Linear Constraint Graph for Floorplan Optimization with Soft Blocks

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Outline

Floorplanning

- Determine the locations and shapes of modules
  - Various objectives: area, interconnect, voltage island, etc.
  - Various constraints: soft blocks, abutment, etc.
- Constructive approaches: fast
  - Usually limited to area and interconnect optimization
- Simulated annealing (SA): flexible
  - Use a floorplan representation to explore different floorplans
  - Manage objectives through a cost function

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Floorplan Exploration

- To explore all non-overlapping floorplans. How?
  - Generate a floorplan topology (in some representation) in SA
  - Map from the floorplan topology to physical floorplans
- Packing: area minimized physical floorplans only, when module sizes are known
- Constraint graph + mathematical programming: all possible physical floorplans
  - Soft blocks [Young et al. 2001], [Lin et al. 2006], [Lee et al. 2007]
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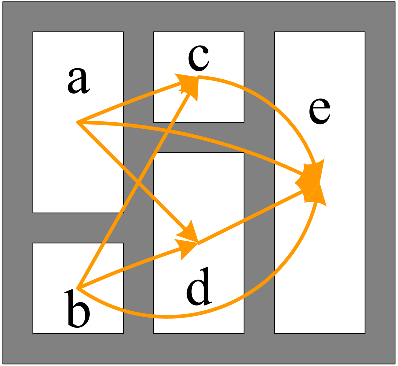
Constraint Graph Basics



- Horizontal graph: *left-to* relations
- Vertical graph: *below* relations
- At least one relation between any pair of modules

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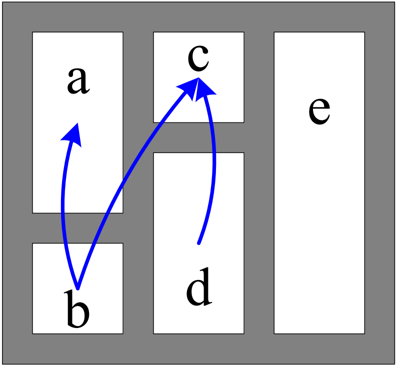

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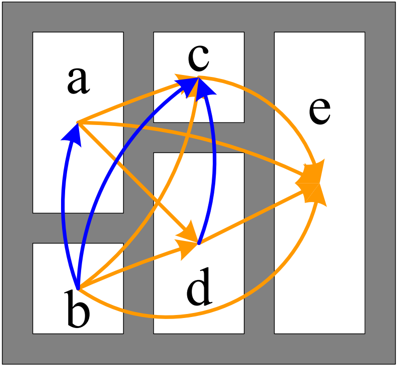

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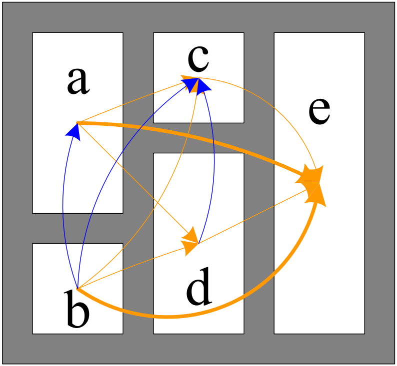
Redundancy in Constraint Graph



- Transitive edges: relations implied by others
- Over-specification: more than one relation between two modules

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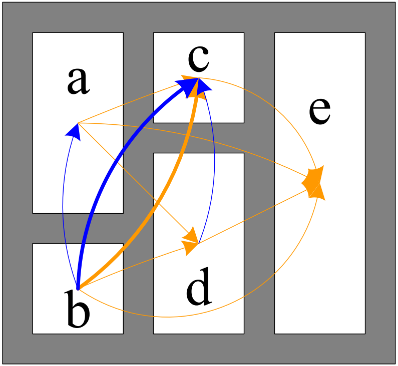

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Ad-Hoc Approaches for Constraint Graph Generation

