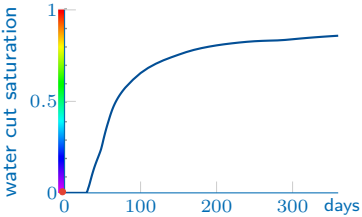
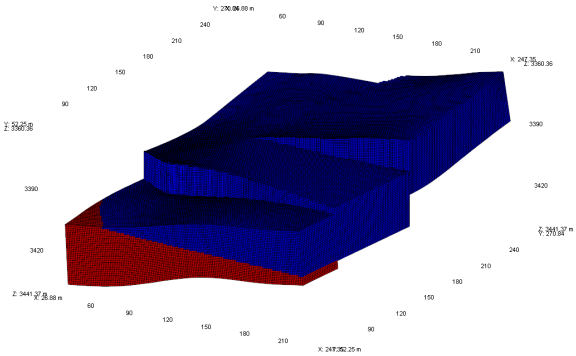
Teaser



Simulation output



Flow simulation in a reservoir

What are the sufficient resolution and precision for simulation?

Refinable resolution & precision for volume mesh compression & simulation in geosciences

PhD defense

Lauriane Bouard[1,2]

supervised by: Laurent Duval[1], Frédéric Payan[2], Marc Antonini[2]

[1]IFP Energies nouvelles, France

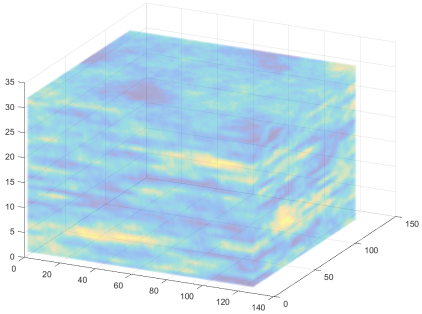
[2]Université Côte d'Azur, CNRS, I3S, France

March 1st, 2021

1.1 Context: resolution & precision

Numerical data sample (128x128x32) & visualisation using color scale

```
--Original name in OpenFlowSuite : PERMX
PERMX
 26.314125   75.134232   85.466339   38.975594   38.207466   124.22842
 96.443436   65.035629   30.432631   38.038654   32.118565   167.13992
 350.38806   532.47803   725.21722   206.54999   156.83121   69.182892
 50.475800   128.65318   87.062843   165.05464   25.971411   34.263180
 47.647865   49.585426   119.76465   266.48260   77.984566   35.045452
 64.941391   151.76199   237.53284   425.93784   209.88492   88.224564
 137.20033   219.96822   90.803192   67.491493   78.149750   44.550072
 51.777977   21.281700   8.3894510   37.029186   44.643394   58.548313
 56.100018   56.683067   97.258797   250.96591   131.85550   152.47266
 96.702827   143.60780   63.052452   52.729099   90.841110   125.83300
 150.59875   142.47940   133.00090   32.662064   9.6383276   6.6885986
 2.5453172   0.36911201   0.13882042   0.43889502   0.14942573   0.18742472
 0.23326379   0.49800286   0.43879494   0.25002083   0.17376700   0.077048026
 0.056770172   0.057687003   0.22902893   0.082185000   0.049731109   0.054618347
 0.047648285   0.055136342   0.10453968   0.18202992   0.17403004   0.12496775
 0.17153382   0.13760087   0.16105503   0.083738290   0.16634125   0.28145534
 0.46834838   0.41442880   0.50629205   1.4719200   1.6153352   0.96782684
```



Binary writing of 26.314125 at IEEE-754 floating-point standard, 32 bits per value

0	1	0	0	0	0	0	1	1	1	0	1	0	0	1	0	1	0	0	0	0	0	1	1	0	1	0	1	0	1	0	0

Sign

Exponent, 8bits

Mantissa, 23bits

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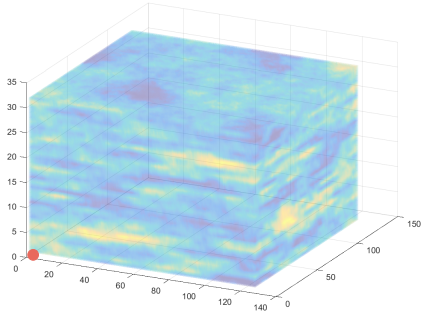

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1.1 Context: growing data in simulation sciences

Scientific workflow

Data acquisition

Input

↓

Simulation Workflow

↓

Output

Analysis

All up!

