Satisfying Real-Time Constraints with Custom Instructions

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Custom Instructions
- Extend ISA with application-specific custom instructions
- Hardware implementation with custom functional units

Motivation: ACET versus WCET
- Traditional custom instructions selection
  - Improves average-case execution time (ACET) thru profiling
- Custom instruction selection for real-time tasks
  - Should improve Worst-Case Execution Time (WCET)
- ACET savings depend on execution frequency of paths
- WCET savings depend on which path is more critical (longer)

Challenges in improving WCET
- Naive approach: Greedily optimize current WCET path till it shifts to another path
  - Ignoring non-WCET paths may result in local optima
- Example of two patterns on different sides of a branch
  - A and B saves 2 and 3 cycles, respectively
  - We can select only one
  - Greedy: WCET = 9
  - Optimal: WCET = 8

Optimal WCET Reduction: ILP Formulation
- Objective function: min : \( \text{wcet}_{\text{main}} \)
- Structural Constraints:
  - Sequence \( (V_1, …, V_k) \):
  - Path 1:
    - Branch if \( V_1 \) then \( V_2 \) else \( V_3 \):
      - Sequence \( (V_1, …, V_n) = \text{wcet}(V_1) + \text{wcet}(V_2) + \text{wcet}(V_3) \)
    - Loop:
      - \( \text{wcet}_{V_1} + \text{wcet}_{V_2} + \text{wcet}_{V_3} \)
  - Basic block:
    - \( \text{wcet}_i = T_{\text{opt}} - (P_i \times x_{i, A} + … + P_i \times x_{i, B}) \)
- Topological & Design Constraints:
  - At most one pattern covers an operation
  - Variables:
    - \( x_{i, A} + … + x_{i, B} \) \( \leq 1 \)
    - \( R \) — area requirement of \( P_i \) pattern
    - \( M \) — number of custom instructions constraint

Experimental Results

<table>
<thead>
<tr>
<th>Program</th>
<th>Test</th>
<th>Custom Instructions</th>
<th>WCET Reduction</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
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<td>Adpcm</td>
<td>51</td>
<td>12</td>
<td>9%</td>
<td>0.012</td>
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</tbody>
</table>

Significant WCET improvement by utilizing custom instructions
- Heuristic is much faster than optimal solution
- Heuristic achieves optimal WCET reduction in most cases
- Heuristic is scalable with larger problem sizes