Scalable Compression and Transmission of Large, Three-Dimensional Materials Microstructures

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Outline

- Description of scalable image compression
  - Characteristics
  - Tutorial on our method and some results
- Large 3-D microstructural datasets
  - Efficient lossless compression and storage
  - Rapid retrieval and scalable decompression
    - Progressive in quality and resolution
  - Remote visualization of 3D data and images
  - Roaming random access to volume of interest (VOI) in codestream

Compression Requirements

- Very efficient – exploits intra- and inter-slice redundancies
- Fast lossless encoding
  - No data reduction, completely reversible
  - Integer or finite precision data only
- Real-time decoding
  - progressive in resolution
  - progressive lossy to lossless reconstruction
- Random access decoding
  - Decode and reconstruct Region–Of-Interest (ROI) directly from portion of coded bitstream

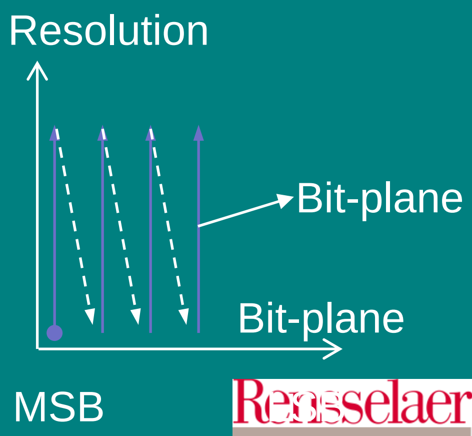
❖ No need to transmit, decompress, and/or process full dataset

Quality / SNR Scalability

- Resolution fixed, quality of each pixel increases

SNR : Signal
to Noise Ratio
bpp : bits per pixel

Scanning order



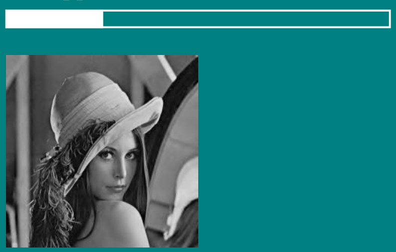
Resolution Scalability

- Quality of pixels fixed, number of pixels grows

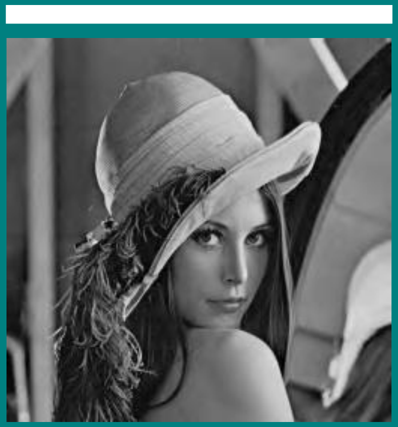
0.05 bpp

0.1bpp

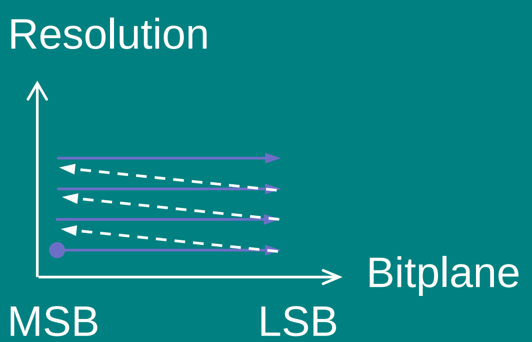
0.2 bpp



1.0 bpp

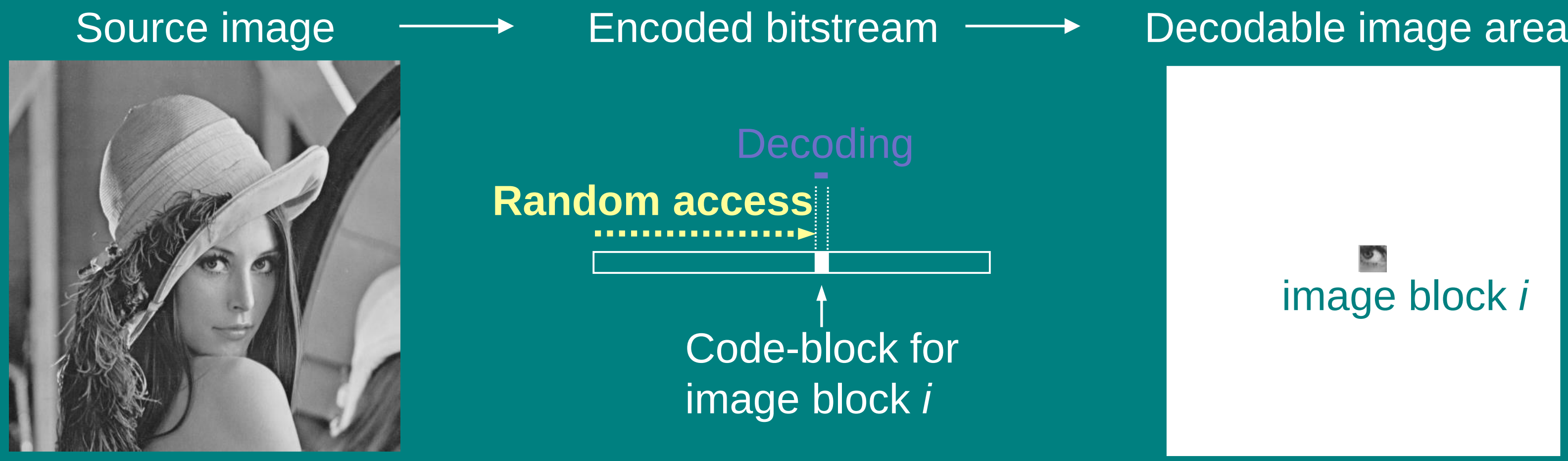


Scanning order

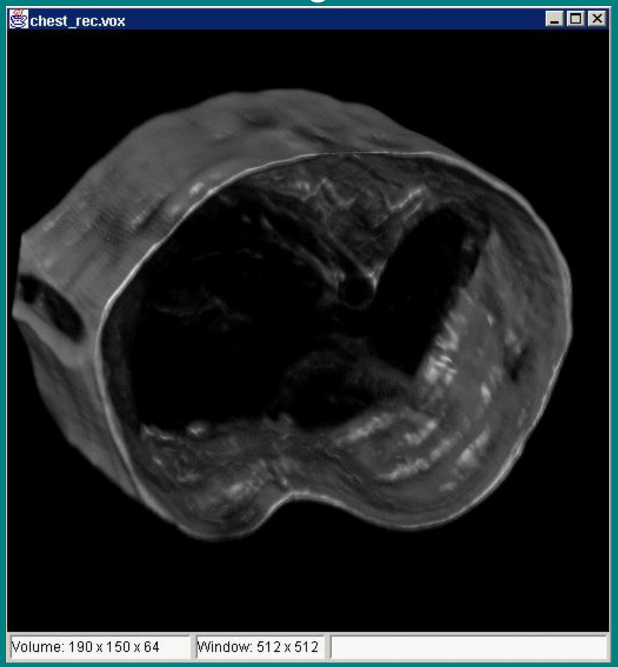


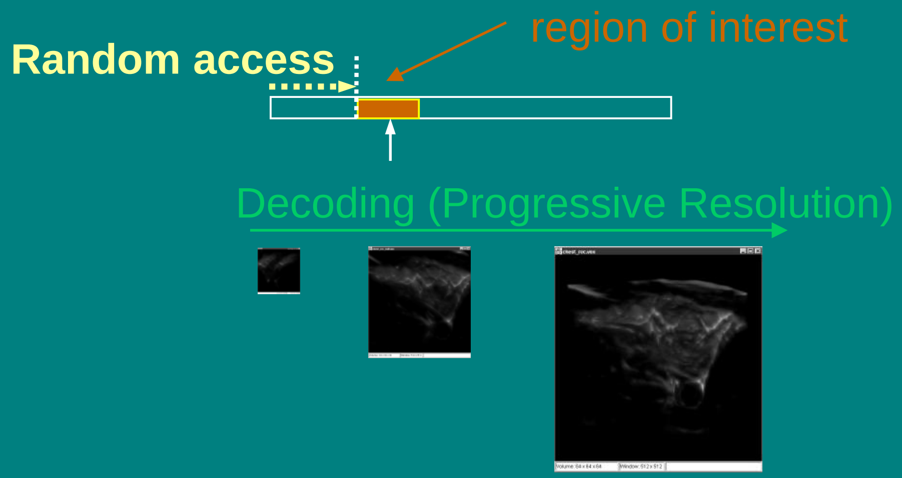
Random Access Decoding

- Decode the region of interest in the codestream with a minimal decoding work
- A code-block seek time can be minimized



Source image → Encoded bitstream





MRChest, 256x256x64, ROI = 64x64x64, 0.5 bpp (16:1)

