QuYK: A Universal, Lossless Compression Method for Quantization Matrices

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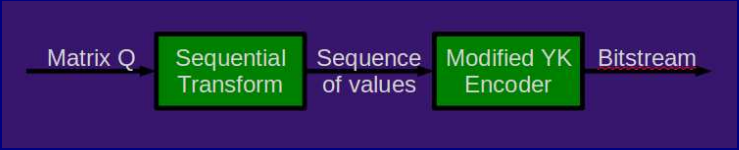
Outline

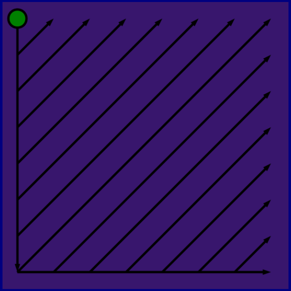
QuYK: A Universal Lossless Compression Method

- Efficient compression of quantization matrices is required to transmit large matrices in the bitstream
- We propose an algorithm using context-free grammars
  - Lossless
  - Universal
  - Provides good compression for the target size
  - Decoding complexity is very low

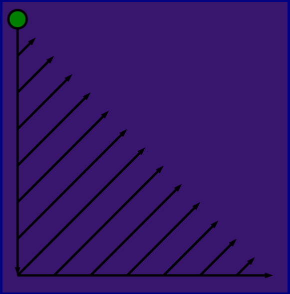


Sequential Transform

- Applies reversible differential coding to the matrix values



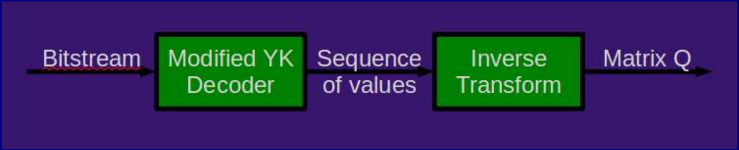
For asymmetric matrices



For symmetric matrices

QuYK Encoding and Decoding

- Encoder is based on a substitutional algorithm using context-free grammars
- Provides lossless reconstruction of the quantization matrix Q
- A special modification makes decoding very simple
  - Version 1 reconstructs the matrix using only string copying
  - Version 2 deploys entropy coding for improved performance



Results

- We demonstrate the performance of our algorithms on the matrices described in JCTVC-D024 [1]

	Number of bits		
Block size	Original	H.264 AVC	QuYK
8x8	512	344	168
16x16	2048	702	432
32x32	8192	1578	664

Existing Lossless Source Codes

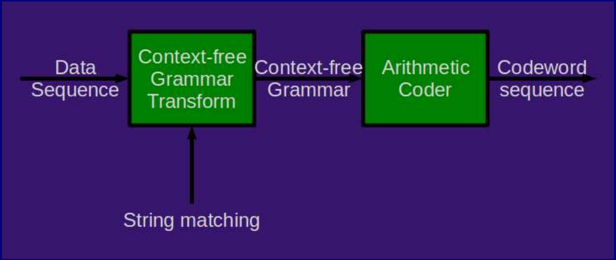
- Statistical model-based algorithms and their variants
  - Prediction by Partial Matching
  - Dynamic Markov Coding
  - Context Tree Weighting
  - Process data in symbols
- Dictionary-based algorithms and their variants
  - Lempel-Ziv codes
  - Parse data into phrases

Grammar-Based Coding

- Use admissible grammars for data compression
- First systematic treatment
  - [2] J.C. Kieffer and E.-h. Yang, "Grammar-based codes: A new class of universal lossless source codes," *IEEE Trans. Inf. Theory*, May 2000.
- Context-free grammar-based (CFG-based) codes were proposed in [3]

Context-Free Grammar-Based Codes

- Typical structure of CFG-based code



- Examples
  - Lempel-Ziv algorithms
  - Multi-level pattern matching
  - Context-free Yang-Kieffer algorithms

Context-Free Grammar: An Example

$$x = 01023010201$$

Context-Free Grammar: An Example

$$x = 01023010201$$

G_1

$$s_0 \to 01023010201$$

Context-Free Grammar: An Example

$$x = 01023010201$$

G_1

$$s_0 \rightarrow 01023010201$$

G_2

$$\begin{aligned} s_0 &\rightarrow s_1 3 s_1 s_2 \\ s_1 &\rightarrow s_2 02 \\ s_2 &\rightarrow 01 \end{aligned}$$

