# The JPEG-2000 Standard

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# Outline

What is JPEG 2000?

Why did we need another image compression standard?

Where can JPEG 2000 be used?

How good is it?

When will it be available?

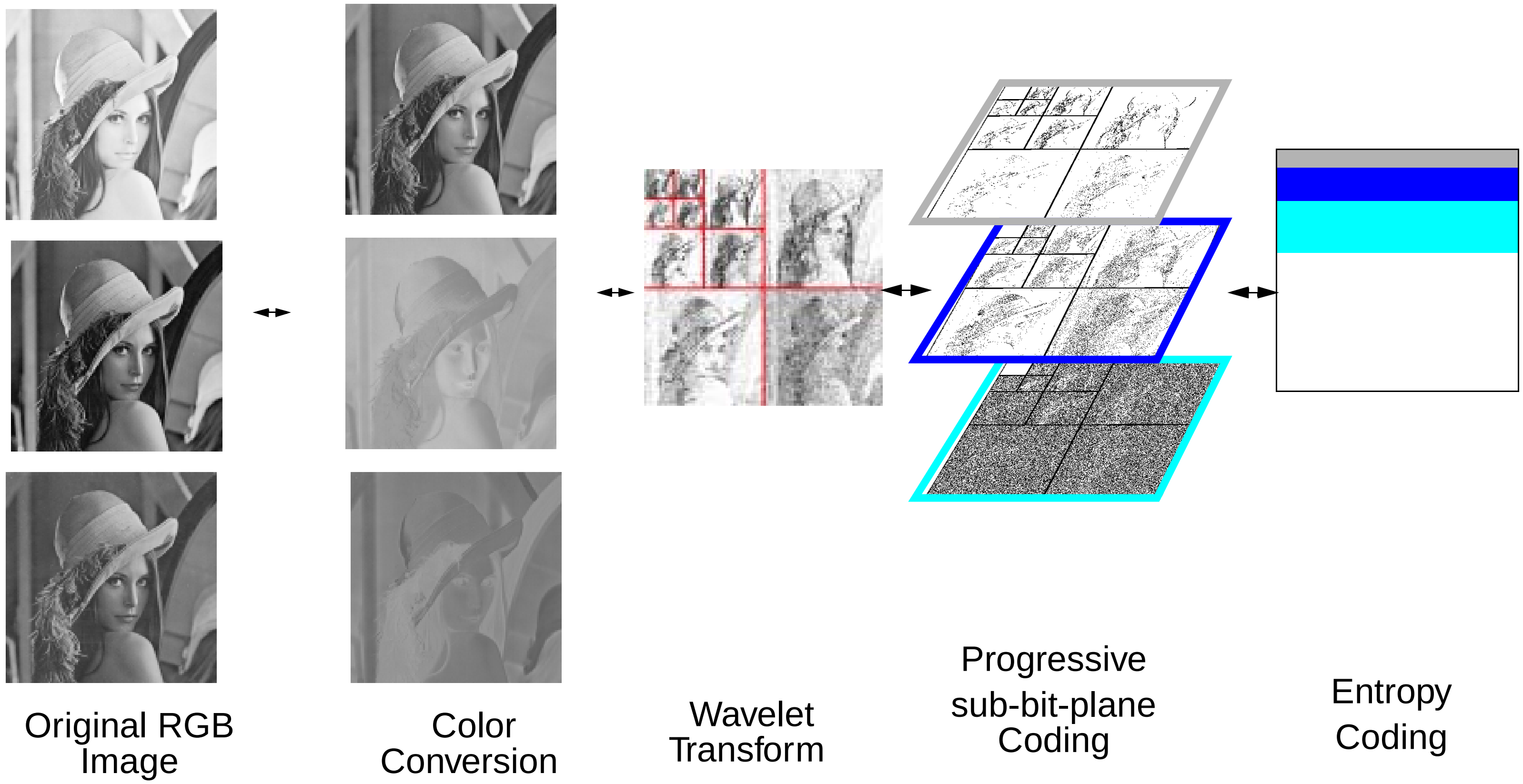
Who's responsible?

How does it work?

How does it really work?

High Resolution Grid and Image Components, Tiles and Tile-Components, Decorrelation of Components, Wavelet Transform, Resolutions and Subbands, Quantization, Precincts and Codeblocks, Bitplane Coding, Packets and Layers, Progression, Tile Parts, Region of Interest, Error Resilience

# What is JPEG 2000?




JPEG 2000 is a standard for image compression produced by the ISO which defines “a set of lossless (bit-preserving) and lossy compression methods for coding continuous-tone, bi-level, grey-scale, or colour digital still images.”

# Why Another Image Compression Standard?

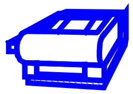
## Digital Image Sizes

| Type | Size | Bits |
|---|---|---|
| Corporate Web Logo | 128x94x1x8 | 96,256 |
| Fax (200dpi by 100dpi) | 1728x1188x1x1 | 2,052,864 |
| Low End Monitor | 640x480x1x8 | 2,457,600 |
| High End Monitor | 1280x1204x4x8 | 41,943,040 |
| 300dpi Inkjet Printer | 2550x3300x1x4 | 33,660,000 |
| SHD Microscope | 2048x2048x3x10 | 125,829,120 |
| 400dpi Color Copier | 4400x5100x4x8 | 718,080,000 |
| Hyper-spectral Imagery | 1024x1024x256x8 | 2,147,483,648 |
| Stained Glass Window | 20480x12800x3x8 | 6,291,456,000 |
| 2400dpi High End Scanner (11x17) | 26400x40800x4x10 | 43,084,800,000 |

Image size covers six orders of magnitude

# Image Quality Requirements

Is this the image I want?



Is it worth looking at this in more detail?

Look what I saw on vacation.

Should I buy this sweater?

Is that a tank or a tree?

Should we spend $$$$ on this magazine page?

Is that a tumor or block boundary-itis?

**Quality requirements also span orders of magnitude**

# Current Image Compression Standards

| Compression Method | Type of Image | Compression Ratio | Controllability |
|---|---|---|---|
| G3 Fax | Binary | 1/2 - 10:1 | Lossless Only |
| JBIG | Binary | 2-40:1 | Lossless Only |
| JPEG[a] (Baseline) | 8 Bit Grayscale and Color | 5-25:1 | Iterate on Q-table |
| Lossless JPEG | 4-12 Bit Image Components | 2-10:1 | Lossless Only |
| JBIG-2 | Binary | 2-40:1 | Lossy/Lossless |
| JPEG-LS | 4-12 Bit Image Components | 2-10:1 | Lossless/Near Lossless |
| JPEG2000 | ANY | Lossless-200:1 | Tremendous |

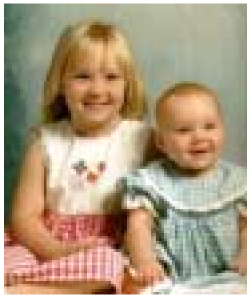
a. JPEG defines four algorithms: sequential, progressive, hierarchical, and lossless, sequential and progressive are commonly implemented, files compressed in the other algorithms, or with the QM-coder will not be decodeable by 99% of JPEG applications

Prior standards serve only a limited applications

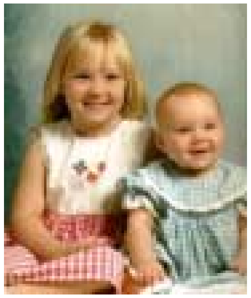
Thus a new image compression standard is useful to serve applications not provided for by current standards, to cover some current needs with one common system, and to provide full employment for image compression researchers.

