An analytical placement tool for the Coriolis toolchain

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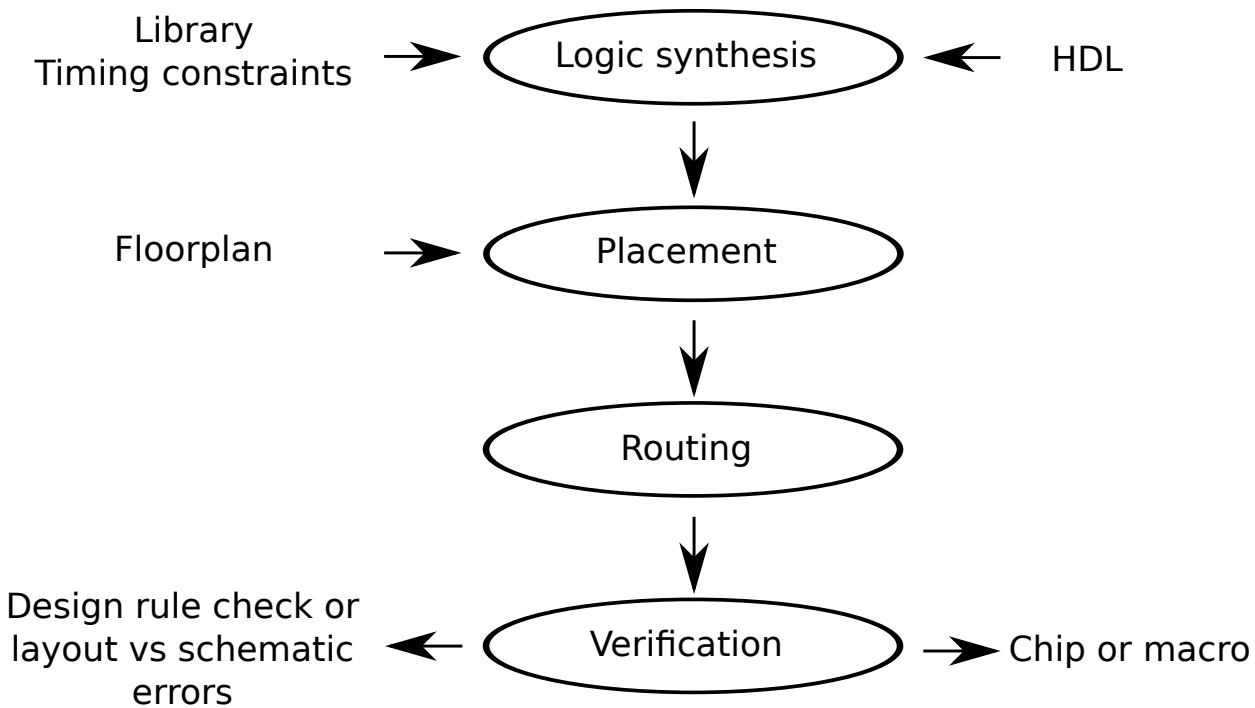
The Coriolis toolchain

The digital synthesis flow



Remember Alliance?

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An complete, open toolchain developped in the lab

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An complete, open toolchain developped in the lab
Coriolis: Physical design only

Hurricane: a powerful database

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- Hierarchical

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- Hierarchical
- Powerful access methods

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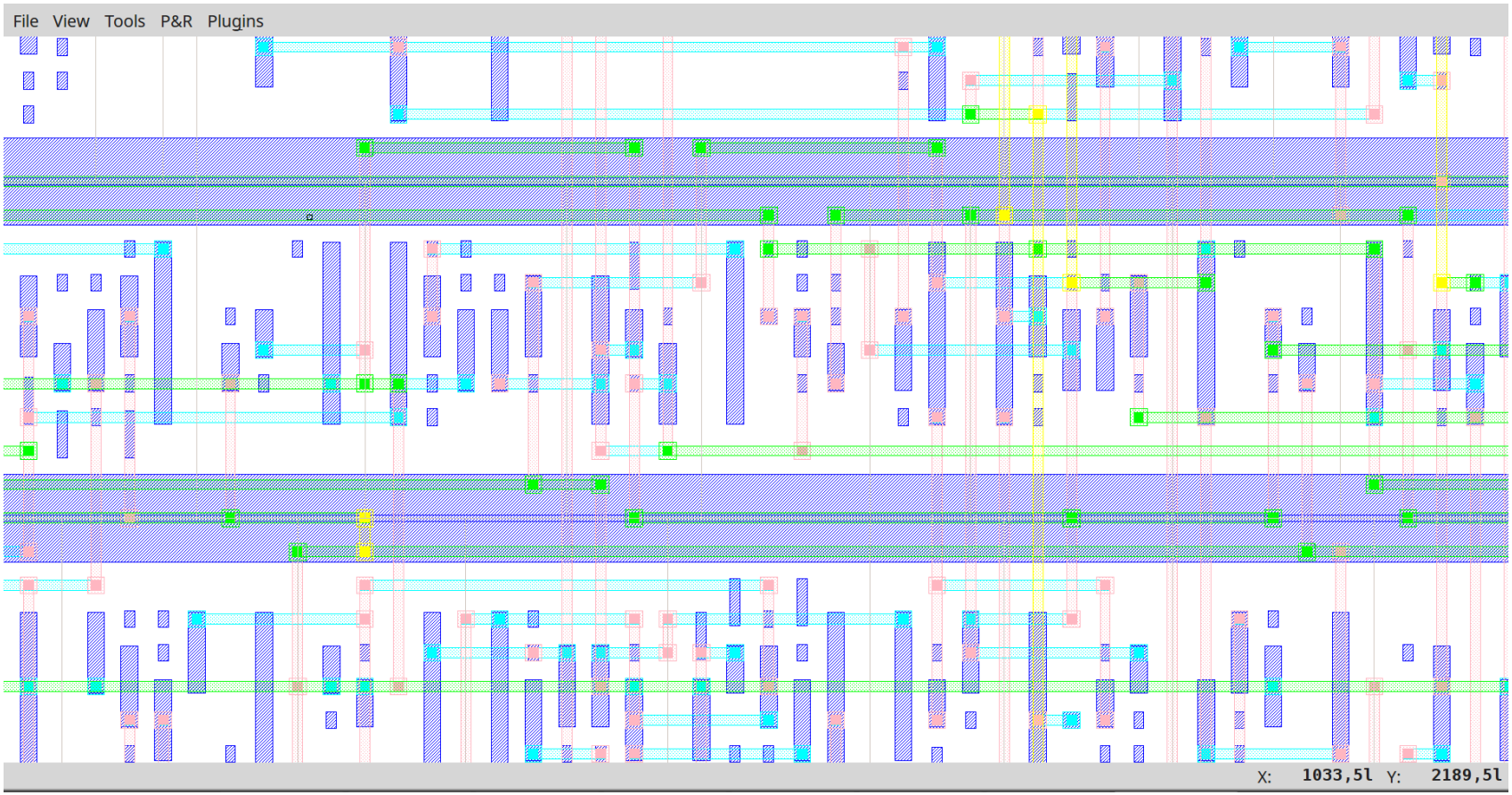
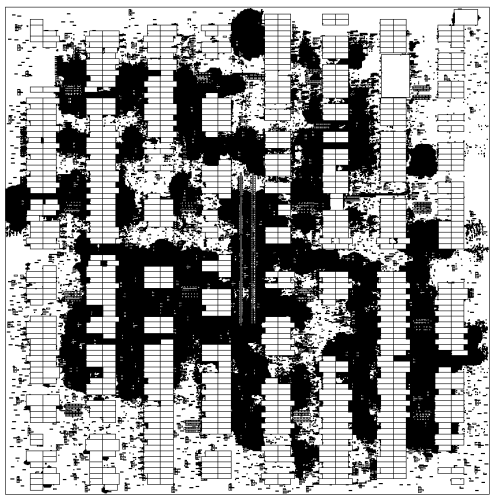
- Hierarchical
- Powerful access methods
- Frontends/Backends

Kite: an efficient router



The need for placement tools



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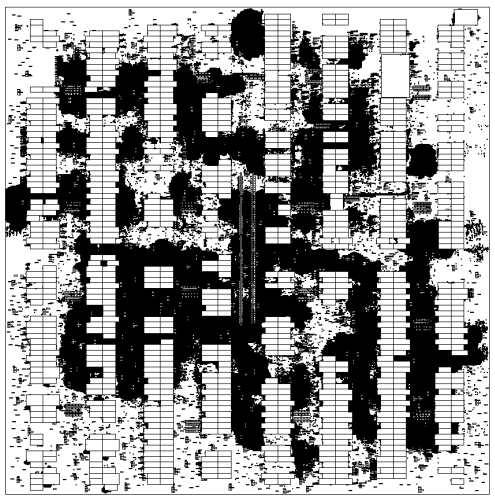


- Several thousands – millions – of cells
- Partly determines the circuit's quality

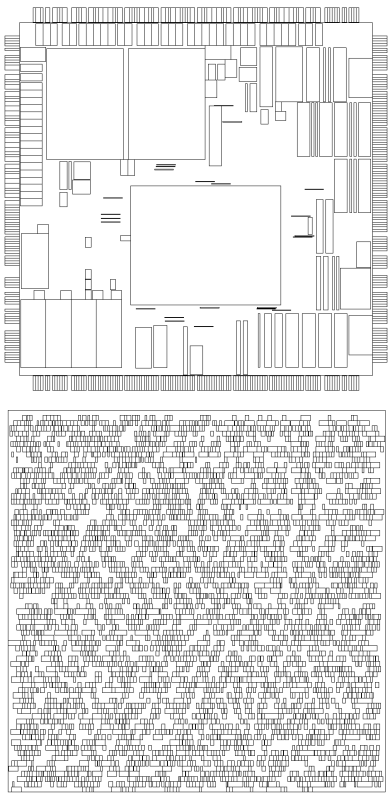
What is a good placer?

