Format Conversion Design Challenges for Real-Time Software Implementations

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DTV Challenges

• DTV has provided the broadcaster with a seemingly endless set of choices.

• Video format choices pose many questions but few answers.

• DTV broadcasters will find that video format conversion will be a well-used tool in the DTV “Tool Box”.

• MPEG 2 Pioneer
• Grand Alliance Founder
• MultiMedia Technology Leader

• Mission Critical Systems
• High Performance Platforms
• Parallel Processing Imaging Technology
AgileVision System

SD - HD Conversion path shown highlighted

19.4 Mb/s ATSC Stream

45 Mb/s Distribution

ASI

SD SMPTE 259

HD SMPTE 292

Format Conversion

MPEG Video Encoder

Transcoder

Compressed Content

Bit-Stream Router

Bit-Stream Splicer

Selected Stream

Pre-Selected Stream

Spliced Stream
SD ‡ HD Upconversion
General Block Diagram

SD Input
SMPTE 259M

Interlace-to-Progressive Conversion
480p
I -> P Mode

Spatial Upconversion
480p
720p
1080i
Upconversion Mode

Aspect Ratio Control

HD Output
SMPTE 292M

720 x 480i (4:3)
720 x 480i (16:9)

720 x 480p (4:3)
720 x 480p (16:9)
1280 x 720p (16:9)
1920 x 1080i (16:9)
HD → HD Conversion
General Block Diagram

HD Input
SMPTE 292M

Interlace-to-Progressive Conversion

Spatial Conversion

Aspect Ratio Control

HD Output
SMPTE 292M

480p
720p
1080p

720 x 480p (4:3)
720 x 480p (16:9)
1280 x 720p (16:9)
1920 x 1080i (16:9)

I -> P Mode
Up/Down Conversion Mode
AR Mode
Format Conversion Techniques

- Interlaced Inputs Converted to Progressive Scan
  - from simple non-adaptive to advanced motion-aware algorithms
- Spatial Resizing to New Format Size
  - polyphase frame filtering employed
- Aspect Ratio Control of Output
  - three modes supported
- Seamless Transitions With Format Changes
Interlace-Progressive Conversion

- Scalable operating modes:
  - line-repeat
  - spatial average
  - field-jam
  - temporal average
  - motion adaptive
    - simple
    - complex
    - auto-3:2 detect
  - motion compensated

Automatic throttling to lower quality modes upon demand.

Normal Operating Range.
Spatial Upconversion

- Polyphase filters used to perform spatial conversion
- Length of filters (complexity) can be traded off against quality
- Less complex filters can be switched in upon demand
- Sharpening is a parameter under user control
Aspect Ratio Control
4:3 to 16:9

Note: Mini- and No Sidebar Modes Require Vertical Panning Control
## Format Conversion Matrix

<table>
<thead>
<tr>
<th>In</th>
<th>Out</th>
<th>480i (4:3)</th>
<th>480p (4:3)</th>
<th>480i (16:9)</th>
<th>480p (16:9)</th>
<th>720p</th>
<th>1080i</th>
</tr>
</thead>
<tbody>
<tr>
<td>480i (4:3)</td>
<td>480i</td>
<td>A</td>
<td>A B</td>
<td>A B</td>
<td>4 B</td>
<td>3 B</td>
<td>3 B</td>
</tr>
<tr>
<td>480p (4:3)</td>
<td>480p</td>
<td>B</td>
<td>B</td>
<td>4 B</td>
<td>3 B</td>
<td>3 B</td>
<td>3 B</td>
</tr>
<tr>
<td>480i (16:9)</td>
<td>480i</td>
<td>A B</td>
<td>A B</td>
<td>A</td>
<td>A B</td>
<td>3 B</td>
<td>3 B</td>
</tr>
<tr>
<td>480p (16:9)</td>
<td>480p</td>
<td>B</td>
<td>B</td>
<td>4 B</td>
<td>3 B</td>
<td>3 B</td>
<td>3 B</td>
</tr>
<tr>
<td>720p</td>
<td>480p</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>4 B</td>
<td>4 B</td>
</tr>
<tr>
<td>1080i</td>
<td>480i</td>
<td>A B</td>
<td>A B</td>
<td>A B</td>
<td>A B</td>
<td>4 B</td>
<td>4 B</td>
</tr>
</tbody>
</table>

A: Requires Interlace-Progressive Conversion  
B: Requires Spatial Resizing  
Examples shown in this paper
Pixel Throughput

- Mpixel/sec processed determined by formats
- Interlace to Progressive Conversion (I2P)
  - only contributes for interlaced input signals
  - depends on input image size and sidebar mode
- Spatial Resizing (FIR)
  - depends on output image size
- Following charts show pixel throughput for two output formats:
  - 720p
  - 1080i
Conversion to 720p: MPixels/sec Processed

- 480i to 720p NSB
- 480p to 720p NSB
- 1080i to 720p

Bar chart showing conversion rates for different input formats to 720p.
Conversion to 1080i: MPixels/sec Processed

- 480i to 1080i NSB
- 480p to 1080i NSB
- 720p to 1080i
Computational Complexity

• Computational complexity is product of pixel throughput and number of operations/pixel
• Tradeoffs: Complexity and Quality
• Interlace to Progressive Conversion (I2P)
  – estimate: 20 operations/pixel
• Spatial Resizing (FIR)
  – each output pixel requires a polyphase filter operation
  – typical good filters are up to 16 taps in length
  – estimate of 60 operations/pixel
Conversion to 720p: Number of Gops/sec

- 480i to 720p NSB
- 480p to 720p NSB
- 1080i to 720p

Bar graph showing conversions and Gops/sec.
Conversions to 1080i: Number of Gops/sec

- 480i to 1080i NSB
- 480p to 1080i NSB
- 720p to 1080i
Processor Assumptions

• 400 MHz G4 with AltiVec™ technology
  – can perform sixteen 8-bit or eight 32-bit operations/cycle
  – processing range is 3.2 to 6.4 Gops/sec
  – Assume 4 Gops/sec average

• 3 to 5 Processors Needed for Conversions to HD output formats

• HD 1080i to HD 720p is most complex
Processor Allocation

- Horizontal stripes
- Vertical Stripes
- “Window Panes”
Synergy: Conversion Before Compression
...

 avoids full motion estimation...

Input Video

Video Format Converter

Converted Video

Dense MV Field

Temporal Scaling & Spatial Subsampling

Refined MV’s

MV Refinement

Reconstructed Video

MPEG-2 Video Encoder

Video Bitstream
Synergy: Conversion After Decompression

...re-uses upstream motion vectors...

MPEG-2 Video Decoder

Input Video

Video Format Conversion

Converted Video

Coarse MV’s - for motion-adaptive conversion

Fine MV’s - for motion-compensated conversion

Video Bitstream

Temporal Scaling & Spatial Interpolation

Coarse MV Field
Conclusions

• DTV video format conversions are necessary, and can be done with high quality in real-time on a multiprocessor platform
• At current speeds, 3 to 5 processors are needed to perform conversions to HD output formats in real-time
• Exploiting synergy with MPEG compression can lower overall system complexity
• A future AgileVision product will validate this
Acknowledgments

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