New High Fidelity RGB Video Coding

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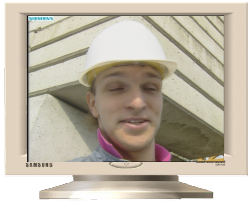
Why RGB Coding

- Video coding using color conversion
  - Has been prevalent since black & white TV
  - Cannot avoid color distortion
- RGB has been regarded as bad space for compression



Input video (RGB)

R G B

RGB color redundancy

Color conv.

RGB ? YUV

Y U V

Bias to Y (luminance)

Color conv.

Output video (RGB)

R G B

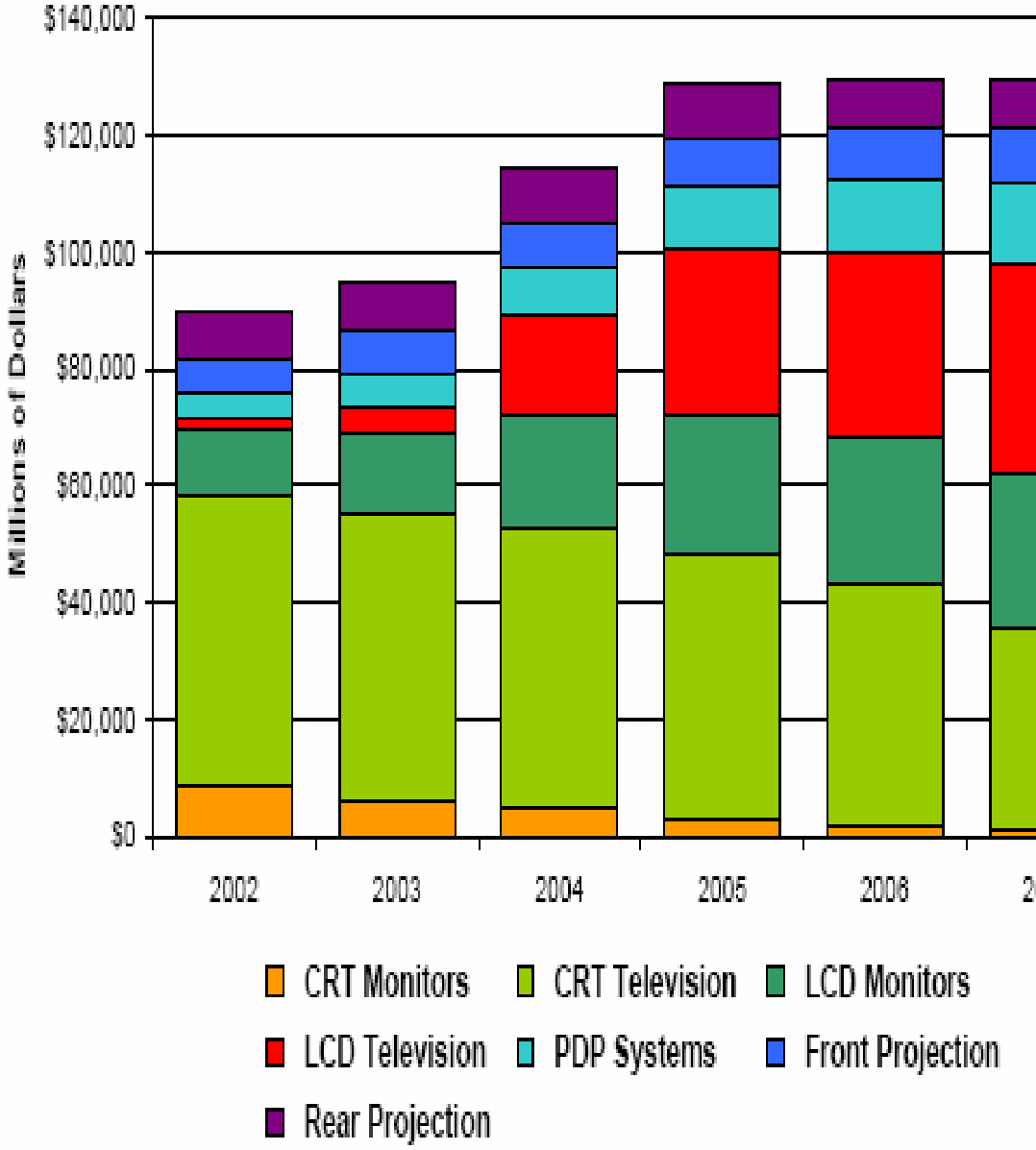
Color distortion

Why RGB Coding

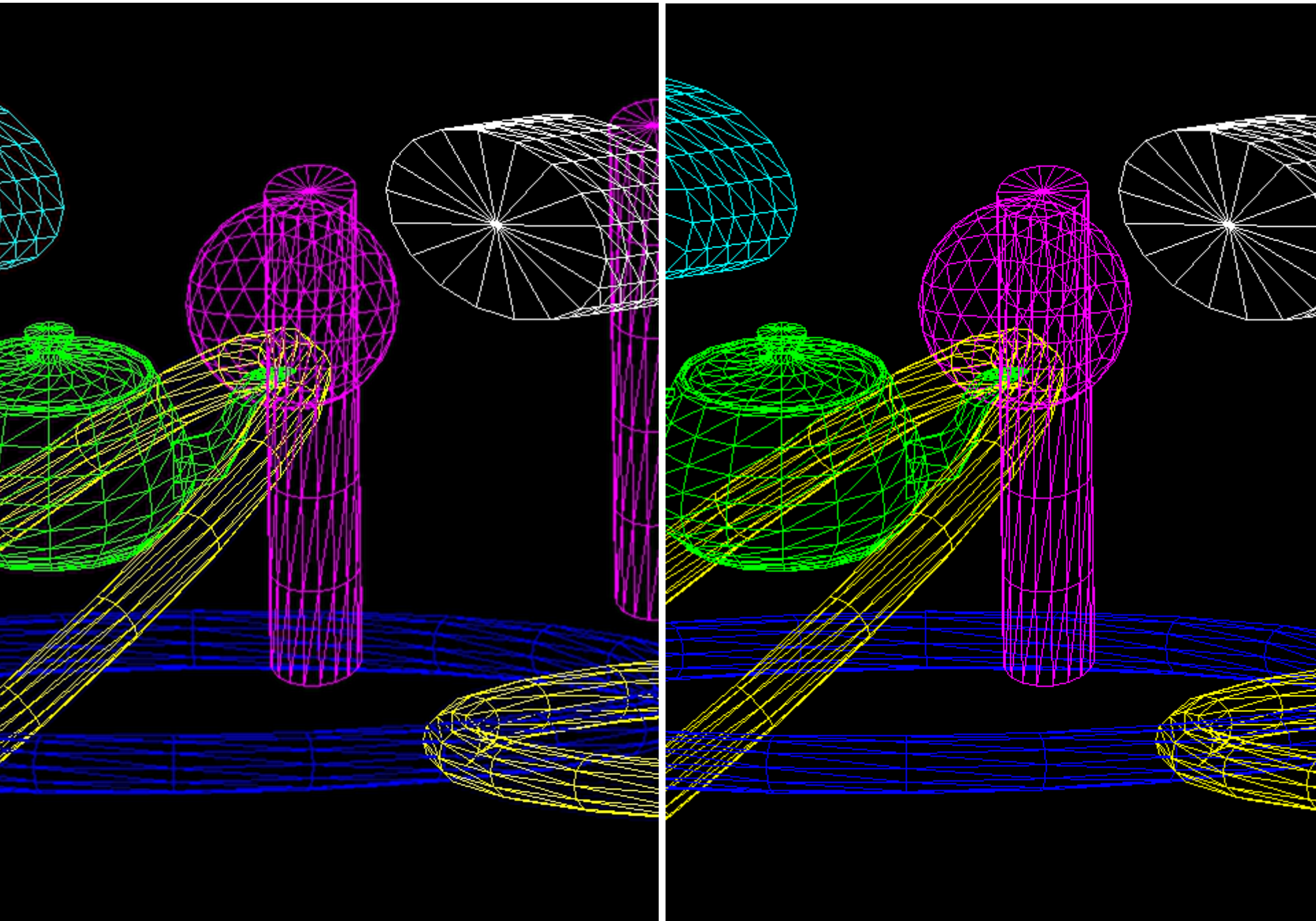
- Request for high quality multimedia
  - Professional applications require very high fidelity
    - Digital Cinema / Digital broadcast delivery / Post production
    - Geographical images / Medical imaging
  - High quality consumer applications are increasing
    - Large and vivid flat panel display has been emerging
    - High quality contents are available