# Conventional compression method (JPEG)

***Encode choices***
color space
quantization
entropy coder
preprocessing



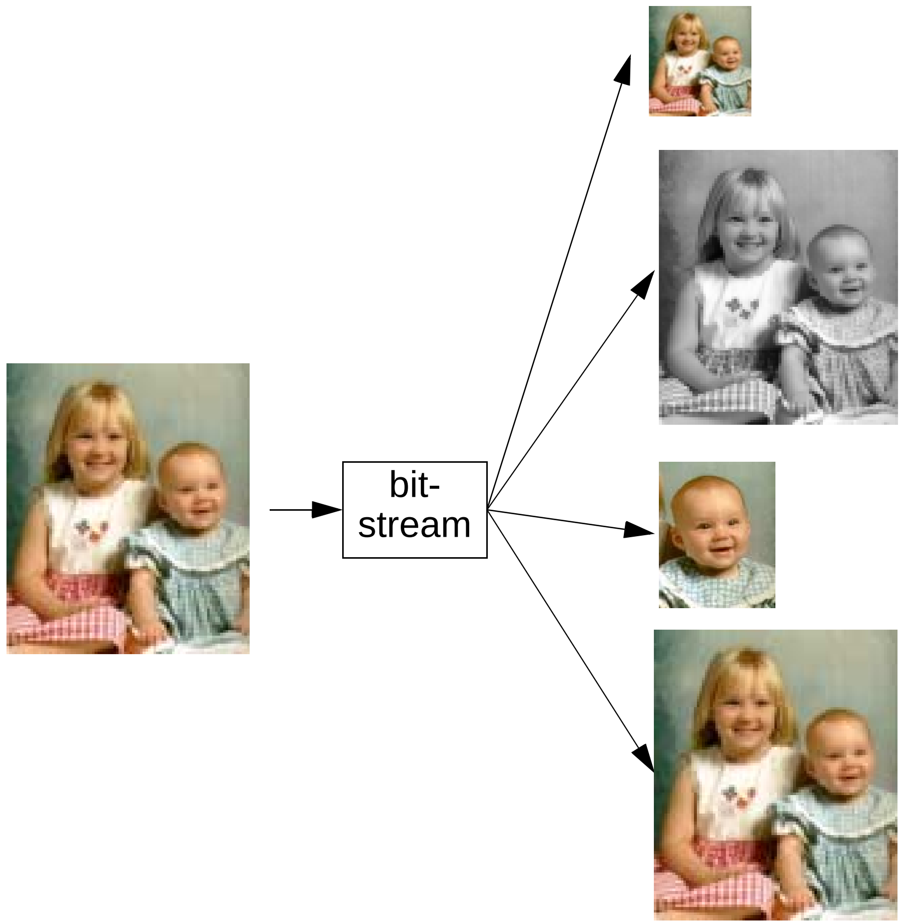
→ bit-stream →



***No decode choices***
only one image
bit-rate unknown

# JPEG 2000 offers flexible decoding

***Encode choices***
tiling
lossy/lossless
+ old paradigm
choices




***Decode choices***
image resolution
image fidelity
quantization
region-of -interest
fixed-size
fixed-rate
components

# Where can JPEG 2000 be used?

| | |
|---|---|
| Medical imagery | Satellite imagery |
| Scanners | Printers |
| Network imagery (WWW) | Pre-press imagery |
| Image archival (CD-ROM) | Interframe video |
| Page description languages | Multi-function copiers |
| Digital cameras | Facsimile |
| Compound documents | Set Top Box |
| Graphic images | etc. |

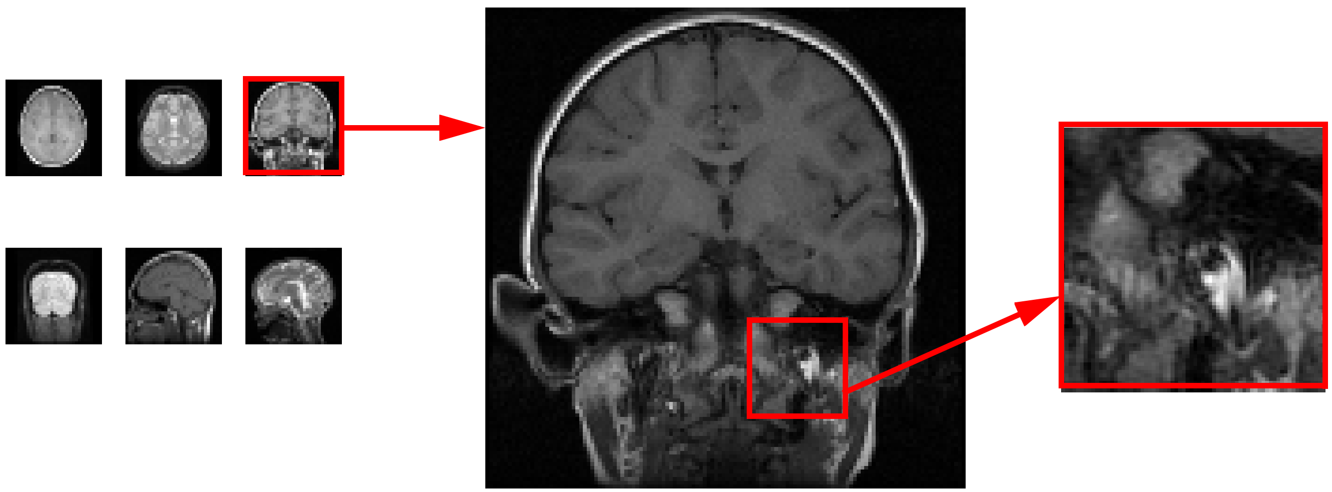
# Medical imagery

Lossless very important for medical imaging

Interact with Doctor: thumbnail -> higher resolution -> ROI

(Actually this is not what doctors want, but...)

