Constraint-Driven Floorplan Repair

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Outline of Talk

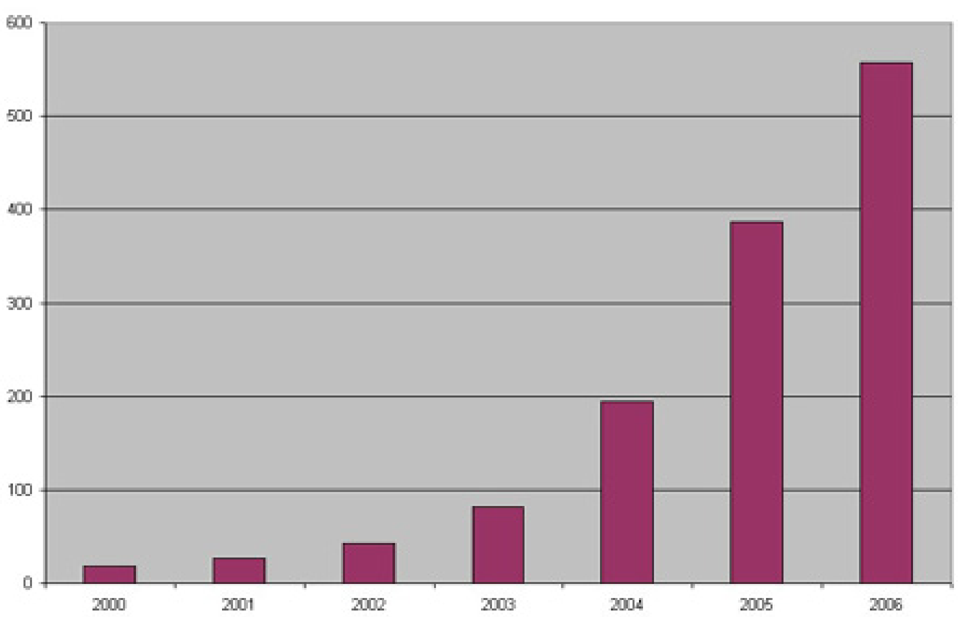
- Legalization: Motivation and Previous Work
  - Correct-by-construction approaches
  - Post-placement legalization
- The FLOORIST ("Floorplan Assistant") Algorithm
  - Step 1: Creation of constraint graphs
  - Step 2: Conflict-Directed Iterative Repair
  - Step 3: Translation to Fixed-placement via Emulation
- Experimental Setup and Results
- Conclusion and Future Work

Why floorplanning?

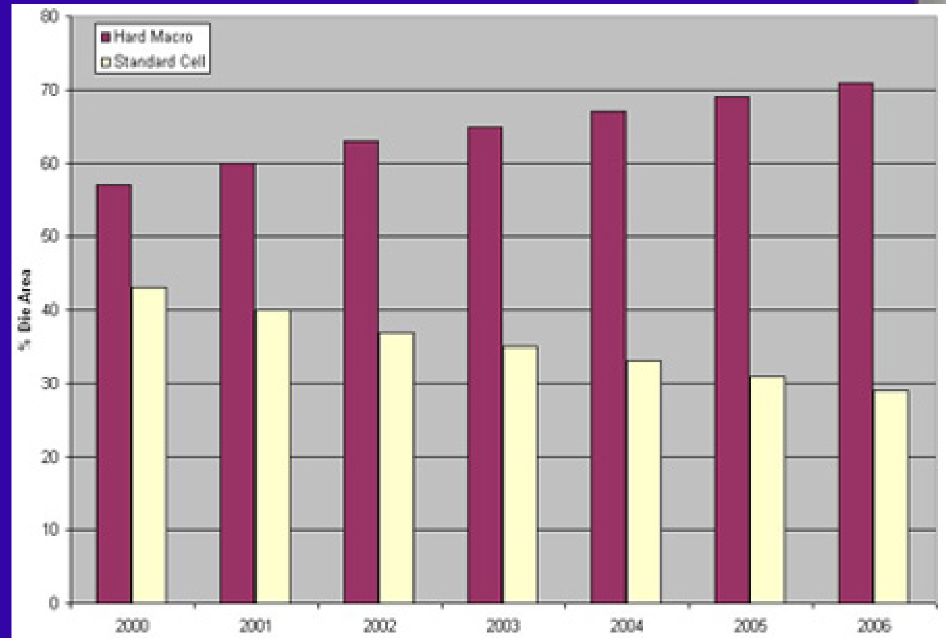
"Hard macros will revolutionize SoC design"

Enno Wein & Jacques Benkoski, *EEDesign*, Aug 20, 2004

- Hundreds of predesigned macros
  - Embedded memories, analog circuitry, IP blocks
- **Macro placement is usually separate from standard cell placement** (done once & never repeated)