- From polar graphs ([Ohtsuki et al. 1970])
  - There is no method to explore them in SA
  - Apply to mosaic floorplans only
- From sequence-pairs ([Murata et al. 1996])
  - Relatively straightforward and widely used in previous works
  - No over-specification. Transitive edges can be removed
  - Worst-case complexity: $\Theta(n^2)$ edges
  - $O(n \log n)$ edges on average [Lin 2002]

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Constraint Graphs as Floorplan Representation

- TCG – Transitive Closure Graph ([Lin et al. 2001])
  - Keep pair-wise relations including transitive edges
  - No over-specification
  - Always $\Theta(n^2)$ edges
- ACG – Adjacent Constraint Graph ([Zhou et al. 2004])
  - Intentionally reduce complexity
  - Forbid transitive edges, over-specification, and "crosses"
    - Cross: a structure that may result in $\Theta(n^2)$ edges
  - Complexity: at most $O(n^{\frac{3}{2}})$ edges [Wang 2005]

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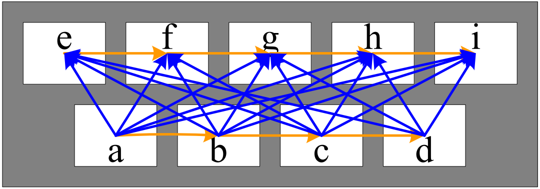
Our Contribution: *Linear* Constraint Graph

- A general floorplan representation based on constraint graphs
- At most $2n + 3$ vertices and $6n + 2$ edges for n modules
- Intuitively combine the ideas of polar graphs and ACGs
- One application: floorplan optimization with soft blocks

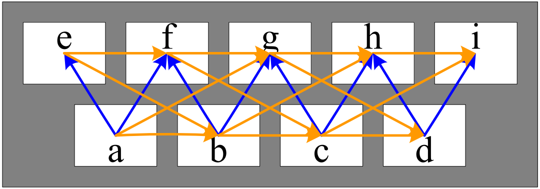
Outline

Cross Avoidance



- Crosses may result in $\Theta(n^2)$ edges
- Use alternative relations as proposed by ACG
  - However, still have complicated patterns/relations
- Use a "bar" similar to polar graphs
  - Require a dummy vertex in the graph
  - Need a systematic approach!

Cross Avoidance



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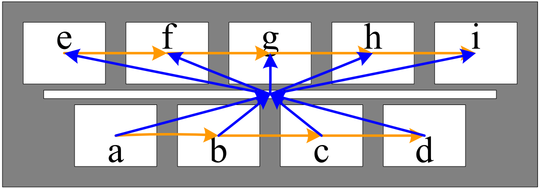

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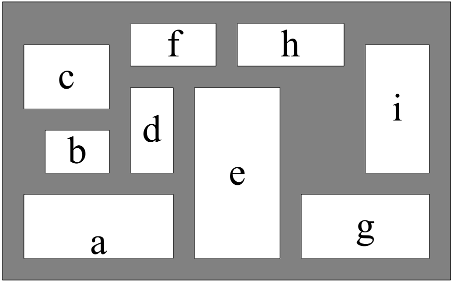
Intuitions for Linear Constraint Graph (LCG)

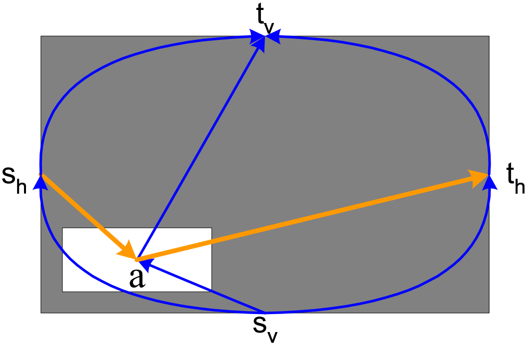
- Avoid horizontal crosses: use alternative relations as ACGs
- Avoid vertical crosses: use horizontal bars as polar graphs
- Introduce dummy vertices to constraint graphs to reduce number of edges