**Quantize by resolution, bit-depth, and region-of-interest**

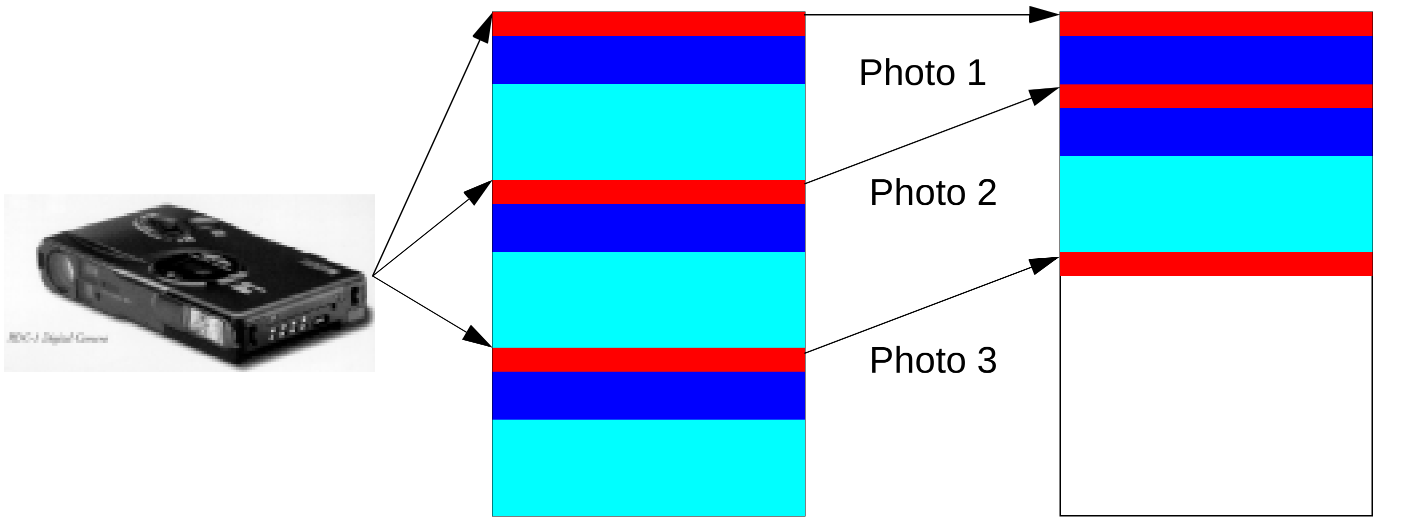


# Optimal memory use in the Digital Camera

Lossless as long as possible, lossy once the card is full

Quality better than JPEG at low bit-rate, stores more images

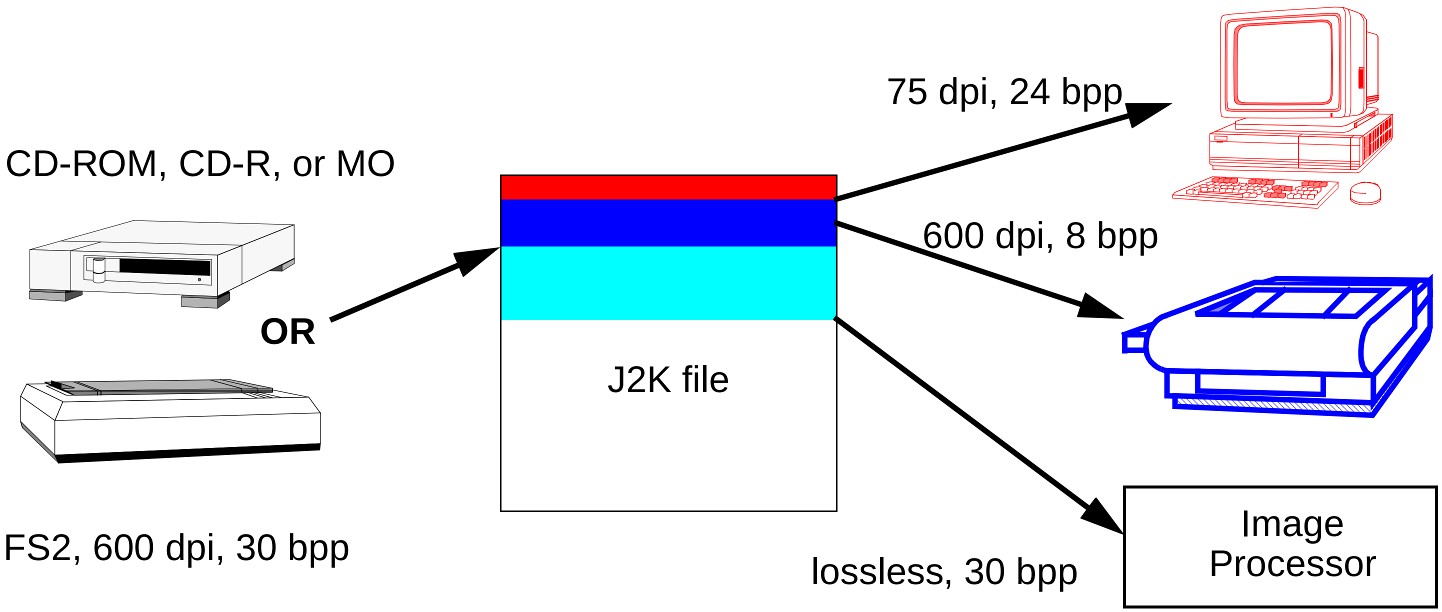
**Quantize for "fixed-size" memory**



# Scanner, CD-ROM, archival applications

All information stored

**Quantize depending on the target device**

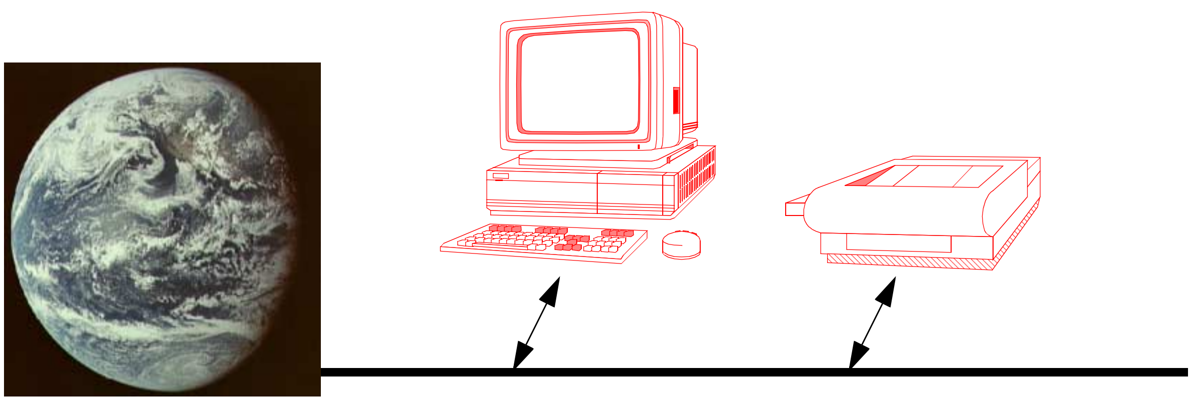


# World Wide Web

Send only the bits wanted or needed

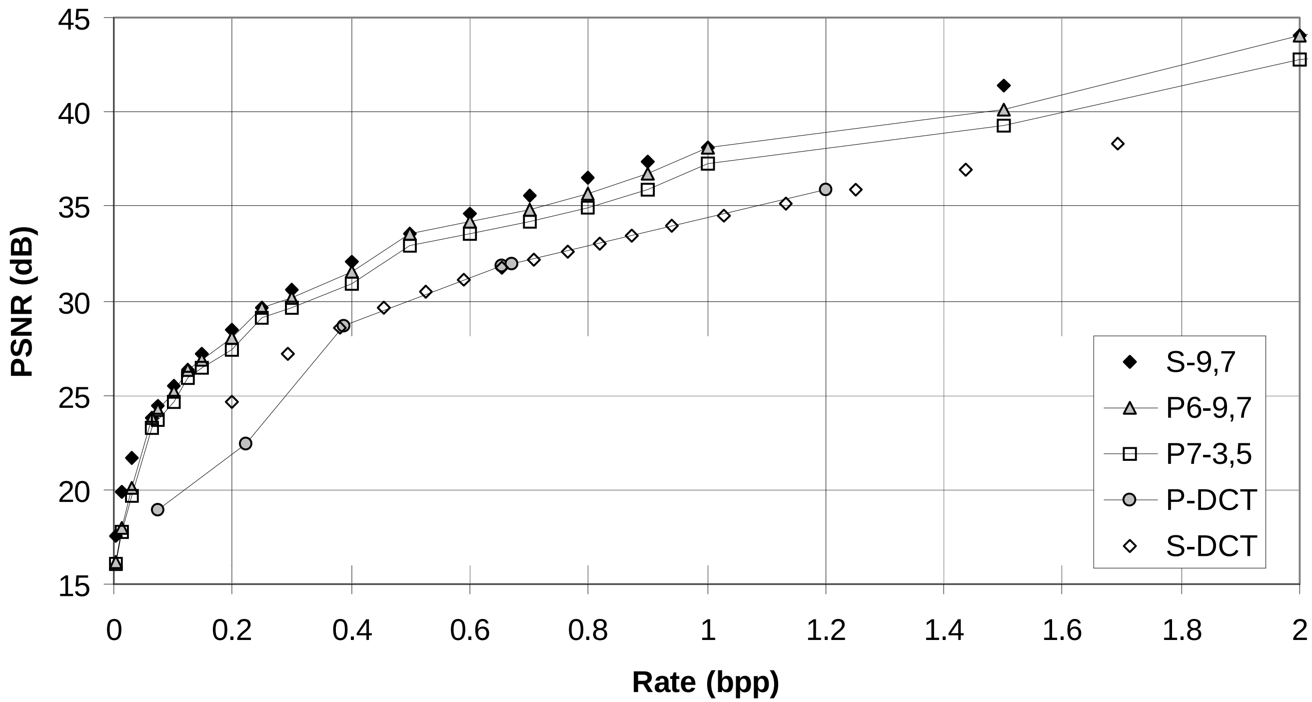
**Dialog for more or different data**

Quantize depending on the target bit-rate and device



World Wide Web

# JPEG2000: How good is it?
# PSNR for SCID Bike image




JPEG 2000 Quality depends on which filter is being used, and progression type (and many other factors not illustrated in this graph).

# JPEG2000: How good is it visually?

Visual Test

- High resolution color images: bike, bottles, bride, harbor, woman, wool
- Place JPEG 2000 print between 10 JPEG images
- 6 observers

| JPEG 2000 Bitrate | Equivalent JPEG Bitrate | % larger for JPEG[a] |
|---|---|---|
| 0.25 | 0.53 | 112% |
| 0.50 | 0.78 | 56% |
| 0.75 | 0.92 | 23% |
| 1.00 | 1.13 | 13% |

a. The more honest “% improvement of JPEG 2000 numbers are: 53%, 36%, 18%, and 11%

Source: Troy Chinen, Fujifilm Software

Sample Images Available (See for yourself)

# Lossless JPEG 2000 Performance

| Method | Aerial2 | Bike | Barbara | Cmpnd1 |
|---|---|---|---|---|
| JPEG[a] | 5.589 | 4.980 | 5.663 | 2.478 |
| JPEG-LS | 5.286 | 4.356 | 4.863 | 1.242 |
| JPEG-2000 (50 layers) | 5.467 | 4.562 | 4.823 | 2.166 |
| JPEG-2000 (one layer) | 5.441 | 4.541 | 4.783 | 2.138 |

a. The uncommon, lossless JPEG, with the best possible preditor of the image selected independently for each image and Huffman coding.

- JPEG 2000 with fully scalable progressions is better than the (unused) lossless JPEG-1
- JPEG 2000 is with 5% of JPEG-LS for “natural” imagery
- JPEG 2000 is much lower compression than JPEG-LS for “compound” or “document” images
- JPEG 2000 is much higher complexity than JPEG-LS and JPEG

# Items Affecting JPEG 2000 Performance

| Encode Method | PSNR (dB) | |
|---|---|---|
| | 1.0 bpp | 0.25 bpp |