Growth in the number of hard macros in SoC designs

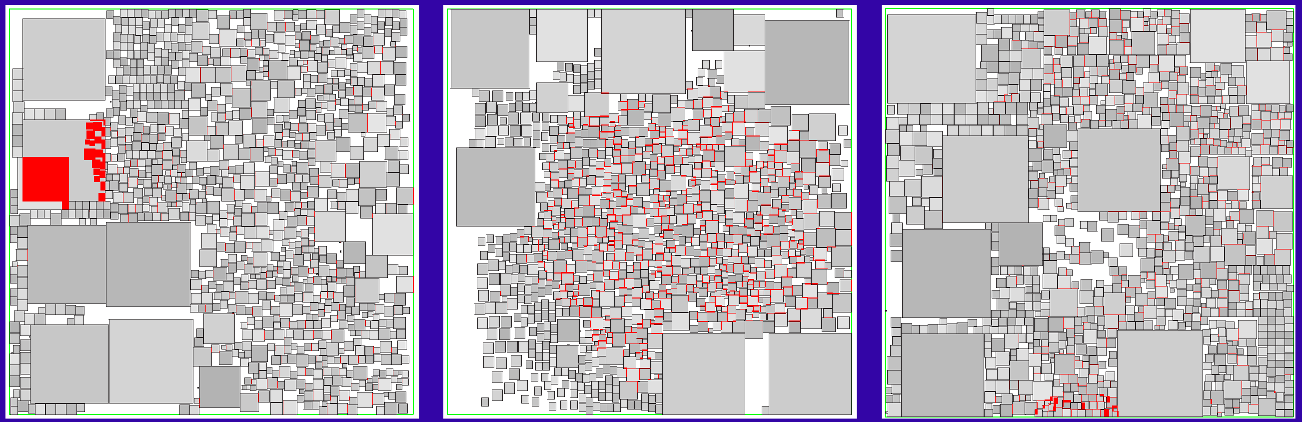


Hard macros vs. standard cell area

Why floorplan *legalization*?

- Reason #1: Existing packages fail to produce legal floorplans

Solutions to IBM-HB 09:



Feng Shui 5.1 [Khatkhate et al., 2004] | APlace 2.0 [Kahng et al., 2005] | Capo 9.4 [Roy et al., 2005]

- Reason #2: Legal floorplans susceptible to change
  - Resizing of blocks
  - Dynamically acquired design constraints
  - Minor adjustments from chip architect

Correct-by-Construction Approaches

- Guarantee (or at least attempt) legalization at each step in search
- mPG [Chang et al., 2003]
  - Enforces legalization at every level of a cluster hierarchy
- Capo 9 [Adya et al. 2004, Roy et al., 2006]
  - Performs legalization of subproblems resulting from min-cut placement
  - Legalization failures propagate upwards
- PolarBear [Cong et al., 2005]
  - “Pre-legalization”: all subproblems are ensured to be legal
  - Uses a simple row-based block packing scheme

