New Modeling Techniques for the Global Routing Problem

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November 2, 2004

Outline

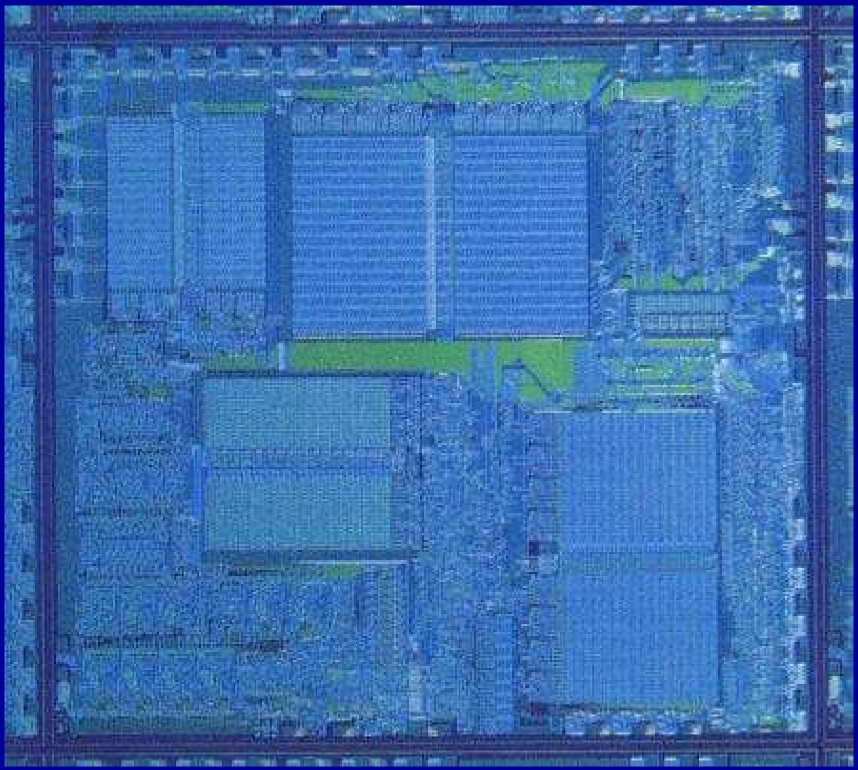
- Introduction
- Global Routing
- Modeling Techniques
- Optimization Techniques
- Summary and Conclusions

Major Contributions

- Development of route construction techniques based on congestion.
- Development of congestion estimation techniques.
- Development of flexible and powerful multi-objective formulations.
- Enhancement of numerical techniques to solve the global routing problem.

Introduction

- Today's ICs contain millions of transistors.
- VLSI: *"Very Large Scale Integration"* .
- Performance criteria:
  - Ø Delay
  - Ø Power
  - Ø Size
- Routing is one of the most important factors in VLSI design.

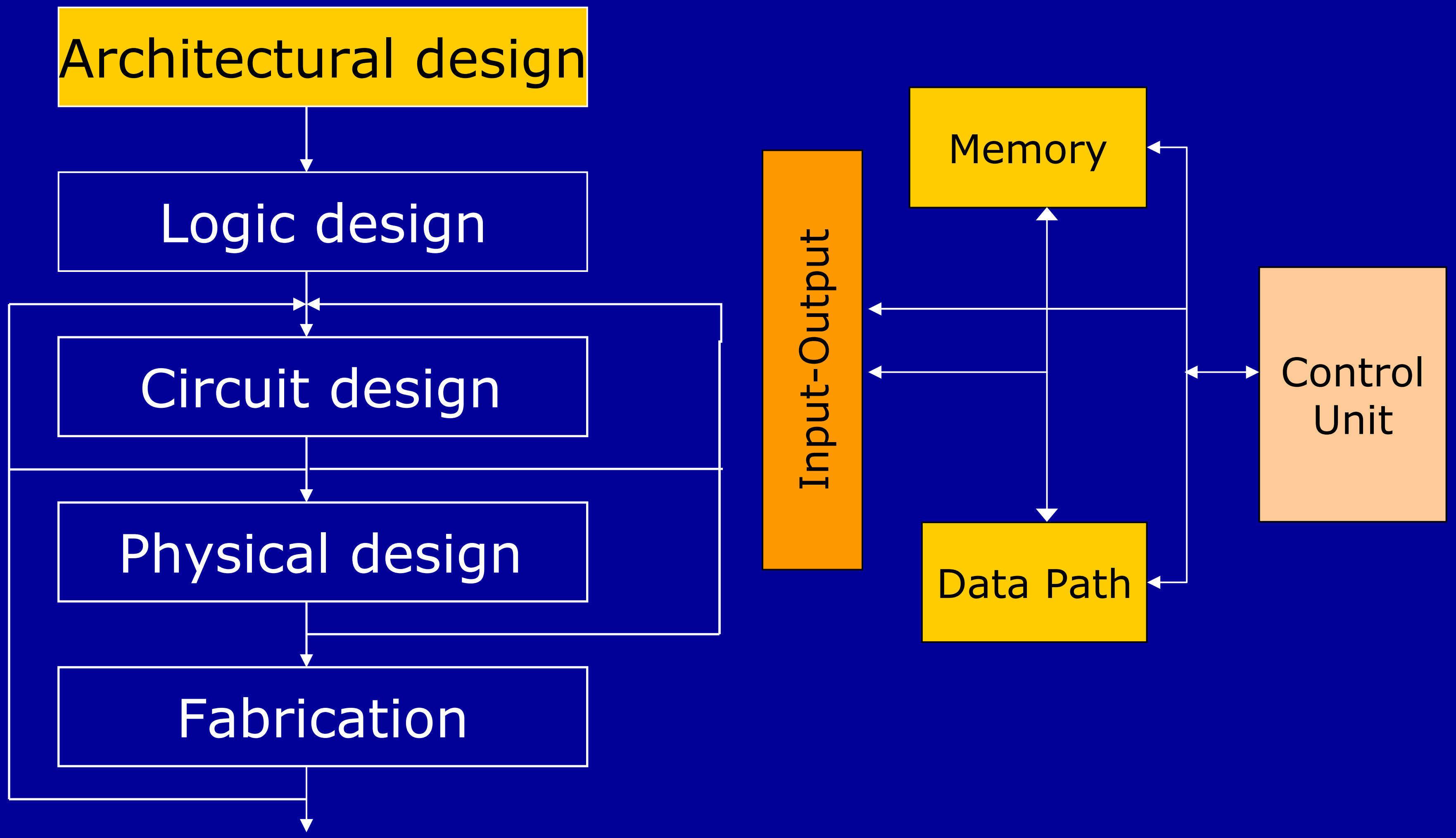


Why Is Routing Important?

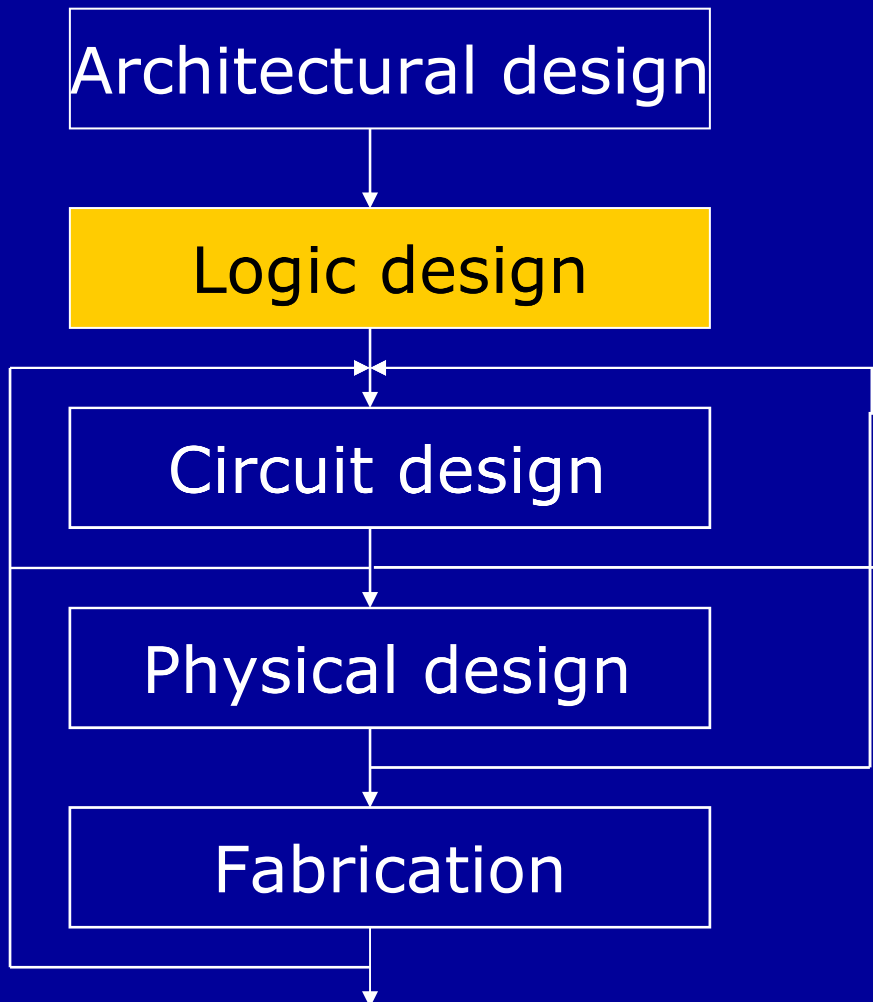
Intel Microprocessors

microprocessor	Date of introduction	Number of transistors	Feature size (microns)
80286	1982	**134,000**	1.5
80386	1985	**275,000**	1.5
80486	1989	**1,200,000**	1.0
Pentium	1993	**3,100,000**	0.8
Pentium Pro	1995	**5,500,000**	0.6
Pentium 4	2000	**46,000,000**	0.18

VLSI Design


Architectural design
Logic design
Circuit design
Physical design
Fabrication
Input-Output
Memory
Data Path
Control Unit

VLSI Design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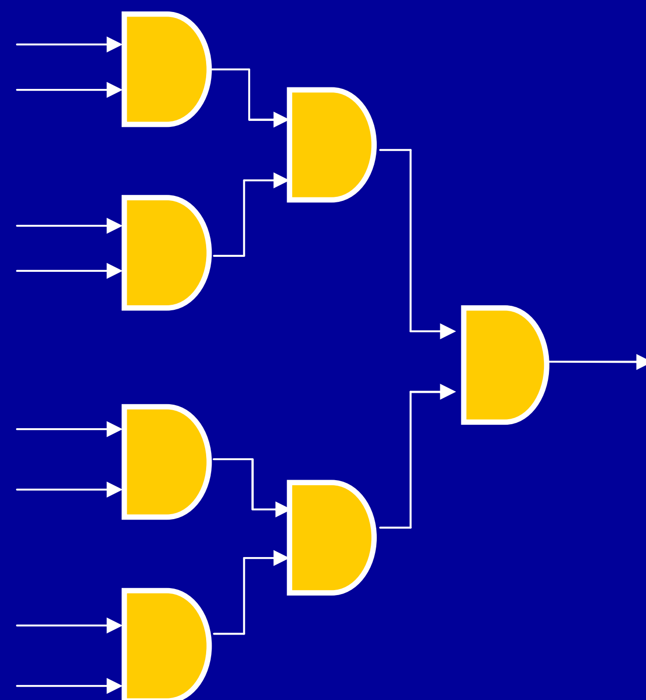
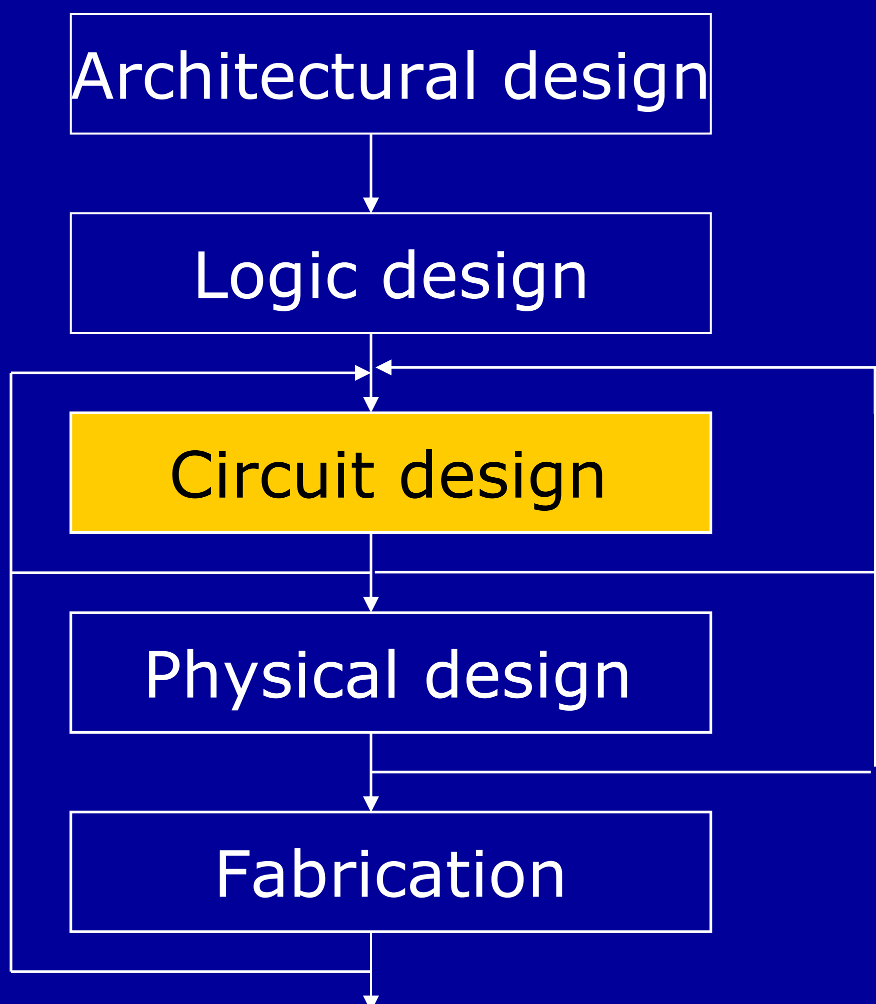
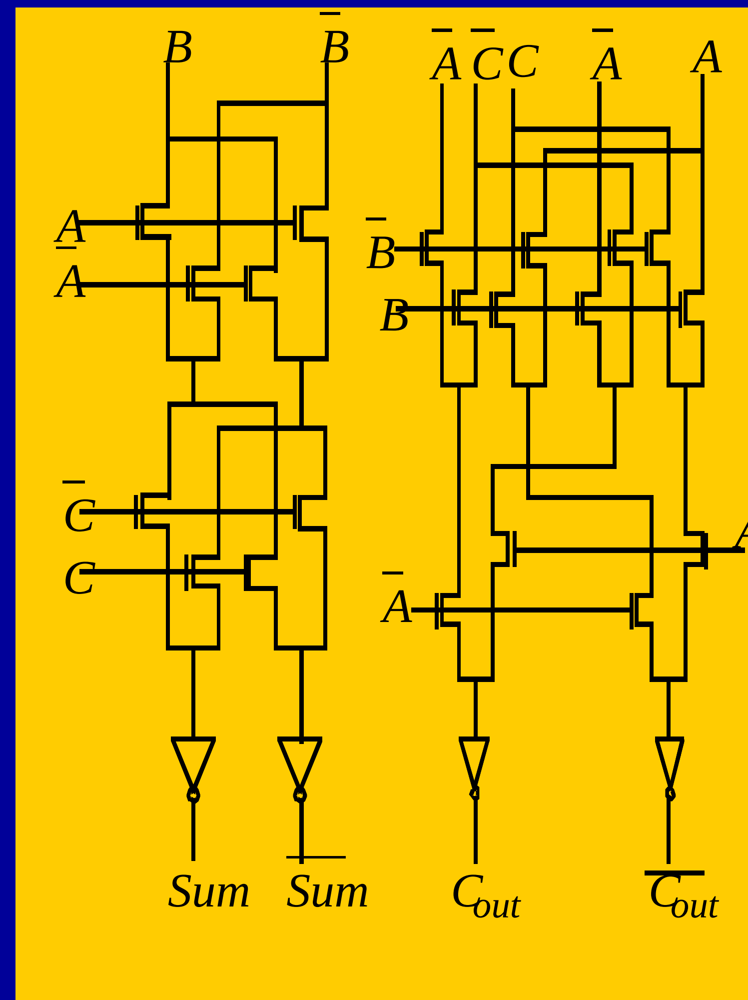
Circuit design
Physical design
Fabrication