- Various optimization objectives
  - Wirelength
  - Routability
  - Timing
- Lots of open benchmarks [3]

What is a good placer?

- Various optimization objectives
  - Wirelength
  - Routability
  - Timing
- Lots of open benchmarks [3]
- In practice, we want everything:
  - Error-free routing
  - Fast placement
  - Fast and low-power circuit

Two types of placement problems



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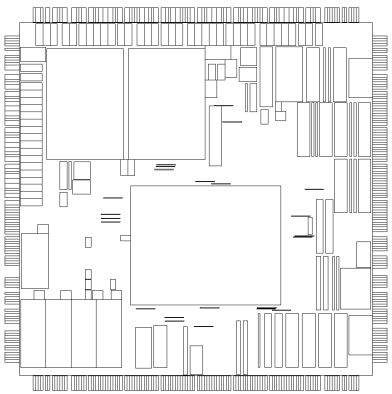
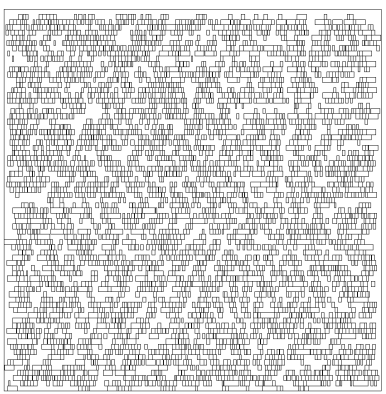
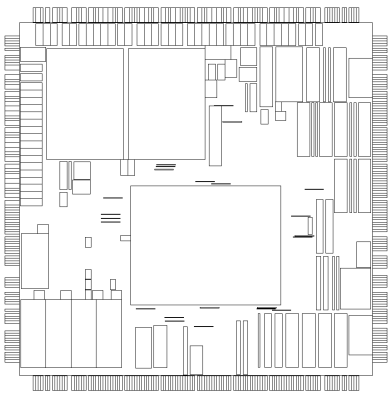
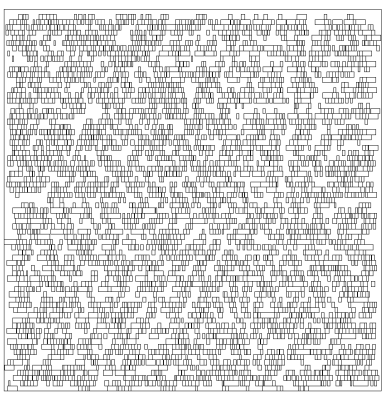




- Big modules $\rightarrow$ Floorplanning
  - Irregular rectangles
  - Few modules

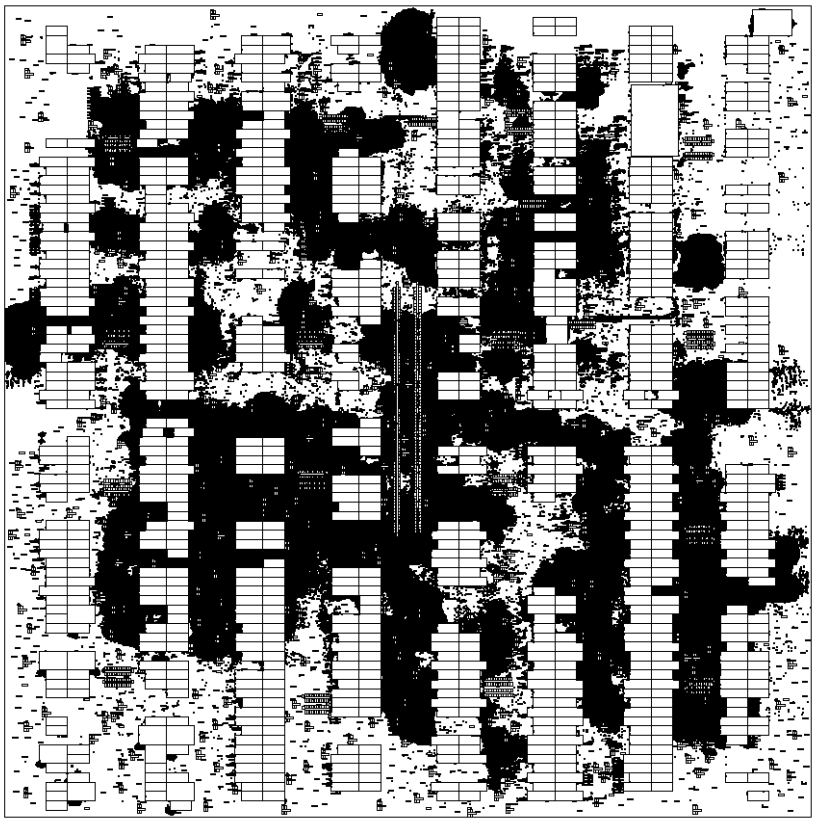
Two types of placement problems





- Big modules $\rightarrow$ Floorplanning
  - Irregular rectangles
  - Few modules
- Standard cell placement
  - Uniform height $\Rightarrow$ placed in rows
  - 10^6 cells or more

The real worlds: mixed-size placement



In practice, circuits have both macros and standard cells

Before the technical stuff...

Obviously....

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Obviously.... It is NP-complete.

Before the technical stuff...

Obviously.... It is NP-complete.

- Bin-packing
- Multiple-machine scheduling
- Graph partitioning
- Steiner trees

Algorithms

Simulated annealing and metaheuristics

Simulated annealing

- Accepts bad moves depending on a temperature
- *Theoretically* converges

Simulated annealing and metaheuristics

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- But not in *reasonable* time

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Made it quite far thanks to Timberwolf [6]

Three-step placement

Use multiple steps to obtain a good placement

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- A global placement step
  - Approximate positions
  - Overlaps are possible
  - Only density constraints

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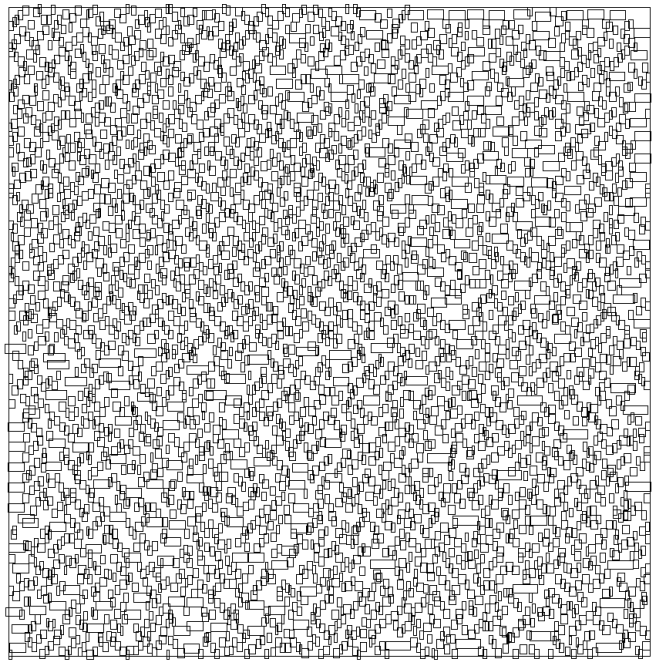
Three-step placement

Use multiple steps to obtain a good placement

- A global placement step
  - Approximate positions
  - Overlaps are possible
  - Only density constraints
- A legalization step
  - Obtain an overlap-free placement
- A detailed placement step
  - Remove local suboptimalities

Visually



Global placement result

Final placement

Global placement is everything

Global placement is the *most performance-critical* part

Global placement is everything

Global placement is the *most performance-critical* part

- There is only so much you can do with detailed placement

Detailed placement is limited

Legalization

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Legalization

- Simple algorithms
- Needs to succeed, but not critical for quality

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Detailed placement

- Simple concepts
  - Swaps
  - Reordering
  - Moves

Detailed placement is limited

Legalization

- Simple algorithms
- Needs to succeed, but not critical for quality

Detailed placement

- Simple concepts
  - Swaps
  - Reordering
  - Moves
- Small search space

Global placement algorithms

Two approaches:

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- Discrete view: the circuit is a graph
  $\Rightarrow$ Partitioning

Global placement algorithms

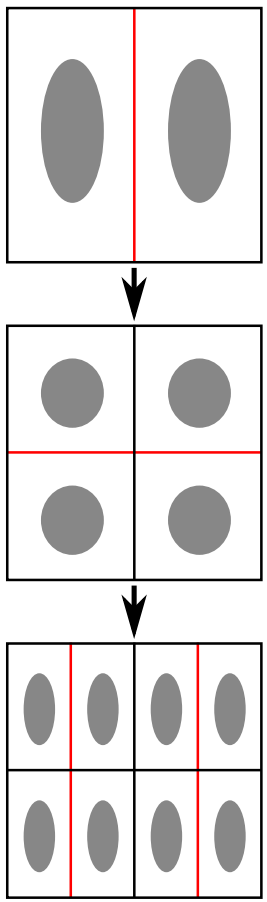
Two approaches:

- Discrete view: the circuit is a graph
  $\Rightarrow$ Partitioning
- Continuous view: it is a vector of positions
  $\Rightarrow$ Analytical placement

Partitioning placers

Basic idea

- Partition the circuit
- Cut as few wires as possible
- Allocate the parts to placement regions



Some nice achievements with Capo [5]

Lots of variations and improvements

- Partitioning algorithm (Fiduccia-Mattheyses)
- Cut costs and fixed terminals
- Free-space handling