2.0 GHz Intel Xeon Processor,Windows OS

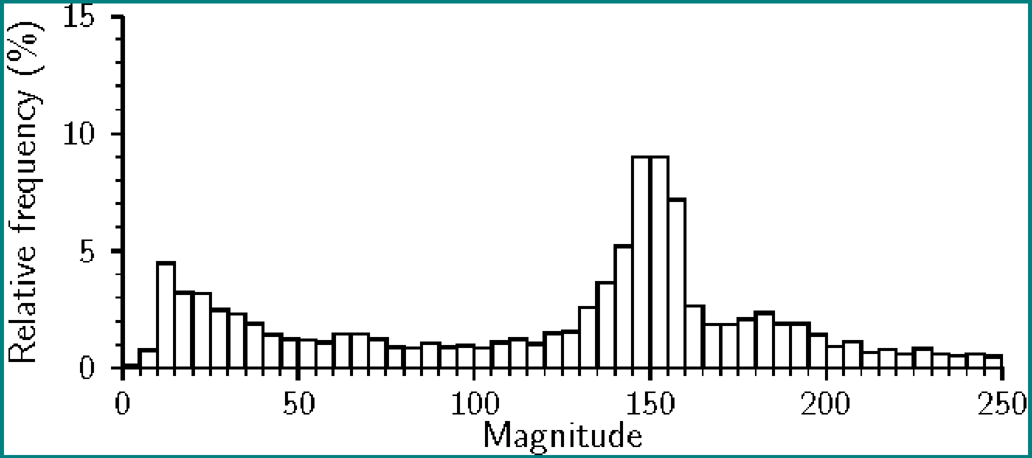
Decoding region	Resolution	3D-PROGRES decoding time (sec)	IDWT +I/O (sec)	Total decoding time (sec)
full 3D image	¼	0.01	0.01 + 0.04	0.05
	½	0.01	0.09 + 0.11	0.11
	full	0.04	0.75 + 0.61	1.40
ROI	¼	0.01	0.01 + 0.01	0.02
	½	0.01	0.02 + 0.05	0.08
	full	0.02	0.28 + 0.19	0.49

Compression Method

- Type of compression: *set partition coding (SPC)*
- Principles of SPC:
  - discover sets of samples with integer values below given threshold value, $t = 2^n$
    - Values written with $\log_2 t = n$ bits.
    - Splitting of sets in sample array guided by threshold test
    - Sets recursively split as threshold lowers in steps by factor of 2 ($n \to n-1$)
  - discover sets of integer samples with values from 2^n to $2^{n+1}-1$
    - Need only n bits, since 2^n integers in set
- Beneficial to data having large regions of low values, especially value of 0.
  - 1 bit (0) encodes all samples in all-0 region
- Location of regions conveyed very efficiently

Comparative Magnitude Distributions

Natural image



Wavelet Transform

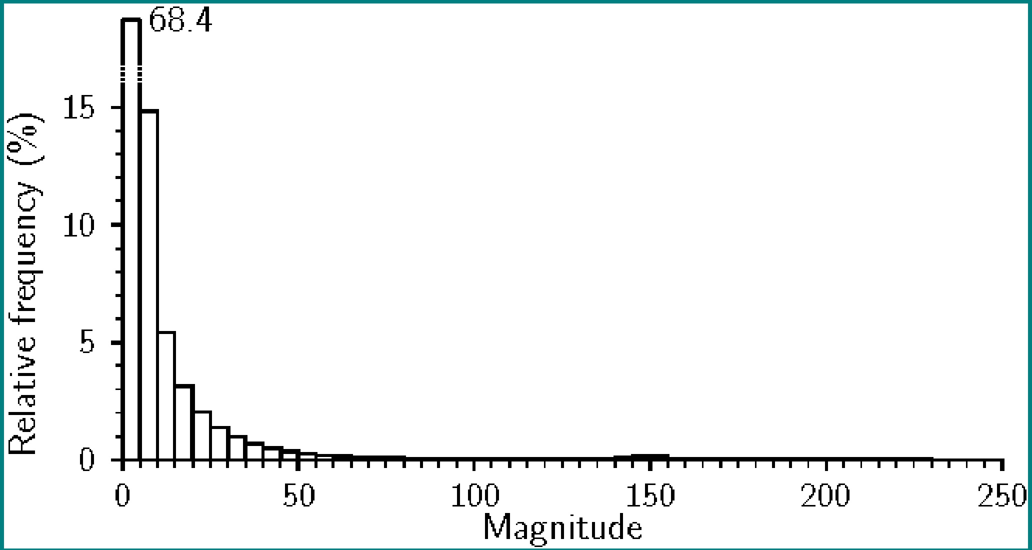


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Image Wavelet Transform

- Energy decreases from low to high resolution (scale)

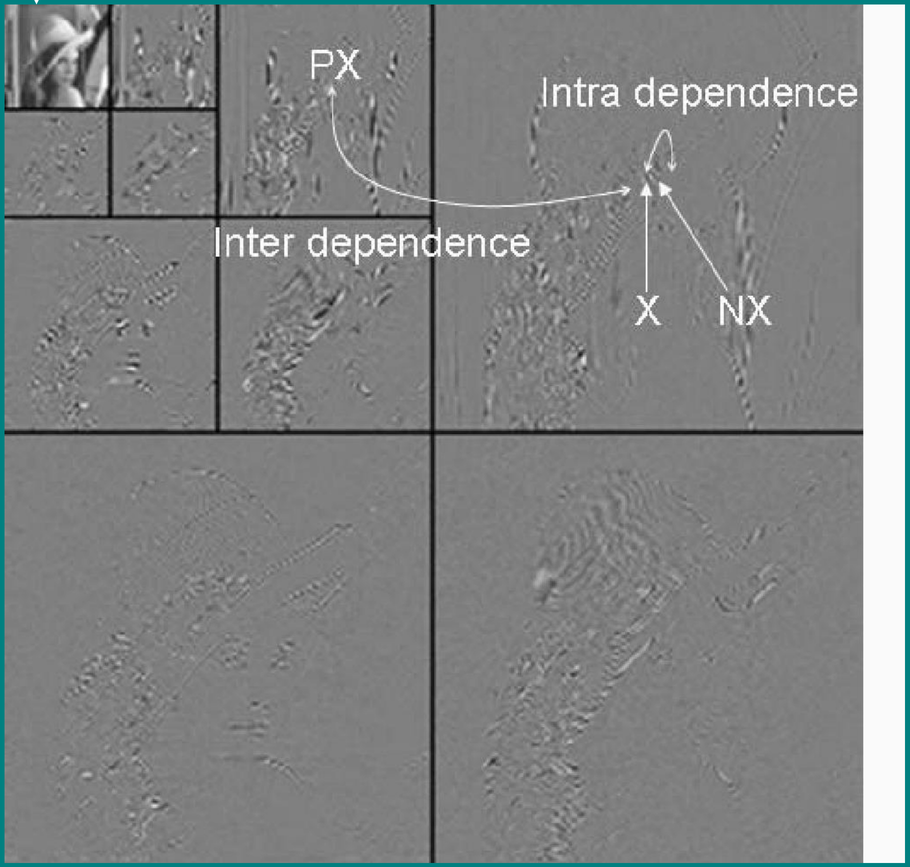
- Dependence within subbands and across scales at same spatial orientation

- Large areas of 0's exist, especially in highest scale subbands

- Integer transform necessary for perfect reversibility

❖ Ready for coding

LL band



Mid-gray 128 = 0,except LL band

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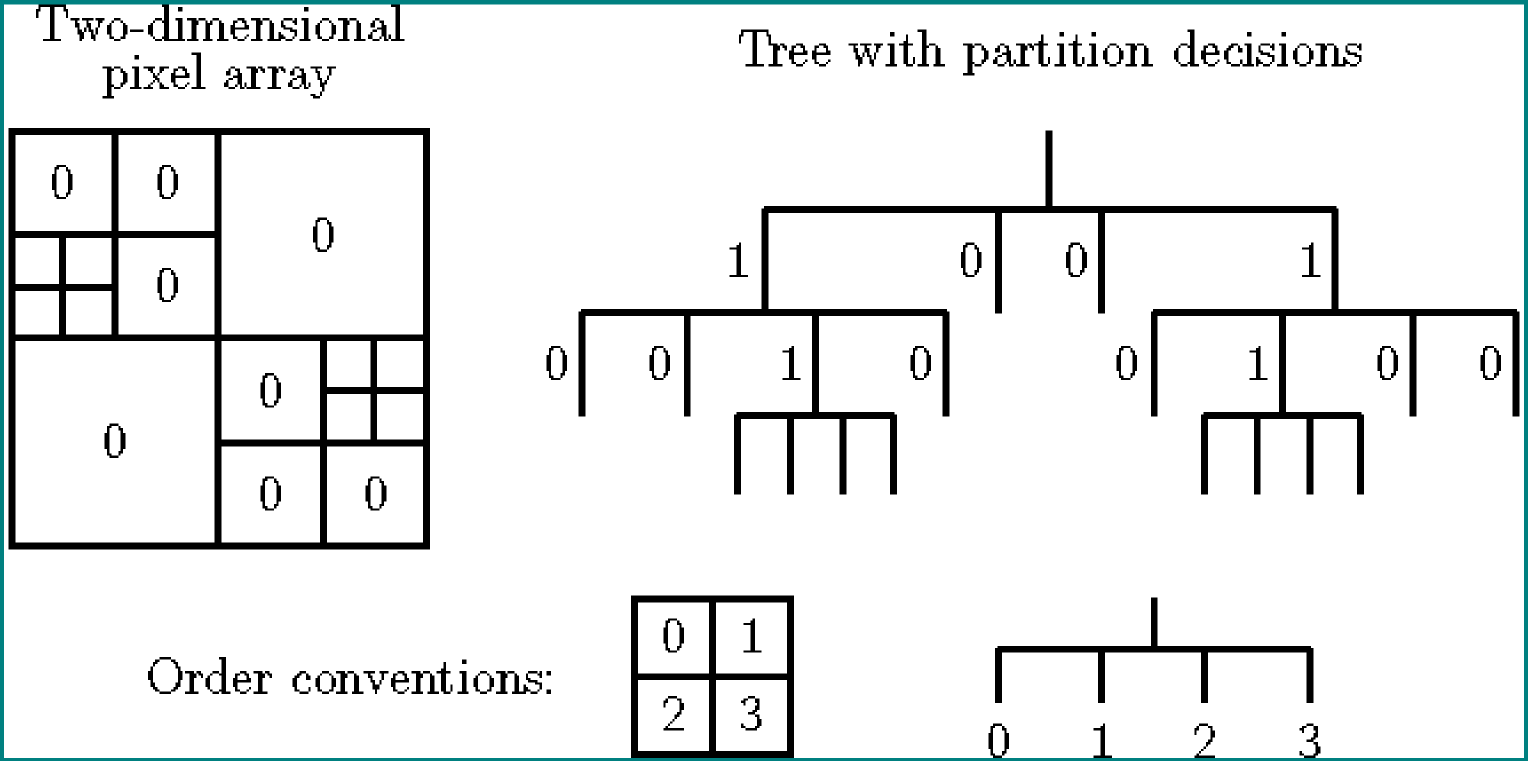
Block splitting and coding:
2-D example



