VFGR: A Very Fast Parallel Global Router with Accurate Congestion Modeling

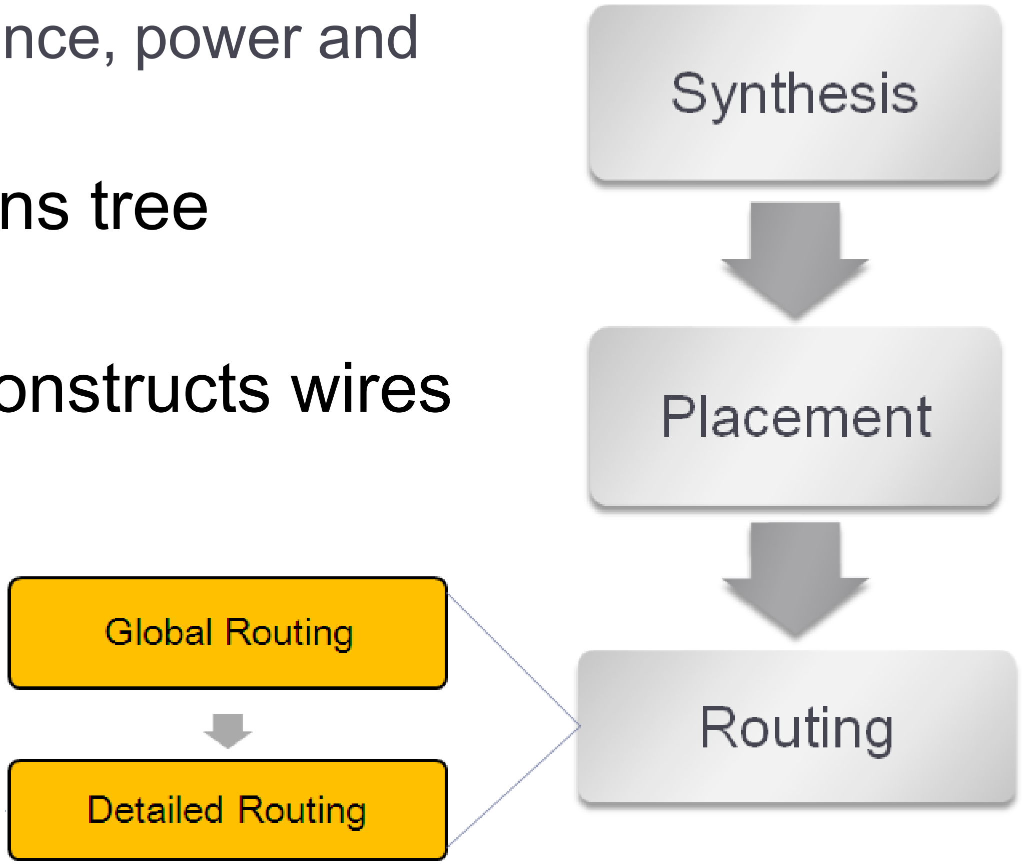
Zhongdong Qi [1], Yici Cai [1], Qiang Zhou [1],
Zhuoyuan Li [2] and Mike Chen [2]
[1] Tsinghua University, Beijing, China
[2] Nimbus Automation Technologies, Shanghai, China

Outline

- Background and Motivation
- Proposed Congestion Model
- Parallel Global Routing
- Experimental Results
- Conclusions

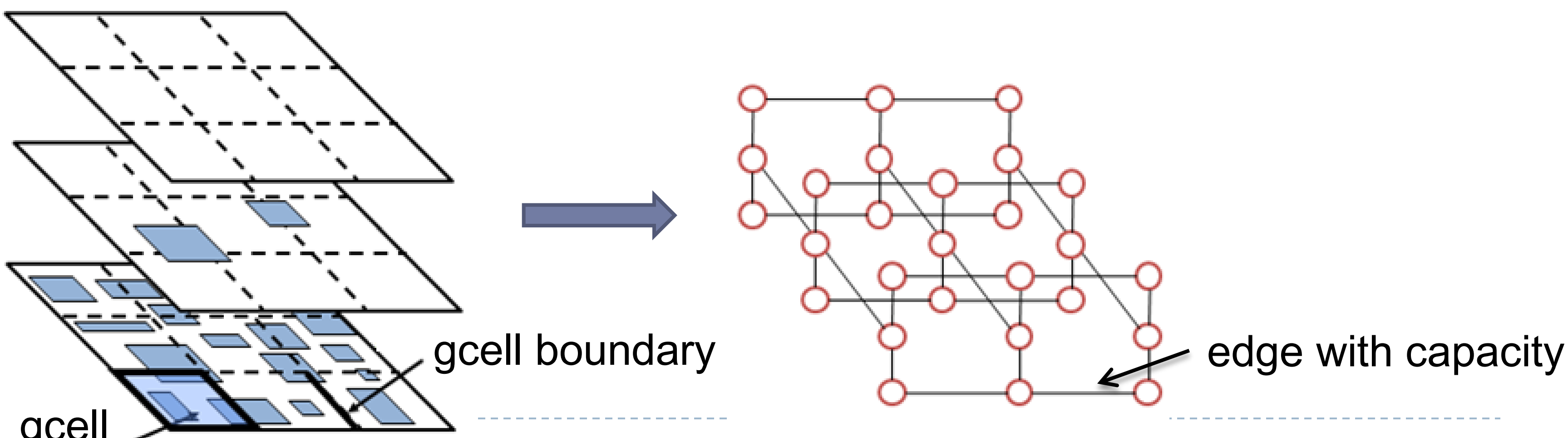
Global Routing in Design Flow

- Routing: complex and important
  - Determines geometry and location of interconnect features under several constr.
  - Largely affects performance, power and yield.
- Global routing (GR) plans tree topologies.
- Detailed routing (DR) constructs wires and vias.



