Sub-Partition Reuse For Fast Optimal Motion Estimation
In HEVC Successive Elimination Algorithms

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1. Introduction
- Motion Estimation (ME) is a crucial tool for video encoders.
- ME seeks the best candidate block \( C \) from a search area \( S \) in a previously coded frame to predict the current block \( B \) (see Fig. 1).
- For HEVC, considering every candidate is prohibitively expensive, so modern search algorithms often find sub-optimal solutions.
- We want to reduce the number of candidates without sacrificing the optimal solution.
- We propose an early termination scheme for square prediction units (PUs) based on information reuse from rectangular ones.

![Figure 1: Motion estimation finds the best candidate to predict the current block.](image)

2. Successive Elimination Algorithm
- Let \( S \subseteq \{\mathcal{S}, \mathcal{V}, \mathcal{H}\} \) be the partitioning shape of a PU and \( p \) be the partition index
  \[
  \begin{pmatrix}
  0 & 0 & 1 & 0 \\
  \mathcal{S} & \mathcal{V} & \mathcal{H} & \mathcal{S}
  \end{pmatrix}
  \]
  The first partition index is 0 and if a second partition exists, its index is 1.
- The candidate at position \((x, y)\) is evaluated using
  \[
  \text{RCSAD}(s, p, x, y) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} |B_{s,p,m,n}(m) - C_{s,p,x,y}(m,n)| + \lambda R(x, y) .
  \]
- Successive elimination uses a lower bound approximation of the RCSAD
  \[
  \text{RCAOS}(s, p, x, y) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} |B_{s,p,m,n}(m) - C_{s,p,x,y}(m,n)| + \lambda R(x, y) .
  \]
- Let \((\hat{x}, \hat{y})\) be the position of the current best candidate. By transitivity:
  \[
  \text{RCAOS}(s, p, x, y) \geq \text{RCSAD}(s, p, \hat{x}, \hat{y}) \implies \text{RCSAD}(s, p, x, y) \geq \text{RCSAD}(s, p, \hat{x}, \hat{y}) .
  \]

3. Information Reuse Between PU Shapes
- Traditionally, PUs are evaluated in the order
  \[
  \mathcal{S} \rightarrow \mathcal{V} \rightarrow \mathcal{H} .
  \]
- Consider the following orders
  \[
  \mathcal{V} \rightarrow \mathcal{H} \rightarrow \mathcal{S} \quad \text{and} \quad \mathcal{H} \rightarrow \mathcal{V} \rightarrow \mathcal{S} ,
  \]
  which allow for information reuse from \( \mathcal{V} \) and/or \( \mathcal{H} \) into \( \mathcal{S} \). Such as
  \[
  \text{SAD}^I = \max \left\{ \frac{\text{minSAD}(\mathcal{V}, 0) + \text{minSAD}(\mathcal{V}, 1)}{\text{minSAD}(\mathcal{H}, 0) + \text{minSAD}(\mathcal{H}, 1)} \right\} .
  \]
- It follows that
  \[
  \text{SAD}^I \leq \text{SAD}(S, 0, x, y), \quad \forall (x, y) \in S_{0,0} .
  \]
- At worst, the min SAD of a partitioning is the min SAD of the block
  \[
  \text{SAD} \left( \begin{array}{c}
  \hat{x} \\
  \hat{y}
  \end{array} \right) \leq \text{SAD} \left( \begin{array}{c}
  0 \\
  0
  \end{array} \right) .
  \]

4. Improved Early Termination For \( \mathcal{S} \)
- We evaluate candidates in increasing order of rate. When the rate is large the search can terminate (without evaluating the remainder of \( \mathcal{S} \)).
- Early termination rate proposed at ICIP 2014
  \[
  R(x, y) \geq \frac{\text{SAD}(s, p, \hat{x}, \hat{y})}{\lambda} + \hat{R}(x, y) .
  \]
- Improved early termination rate for \( \mathcal{S} \)
  \[
  R(x, y) \geq \frac{\text{SAD}(S, 0, \hat{x}, \hat{y}) - \text{SAD}^I}{\lambda} + \hat{R}(x, y) .
  \]

5. Experimental Results

<table>
<thead>
<tr>
<th>Class</th>
<th>Sequence name</th>
<th>Prop. vs HM Speedup</th>
<th>BD-PSNR</th>
<th>Prop. vs Previous (ICIP2014) Speedup</th>
<th>BD-PSNR</th>
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</thead>
<tbody>
<tr>
<td>B</td>
<td>Kimono</td>
<td>6.30</td>
<td>96.7%</td>
<td>0.0006</td>
<td>1.15</td>
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<td></td>
<td>ParkScene</td>
<td>6.42</td>
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<td>0.0014</td>
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<tr>
<td></td>
<td>Cactus</td>
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<td>94.6%</td>
<td>-0.0020</td>
<td>1.36</td>
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<tr>
<td></td>
<td>BasketballDrive</td>
<td>6.05</td>
<td>95.4%</td>
<td>0.0016</td>
<td>1.23</td>
</tr>
<tr>
<td>C</td>
<td>RaceHorses C</td>
<td>4.73</td>
<td>92.7%</td>
<td>0.0011</td>
<td>1.13</td>
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<td>BQMall</td>
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<td>BasketballDrill</td>
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<td>D</td>
<td>RaceHorses</td>
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<td>0.0032</td>
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<td>94.5%</td>
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<td>94.9%</td>
<td>0.0002</td>
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</table>

Table 1: Results for main profile with 8-bit coding and Low Delay P settings (No AMP)

![Figure 3: Geometric representation of the early termination thresholds.](image)

![Figure 4: Results for main profile with 8-bit coding and Low Delay P settings (No AMP).](image)

6. Conclusion
- The proposed early termination scheme for square PUs, based on information reuse from rectangular PUs, results in a \textbf{6.13x} speedup and \textbf{94.9%} SAD savings when compared to HM (Full Search).
- This work considerably decreases the number of candidates imposed by the HEVC standard in order to find the optimal solution.