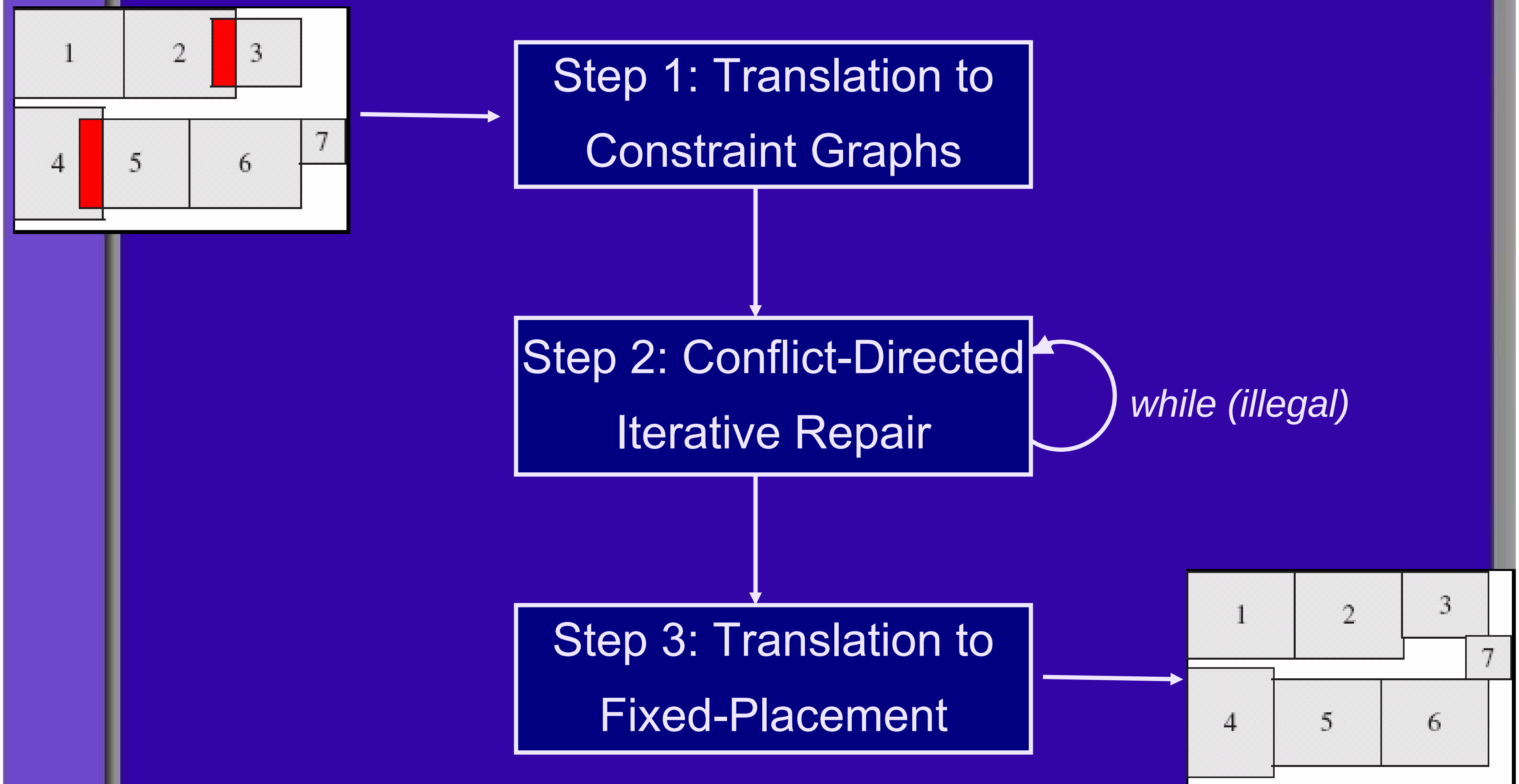
Legalization by Post-processing

- Feng Shui [Khatkhate et al., 2004] and APlace [Kahng et al., 2004]
  - Postpone legalization until global solution obtained
  - Use greedy Tetris-like algorithm [Hill, 2002] to pack cells
- Other works in cell-placement
  - Network flows formulation [Brenner et al., 2004]
  - Diffusion-based approach [Ren et al., 2005]
  - Do not generally extend to macros
- Limited work in floorplanning using sequence pairs [Nag et al, 1999] and traditional constraint-graphs [Cong et al., 2006]
  - Remove all overlaps initially
  - Iteratively "squeeze" floorplan into enclosing space
  - Do not encode violations or extend to other constraints

FLOORIST ("Floorplan Assistant")

- Begins with a coarse, global floorplan
  - May have been produced by a chip architect
  - May have been produced by a global floorplanner
- Constructs a pair of constraint graphs, except…
  - Violated non-overlap constraints are *explicitly encoded*
  - Does *not* correspond to a feasible layout
- Performs a greedy, conflict-directed iterative repair
  - Uses constraint graphs to determine possible pairwise relationships between overlapping modules
  - Extracts explanations for overlaps, removing culprits
- Translates layout back to fixed-placement floorplan
  - Attempts to emulate initial layout as closely as possible

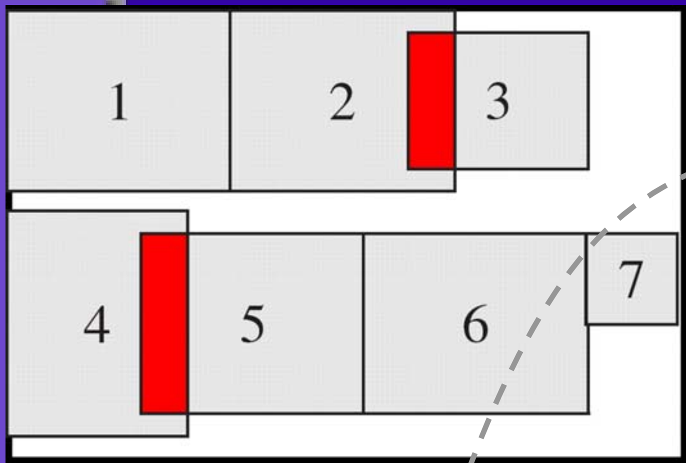
FLOORIST (“Floorplan Assistant”)



Step 1: Translate to Constraint Graphs

- [Liao and Wong, 1983] Horizontal and vertical constraint graphs (G_H and G_V) containing:
  - A node *i* for each module M_i
  - An directed, weighted edge $E_{i,j}$ between pairs of nodes (direction depending on the pairwise relationship of modules M_i and M_j)
- Over past decade, phased out in favor of:
  - Sequence pairs [Murata, 1995]
  - O-Trees [Pang et al., 2000]
  - Many others; see [Yao et al., 2003]
- Some advantages of the graph representation:
  - Recently shown to be extremely efficient for (optimal) area-minimization [Moffitt & Pollack, ICAPS 2006]
  - Can express a wide variety of constraint types [Young et al., 2002]
  - (With some work) it can encode an *infeasible* layout