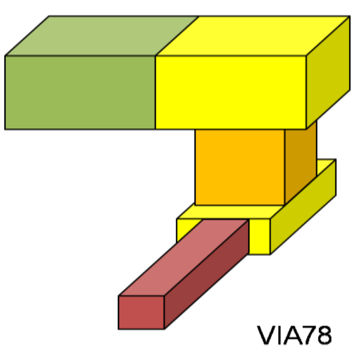
GR Formulation and Research Status

- GR Formulation
  - Input: routing graph, a set of nets
  - Output: routing trees for nets
  - Objectives: congestion, wirelength, via count, etc.
- Long research history, great progress recently
  - High performance and quality routers
    - FGR, BoxRouter 2.0, NTHU-Route 2.0, GRIP, NCTU-GR 2.0 …



Challenges for Global Routing

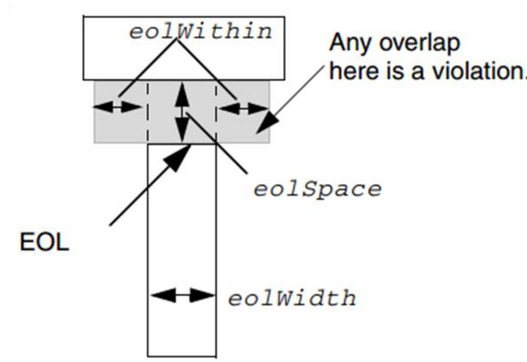
- Technology nodes get smaller
  - More metal layers, e.g. 6(90nm)→9(65nm)→12(45nm)…
  - Varying metal widths
    - Fat vias, more stacked vias
  - More design rules
    - More resource consumption by global and local connections
- Larger design size and problem complexity
  - Increased chip dimension and nets, 3-D problem



Fat via

65nm layer stack

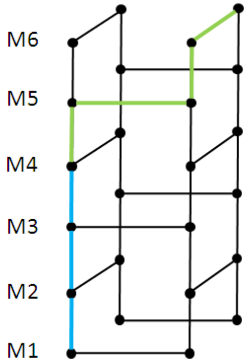
AREA *minArea*



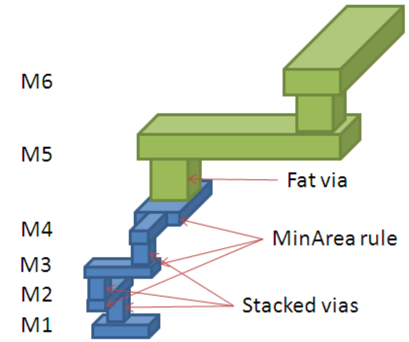
ENDOFLINE *eolWidth* WITHIN *eolWithin*

Facing the Challenges

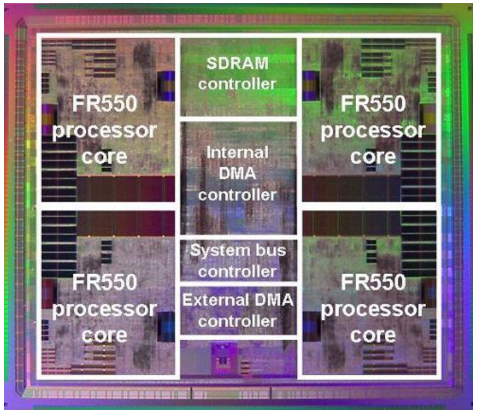
- An practical congestion model
  - Captures the local congestion by vias & local connections
  - Explicitly models most influential design rules
- A multi-threaded global routing algorithm
  - A global routing framework easier to be parallelized
  - Region level parallelism and net level parallelism



A net path in global routing graph



Detailed routing path of this net

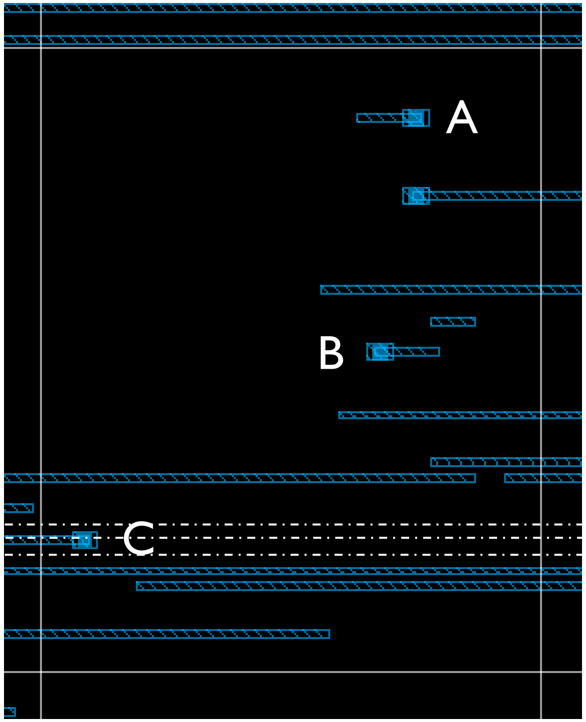


Outline

- Motivation and Background
- Proposed Congestion Model
- Parallel Global Routing
- Experimental Results
- Conclusion