From Floorplan to LCG



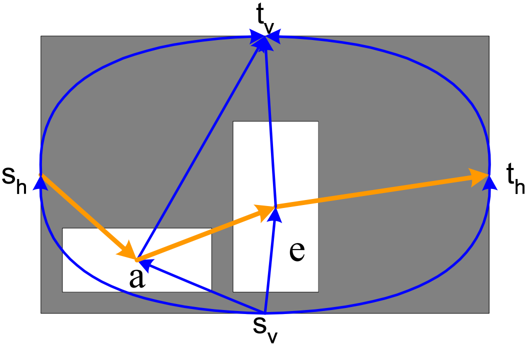
- A floorplan with non-overlapping modules
- Construct LCG by adding modules from bottom to top
  - Horizontal graph: planar, w/o transitive edge
  - Vertical graph: separate modules not separated horizontally

From Floorplan to LCG



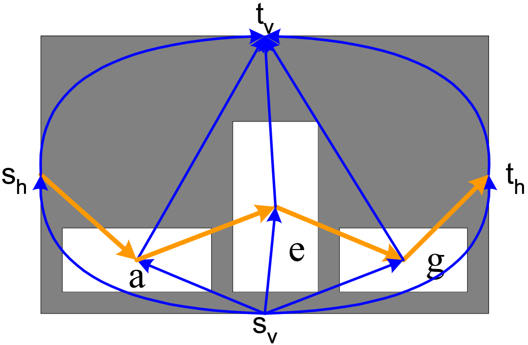
- Boundary: s_h, t_h, s_v, t_v
- Top modules: a
  - Only need to check modules on the top for insertion since modules are inserted from bottom to top

From Floorplan to LCG



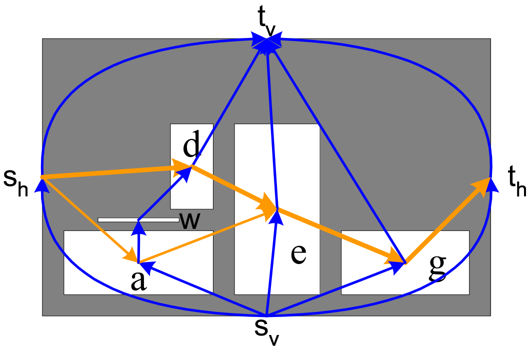
- Insert e between a and t_h
  - Break $a \longrightarrow t_h$ into $a \longrightarrow e$ and $e \longrightarrow t_h$
- Top modules: $a \longrightarrow e$

From Floorplan to LCG



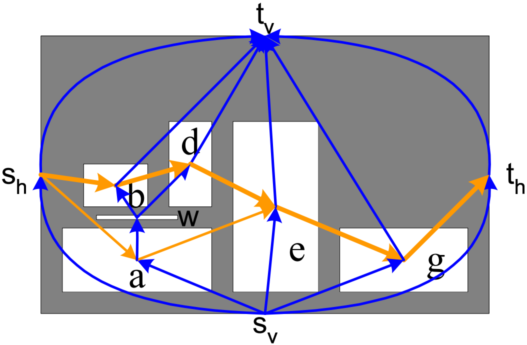
- Insert g between e and t_h
  - Break $e \rightarrow t_h$ into $e \rightarrow g$ and $g \rightarrow t_h$
- Top modules: $a \rightarrow e \rightarrow g$