↗ Data quantity
(high resolution & precision)
↗ Projects

↗ Datacenters
↗ Supercomputer performance

Domains

CFD

Climatology
Oceanography
Geology

Cosmology
Biology
Quantum chemistry

Issues

Visualization
Storage
Transfer
Memory footprint
Checkpointing restart

Energetic
Economic
Ecological

$\Longrightarrow$ Size multiplied by 40,000 in 16 years

(CMIP) Coupled Model Comparison database issued from simulation code:
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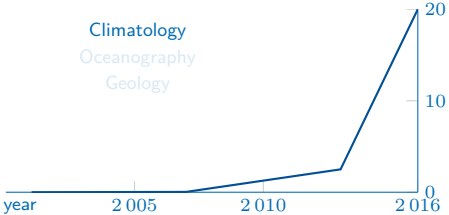
CMIP* Phases in Petabyte



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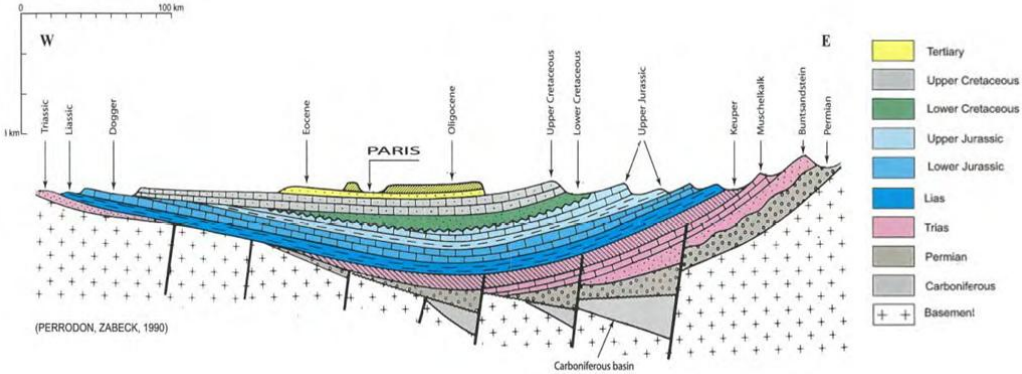
1.2 Input: geological Data

Section of sedimentary basin



(PERRODON, ZABECK, 1990)

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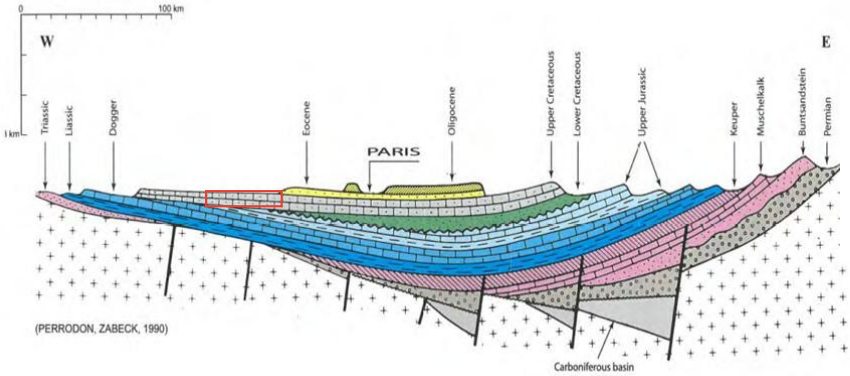

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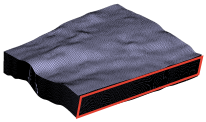
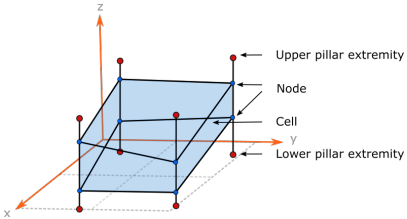
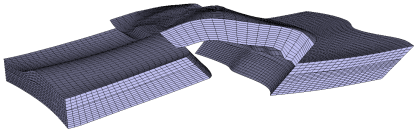


1.2 Input: geological volume meshes

Structure: Corner Point Grid format (CPG)

Pillar extremities	Surface points	(x,y,z) coordinates
Node altitudes	$1D$ data	
Cell activity	$3D$ data	(a boolean value per cell)
Properties	$3D$ data	(a floating-point value per cell)





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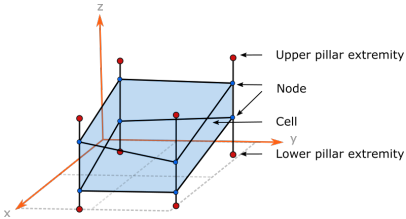