| Reference | 37.27 | 29.00 |
| 128 by 128 Tiles | 36.81 | 28.16 |
| No Tiles | 37.31 | 29.08 |
| 32 by 32 Code-blocks | 37.10 | 28.86 |
| 50 Layers | 37.17 | 28.81 |
| One Layer | 37.73 | 29.19 |
| (9,7) Wavelet | 38.05 | 29.55 |
| JPEG | 34.37 | 27.21 |

Reference image:

- 512 by 512 tiles,
- 64 by 64 code-blocks,
- (5,3) wavelet,
- 7 rate-distortion optimized layers from 0.0625, to 2.0 bpp, and lossless.

## JPEG 2000: When (and where) will it (did it) happen?

## Answer depends on what “part.”

### The JPEG 2000 standard(s)

| **Part** | **JPEG 2000 image coding system:** | **Purpose** |
|---|---|---|
| 1 | Core coding system | Interchange guarantee (20% of tools for 80% of applications) |
| 2 | Extensions | Tools needed for specialized applications |
| 3 | Motion JPEG 2000 | Replacement for multiple nonstandard MJPEG formats |
| 4 | Conformance testing | Assure quality implementations |
| 5 | Reference software | Assure code availability (imagine JPEG without IJG code) |

# JPEG 2000 Part Schedule

| Date | Part I Activity | Parts II-V | WG1 Meeting Location |
|---|---|---|---|
| March 1997 | Call for contributions issued | | Dijon, France |
| July 1997 | Presentations of architectures | | Sapporo, Japan |
| November 1997 | Presentations of technology | | Sydney, Australia |
| ... | Core Experiments | | ...many... |
| December 1999 | Committee Draft (CD) | | Maui, USA |
| March 2000 | Final Committee Draft (FCD) | | Tokyo, Japan |
| July 2000 | | CD | Arles, France |
| September 2000 | Final Draft International Standard (FDIS) | | USA |
| December 2001 | International Standard (IS) | FCD | New Orleans, USA |
| March 2001 | | FDIS | Singapore, Singapore |
| July 2001 | | IS | Stockholm, Sweden |

At CD level, only a “national body comment” can change the text

At FDIS level, national bodies vote without comment

# JPEG 2000: Who is it?

**ISO/IEC JTC1/SC29/WG1**

**International Standards Organization/International Electrotechnical Committee Joint Technical Committee on Information Technology/ Subcommittee 29 - Coding of Audio, Picture, Multimedia and Hypermedia Information/ Working Group 1 JPEG and JBIG**

**Over 300 people have participated at the international level**

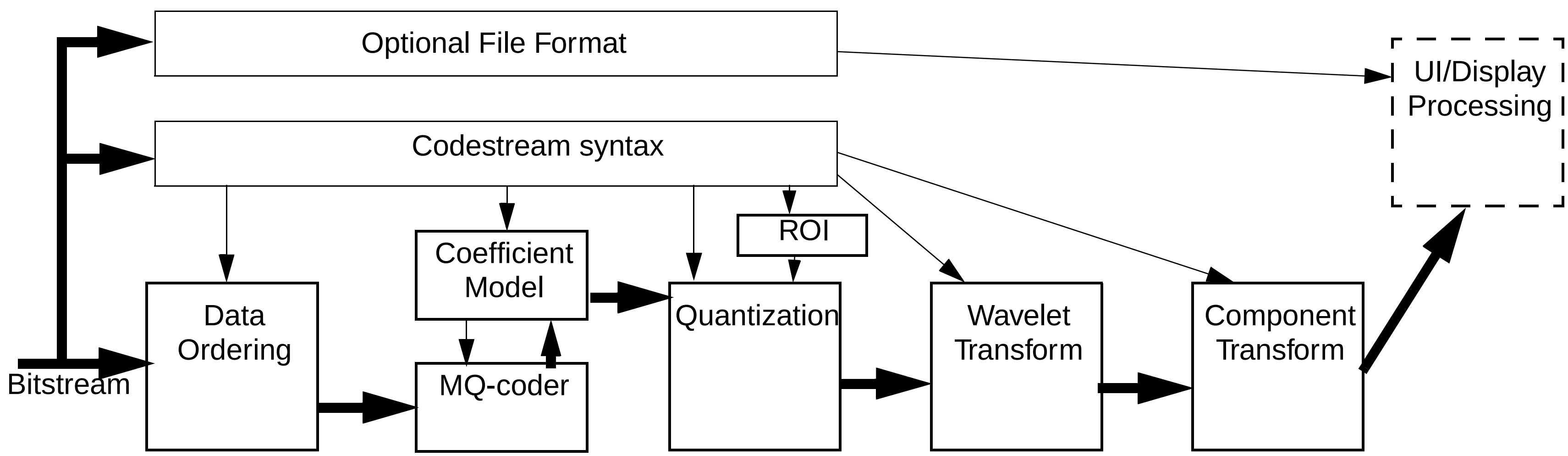
**More have participated in "National Bodies"**