From Floorplan to LCG



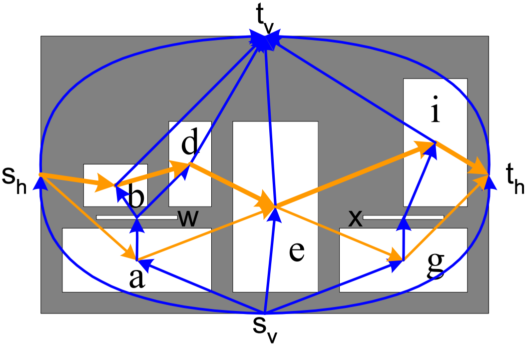
- Insert d between s_h and e
  - Add one bar w on top of a
  - Insert $s_h \longrightarrow d$ and $d \longrightarrow e$
- Top modules: $d \longrightarrow e \longrightarrow g$

From Floorplan to LCG



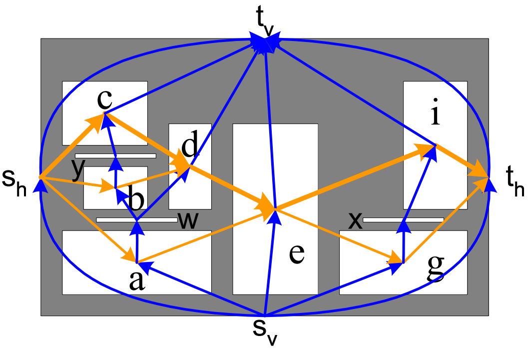
- Insert b between s_h and d
  - Break $s_h \rightarrow d$ into $s_h \rightarrow b$ and $b \rightarrow d$
- Top modules: $b \rightarrow d \rightarrow e \rightarrow g$

From Floorplan to LCG



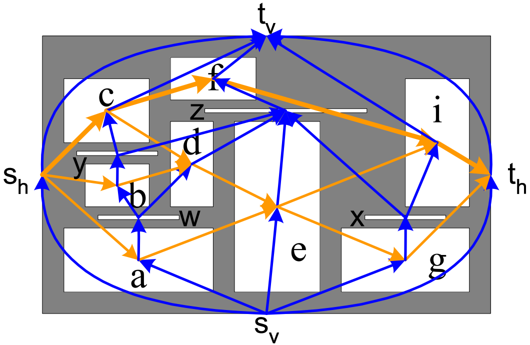
- Insert i between e and t_h
  - Add one bar x on top of g
  - Insert $e \rightarrow i$ and $i \rightarrow t_h$
- Top modules: $b \rightarrow d \rightarrow e \rightarrow i$

From Floorplan to LCG



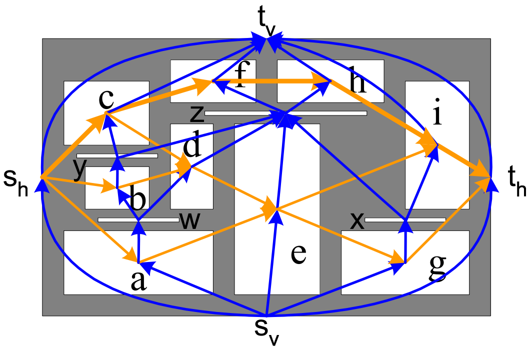
- Insert c between s_h and d
  - Add one bar y on top of b
  - Insert $s_h \to c$ and $c \to d$
- Top modules: $c \to d \to e \to i$

From Floorplan to LCG



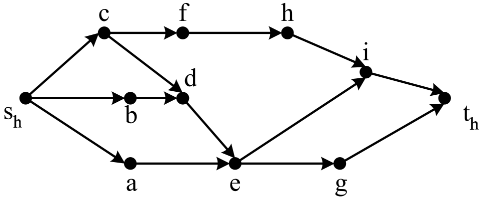
- Insert f between c and i
  - Add one bar z on top of d, e, x, y
  - Insert $c \rightarrow f$ and $f \rightarrow i$
- Top modules: $c \rightarrow f \rightarrow i$

From Floorplan to LCG



- Insert h between f and i
  - Break $f \to i$ into $f \to h$ and $h \to i$
- Top modules: $c \to f \to h \to i$

