Digital Cinema

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Digital Cinema Specifications

- Digital Cinema Initiatives, LLC (DCI)
- Founded by seven Hollywood studios in March 2002
  - Disney
  - Fox
  - MGM
  - Paramount
  - Sony Pictures Entertainment
  - Universal
  - Warner Bros.
- DCI mission:
  - “DCI's primary purpose is to establish and document voluntary specifications for an open architecture for digital cinema that ensures a uniform and high level of technical performance, reliability and quality control. DCI will also facilitate the development of business plans and strategies to help spur deployment of digital cinema systems in movie theaters.”

DCI (cont.)

- System requirements and specifications
  - Completed July 2005
  - Available at www.dcimovies.com
- Specifies requirements for Digital Cinema
  - File format
  - Color space
  - Resolution
  - Compression
  - Encryption
  - Etc

SMPTE DC28

- DC28 is a Technology Committee of SMPTE
  - Society of Motion Pictures and Television Engineers
- Standardizing Digital Cinema
- Creating necessary detailed documents
- Ensure interoperability
  - Content creators/distributors
  - Projector and server manufacturers
- Four study groups
  - DC28.10 – Mastering
  - DC28.20 – Distribution
  - DC28.30 – Exhibition
  - DC28.40 – Stereoscopic

Why Digital Cinema?

- Many viewings conducted at Digital Cinema Lab
  - Side by side butterfly viewing of digital vs. answer prints
  - Digital quality comparable to answer prints
  - Digital 2K slightly softer, 4K slightly sharper
  - Significantly better than distribution prints
    - Distribution prints suffer generational loss
  - Digital does not suffer from spatial jitter
  - Film grain less visible (some say this is a negative)
  - Digital is “cool”

Why Digital Cinema? (cont.)

- Workflow issues
  - Many motion pictures use “digital intermediate” in post-production
  - Processing done digitally, then (currently) film out
- Distribution cost
  - Film distribution costs roughly $1200 per screen
  - Initially, savings may finance roll out
- Single inventory
- Stereoscopic movies
  - Digital projectors can display 48 frames per second
    - Polarized glasses
    - Shuttered glasses

Projectors

- Two resolutions specified
  - 2K – 2048 x 1080
  - 4K – 4096 x 2160
- Some studios believe 2K is sufficient
- Others believe 4K is necessary
  - Motivated by distinction over home theatre
- Two technologies
  - DLP (Texas Instruments) – mature products exist
    - Christie
    - Barco
    - NEC
  - LCOS (Sony, NTT) – products for small screens currently exist
  - Both are micro-display “reflective” technologies

Image Data

- Two max frame sizes
  - 2K (2048 x 1080) – 24 or 48 frames per second
  - 4K (4096 x 2160) – 24 frames per second
- Max not required in both dimensions
  - Accommodates different aspect ratios
    - 4096 x 1714 – 2.39
    - 3996 x 2160 – 1.85
- Pixels are square
- 12 bits per pixel per component
- X'Y'Z' color space
  - Allows for future wide gamut projectors
  - Expands code space

Audio Data

- Uncompressed 24 bits per sample (PCM)
  - 48 Kbps
  - 96 Kbps
- 16 tracks – 8 specified
  - Far left screen
  - Far right screen
  - Center screen
  - Screen low frequency effect subwoofer
  - Left wall surround
  - Right wall surround
  - Mid left to center screen
  - Mid right to center screen

Security

- Compressed image frames individually encrypted
  - AES – 128 bit key
- Preferred system has media block in projector
  - Decryption and decompression occurs in media block
  - If media block outside projector, link encryption must be used
- Audio encryption optional
- Biggest current piracy problem is camcorder
- Forensic watermarking will be employed
  - Watermark insertion in real time at media block
  - Watermark specific to location and time (accurate to 15 minutes)
  - Watermark must appear in every five minute segment

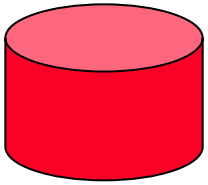
Distribution

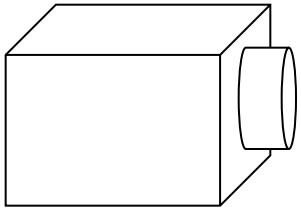
- Image frames compressed via JPEG2000
- Compressed image, (uncompressed) audio, captioning, subtitling wrapped via MXF
  - MXF = SMPTE standard file format
  - Organized as “reels”
- Packing list
- Playlist
- Digital signature
- Distribution is store-and-forward (no streaming)
  - Physical media delivery in short to medium term

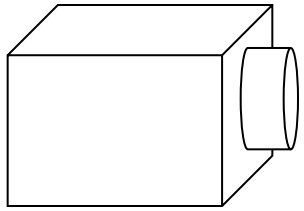
JPEG2000

- The latest International Standard for image compression
- Selected by DCI for distribution of motion pictures