Analytical placers

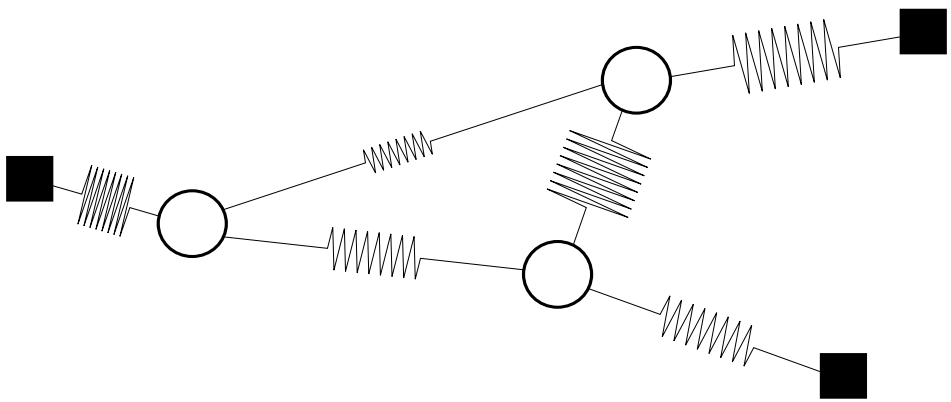
Basic idea

- A convex cost function
- A *huge* vector of positions
- Optimize

Most current placers [3]

Optimization methods: quadratic placers

Model wires as springs [1]



Optimization methods: quadratic placers

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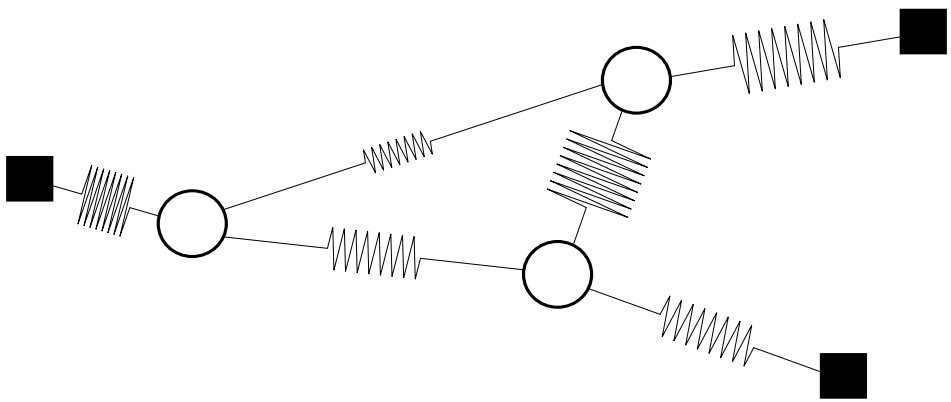

Easy to solve: sparse symmetric linear system

Optimization methods: nonlinear placers

Closer model of the cost function

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Only first-order methods:

- Conjugate gradient
  - Needs line-search
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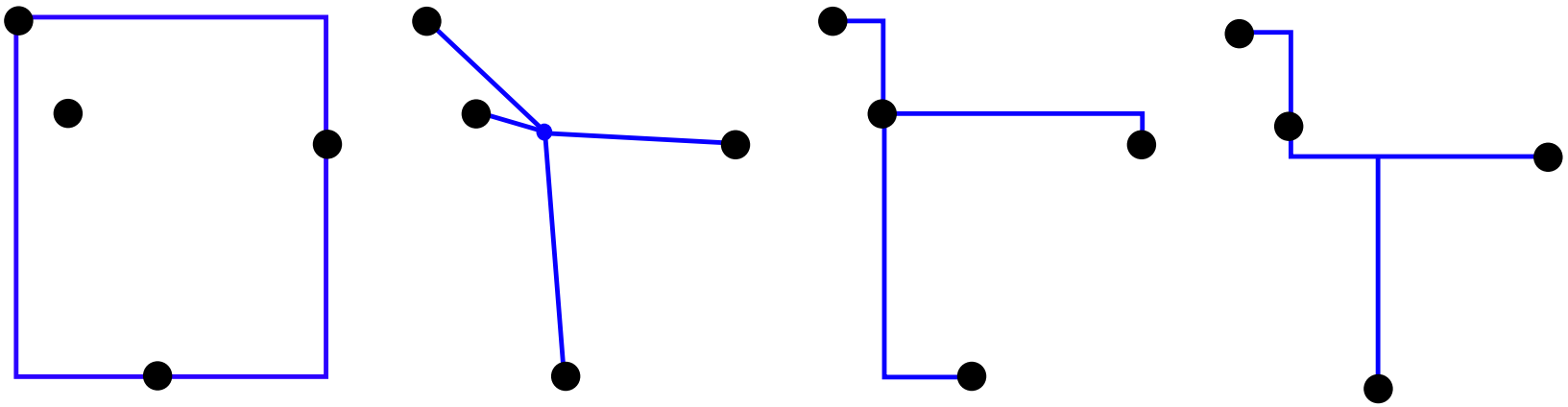
Optimization methods: nonlinear placers

Closer model of the cost function

Only first-order methods:

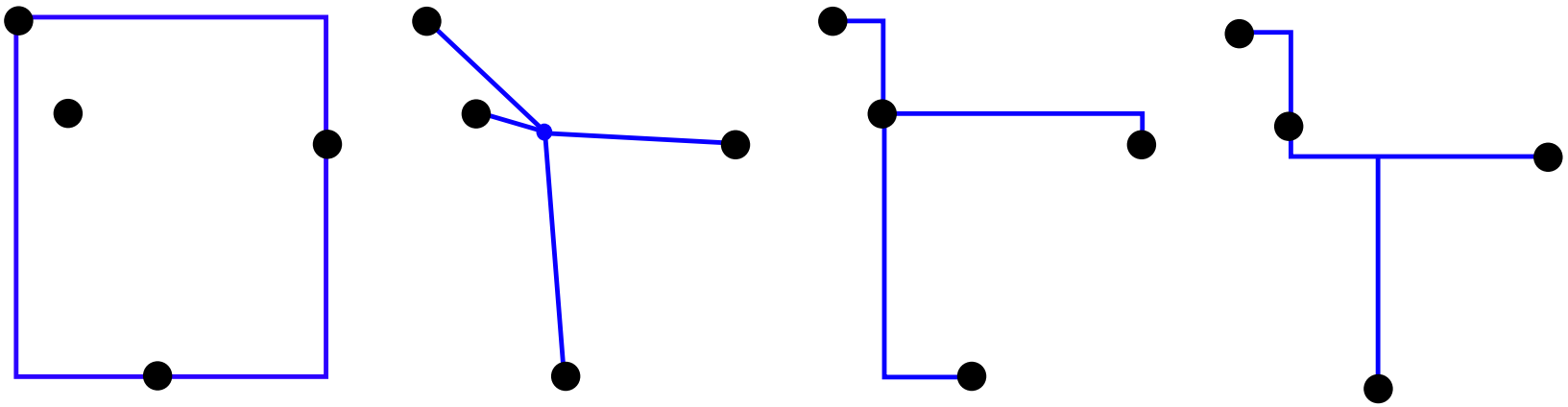
- Conjugate gradient
  - Needs line-search
  - Slower than the linear one
- Nesterov
  - Constant steps
  - Recent comeback of nonlinear methods [3]

Usual cost functions



Wirelength models

Usual cost functions



Wirelength models

$$HPWL = \sum_{c \in \{x,y\}} \sum_{n \in nets} \left(\max_{pin \in n} c_{pin} - \min_{pin \in n} c_{pin} \right)$$

Beware!

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Non-convex solution space!

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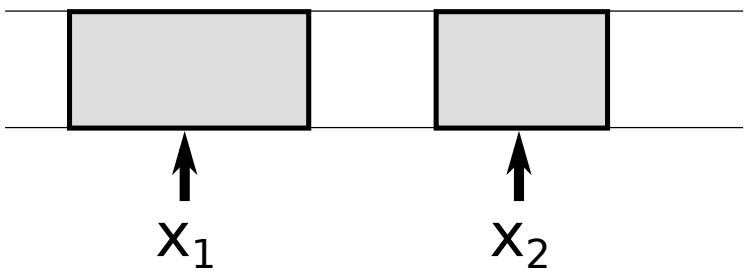
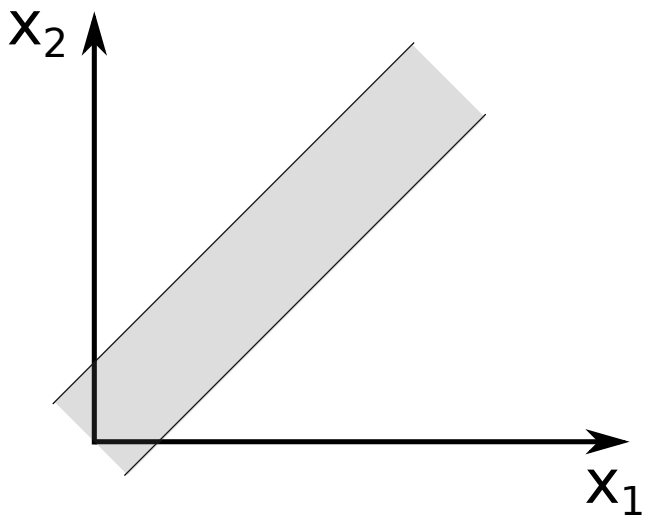
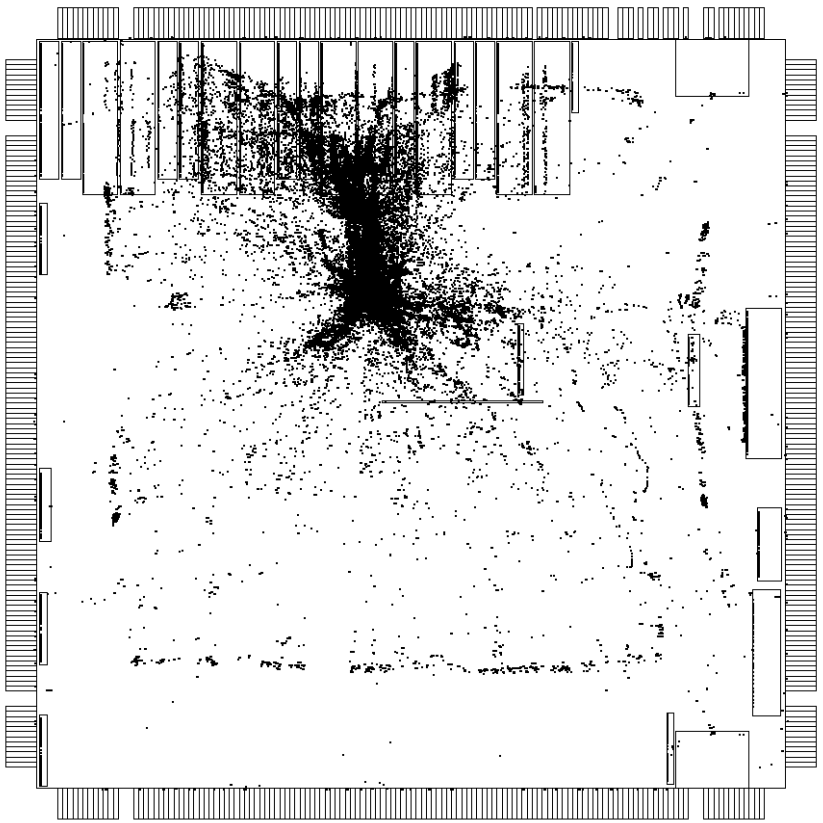
Non-convex solution space!





