everything you always wanted to know

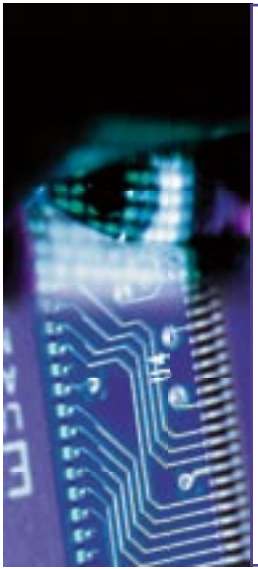
about JPEG 2000

2000 JPEG 2000

1998 MPEG 4

1994 MPEG 2

1992 JPEG



As stated by the Joint Photographic Expert Group (JPEG):

"**JPEG 2000** is a new image coding system that uses state-of-the-art compression techniques based on wavelet technology. Its architecture should lend itself to a wide range of uses from portable digital cameras through to advanced pre-press, medical imaging and other key sectors."

In 2004, **JPEG 2000** was selected as the mandatory image compression format for Digital Cinema.

index

JPEG 2000 Benefits

License-Free

The JPEG committee has stated:

"It has always been a strong goal of the JPEG committee that its standards should be implementable in their baseline form **without payment of royalty** and license fees.

[...]

Agreements have been reached with over 20 large organizations holding many patents in this area to **allow use of their intellectual property** in connection with the standard without payment of license fees or royalties".

Improved Compression Efficiency

ORIGINAL IMAGE COMPRESSED WITH JPEG
WITH A 100 TO 1 COMPRESSION RATIO

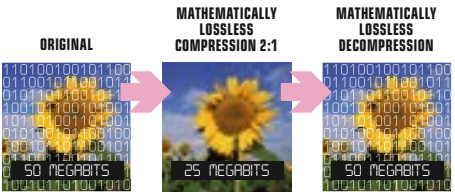
IMAGE COMPRESSED WITH JPEG 2000
WITH A 100 TO 1 COMPRESSION RATIO

Mathematically Lossless Compression

To maximize image quality JPEG 2000 incorporates a mathematically Lossless mode.

Mathematically Lossless compression enables a reduction in the storage requirement of, on average, 2:1 while still being able to recover the exact original image information.

This feature is extremely important in fields such as digital archiving, cinema acquisition and medical imaging. It is also a unique advantage in comparison to other popular formats like JPEG or MPEG (MPEG2, MPEG4).



Lossy and Visually Lossless Compression

At visually Lossless compression ratios, **even a trained eye is unable to differentiate between the original and compressed versions of an image.**

Visually Lossless typically achieves compression ratios of 10:1 to 20:1.

Lossy compression allows higher compression ratios i.e. 50:1 up to 100:1. In this case the compression becomes visible but remains perfectly adequate for e.g. web browsing.

Note: Visually Lossless and Lossy compressions both lead to a permanent loss of data.

Graceful Degradation

In JPEG 2000 the effect of image compression is a soft blur on high-frequency areas.

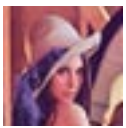
Contrary to JPEG and MPEG compression formats there are no visible blocking artefacts in JPEG 2000, hence its more homogeneous or graceful image degradation at high compression ratios.

IMAGE COMPRESSED WITH JPEG 2000
WITH A 2:1 COMPRESSION RATIO

IMAGE COMPRESSED WITH JPEG 2000
WITH A COMPRESSION RATIO OF 400:1

Scalability

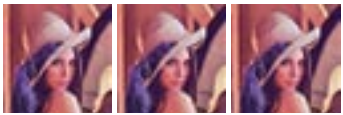
A coding format is said to be scalable when the user is able to extract **multiple versions out of a single compressed file.** JPEG 2000 offers resolution, color component, quality and position progression scalability.