Context-Free Grammar: An Example

$$x = 01023010201$$

G_1

$$s_0 \rightarrow 01023010201$$

CFG size: 11

G_2

$$\begin{aligned} s_0 &\rightarrow s_1 3 s_1 s_2 \\ s_1 &\rightarrow s_2 02 \\ s_2 &\rightarrow 01 \end{aligned}$$

CFG size: 9

Context-Free Grammar Transform

$$s_0 \rightarrow \underline{0102}3\underline{0102}01$$

Context-Free Grammar Transform

$$s_0 \rightarrow \underline{0102}3\underline{0102}01 \Longrightarrow \begin{array}{lcl} s_0 & \rightarrow & s_1 3 s_1 \underline{01} \\ s_1 & \rightarrow & \underline{01}02 \end{array}$$

Context-Free Grammar Transform

$$s_0 \rightarrow \underline{0102}3\underline{0102}01 \Longrightarrow \begin{array}{lcl} s_0 & \rightarrow & s_1 3 s_1 \underline{01} \\ s_1 & \rightarrow & \underline{01}02 \end{array} \Longrightarrow \begin{array}{lcl} s_0 & \rightarrow & s_1 3 s_1 s_2 \\ s_1 & \rightarrow & s_2 02 \\ s_2 & \rightarrow & 01 \end{array}$$

Context-Free Grammar Transform

$$s_0 \rightarrow \underline{0102}3\underline{0102}01 \Longrightarrow \begin{array}{lcl} s_0 & \rightarrow & s_1 3 s_1 \underline{01} \\ s_1 & \rightarrow & \underline{01}02 \end{array} \Longrightarrow \begin{array}{lcl} s_0 & \rightarrow & s_1 3 s_1 s_2 \\ s_1 & \rightarrow & s_2 02 \\ s_2 & \rightarrow & 01 \end{array}$$

- String matching
- The resulting CFG is a compact representation of the original sequence

$$|G| = O\left(\frac{|x|}{\log|x|}\right)$$

Performance for Sources with Finite Alphabets: Redundancy Result

- Result 1 A CFG-based code's worst case redundancy against the k-context empirical entropy among al length n individual sequence from a finite alphabet is upper bounded by

$$\max_{x \in A^n}\{r^{\phi}(x) - r_k^*(x)\} = O\left(\frac{\log \log n}{\log n}\right)$$

$r^{\phi}(x)$ the entropy of CFG-based codes followed by arithmetic coding

$r_k^*(x)$ the k-context empirical entropy of x, which represents the smallest compression rate in bits per symbol among all arithmetic coding algorithms with k contexts

Performance for Sources with Finite Alphabets: Universality

- **Result 2** Let A denote a finite alphabet. A CFG-based code is universal with respect to the class of all stationary, ergodic sources with alphabet A.
  $X = \{X_i\}_{i=1}^{\infty}$: a stationary, ergodic source from A

  $$r^{\phi}(X_1 X_2 \ldots X_n) \to H(X)$$

  with probability 1 as n approaches infinity.

Remarks

- CFG-based codes have
    - Good theoretical performance
    - Good performance in practice (context-free Yang-Kieffer algorithms)
    - Very low computational complexity at the decoder's side

Grammar Transform for QuYK

- Generate the final irreducible grammar for the sequence
- Reorder the production rules for instantaneous access at decoding
  - Rules are written into bitstream in a certain order
  - Any rule may refer only to rules preceding it
- Write the grammar into the bitstream

Clear coding	Use approx. $log\|A\|$ bits for a joint symbol-variable alphabet A
Arithmetic coding	Improved compression

Conclusions

- Efficient compression of quantization matrices is required to transmit those matrices in the bitstream
- A universal algorithm using context-free grammars provides good performance, at very low decoding complexity
- We propose to study further in the quantization ad-hoc group the compression of quantization matrices, and to define test conditions for their compression

Bibliography

- Minhua Zhou and Vivienne Sze,
  "Compact representation of quantization matrices for HEVC,"
  JCTVC-D024, January 2011.

- John C. Kieffer and En-hui Yang,
  "Grammar Based Codes: A New Class of Universal Lossless Source Codes,"
  IEEE Trans. Inf. Theory, vol. 46, pp. 737–754, May 2000.

- En-hui Yang and John C. Kieffer,
  "Efficient Universal Lossless Data Compression Algorithms Based on a Greedy Sequential Grammar Transform—Part One: Without Context Models,"
  IEEE Trans. Inf. Theory, vol. 46, pp. 755–777, May 2000.