Problem



Lots of overlaps

Handling density constraints

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Back to partitioning

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Back to partitioning $\Leftarrow$ based on the positions

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Force-directed placers $\Leftarrow$ add a penalty function

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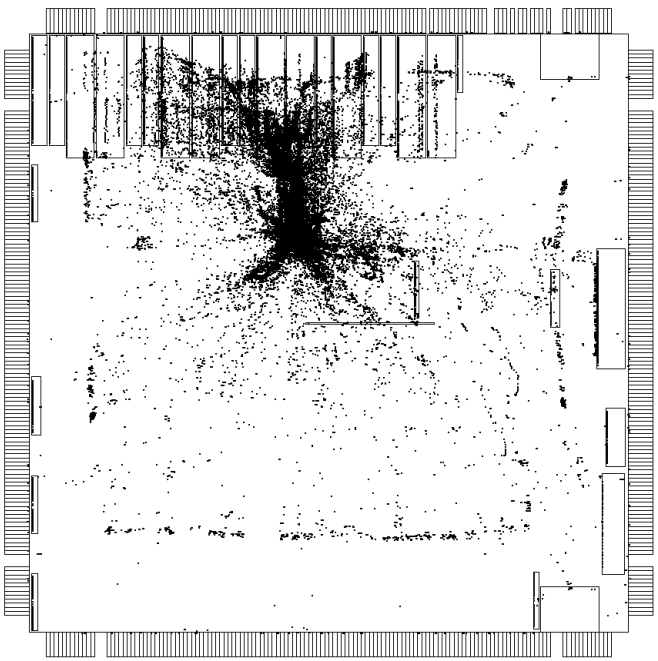
Repeat

Obtaining a feasible solution: lookahead legalization

Remove density overflow, minimize the displacement



Optimization result

Obtaining a feasible solution: lookahead legalization

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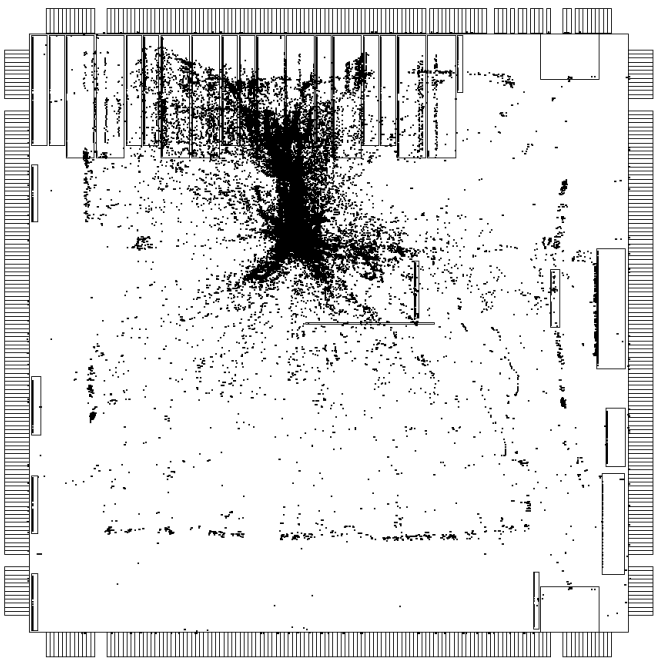

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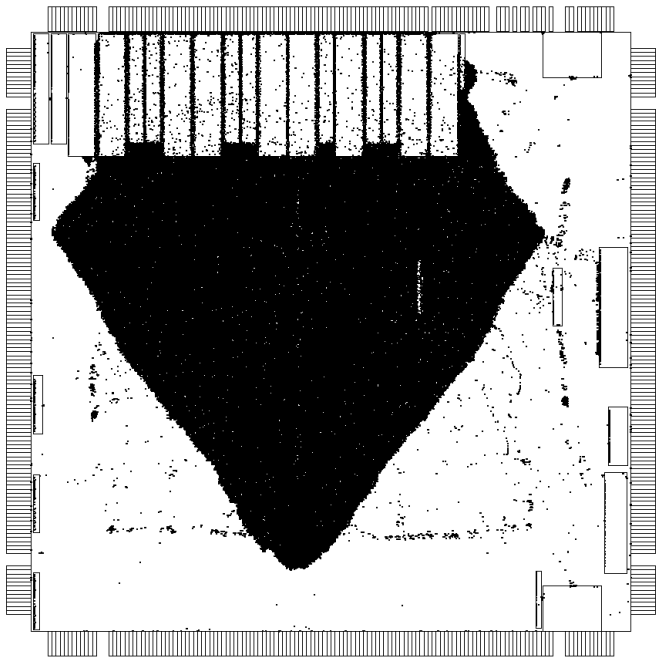

Projection

Lots of variations and improvements

- Penalty function
- Cost function
- Legalization algorithm

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- Penalty function
- Cost function
- Legalization algorithm
- Additional refinements

Benchmark winners

The best placers are analytical. No other rule

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Placer	Optimization	Density handling	Refinement
ePlace	Nonlinear	FD (potential)	No
Maple	Quadratic	FD (legalizing)	Yes
Polar	Quadratic	FD (legalizing)	Yes
BonnPlace	Quadratic	Partitioning	No?

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- Rather force-directed
- + various algorithms
- + **trial-and-error**

Coloquinte is a force-directed quadratic placer

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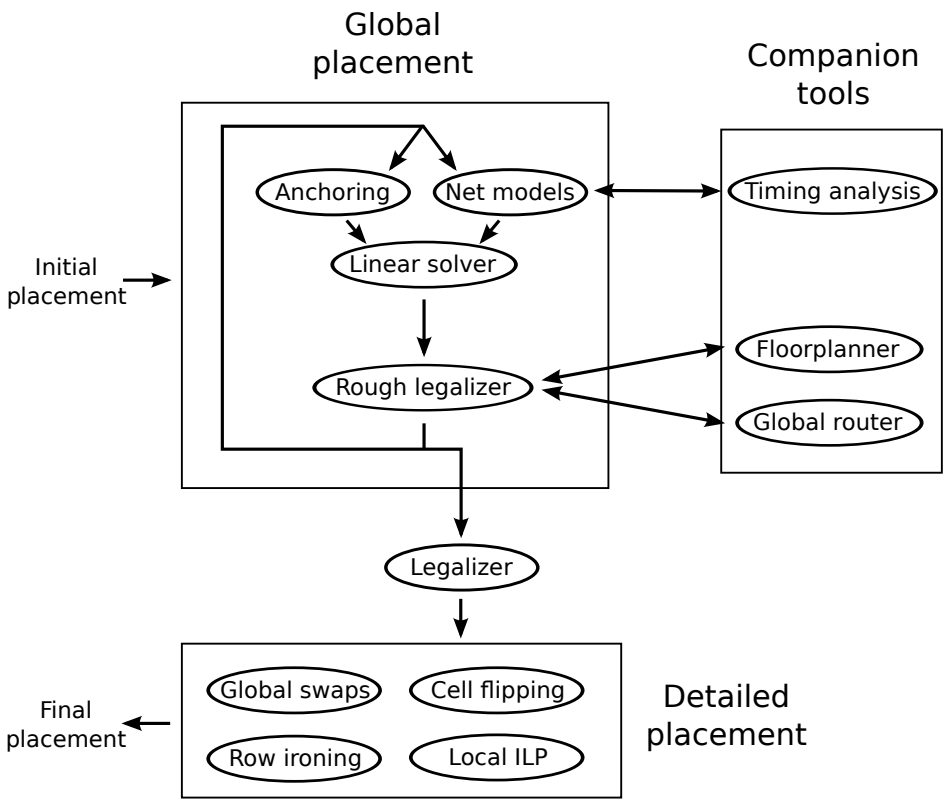
- Force-directed $\Rightarrow$ best results
- Lookahead legalization $\Rightarrow$ Local density control
- **But** no refinement

Coloquinte's structure



What is new in Coloquinte?