Step 1: Translate to Constraint Graphs



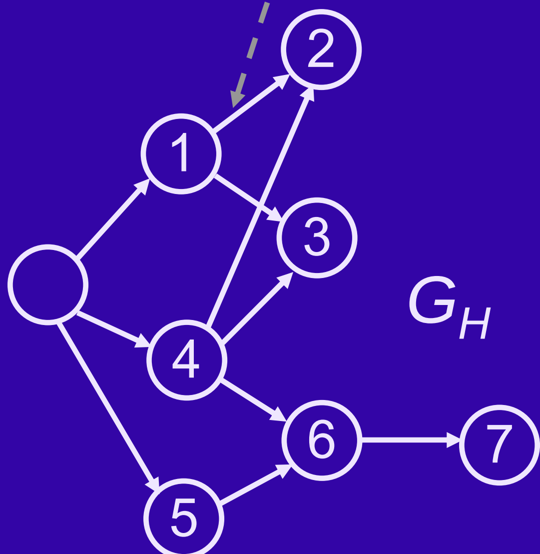
Relational view:

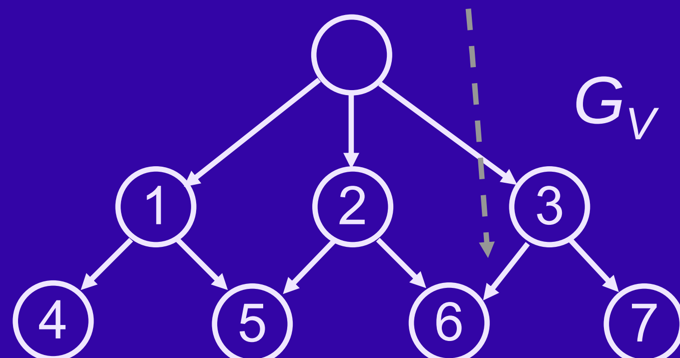
L(1, 2) … "1 to the left of 2"

A(3, 6) … "3 is above 6"

Blocks that overlap?

no edge
E(4, 5) … *empty relationship*
E(2, 3) … *empty relationship*

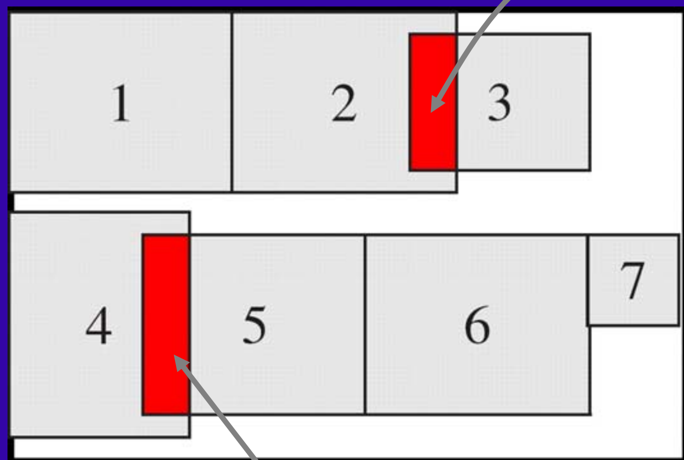


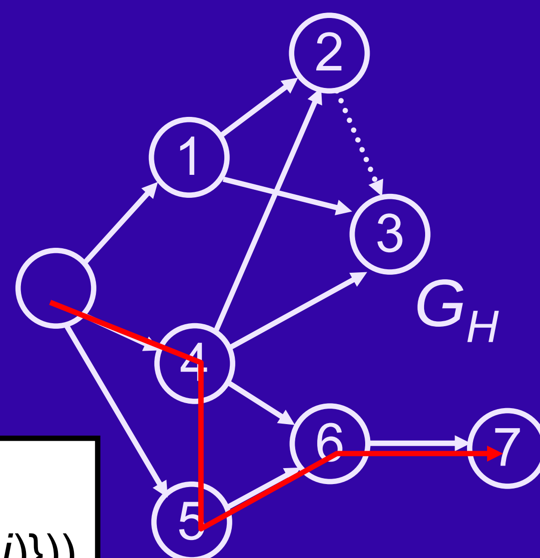


Step 2: Conflict-Directed Iterative Repair

- First Phase: Remove "trivial" overlaps

Can be resolved by sliding Block 3 to the right!