VLSI Design



Architectural design
Logic design
Circuit design
Physical design
Fabrication



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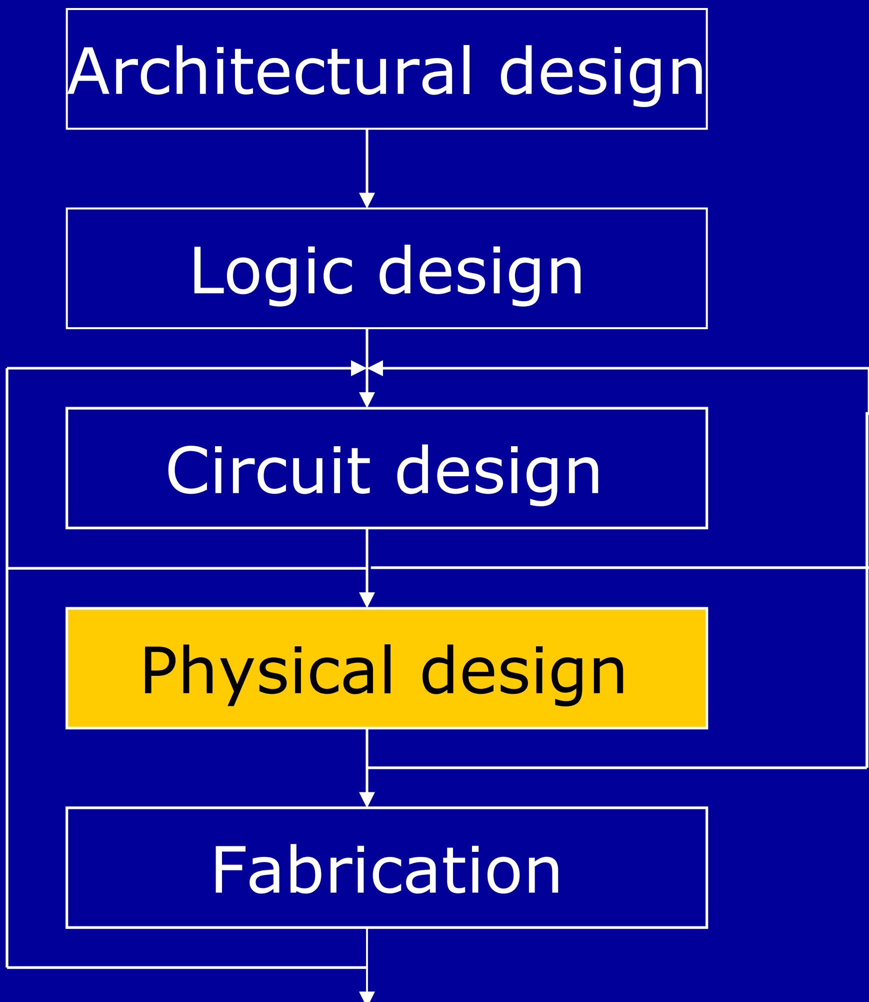
VLSI Design


Architectural design
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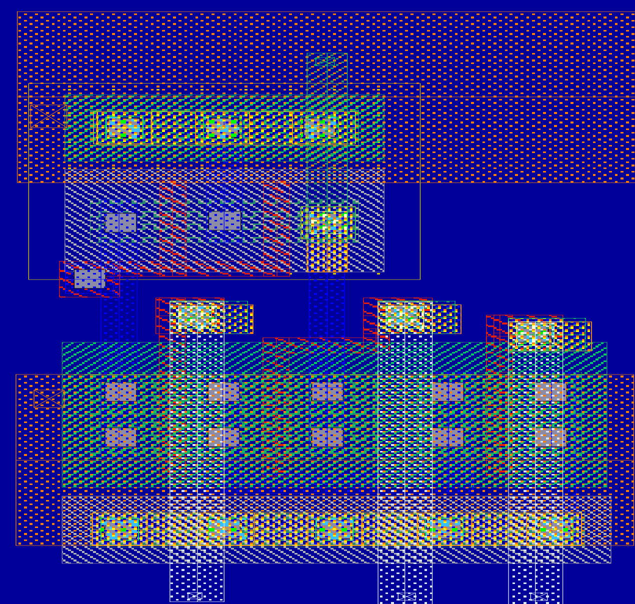
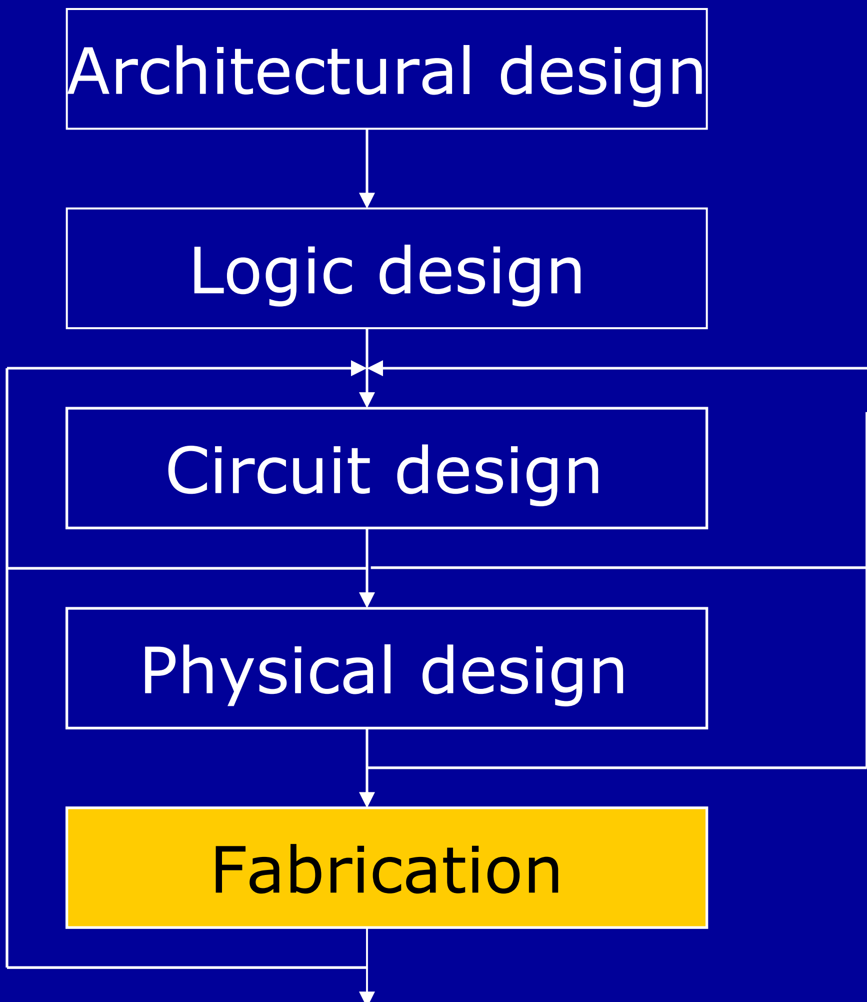
Fabrication



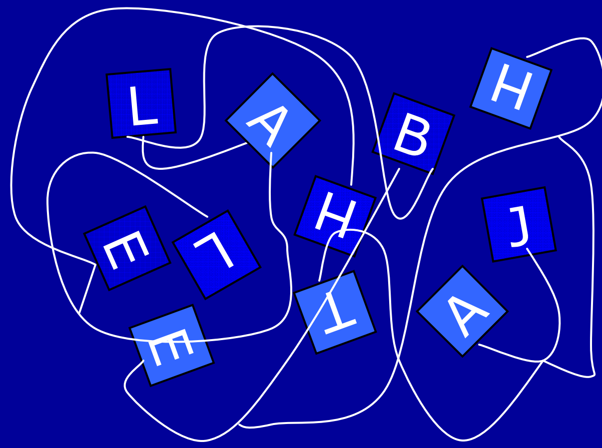
VLSI Design


Architectural design
Logic design
Circuit design
Physical design
Fabrication


Metal 4
Metal 3
Metal 2

Circuit Layout

- Places the modules.
- Runs the wires that connect them.



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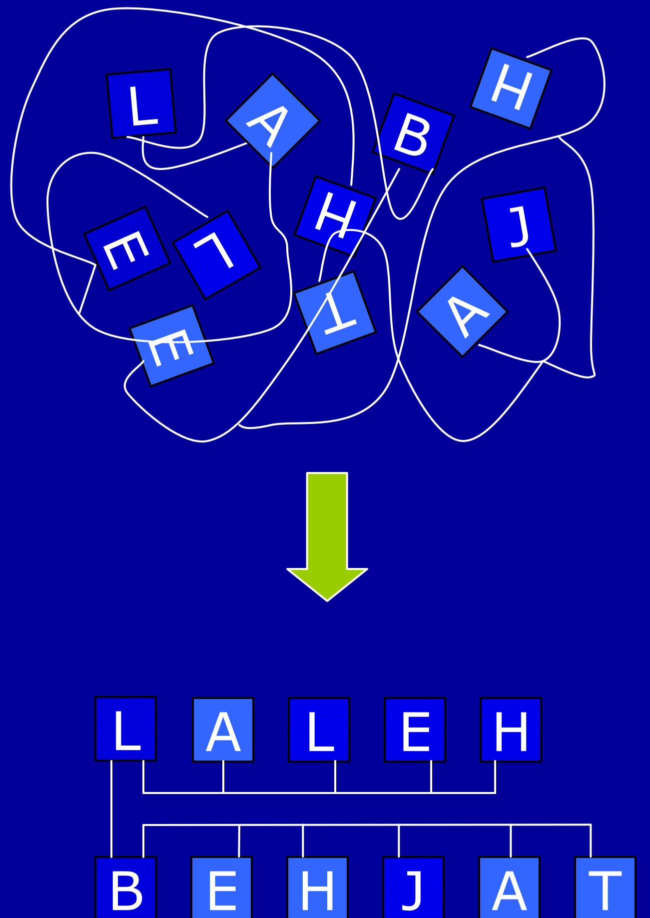

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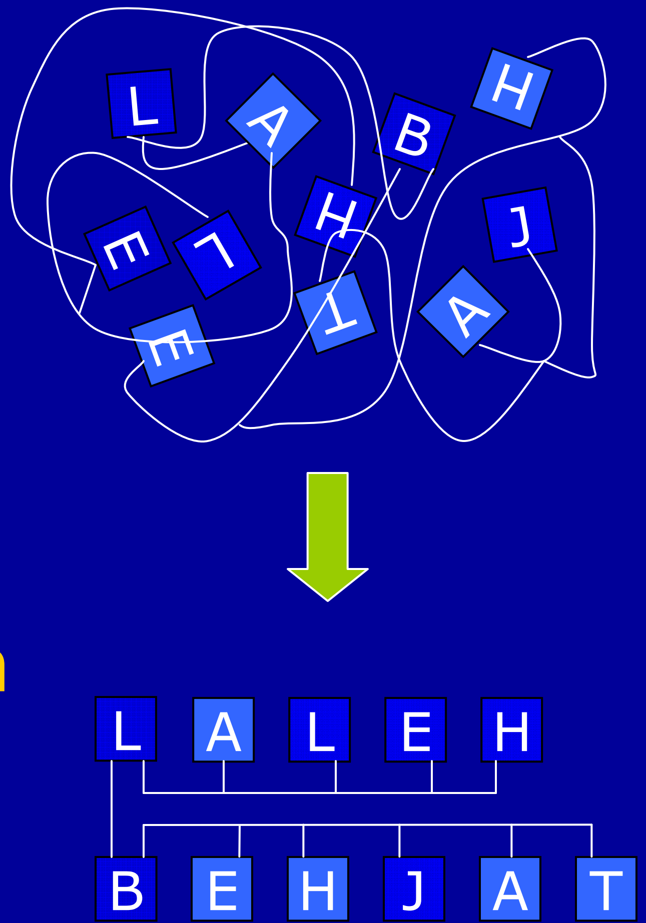
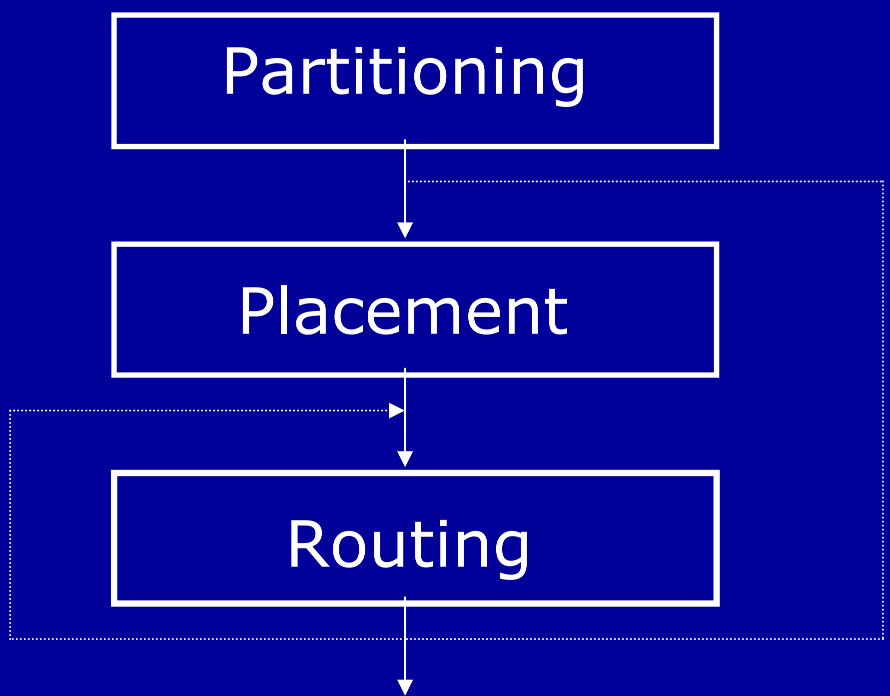