Three levels of quadrisection of 8 x 8 block and quadtree code;
n -> n-1, test 0-sets remaining from tests at *n*, *n+1,…*

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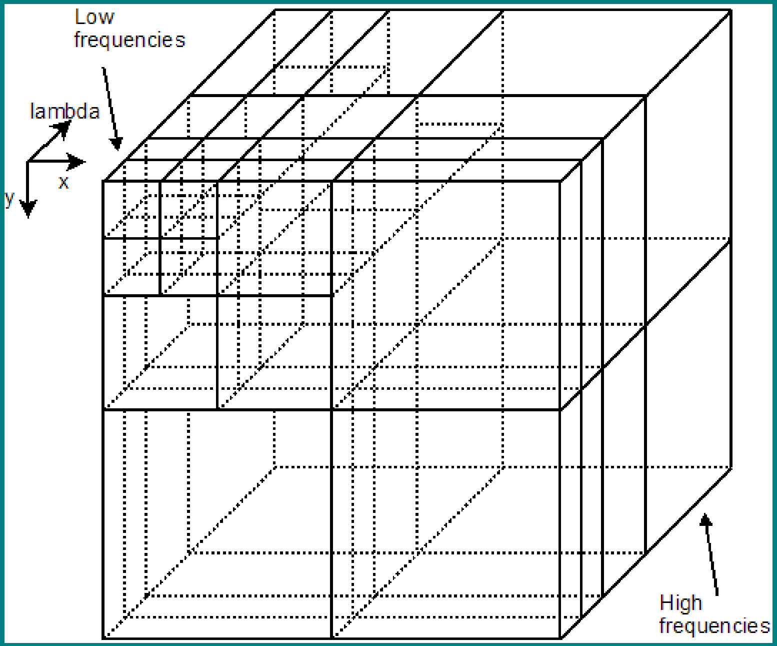
Coding Procedure

Subband structure of 3D DWT



3 Lists to keep track of set states

- LIS – List of Insignificant Sets
- LIP – List of Insignificant Pixels
- LSP – List of Significant Pixels

- Apply 3D-DWT, GOS = 16
- Divide each subband into code-blocks (e.g. 64x64x4)
- Use recursive set partitioning according to significance test:
  - A set S is significant with respect to bitplane n, if

    $$\max_{(i,j,k)\in S} |c_{i,j,k}| \geq 2^n$$

  - Significant – ‘1’, Insignificant - ‘0’ to codestream
  - Insignificant sets/pixels put on LIS/LIP
- If significant, partition by fixed procedure,

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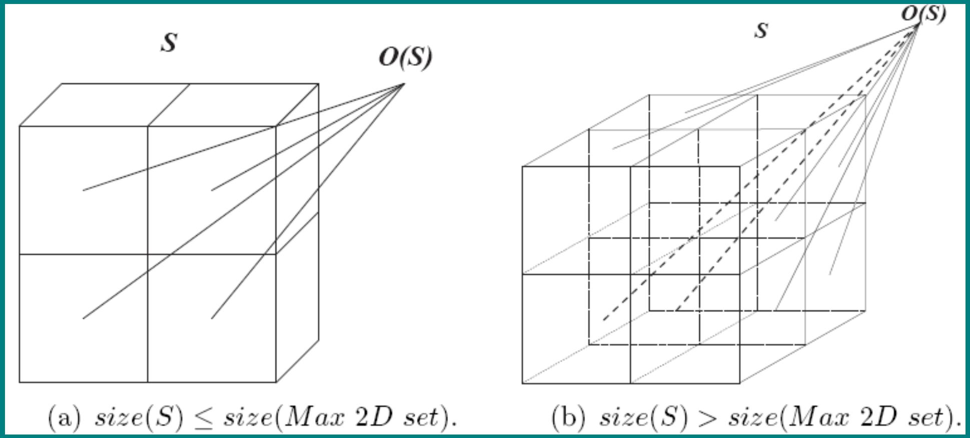
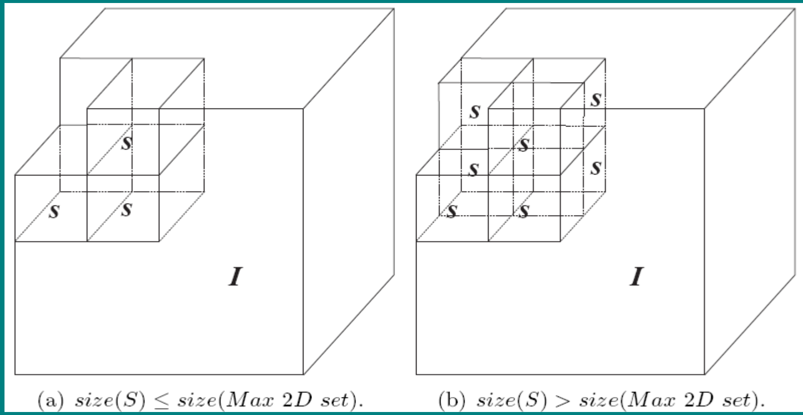
Set-Partitioning



Quadtree/Octtree
Partitioning of set S



Octave-band
Partitioning of set I

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3D-SBHP Algorithm

1) Initialization $n = \lfloor \log_2(\max |c_{i,j,k}|) \rfloor$

- Output
- Set LSP and LIP as empty
- Set LIS = S = {top-left 2x2x1 rectangular prism }

  I = X - S

2) Sorting Pass:

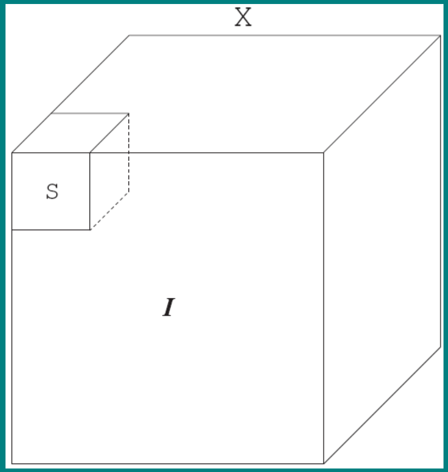
- Encode each coefficient in LIP
- Encode each set in LIS by set-partitioning in increasing order of size of sets

3) Refinement Pass:

Refine the LSP coefficients located from previous passes

4) Quantization Pass:

- Decrement n by 1 and go to step 2



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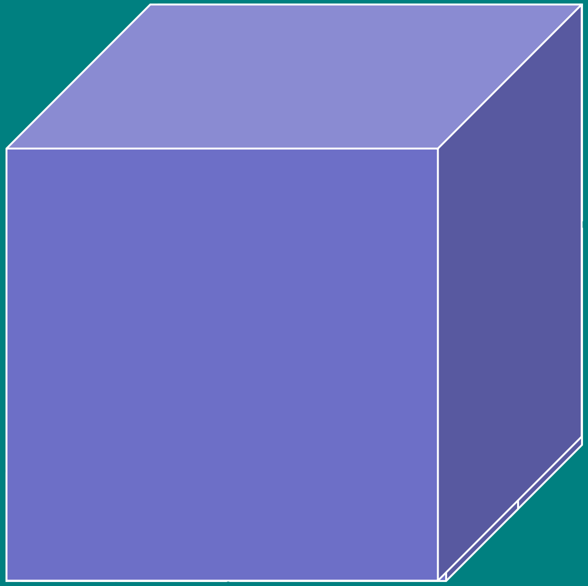
Significance Map for a 8 x 8 x 2 set



1
00100000
0001
0101

Raw bits

Code with 15 symbol fixed Huffman codes

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Sorting by Magnitude and Bit-Plane Transmission

Transmission of magnitude-sorted coefficients

	sign	s	s	s	s	s	s	s	s	s	s	s	s	s
msb	5	1	1	0	0	0	0	0	0	0	0	0	0	0
	4	→	→	1	1	0	0	0	0	0	0	0	0	0
	3	→	→	→	→	1	1	1	1	0	0	0	0	0
	2	→	→	→	→	→	→	→	→	1	1	1	1	1
	1	→	→	→	→	→	→	→	→	→	→	→	→	→
lsb	0	→	→	→	→	→	→	→	→	→	→	→	→	→

Coefficients progressively refined.
Example: stop after completing n=2, max inaccuracy is 3.

