Fixing Double Patterning Violations With Look-Ahead

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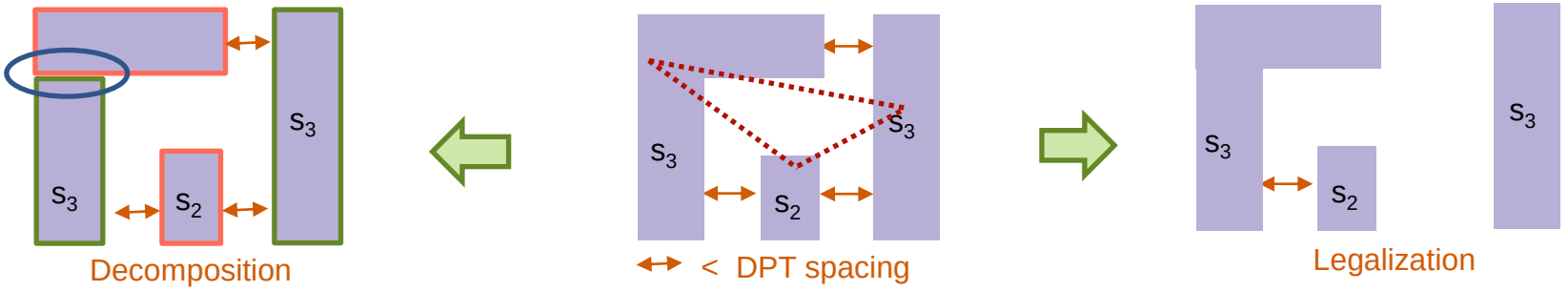
Introduction

Double Patterning Technology (DPT) must at 20nm and below

- Shapes assigned to two masks
- Shapes on same mask must have large separation

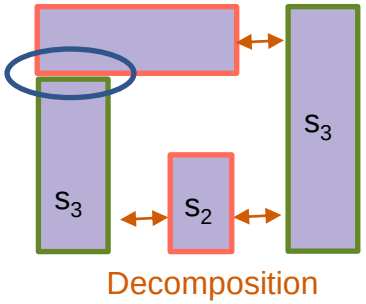
Mask assignment can have conflicts (DPT conflicts)

- Conflicts expressed as odd cycles
- Need to resolve conflicts for manufacturing
- Resolve by decomposition or legalization

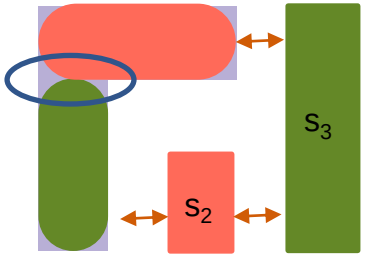


Fixing DPT Conflicts: Approaches

- Layout Decomposition
  - optimal stitch insertion *
  - Overlap problem
- Layout Legalization
  - Increased spacing
  - Apt during early layout creation
- Combined Decomposition and Legalization
  - Simultaneous stitching and spacing #
  - Stitching followed by legalization @
- This work address some issues in legalization method
  - Prevents new DRC creation
  - Avoids new DPT conflict creation



Decomposition



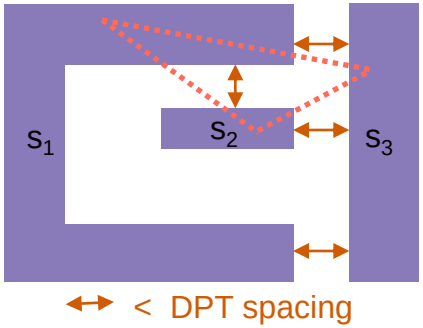
Decomposition Issue

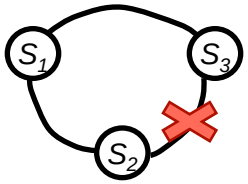
* Tang et al, “Optimal layout decomposition for double patterning technology,” ICCAD 2011

\# Yuan et al, “Wisdom: Wire-spreading enhanced decomposition of masks in double patterning lithography,” ICCAD 2010.

@ Ghaida et al, “Layout decomposition and legalization for double-patterning technology,” TCAD Feb 2013.