**(In the United States: NCITS L3.2 National Committee for Information Technology Standardization)**

Jim Andrew Craig Brown Andrew Dorrell Peter John Igor Kharitonenko Matthew Leditschke Philip Ogunbona David Taubman Jian-Xia Wei Lei Ye Xing Zhang Borma [illegible] elkens Michael Adams Anup Basu Jeff Brewster Guy Cote P. Haighton Chris Hepburn Jaehan In Faouzi Kossentini A Krouglov A. Kwan Stephen Swift Xiaolin Wu Sun Honghui Jin Li Debin Zhao Soren Forchhammer Ole Riis Jensen Bo Martins Jorgen Vaaben [illegible] avid Bouchard Maryline Charrier Felix Henry Catherine Lambert-Nebout Daniel Lecomte Alain Leger Eric Majani Gerard Mozelle Didier Nicholson Patrice Onno Claude Rollin Hofrichter Kai-Uwe Ba [illegible] Ibenthal Klaus Jung Andreas Kaufmann Andreas Kraft Markus Lang Herbert Lohscheller Jens-Rainer Ohm Heiko Purnhagen Niels Rump Jan Sablatnig István Sebestyén Dr. Seiler Thomas Sikora Ralph Sperschneider [illegible] Asher Besserglick Aharon Gill Alon Ironi [illegible] Hara Shoji Hara Shin-ya Hasegawa Masayuki Hashimoto Narumi Hirose Hiroshi Inoue Katsuki Ishii Yasunori Ishikawa Norikazu Ito Hiroshi Kajiwara Keisuke Kato Naoto Kawamura [illegible] rato Maeno Akio Matsubara Makoto Matsuki Yoshihiro Miyamoto Takeshi Mogi Kenichi Nagasawa Tomoyuki Nakajima Mayumi Niwa Tsugio Noda Yasuyuki Nomizu Shigetaka Ogawa Katsumi Ohkuma Takao Omachi Fumitaka Ono Atsushi Sagata Makoto Sato Hiroyuki Satoh Kazuo Shimura Naoto Shiraishi Hideya Takeo Toru Tateishi Toshio Tohne Yoshinori Tomita Takewo Tomokane Yoshihiro Ueda Ikuro Ueno Takashi Urano Zhixiong Wu Yoshihiro Yamazaki Hiroshi Yasuda Yoshio Yoshiura Hiroshi Watanabe Chang Beom Ahn Dae-Sung Cho Heul-Keun Choi Young Huh Euee Jang Dae-Gwon Jeong Jechang Jeong Yong Han Kim Hyung Hwa Ko Jong-Soo Lee Dongkyoo Shin Ton Kalker Arild Fuldseth Haakon Gronning Arne Lie Geir Oien Andrew Perkis Tor A. Ramstad Joao Silvestre Roger Hu Guorong Lim Chong Soon Ge Zhu Joel Askelof Caarilaos Christopoulos Mathias Larsson Anton Martensson Mengxiang Li Per Thorell Alistair Buttar Lubomir Cergel Benoit Duc Touradj Ebrahimi [illegible] Menegaz Marcus Nadenau Julien Reichel Diego Santa Cruz Salma Soudagar David Allen M. Bowers Richard Clark Greg Colyer Gary Dickson Kate Grant Graham Hudson Don Monro Tinku Acharya Osama Alshaykh Dimitris Anastassiou Ron Arps Yiliang Bao Mark Banham Brian Banister Martin Boliek George Borden Christopher Brislawn Bernie Brower Scott [illegible] Chen Alan Chien Troy Chinen Michael Ching Christos Chrysafis Charles Chui Harry Clayton Cornel Consantinescu Bill Craig Maddalena Di Giura Alexander Drukarev Donald Duttweiler Eric Edwards John Elton Vance Faber Nariman Farvardin [illegible] enwade Ibrahim Hajj Tamim Hamid Eric Hamilton [illegible] Paul Howard Yu Hen Hu Lyman Hurd James Kasner Greg Kisor David Knight C C Jay Kuo Tom Lane Glen Langdon [illegible] min Lei Margaret Lepley Jie Liang Dale C. Linne von Berg Sam Liu Jian Lu Ian R. MacKenzie Stephen Mann Michael Marcellin Phil Marchand Eugenio Martinez-Uriegas Lloyd McIntyre Nasir Memon Joan Mitchell Iole Moccagatta Takashi Mochizuki Laura Moore Linda Moore Jim Munro Tanya Nizialek Erik Ordentlich Antonio Ortega Pat Owsley Bill Pearlman Bill Pennebaker Donald Pian Kimberley Poland Majid Rabbani Danny S. Rajan Kathleen Rattell Esteban Rodriguez-Marek Janet C. Rountree Mike Rubinfeld William Rucklidge Amir Said Guillerma Sapiro John F Schiphorst Peter Schirling Gadiel Seroussi Ibrahim Sezan Louis H. Sharpe II Meiyin Shen David Singer Paul Skeberdis Iraj Sodagar Don Speck Jim Spring Parthasarathy Sriram Dolf Starreveld Raj Talluri Bo Tao Bruce Tannenbaum Andrew Tescher Pankaj N. Topiwala Todd N. Tsakiris Alexis Tzannes Steve Urban Marius S. Vassiliou Val Vaughn Greg Wallace Eric Wang Houng-Jyh Wang Marcelo Weinberger Steve Wiles Timothy S Wilkinson Fred Wheeler Timothy Wilkinson Jim Williams Gene Wu John Wus Zixiang Xiong Pen-Shu Yeh Tad Yoshida Wenjun Zeng Michael Zeug Lefan Zhong Kai Uwe Barthel Andrea De Polo Todd Newman Bill Radcliffe Val Valdez Lisa Walker David Clunie

