First Parts of H.264 Decoder

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H.264 Overview

- Works on blocks of 4x4 to 16x16 pixels
- Encoder picks a way to approximate current block using previous data
- Residual data transformed in 4x4 blocks
- Almost everything is entropy coded
- Units of encoded data wrapped in Network Abstraction Layer (NAL)
NAL Unit Unwrapping

- Units separated by 3 byte combination “start code prefix”
- End of units might be padded with bytes with value 0
- Encoder inserts bytes to prevent start code prefix inside units
- Unwrapper reverses these effects
Entropy Decoding

- First checks the type of a NAL unit
- Parses the unit accordingly
- Most syntax elements coded with Exp-Golomb codes
- Transformed residual data coded with Context-based Adaptive Variable Length Coding (CAVLC)
## Exp-Golomb Codes

<table>
<thead>
<tr>
<th>Bit string</th>
<th>codeNum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0 1 0</td>
<td>1</td>
</tr>
<tr>
<td>0 1 1</td>
<td>2</td>
</tr>
<tr>
<td>0 0 1 0 0</td>
<td>3</td>
</tr>
<tr>
<td>0 0 1 0 1</td>
<td>4</td>
</tr>
<tr>
<td>0 0 1 1 0</td>
<td>5</td>
</tr>
<tr>
<td>0 0 1 1 1</td>
<td>6</td>
</tr>
<tr>
<td>0 0 0 1 0 0 0</td>
<td>7</td>
</tr>
<tr>
<td>0 0 0 1 0 0 1</td>
<td>8</td>
</tr>
<tr>
<td>0 0 0 1 0 1 0</td>
<td>9</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>codeNum</th>
<th>syntax element value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>−1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>−2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>−3</td>
</tr>
<tr>
<td>k</td>
<td>((-1)^{k+1}) Ceil( k/2 )</td>
</tr>
</tbody>
</table>

...
CAVLC

- Data encoded in several components
- Each component has a set of tables
- A table is chosen based on context
- Decoded result from neighboring blocks used as context for one component
Hardware Design

Input Generator

H.264 Module

NAL Unit Unwrapper Module

Entropy Decoding Module

CAVLC Context Submodule

CAVLC Functions

Exp-Golomb Functions

Client

CAVLC Memory Module

Server

Output
NAL Unwrapper Module States

- Three byte buffer
- Counter for number of bytes in buffer
- Counter for number of consecutive bytes with value 0
NAL Unwrapper Module Rules

- A rule fills the buffer
- A rule checks for start code prefix
- A rule removes extra bytes that prevent start code prefix from appearing in data
- A rule for normal operation
- A rule for end of file case
Entropy Decoder States

- Parsing state register
- 77-bit input buffer
- Input buffer counter
- 16-element FIFO for intermediate results of CAVLC
- Registers for decoded syntax elements that are needed for parsing
Entropy Decoding Rules

- A rule for initializing
- A rule for checking the NAL unit type
- A rule for filling the input buffer
- A rule for parsing the data
  - Basically a large finite state machine
Residual data (output of CAVLC) usually contains many consecutive zeros.

- Original: outputs zeros one by one
- Change: outputs the consecutive number of zeros
Design Exploration B

- Most of the Exp-Golomb syntax elements only up to 16 bits decoded
- Some infrequent ones are up to 32 bits
- Original: use same decoder function
- Change: two versions of decoder
  - 1-cycle 16 bit decoder function
  - 32 bit decoder split into 2 parts (2 cycles)
Design Exploration C

- The input buffer filler and parser rules of entropy decoder conflict

- Original: buffer filled one byte at a time

- Change: an extra 32-bit buffer is used
  - An extra rule adds bytes into extra buffer
  - 32 bits inserted into main buffer each time
Benchmarks

- Small clips of three different files
  - 5 frames with 176x144 resolution
  - 15 frames with 176x144 resolution
  - 5 frames with 352x288 resolution
**Benchmark Results**

<table>
<thead>
<tr>
<th></th>
<th>Total Cycles</th>
<th>Cycle Delay</th>
<th>Total Time</th>
<th>Area (mm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>654290</td>
<td>6.468 ns</td>
<td>4.232 ms</td>
<td>0.3378</td>
</tr>
<tr>
<td>A</td>
<td>251524</td>
<td>6.405 ns</td>
<td>1.611 ms</td>
<td>0.3283</td>
</tr>
<tr>
<td>A+B</td>
<td>251552</td>
<td>5.955 ns</td>
<td>1.498 ms</td>
<td>0.2820</td>
</tr>
<tr>
<td>A+C</td>
<td>230750</td>
<td>6.400 ns</td>
<td>1.477 ms</td>
<td>0.3690</td>
</tr>
<tr>
<td>A+B+C</td>
<td>230712</td>
<td>6.184 ns</td>
<td>1.427 ms</td>
<td>0.2932</td>
</tr>
</tbody>
</table>