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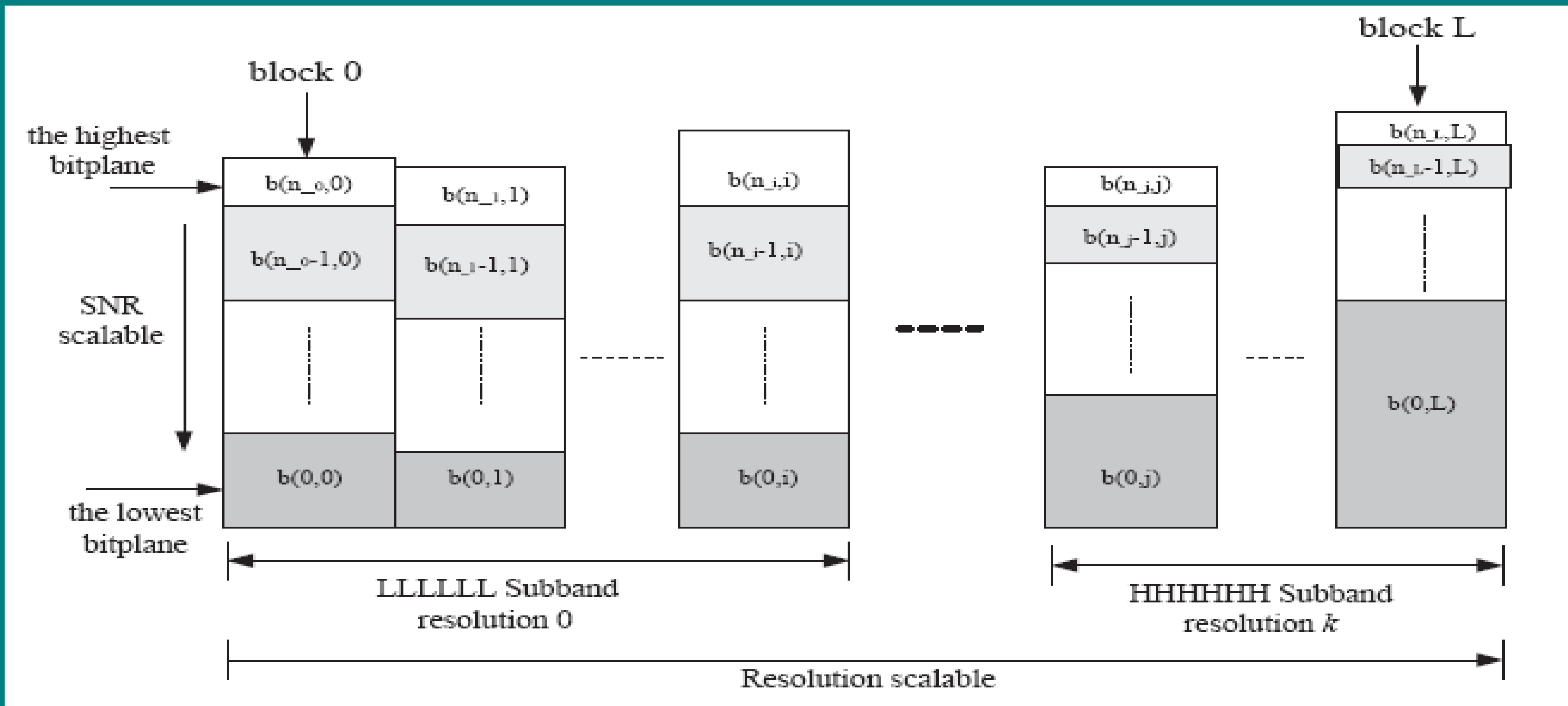
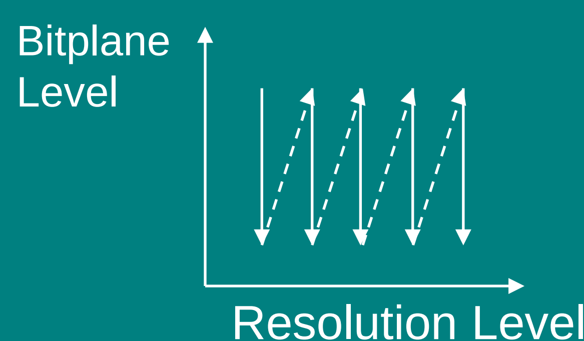
Scalable 3D-SBHP

- Code-blocks are encoded from the lowest subband to the highest subband separately – progressive in resolution
- Progressive bit-plane coding generates progressive in quality or embedded bitstream

SNR and Resolution Scalabilities





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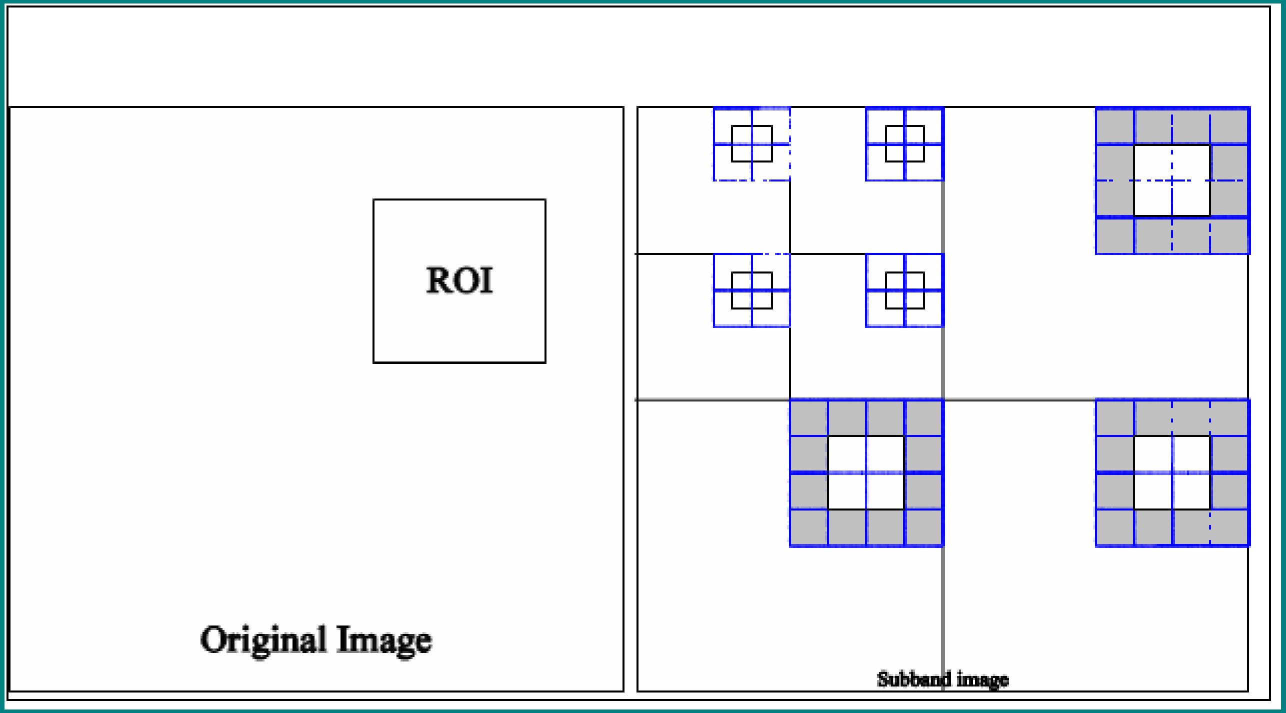
Random Access Decoding

- Code-block selection method is chosen to access piece of bitstream to decompress a given image region.



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Test Image Sequences

- Hyperspectral image sequences
  - Sizes: 512 x 512 x 224
  - Bit depth: 16 bits
- Medical image sequences
  - Sizes: 256 x 256 x X
  - Bit depth: 8 bits
- GOS = 16, Codeblock Size = 64x64x4

  S+P filter

Lossless Coding of 16-bit AVIRIS Image Volumes (bits/pixel)

Name	3D-SBHP	3D-SPECK	3D-SPIHT	J2K-Multi	J2K	Unix gzip
moffett 1	7.03	6.91	6.94	7.18	8.79	11.03
moffett 2	8.43	8.08	7.92	8.41	10.08	11.48
moffett 3	6.83	6.82	6.74	7.00	7.73	10.12
jasper 1	6.78	6.70	6.72	6.90	8.59	10.68

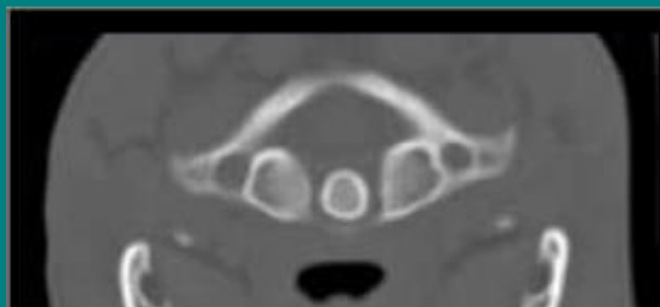
Decomposition level: 5(spatial domain), 2(spectral axis)
J2K: 5/3 filter

Lossless Coding of 8-bit Medical Image Volumes (bits/pixel)

File Name	3D-SPIHT	3D-SBHP	3D-SPECK	JP2K-Multi	JPEG 2000
CT_Skull	2.0051	2.2701	2.0170	1.7450	2.9993
CT_Wrist	1.1570	1.4002	1.2538	1.1771	1.7648
CT_Carotid	1.5498	1.6631	1.6517	1.6785	2.0277
CT_Aperts	1.0313	1.0876	1.1502	0.7290	1.2690
MR_Liver_t1	2.2447	2.5257	2.4331	2.3814	3.2640
MR_Liver_t2e1	1.6914	1.8477	1.8733	1.6247	2.5804
MR_Sag_head	2.1750	2.3219	2.3589	2.5961	2.9134
MR_Ped_chest	1.9218	2.0873	2.1160	1.4884	3.1106
average	1.7220	1.9004	1.8567	1.6775	2.4912

Decomposition level: 3 (all dimensions)
J2K: 5/3 filter

CT_SKULL Visual Result (Lossy-to-Lossless)



al

pp

pp

PSNR and Byte Budget for Resolution Scalable 3D-SBHP (CT_SKULL)