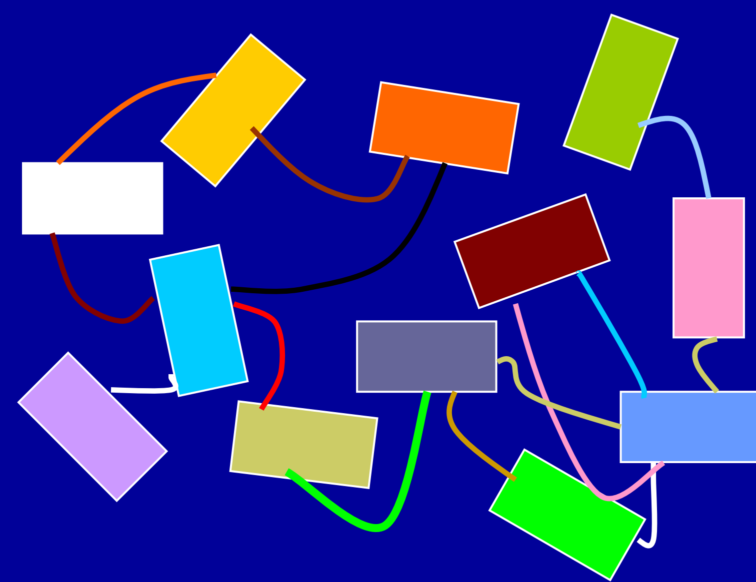
Typical Objectives:

- Minimize the wire length
- Minimize the delay
- Minimize the power

Circuit Layout

Normally divided into steps





Circuit Layout

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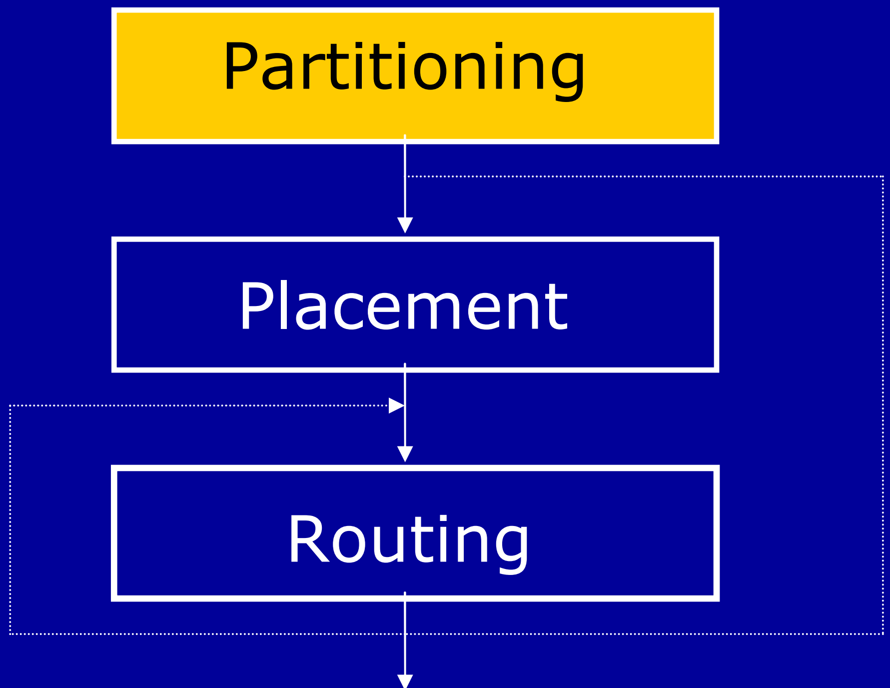
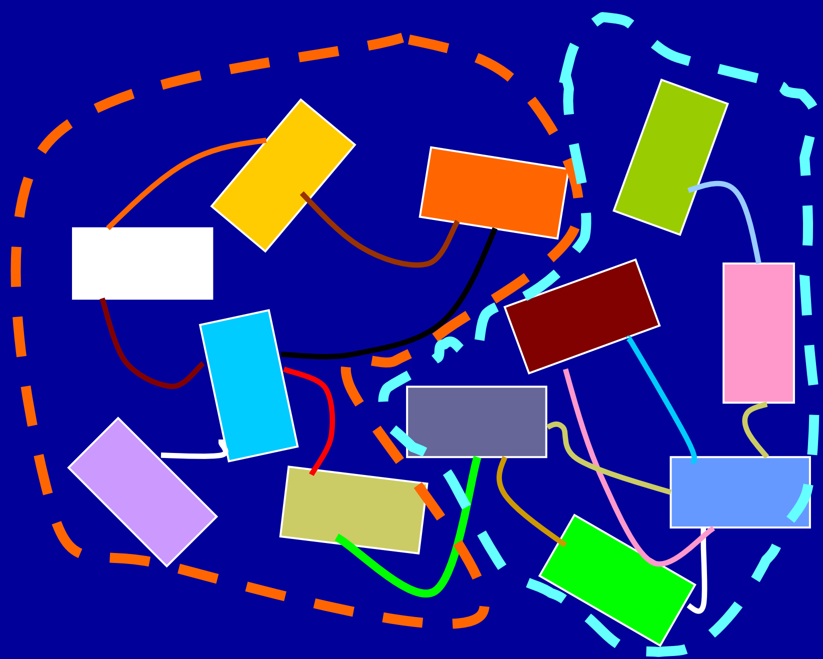
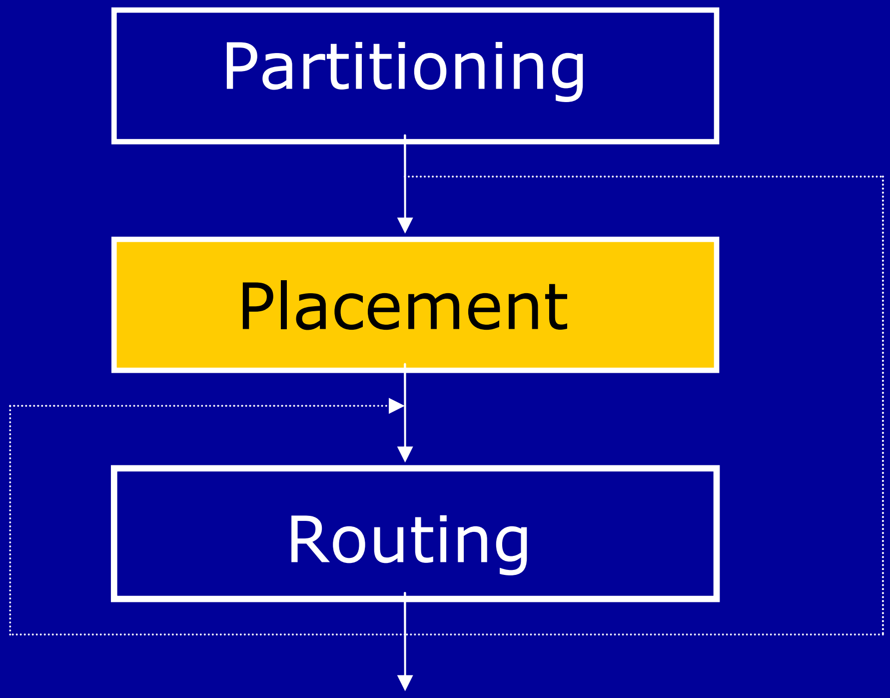
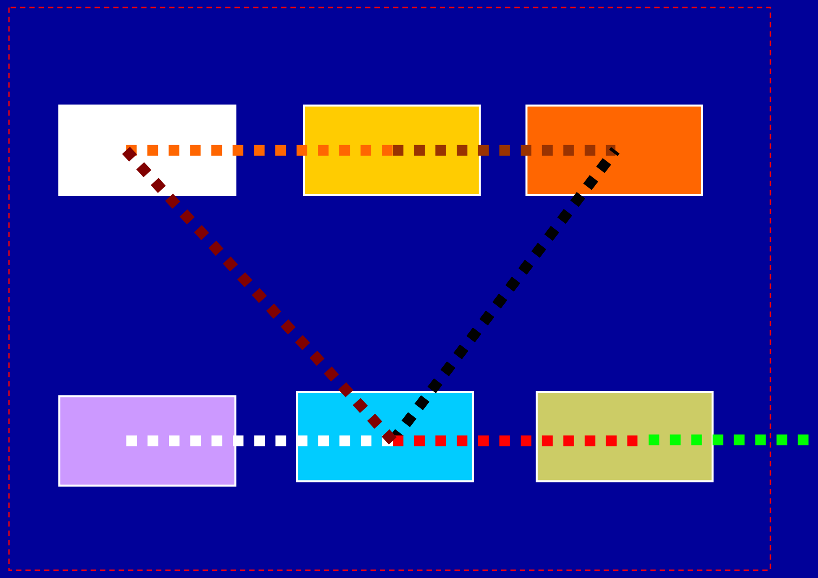