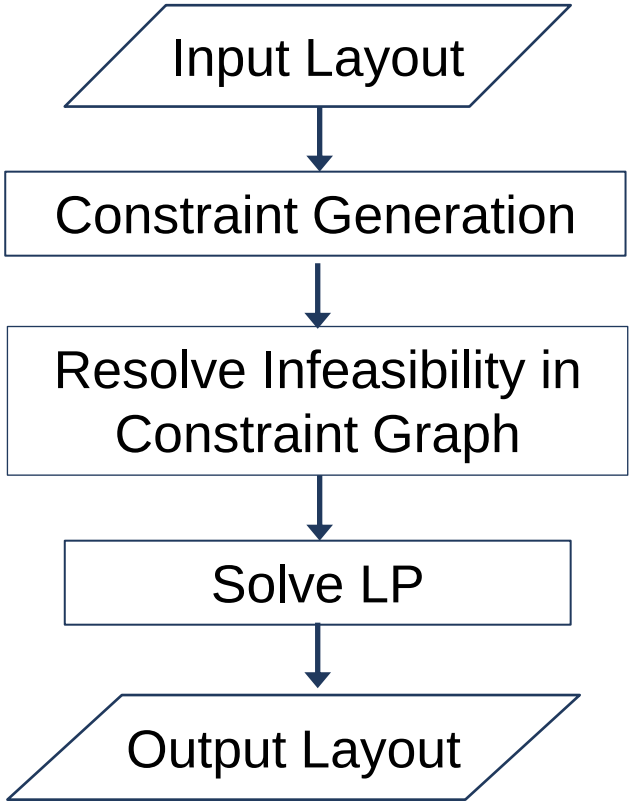
Challenges in Legalization Methods

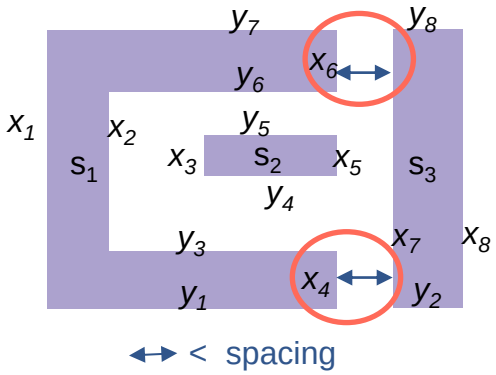


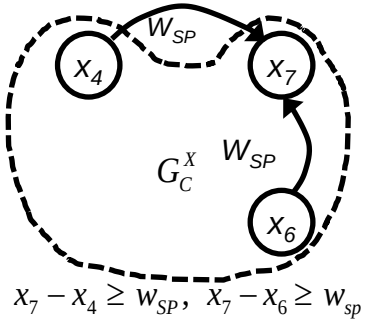


Need to carefully select location for increasing spacing

Layout Legalization: Flow and Model







$$x_7 - x_4 \geq w_{SP},\ x_7 - x_6 \geq w_{SP}$$

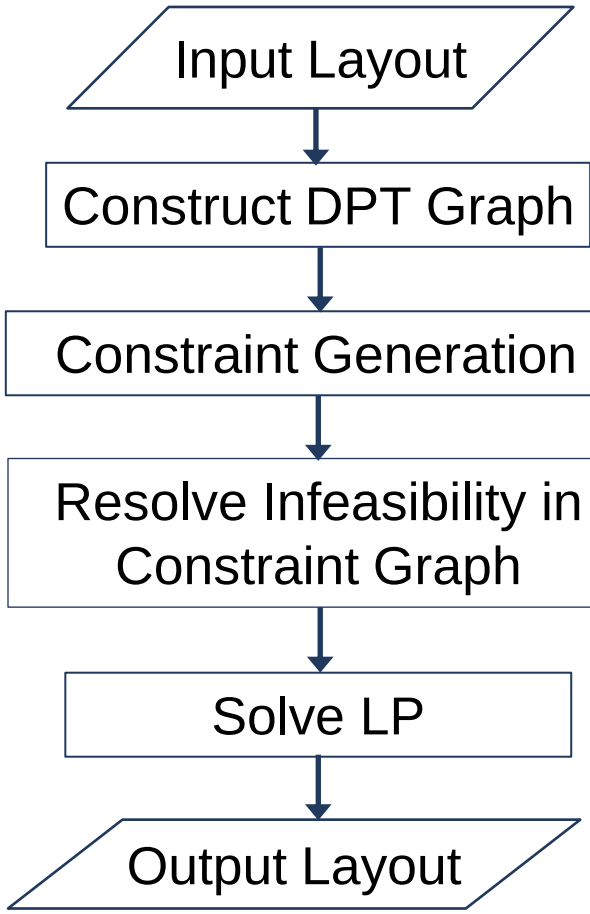
$$min\ \mathbf{C}^T\mathbf{x}$$

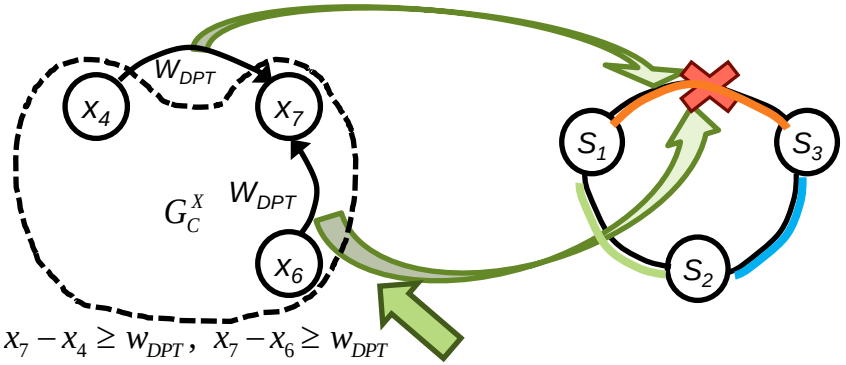
$$subject\ to:\ \mathbf{Ax} \geq \mathbf{b}$$