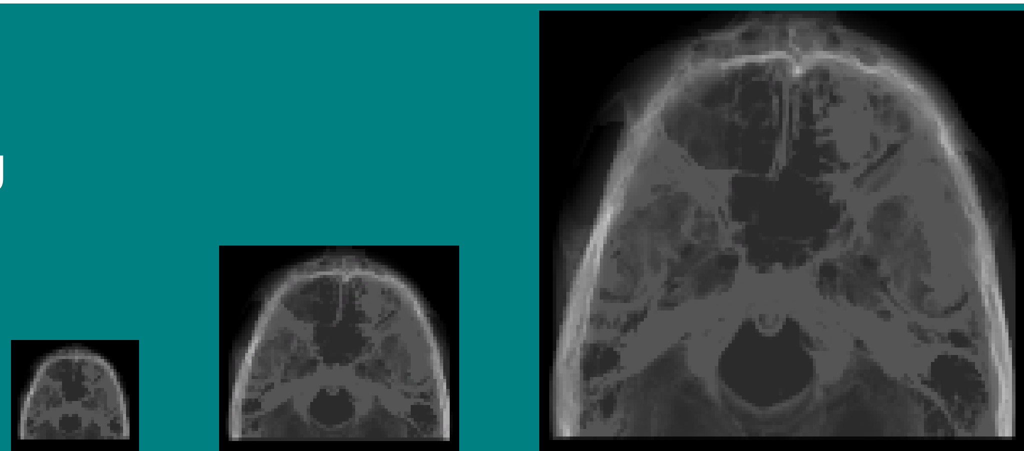
Bit Rate	PSNR (dB)		
	1/4 resolution	1/2 resolution	FULL
0.25	11.10	23.46	37.63
0.5	13.77	29.03	41.85
1.0	24.04	35.71	46.50
2.0	32.58	43.88	50.55

Bit Rate	Byte Budget (bytes)		
	1/4 resolution	1/2 resolution	FULL
0.25	6132	48951	391351
0.5	12284	98258	785364
1.0	24575	196604	1572597
2.0	49151	39321	3145610
Lossless	137333	757110	3725185

Resolution Scalable Visual Results

Resolution
scalable decodin
at 1.0bpp

Resolution
scalable decoding
(Lossless)



Computational Complexity in CPU cycles

Lossless Encoding

6 times faster

File	Total Cycles ($\times 10^6$)		Cycles/pixel	
	3D-SBHP	AT-3D -SPIHT	3D-SBHP	AT-3D -SPIHT
CT_Skull	1643.162	10086.096	130.58	801.570
MR_liver_t1	449.921	2560.516	143.58	813.966

Decoding

6-10 times faster

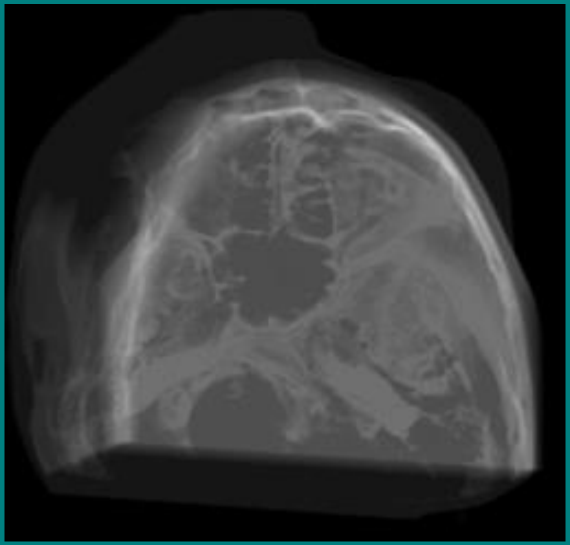
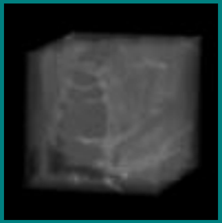
Bit Rate	Total Cycles ($\times 10^6$)		Cycles/pixel	
	3D-SBHP	AT-3D-SPIHT	3D-SBHP	AT-3D-SPIHT
CT_Skull				
0.125	58.130	375.695	4.62	29.86
0.25	107.528	786.145	6.08	62.477
0.5	199.141	1677.159	15.82	133.29
1.0	378.820	3689.307	30.11	293.20
lossless	814.119	8333.717	64.70	662.30
MR_liver_t1				
0.125	14.451	96.860	4.59	30.79
0.25	27.797	174.739	8.837	55.55
0.5	51.634	396.864	16.41	126.16
1.0	97.215	844.629	30.904	268.50
lossless	231.21	2142.805	73.50	681.18

Computational Complexity in CPU cycles (Cont.)

Resolution	Encoding	Decoding
	Total Cycles ($\times 10^6$)	Total Cycles ($\times 10^6$)
CT_Skull		
1/4	41.614	18.638
1/2	255.458	113.901
Full	1643.162	814.119
MR_liver_t1		
1/4	10.605	6.903
1/2	73.128	38.106
Full	449.921	231.21

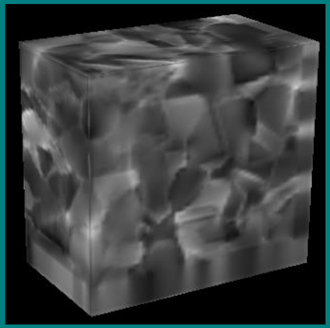
Random Access Decoding Visual Results

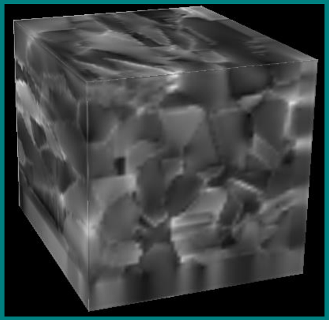
 

(134,117,17) – (198, 181,112)