Circuit Layout

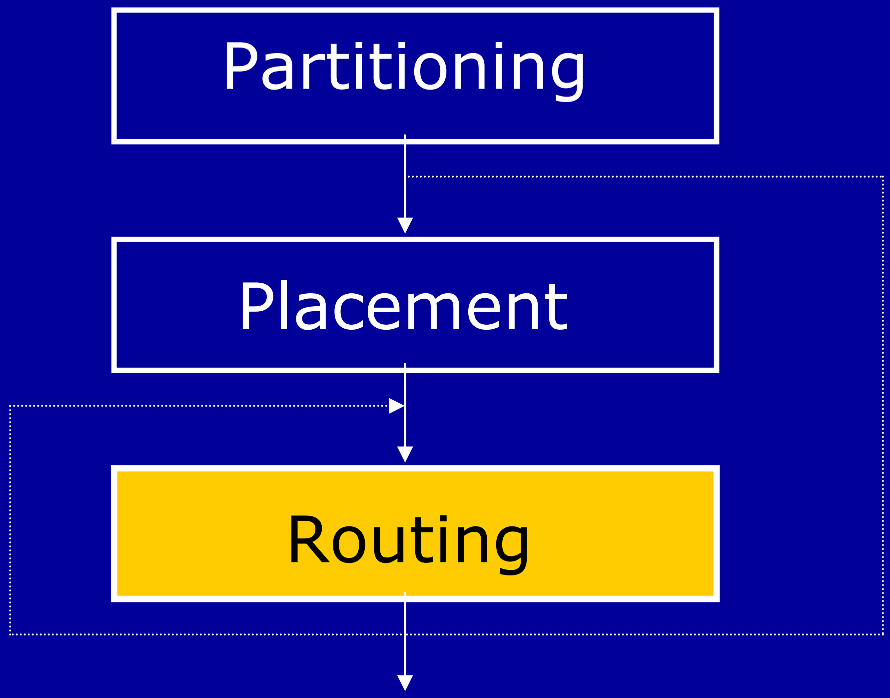
Normally divided into steps

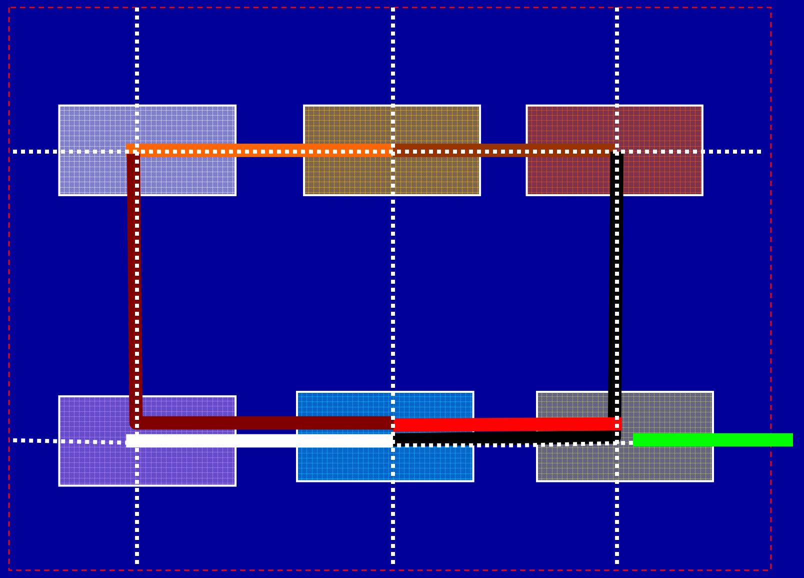




Circuit Layout

Normally divided into steps

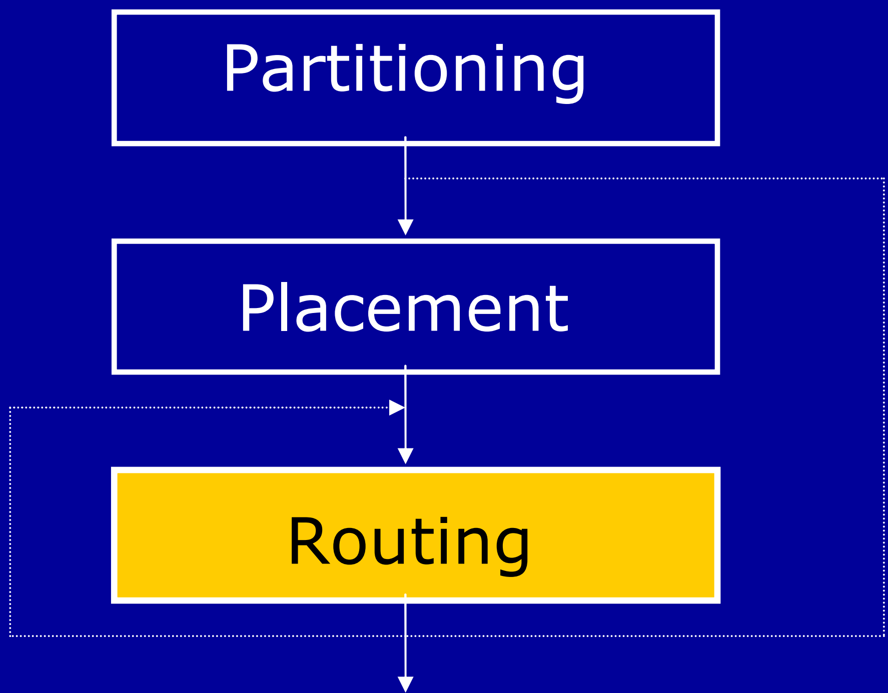


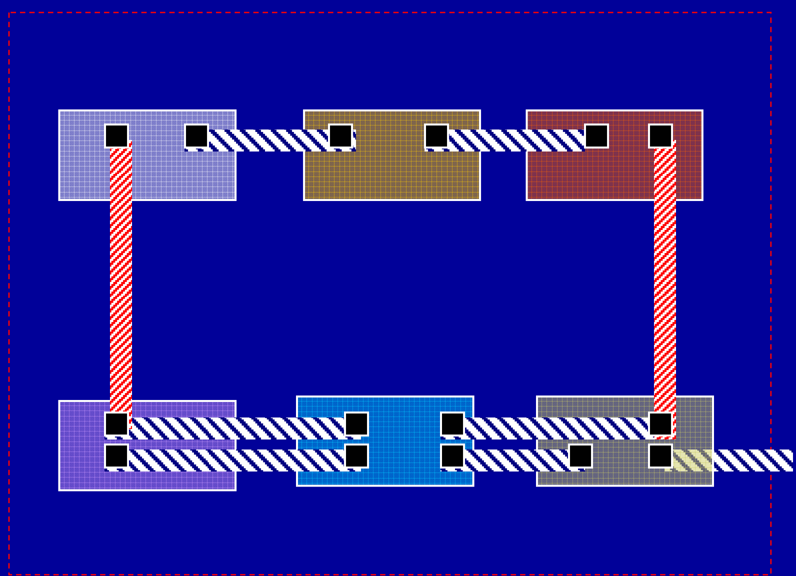


Global Routing

Circuit Layout

Normally divided into steps





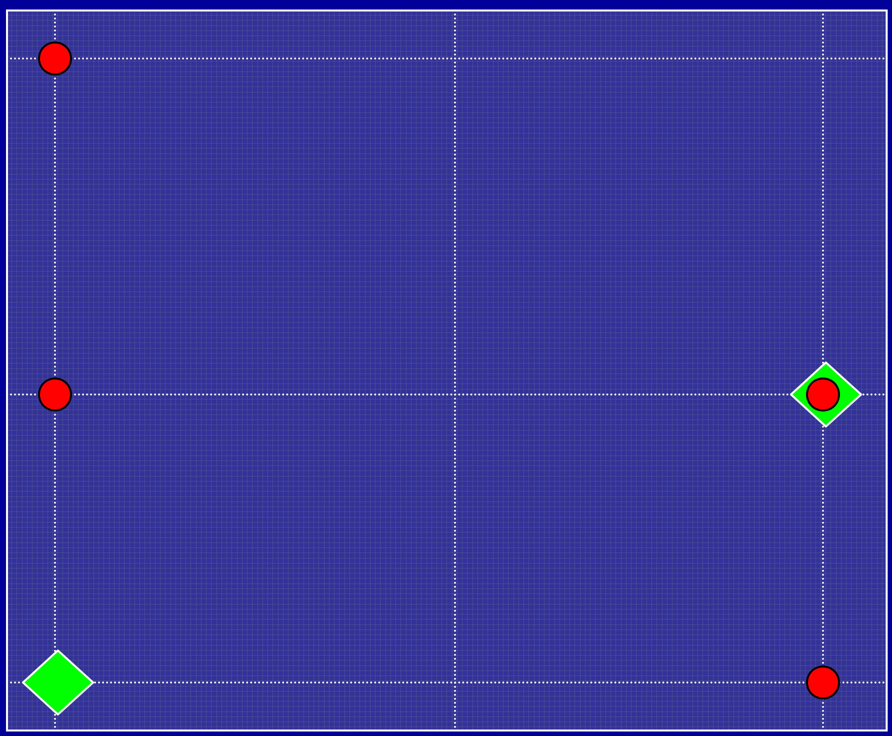
Detailed Routing

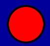
Global Routing

- Global routing is used to find an approximate path for the wires connecting the modules.
- NP-hard problem (i.e. difficult to solve for large problems).
- Solution quality can effect the performance of the circuit.

Illustrative Example

Objective: Minimize the total wire length

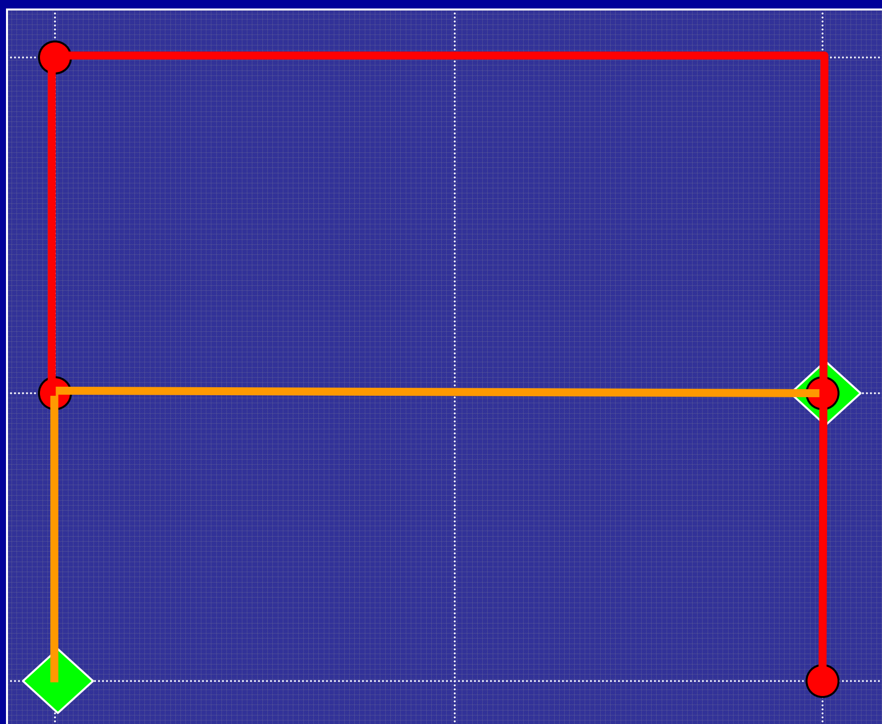


Net *1* terminals: 

Net *2* terminals: 

Illustrative Example

Objective: Minimize the total wire length



Net *1* terminals:

Net *2* terminals:

Total wire length= 8

Global Routing Techniques

Two main techniques:

- Sequential Routing technique:

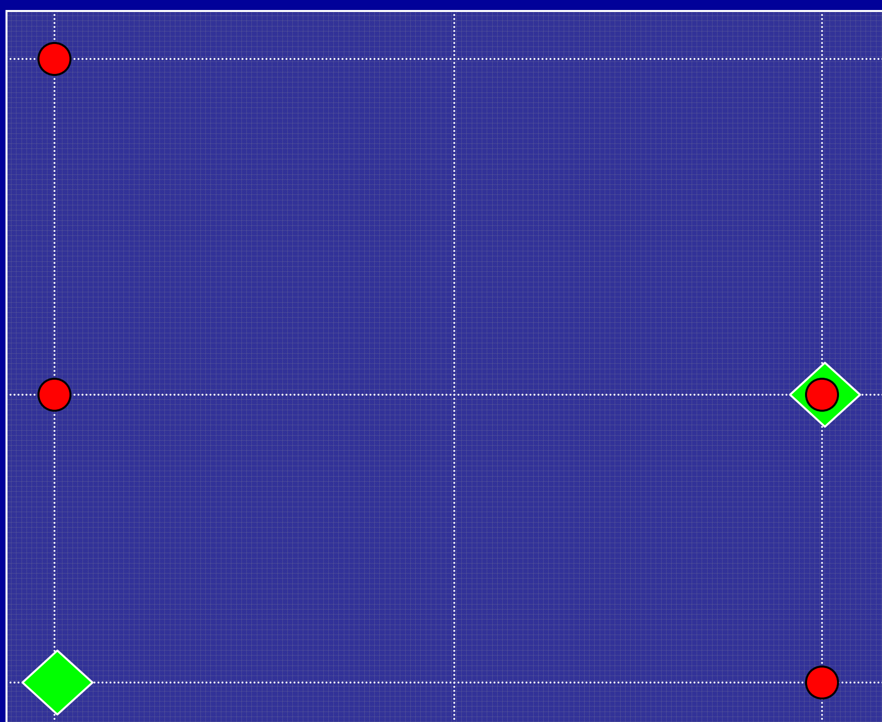
  Nets are routed sequentially.

- Mathematical Programming technique:

  All nets are routed at the same time.

Sequential Routing

- Nets are ordered according to importance.
- Each net is routed separately.

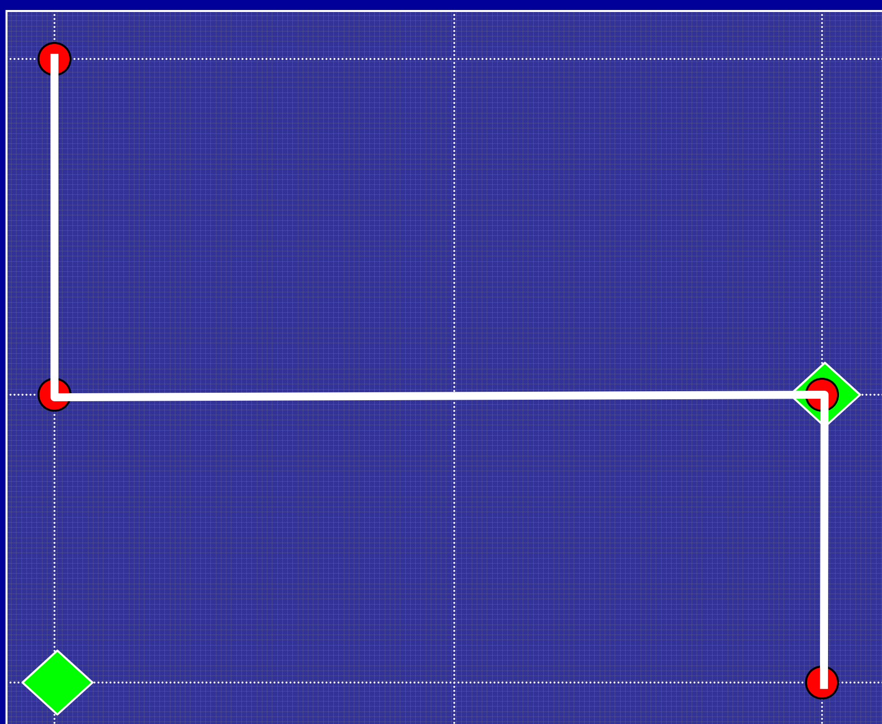


Priority List

1. Net *1*
2. Net *2*

Sequential Routing

- Nets are ordered according to importance.
- Each net is routed separately.



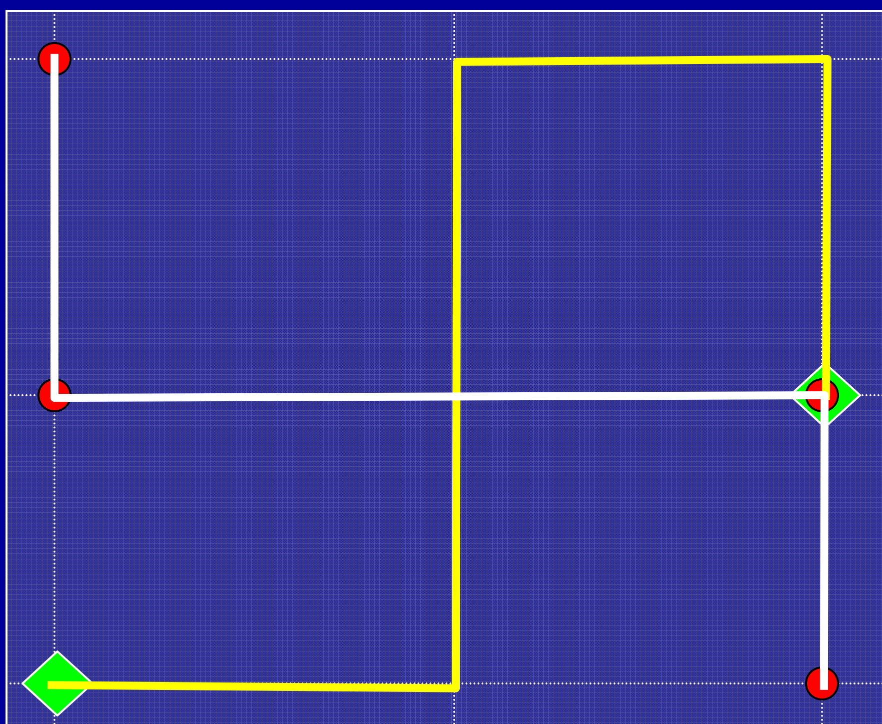
Priority List

1. Net *1*
2. Net *2*

Length of net *1* = 4

Sequential Routing

- Nets are ordered according to importance.
- Each net is routed separately.

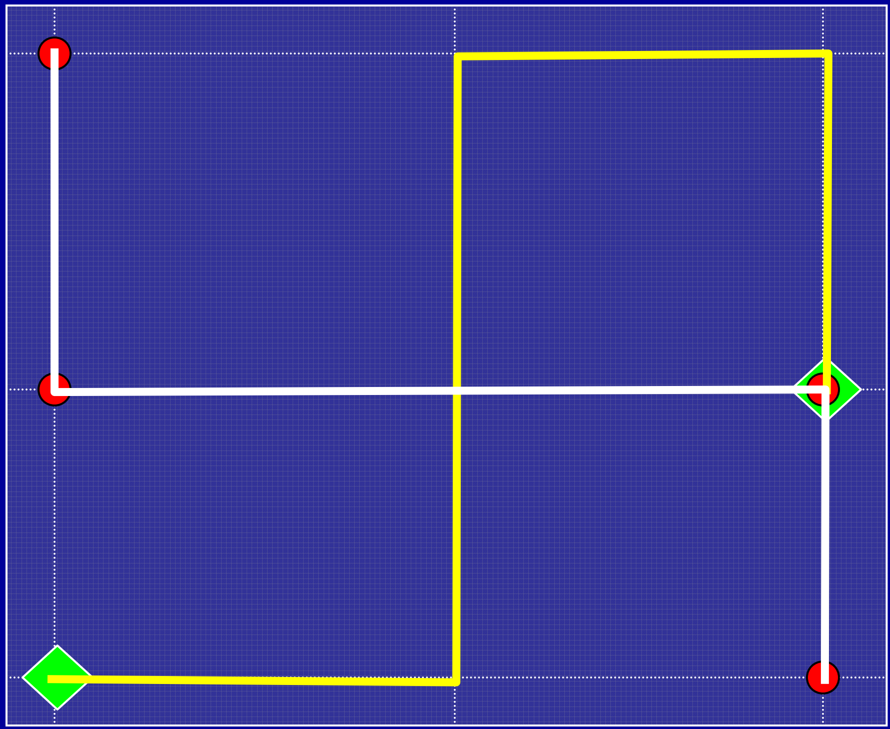


Priority List

1. Net *1*
2. Net *2*

Length of net *1* = 4
Length of net *2* = 5

Sequential Routing



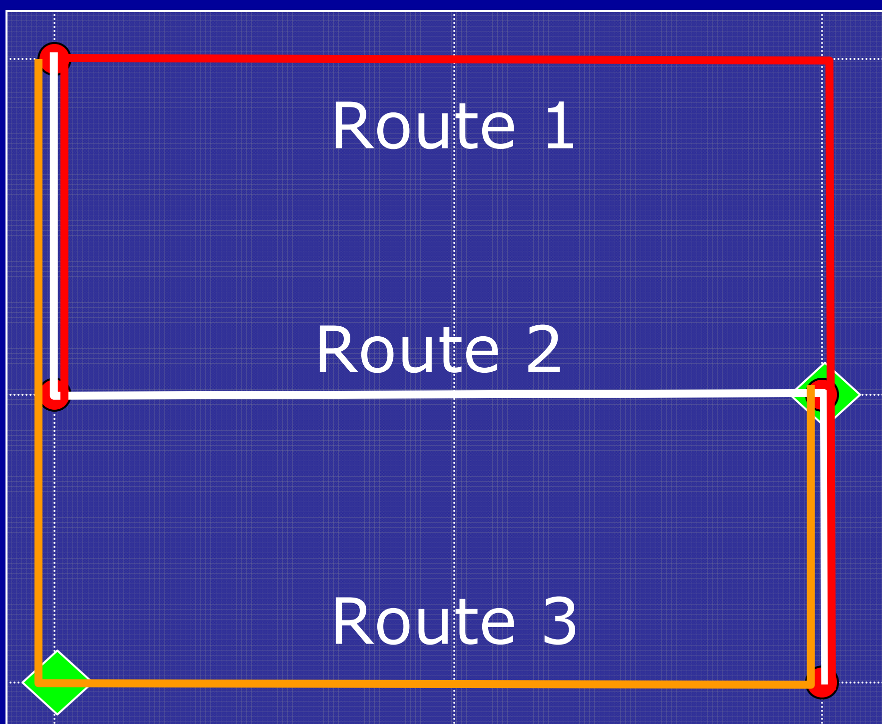
Total wire length:
9

Drawback:

The solution is dependent on net ordering

Mathematical Programming

- A set of routes is made for each net.
- Each route is assigned a binary variable.



