Forward-Looking Objective Functions: Concept and Applications in High Level Synthesis

Jennifer L. Wong, Seapahn Megerian, Miodrag Potkonjak
UCLA Computer Science Department

DAC 2002
June 13, 2002

Motivational Example: Scheduling & Register Assignment

Each operation uses 1 clock cycle
Available time: 8 cycles
Motivational Example: Scheduling and Register Assignment

Traditional OF
1 Adder, 6 Registers

FLOF OF
2 Adders, 3 Registers

Register is \sim60\% of adder area
Overview

- Related Work
- Forward-Looking Objective Functions
  - Problem Overviews
  - Scheduling - Register Assignment
  - Transformations - Scheduling - Register Assignment
- Results
- Conclusion

Global Picture: Optimization Process

- Optimization = Mechanism + Objective Function

- Widely Used Mechanisms: LP, ILP, Branch and Bound, Dynamic Programming, Tabu Search, Simulated Annealing, …

- Objective Function: What is being optimized?
Design Process: Behavioral Synthesis

- Synthesis process is long and complex
- Strategy: separation of concerns

Related Work: Objective Functions

- Scheduling [Paulin, Knight 89]
  - Density distribution graph
- Transformations [Chandrakasan et. al 95]
  - Estimation and statistical techniques
- Logic synthesis [Berkeley CAD]
  - Number of literals in equations
- Testing Sequential Circuits
  - [Cheng, Agrawal 90] Sequential Depth
  - [Dey, Potkonjak 94] Architectural Sequential Depth
Objective Function vs. Utility Function

**Utility Function:** What is the Ultimate Goal?
- Energy, Speed, Power,…

**Objective Function:** Measure of Correlation between Properties of Instance Structure and Utility Function.

Objective Function

**Problem:** Register Assignment

**Utility:** Minimize number of registers, i.e. colors

**OF:** Select node with many uncolored neighbors, color it with the color that does the least number of possibilities from its neighbors.
Forward-Looking Objective Functions: Generic Approach

- Consider impact of particular solution of current task to consequent tasks

- Define Properties of Objects
- Evaluate Properties
  - Is Property Relevant?
  - Is Property Orthogonal to Others?
- Build Model FLOF
- Evaluate Proposed FLOF

Case Study

Scheduling – Register Assignment
Problem Overview: Scheduling

**Problem**: Scheduling

**Instance**: A CDFG C, a time constraint T, parameter N.

**Question**: Does there exist a Scheduling of C into T control steps such that the number of operations from C in each control step is less than N and all precedence constraints in C are satisfied?

Problem Overview: Register Assignment

**Problem**: Graph Coloring

**Instance**: A graph G(V,E) with vertex set V and edge set E, number of colors k.

**Question**: Does there exist a coloring of the graph G that assigns colors to each vertex v in V such that for any edge e in E the vertices connected by e have different colors, and that no more than k unique colors are used?
FLOF: Scheduling – Register Assignment

FLOF = 
\( f(\text{scheduling difficulty, lifetime of variables}) \)

Scheduling difficulty \((x) = \)
\( f(\text{ALAP}(x), \text{ASAP}(x), \text{operation cost}) \)

Lifetime of variable \((y) = \)
\( f(\text{expected creation time (y), expected consumption time (y)}) \)

Illustrative Example
Illustrative Example: Scheduling

Schedule

Variable conflict graph

2 Adders, Registers: 6
Illustrative Example: Scheduling - Register Assignment

Schedule

Variable conflict graph

2 Adders, Registers: 4
Illustrative Example: Scheduling - Register Assignment

Traditional OF
Registers: 6

FLOF OF
Registers: 4

Case Study

Transformations - Scheduling - Register Assignment
Preliminaries: Transformations

Distributivity

Associativity

Retiming

Replication
FLOF: Original Instance

2 Adder, 2 Multiplier, 6 Registers
FLOF: Transformations - Scheduling

1 Adder, 1 Multiplier, 6 Registers
FLOF: Transformations - Scheduling
- Register Assignment

1 Adder, 1 Multiplier, 5 Registers
FLOF: Transformations - Scheduling - Register Assignment

\[ \text{FLOF} = f(\text{scheduling difficulty, lifetime of variables}) \]

Scheduling difficulty \( (x) = f(\text{ALAP}(x), \text{ASAP}(x), \text{operation cost}) \)

Lifetime of variable \( (y) = f(\text{expected creation time (y), expected consumption time (y)}) \)

Experimental Results
Experimental Setup

- 0.25 micron technology
- Hyper Tool [Rabaey et.al 91]

<table>
<thead>
<tr>
<th>Design Name</th>
<th># Nodes</th>
<th># Operation Types</th>
<th>Active Area(mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volterra (mult)</td>
<td>30</td>
<td>4</td>
<td>2.13</td>
</tr>
<tr>
<td>ii7</td>
<td>33</td>
<td>5</td>
<td>5.46</td>
</tr>
<tr>
<td>cascade8</td>
<td>34</td>
<td>4</td>
<td>2.41</td>
</tr>
<tr>
<td>parallel8</td>
<td>39</td>
<td>4</td>
<td>2.85</td>
</tr>
<tr>
<td>sine</td>
<td>49</td>
<td>6</td>
<td>1.45</td>
</tr>
<tr>
<td>Hilbert</td>
<td>49</td>
<td>5</td>
<td>3.81</td>
</tr>
<tr>
<td>Wavelet</td>
<td>53</td>
<td>5</td>
<td>4.33</td>
</tr>
<tr>
<td>LinearCntrl3</td>
<td>56</td>
<td>3</td>
<td>13.03</td>
</tr>
<tr>
<td>Differentiator</td>
<td>80</td>
<td>5</td>
<td>4.56</td>
</tr>
<tr>
<td>Winogradfft11</td>
<td>104</td>
<td>4</td>
<td>8.85</td>
</tr>
<tr>
<td>Dsfir51</td>
<td>127</td>
<td>4</td>
<td>10.88</td>
</tr>
<tr>
<td>fir333</td>
<td>130</td>
<td>3</td>
<td>11.96</td>
</tr>
<tr>
<td>Dskais55</td>
<td>137</td>
<td>4</td>
<td>13.12</td>
</tr>
<tr>
<td>fir100</td>
<td>302</td>
<td>3</td>
<td>12.59</td>
</tr>
</tbody>
</table>

Active Area Improvement with FLOF Scheduling and Register Assignment

Average: 11.2%
Transformations, Scheduling and Register Assignment

Future Directions

- Use of Structural and Functional Properties to Develop FLOFs
- Interaction Between FLOFs and Optimization Mechanisms
- Complex FLOFs
- Beyond CAD
Conclusion

- Optimization = Mechanism + Objective Function
- Concept of FLOF
- Case Studies
  - Scheduling - Register Assignment
  - Transformations - Scheduling - Register Assignment