Overview of SIPL Activity in
Transrating and Transcoding of Coded Video Signals

Naama Hait, Michael Lavrentiev, Zeev Maor, Michael Tolchinsky
Supervisors: Ran Bar-Sella and Prof. David Malah

Lab support: Nimrod Peleg, Yair Moshe

SIPL Annual Project Presentation Day - June 22th, 2005
Video Transcoding

Compressed-domain transcoding

Advantages over trivial “decoder + encoder”:
- Efficient, suitable for real time applications
- Uses first encoder’s coding decisions
Transcording Goals

• Convert input stream to match end-user requirements. Examples:
  – Format conversion (between standards)
  – Spatial resolution reduction
  – Temporal resolution reduction
  – Bit rate reduction
• Achieve the highest quality at the target bit rate
• Minimal complexity – Use as much information from the coded bit stream
Transcoding Activities at SIPL

- Focus on the following Advanced Video Coding Standards: MPEG-2, H.264

1. Transrating (Bit rate reduction):
   MPEG-2 → MPEG-2

2. Transcoding (Format conversion):
   MPEG-2 → H.264

3. Transrating (Bit rate reduction):
   H.264 → H.264

4. Transcoding and transrating:
   MPEG-2 → H.264
MPEG-2 Transrating

- Transrating of Coded Video Signals via Optimized Re-quantization – Michael Lavrentiev (M.Sc., July 2004); Supervisor: Prof. David Malah

- Re-quantization by Lagrangian Optimization

\[
\begin{align*}
\min_{Q_1, Q_2, \ldots, Q_N} & \sum_{i=1}^{N} d_i(Q_i) \\
\text{s.t.} & \sum_{i=1}^{N} r_i(Q_i) \leq R_T
\end{align*}
\]

- Rate and Distortion are merged using Lagrangian parameter, \( \lambda \geq 0 \),

\[
J = D + \lambda R
\]

(Assunção and Ghanbari, 1997)

Decompose cost into sum of independent costs for each block
MPEG-2 Transrating (cont.)

- Extended Lagrangian Optimization (trellis-based)

MPEG-2 entropy coding:

Quantized DCT block → Zig-zag scan → (run, level) ordering → VLC table → Coded block

Extension: Allow modification of the quantized coefficient indices

Quantized DCT block → Zig-zag scan → Coefficient indices modification → (run, level) ordering → VLC table → Coded block

Solution: block-level trellis
- HVS-based bit allocation

Segmentation into regions: Texture, Edge, Smooth

Block distortion weights

Modify the distortion metric accordingly:

$$\min_{Q_1, Q_2, \ldots, Q_N} \sum_{i=1}^{N} w_i \cdot d_i(Q_i)$$

s.t.

$$\sum_{i=1}^{N} r_i(Q_i) \leq R_T$$

$${d_i}$$ – Distortion for block #i, $${r_i}$$ – rate for block #i, $${R_T}$$ – Target rate, $${w_i}$$ – Weight for block #i

$${N}$$ – Number of blocks in the frame, $${Q_i}$$ – Quantization step for block #i

Transrating and Transcoding of Coded Video Signals

SIPL Annual Project Presentation, June 22th 2005
MPEG-2 → H.264 Transcoding Project

Naama Hait, Zeev Maor, Michael Tolchinsky; Supervisor: Ran Bar-Sella

• Major standards’ differences:
  – Transform (DCT→ICT)
  – De-blocking filter
  – Quantization
  – Advanced entropy coding
  – Intra prediction
  – Motion Compensation

• Design guidelines:
  – MPEG-2 tools are a sub-set of the tools used in H.264
  – “Translate” MPEG-2 coding tools to their H.264 counterparts:
    – Try to get similar quality and measure bit rate
Transform Conversion

Break down to:
1. DCT 8x8 \rightarrow 4 DCT 4x4
2. DCT 4x4 \rightarrow ICT 4x4
Transform Conversion (cont.)

1. DCT 8x8 → 4 DCT 4x4

- Pixel domain quadrant extraction:

\[
\begin{align*}
\mathbf{A}_1 & \cdot \begin{bmatrix} X_1 & X_2 \\ X_3 & X_4 \end{bmatrix} \cdot \mathbf{B}_1 = X_1 \\
\end{align*}
\]

- DCT domain split:

\[
\begin{align*}
\text{DCT}_{4x4} \left( \begin{array}{c} X_1 \\ \end{array} \right) &= \\
\text{DCT}_{4x8} \left( \begin{array}{c} \mathbf{A}_1 \\ \end{array} \right) \cdot \text{DCT}_{8x8} \left( \begin{array}{c} X_1 & X_2 \\ X_3 & X_4 \end{array} \right) \cdot \text{DCT}_{8x4} \left( \begin{array}{c} \mathbf{B}_1 \\ \end{array} \right)
\end{align*}
\]