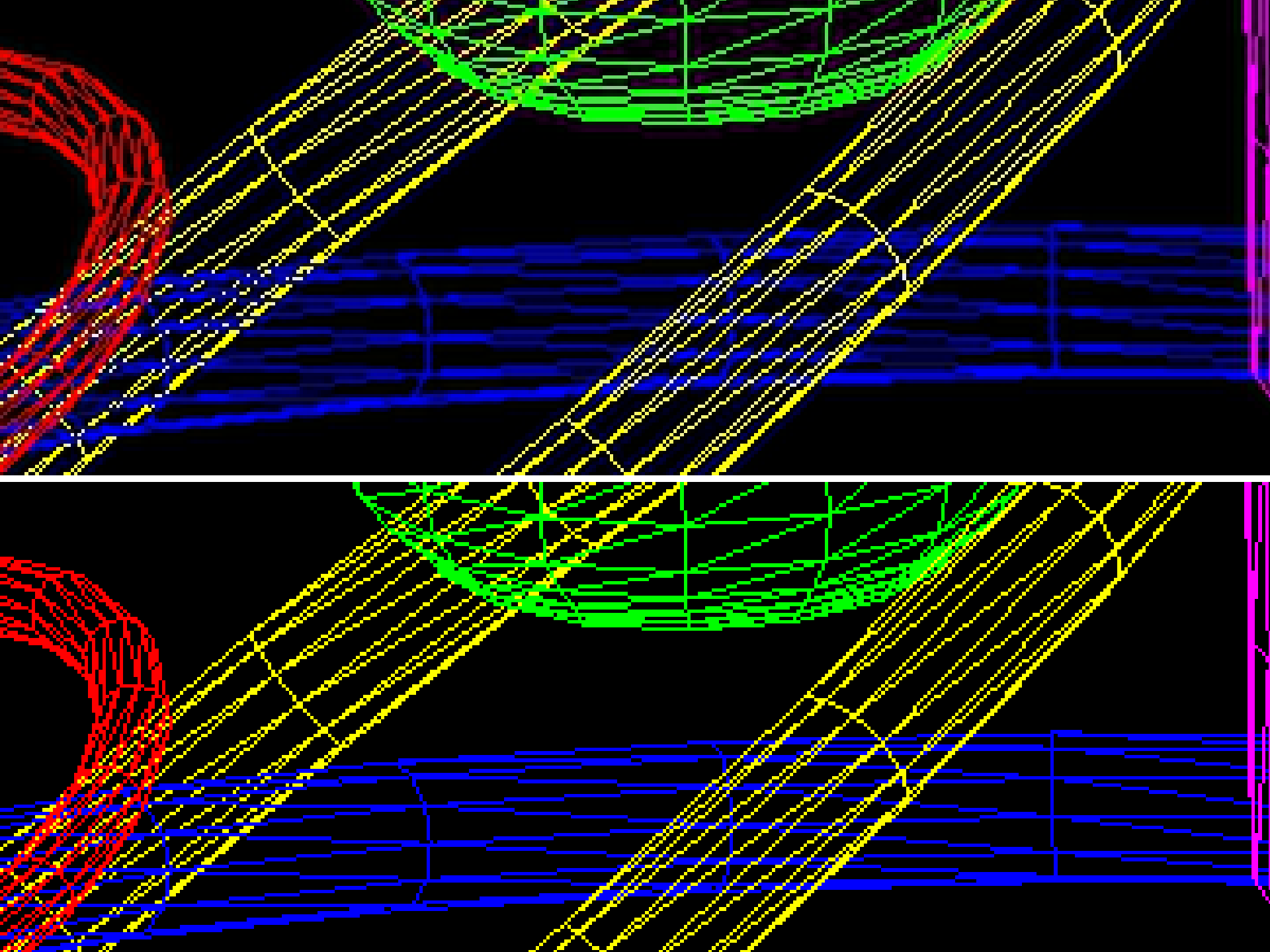
Why RGB Coding

- Trends in the Television Market
  - Shift towards larger sizes
  - Newer technologies gaining momentum
  - Increasing panel production capacities
  - Price breaks
  - Competing technologies in large screen market



Example of Color Distortion





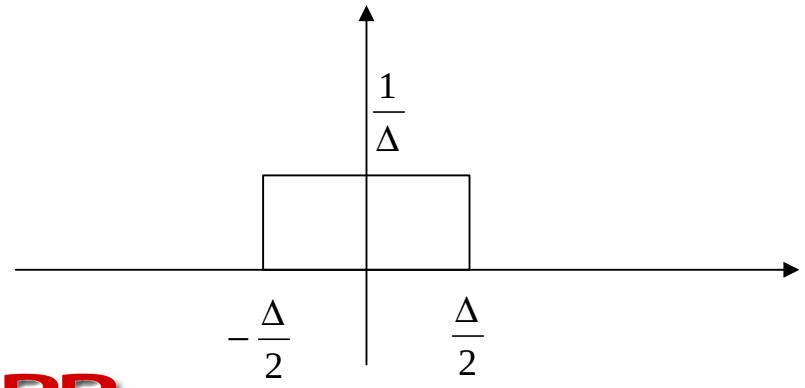
Color Distortion by Color Conversion

- Forward color transform (for RGB → YCbCr)

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.2126 & 0.7152 & -0.0722 \\ -0.1146 & -0.3854 & 0.5 \\ 0.5 & -0.4542 & -0.0456 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- The rounding operations on YCbCr space here introduce 1/12 MSE (assuming uniform distribution)

$$E_{forward} = \frac{1}{12} \cong 0.08$$



$$\begin{aligned} \text{MSE} &= \frac{1}{\Delta}\int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} x^2 dx \\ &= \frac{1}{\Delta}\cdot\frac{2}{3}x^3\Big|_0^{\frac{\Delta}{2}} \\ &= \frac{\Delta^2}{12} \end{aligned}$$

Color Distortion by Color Conversion

- Backward color transform (for YCbCr → RGB)

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.0 & 0.0 & 1.5748 \\ 1.0 & -0.1873 & -0.4681 \\ 1.0 & 1.8556 & 0.0 \end{bmatrix} \begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix}$$

- The rounding operation here introduce $\frac{1}{12}\sigma^2$ MSE
  - It is proportional to the sum of the square of each conversion coefficients a of YCbCr to RGB conversion matrix
- The overall conversion MSE for G is as follows:

$$E_{G,backward} = \frac{1}{12}(1^2 + 0.1873^2 + 0.4682^2)$$

$$E_G = \frac{1}{12}(1^2 + 1^2 + 0.1873^2 + 0.4682^2) = 0.1878$$

- The backward conversion error is greater than the forward conversion

Color Distortion by Color Conversion

- The achievable PSNR value for each components (8 bit depth) is as follows:

$$PSNR_R = 10 \cdot \log_{10} \frac{255^2}{E_R} = 52.4 \ dB$$

$$PSNR_G = 10 \cdot \log_{10} \frac{255^2}{E_G} = 55.4 \ dB$$

$$PSNR_B = 10 \cdot \log_{10} \frac{255^2}{E_B} = 51.6 \ dB$$

* PSNR : Peak Signal to Noise Ratio

$$Y = 10 \cdot \log_{10} \left(\frac{b}{\|F - F'\|_2} \right)^2 \quad (dB)$$

- **There is an achievable PSNR limit due to color conversion**

Approaches to RGB Coding

Problem

- Redundancies among color components
- Need to decorrelate in RGB space without color distortion