JPEG2000 Compression







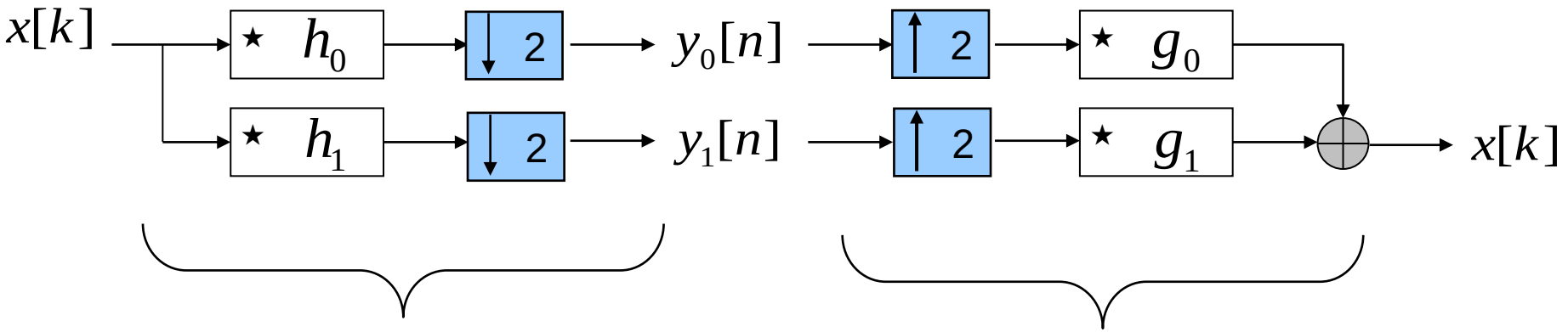
ECE160

Component Transform: Improves Compression Efficiency

- Three components – no subsampling
  - Typically RGB
  - X'Y'Z' for digital cinema (12 bits)
- Applied independently to each color pixel
- Most energy is in resulting Y component
  - Cz and Cx are highly compressible
- Improves compression efficiency
- 2:1 rate improvement for same quality