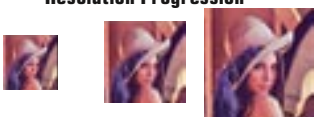
COMPRESSION

STORAGE

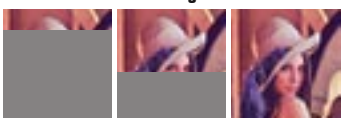
Quality Progression



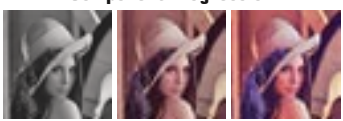
Resolution Progression



Position Progression



Component Progression



This scalability provides many benefits, such as:

- Easy proxy generation
- Region of Interest
- Bandwidth optimization and adaptive transmission

A

EXAMPLE OF A PROGRESSION IN QUALITY

2% ACCESS

29% ACCESS

64% ACCESS

100% ACCESS

Dynamic Bandwidth Allocation

Using JPEG 2000 scalability over highly variable channels, e.g. over-IP or Wireless, provides a **powerful dynamic quality allocation.**

- Giving priority to fundamental data packets allows an automatic adaptation to the transmitted bit rate and ensures a consistent 'best achievable quality' for the available bandwidth.
- Increasing redundancy of fundamental data packets also guarantees a minimum image quality when the signal is weak.

Scalability and Adaptive Reception

JPEG 2000 easily **scales the transmitted data amount to fit the channel bandwidth and destination resolution**

- In a Video on Demand (VOD) service, a PDA client with a slow connection would receive a low resolution or quality content version.

When receiving a broadcasted signal, each receiver could easily use the image part corresponding to its viewing capability.

- In a broadcast service, a PDA user would receive the news on his PDA while his neighbor receives the same signal in full resolution on his HD TV set.

Robust Transmission

JPEG 2000 **intrinsic robustness prevents having dramatic visual impact when some packets are missing or corrupted.**

Furthermore, its intra-frame nature also gives JPEG 2000 another advantage to long-GOP formats: it limits the impact of the missing or corrupt packet to a single frame.

EMBEDDED ERROR OF 16 BYTES SET TO ZERO ON A JPEG 2000 IMAGE: THE RESULT IS A HALF IMAGE CORRUPTED WITH SOFT HIGH FREQUENCIES

EMBEDDED ERROR OF 16 BYTES SET TO ZERO ON A JPEG IMAGE: THE RESULT IS A HALF IMAGE WITH A DRAMATIC LOSS IN COLOR QUALITY

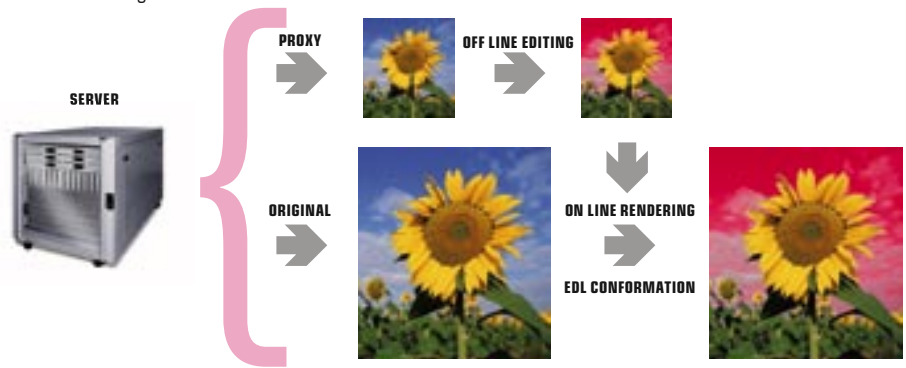
Easy Post-Production

Easy-Proxy

- Resolution scalability facilitates post-production data flow.
- From a single file depository **the editors can easily extract a proxy** for editing and color correction and use the full resolution image version for the rendering chain.

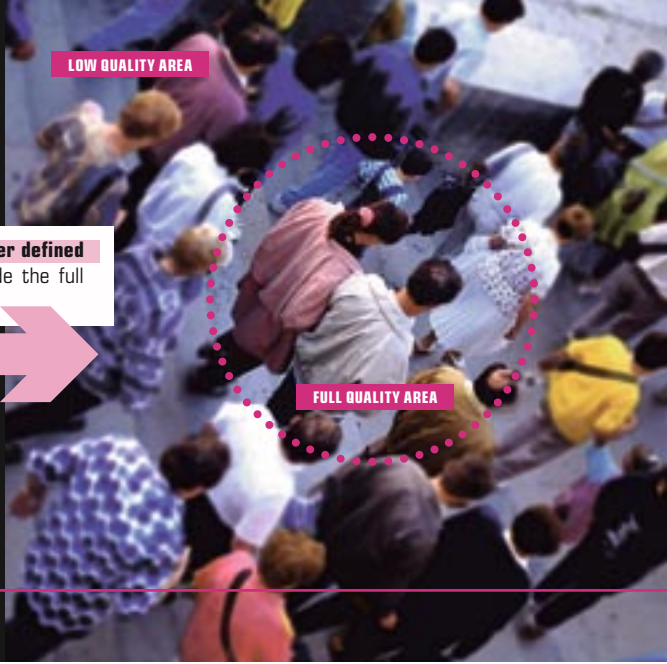
Easy Editing

- **Intra-frame coding enables editors to easily access each frame** without needing to decode entire groups of frames as in the case of long-GOP compression formats.