Real Congestion in Sub-65*nm* Technologies

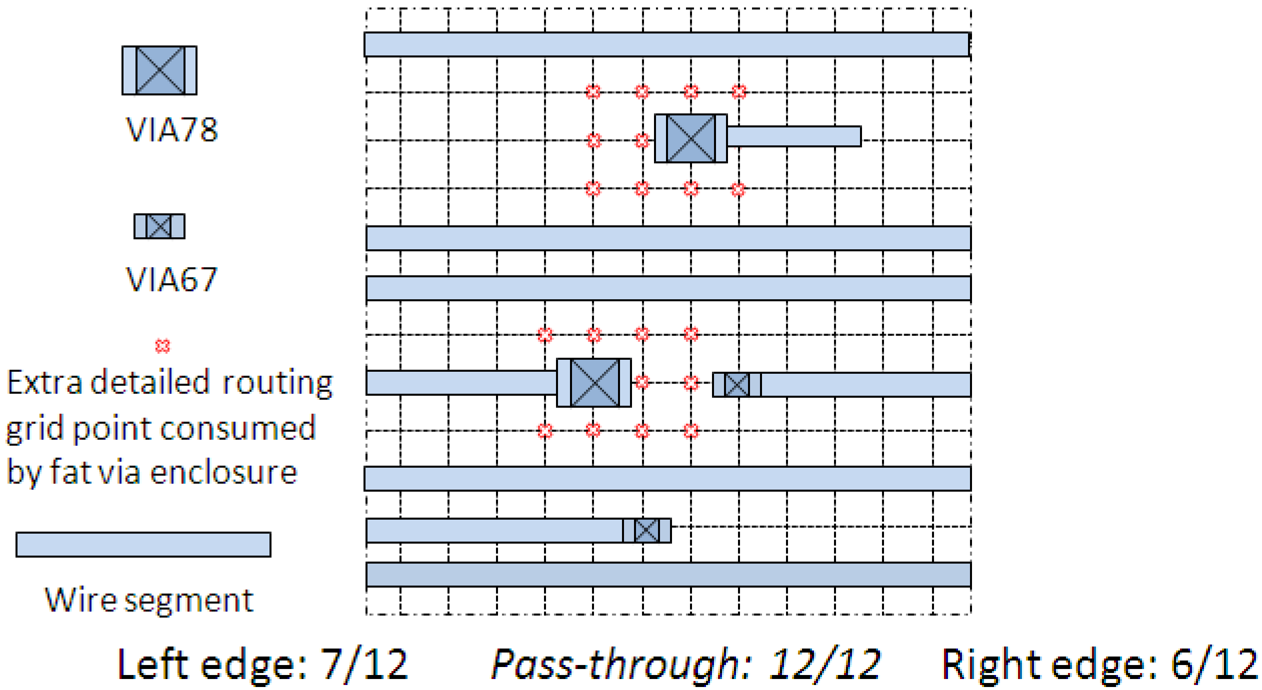
M2



M5

- Not measured in conventional congestion model
- Make a big gap between global routing and detailed routing

Proposed Concept: Pass-through Capacity and Demand



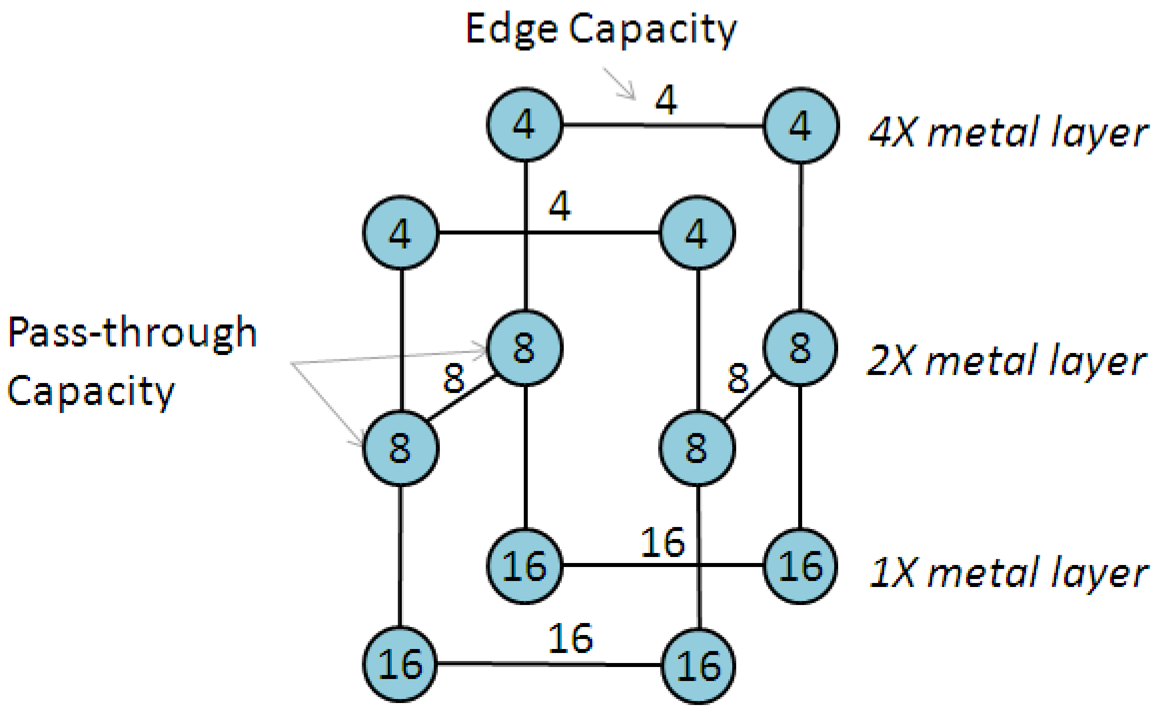
Use pass-through capacity/demand to model intra-gcell congestion

Proposed Model: Pass-through Capacity and Demand (cont'd)

- Capacity: available tracks and partial tracks
- Demand contributors
  - Fat via enclosure and stacked via enclosure
    - Affected by MinArea, EOL-Spacing and normal spacing
  - Local net connection
    - Net connection tree: RSMT generated by FLUTE
    - Affected by MinArea and EOL-Spacing
  - Global net segments

Feature	Demand
Fat via enclosure	3
Stacked via enclosure or local net connection	(minArea/width+2*eolSpace)/gcellWidth (if necessary)
Segment crossing gcell	1
Segments connecting to gcell	max $\{N_l, N_r\}$

Proposed Congestion Model in 3-D Routing Graph



Compatible with widely used path search algorithms in GR, e.g. pattern routing, maze routing, layer assignment etc.