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- Focus on good lookahead legalization
- Algorithms for detailed placement
- Penalty scheduling
- Net models

The need for extensive benchmarking

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Small change $\Rightarrow$ random quality variations

The need for extensive benchmarking

Small change $\Rightarrow$ random quality variations

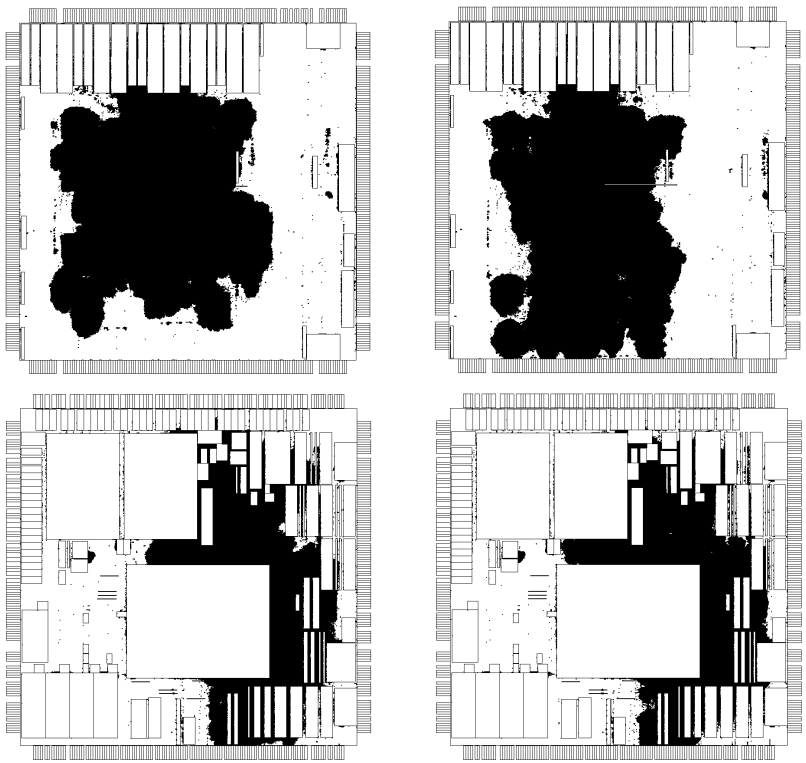
Experienced with:

- Penalty type
- Penalty weight

The need for extensive benchmarking

Bigblue1: WL +0.8%

Adaptec2: WL -2.1%



A simple change: linear vs quadratic penalty

Can we suppress these variations?

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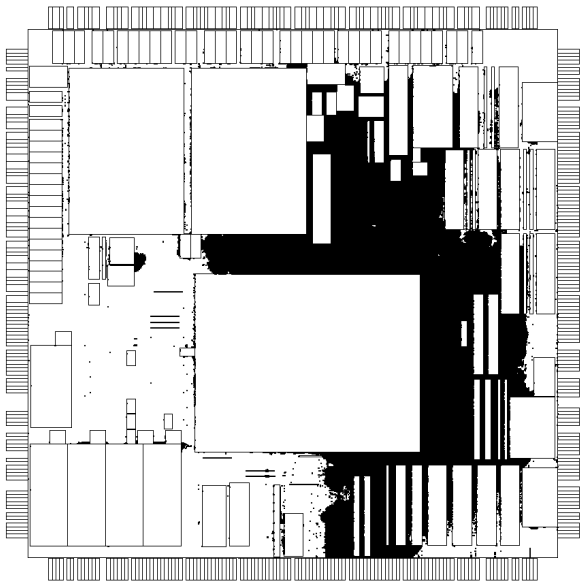
No!

Can we suppress these variations?

No!

Definitely not

$\Rightarrow$ measure again and again



Lookahead legalization

- Introduced by SimPL [2]

Lookahead legalization

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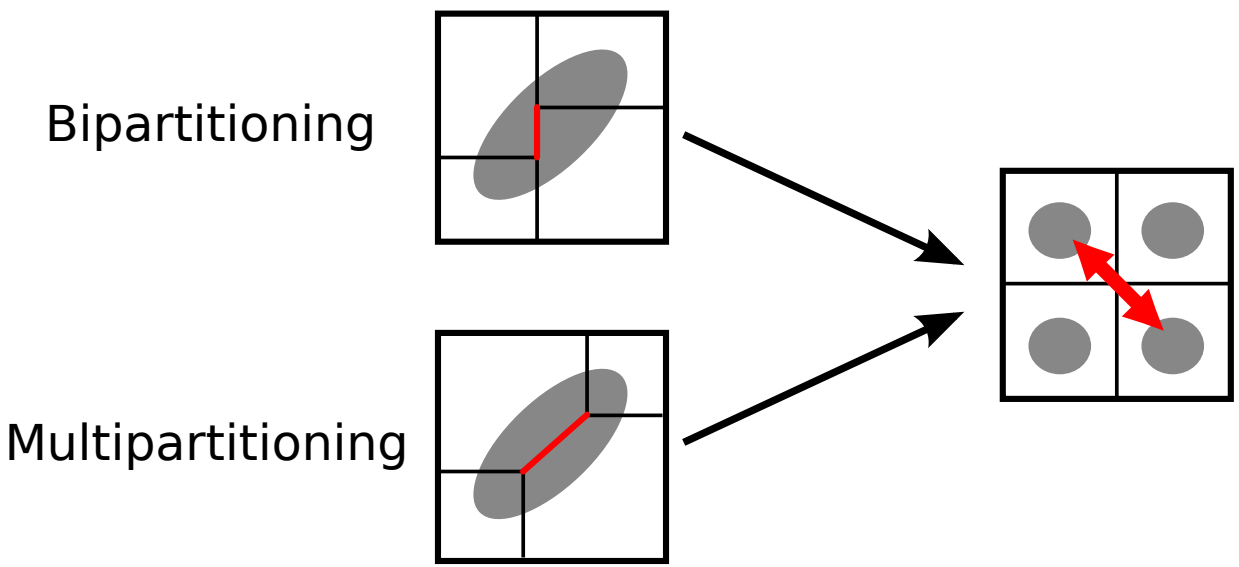
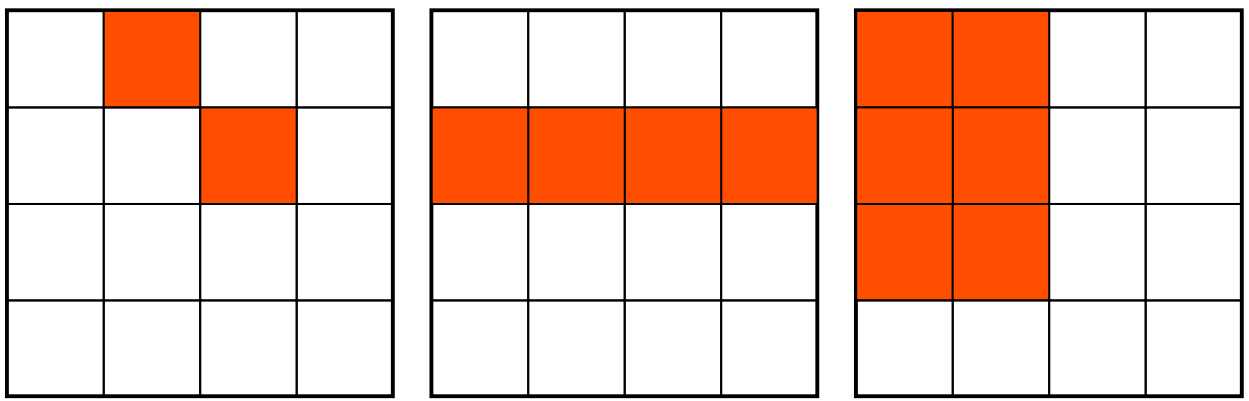
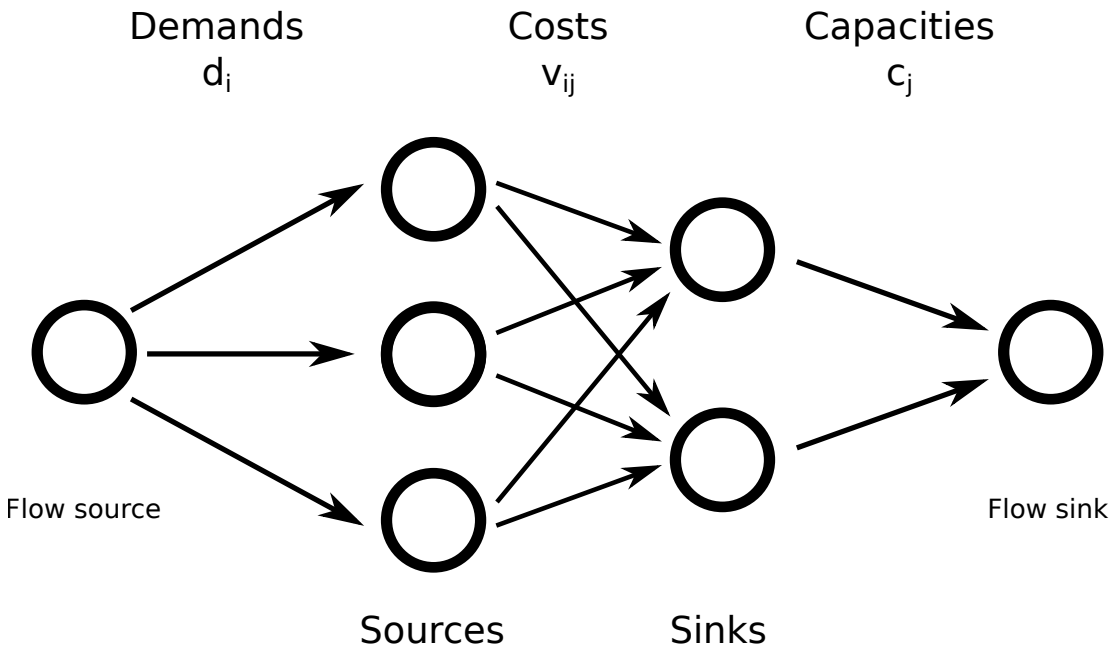
- Always based on partitioning