Region of Interest (ROI)

JPEG 2000 is also able **to prioritize a user defined area of the image**, to which it will provide the full quality layer.



Low Latency

The intra-frame nature of JPEG2000 allows every frame to be encoded independently. Combined with the scalability by position, it allows **latency of less than 1 frame for the full encoding-decoding process.**

In comparison, inter-frame encoding formats (e.g. MPEG2, MPEG4) need to work with Groups of Pictures (GOP) that require a longer processing time.

Low latency is a critical consideration in many applications - including live broadcast, **and even more so in the image compression for medical remote operation.**

Constant Quality through Multiple Generations

JPEG 2000 does not introduce image corruption other than that directly related to the compression process.

ORIGINAL UNCOMPRESSED IMAGE

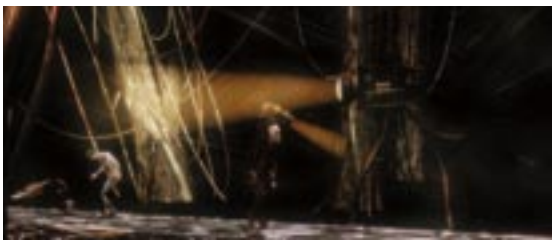
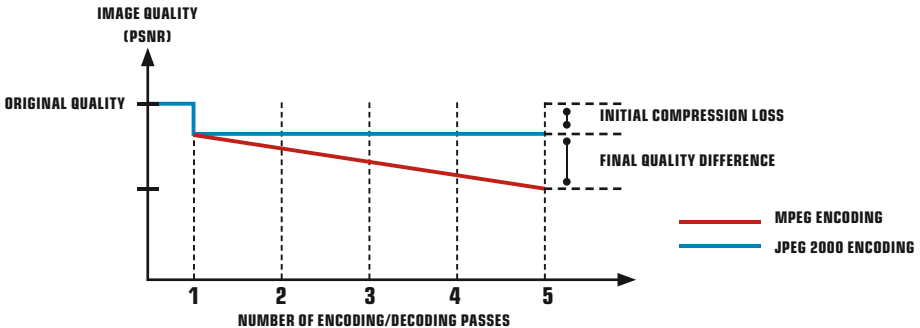


IMAGE AFTER 100 SUCCESSIVE JPEG 2000 ENCODING-DECODING PASSES

Successive encoding-decoding passes are usually required throughout the Broadcast and Digital Cinema post-production processing chain.

Using JPEG 2000 the image quality is preserved throughout the production process. Furthermore, the wavelet based JPEG 2000 compression does not interfere with the final, usually DCT based, broadcast format.

On the other hand, the MPEG compression-decompression process introduces additional degradation at each step, creating a cumulative deterioration of the image.



Encoding - Decoding Processing Power

JPEG 2000 is a symmetrical compression technology requiring approximately the same processing power to encode or to decode at any compression quality.

JPEG 2000 is thus ideal for Acquisition, Storage, Contribution and Archiving applications where there are as many encoders as decoders.

MPEG is an asymmetrical compression technology; its highly complex encoding and simpler decoding processes are better suited to e.g. DVD duplication or Broadcast Distribution applications where many more decoders than encoders are used.

State-of-the-art JPEG 2000 codecs run on a single FPGA to provide a more cost-effective solution.

Open Standard

The JPEG 2000 standard supports every resolution, color depth, number of components and frame rate.

It is the image compression format most ready to address future applications.

In spatial imaging for instance JPEG 2000 could address images with resolution of 10.000 by 5.000 pixels and 4 color components (3 for visual color primaries plus one for thermal capture).