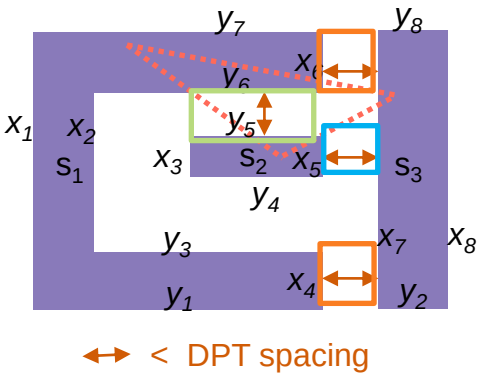
$$with\ constraint\ of\ \ form:\ x_i - x_j \geq b_k$$

Framework to modify layouts in a design-rule aware way

Layout Legalization in Presence of DPT







↔ < DPT spacing

$x_7 - x_4 \geq w_{DPT}$, $x_7 - x_6 \geq w_{DPT}$

OR

$y_6 - y_5 \geq w_{DPT}$

OR

$x_7 - x_5 \geq w_{DPT}$

$$min \ \mathbf{C}^T\mathbf{x}$$

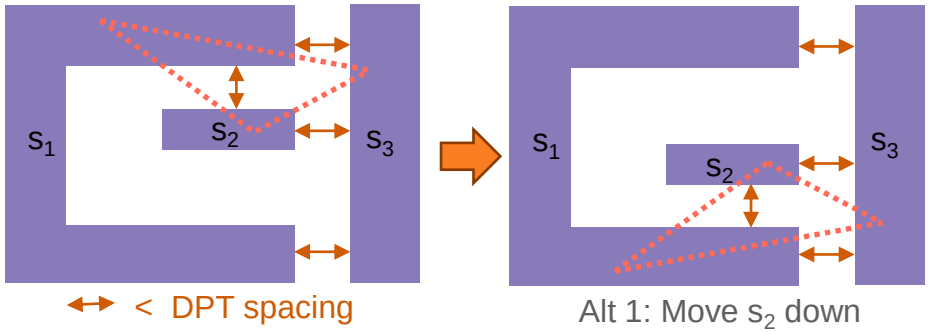
$$subject\ to: \ \mathbf{Ax} \geq \mathbf{b}$$