In Coloquinte: local optimizations



A transportation problem



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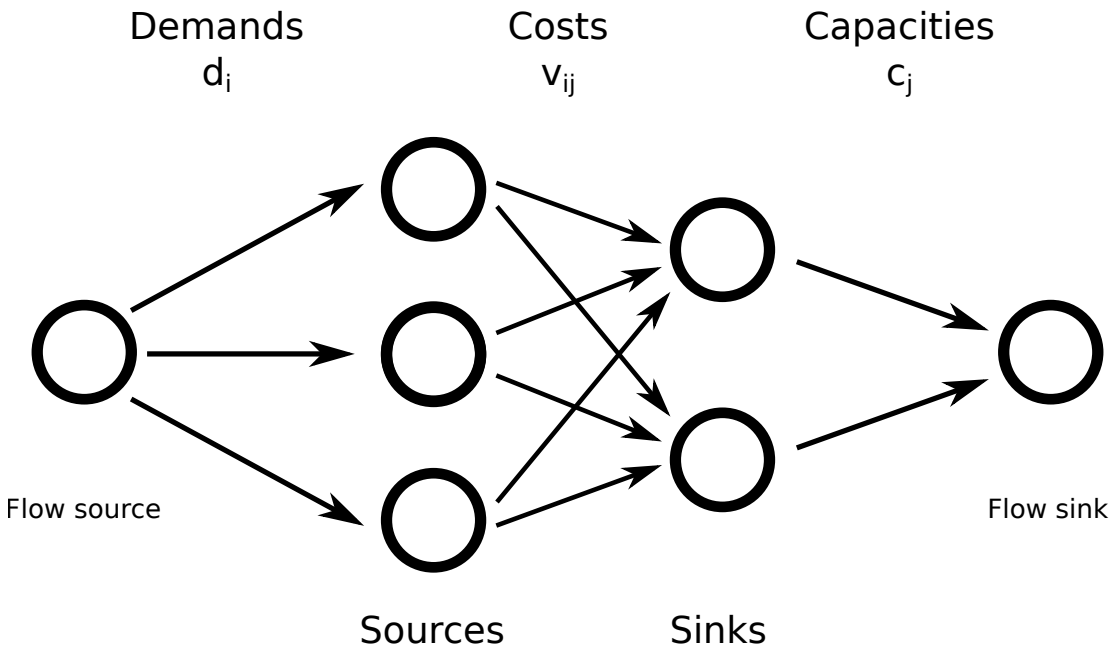

$\Omega(n^3)$ algorithms

Visual results

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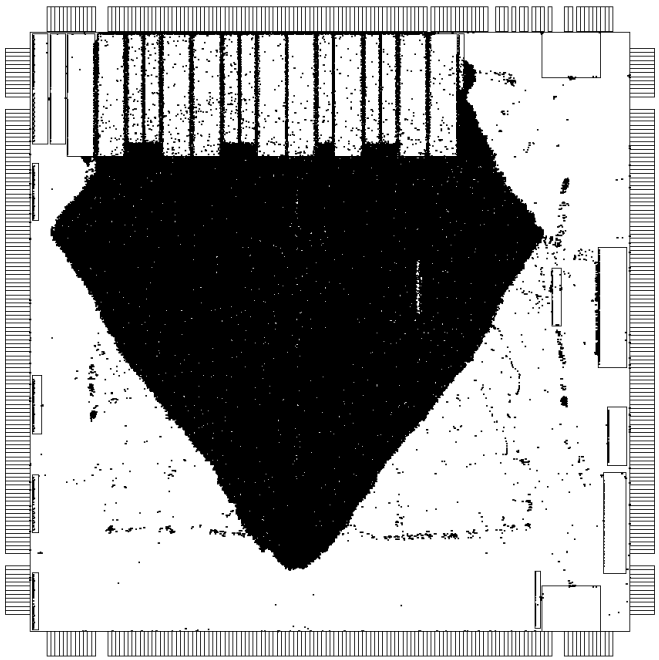

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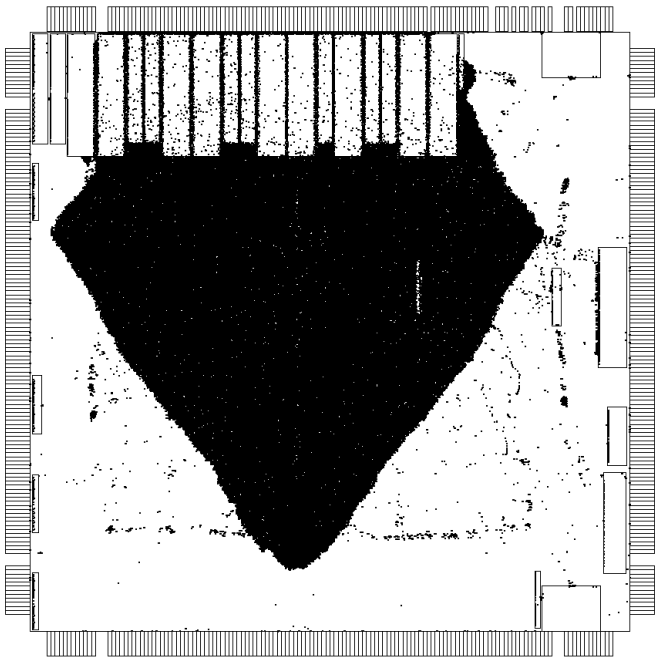

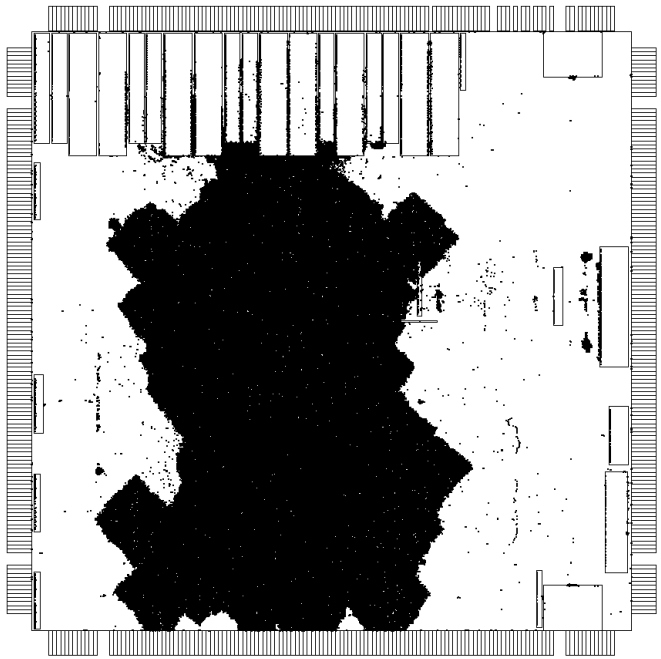

True legalization

Usually greedy

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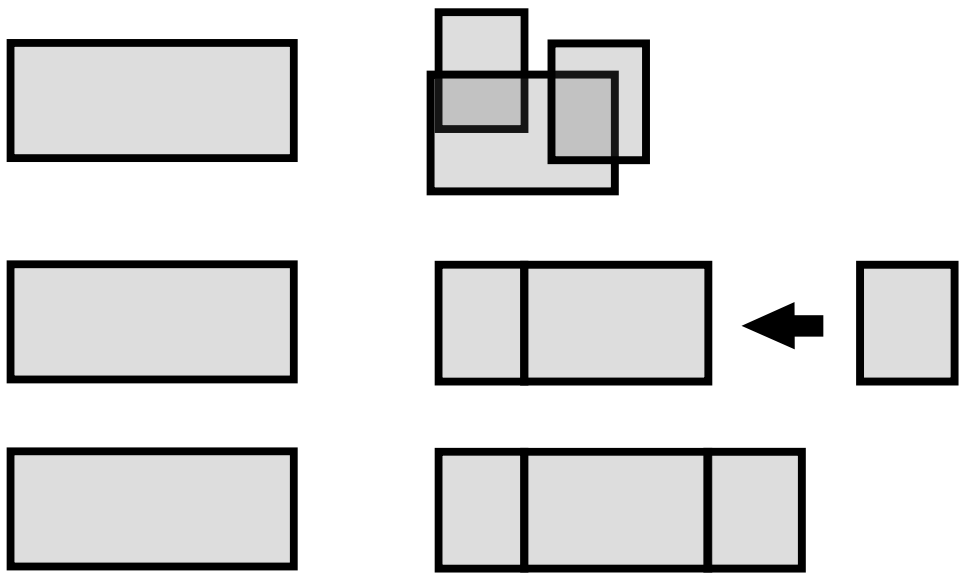

True legalization in Coloquinte

Push the previous cells [7]

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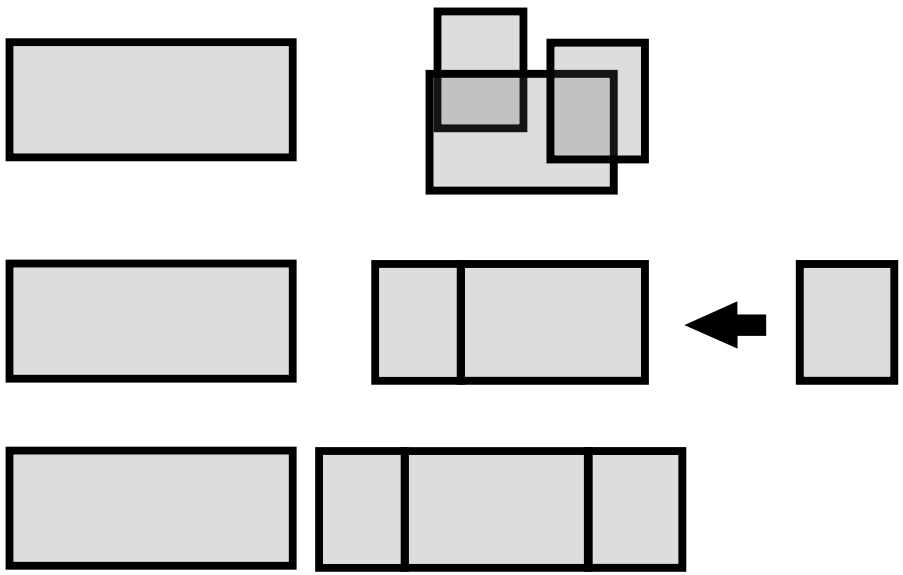