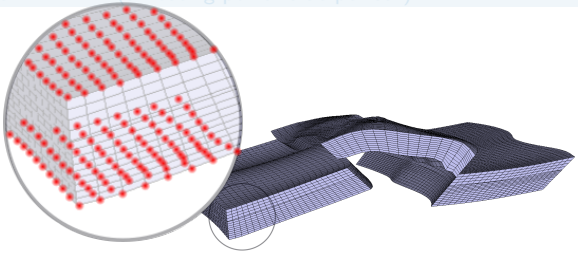

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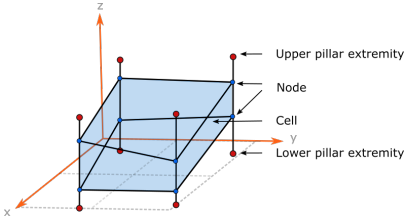

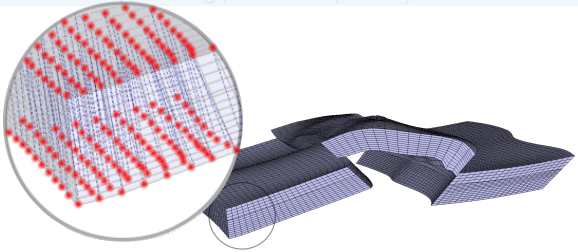

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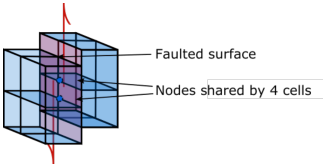
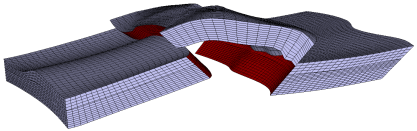
Cell activity	$3D$ data	(a boolean value per cell)
Properties	$3D$ data	(a floating-point value per cell)





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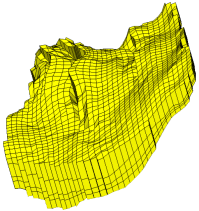

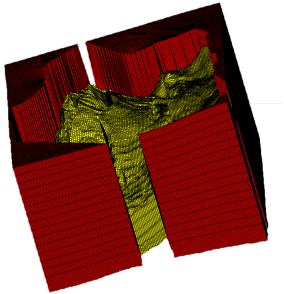

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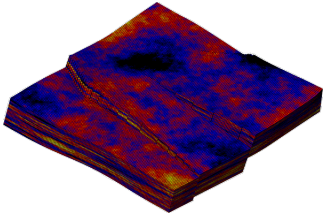
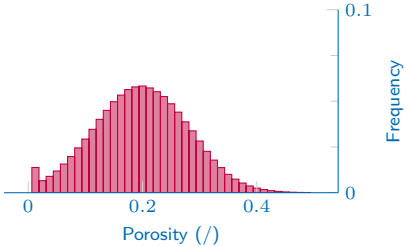
Porosity		





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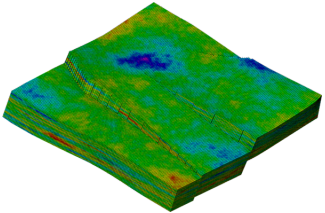
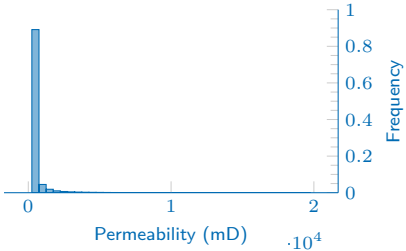
Permeability (with high dynamic)

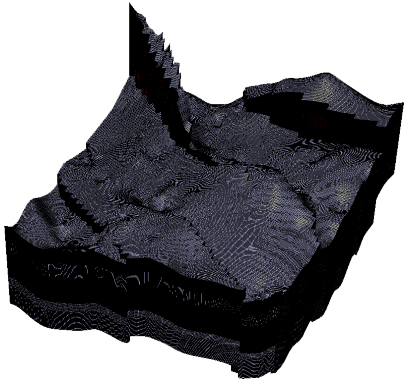




1.3 Problematic

- Resolution → 240x295x197
- Binary quantity → 580.94 MB

Dynamic data considerably increases data size



- Transmission & storage
- Visualization
- Simulation

Does a suitable method exist to help all three?