Wavelet Transform: Enables Resolution Scalability

- The filtering perspective

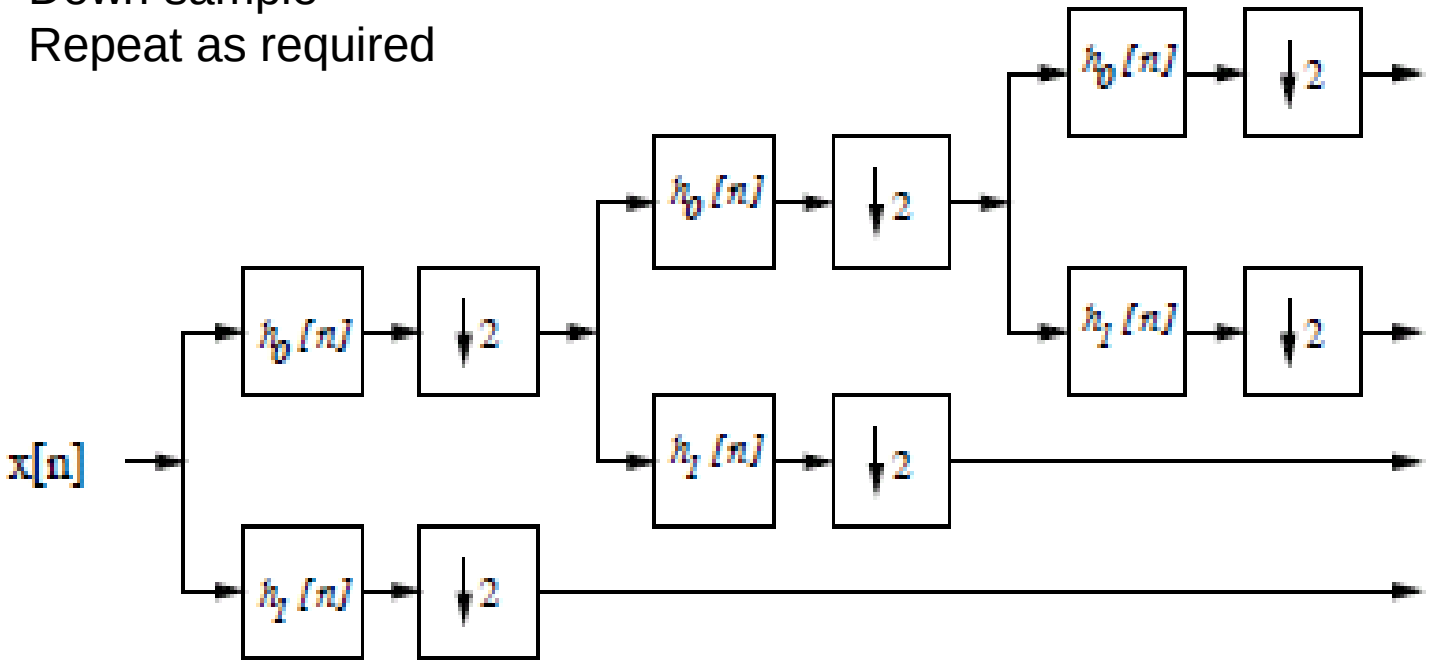


1-D Forward Wavelet Transform

1-D Inverse Wavelet Transform

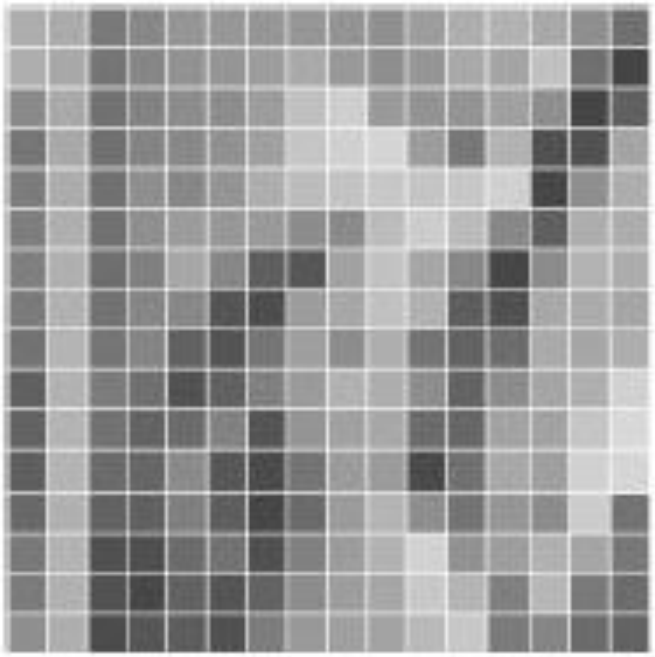
Wavelet Transform

High pass and low pass filters
Down sample
Repeat as required



Down Sampling

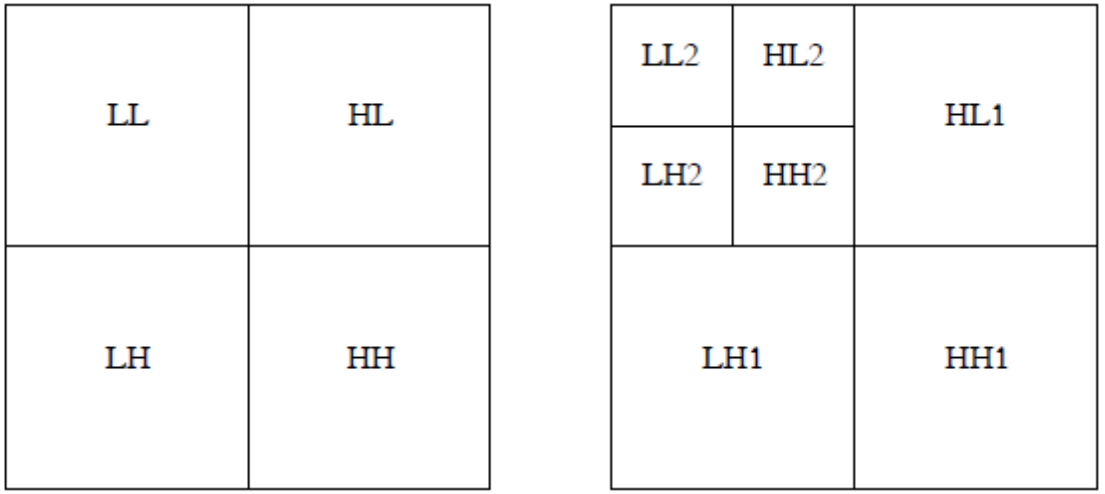
128x128 image



Downsampled to 16x16