Horizontal Relations in LCG



- Observation: for each new module, we either
  - Break a horizontal edge into two
  - Insert two horizontal edges and a horizontal bar
- Horizontal Adjacency Graph (HAG)
  - Each edge connects two modules adjacent to each other
  - $n+2$ vertices, at most $2n$ edges, at most $n-1$ bars
  - Planar – faces correspond to horizontal bars

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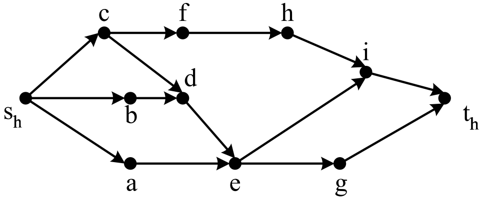

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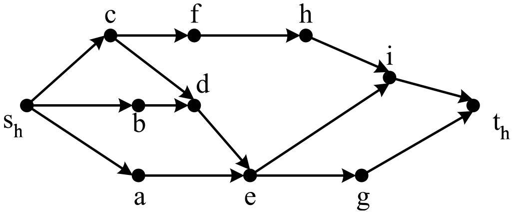
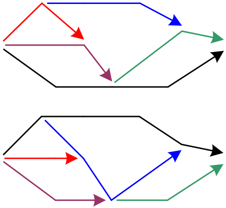
Above and Below Paths





- Each face of HAG is surrounded by two paths:
  the above path and the below path.
  - The left/right-most modules are the same
  - Other modules on the above path are above the bar
  - Other modules on the below path are below the bar
- The length of each path is at least 2
  - Otherwise there is a transitive edge

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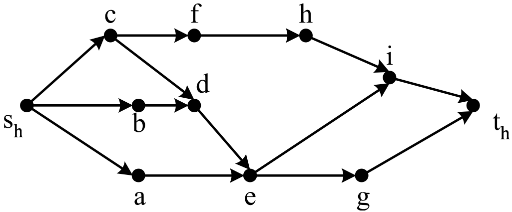

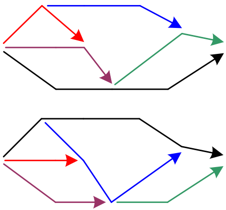

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Vertical Relations in LCG

- Implied by HAG
  - Separate modules not separated horizontally
  - From a bar to a module, a module to a bar, or a bar to a bar
  - Each module connects to 2 bars: above and below
  - Each bar connects to at most 4 bars
- Vertical cOmpanion Graph (VOG)
  - At most $n-1$ bars
  - At most $2n+3$ vertices, at most $4n+2$ edges

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Linear Constraint Graph

- Combine HAG and VOG into a constraint graph
- At most $2n + 3$ vertices and $6n + 2$ edges
- Can represent any non-overlapping floorplan

Outline

Perturbations of LCG

- The planar HAG allows relatively easy perturbations
  - Update VOG accordingly
- Three perturbations with $O(n)$ complexity
  - Exchange two modules: no change in topology
  - insertH: change vertical relation to horizontal
  - removeH: change horizontal relation to vertical
- The perturbations are complete
  - Any LCG can be converted to any other LCG by at most $3n$ perturbations

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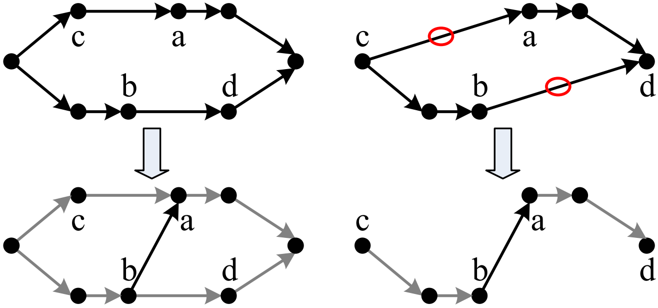
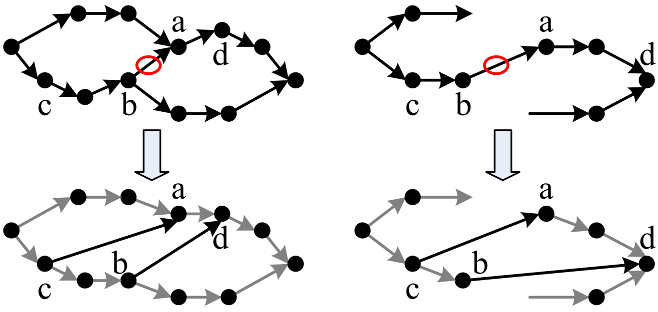
The insertH Operation