Approach

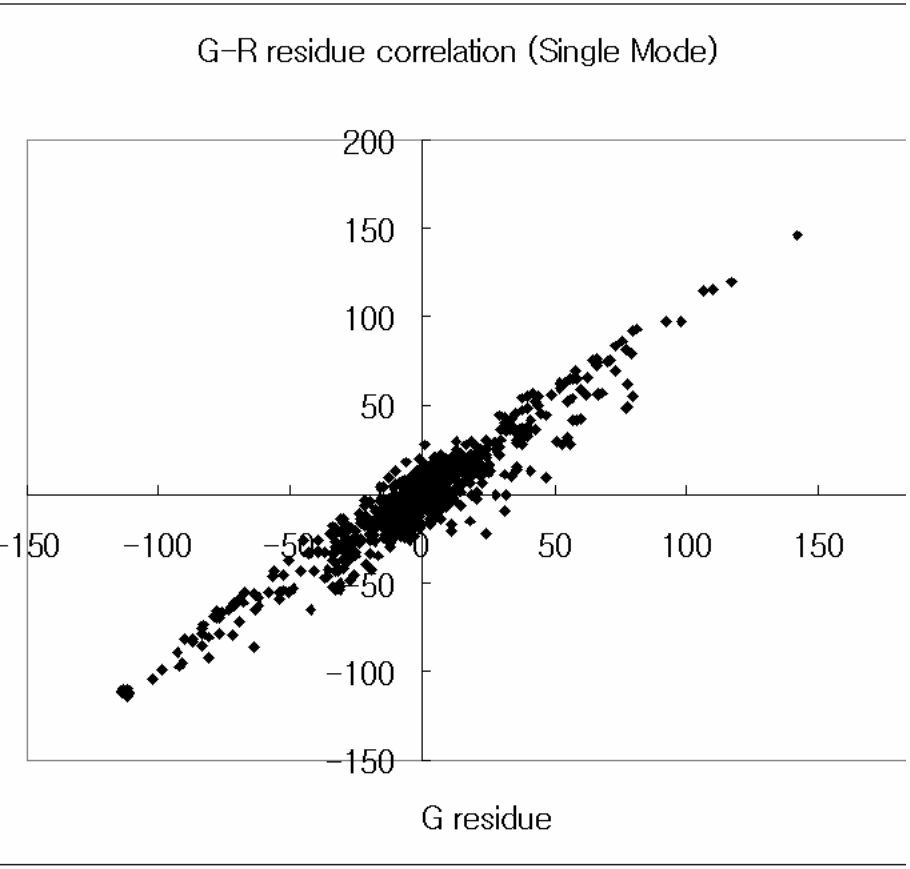
- **Very strong correlation among RGB residual signals after intra/inter prediction**
- Inter-plane redundancies in RGB residual signals can be removed easily without color distortion

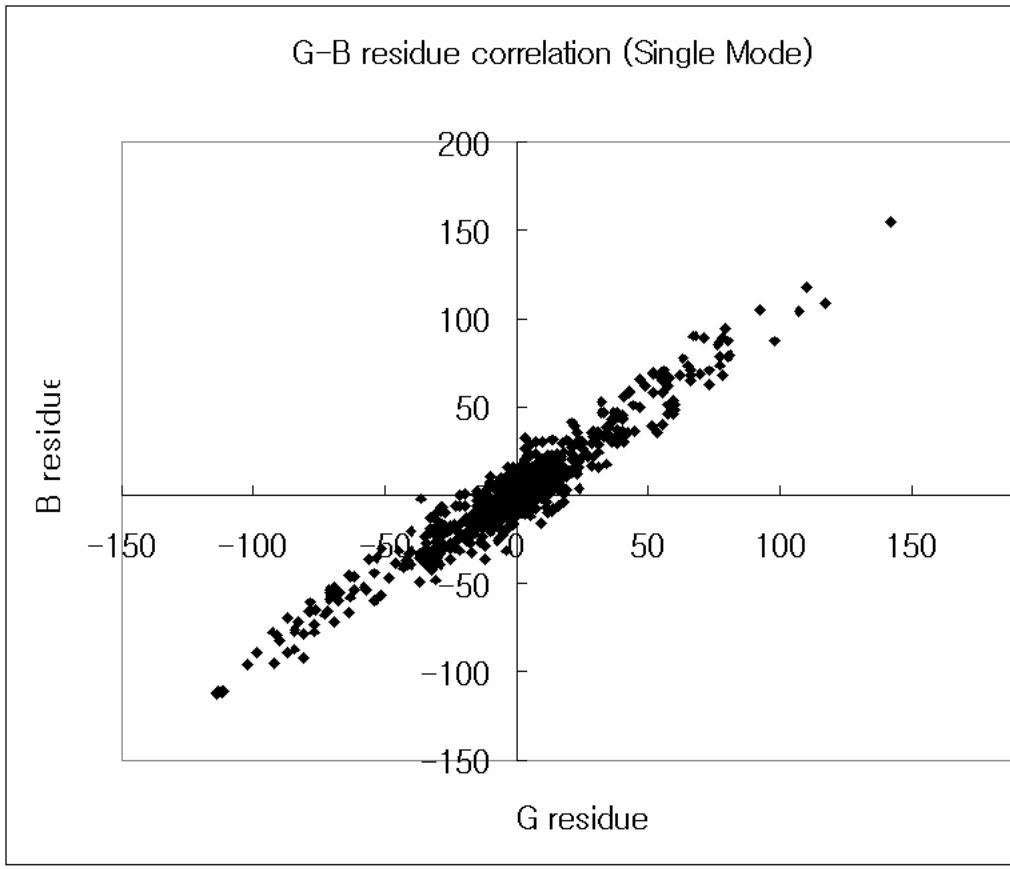
ntra prediction : removing spatial redundancy between neighboring blocks in current frame by DPCM

nter prediction : removing temporal redundancy between previous frame and current frame by DPCM

Single Mode Prediction

- Single mode intra prediction and single MVs in inter prediction result in very strong correlation among color components