72 hours to compute simulation on this model using scientific laptop

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- Resolution → 128x128x32
- Binary quantity

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- Transmission & storage
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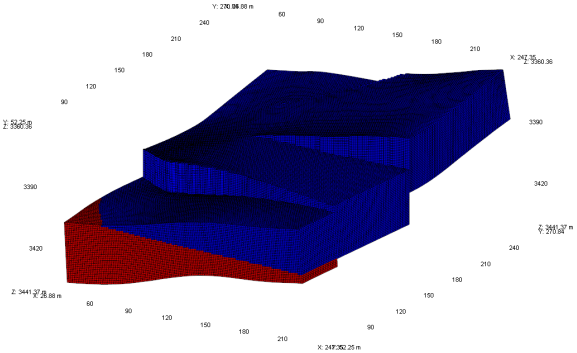

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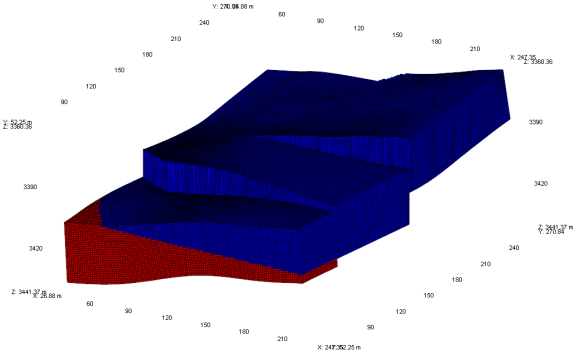


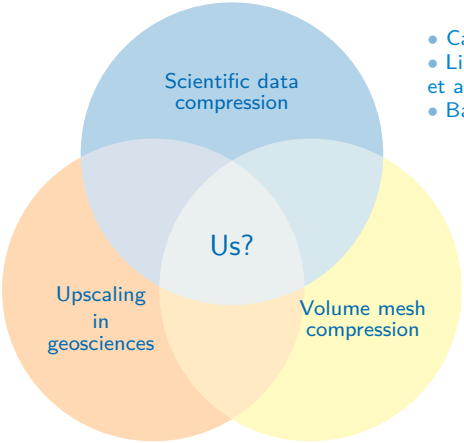
Does a suitable method exist to help all three?

72 hours to compute simulation on this model using scientific laptop

1.4 State of the art

- Cappello et al. (2019)
- Lindstrom (2014); Lindstrom et al. (2016)
- Baker et al. (2019)

- Durlofsky and Chen (2012)
- Li and Beckner (2000)
- Qi and Zhang (2009)



- Isenburg and Alliez (2003)
- Krivograd et al. (2008)
- Lindstrom and Isenburg (2008)

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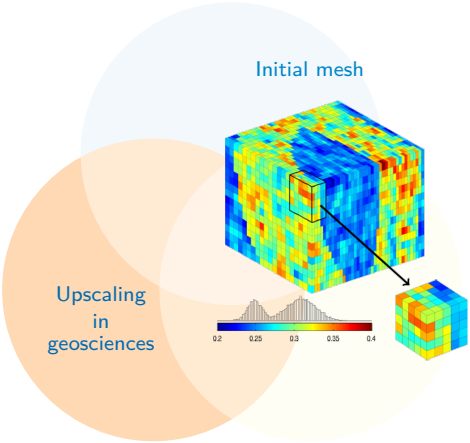

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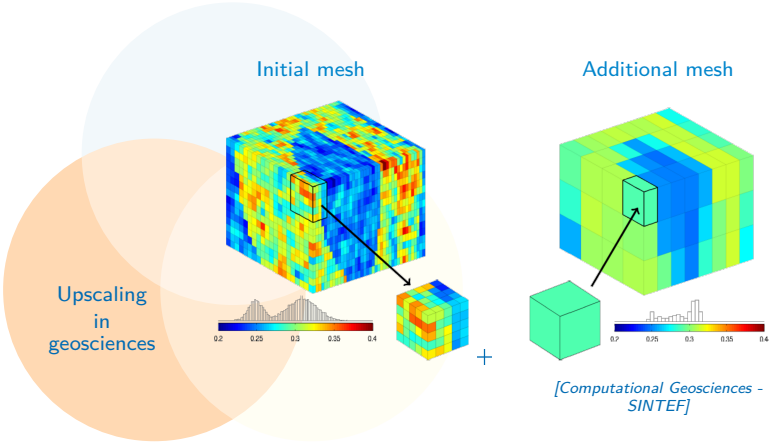

[Computational Geosciences - SINTEF]