Net 1 Routes:

Route 1: Y_1

Route 2: Y_2

Route 3: Y_3

$$Y = \begin{cases} 1 \text{ - Route selected} \\ 0 \text{ - Otherwise} \end{cases}$$

Mathematical Programming

- An Integer Linear Programming (ILP) problem is written:

$$\min \; \Sigma\, \omega_L\, y_i$$

Subject to:

- *For each net only one route can be chosen.*
- *Number of routes passing through a channel can not exceed the maximum channel capacity.*
- *Binary constraints on routes.*

Drawbacks

- The total number of possible routes can be very large.
- Each route is a binary variable in the optimization problem.
- Optimization problem becomes very large and hard to solve.

Example: MCNC *Fract* Test Circuit

147 nets $\Rightarrow$ more than 28,000 possible routes

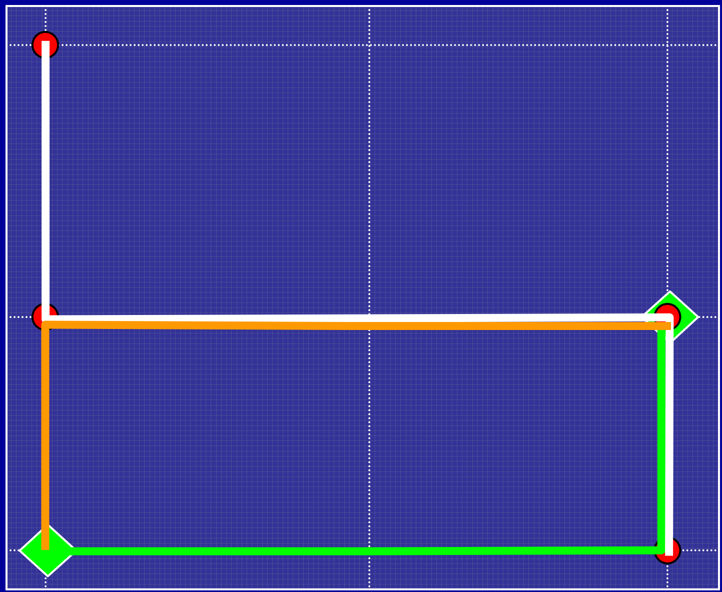
Modeling Techniques

- Develop congestion estimation techniques to construct an optimal set of routes:
  - Least number of routes possible.
  - Least amount of congestion.
- Develop multi-objective modeling techniques.

Route Construction

Initial approach:

- Limit the number of routes considered by making only minimum-length minimum-bend routes.



⇒ Can result in sub-optimal and infeasible solutions.

Route Construction

Proposed enhancement:

- Use congestion techniques to estimate where additional possible routes should be generated.
  - ⇒ Limits the size of the problems.
  - ⇒ Gives feasible and optimal solutions.

Congestion

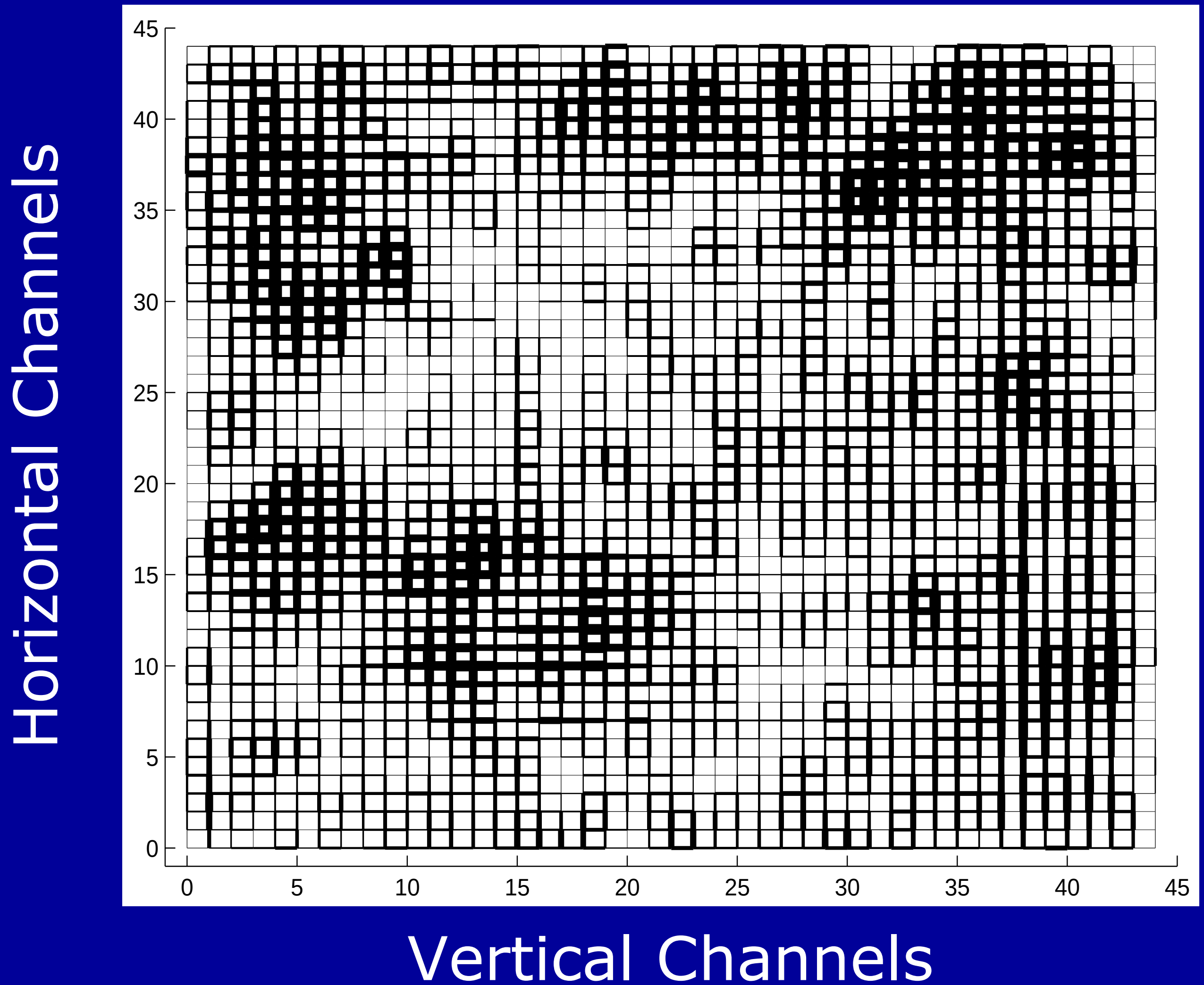
Definition:

In the final solution, there are too many routes in a given channel.

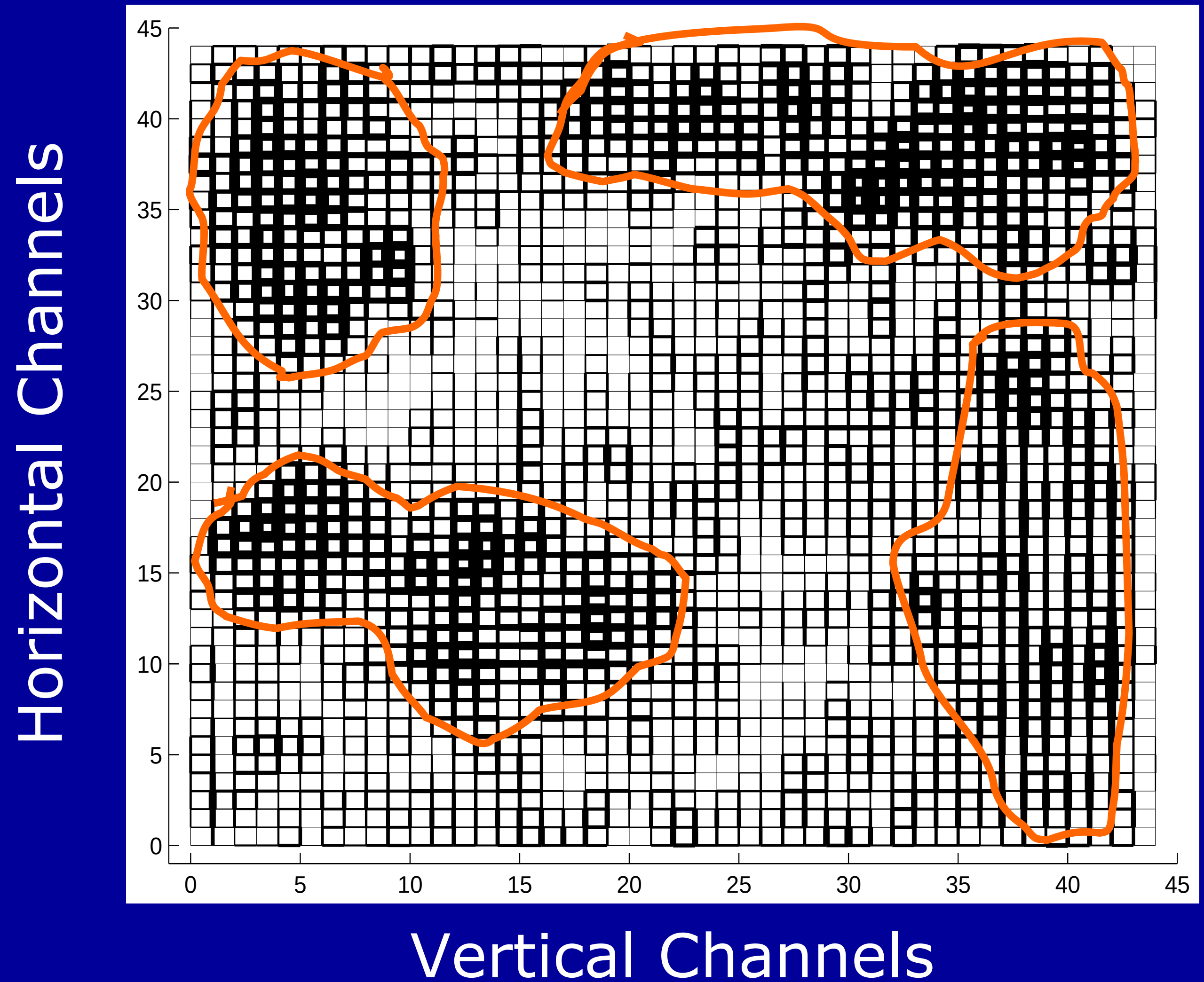
Congested areas can cause:

- Infeasibility
- Hotspots

Example: MCNC *BIO* Test Circuit



Example: MCNC *BIO* Test Circuit



Congestion Estimation Model

Data:

- Number of routes produced for each net.
- Which edge each route passes through.

Objective:

- To estimate the number of routes that might pass through each edge.

Routing Demand

Definition:

- The probability of each route to be chosen:

$$p(Y) = \frac{1}{\text{number of routes in a net}}$$

- *Routing Demand*, *r(e),* of each edge is the sum of the probabilities of the routes that pass through the edge.