Residual Color Transform

- Correlation removal by YCgCo transform in residual image

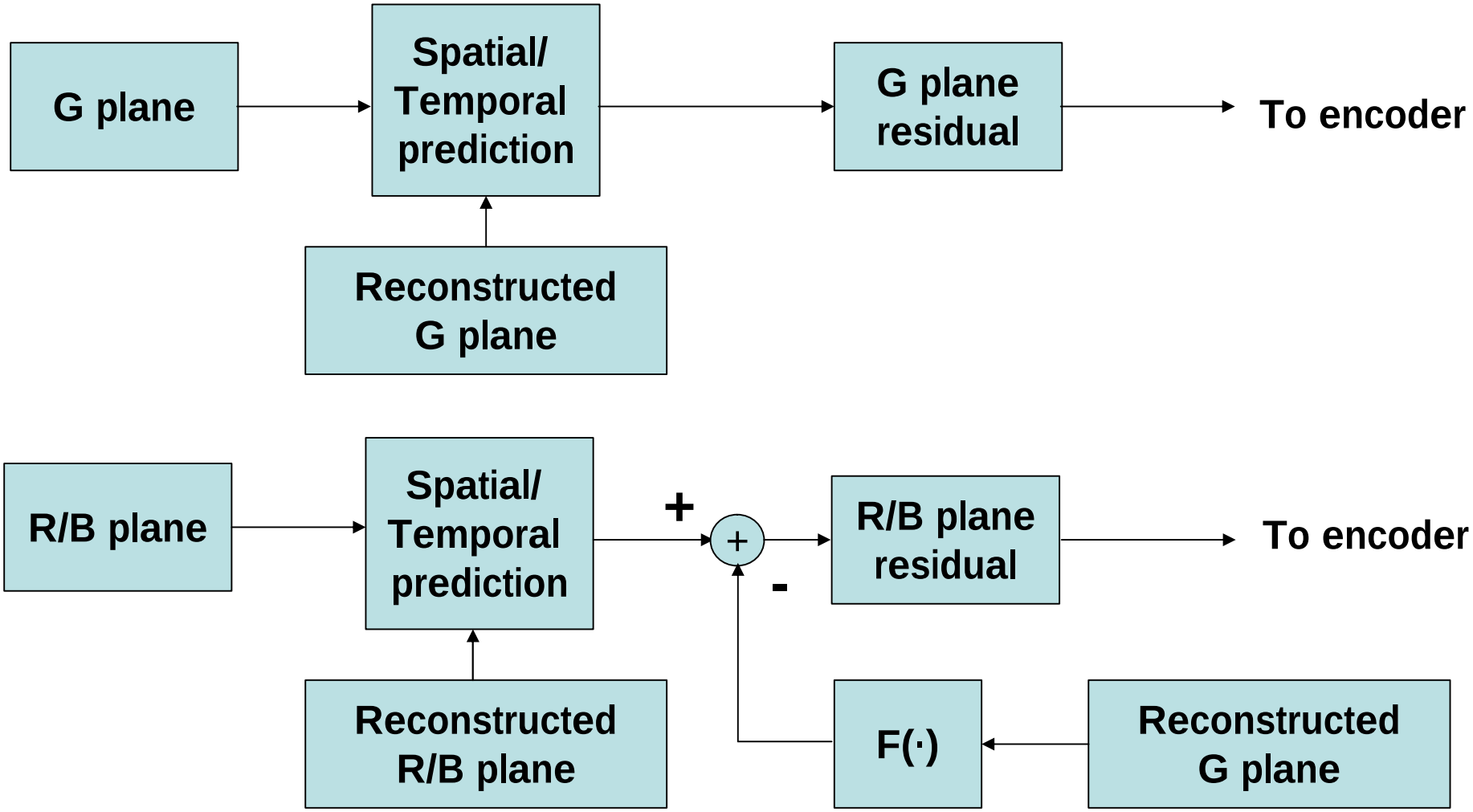
$$\begin{bmatrix}\Delta^2 G\\ \Delta^2 B\\ \Delta^2 R\end{bmatrix}=\begin{bmatrix}1/4 & 1/2 & 1/4\\ 1 & 0 & -1\\ -1/2 & 1 & -1/2\end{bmatrix}\begin{bmatrix}\Delta R\\ \Delta G\\ \Delta B\end{bmatrix} \qquad \begin{bmatrix}\Delta R\\ \Delta G\\ \Delta B\end{bmatrix}=\begin{bmatrix}1 & 1 & -1\\ 1 & 0 & 1\\ 1 & -1 & -1\end{bmatrix}\begin{bmatrix}\Delta^2 G\\ \Delta^2 B\\ \Delta^2 R\end{bmatrix}$$

$$\Delta^2 B = \Delta R - \Delta B$$
$$t = \Delta B + \left(\Delta^2 B >> 1\right)$$
$$\Delta^2 R = \Delta G - t$$
$$\Delta^2 G = t + \left(\Delta^2 R >> 1\right)$$

$$t = \Delta^2 G' - \left(\Delta^2 R' >> 1\right)$$
$$\Delta G' = \Delta^2 R' + t$$
$$\Delta B' = t - \left(\Delta^2 B' >> 1\right)$$
$$\Delta R' = \Delta B' + \Delta^2 B'$$

Inter-Plane Prediction (IPP)

- Block diagram of the inter-plane prediction



Inter-Plane Prediction (IPP)