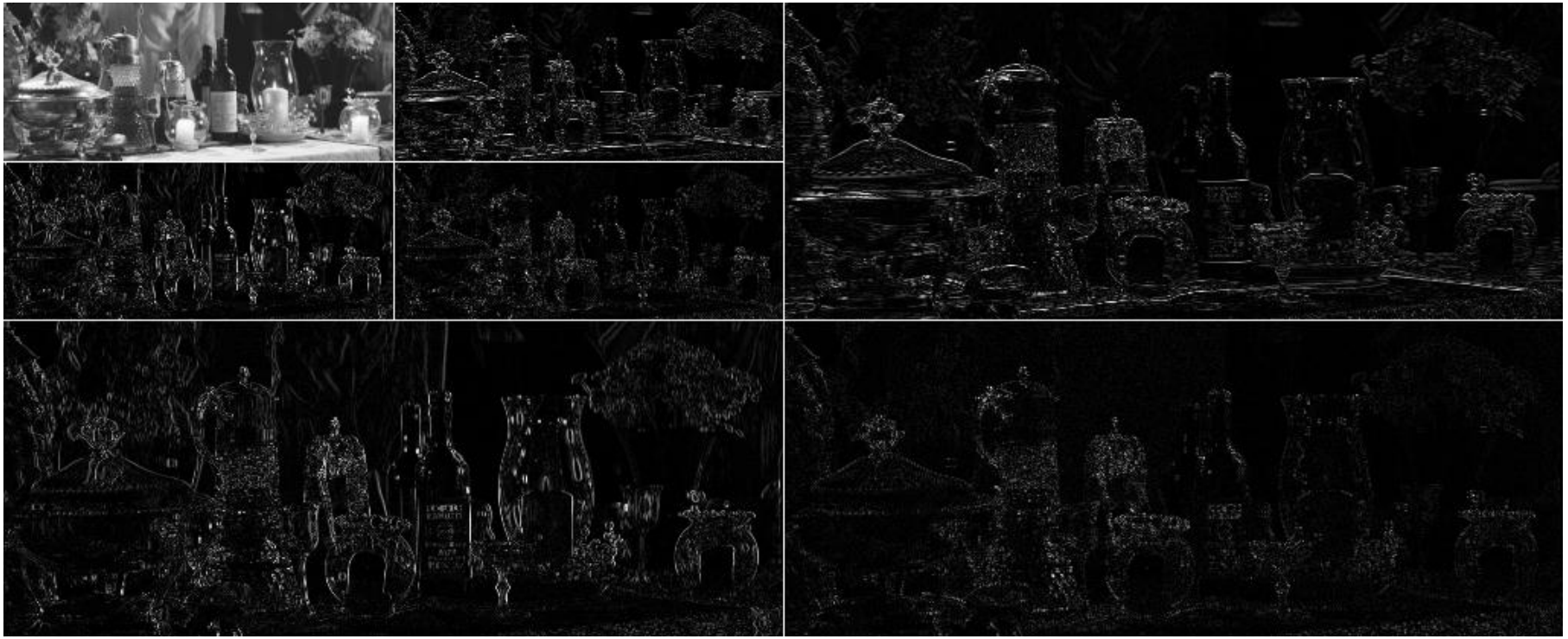
Wavelet Transform

- Low pass and high pass in both x and y followed by down sampling by 2



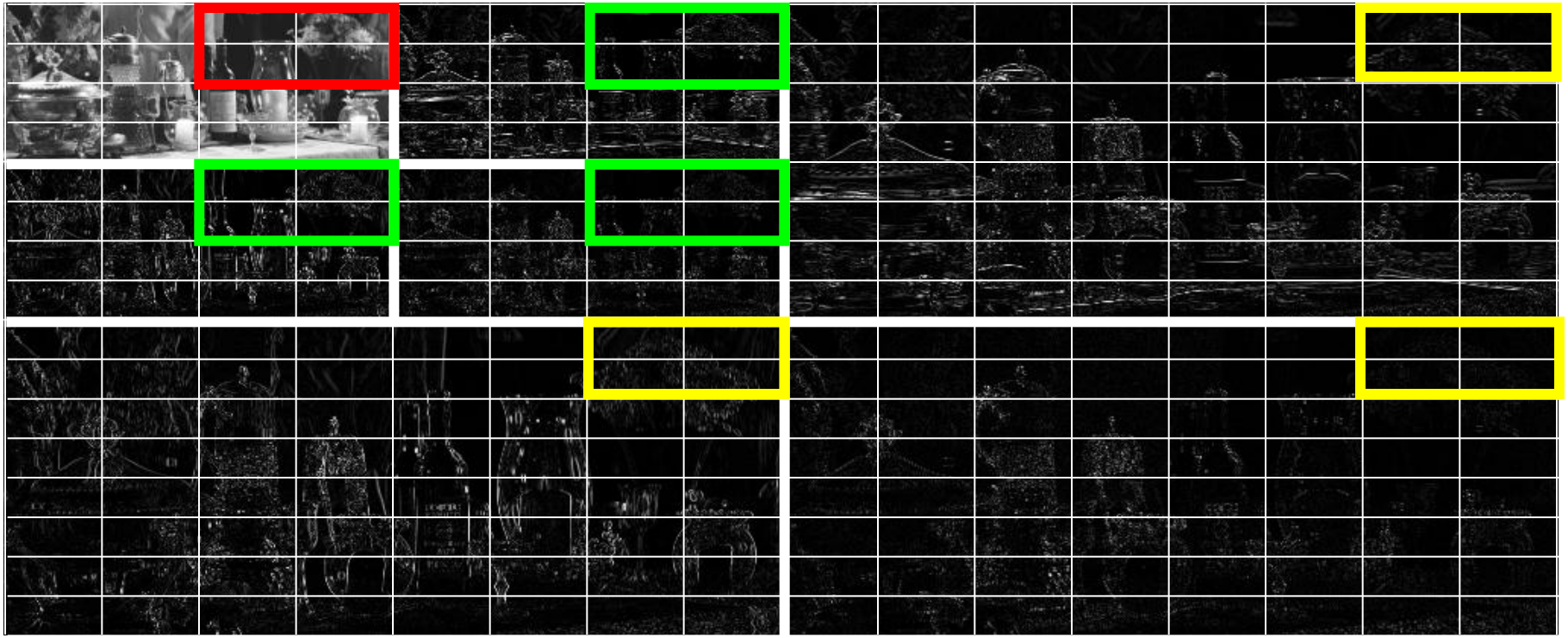
2D Transform: An Example

Wavelet Transform Example: Two Levels (Three Resolutions)



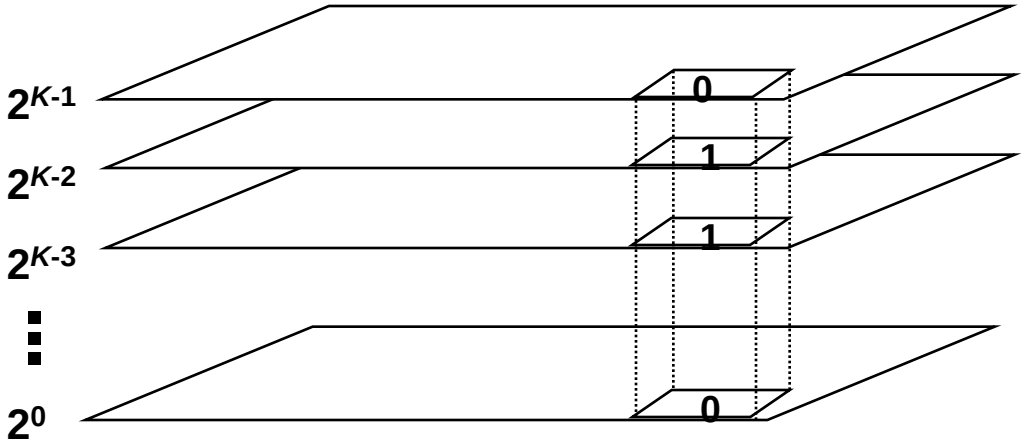
Note: High frequencies scaled for display

Codeblocks and Precincts: Enable Spatial Random Access and Low Memory



Bitplane Coding: Enables Quality Scalability and Precise Rate Control

- Bitplane coding applied independently to each codeblock
- Each bitplane coded in three “coding passes”
- Each coding pass has an associated “distortion reduction” and a “compressed length”
- “Distortion-rate slope” = figure of merit for a coding pass
- Goal of rate allocation
  - Include coding passes with largest slopes