Outline

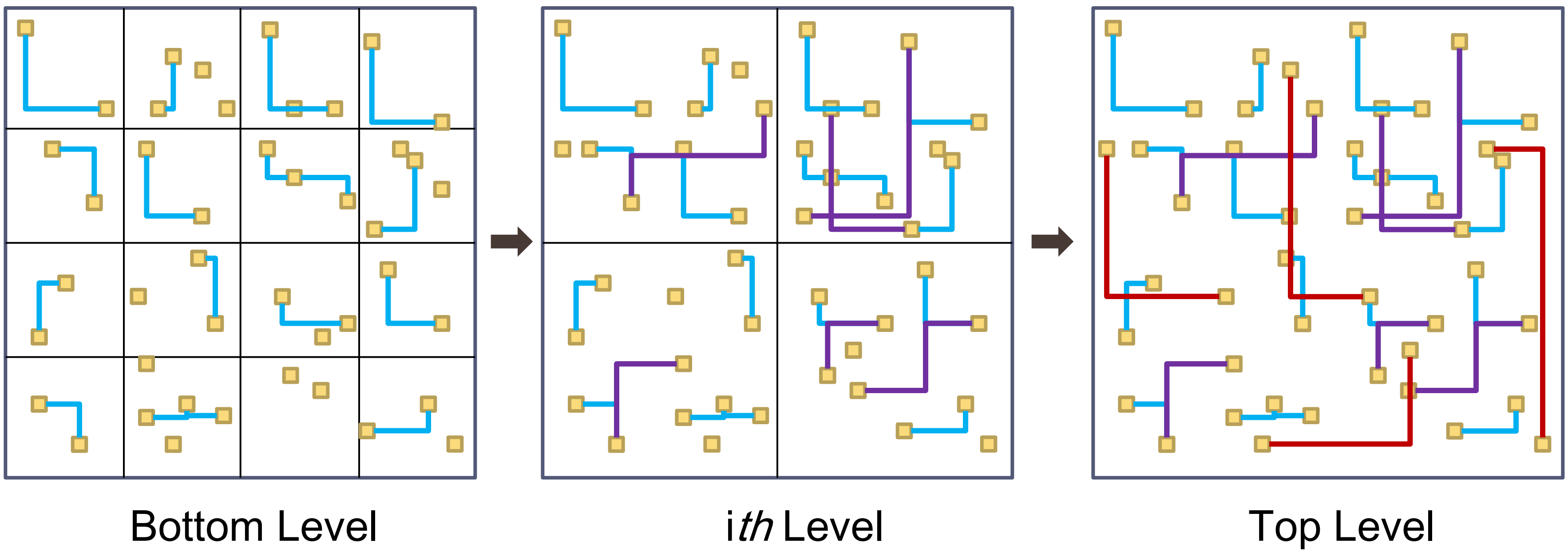
- Motivation and Background
- Proposed Congestion Model
- Parallel Global Routing
- Experimental Results
- Conclusion

Global Routing Framework

- Take negotiated-congestion routing as foundation.
  - Adopted most in state-of-the-art global routers.
- Observation
  - Smaller nets: in local region and lower layers
  - Larger nets: in larger scope and higher layers
  - Smaller nets has less flexibility, larger ones more
- Hierarchical global routing framework
  - From local region nets(lower level) to global region nets (higher level)
  - Progressively construct the routing solution using negotiated-congestion routing

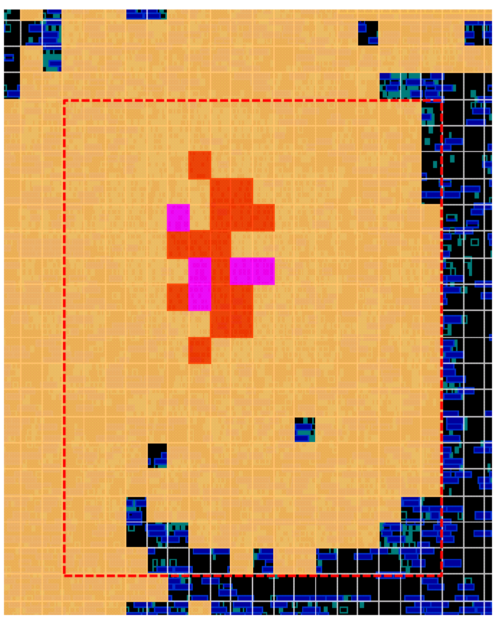
Global Routing Framework (cont.)

- Progressively construct the routing solution
  - Multiple hierarchies with different-size regions
  - From bottom level to top level
  - In each level, all the nets inside regions are routed using negotiated-congestion routing

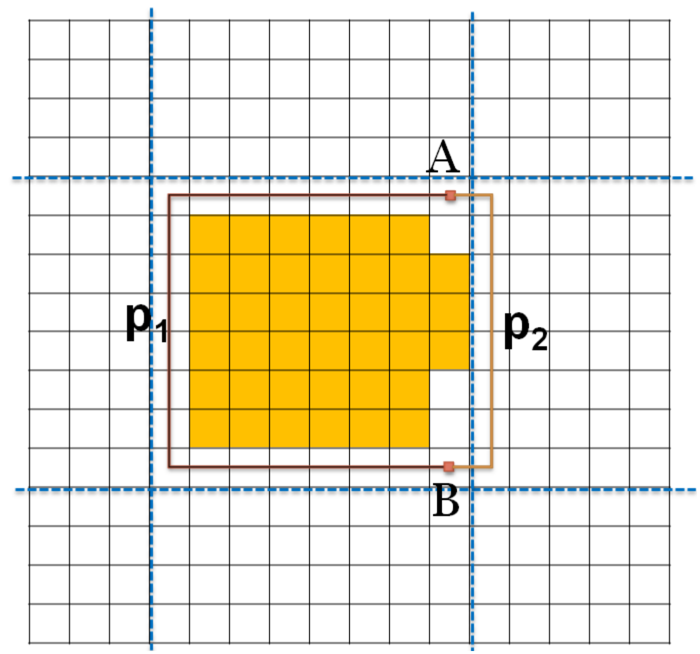


Issue to Handle

- Region restriction
  - No enough resources in some regions
  - Congestion and(or) detours
  - Solution: deferring congested nets and detoured nets to next level