- Inter-plane redundancy removal by DPCM Coding of RGB residual signals using linear regression

$$F(x) = m_y + r\frac{s_x}{s_y}(x - m_x) \cong x$$

$$\Delta G = G - G_p$$

$$\Delta R = R - R_p$$

$$\Delta B = B - B_p$$

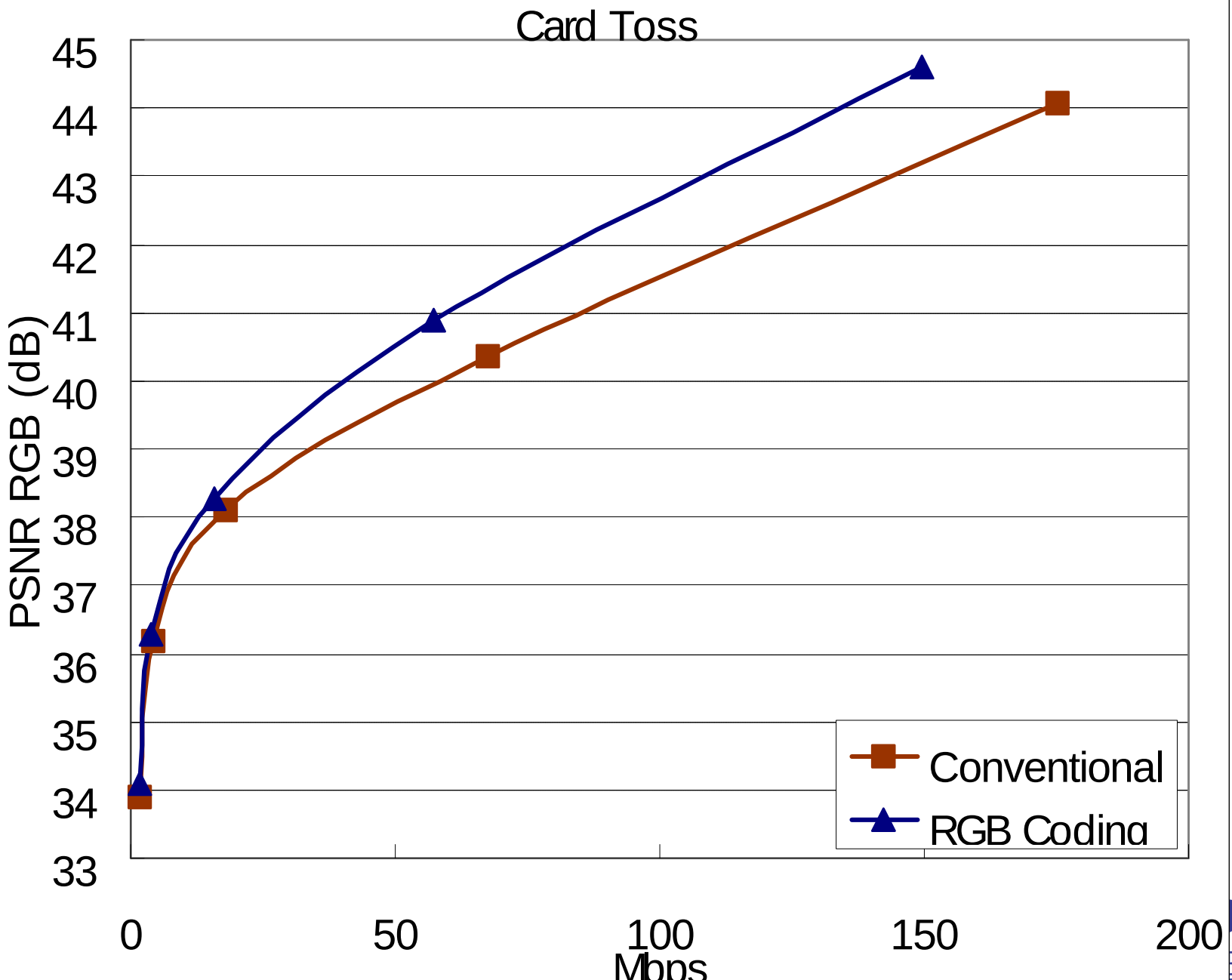
$$\Delta^2 R = \Delta R - \Delta R_p = \Delta R - f(\Delta G) = \Delta R - \Delta G$$

$$\Delta^2 B = \Delta B - \Delta B_p = \Delta B - f(\Delta G) = \Delta B - \Delta G$$

Experimental Results

- Various test materials targeted for high quality applications
  - HD material with 1280x720@60fps, 8 bits per pixel
  - Film scanned material with 1920x1080@24fps, 10 bits per pixel
  - Thomson Viper (very high quality CCD camera) with 1920x1080@24fps, 10 bits per pixel
- MPEG-4 AVC reference S/W (JM93) is used for simulation
- Coding conditions
  - CABAC
  - IBBP…, I frame/0.5sec
  - Fixed QP (w/o rate control)
  - RD-optimized mode selection
- Measure
  - RD-curve with total bitrate and average RGB PSNR
  - RD-curve with total bitrate and Y PSNR in YCgCo domain