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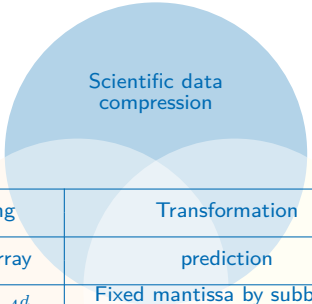
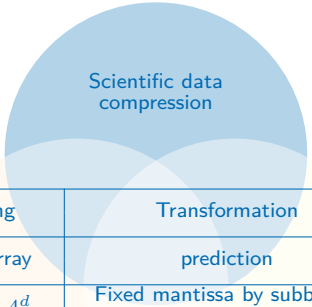


- (1) Cappello et al. (2019)
- (2) Lindstrom (2014); Lindstrom et al. (2016)
- Baker et al. (2019)

	Preprocess	Blocking	Transformation	Quantization	Encoding
$\mathrm{SZ}^{(1)}$	float to int	flatten array	prediction	uniform	Huffman
$\mathrm{ZFP}^{(2)}$		subblock 4^d	Fixed mantissa by subblock, DCT	Zerotree	

Generate the data at refinable precision

1.4 State of the art



- (1) Cappello et al. (2019)
- (2) Lindstrom (2014); Lindstrom et al. (2016)
- Baker et al. (2019)
- (3) Peyrot et al. (2019)

	Preprocess	Blocking	Transformation	Quantization	Encoding
SZ(1)	float to int	flatten array	prediction	uniform	Huffman
ZFP(2)		subblock 4^d	Fixed mantissa by subblock, DCT	Zerotree	

Generate the data at refinable precision

HexaShrink(3)	float to int		Dyadic wavelet	Zerotree

Generates the data at refinable resolution & precision

1.4 State of the art

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Generate the data at refinable precision

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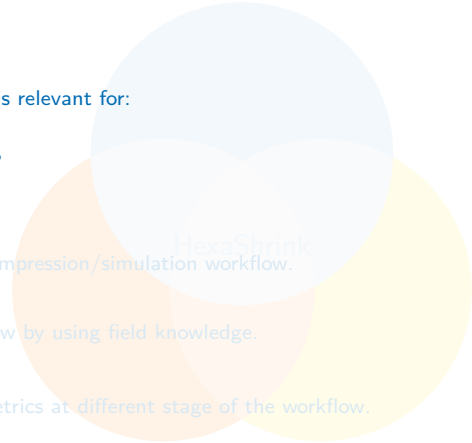
Generates the data at refinable resolution & precision

1.4 Our contributions

- Test if HexaShrink is relevant for:
  - Compression?
  - Visualization?
  - Simulation?



- Design complete compression/simulation workflow.
- Improve the workflow by using field knowledge.
- Develop suitable metrics at different stage of the workflow.

1.4 Our contributions

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1.4 Our contributions

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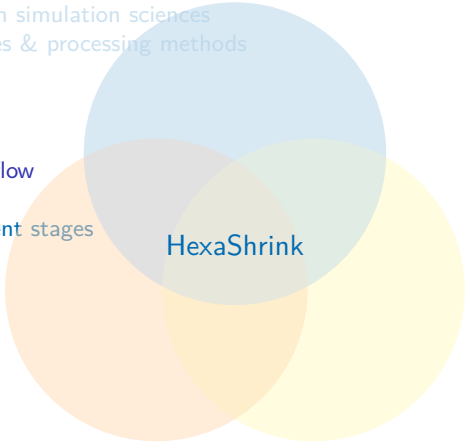
1. Introduction
   Context: Growing data in simulation sciences
   Geological volume meshes & processing methods
   Problematic
   State of the art

2. Presentation of our workflow
   Complete workflow
   Description of the different stages

3. Experimentations
   Coding
   Simulation
   Going further

4. Conclusion & perspectives



Is our method relevant for:

- Compression
- Visualization
- Simulation

... ?

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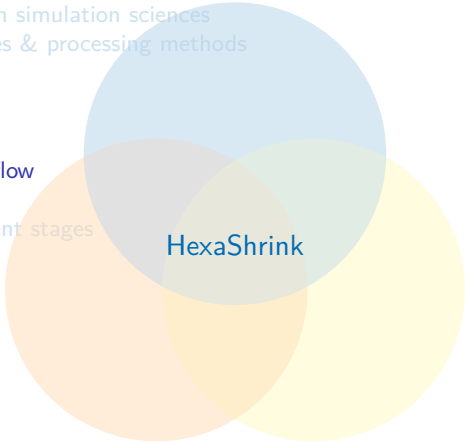

Is our method relevant for:

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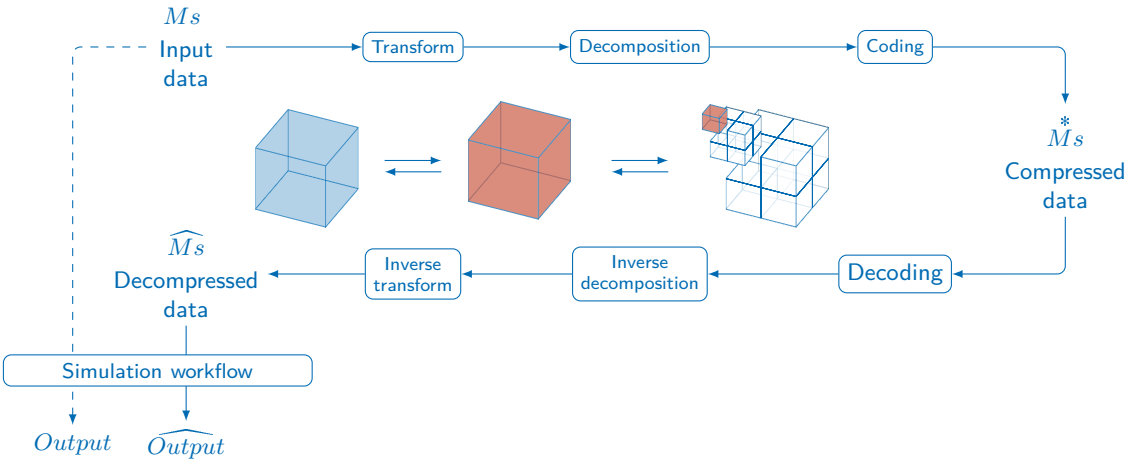
- Visualization
- Simulation

... ?

2.1 Complete workflow



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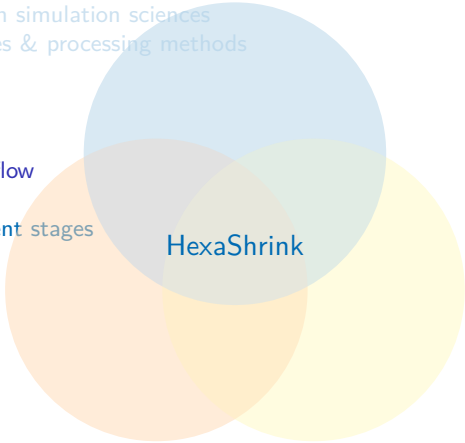

Is our method relevant for:

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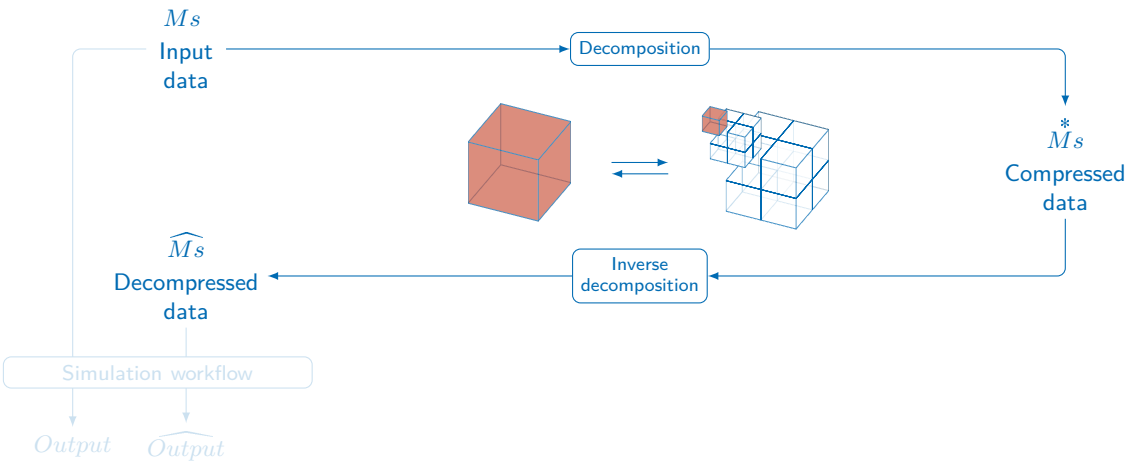
... ?