# JPEG 2000 Architecture/Annexes.

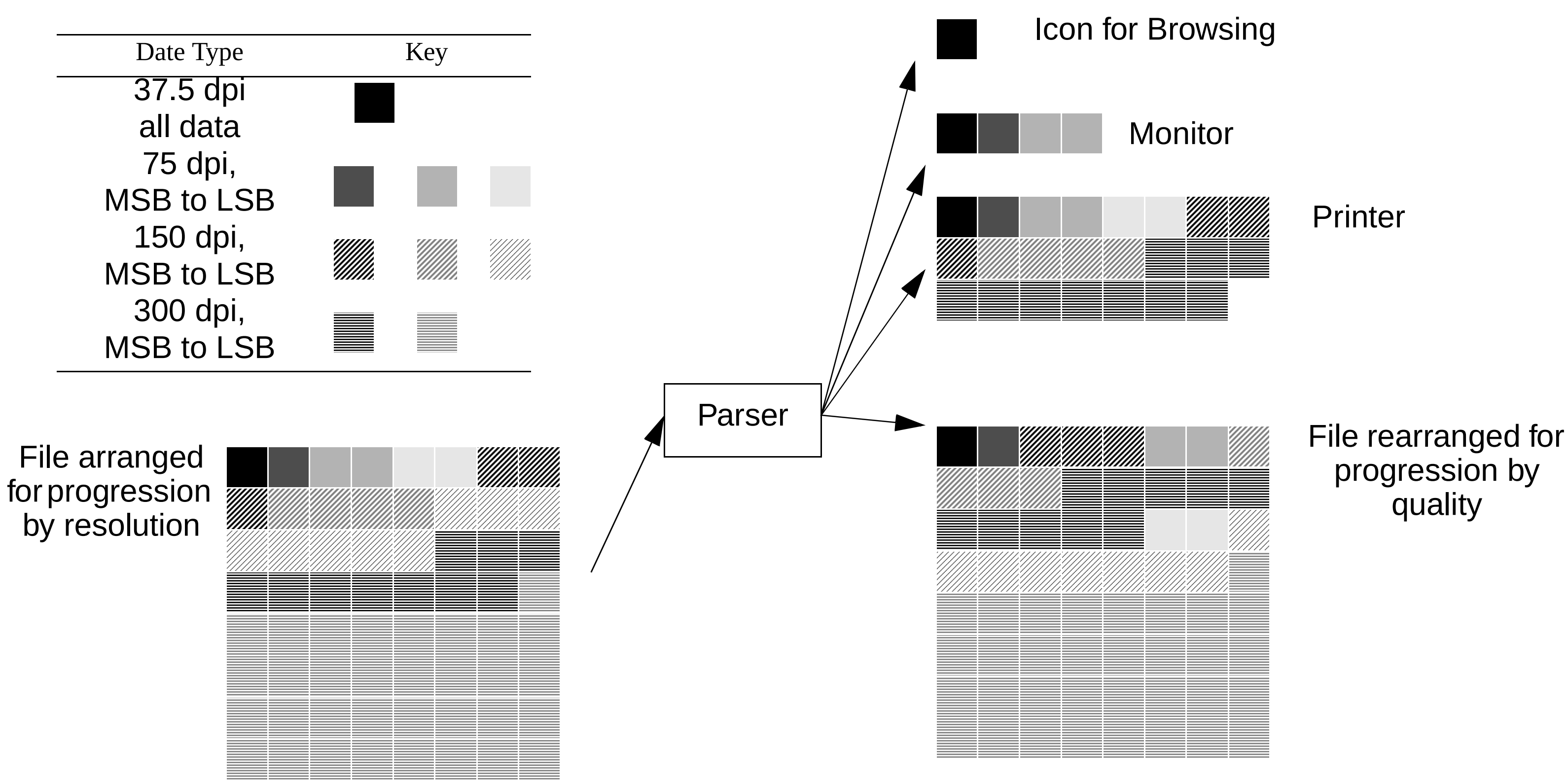
A. **Codestream syntax**
B. **Data Ordering**
C. **Arithmetic entropy coding**
D. **Coefficient bit modeling**
E. **Quantization**
F. **Discrete wavelet transformation of tile components**
G. **DC level shifting and component transformations**
H. **Coding of images with Regions of Interest**
I. **JP2 file format syntax**
J. **Examples and Guidelines**
K. **Bibliography**
L. **Patent Statement**



# Technology Details

| | Part I | Part II |
|---|---|---|
| Codestream syntax | Fixed and variable length markers. | New parameters for old markers. New markers? |
| Arithmetic coder | MQ-coder, same as JBIG-2 | same? |
| Coefficient bit modeling | Independent coding of blocks within subbands. Division of coefficients into 3 sub-bitplanes. Group sub-bitplanes into "layers." | same? |
| Bit-stream ordering | 5 types of progression, instream progression change possible. | same? |
| Quantization | Scalar Quantizer with dead zone, plus throwing away data | Trellis Coded Quantization |
| Transformation of images | Low complexity 5-3 and high performance Daubechies 9-7. Mallat decomposition. | Many more fixed filters. Perhaps arbitrary filters. Packet and Spacl decompositions. |
| Multiple component images | Reversible component transform (RCT) and YCbCr. | Arbitrary point transform, Wavelet component transform |
| Region of interest | "Boosted" coefficients, disjoint from background | Smaller boosts, decoder computes "boost" map |

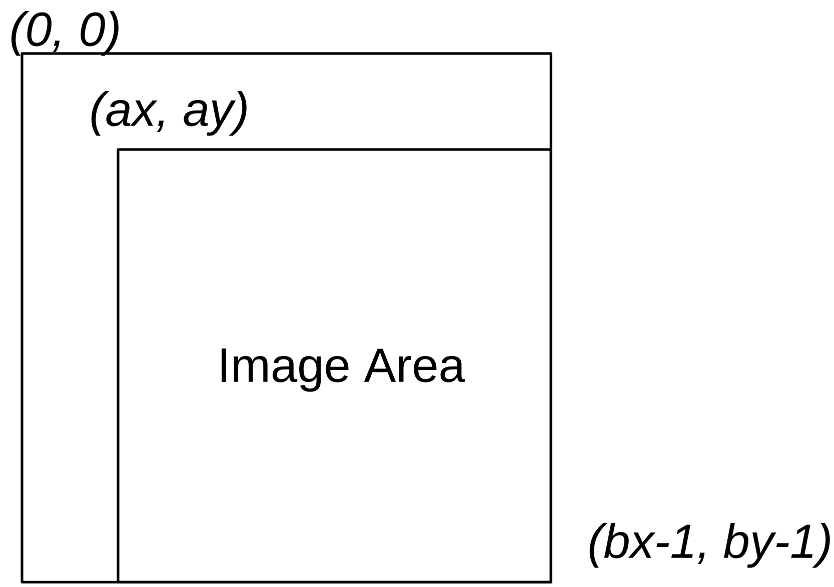
# Parsing JPEG 2000 Codestreams.



# Algorithm Description: Outline

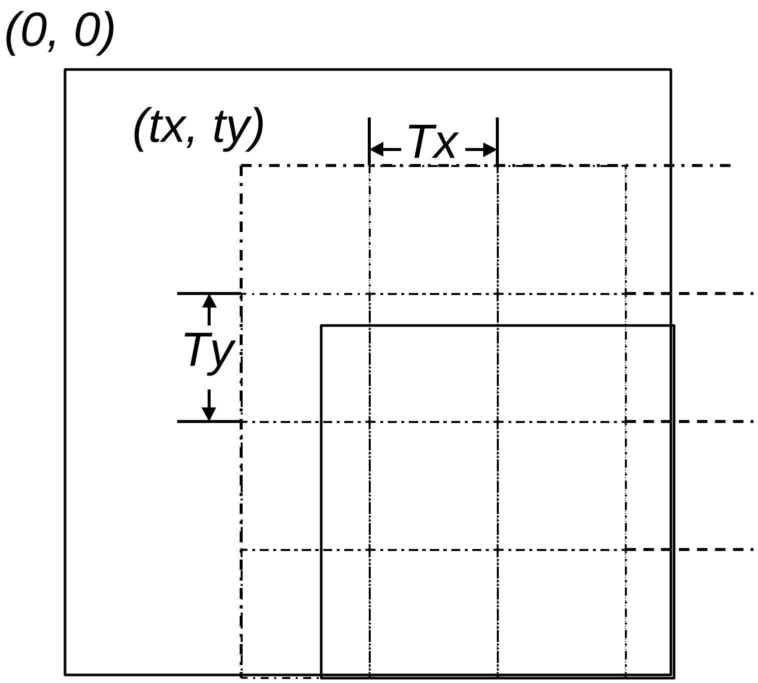
- High Resolution Grid and Image Components
- Tiles and Tile-Components
- Decorrelation of Components
- Wavelet Transform
- Resolutions and Subbands
- Quantization
- Precincts and Codeblocks
- Bitplane Coding
- Packets and Layers
- Progression
- Tile Parts
- Region of Interest
- Error Resilience