Codec's Comparison Chart

	Compression Efficiency	Inter-Frame Coding	intra-Frame Coding	Lossless Compression	Error Resilience	Scalability	Graceful Degradation	Region of Interest	Low Latency	Multigeneration Robustness	Encoder Simplicity	Decoder Simplicity	Main Applications
JPEG			✔								✔	✔	**Still Picture**
MPEG2	✔	✔											**DVD, DVB**
MPEG4-AVC	✔	✔											**DVD, DVB**
MPEG4-AVC-intra		✔											**Production**
JPEG 2000			✔	✔	✔	✔	✔	✔	✔	✔			**Digit. Cin., Archiving**

LEGEND: ☐ **POOR OR NONE** ▭ **MEDIUM** ✔ **HIGH**

JPEG 2000 Profiles by Application

High Quality Broadcast Contribution

It is essential to maintain image quality when transferring content files between Post Production facilities.

PREFERRED SCALABILITY	RESOLUTION	COMPONENT	COLOR SUBSAMPLING	BIT DEPTH	QUALITY	CODE STREAM BIT RATE
		Mono		8	Math Lossless	>1Gps
Quality	HD	YUV	4:2:2	10	Near Lossless	Max 1Gps
Resolution	2K	XYZ	4:4:4	12	Visually Lossless	< 250 Mbps
Position	4K	RGB		16	Lossy	<100 Mbps
Component	2K+	RGBA				
	4K+					

Live Broadcast Streaming

Live streaming requires very low latency and bit-rates in order to transmit video content in real time.

B

PREFERRED SCALABILITY	RESOLUTION	COMPONENT	COLOR SUBSAMPLING	BIT DEPTH	QUALITY	CODE STREAM BIT RATE
					Math Lossless	>1Gps
					Near Lossless	Max 1Gps
		Mono		8	Visually Lossless	< 250 Mbps
Quality	HD	YUV	4:2:2	10	Lossy	<100 Mbps
Resolution	2K	XYZ	4:4:4	12		
Position	4K	RGB		16		
Component	2K+	RGBA				
	4K+					

Digital Cinema Distribution

Working at 4:4:4, 12 bits and at 4K resolution enables Digital Cinema Distribution to respect the pristine image quality demanded by movie Directors.

PREFERRED SCALABILITY	RESOLUTION	COMPONENT	COLOR SUBSAMPLING	BIT DEPTH	QUALITY	CODE STREAM BIT RATE
Quality						
Resolution		Mono		8	Math Lossless	>1Gps
Position	HD	YUV	4:2:2	10	Near Lossless	Max 1Gps
Component	2K	XYZ	4:4:4	12	Visually Lossless	< 250 Mbps
	4K	RGB		16	Lossy	<100 Mbps
	2K+	RGBA				
	4K+					

Digital Cinema Archiving

Using mathematically Lossless compression in Archiving guarantees that the highest image quality is maintained and allows the prioritization of resolution scalability for easy file navigation and archive valorization.

B

PREFERRED SCALABILITY	RESOLUTION	COMPONENT	COLOR SUBSAMPLING	BIT DEPTH	QUALITY	CODE STREAM BIT RATE
		Mono		8		
Quality	HD	YUV	4:2:2	10		
Resolution	2K	XYZ	4:4:4	12	Math Lossless	>1Gps
Position	4K	RGB		16	Near Lossless	Max 1Gps
Component	2K+	RGBA			Visually Lossless	< 250 Mbps
	4K+				Lossy	<100 Mbps

How JPEG 2000 Works

JPEG 2000 Overview

Pre-processing

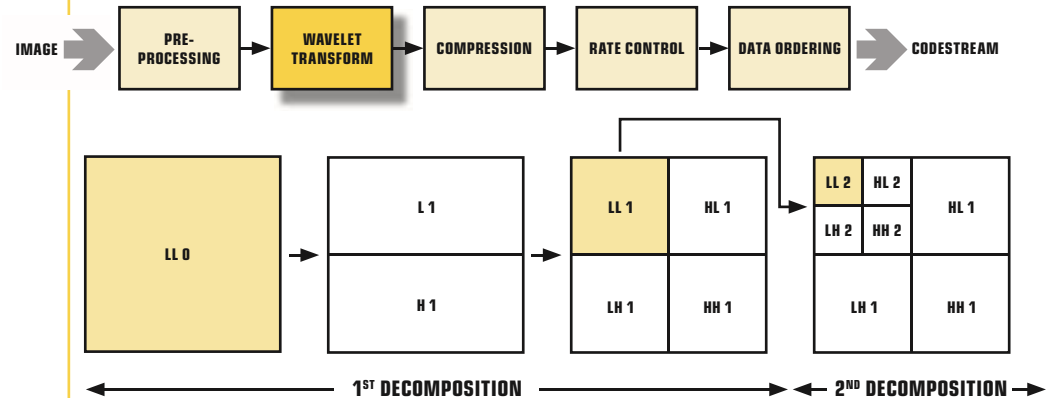
The pre-processing block mainly deals with color conversion (or decorrelation; RGB to YUV):

