

# Rate-Distortion-Complexity Optimized Coding Scheme for Kvazaar HEVC Intra Encoder

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This paper summarizes a low-complexity *rate-distortion optimization (RDO)* scheme for Kvazaar HEVC intra encoder ([github.com/ultravideo/kvazaar](https://github.com/ultravideo/kvazaar)). Our work particularly addresses *RDO quantization (RDOQ)* since it is the most complex intra coding tool taking almost 60% of the Kvazaar complexity. Our three primary optimization techniques are:

- 1) Utilization of early termination mechanisms: Kvazaar accelerates the depth-first search in HEVC quadtree by selecting a coding unit without any further search if there are no coded coefficients in the unit. This work speeds up the search further by ignoring the remaining subquadrants when the accumulated cost exceeds that of the undivided unit.
- 2) Reduction of RDO search space: Logarithmic rough mode search in Kvazaar sorts intra modes by estimated RD costs. In this work, the shortlist of the candidate modes explored in the RDO stage is reduced separately for each block size. The best tradeoff between coding efficiency and complexity is obtained by exploring three modes for 4×4 blocks and two modes for the other block sizes.
- 3) Removal of unnecessary operations in RDOQ: Kvazaar inherits algorithms with non-optimal steps from HM. Here, calculation of error, cost, and sign hiding data is postponed until the last possible non-zero coefficient is found. Secondly, initializations of data structures are removed if they are assigned a new value right after. Thirdly, inline hints are added to short RDOQ child functions to improve CPU usage.

Table 1 compares intra coding speed and BD-rate of our proposal (Kvazaar v1.2.0, veryslow preset with RDO enabled and full RDOQ) with the original Kvazaar, x265 encoder v2.5, and *HEVC Test Model (HM)* v16.8. The speedup was measured on Intel 8-core i7-5960X processor with 8-bit HEVC common test sequences and quantization parameters of 22, 27, 32, and 37. Our scheme is shown to accelerate Kvazaar RDO coding by 2.1× with a diminutive bit rate overhead of 0.15%. It has 1.87% higher bit rate than HM but it is also more than 46 times as fast. Compared with veryslow preset of x265, our proposal is 18% faster with 0.80% loss in coding efficiency. These results indicate that Kvazaar is currently the leading open-source encoder in high-quality HEVC intra coding when complexity aspect is taken into account.

**Table 1:** Features of the optimized Kvazaar over the original Kvazaar, HM, and x265.

Format	Class	Impact of optimizations		Kvazaar vs. HM			Kvazaar vs. x265	
		Speedup 16 threads	$\Delta$ BD-rate	Speedup 1 thread	Speedup 16 threads	BD-rate	Speedup 16 threads	$\Delta$ BD-rate
2560×1600	HEVC-A	2.2×	0.11 %	5.6×	48.2×	1.92 %	1.1×	1.37 %
1920×1080	HEVC-B	2.2×	0.01 %	5.7×	48.6×	1.51 %	1.1×	0.90 %
832×480	HEVC-C	2.1×	0.17 %	4.7×	40.4×	1.93 %	1.1×	1.08 %
416×240	HEVC-D	2.1×	0.30 %	4.2×	36.4×	1.80 %	1.4×	0.25 %
1280×720	HEVC-E	2.1×	0.15 %	7.7×	64.9×	2.44 %	1.3×	0.60 %
Average		2.1×	0.15 %	5.4×	46.7×	1.87 %	1.2×	0.80 %