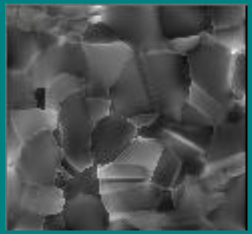
Resolution Scalable Visual Results

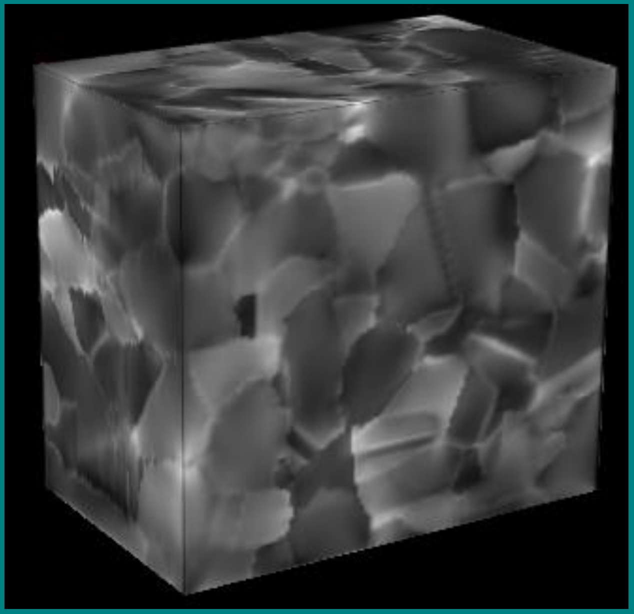


½ XYZ
101229 bytes



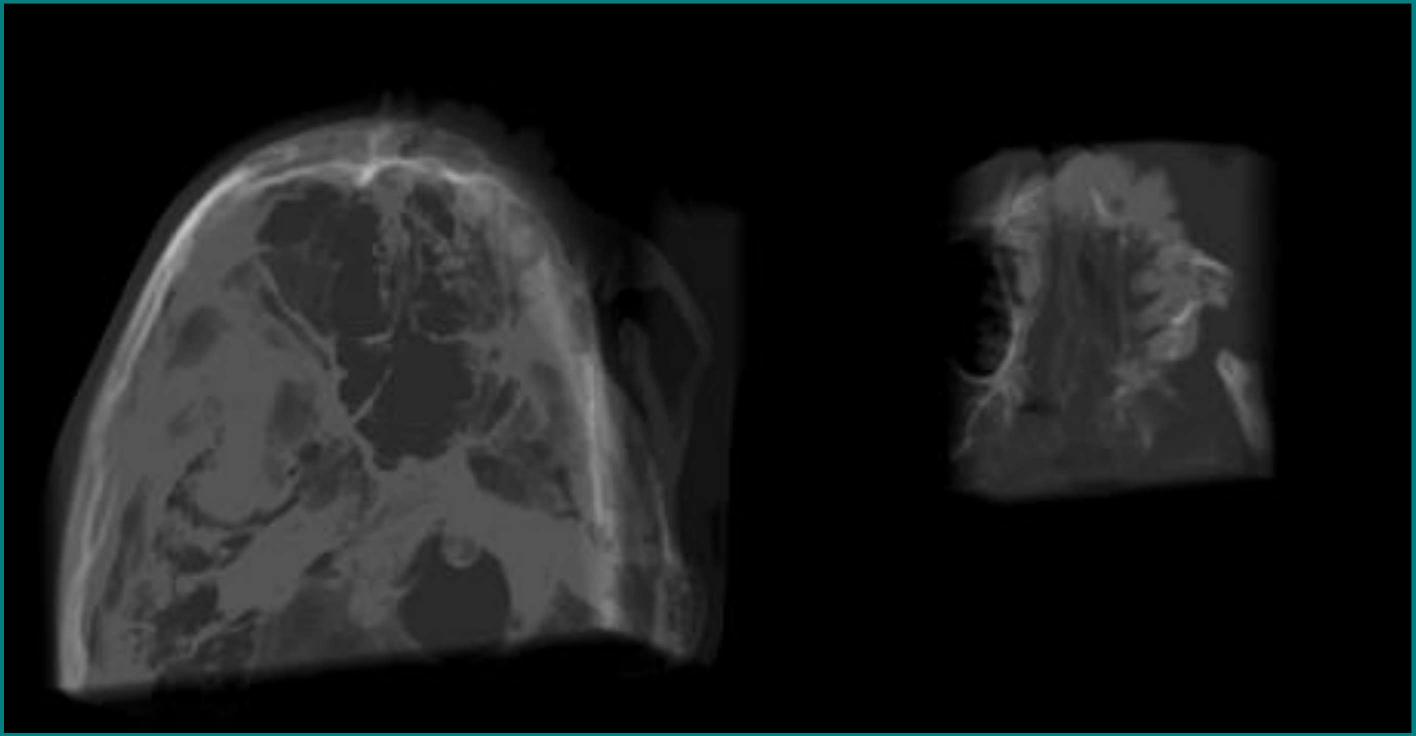
½ XY 1Z
198643 bytes





Full resolution
670371
bytes

3D Demonstration



Demo

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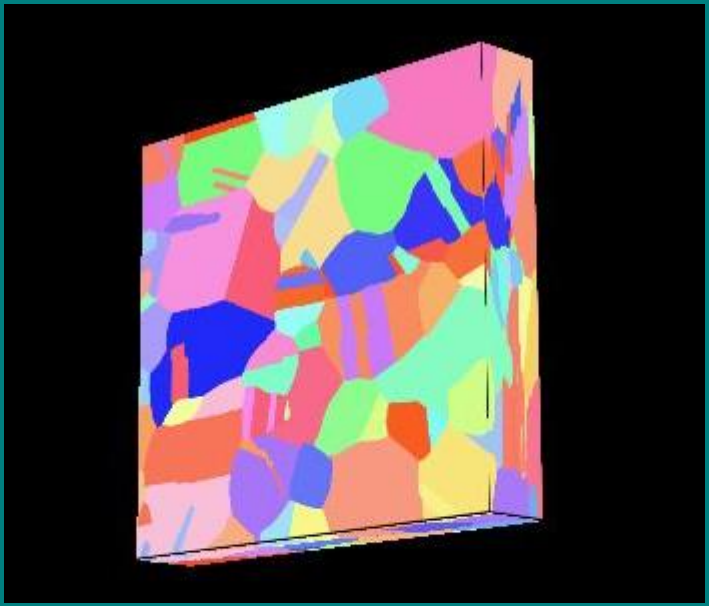
Microstructure Data Characteristics

- Irregularly shaped grains; nearly uniform values
- Segmentation will not help compression
  - requires too many bits to code grain boundaries



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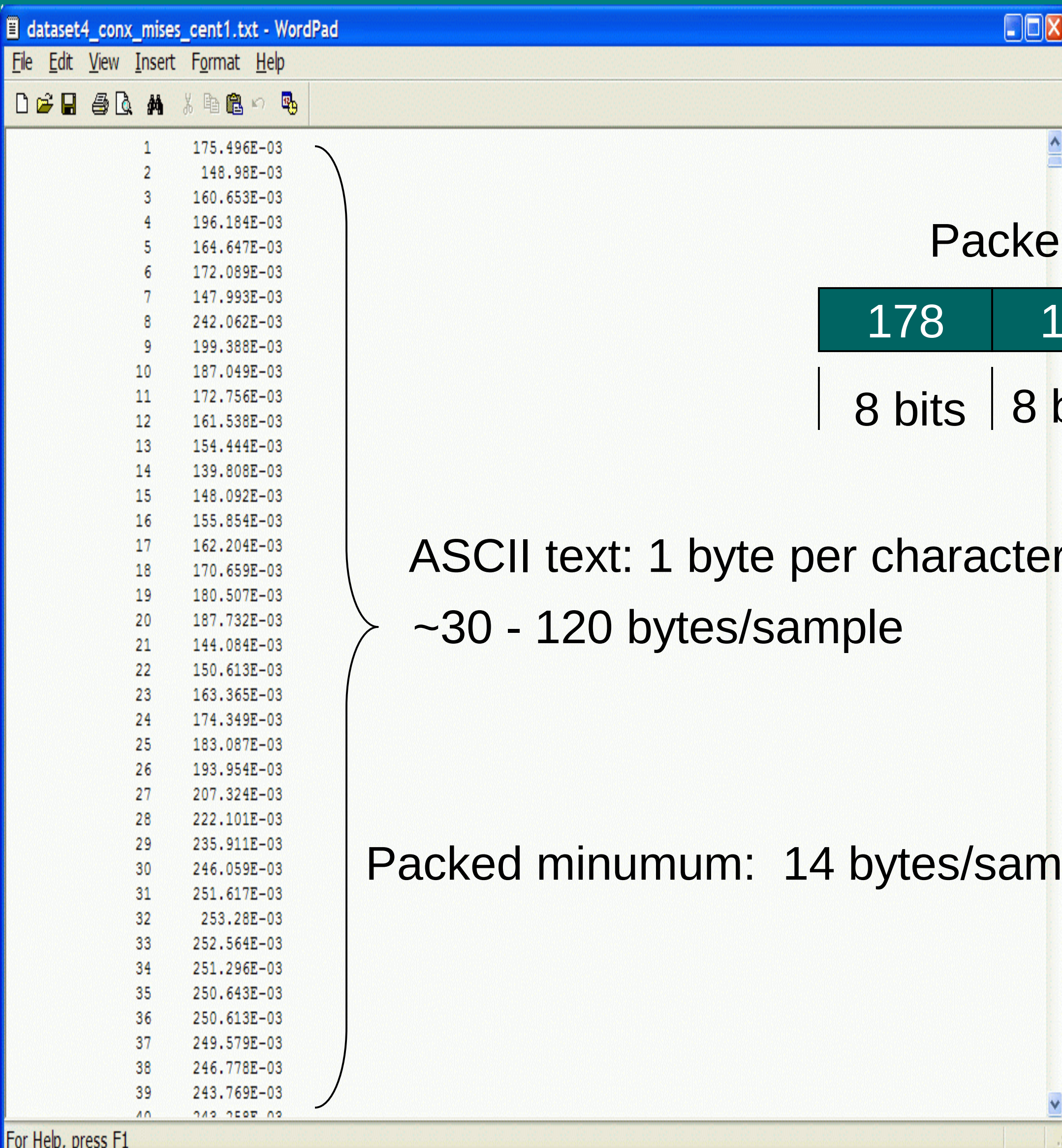
Data Formats



ASCII text: 1 byte per character

~30 - 120 bytes/sample

Packed minumum: 14 bytes/sample

Packed Integer Format

178	148	160	196	• • •
8 bits	8 bits	8 bits	8 bits	8 bits

- Can choose integer type:
  - 8 bit – 1 byte
  - 16 bit - signed or unsigned – 2 bytes
  - 32 bit integer - 4 bytes
    - 3 to 9 decimal digits

- Data packing is not true compression
- Compression of images measured relative to packed format

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xZIP vs. Scalable Wavelet Coding

xZIP	Scalable wavelet coding
~1.5-5:1 CR lossless time/storage savings	~50-320:1 CR lossless (includes packing gain) time/storage savings
Whole file needed in decompression	Partial file selection
Large memory space	Small memory space
Full decompression required for postprocessing	Features inherent in compressed file-no postprocessing
No lossy capability for greater compression	Lossy capability for greater compression
Decodes only to full resolution	Decodes to multiple resolutions

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Goals

- Easily navigable web interface for
  - Transfer and visualization of **large** raw 3D and 4D datasets
- Enabling technology – **compression**
  - Large datasets hard to handle and too slow to transmit in uncompressed form
  - Capability of direct access to portions of compressed bitstream to reconstruct selected region with desired quality and resolution
- Web-Based Tool
  - Ability to browse thru large compressed 3D data
  - Preview different 3D datasets for final selection of whole or specific ROI's
  - Download
    - Data files and sub-files
    - Compression, decompression, display, and utility tools/software
  - Upload
    - Compressed data files
  - Ties into Atlas Database and Query GUI

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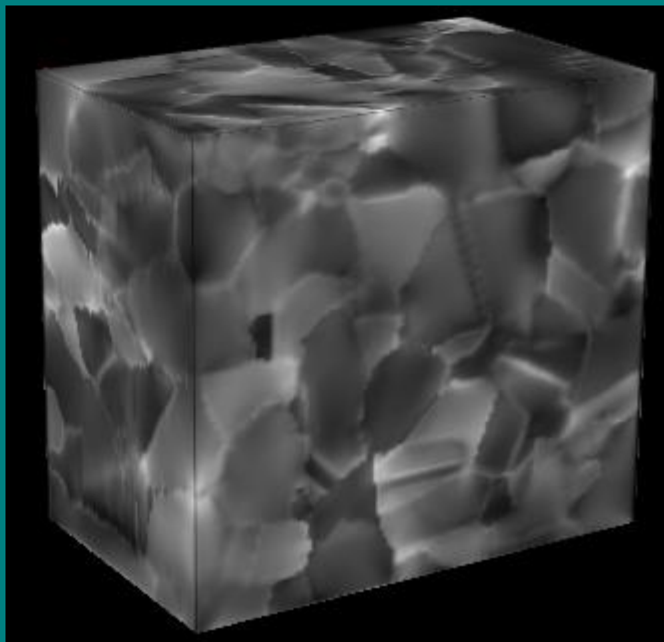
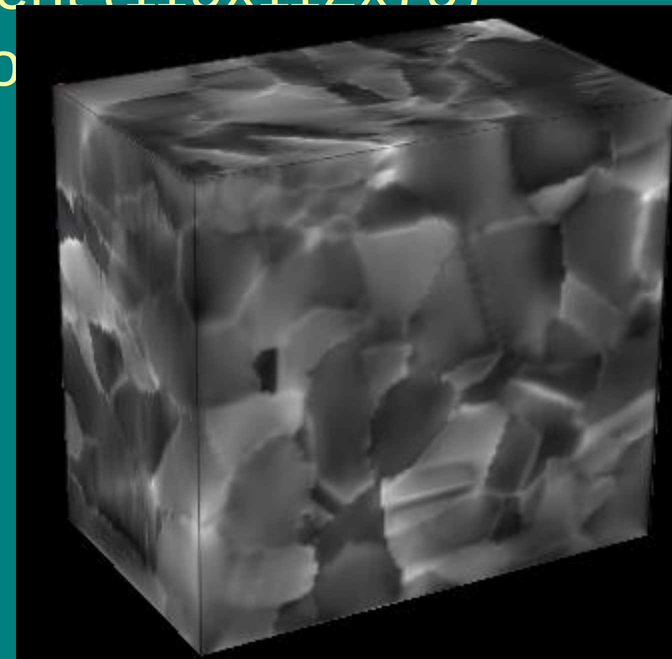
Von Mises dataset4_conx_cent (119x112x79)