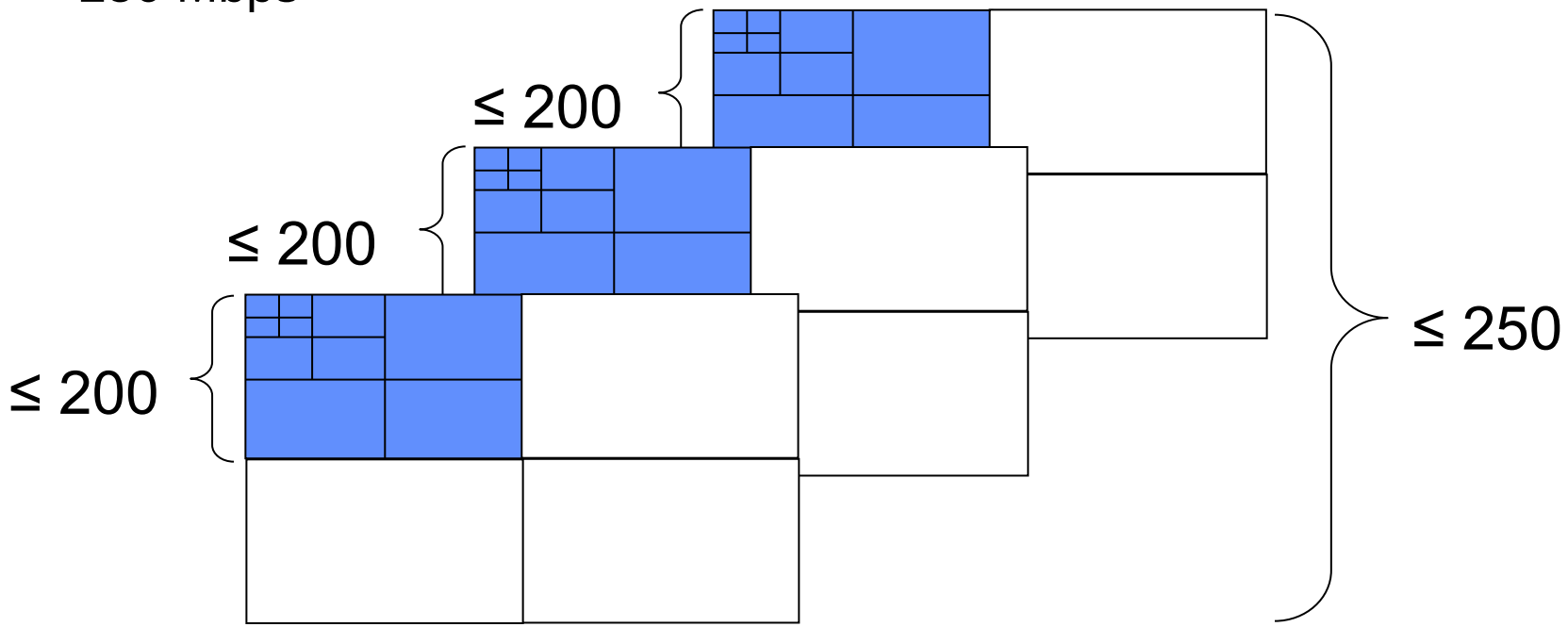


Codestream Restrictions for Digital Cinema

- Each frame compressed as one tile
- No chroma subsampling (e.g., 4:4:4)
- 12 bits per pixel per component
- Codeblock size 32 x 32
- Precinct size 256 x 256 (LL 128 x 128)
- “Default” arithmetic coder modes
- One quality layer
- Progression
  - 2K: by component
  - 4K: 2K subbands by component – then, 4K subbands, also by component

Codestream Restrictions (cont.)
Only 24 fps discussed here for simplicity

- No more than 1,041,666 bytes in the 2K portion of any color component of any frame
  - 200 Mbps
- No more than 1,302,083 bytes in any frame (aggregate all three color components)
  - 250 Mbps