Doesn't work for $E(4,5)$

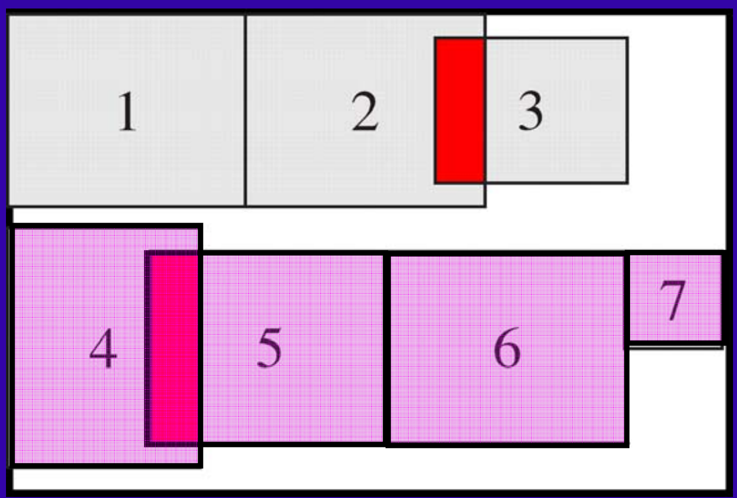
For every $E(i,j) \in S$

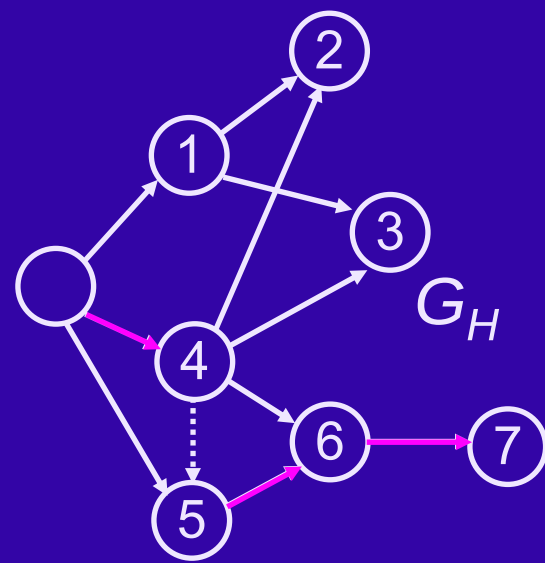
If (exists $P(i,j)$ such that **consistent**(S U {$P(i,j)$}))

$S = S \cup \{P(i,j)\} - \{E(i,j)\}$

Step 2: Conflict-Directed Iterative Repair

- Second Phase: Identify culprits and perform “safe” swaps



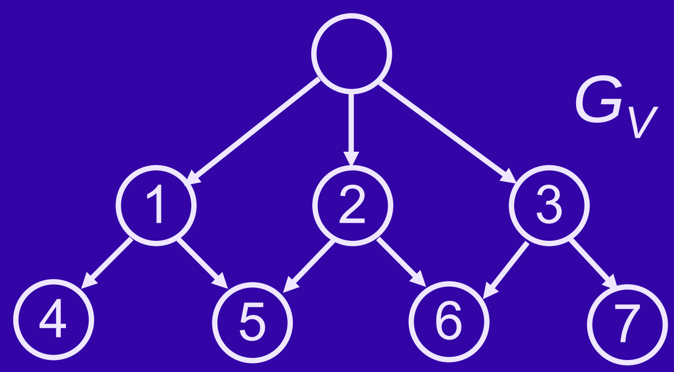


Identity blocks on critical paths

Check if slack available in alternate graph

If so, swap edge

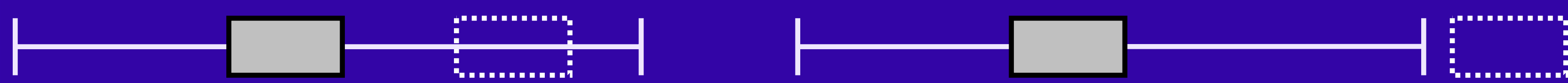
Repeat first phase



Step 3: Translation to Fixed-Placement

- **Goal**: <u>Emulate</u> the initial placement as closely as possible
- **Solution**: For each module (in descending order of size),

  - Can it be given its original *horizontal* coordinate?
    - If so, add additional edges to enforce this
    - If not, slide it as far left / right as slack allows

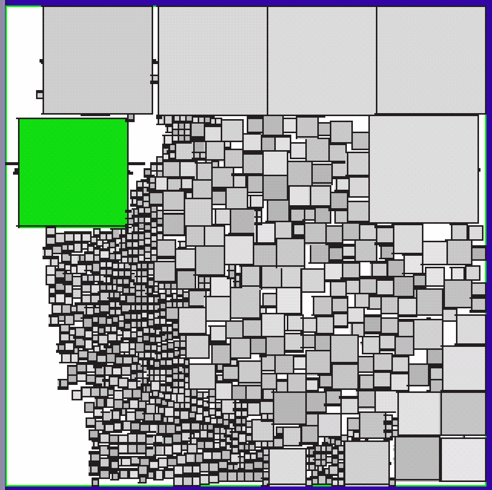


  - Can it be given its original *vertical* coordinate?
    - If so, add additional edges to enforce this
    - If not, slide it as far up / down as slack allows

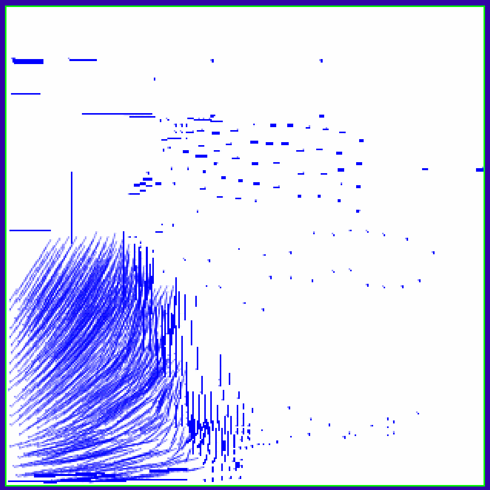
  - Propagate these adjustments through graphs