# High Resolution Grid and Image Components




- An image consists of one or more components (e.g., RGB or YUV) placed on a high resolution grid
- A component with subsampling factors *(rx, ry)* occupies all grid points within the image area that are multiples of *(rx, ry)*
- Component registration is with respect to *(0, 0)*
- The size and spacing of the grid must be compatible with the component subsampling factors
- One interpretation at the image area: A larger image, which started at *(0, 0)*, has been cropped

# Tiles and Tile Components




- Tile grid is anchored at *(tx, ty)*
- A tile-component is comprised of all samples of one component which lie within one tile

# Component Decorrelating Transforms

- Allowed only for three components with same subsampling and bit depth
- Two versions
  - Irreversible color transform (ICT)
    - Floating point YUV
    - For use with irreversible (floating point 9/7) wavelet
  - Reversible color transform (RCT)
    - Integer approximation to YUV
    - For use with reversible (integer 5/3) wavelet
- More transforms allowed for Part-2 (e.g., KLT, wavelet)

# Wavelet Transform

- Two versions
  - Irreversible (floating point 9/7)
  - Reversible (Integer 5/3)
  - More flexibility in Part-2
- Specified via lifting (interleaved)
  - Even samples low pass
  - Odd samples high pass
  - Low or high pass gets “extra sample” depending on image coordinates on grid
- Symmetric extension used along the borders of the “active area” of each tile

# Resolutions and Subbands

SAIC
An Employee-Owned Company
The University of Arizona

- Dyadic decomposition only
  - More flexibility in Part-2
- Define original image as *0LL*
- *(n-1)LL* decomposed to *nLL, nLH, nHL, nHH* n=*1,2,…, N*
- Images available at *N+1* resolutions, *0LL, 1LL,…, NLL*

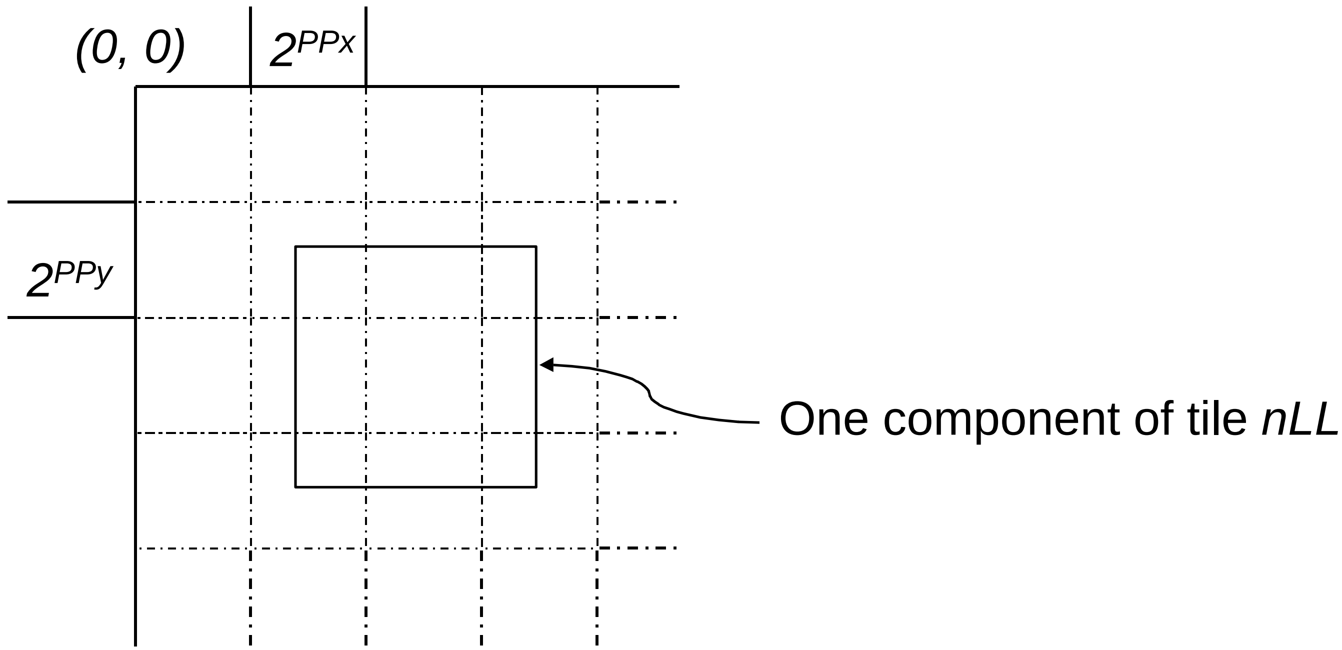
# Quantization

- Scalar quantization with deadzone
- Separate stepsize for each subband

  *NLL, NLH, NHL, NHH, (N-1)LH, (N-1)HL, (N-1)HH, …, 1LH, 1HL, 1HH*
- Trellis Coded Quantization included in Part-2

# Precincts

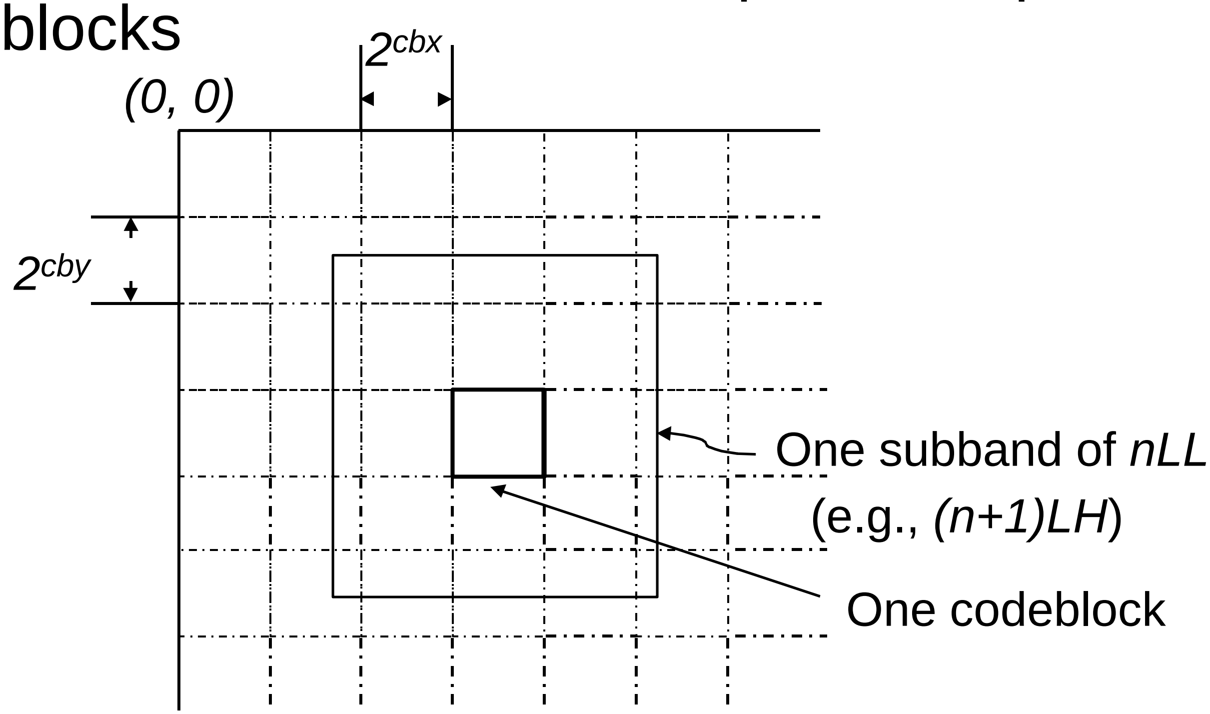
- Each tile-component at each resolution (*nLL*) is partitioned into “precincts”