2.2 Decomposition step: HexaShrink (HS)

(Peyrot et al., 2019)



2.2 Decomposition step: HexaShrink (HS)

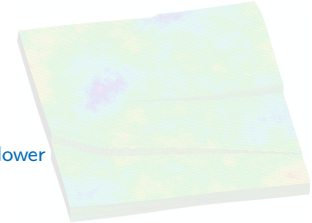
(Peyrot et al., 2019)

Structure		
Pillar extremities	Surface points	$2D$ morphological wavelet
Node altitudes	$1D$ data	Non linear $1D$ wavelet
Cell activity	$3D$ data (boolean)	
Properties	$3D$ data	$3D$ wavelet

Initial data

Our motivations:

- Structure & Faults preservation
- Properties coherency at lower resolutions.



Initial mesh

2.2 Decomposition step: HexaShrink (HS)

(Peyrot et al., 2019)

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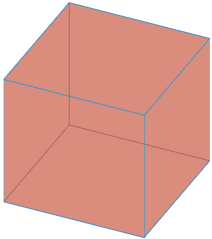
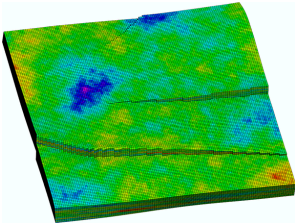
Initial data





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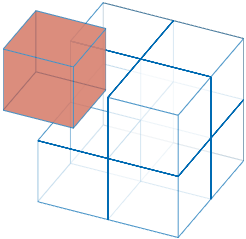
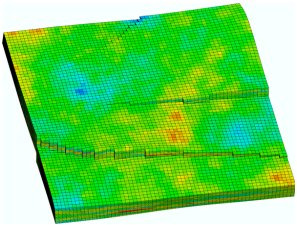
An.

D^{-1}





Generated from Analysis (An.) output

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Pillar extremities	Surface points	$2D$ morphological wavelet
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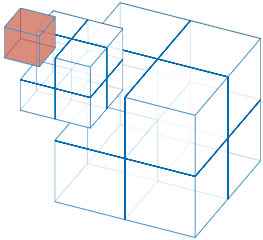
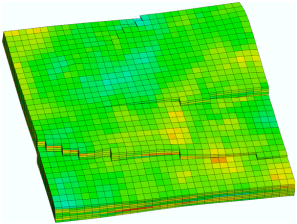
Properties	$3D$ data	$3D$ wavelet

An.

D^{-2}

D^{-1}





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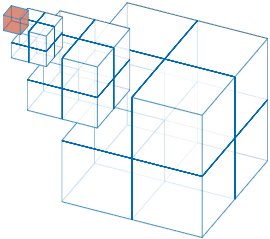
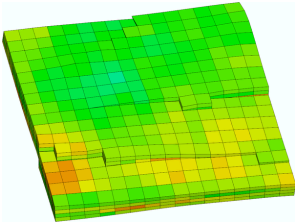
An.