Repairing Other Constraint Types

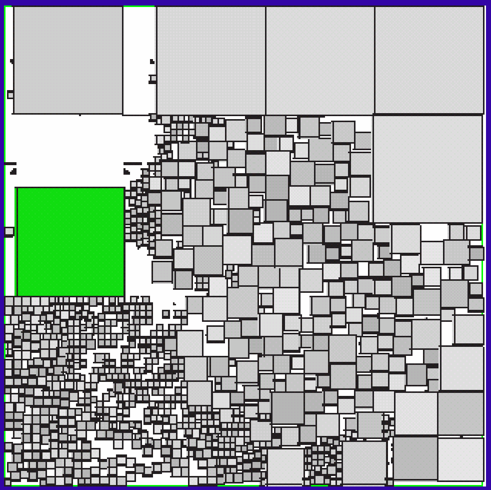
- Non-overlap constraints are just one type of violation
- The violation of any “edge-based constraint” can be repaired in the same manner!



Initial Placement



Module Movement



Final Placement

Experimental Setup

- IBM-HB Benchmarks [Cong et al., 2004]
  - 18 instances, between 550 and 1650 macros
  - No cells (pure floorplanning instances)
- Three global floorplanners
  - Capo 9.4 [Roy et al., 2005] (Note: recent Capo 10 is better)
  - Feng Shui 5.1 [Khatkhate et al., 2004] (only global placer)
  - APlace 2.01 [Kahng et al., 2005]
- Three legalization tools
  - Feng Shui 5.1's legalizer [Khatkhate et al., 2004]
  - Parquet 4.5 [Adya and Markov, 2003]
  - FLOORIST (our work)
- Measure % overlap, HPWL, legalization time

Experimental Results (Capo 9.4 layouts)

white-space 15%	Capo 9.4 Solution		
	ovlp (%)	HPWL (e+06)	time (sec.)
HB01	0.16	3.57	988
HB02	0.21	16.5	2659
HB03	0.07	17.1	2404
HB04	0.17	11.6	3404
HB05	0.24	14.6	757
HB06	0.13	9.32	462
HB07	0.16	17.8	577
HB08	0.12	22.6	1257
HB09	0.20	35.8	2684
HB10	0.26	72.9	5185
HB11	0.06	69.4	6479
HB12	0.03	93.1	4408
HB13	0.08	45.6	960
HB14	0.13	65.6	1329
HB15	0.09	98.1	5752
HB16	0.12	149.	3690
HB17	0.07	153.	2149
HB18	0.10	74.2	1390
Avg.	0.12	53.9	2585