2. DCT 4x4 → ICT 4x4

The transformed blocks share 4 coefficients, and the difference in the other terms is small

\[
\begin{align*}
\text{DCT-1 picture} & \quad \text{Scaled difference (X 50)} \\
\text{Intra frame:} & \\
\text{Inter frame:} & \\
\rightarrow \text{We can use the DCT 4x4 coefficients as is with little introduced error}
\end{align*}
\]
Re-quantization

**Goal:** Minimize re-quantization distortion (no target rate)

Overcome standards’ differences by breaking down to:
- Block-level data “preservation” (steps’ matching, MPEG-2 intra Q. matrix)
- Frame level (H.264 ∆QP limiter)

**Algorithm:**
- **Block level**
  1. Inter blocks: single MPEG-2 step $\rightarrow$ closest H.264 step
  2. Intra blocks:

```
MPEG-2 Quant.       Intra DCT block
```

Multiple MPEG-2 steps $\rightarrow$ Ranked list of H.264 steps

Rank H.264 steps according to re-quantization distortion definition:

```
Coefficient re-quantization distortion $\sim$ Coefficient magnitude $\times$ Step-size mismatch
```

Transrating and Transcoding of Coded Video Signals

SIPL Annual Project Presentation, June 22th 2005
Re-quantization (cont.)

Since few DCT 8x8 coefficients \(\rightarrow\) one ICT 4x4 coefficient, there is more than one original step that created each ICT coefficient:

- Choose the most dominant DCT 8x8 “parent” coefficient as the step size representative & sum over all ICT coefficients

• **Frame level**

Minimize the total distortion, subject to the \(\Delta QP\) limiter using dynamic programming

\[ \Delta QP = 1 \]

Legend:
- Valid candidate
- Invalid candidate
- Path mark
- \(\Delta QP\) limiter mark
Transcoding – Partial Results

‘Flower garden’ sequence example

**Intra frame:**

**Inter frame:**

Preliminary results:

- **PSNR:**
  - MPEG-2 input: 34.4 [dB]
  - H.264 output: 30.7 [dB]
- **Bit rate reduction factor:** 1.2

- **PSNR:**
  - MPEG-2 input: 30.7 [dB]
  - H.264 output: 29.2 [dB]
- **Bit rate reduction factor:** 1.77

Planned additions:

- Closed-loop architecture to compensate for the drift error
- Bit rate control

Transrating and Transcoding of Coded Video Signals

SIPL Annual Project Presentation, June 22th 2005
H.264 Transrating

Bit rate reduction via Re-quantization

1. Student project: Bit rate control for H.264 Transrater
   Mikael Cohen, Yohann Sabbah; Supervisor: Naama Hait

   • One pass rate control algorithm (non optimal)
     subject to the $\Delta QP$ limiter

   • Compensate for the drift error (closed loop)
Model-based Transrating in H.264

2. Model-based Transrating of Video Signals – Naama Hait (M.Sc.); Supervisor: Prof. David Malah

- Non-model based evaluation of rate and distortion:

\[ Y \xrightarrow{Q} \text{Quantization} \xrightarrow{R} \text{Entropy coding} \xrightarrow{d(Y,q)} \]
\[ \xrightarrow{q} \text{Distortion calculation} \xrightarrow{r(Y,q)} \]

- Multiple repetition for every (block, step size) combination

- Use R-D models in the \( \rho \) domain (fraction of zeroed coefficients):

\[ (He \text{ and Mitra, 2002}) \]
Model-based Transrating in H.264 (cont.)

Frame Level Optimization

- Estimate rate and distortion for all (block, step size) combinations
- Solve R-D optimization subject to the $\Delta QP$ limiter:
  - Define Lagrangian cost: $J = D + \lambda \cdot R$
  - Solve constrained dynamic programming problem:
    - Change Lagrangian parameter $\lambda$ to improve rate guess
Planned Activity

- Incorporate the model-based transrating algorithms into the H.264 transrating system
- Add the closed-loop architecture and bit rate control to the MPEG2 → H.264 transcoding system
- Transcoding and transrating of MPEG-2 → H.264

Examine different integrations of previous developments:

1. MPEG-2 Bit Stream → MPEG-2 Transrating → MPEG-2 → H.264 Transcoding → H.264 Bit Stream
2. MPEG-2 Bit Stream → MPEG-2 → H.264 Transcoding → H.264 Transrating → H.264 Bit Stream
3. MPEG-2 Bit Stream → MPEG-2 → H.264 Transcoding + Transrating → H.264 Bit Stream