- Insert $b \longrightarrow a$
- Remove transitive edges
  - Remove $c \longrightarrow a$ if c starts the above path
  - Remove $b \longrightarrow d$ if d ends the below path

The removeH Operation



- Remove $b \longrightarrow a$
- Insert $c \longrightarrow a$ and $b \longrightarrow d$
  - $c \longrightarrow a$ is optional iff a has at least 2 incoming edges
  - $b \longrightarrow d$ is optional iff b has at least 2 outgoing edges

Floorplan Optimization w/ Soft Blocks

[Young et al. 2001], [Lin et al. 2006]

- The area of each soft block is known.
- The decision variables are the widths of the soft blocks and the positions of all the modules
- Derive non-overlapping condition for the modules from LCG as a system of difference equations
- Apply Lagrangian relaxation to minimize the perimeter of the floorplan

Outline

Experimental Results for General Floorplans

- 3 GSRC benchmarks with hard blocks
- Compare to Parquet [Adya et al. 2003] and ACG [Zhou et al. 2004]
- Wire length optimization (wire length + chip area)

	Parquet			ACG			LCG		
name	ds(%)	wl	t(s)	ds(%)	wl	t(s)	ds(%)	wl	t(s)
n100	**7.95**	324k	30	8.33	308k	30	8.60	**300k**	27
n200	10.99	581k	150	10.26	540k	137	**9.03**	**538k**	133
n300	12.05	709k	288	13.00	644k	357	**11.44**	**639k**	274

Area Optimization w/ Soft Blocks

- 5 modified MCNC benchmarks with soft blocks
- Aspect ratio bound: $[0.5, 2]$
- Compare to [Lin et al. 2006] (SP+TR)

name	n	SP+TR			LCG+TR		
		ds(%)	t(s)	$\|E\|$	ds(%)	t(s)	$\|E\|$
apte	9	**0.04**	34	40	**0.04**	21	34
xerox	10	**0.08**	43	47	**0.08**	41	38
hp	11	**0.09**	41	54	0.13	26	41
ami33	33	0.28	383	347	**0.24**	179	125
ami49	49	**0.24**	694	679	0.27	319	182

Wire Length Optimization w/ Soft Blocks

- 5 modified MCNC benchmarks with soft blocks
- Aspect ratio bound: $[0.5, 2]$
- Compare to [Lin et al. 2006] (SP+TR)

	SP+TR			LCG+TR		
name	ds(%)	wl(mm)	t(s)	ds(%)	wl(mm)	t(s)
apte	0.09	125.29	35	**0.08**	**125.28**	26
xerox	0.21	**145.16**	46	**0.15**	152.69	36
hp	0.26	43.42	37	**0.22**	**42.60**	27
ami33	0.50	57.89	349	**0.49**	**52.46**	236
ami49	1.17	290.89	615	**0.64**	**272.23**	442

Outline

Conclusions

- *Linear Constraint Graph*s (LCG) are proposed as a general floorplan representation based on constraint graphs
  - For n modules, each LCG has at most $2n+3$ vertices and at most $6n+2$ edges
  - LCGs can represent any non-overlapping floorplans
- Simulated annealing based floorplanner is presented
- The advantages of LCGs is confirmed by the experimental results.

Q & A

Thank you!