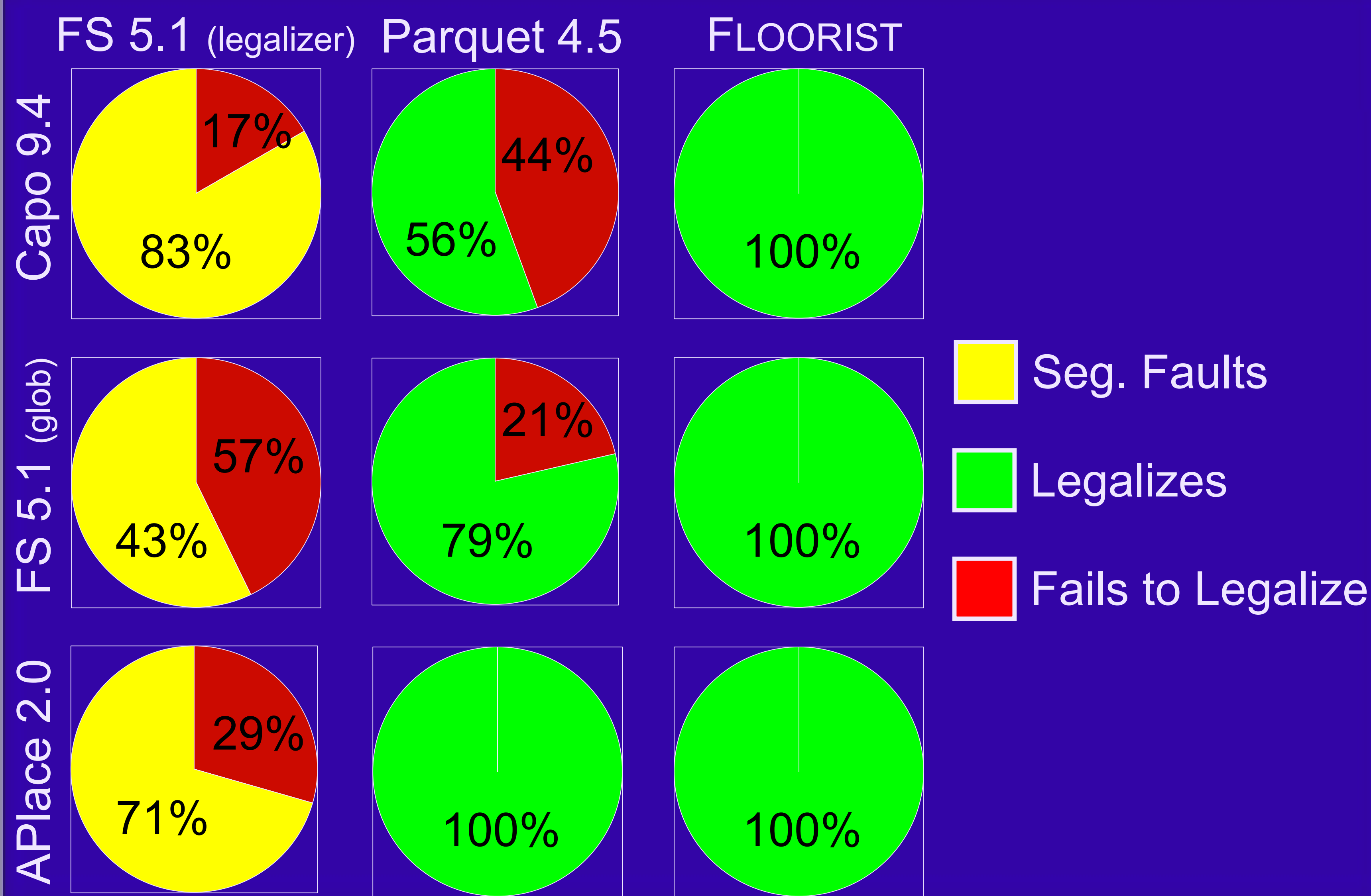
Very minor violations

All layouts legal

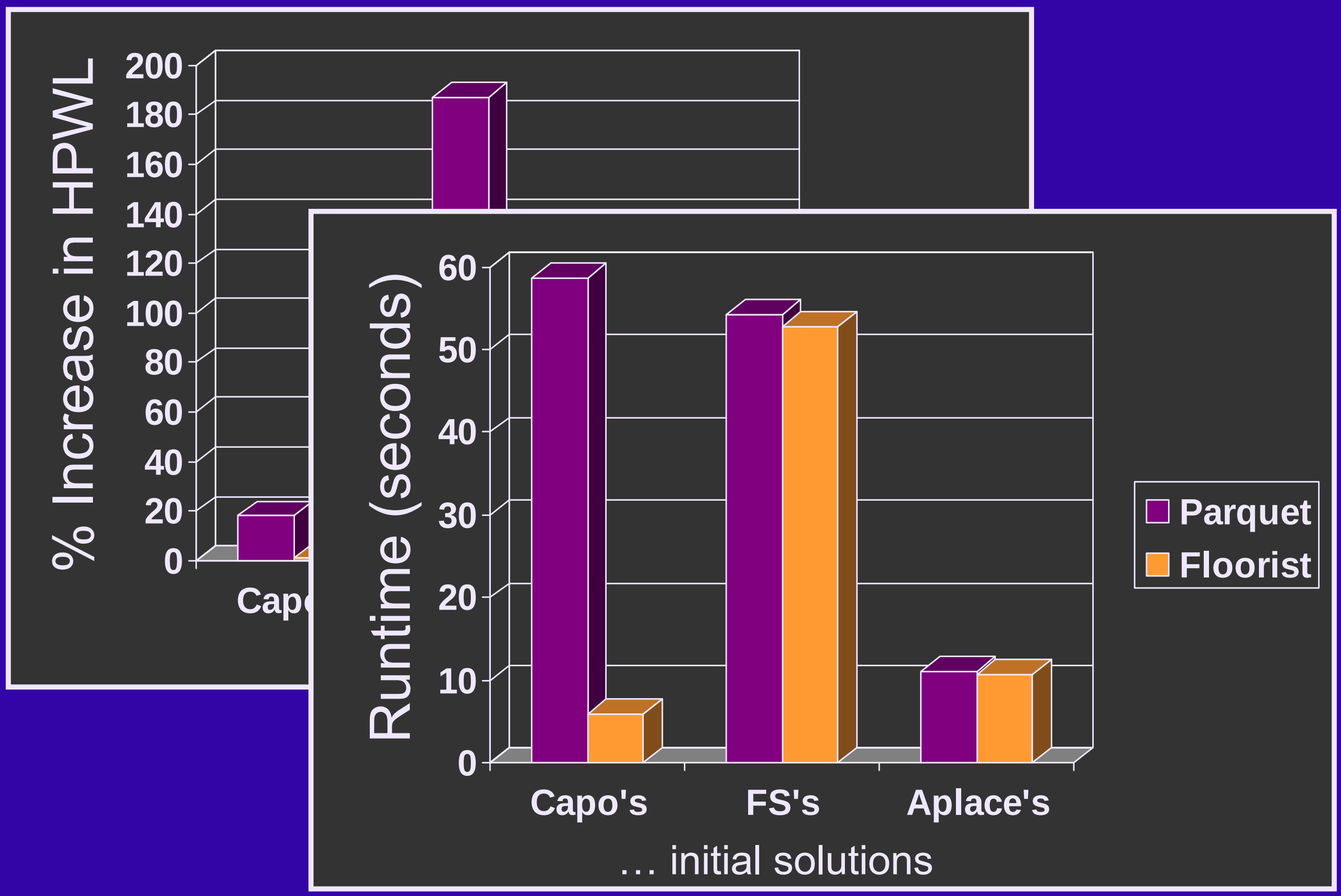
Negligible wirelength increase

Extremely fast

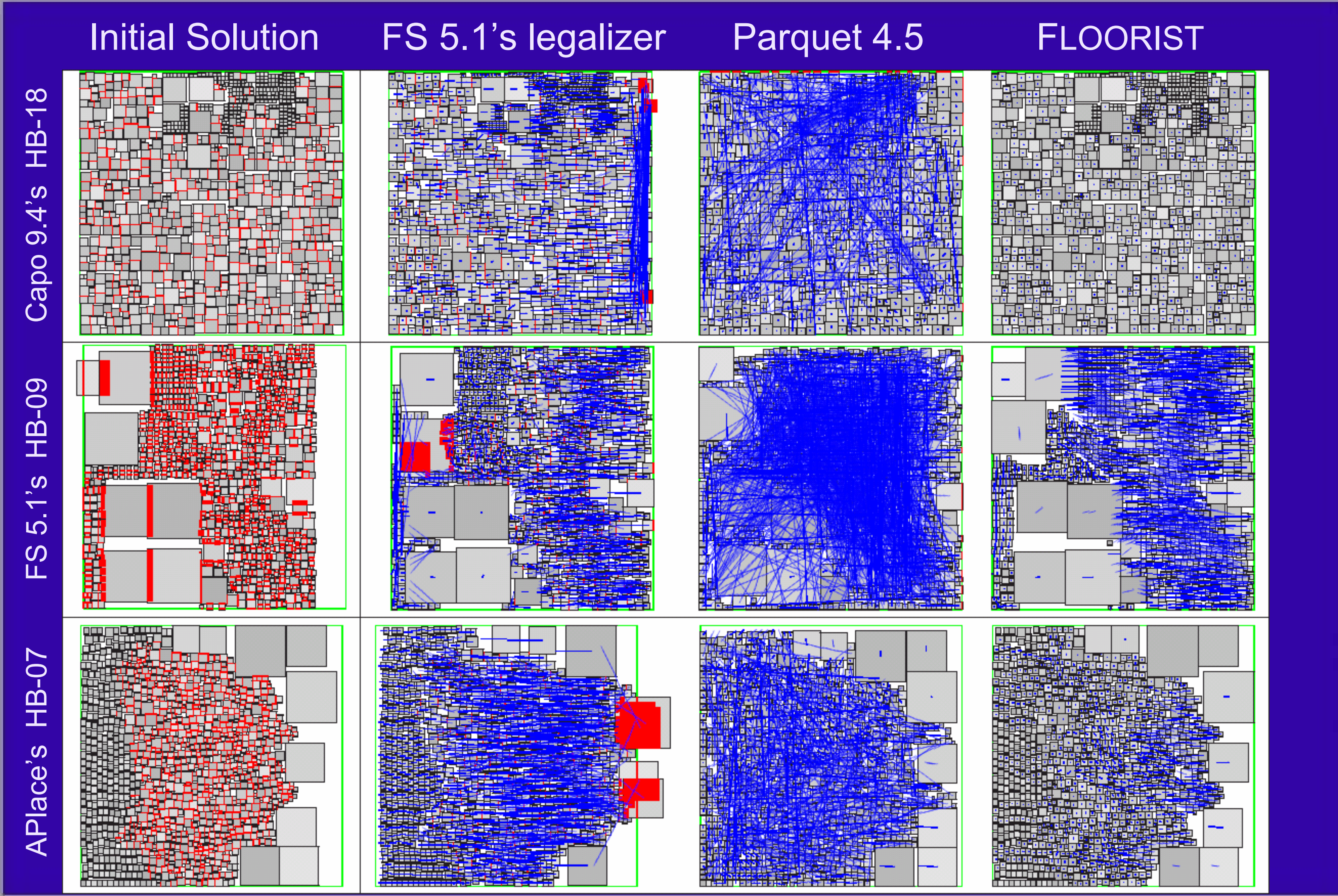
Experimental Results: Legalization Success



Experimental Results: Wirelength & Runtime



Experimental Results (Pictures)



Ongoing Work

- Heuristics for choosing swaps made during repair phase
  - Currently guided by amount of available slack
  - Could potentially identity most “common” culprits
- Replace emulation phase with explicit optimization
  - Employ an LP-formulation to minimize wirelength
- Create a tighter coupling between FLOORIST and global floorplanning system
  - Use as subroutine within placement algorithm
  - Communicate hierarchical cuts to improve speed of graph operations

Conclusion

- FLOORIST: a tool for legalizing layouts when
  - Global floorplanner fails to legalize
  - Layout undergoes dynamic changes
  - Chip architect sketches rough floorplans manually
- Performs iterative repair by:
  - Identifying conflicts responsible for violated constraints
  - Invoking gradual changes that preserve initial quality
- By postprocessing APlace layouts, generates floorplans 7% better in wirelength than best known solutions