Wire Length Prediction Using Statistical Techniques

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Motivation

• Wire length is important in deep submicron
• Buffers reduce wire length delay, but costly (area, power) and impact floorplan and routing
• Fast and rapid floorplanning, detailed routing costly
• Goal: to predict long wires for reducing clock cycle time (eg. using efficient buffer placement)
Synthesis Paradigms

- Traditional Deterministic Approaches
  - Objective function and set of constraints
  - Optimize objective function value
- Probabilistic Synthesis Approaches
  - Probability of occurrence
  - Objective is to maximize the likelihood
  - Statistics (parametric & non-parametric)

Net Routing: Wire Length
Talk Overview

• Summary of Wire Length Prediction and Buffer Insertion
• Model Building Approach
  – Statistical Background
  – Feature Extraction
  – Derivation of PDF and CDF
  – Evaluation and validation
• Wire Length Prediction Model
• Application to Buffer Insertion

Related Work: Wire Length Estimation

Related Work: Statistics


Related Work: Buffer Insertion

Data Collection

- Cadence (QPlace) – placement and routing
- IBM designs – provide data points

<table>
<thead>
<tr>
<th></th>
<th>Layers</th>
<th>Nets</th>
<th>Area</th>
<th>Terminals</th>
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<tbody>
<tr>
<td>ibm01</td>
<td>8</td>
<td>11507</td>
<td>5 mm</td>
<td>44,266</td>
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<tr>
<td>ibm02</td>
<td>10</td>
<td>18429</td>
<td>7 mm</td>
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<td>ibm07</td>
<td>10</td>
<td>44394</td>
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<td>ibm08</td>
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<td>ibm10</td>
<td>10</td>
<td>64227</td>
<td>29 mm</td>
<td>269,000</td>
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<td>ibm11</td>
<td>10</td>
<td>67016</td>
<td>23 mm</td>
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<td>ibm12</td>
<td>10</td>
<td>67739</td>
<td>34 mm</td>
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Problem Formulation

- **Goal**: To identify long nets which would require buffer placement

- Deduce likelihood each net will have a particular length
  - Cost analysis (2-20 buffers?)
  - Using features with low computation effort and rapid extraction
Statistical Tasks

1. Classification: YES/NO, outlier?
   - CART Model

2. Regression: $y = f(x)$, $L_1$, $L_2$, ..., $L_\infty$
   - Polynomial regression
Statistical Tasks

3. Density/Kernel Estimation: likelihood of occurrence
   • Regression/Percentiles

Evaluation & Validation

• Rebsubstitution
  – Data resampling to prevent overfitting

[Graph showing data distribution]
Statistical Tasks

• Question:
  – Which features to use?
  – Which models to use?
  – Any unique insights?

Modeling Approach
Net Characterization

• Cadence Placement and Routing Tool (QPlace)
  – Post placement information as input
• **Goal**: Identify metrics that influence the post routing wire length of each net

Features - Net Characteristics

• # of Net Terminals
Features - Net Characteristics

• $\frac{1}{2}$ Perimeter Bounding Box (BBOX)

Features - Net Characteristics

• Minimal Spanning Tree (MST)
Features - Net Characteristics

- Convex Hull (CHULL)

Features - Net Characteristics

- Single Net Interaction
  - Unique Terminals in BBOX
  - White Space of Net
  - Space Utilization Factor of Net
- Resource Competition Metric of Net
- Interaction Between Neighboring Nets
  - # of Overlapping Neighbors
  - Amount of Overlapping Area of Net with Neighboring Nets
  - Neighbor Utilization Factor
  - Neighbor Hardness Factor
Model Features

- ½ Perimeter BBox
- Net Length / BBox (Normalized)

Outlier Detection

Ibm12: 5-terminals
Outlier Detection

Outlier Detection: CART Model
Outlier Detection

- CART Model
  - # of terminals (2 term, 3-5 term, 6+ term)
  - Resource Competition Metric of the net
  - Resource Competition Metric of overlapping neighbors
  - # of overlapping neighbors
  - # of common terminals for net
- Misclassification rate: 6.7%

Partitioning of Data Set

- Separation of data into 2+ groups
  - Classify behavior of groups separately

- Short (< 6,000) & Long Nets (> 6,000)
  - Short nets: handle reasonably, grid uniformity
  - Long Nets: susceptible to impact from many small nets
Polynomial Regression Model
Evaluation & Validation

• Rebsubstitution
  – 100 data subsets, 70% of data
  – Interval of Confidence ± 10% in 86% of the cases

Accuracy of Model: Visual Inspection
Inter-design Modeling

- **Goal:** To use the wire length model built for a given design to predict the wire lengths of an alternate design

- **Model Features**
  - $C$: Overall congestion
  - $NL$: Number of Layers used in the design
  - $L$: Length of Net

\[
L_i = L_j \left( \frac{NL_j}{NL_i} \right) \left( \frac{C_i}{C_j} \right)^{0.48}
\]

Evaluation & Validation

- **Learn-and-test**
  - Comparison of built model (4 learn designs) to a model built using a single design (3 test designs)
  - Prediction within 3% accuracy for 96% of the designs
Experimental Results

• Buffer Insertion Problem
  – Given: Fan-out wiring tree delay constraint, wirelengths etc
  – Find: Buffer placement for: max gate arrival time, min buffers

<table>
<thead>
<tr>
<th></th>
<th>Statistical Model</th>
<th>Standard BBOX</th>
<th>%</th>
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<tbody>
<tr>
<td>ibm08</td>
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<tr>
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<td>1546</td>
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<td>Net2</td>
<td>865</td>
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<td>690</td>
<td>1413</td>
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<td>Net4</td>
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<td>Net5</td>
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<td>2892</td>
<td>17.8</td>
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</tbody>
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Average of 21% Reduction in Delay using the Probabilistic Model

Conclusion

• Statistical wire length prediction density estimation model
• Accurate model for IBM designs set and Cadence tool
• Important for reducing delay in buffer insertion