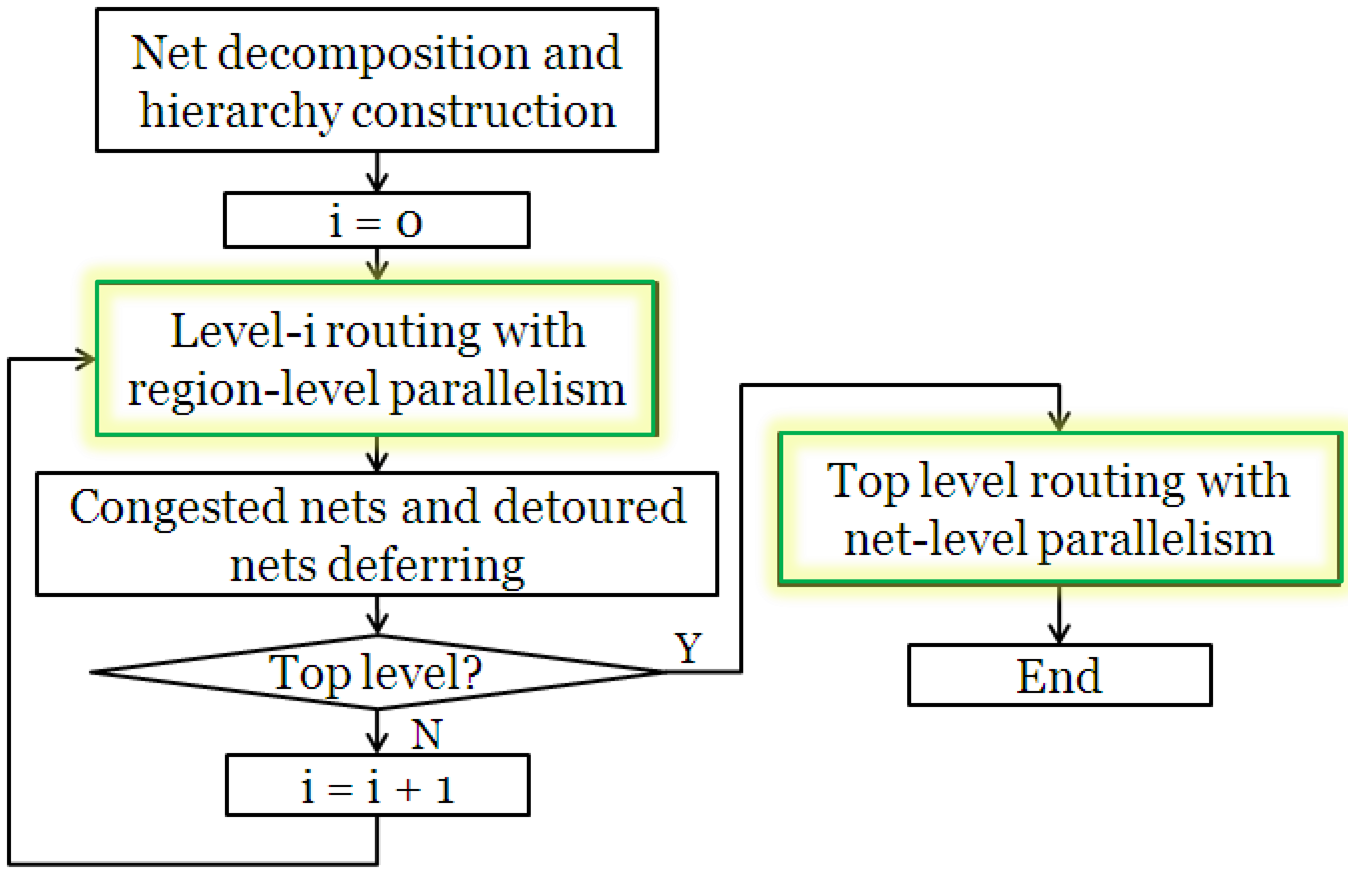


Congestion due to region restriction



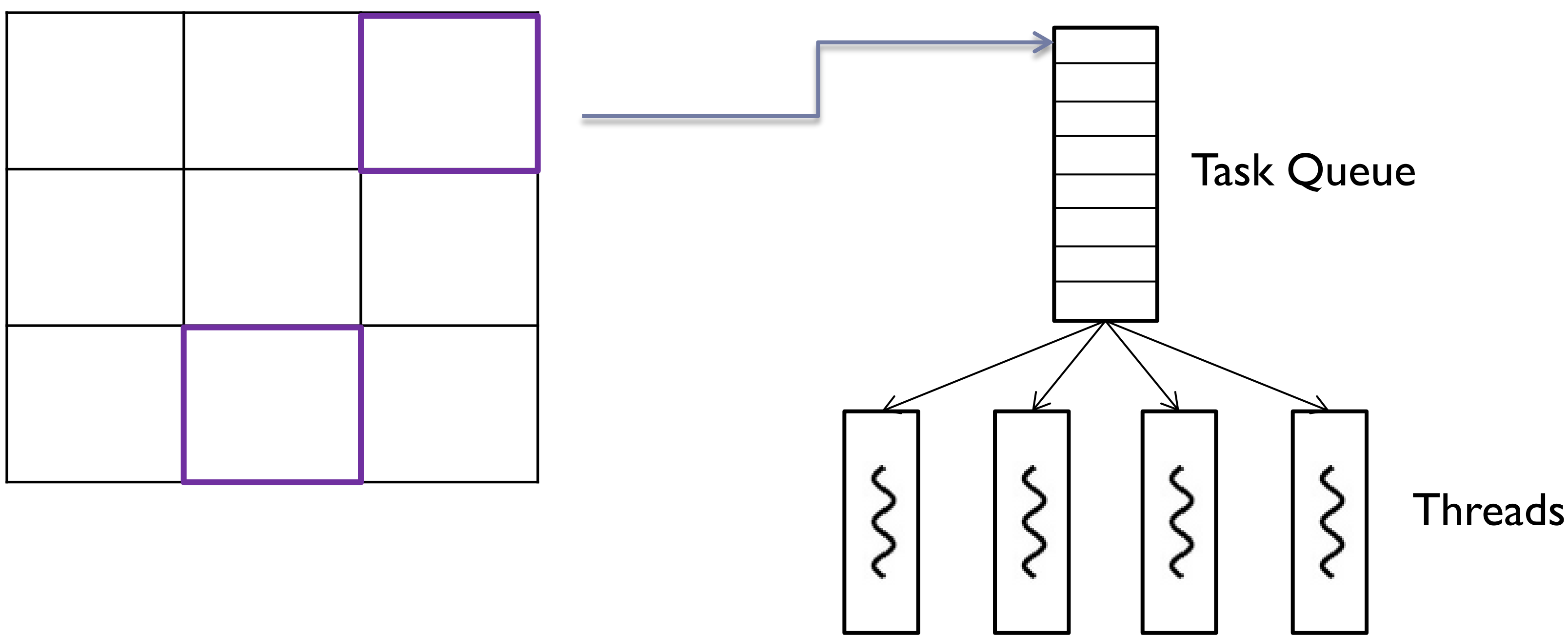
Detour due to region restriction

Global Routing Flow



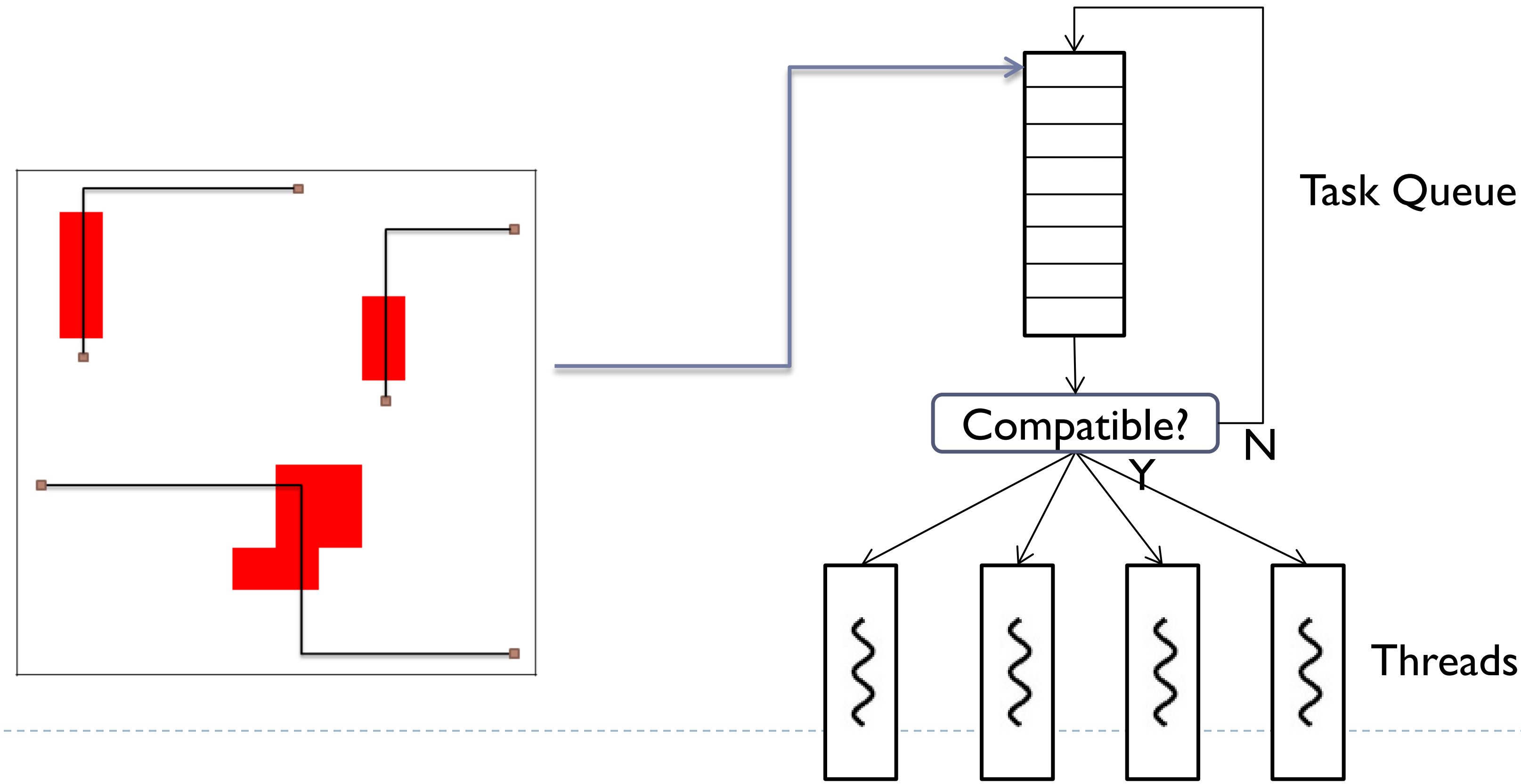
Region Level Parallelism

- In lower levels, routing nets in different regions are independent.
- Routing in each region is constructed as a task.



Net Level Parallelism

- In top level, routing each net is regarded as a task.
- Dynamically select nets; bounded box A* search;
- Compatibility: path search bbox overlap-free.