$$with\ constraint\ of\ \ form: \ x_i - x_j \geq b_{ij}$$

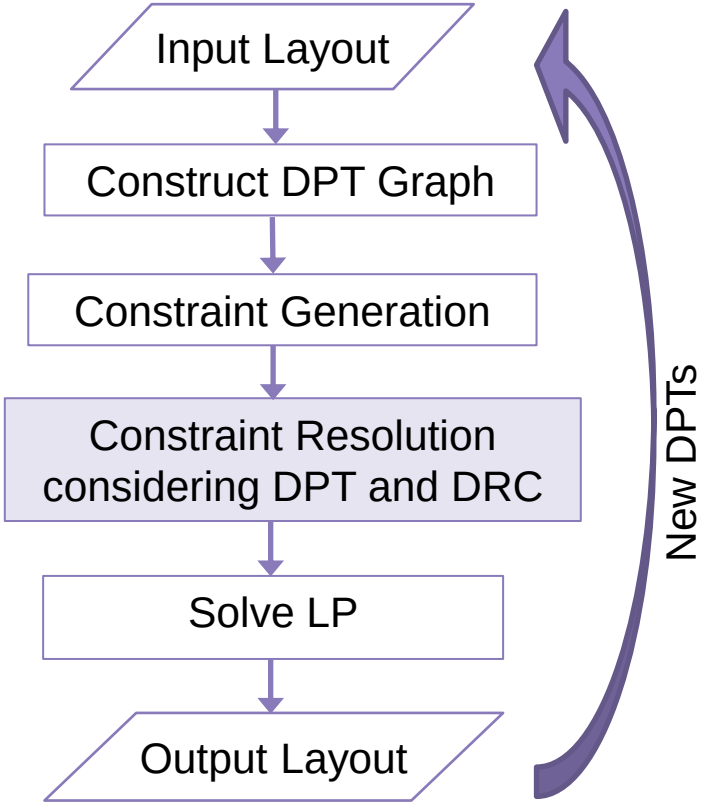
And additional relation across rows

Method to apply large spacing constraints and break odd cycles

Possible Iterative Approach



Layout changes may create new conflicts

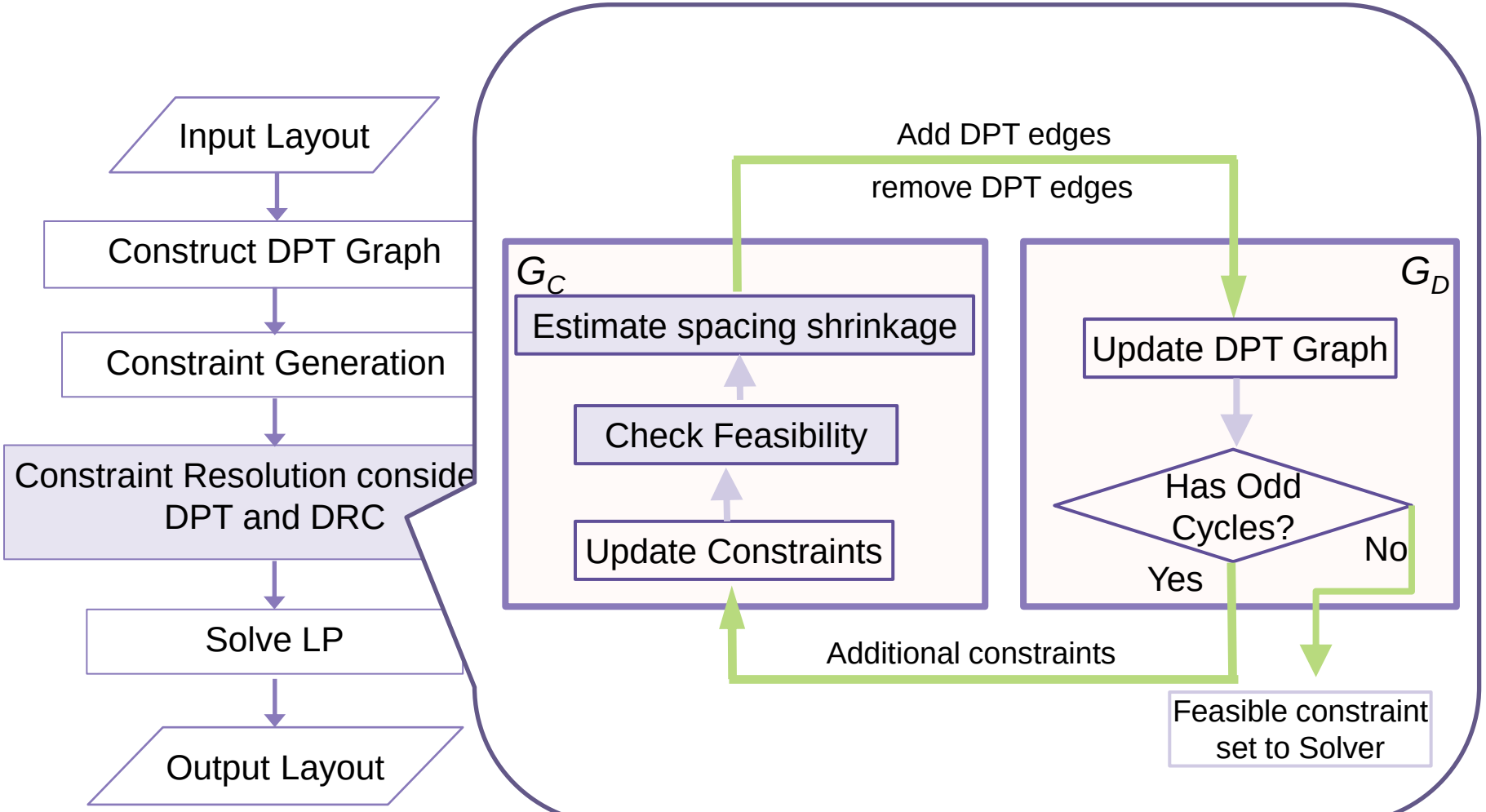


Issues with this approach

- Can hop across bad solutions
- Longer runtimes

Need a way to up-front know ‘good’ and ‘bad’ modifications

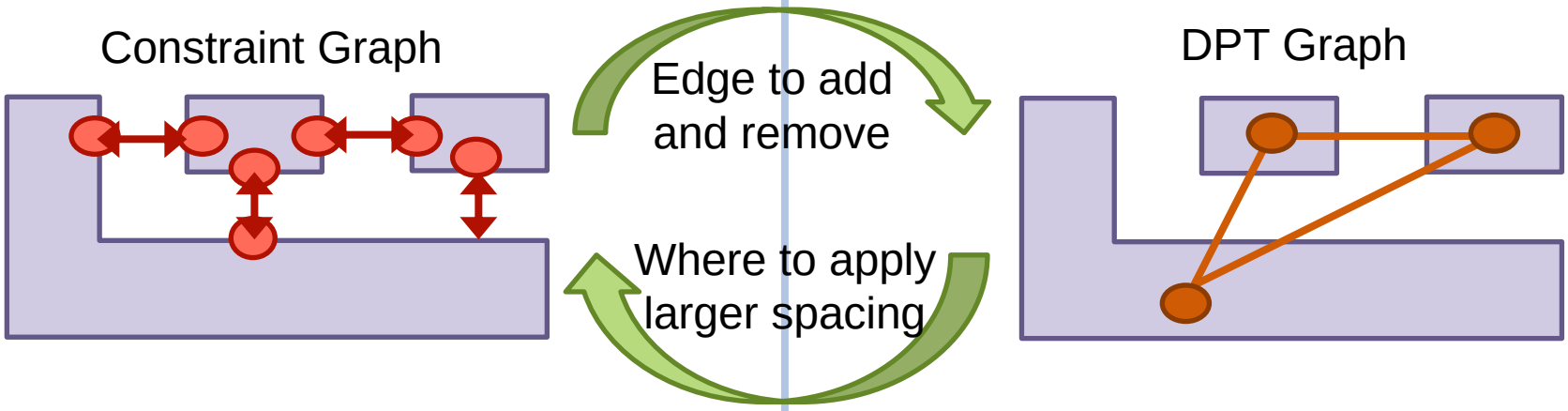
Look-Ahead Approach



Replaced external iterations. Predict spacing shrinkage

Graph Interactions

Feasibility	Bicolorability

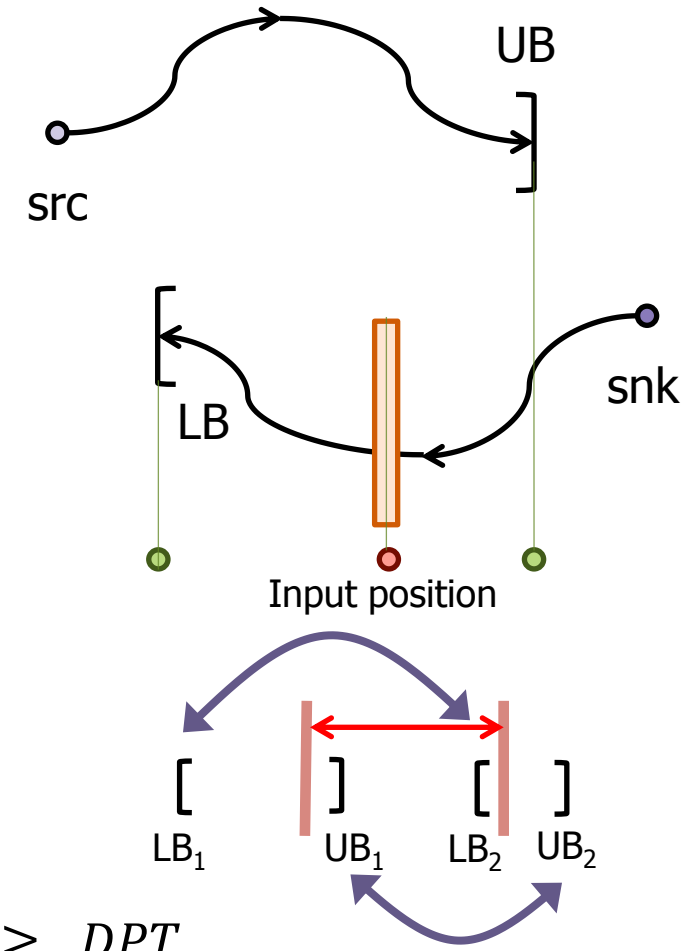


G_C checks if constraints solvable	G_D Checks if bipartite