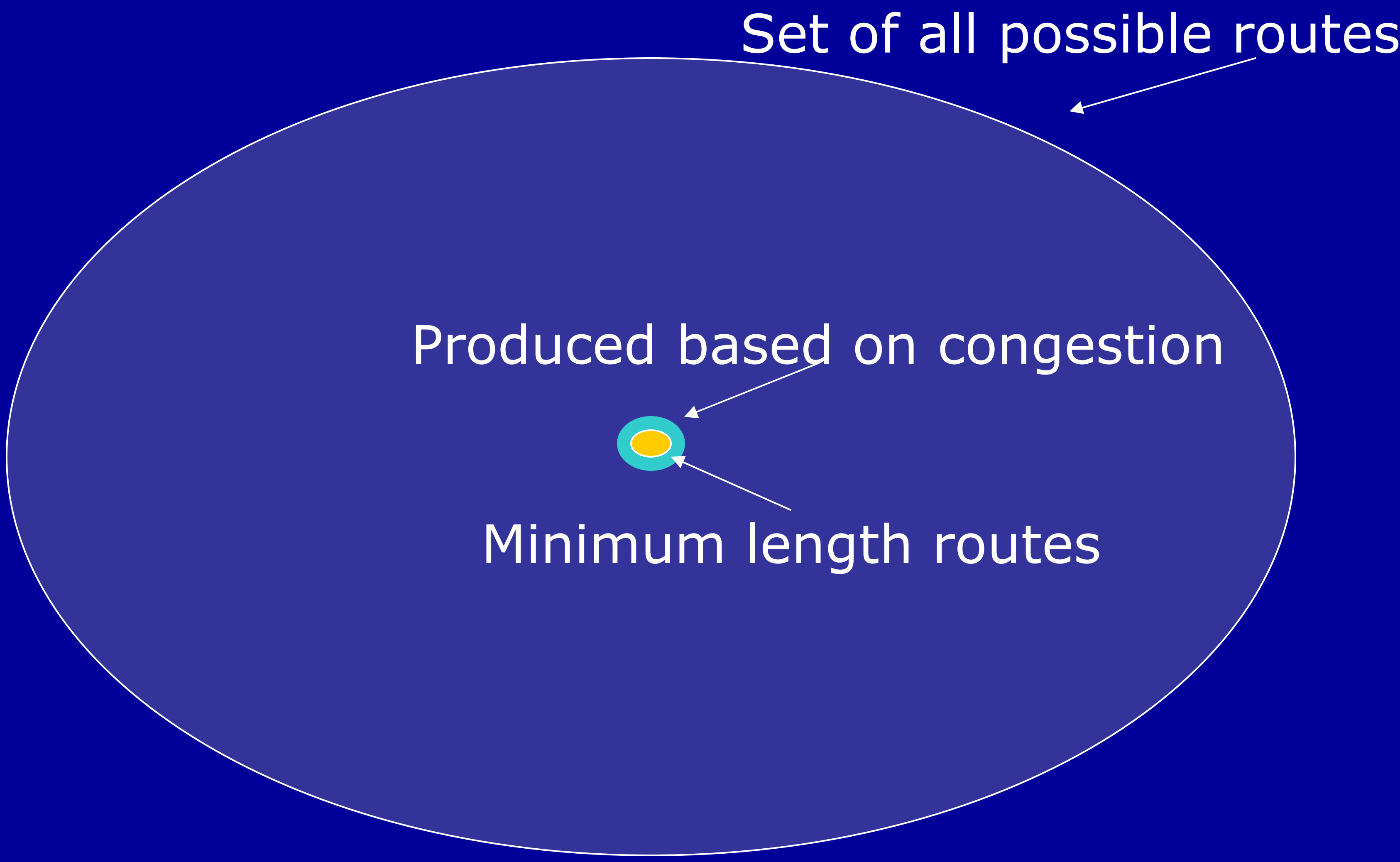
Proposed Approach

Calculated routing demands are used to identify congested areas;

1. Generate additional routes for the nets in the areas where congestion is most likely to occur.

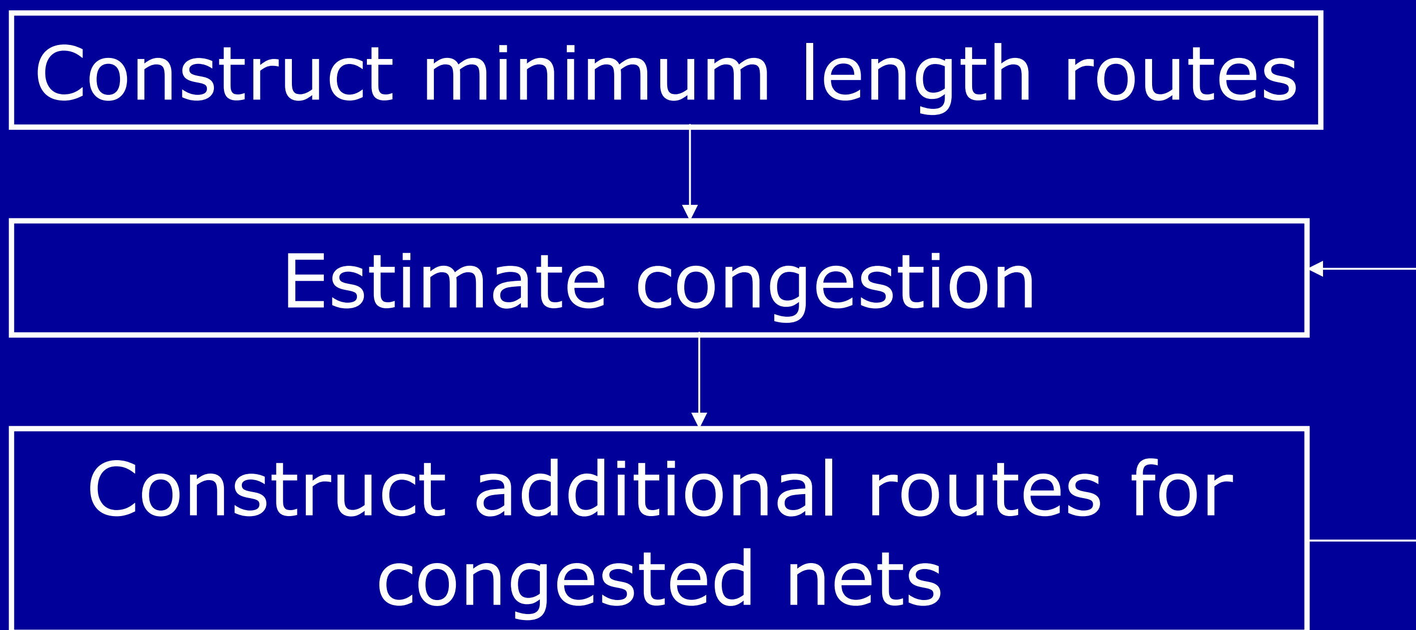
2. Construct additional routes through areas where congestion is less likely to occur.

Set of Possible Routes

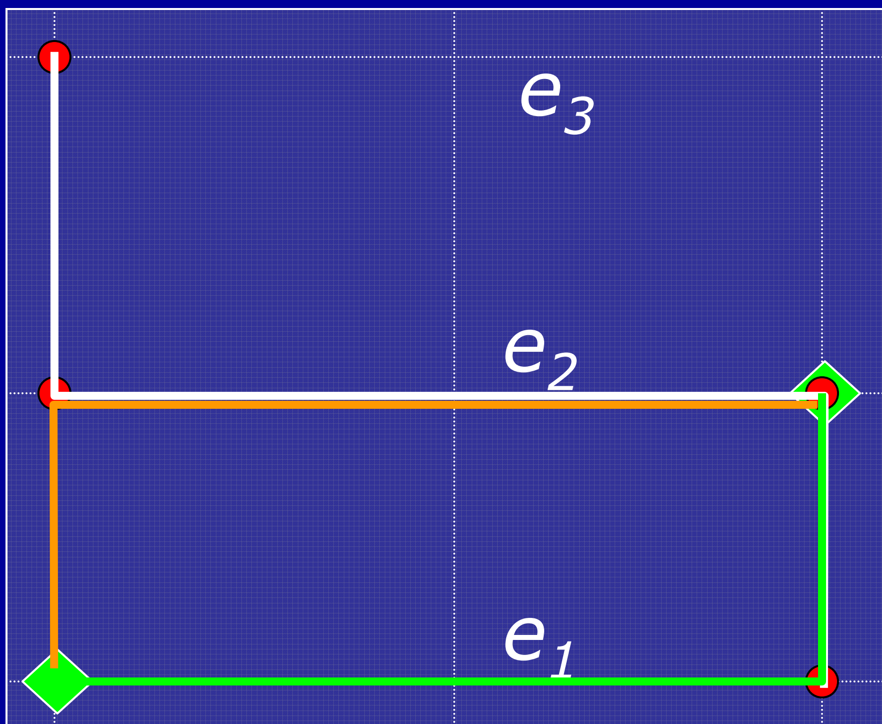


Proposed Route Construction

Congestion Based Route Construction



Illustrative Example



Net *1*:

Route Y_1 —

$p(Y_1) = 1$

Net *2*:

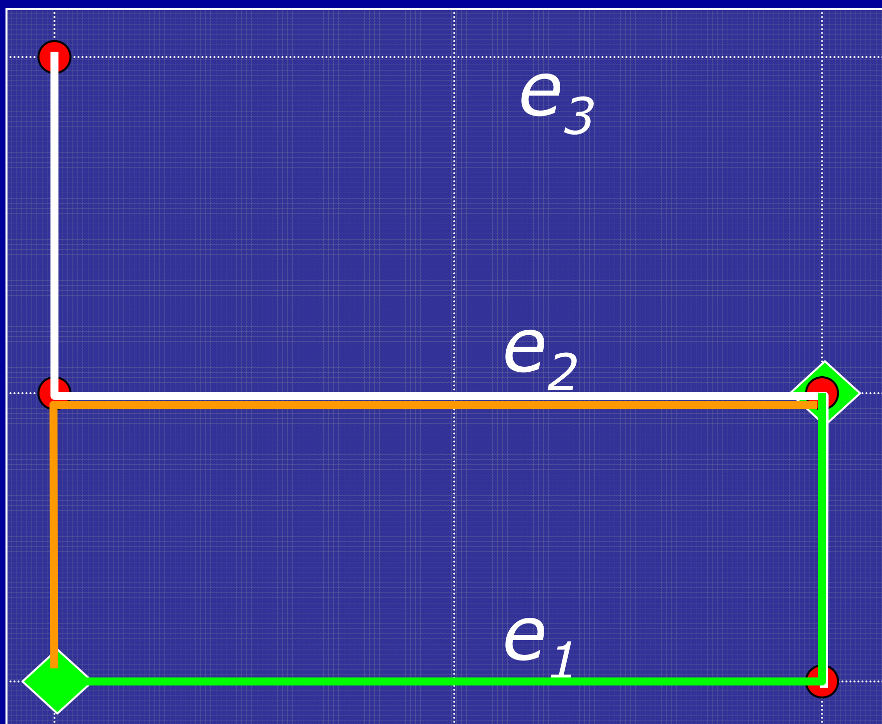
Route Y_2, —

$p(Y_2) = 1/2$

Route Y_3, —

$p(Y_3) = 1/2$

Illustrative Example



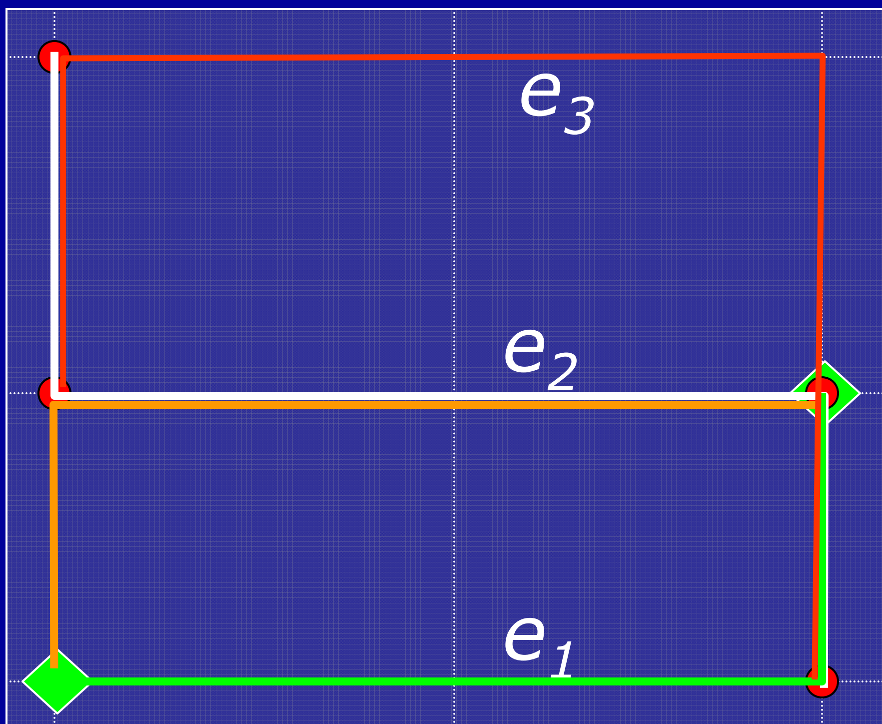
Routing Demands:

$r(e_1) = p(Y_2) = 1/2$

$r(e_2) = p(Y_1) + p(Y_3)$
$= 3/2$

$r(e_3) = 0$

Illustrative Example



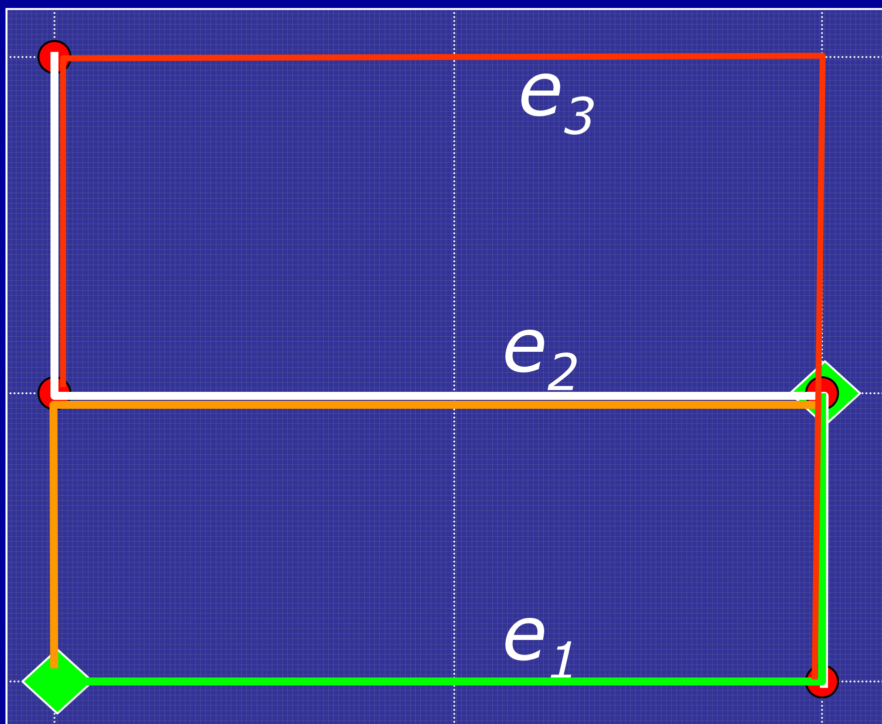
Additional Trees:

For net 1

Y_4 — $p(Y_4)$

$p(Y1) = 1/2$
$p(Y4) = 1/2$

Illustrative Example



Routing Demands:

$r(e_1) = p(Y_2) = 1/2$

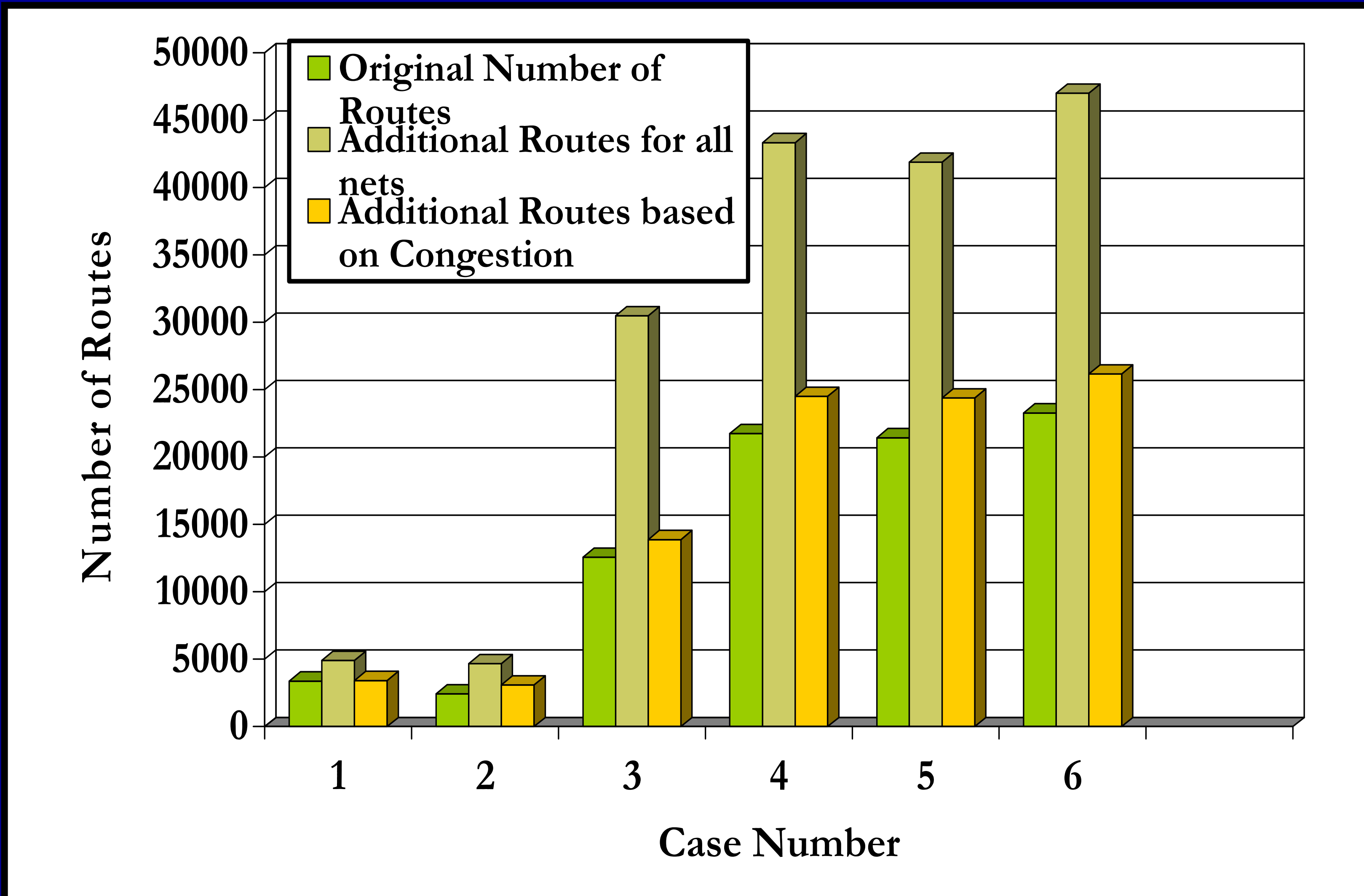
$r(e_2) = p(Y_1) + p(Y_3)$
$= 1/2 + 1/2 = 1$

$r(e_3) = p(Y_4) = 1/2$

Test Circuits

	Name	# nets	Grid sizes
Case 1	bio	5742	46x46
Case 2	ind1	2478	27x27
Case 3	ind2	13419	71x71
Case 4	ind3	21938	54x54
Case 5	avq.small	22124	66x66
Case 6	avq.large	25384	66x66

Numerical Results



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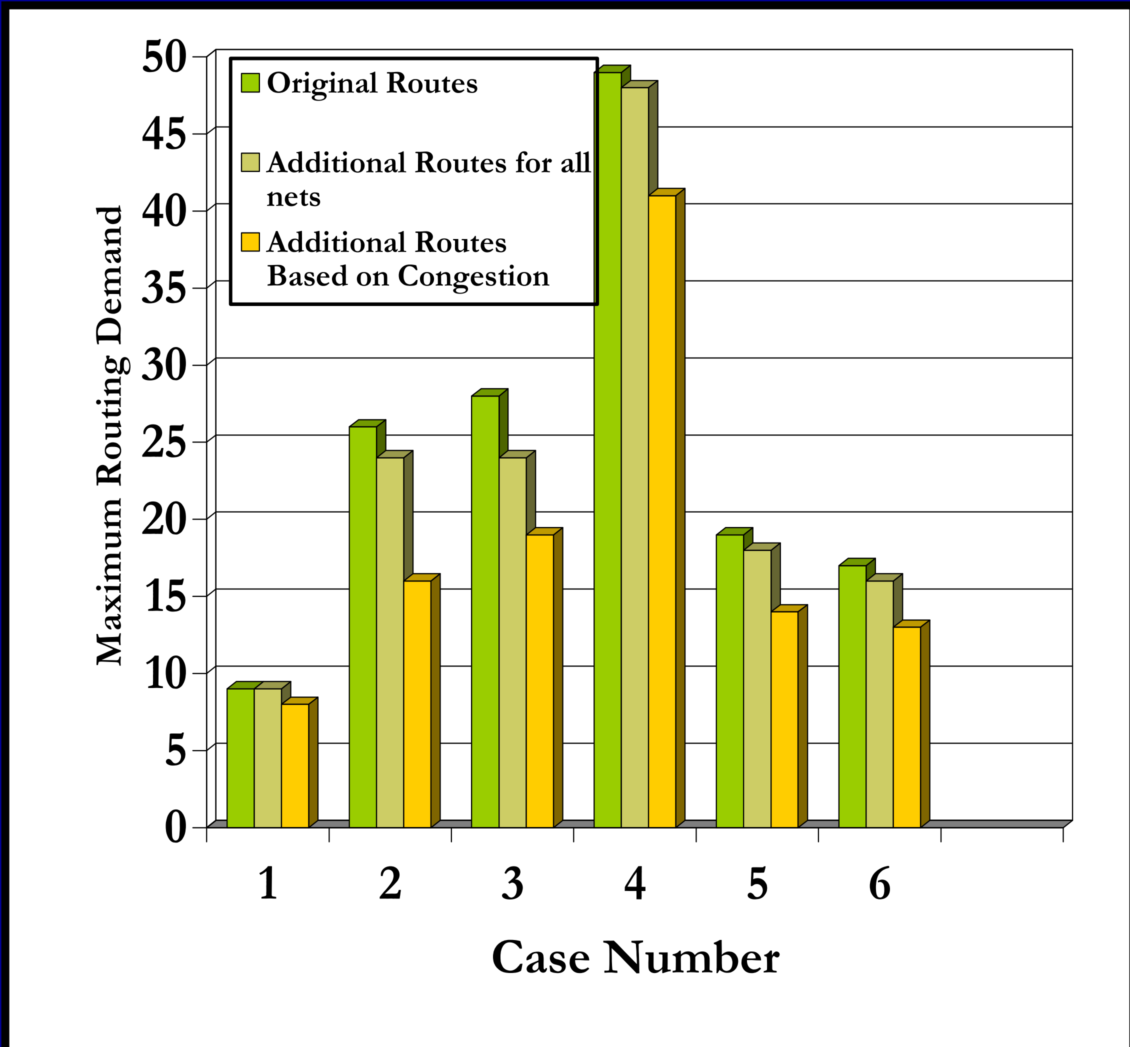

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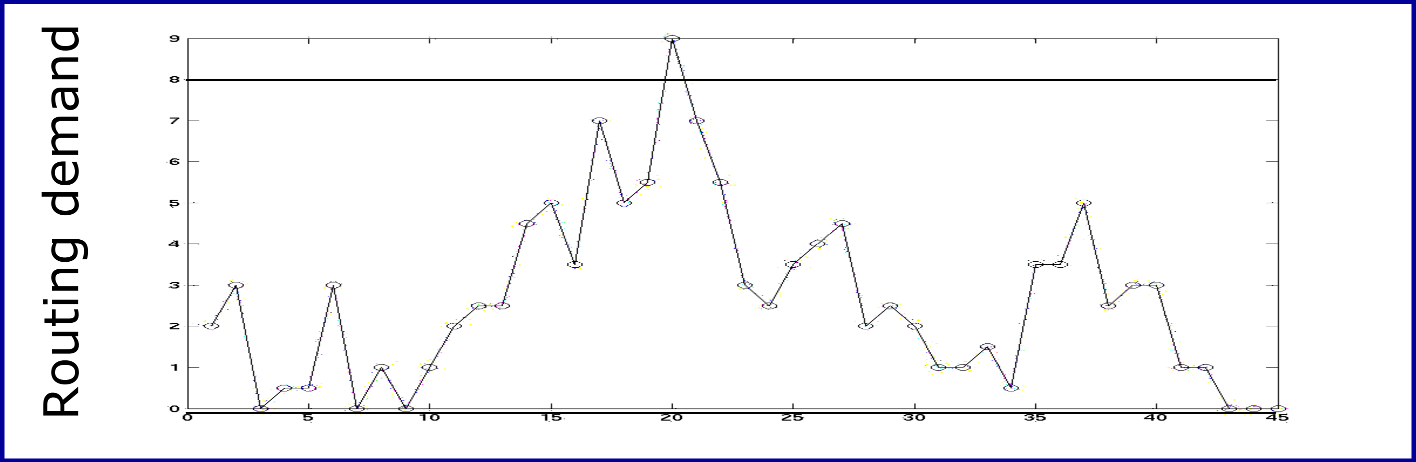
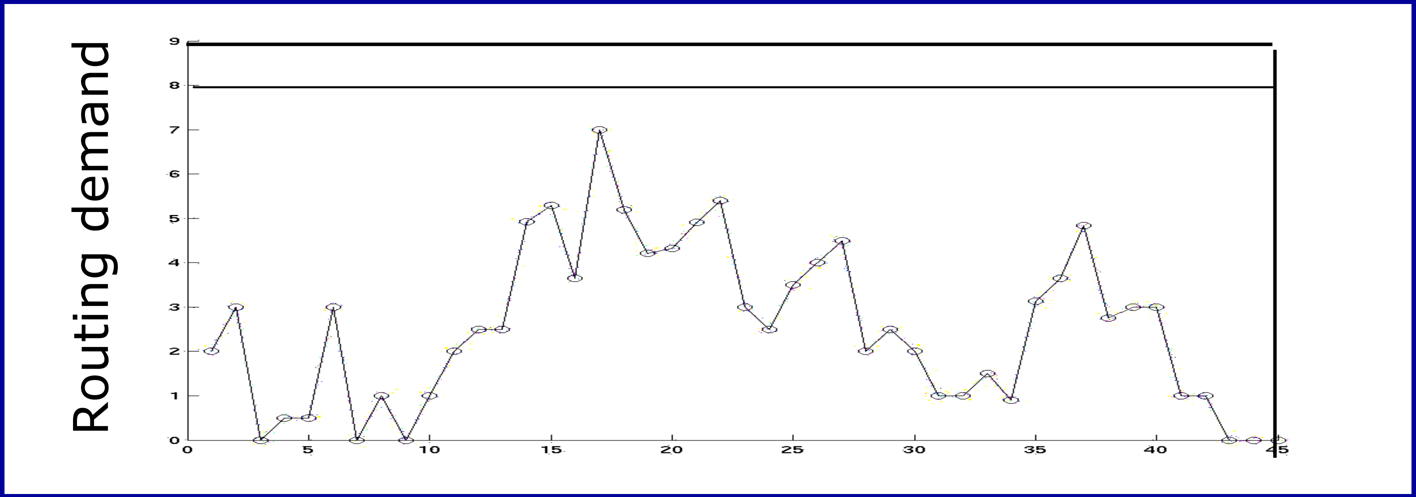


Before constructing additional trees



After constructing additional trees

Modeling Formulations

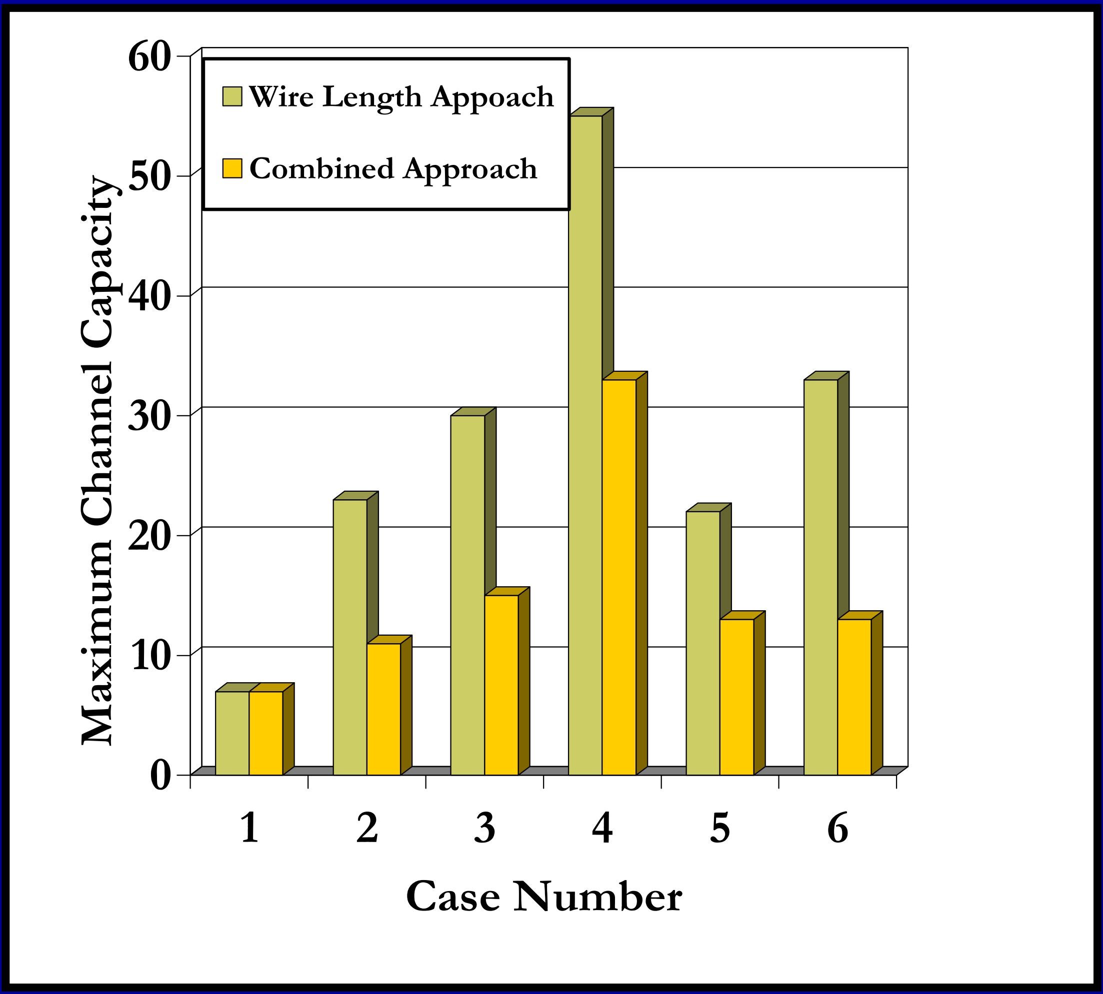
Traditional Approaches:

