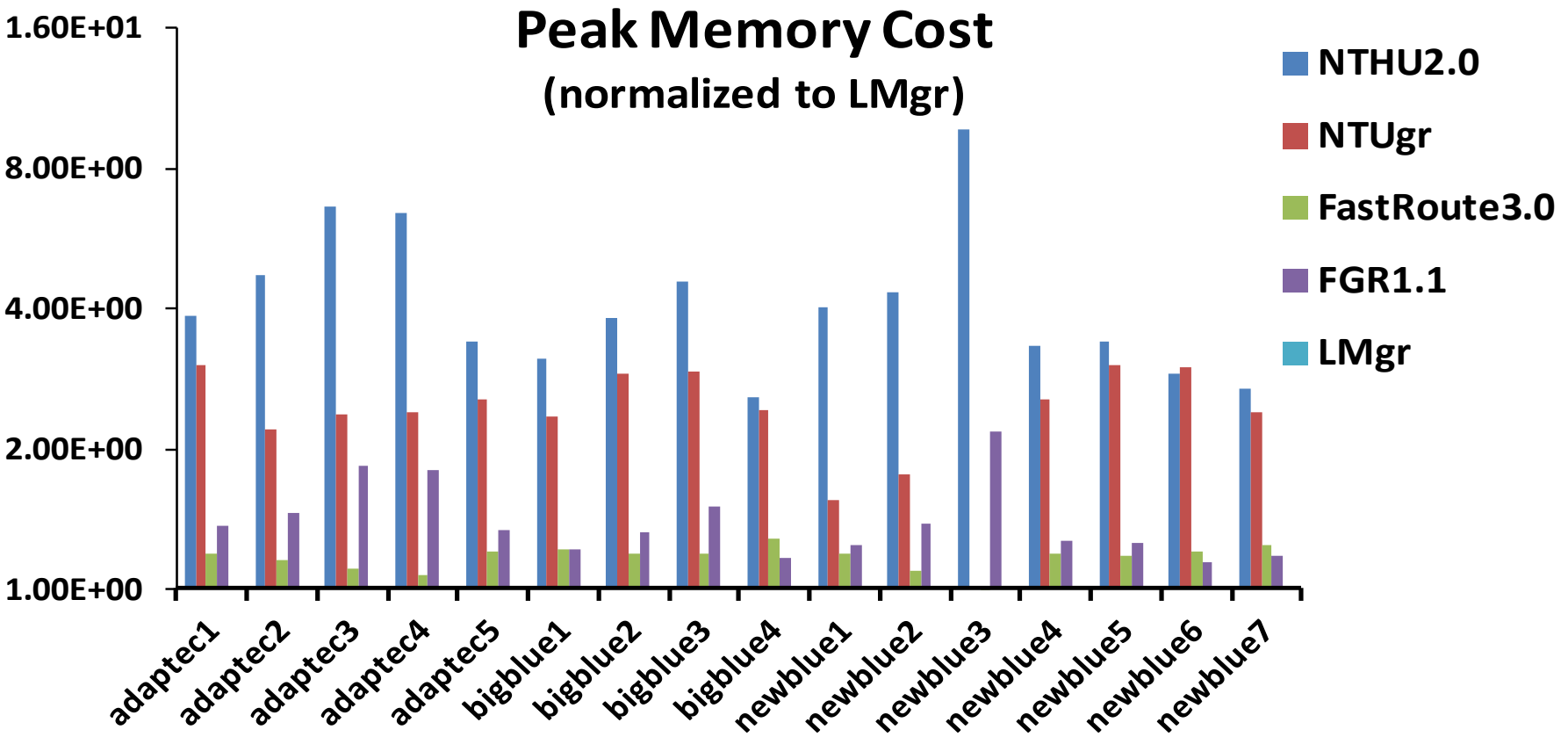
- ISPD08 GR benchmark suite [ISPD08]
  - Official evaluation script

- Four sensitivity-driven routers
  - NTHU2.0 [Chang08] NTUgr [Chen09] FastRoute3.0 [Zhang08] and FGR1.1 [Roy07]
    - Winners of ISPD 07-08 contests [ISPD08]
  - Same IRR structure as LMgr
  - Other routers [Xu11, Hu10] are not included due to their incompatibility to our techniques

Routing Solution Quality



Peak Memory Cost



Conclusion

- Three new techniques
  - Low-memory global routing
  - Dynamic RSMT update
  - Bending-aware optimum routing
- Integration in LMgr
  - Performance validation through experiments
- Future work
  - Parallel routing [Liu10]
  - Three-dimensional routing [Chen09]

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Questions?

THANK YOU!