- Dimensions in this figure are subsampled by $(rx2^n, ry2^n)$
- Precincts can be traced into the three subbands associated with this resolution
- Precincts are similar to tiles, but without transform boundary effects

# Codeblocks

- Each subband of each tile component is partitioned into codeblocks

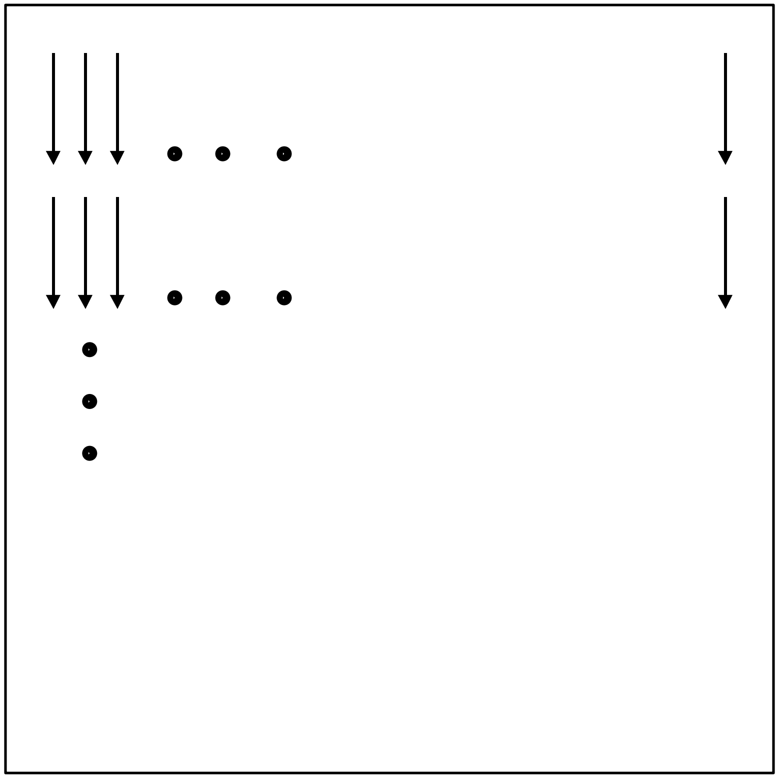



- Dimensions in this figure are subsampled $(rx2^{n+1}, ry2^{n+1})$
- Each codeblock is compressed independently using bitplane coding as described next

# Bitplane Coding of a Codeblock

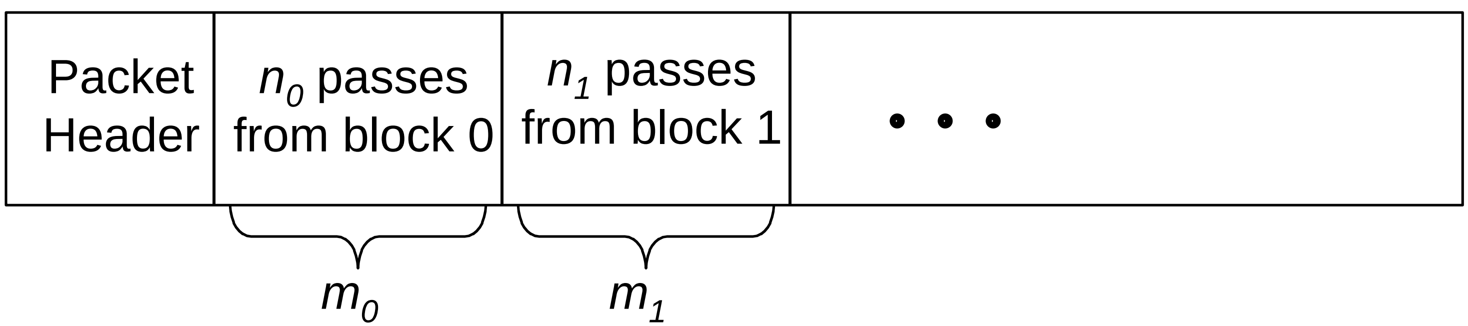
- Quantized coefficients represented in sign-magnitude form
- Leading “all-zero” bitplanes are skipped
- Each bitplane is coded in three passes
  - Significance propagation
    - A bit is coded in this pass if its location is insignificant but has a significant neighbor
    - If the bit coded is 1, the sign bit is coded immediately afterward
  - Magnitude refinement
    - A bit is coded in this pass if its location became significant in a previous bitplane
  - Cleanup
    - All bits in the current bitplane, not coded in one of the previous passes
- In the simplest case, all bits are coded using context dependent adaptive arithmetic coding (MQ coder) with termination (only) at the end of the last bitplane
- Run coding (of zeros) is also employed in the cleanup pass

# Scan Pattern for Bitplane Coding



# Packets

- A packet contains coded data from each codeblock within one precinct (one spatial region of one resolution {three subbands} of one component of one tile).
- Each codeblock contributes a whole number of coding passes (0 is allowed)
- This number can vary codeblock-by-codeblock




- The packet header contains auxiliary info required to locate and decode the passes for each block.
  - For block *i*, included or not, number of skipped (all zeros) bitplanes, number of passes($n_i$), length of compressed data ($m_i$)

# Layers

- A layer consists of one packet from each precinct of a tile
- A packet can be thought of as one quality increment in one precinct
- A layer is then one quality increment for an entire tile
- The verification model software allocates to one layer all passes with roughly equal rate-distortion slopes
  - Rate Allocation: Encoder issue -- Not standardized
  - Optimal embedded MSE performance
  - Spatial and frequency selective weightings are easily incorporated

# Progression

- Progression order is determined by ordering of packets in the codestream
- Packets can be indexed by layer, resolution, precinct, component
- Five progression orders are supported via index nesting order
  - Layer-resolution-component-position
  - Resolution-layer-component-position
  - Resolution-position-component-layer
  - Position-component-resolution-layer
  - Component-position-resolution-layer
- Progression order can be changed within the codestream

# Tile Parts

- Division of codestream for a tile (at packet boundaries) into “tile parts”
- Tile parts from different tiles can be interleaved
- Enables progression of the entire image even when tiles are present

# Region of Interest

- Spatial random access to the codestream is possible by tile, by precinct, or by codeblock
  - (Increasingly finer granularity with increasing difficulty)
- Even finer control available via “pre-emphasis” or “shifting” of wavelet data prior to bitplane coding.  De-emphasis or de-shifting after bitplane decoding

# Error Resilience Tools

- Resynch markers
- Segment markers
- Precincts
- Frequent (and careful) arithmetic coder termination