Experimental Results



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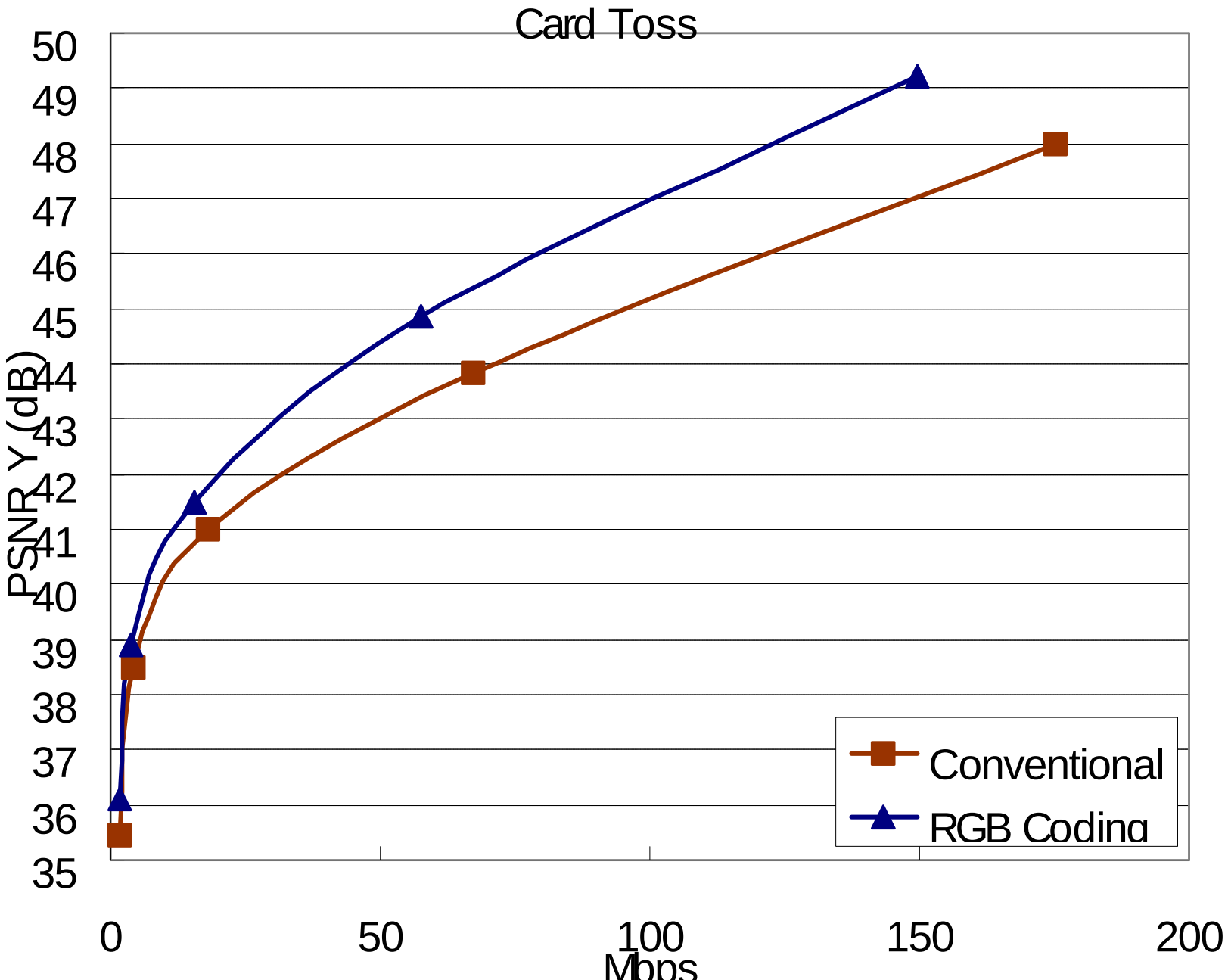