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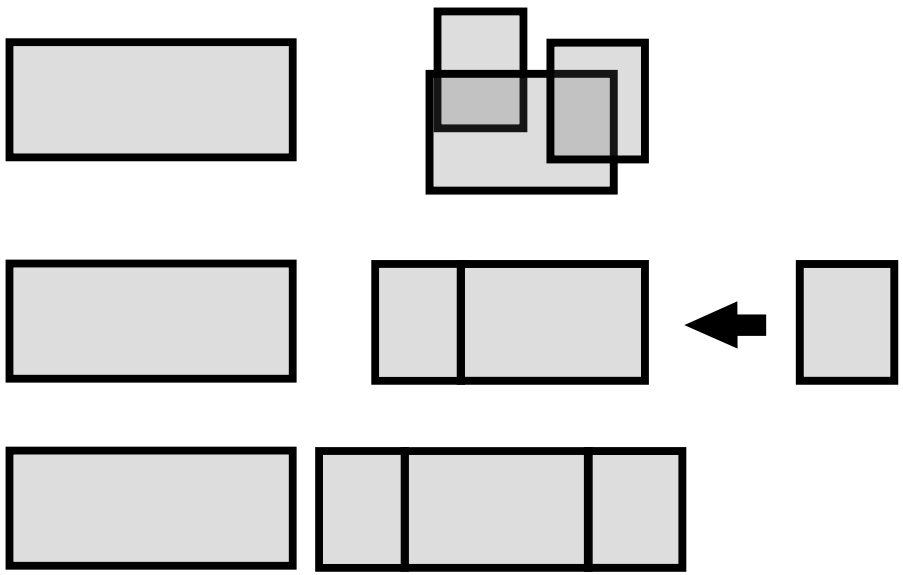

Even better: after a rough legalization

Placement $\approx$ scheduling

$$\text{Machines} \Leftrightarrow \text{Rows}$$
$$\text{Tasks} \Leftrightarrow \text{Uniform-height cells}$$
$$? \Leftrightarrow \text{Wirelength}$$

Our cost function is complicated

$\Rightarrow$ The cells are not independent

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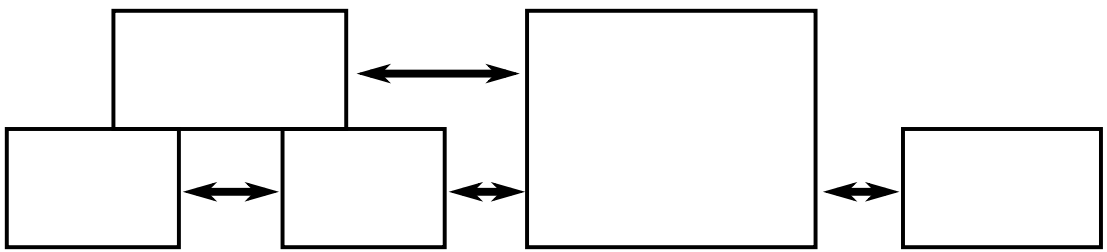
$\Rightarrow$ The cells are not independent

At fixed scheduling-order, dual of a *Minimum-cost flow problem*

Minimize $\sum \alpha_i x_i$
Subject to $x_{i_k} - x_{j_k} \leq d_k$



A simplified problem

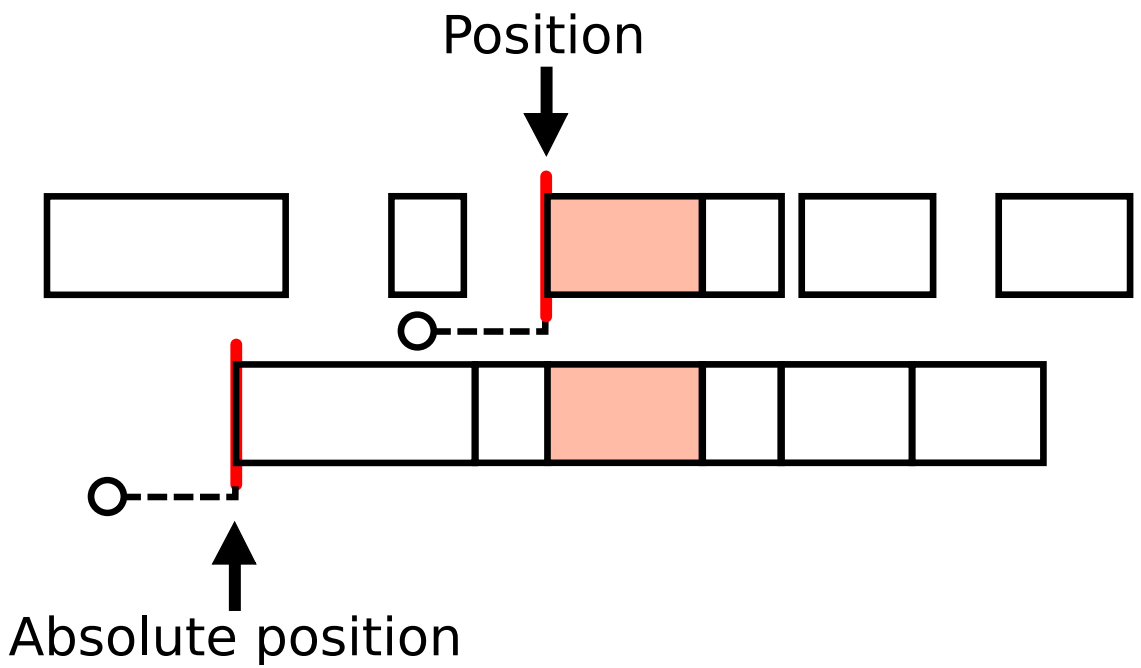
Single row with fixed ordering
=
Single machine with fixed ordering

The cascading descent algorithm

Greedy algorithm with a single heap

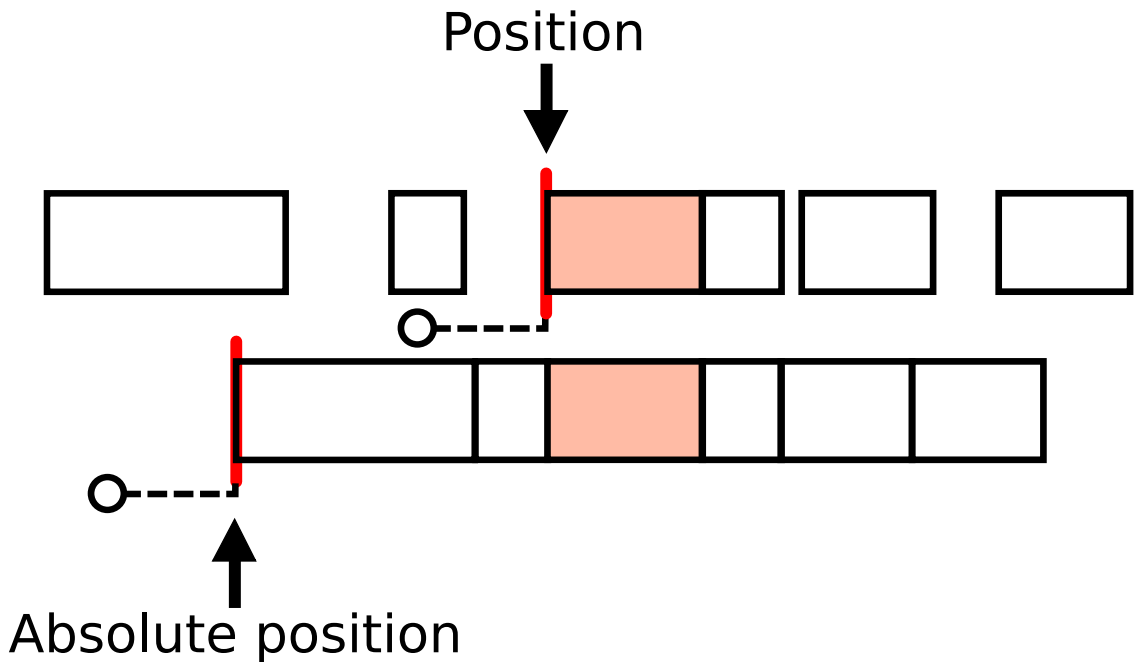
The cascading descent algorithm

Greedy algorithm with a single heap



The cascading descent algorithm

Greedy algorithm with a single heap



$O(n \log n)$ [4]

First use for placement

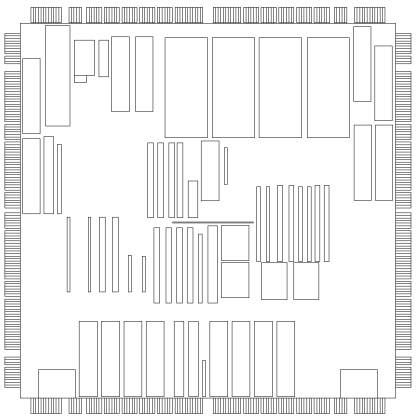
Everywhere in Coloquinte:

First use for placement

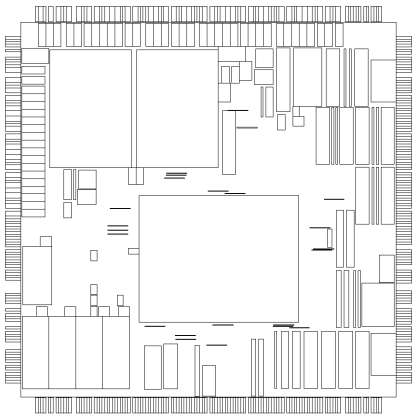
Everywhere in Coloquinte:

- Lookahead legalizer
- True legalizer
- Detailed placement reordering
- Whitespace allocation in detailed placement

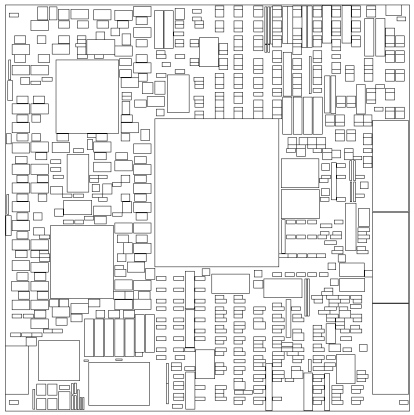
The ISPD05 benchmarks



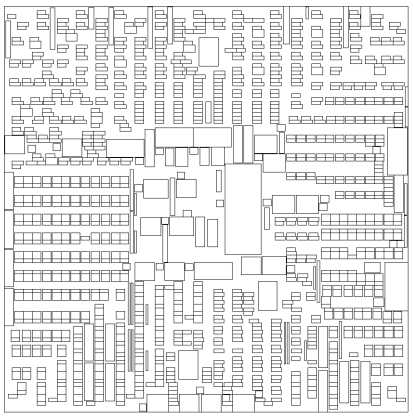
Adaptec1



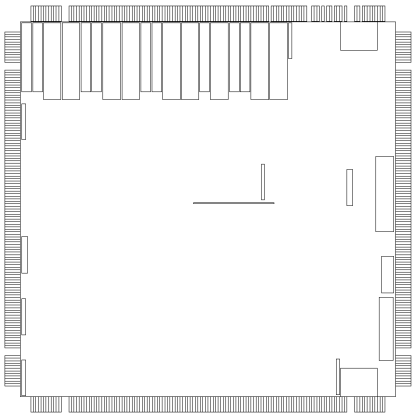
Adaptec2



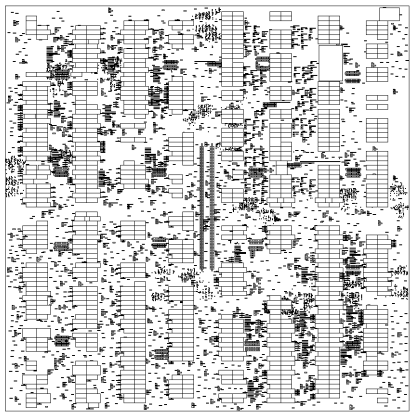
Adaptec3



Adaptec4

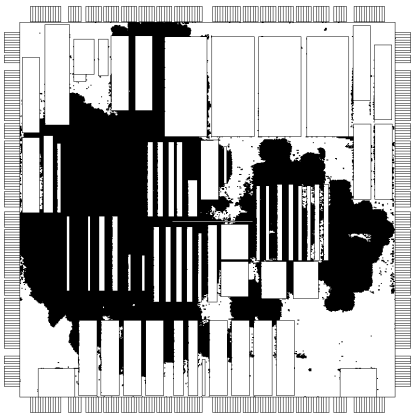


Bigblue1

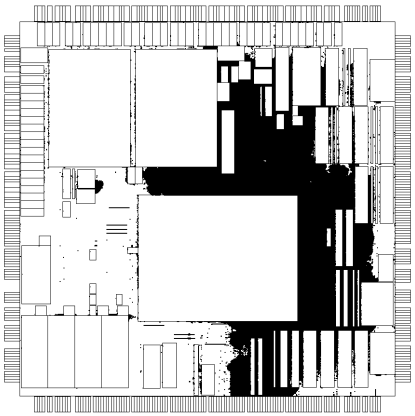


Bigblue2

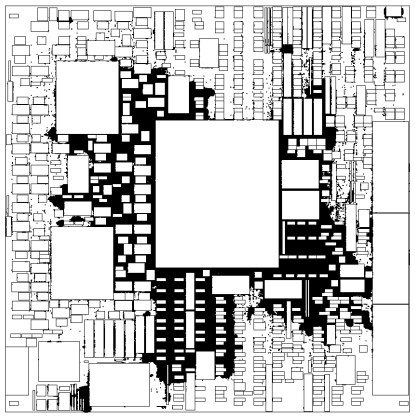
ISPD05 placements



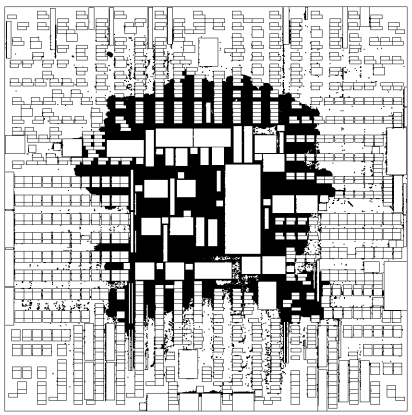
Adaptec1



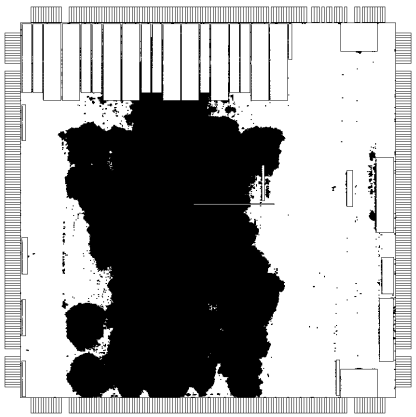
Adaptec2



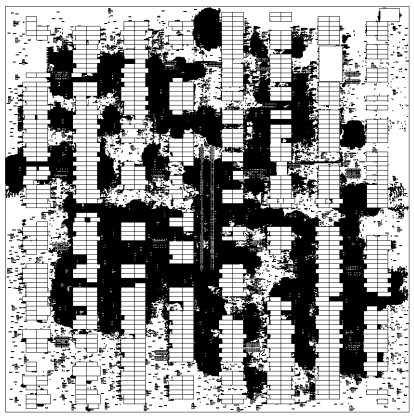
Adaptec3



Adaptec4



Bigblue1



Bigblue2

Not bad

Problem	ePlace	Best quadratic	Coloquinte	%
Adaptec1	**74.63**	76.36 (Maple)	76.49	+2.49
Adaptec2	**84.84**	86.16 (POLAR)	87.90	+3.61
Adaptec3	**194.57**	201.30 (POLAR)	202.12	+3.88
Adaptec4	**179.02**	179.91 (Maple)	182.27	+1.82
Bigblue1	**90.99**	93.74 (Maple)	94.76	+4.14
Bigblue2	141.83	143.95 (POLAR)	**141.16**	**-0.47**
Bigblue3	**308.77**	317.17 (Bonn)	#	#
Bigblue4	**753.20**	775.71 (Maple)	#	#

Quality comparison: HPWL (10^6 units)

Further work: placement

Further work: placement

- Switch to Nesterov optimization

Further work: placement

- Switch to Nesterov optimization
- More legalization improvements

Further work: placement

- Switch to Nesterov optimization
- More legalization improvements
- Performance tuning

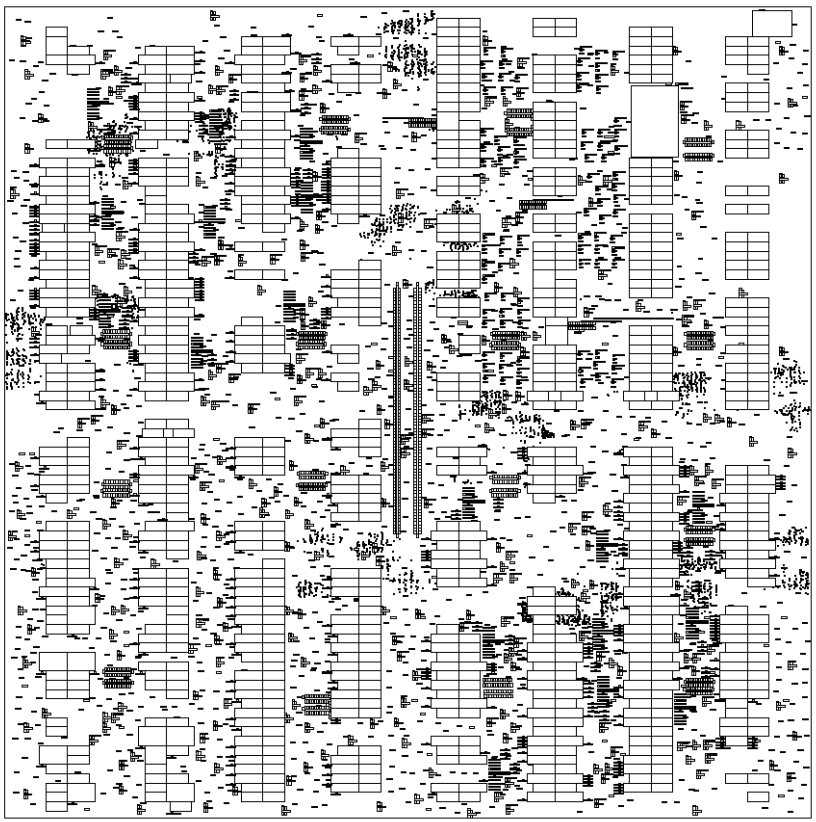
Further work: placement

- Switch to Nesterov optimization
- More legalization improvements
- Performance tuning
- Integer programming in detailed placement

Further work: routing, synthesis

- Gridless routing
- Specialized multiplier synthesis
- Placement-aware resynthesis

Questions



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