- ICT (Irreversible Color Transform)
- RCT (Reversible Color Transform)

The Discrete Wavelet Transform

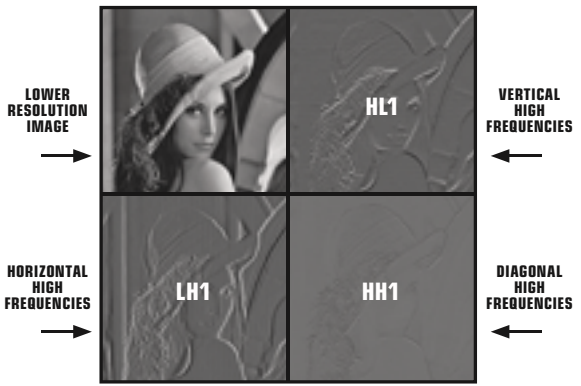
During the Wavelet Transform, image components are passed recursively through low pass and high pass Wavelet filters.

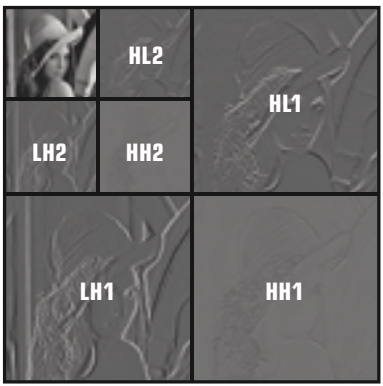
This enables an intra-component decorrelation that concentrates the image information in a small and very localized area. It enables the multi-resolution image representation.



Result: 4 subbands with the upper left one containing all low frequencies.

... Successive decompositions are applied on the low frequencies.





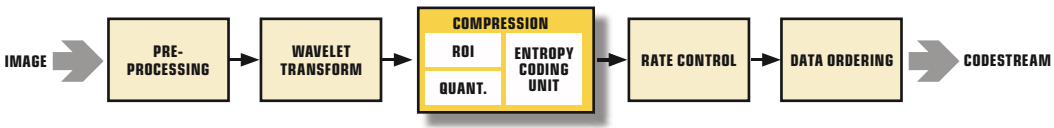
C

HOW WAVELET DECOMPOSITION ACHIEVES MULTI-RESOLUTION

Compression of the Wavelet Coefficients

By itself the Wavelet Transform does not compress image data; **it restructures the image information so that it is easier to compress.**

Once the Discrete Wavelet Transform (DWT) has been applied, the output is quantified. The quantized data is then encoded in the Entropy Coding Unit (ECU).

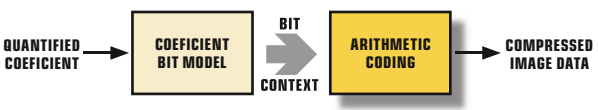


The Entropy Coding Unit

The Entropy Coding Unit is composed of a Coefficient Bit Modeler and the Arithmetic Coder itself.

The Arithmetic Coder removes the redundancy in the encoding of the data. It assigns short code-words to the more probable events and longer code-words to the less probable ones.

The Bit Modeler estimates the probability of each possible event at each point in the coding stream.