Many edges map to one in G_D	One edge maps to many in G_C
Provides info on potential DPT edge	Feeds back set of large spacings
Produces a virtual layout instance	Checks if virtual instance is bi-colorable

Feedback scheme to tighten constraints to meet DPT requirements

Predicting Spacing Shrinkage

- Run modified Bellman-Ford algorithm *
  - Initialize constraint graph nodes with input layout locations
  - In Forward run, update if ‘relaxed’ to value above input layout position
  - Forward run produces upper bound
  - In reverse run, update if ‘relaxed’ to a value below input layout position
  - Reverse run produces lower bound



- Potential DPT if :

$$\Delta UB \leq DPT \;\vee\; \Delta LB \leq DPT \;\; and \;\; \Delta LYT \geq DPT$$

* Salodkar et al, “Automatic Design Rule Correction in Presence of Multiple Grids and Track Patterns”, DAC 2013

Results

Expt.	#Lyt obj	#Nodes	#Edges	Input DPT	Input DRC	Output DPT	Output DRC	Runtime
1	634	2513	14840	150	182	0	0	0.45 s
2	1354	5393	32257	330	370	0	0	1.49 s
3	1854	7173	41206	459	529	1	4	4.86 s
4	2654	9953	59594	635	750	40	100	5.87 s
5	3946	13749	80391	854	1066	40	19	12.83 s

Expt.	Simple Legalization		Look-ahead Legalization	
	Output DPT	Output DRC	Output DPT	Output DRC
1	30	0	0	0
2	70	0	0	0
3	115	4	1	4
4	170	100	40	100
5	234	19	40	19

Look-ahead helps fix many more DPT conflicts

Conclusions

- Proposed a method to fix DPT conflicts
  - Based on legalization
- Looks ahead to
  - Avoid creating new DPT conflicts
  - Avoid creating DRC violations

Thank You