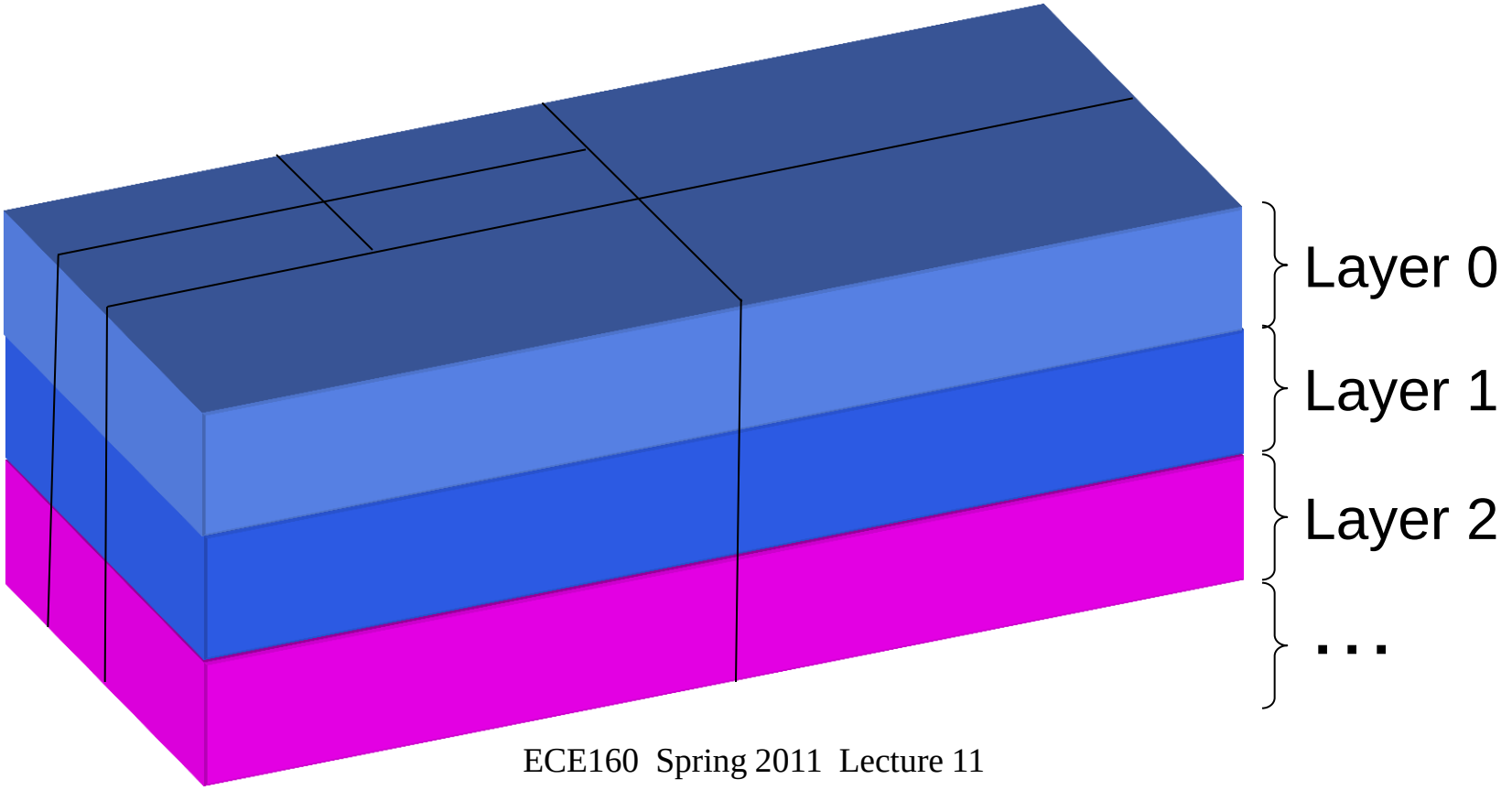


Single Layer VBR Encoding

- Assume 2k for simplicity --- 4k is similar
- Determine desired total bytes for compressed sequence
- For each frame in sequence
  - For each component in frame
    - Include coding passes with largest slopes until total bytes for component are1,041,666
  - Discard coding passes with smallest slopes until total bytes for frame are 1,302,083
- Discard coding passes with smallest slopes (from entire sequence) until total bytes for sequence are as desired