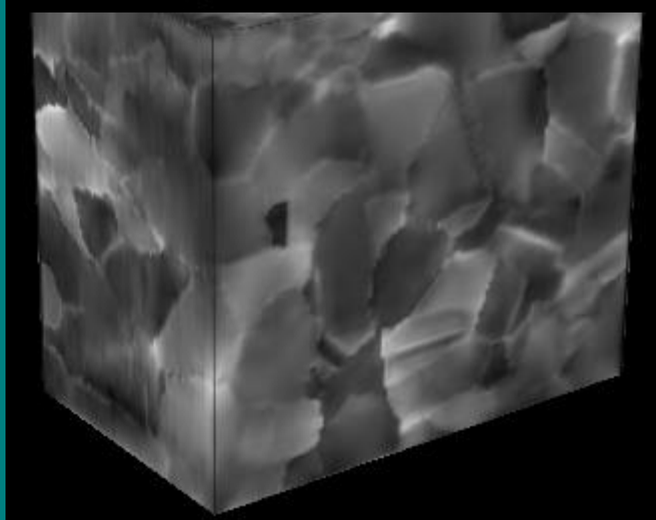
esult (Lossy-to

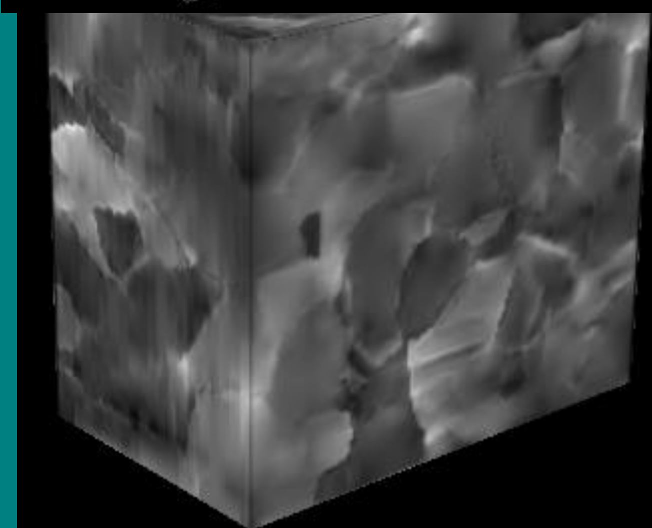




ssless

:1

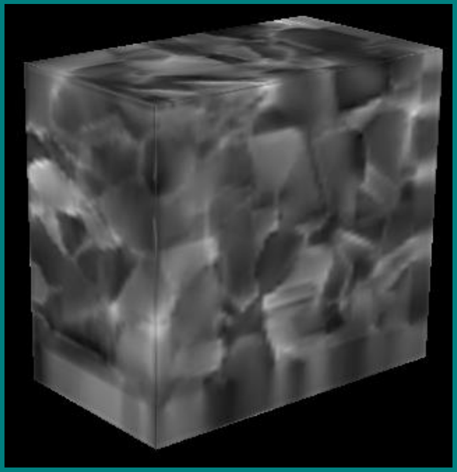


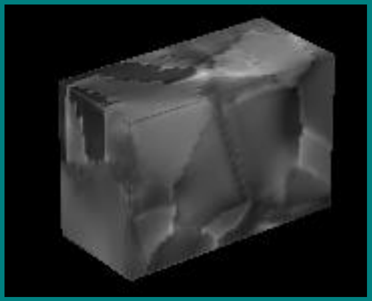


4:1

ASCII – 35.8 MB Compressed to 670 kB: 53:1

ROI Visual Result





½ XY

Selected region

Communication/Display GUI

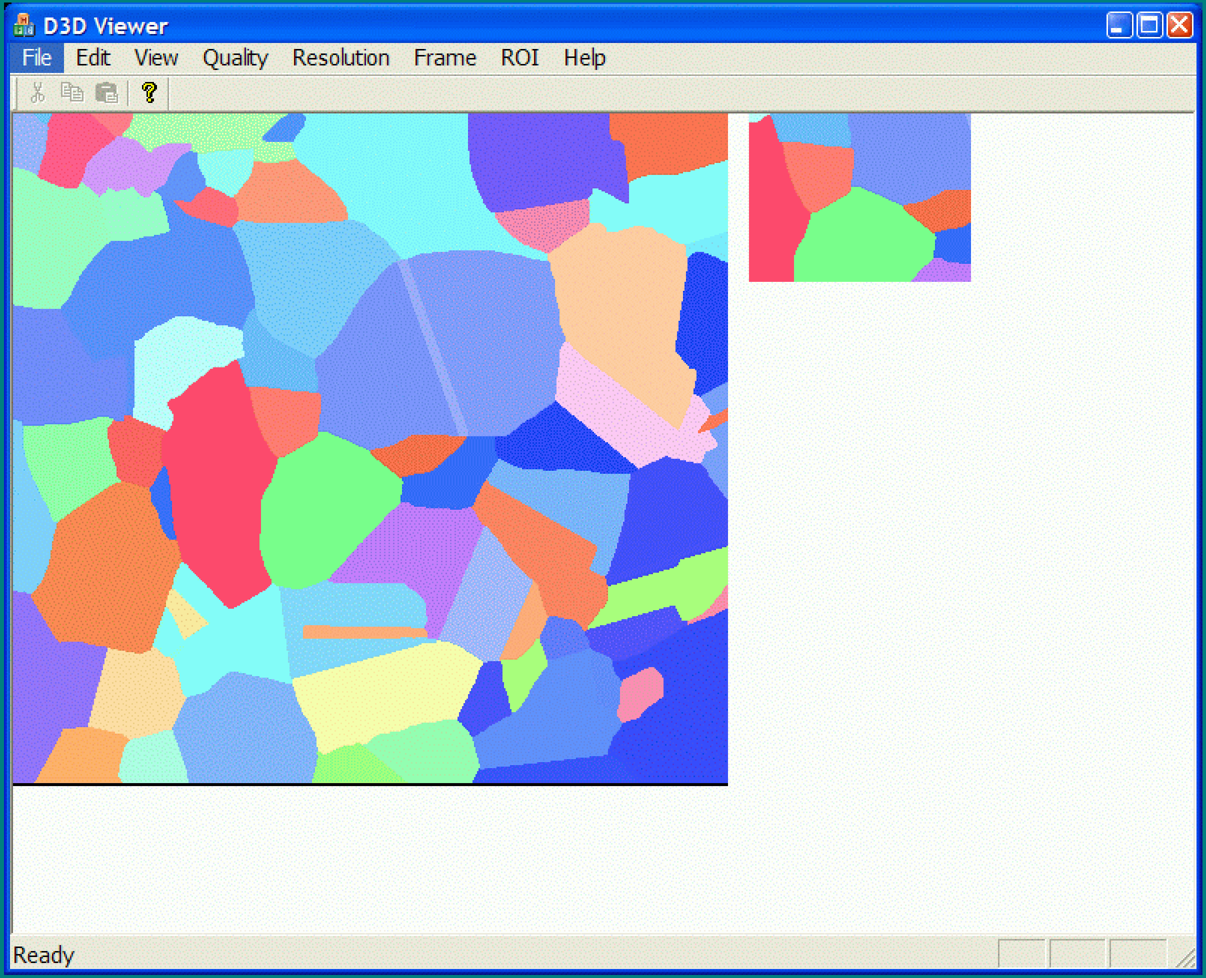
http://www.cipr.rpi.edu/D3D_MICRO

Click on file name in web site and left image appears.