Rate Control

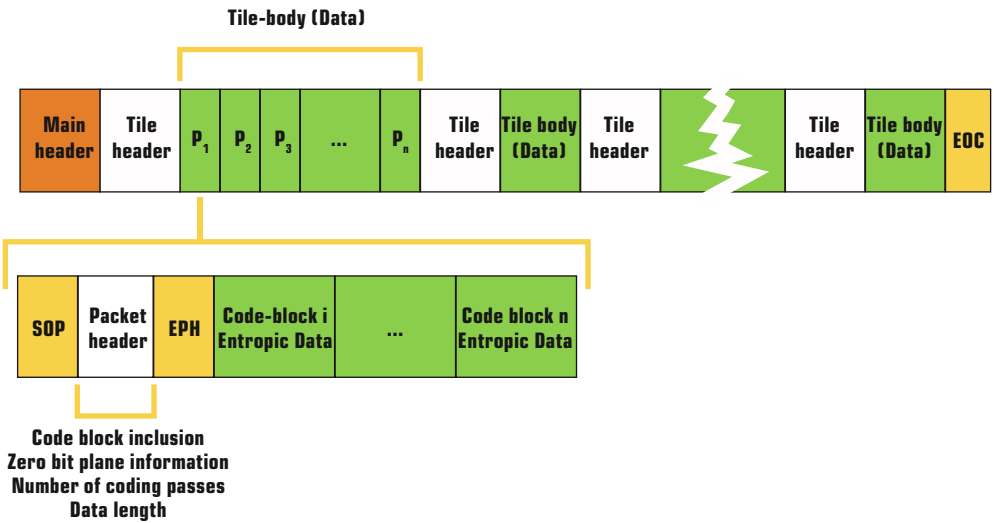
Given a targeted bit-rate, the Rate-Control module adjusts the coding precision of each pixel (actually small groups of pixels: the code-blocks)

Data Ordering

The data ordering module embeds all groups of pixels in a succession of Packets. These Packets, along with additional headers, form the final JPEG 2000 code-stream.

In the last 'data ordering' block the preferred scalability (or progression order) is selected.

Codestream Syntax



JPEG 2000 Implementation

Implementation

According to the application need JPEG 2000 will be implemented in software or hardware.

Software processing is generally used when working with still or low resolution pictures.

Hardware processing is used where image size, image quality, or the number of images to process per second requires higher performance.

Hardware solutions, including ASIC and FPGA, offer convenient processing platforms.

ASICs (Application Specific Integrated Circuits) are usually used in large volume applications such as video surveillance.

FPGAs (Field Programmable Gate Arrays) combine the flexibility of software processing with the power of the ASIC hardware implementation and are an ideal solution for lower volume applications.

intoPIX
secure image technology

The intoPIX Implementation

intoPIX provides the most flexible and powerful range of JPEG 2000 implementations available.

intoPIX efficient image processing allows implementation on a single FPGA.

intoPIX technology currently addresses Digital Cinema and Broadcast markets.

Since 2004 **intoPIX** founders have been the editors of the reference open source code - OpenJPEG: **www.openjpeg.org**

D

www.intopix.com

References

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- **D. Taubman and M. Marcellin:**
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- **D. Taubman:**
  High performance scalable image processing with EBCOT. IEEE Trans. on Image processing. July 2000.
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  An overview of the JPEG 2000 still image compression standard, Signal processing: Image communication. 2002.
- **Special issue on JPEG 2000, Signal Processing:**
  Image Communication. Elsevier, Volume 17, Issue 1, January 2002.
- **Illustrations from pages 6 and 14:**
  Elephants Dream, the open source animation movie. http://www.elephantsdream.org
- **Illustrations from pages 4, 8 and 10:**
  DCI's Standard Evaluation Material (StEM): http://www.dcimovies.com
- **Illustrations from pages 7, 9, 12, 25 and 26**
  have been created using the "Lenna" test image: http://en.wikipedia.org/wiki/Lenna

Glossary

- **Intra-Frame formats:**
  Coding formats that encode each frame independently without taking into account previous or next frames in the sequence e.g. JPEG, JPEG 2000, MPEG-4-AVC intra, etc.

- **Inter-Frame formats:**
  Coding formats that exploit the temporal redundancy of a sequence by using information appearing in adjacent frames e.g. MPEG2, MPEG4, MPEG-4-AVC, etc.

- **GOP:**
  Stands for "Group Of Pictures" i.e. the number of pictures that an Inter-Frame format needs to perform the coding.

- **FPGA:**
  Stands for "Field-Programmable Gate Array"; a semiconductor device containing reprogrammable logic blocks.

- **ASIC:**
  Stands for "Application-Specific Integrated Circuit".It is an integrated circuit customized for a particular use, rather than intended for a general-purpose use.

Useful Links

- Single chip JPEG 2000 codecs: **www.intopix.com**
- Joint Photographic Experts Group: **www.jpeg.org**
- JPEG 2000 on Wikipedia: **http://en.wikipedia.org/wiki/JPEG_2000**
- The open source JPEG 2000 codec: **www.openjpeg.org**
- Official DCI web site: **www.dcimovies.com**

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