- Ø Consider only wire length

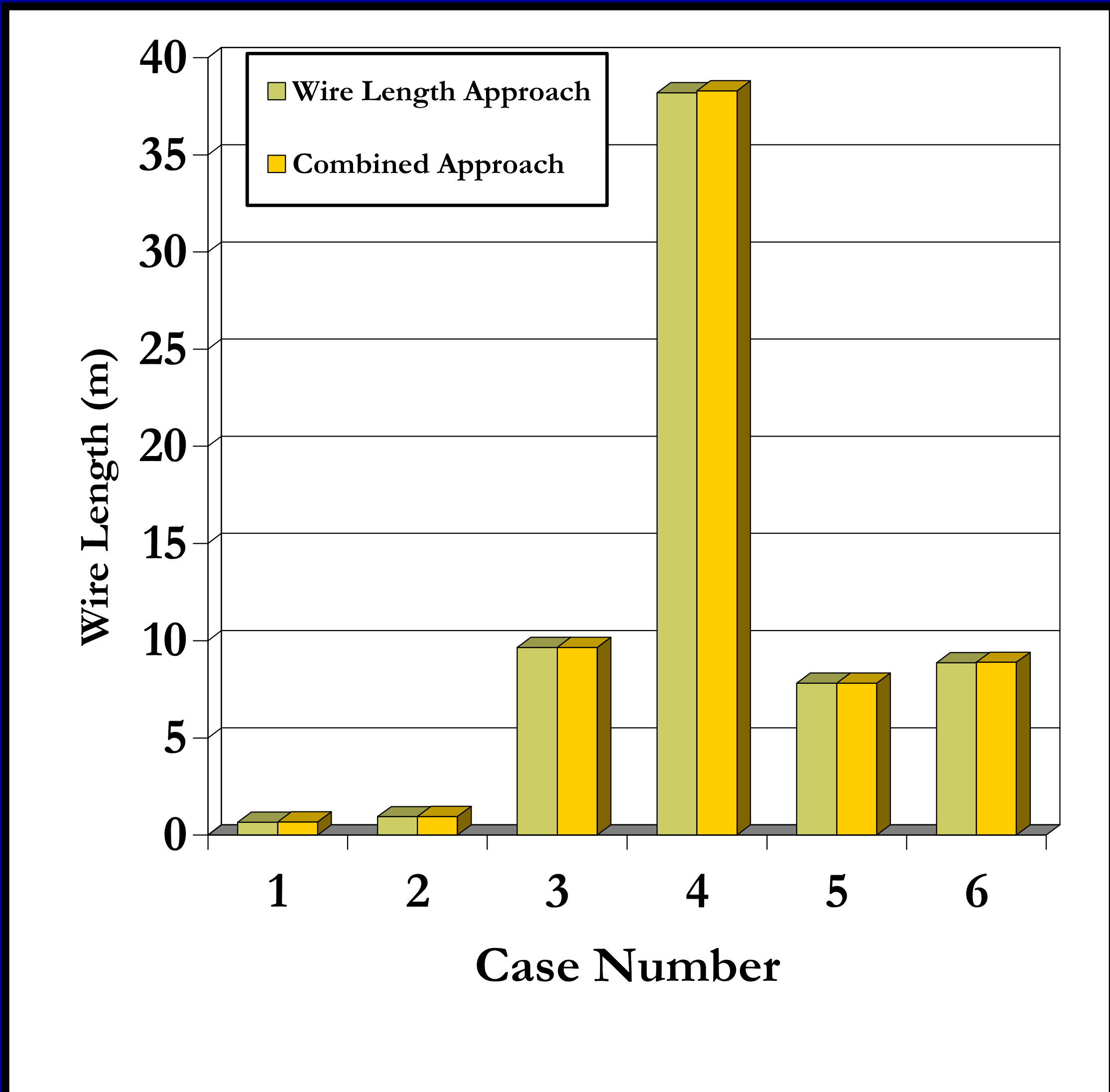
Proposed Multi-Objective Approaches:

- Ø Wire length
- Ø Congestion
- Ø Number of bends
- Ø Channel Capacity

Numerical Results



Numerical Results



Optimization Techniques

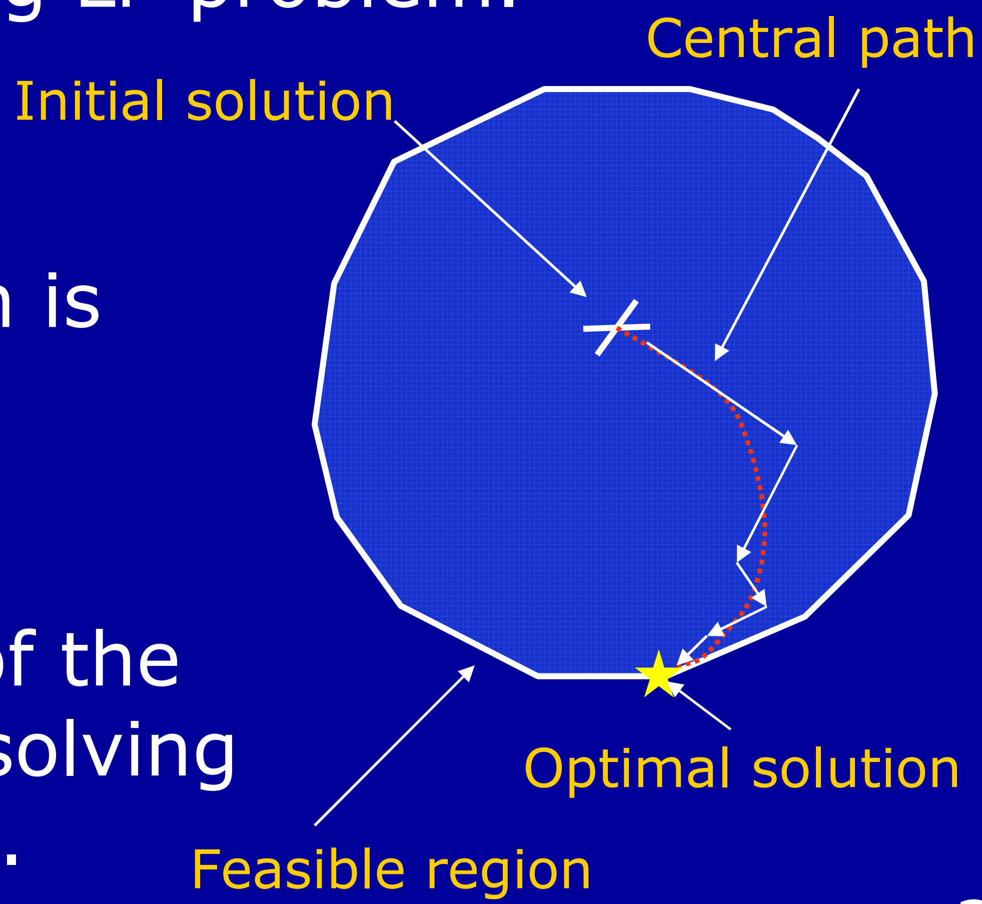
Global routing problem is formulated as a Linear Programming (LP) problem.

$$\min \mathbf{w}^T\mathbf{x}$$
$$\text{Subject to: } \mathbf{A}\,\mathbf{x} \le \mathbf{b}$$
$$\mathbf{0} \le \mathbf{x}$$

Number of constraints is very high.

Interior Point Methods

- Interior Point methods are used to solve the global routing LP problem.
- One step in the Newton direction is taken at each iteration.
- The bottleneck of the IP method is in solving the Newton step.



Matrix Re-ordering

Objective:

Find a faster solution to the Newton equations by reordering the constraint matrix of the LP problem.

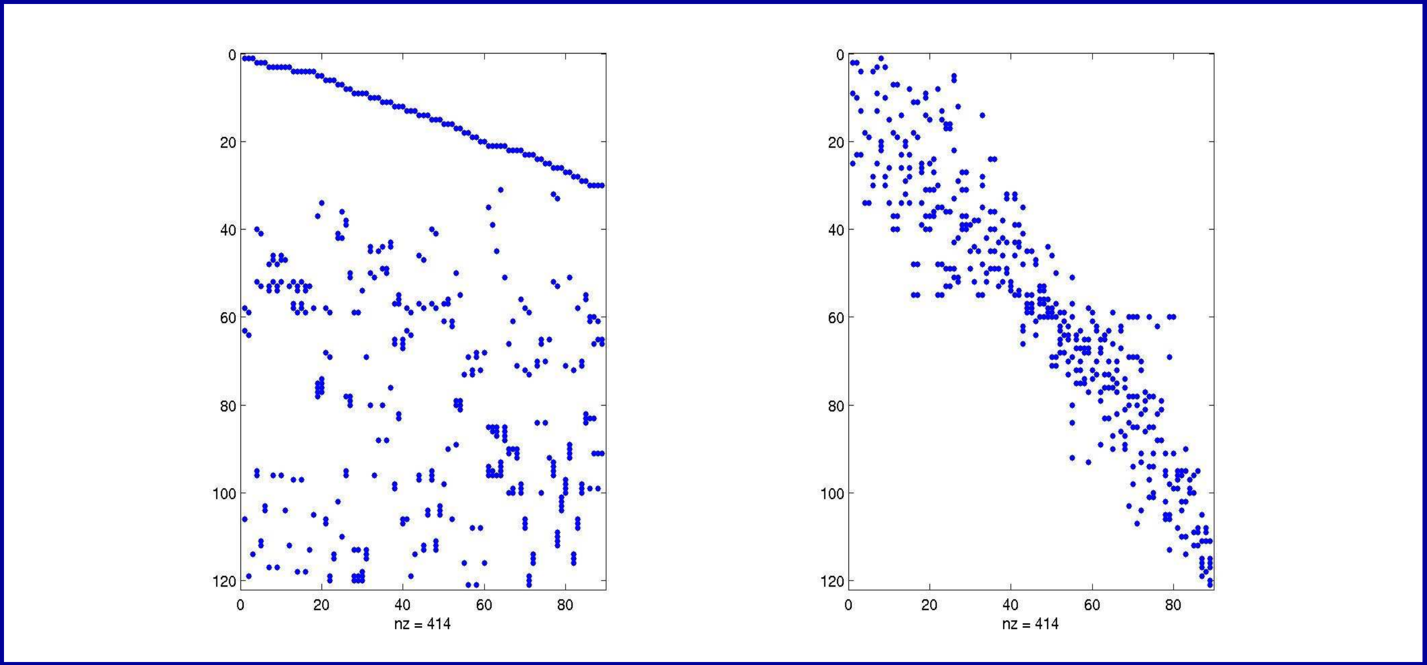
Proposed Approach:

Apply an eigenvalue based reordering technique to the constraint matrix.

Constraint matrix is only reordered at the start of the Interior Point solution.

Matrix Re-ordering

The constraint matrix of the global routing problem is a 0/1 matrix.

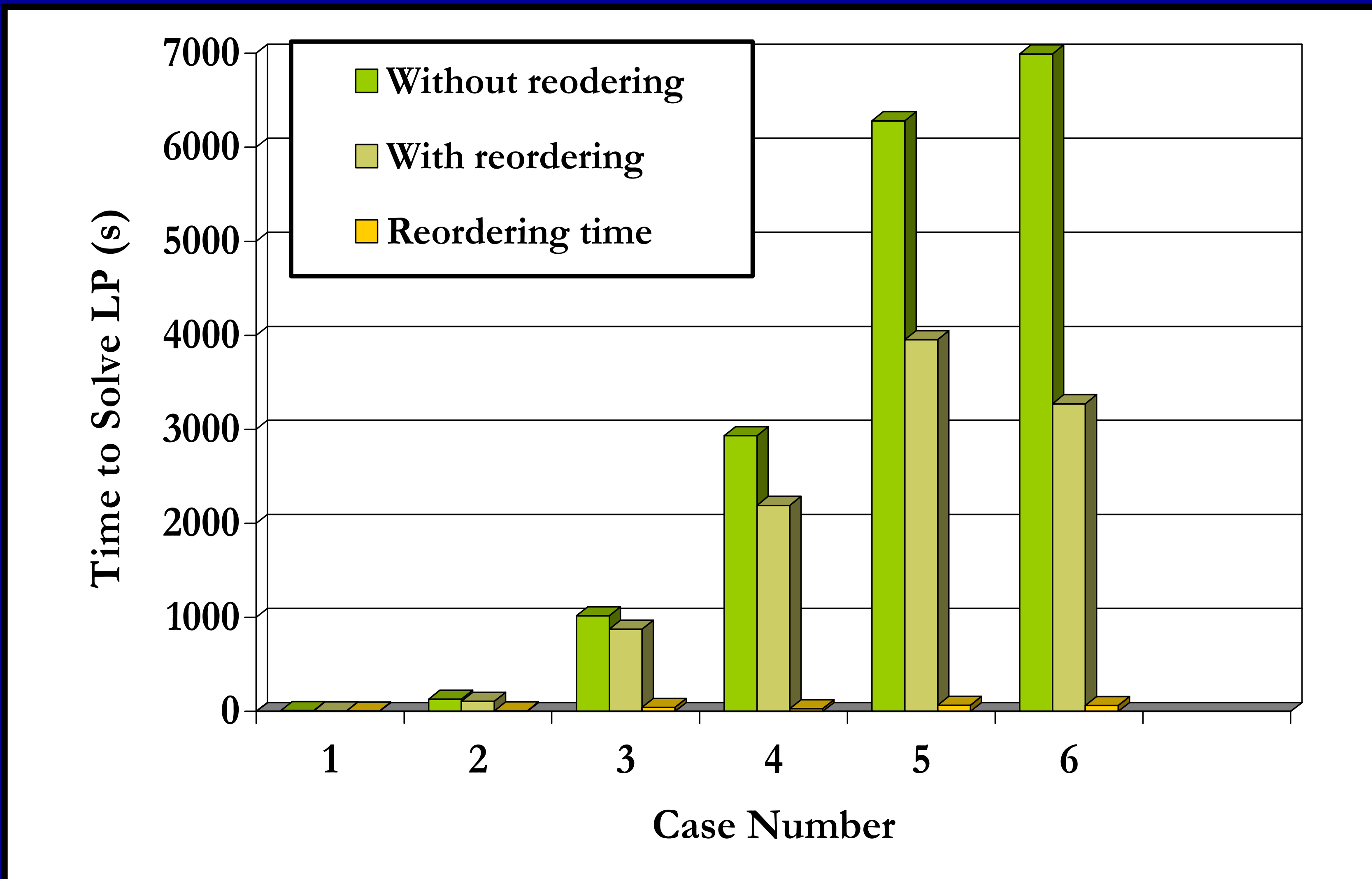


Before reordering After reordering

Programs Developed

- C Program to convert placement results to routing grid model.
- C^{++} program to produce routes.
- C^{++} program to estimate congestion.
- C^{++} program to produce objective function and constraint matrix of the global routing problem.
- Matlab program to perform matrix reordering.
- Matlab program to for rounding.
- Matlab program for visual illustration of channel capacities.

Numerical Results



Conclusions and Summary

- Incorporating congestion in global routing leads to compact problems that give high quality solutions.
- Results obtained from benchmarks show the multi-objective formulation results in less congestion and reduces the wire length.
- Matrix reordering is effective in reducing the solution time of the LP problem.