Experimental Setup

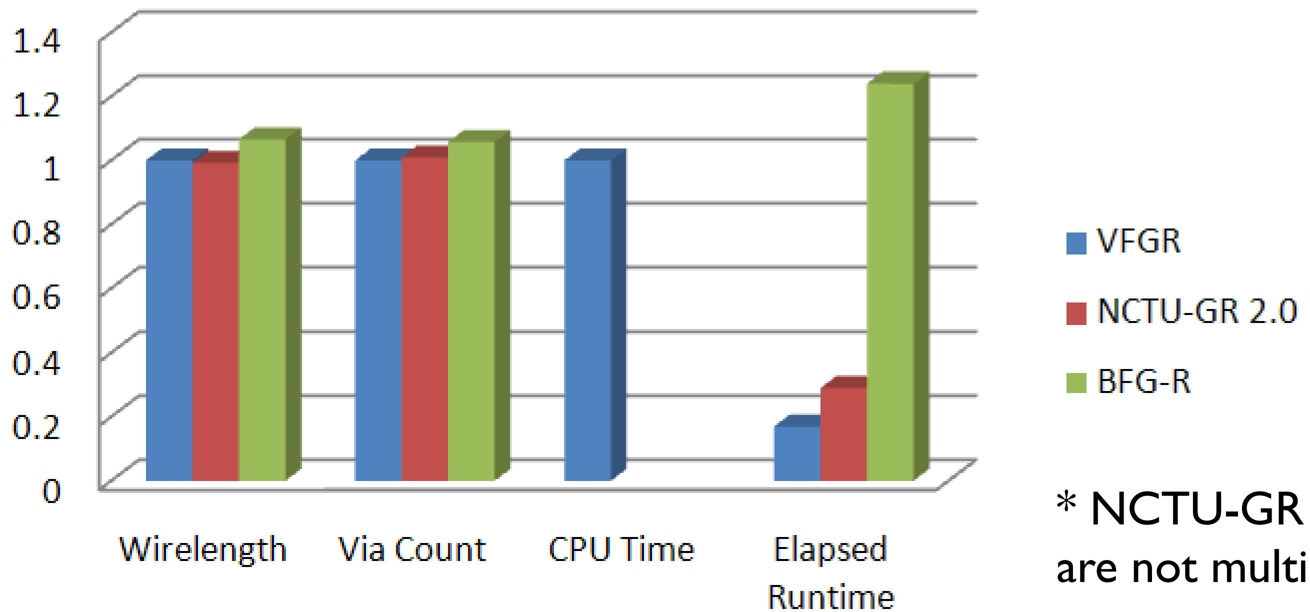
- Benchmarks: DAC 2012 Benchmark Suite
  - 1X for M1-M4, 2X for M5-M7, 4X for M8-M9
  - Added 65nm design rules
- Machine: Intel 8-core 2.40GHz CPU & 24GB memory

	#Net	#Layer	Grid	#G-Net	Grid	#G-Net
superblue2	990899	9	770 x 891	698751	2738 x 3960	910675
superblue3	898001	9	800 x 415	554046	2845 x 1845	796005
superblue6	1006629	9	649 x 495	643532	2308 x 2200	912526
superblue7	1340418	9	499 x 713	899583	1775 x 3169	1236238
superblue9	833808	9	625 x 570	528664	1515 x 2534	771628
superblue11	935731	9	631 x 878	678379	2244 x 3903	879756
superblue12	1293436	9	444 x 518	919016	1579 x 2303	1213706
superblue14	619815	9	406 x 473	433978	1444 x 2103	579239
superblue19	511685	9	321 x 518	339259	1142 x 2303	470070

DAC 2012 Benchmarks — Fine-gcell Settings

Experimental Results (1)

- GR performance and solution quality
  - Benchmark: DAC 2012 benchmark suite
  - Compared with: NCTU-GR 2.0 and BFG-R



* NCTU-GR 2.0 and BFG-R are not multi-threaded.

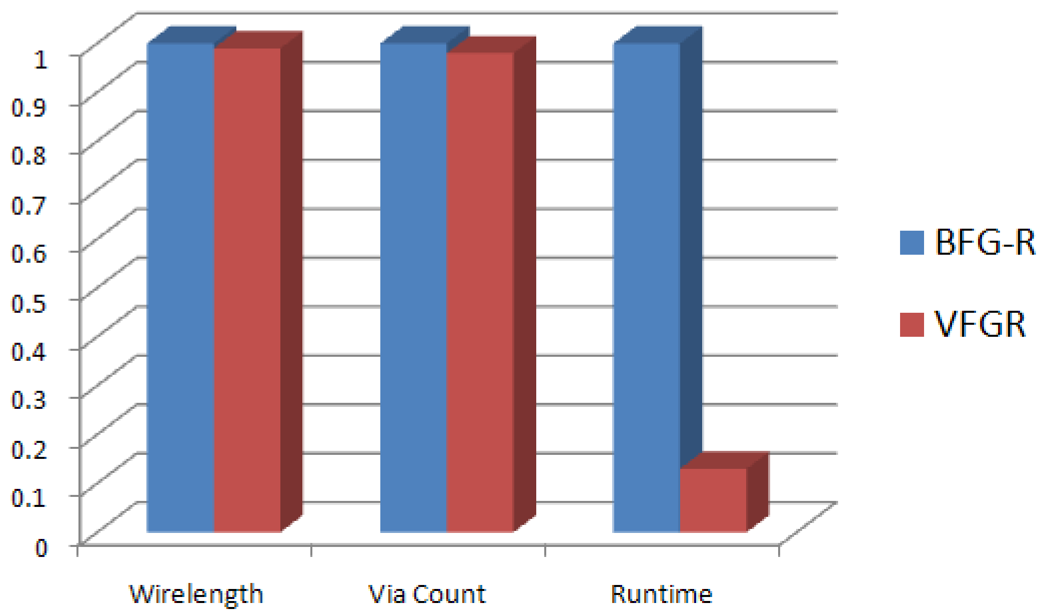
Three routers all eliminate overflow for all testcases.