Multi-Layer Encoding

- May have applications in archiving and/or "enhanced" distribution



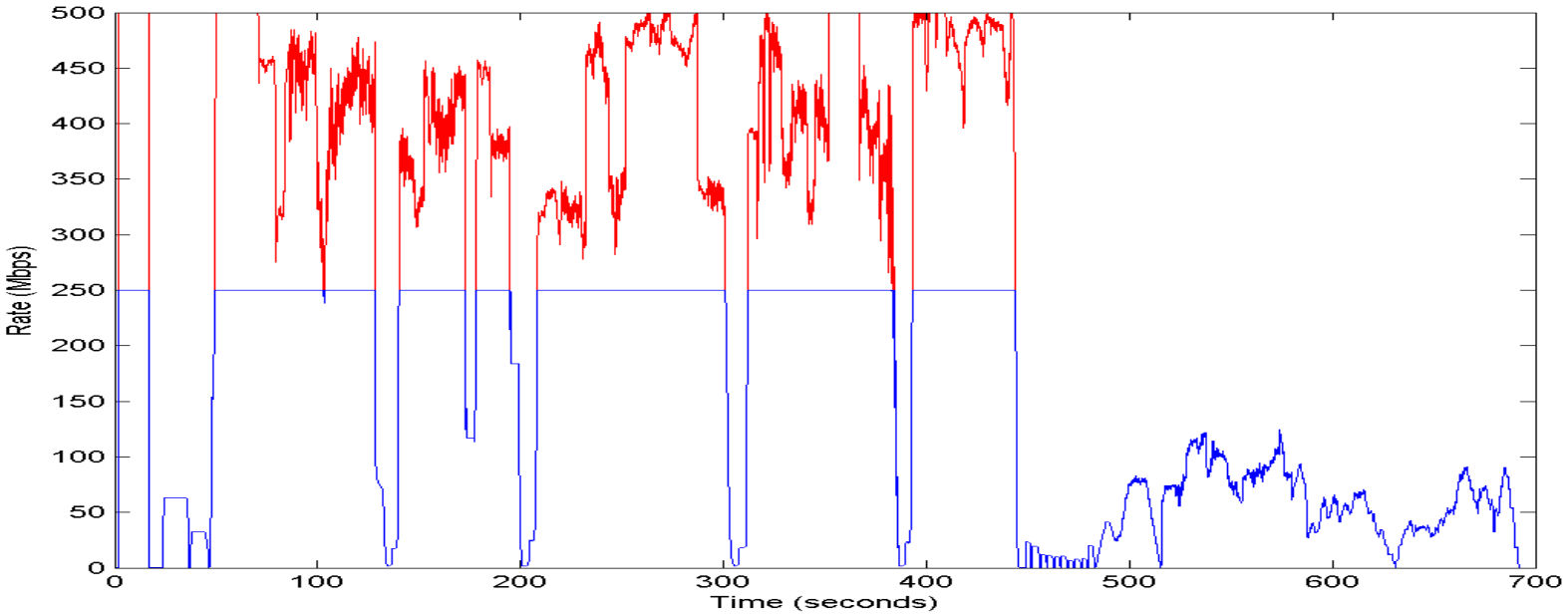
Multi-Layer Algorithm

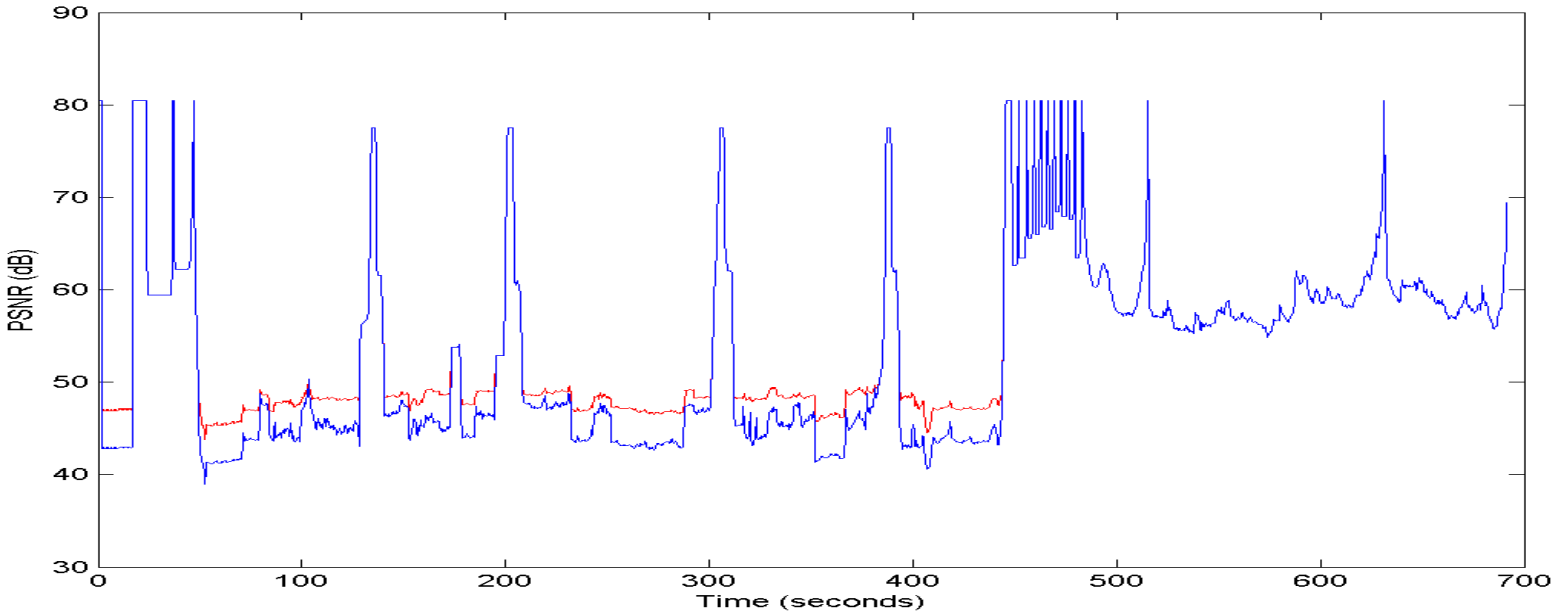
- Apply single layer algorithm recursively
- Assume two layers for simplicity

a) Set constraints for layers 0 and 1 together (e.g., archive quality)
b) Set constraints for just layer 0 (e.g., DCI constraints)
c) Run single layer algorithm for constraints in a)
d) Divide results of c) into two layers
   - Run single layer algorithm on results of c) using constraints of b)
   - Selected coding passes go in layer 0
   - The remainder go in layer 1

Encoding Example

- 4k StEM
- Constraints for Layer 0
  - Peak frame constraint: DCI (250 Mbps)
  - Peak component constraint: DCI (200 Mbps - 2k portion)
  - Average rate 150 Mbps
- Constraints for Layers 0 and 1 together
  - Peak frame constraint: 500 Mbps
  - Peak component constraint: none
  - Average rate 250 Mbps


Rate (Mbps)
Time (seconds)
0
50
100
150
200
250
300
350
400
450
500
0
100
200
300
400
500
600
700


PSNR (dB)
Time (seconds)
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700