Area Recovery under Depth Constraint by Cut Substitution for Technology Mapping for LUT-based FPGAs

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Technology mapping problem for LUT-based FPGAs to minimize area under depth minimum constraint

- Input: Subject graph
  - DAG (Directed Acyclic Graph)
  - Each node represents a Boolean function of up to k variables
    - k: the maximum number of inputs of an LUT (Lookup-table)

- Output: LUT network
  - DAG whose nodes represent LUTs

- Object
  Minimize the number of LUTs of LUT network

- Constraint
  Depth of LUT network

Difficult problem
Technology mapping based on K-feasible cut selection

- A K-feasible cut at a node $t$ is a partitioning $(X, \overline{X})$ of transitive fanin (TFI($t$))
  
  \[ TFI(t) = \text{fanin}(t) \bigcup_{u \in \text{fanin}(t)} TFI(u) \]

  \[ |\text{cutset}(X, \overline{X})| \leq k \]
  - cutset is border nodes in $X$

- A subgraph induced by $X$ can be implemented in a k-input LUT
  - $\text{cutset}(X, \overline{X})$ is inputs of LUT
Technology mapping based on K-feasible cut selection

- A K-feasible cut at a node \( t \) is a partitioning \((X, \overline{X})\) of transitive fanin \((\text{TFI}(t))\)

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\]

\[|\text{cutset}(X, \overline{X})| \leq k\]

- cutset is border nodes in \( X \)

- A subgraph induced by \( \overline{X} \) can be implemented in a k-input LUT

\[- \text{cutset}(X, \overline{X}) \text{ is inputs of LUT}\]
Proposed technique : Cut Substitution

- Cut Substitution: a post-processing of technology mapping to generate a local optimum solution by eliminating excessive LUTs while the depth of network is maintained
  - Cut Substitution directly eliminates several excessive cuts from the set of cuts selected at technology mapping

- The processing of Cut Substitution is loop iteration

1. Excessive cut enumeration
2. Choice of a best-cut
3. Cut elimination
The processing of a iteration of Cut Substitution

Phase 1: Excessive cut enumeration

LUT network
The processing of a iteration of Cut Substitution

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LUT network
The processing of a iteration of Cut Substitution

Are there cut at \( \times \) and \( \circ \) not to use \( \bigcirc \) as input?

Excessive cut?
The processing of a iteration of Cut Substitution

Are there cut at \( \times \) and \( \circ \) not to use \( \Box \) as input?

Excessive cut?

Not to make depth increase

LUT network
The processing of a iteration of Cut Substitution

LUT network
The processing of a iteration of Cut Substitution

Phase 2: Choice of a best-cut

LUT network
The processing of a iteration of Cut Substitution

Gain(\(\square\)) : the number of cuts those are not necessary if \(\square\) doesn’t exist
The processing of a iteration of Cut Substitution
The processing of a iteration of Cut Substitution

Phase 3 : Cut elimination

LUT network
The processing of a iteration of Cut Substitution

Phase 3: Cut elimination

LUT network
The processing of a iteration of Cut Substitution

Phase 3: Cut elimination

LUT network
The processing of an iteration of Cut Substitution

Phase 3: Cut elimination

LUT network
Experiment

• Comparison of the number of LUTs of LUT networks
  – Cut Substitution --- our method
    • The initial selected cuts given to Cut Substitution are generated by Ddmap
      ( Ddmap : A simple technology mapping algorithm to generate depth minimum network )
    • A heuristic algorithm to generate area minimum network under depth minimum constraint

• Benchmarks
  – MCNC benchmark set
  – ITC’99 benchmark set

• Computing machine
  – CPU : Intel Xeon 3.0 GHz
  – Memory : 15 GB
Experimental results

The number of LUTs of LUT networks

Compared to DAOmap, Our method is 9% advantage

The average run time of Ddmap + Cut Substitution is 3% shorter than that of DAOmap

Cut Substitution reduced 11% LUTs of Ddmap
Conclusion

• We presented Cut Substitution, the post-processing for technology mapping for LUT-based FPGAs to minimize area under depth constraint

• Ddmap + Cut Substitution generated networks with 9% less LUTs than the networks generated by DAOmap on average
  – The run time of Ddmap + Cut Substitution is 3% shorter than that of DAOmap

• Future work: examining the effect of Cut Substitution combined to other technology mapping algorithms
Thank you all for your attention
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  - Cut Substitution directly eliminates several excessive cuts from the set of cuts selected at technology mapping
- The processing of Cut Substitution is loop iteration
  1. Excessive cut enumeration
     Enumerate all the excessive cuts among the selected cuts
  2. Choice of a best-cut
     Decide a best-cut among the excessive cuts with a heuristic metric
  3. Cut elimination
     Eliminate the best-cut by substitution of some other cut(s)