Right mage appears using ROI Menu and mouse Selection of region

Any slice can be viewed by dropping Frame menu and entering number

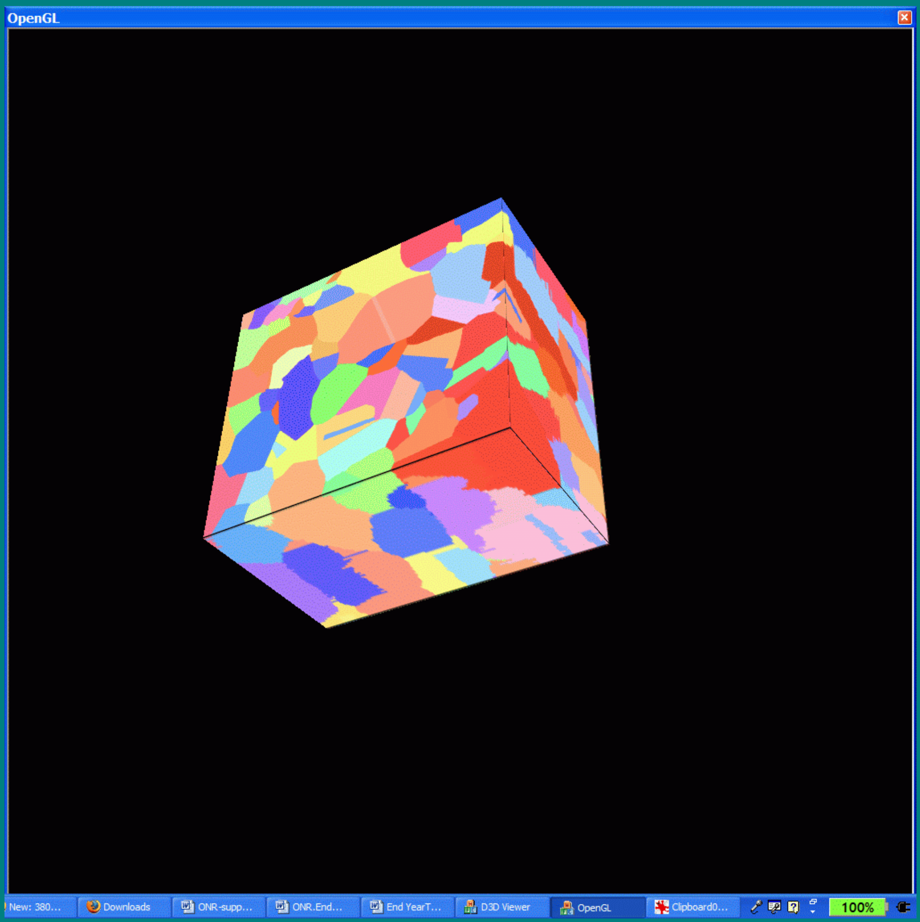
In View menu, can select Full volume and ROI views In 3-D -- see next slide



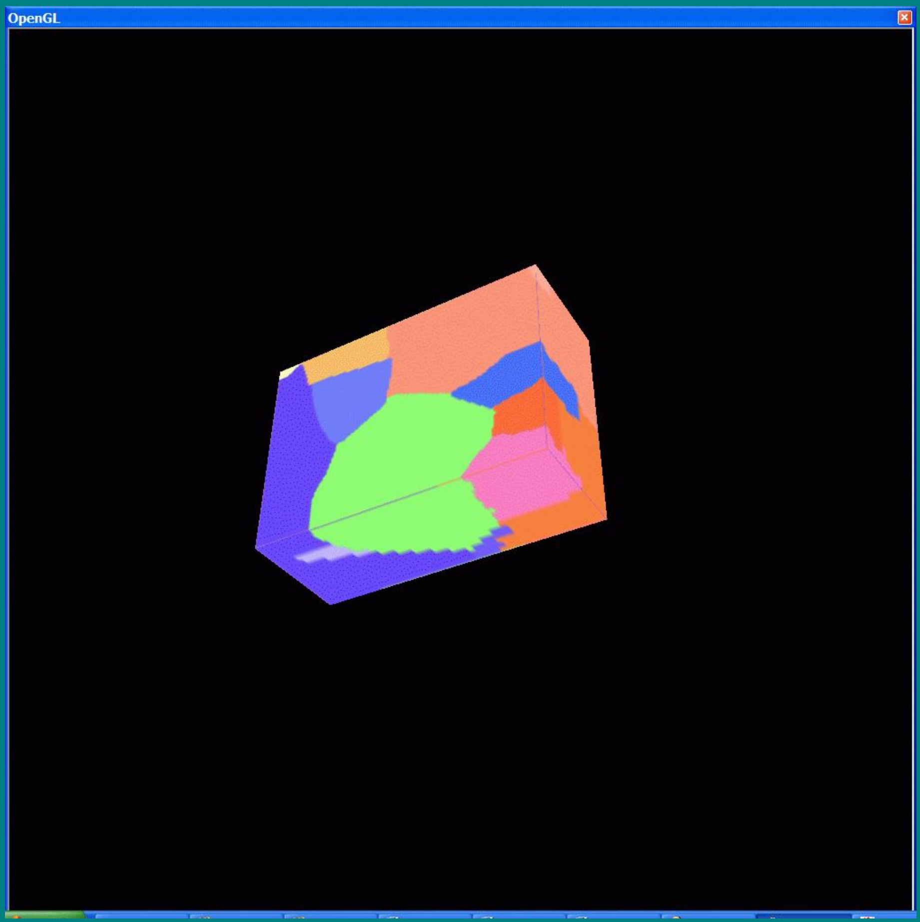
167 MB → 4 MB compressed 41:1

3-D Views

Full volume



ROI



Rotation by mouse manipulation

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Satellite Web Site

http://www.cipr.rpi.edu/D3D_MICRO

- Resource for
  - File conversion software
  - Compression software
  - Viewer

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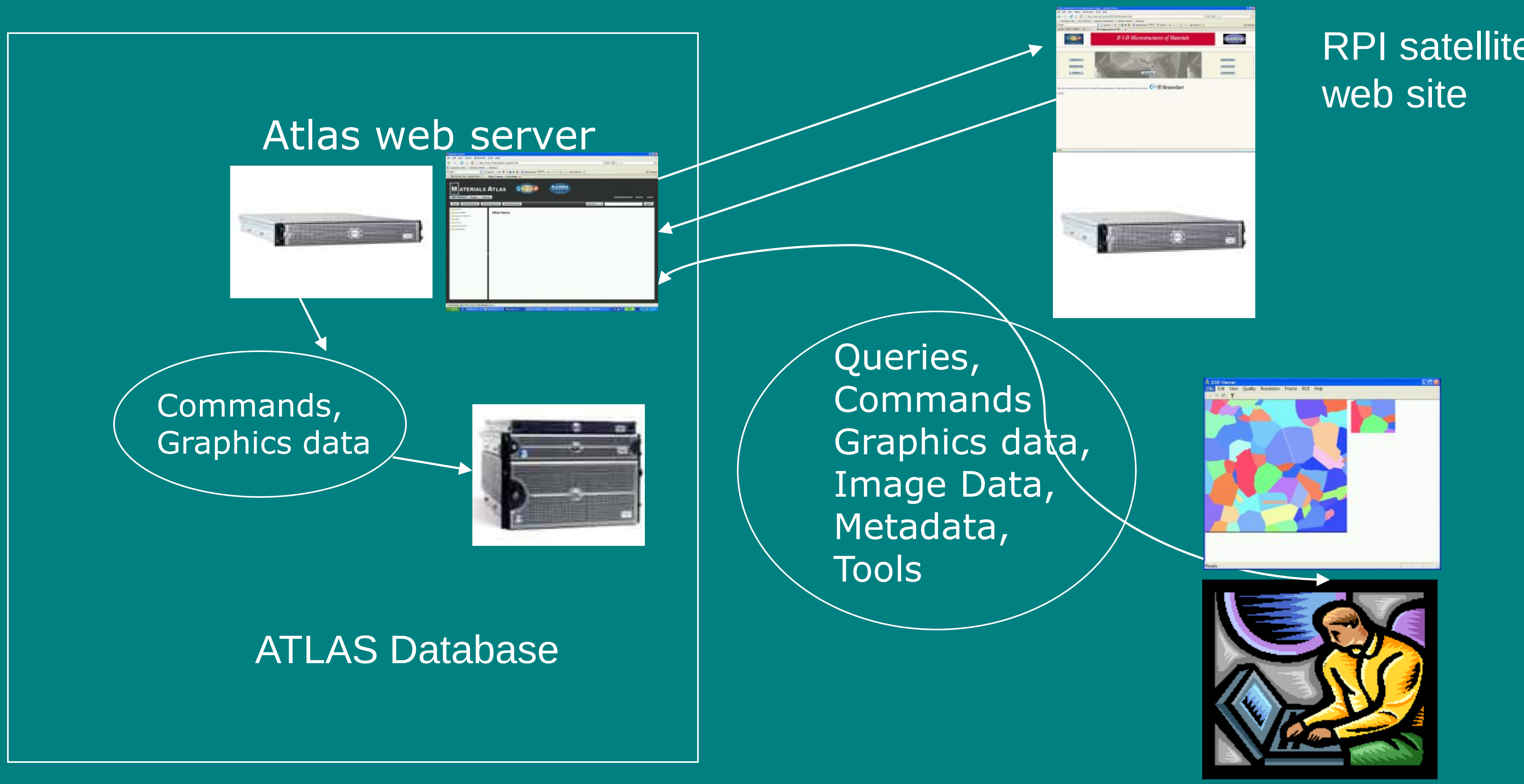
Client - Server Interactions



Client-Server Live Demo

1. Go to http://www.cipr.rpi.edu/D3D_MICRO
2. Click on “Images Database” to show datasets
3. Click on selected file name – Viewer activates locally and displays initial slice
4. Client shows volume- and surface-rendered views
5. Client selects ROI with mouse
6. Client displays ROI in 3D
7. Client saves ROI either in compressed or uncompressed ASCII format
8. Client shows results of analysis on displayed file.

Compression Results

- Lossless Compression for Data Uploads
  - 40-320:1– full resolution
    - depends on dataset and original precision
    - Von Mises Hi Res area 2 – 123:1 (82,590 K / 670 K)
- Decompression Savings for Downloads and Visualization
  - 4:1 additional for lossy decompression with high visual quality
  - Reduced resolution
    - 4:1 **additional** savings for lossless 1/2 resolution
    - 16:1 **additional** savings for lossless 1/4 resolution
  - Region of interest selection
    - **Additional** reduction ~ (full volume)/(ROI volume)

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Summary

- Explained advantages and attributes of scalable wavelet coding
- Presented communications/codec viewer for progressive retrieval, transmission, decompression, and visualization of compressed materials microstructures

Thank you!