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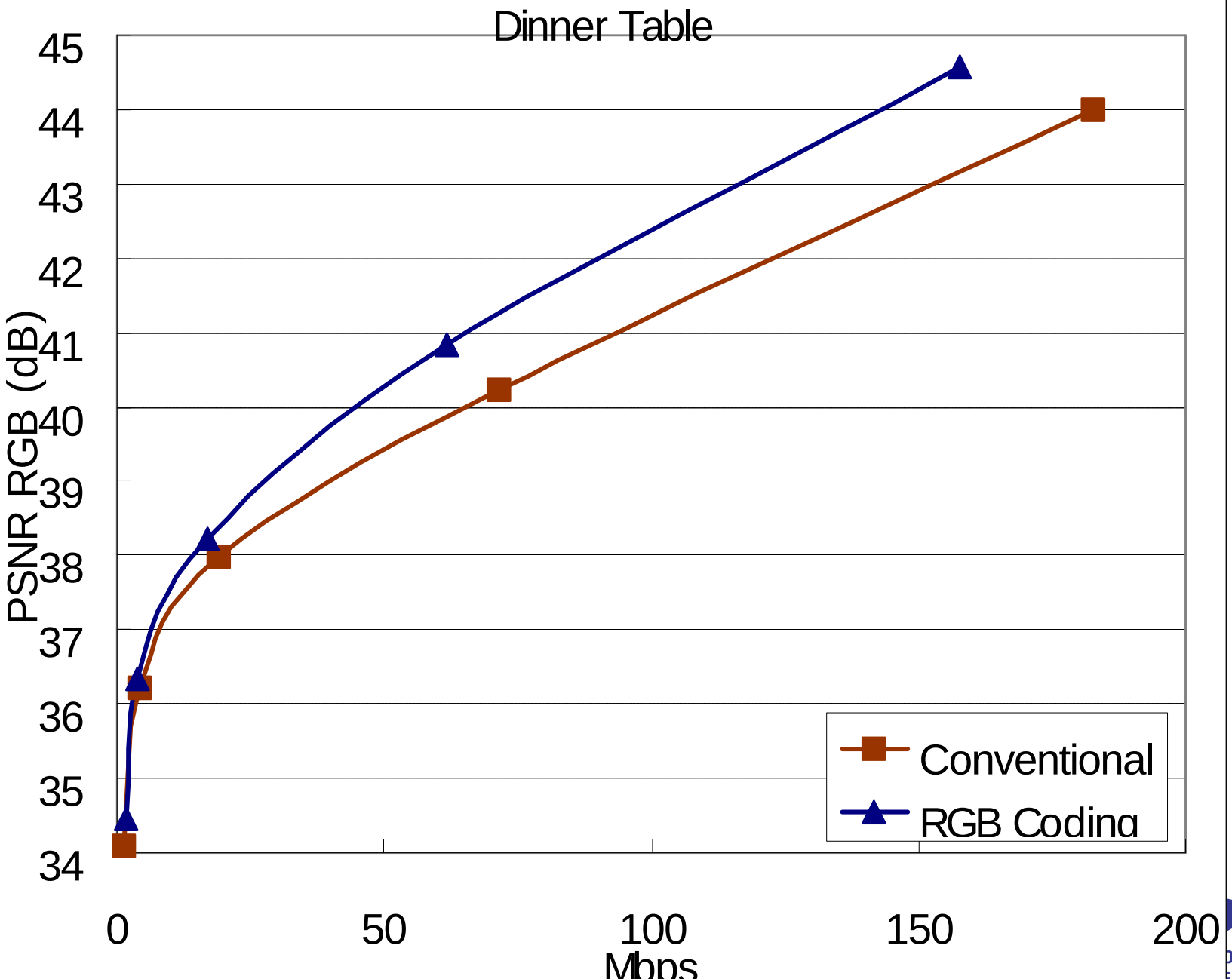
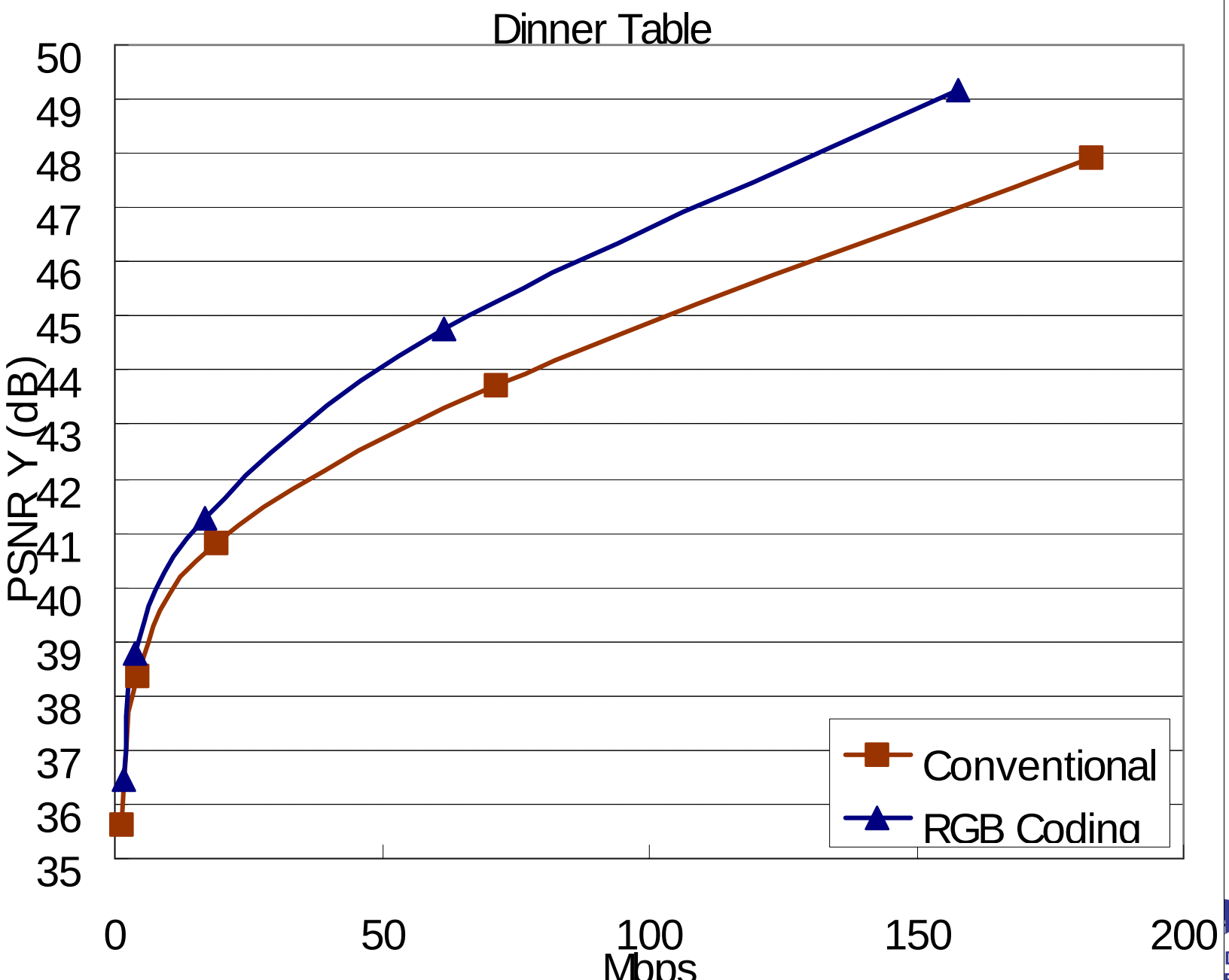


Experimental Results



Conclusions

- RGB coding without color conversion is introduced for future video coding
  - Showed why RGB coding is necessary to preserve the original color fidelity
  - We can efficiently code RGB video without color conversion
  - Showed RGB is not a bad space for compression
- Open a new paradigm for RGB video coding
  - High quality without color distortion
  - High compression ratio
  - Low computational complexity
- Promising technology area for near-future consumer multimedia applications
  - Consumers will demand more high quality multimedia as current high-end displays penetrate into regular households
  - We showed one way to code RGB video and there are many rooms for exploration for this new video coding paradigm
  - Would like to invite many companies and organizations