Comparable or better wirelength and via count

About 6X speed up for parallelization

Experimental Results (2)

- Effectiveness of proposed congestion model
  - **GR** by BFG-R / VFGR + **DR** by a commercial drouter
  - Benchmark: fine-gcell DAC 2012 benchmark suite
  - Global routing results:

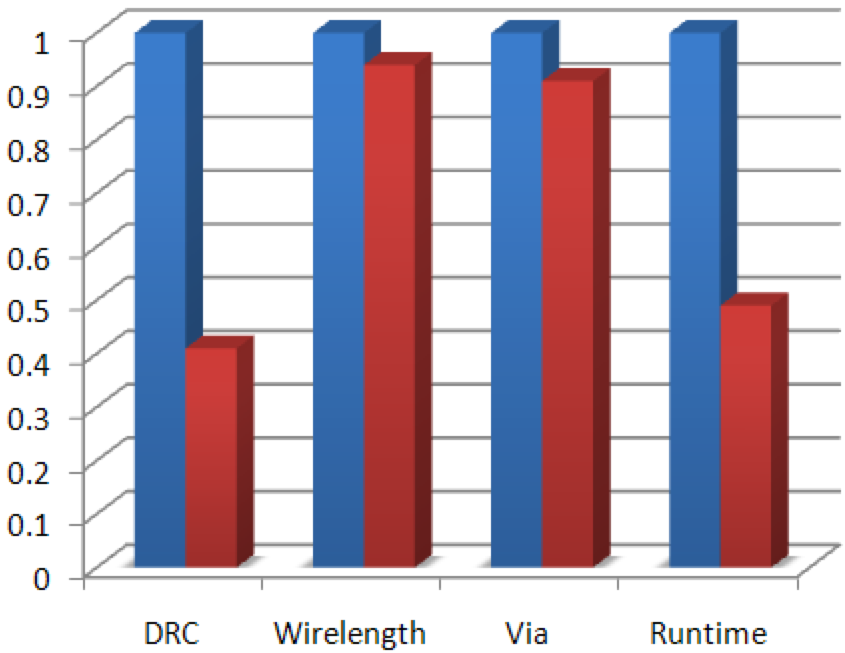


Testcase	BFG-R edge overflow OF	VFGR edge & pass-through overflow OF
superblue2	0	2056
superblue3	0	2408
superblue6	0	1516
superblue7	0	994
superblue9	0	330
superblue11	0	4708
superblue12	0	1302
superblue14	0	10716
superblue19	0	9407

Performance on designs with large routing grid:
Parallelized router is 8 times faster than BFG-R

Experimental Results (3)

- Effectiveness of proposed congestion model
  - GR by BFG-R / VFGR + DR by a commercial drouter
  - Benchmark: fine-gcell DAC 2012 benchmark suite
  - Detailed routing results:



- 59% fewer design rule violations
- 6% shorter DR wirelength
- 9% fewer DR via count
- 51% shorter DR runtime

Captures DR congestion
Guides detailed router better

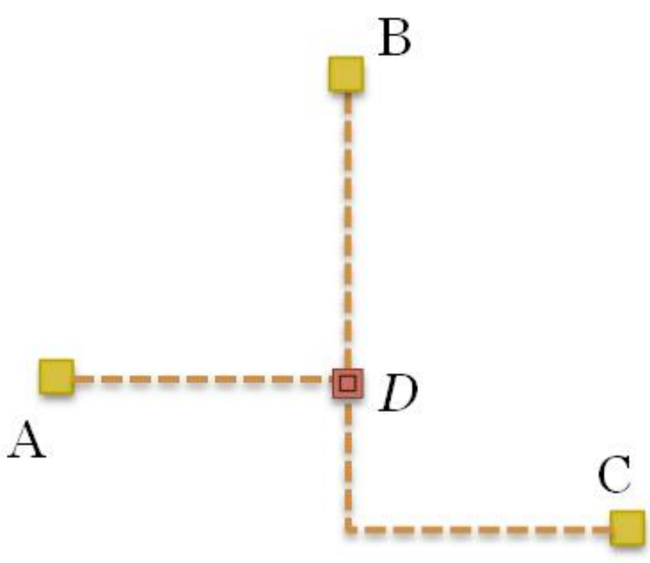
Conclusion

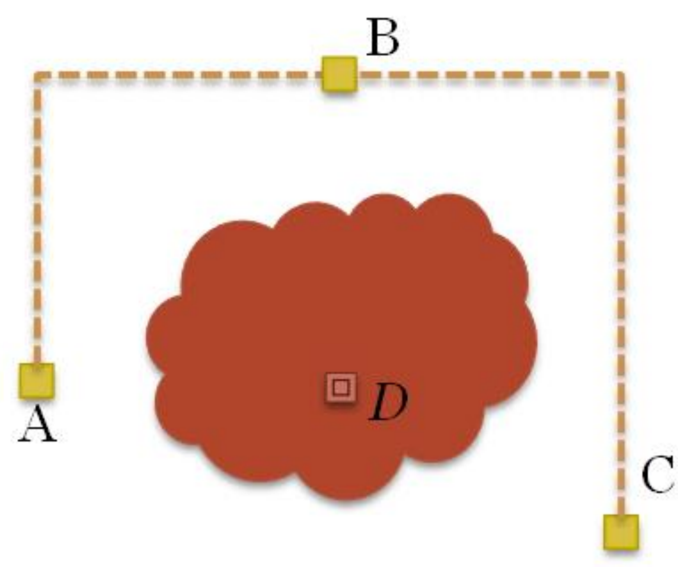
- Proposed pass-through capacity and demand to model intra-gcell congestion, better correlated to DR resource consumption.
- Considering DR effects in GR leads to much shorter DR runtime and better DR results.
- Hierarchical global routing framework, which enables easier parallelization.
- Achieved comparable GR solution quality with NCTU-GR 2.0 and BFG-R, and near 6X speedup for parallelization.

Thank you!

Net Decomposition

- Use both RSMT and RMST
  - MST edges as sub-nets; small cost for Steiner nodes.
  - Flexibility of path search; short wirelength
  - Refer sub-net as “net” in the following pages.





Nets in different levels

- Order of different levels
  - Lower level nets are routed ahead of higher level nets
  - Higher level nets may have less flexibility
  - Solution: all the nets inside the current region can be rerouted using negotiated-congestion routing