D^{-3}

D^{-2}

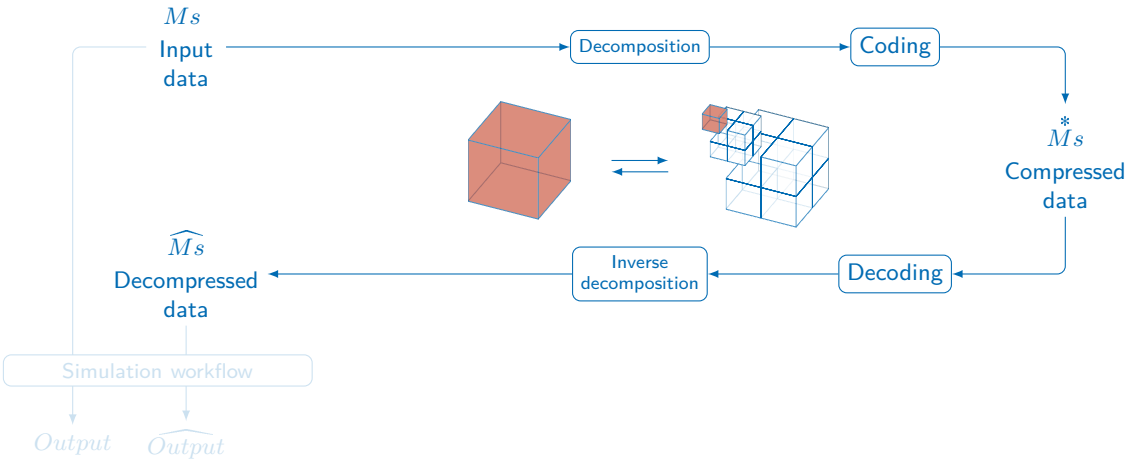
D^{-1}





Generated from Analysis (An.) output

2.2 Coding step



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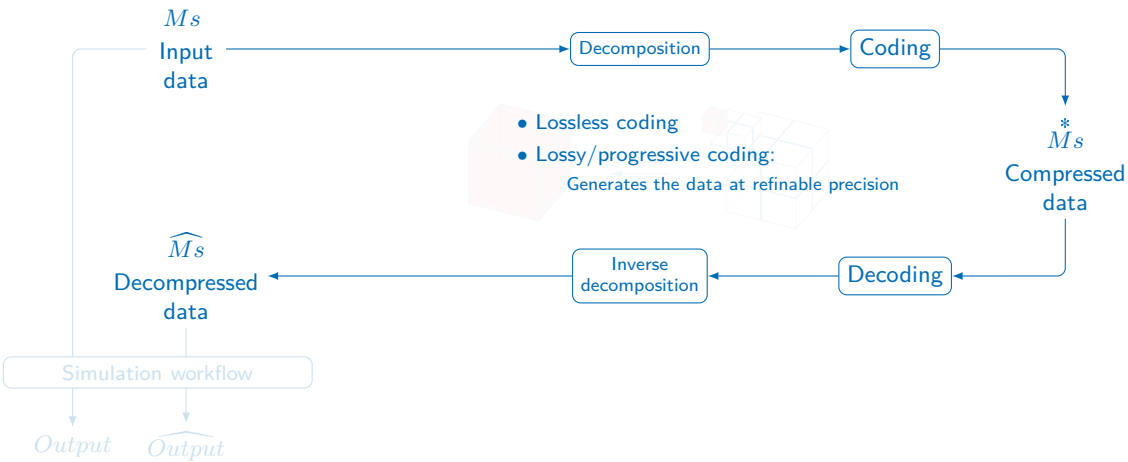
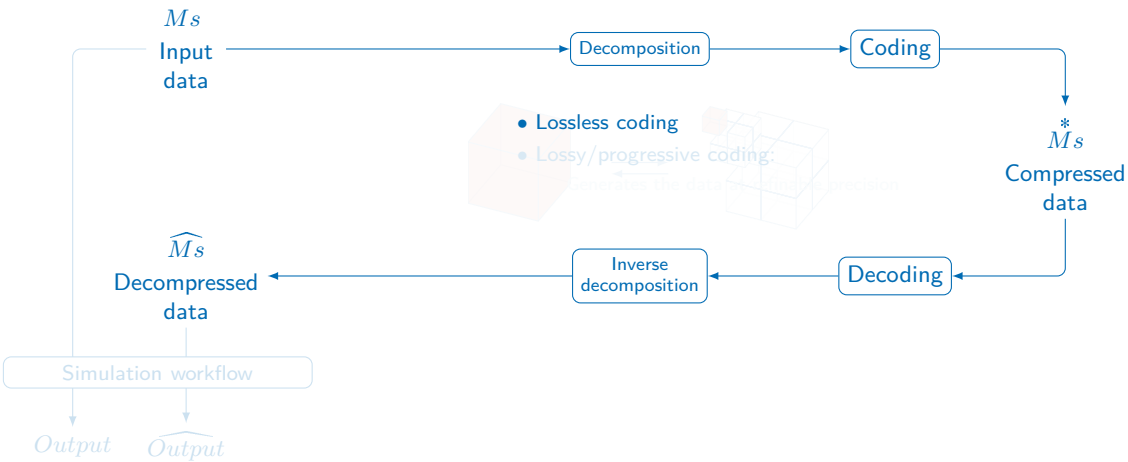


- Lossless coding
- Lossy/progressive coding:
  Generates the data at refinable precision

2.2 Coding step



- Lossless coding
- Lossy/progressive coding:

2.2 Lossless approach: principle

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

Original data

2.2 Lossless approach: principle

Res. 0

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
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15	12	7	8	4	7	5	20
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10	15	8	11	4	5	22	15
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10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4	13	21	28	-1	-9	-2	-4
5	22	22	16	-5	2	1	-1
10	6	12	18	-1	-2	2	8
14	10	6	15	-1	2	-1	-16
-2	-6	3	3	-5	9	-6	-1
-6	1	3	3	5	7	2	0
-6	-7	16	-2	8	2	5	1
-2	-6	0	-5	7	-5	-4	1

1 decomposition level

2.2 Lossless approach: principle

Res. 0

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

4	13	21	28	-1	-9	-2	-4
5	22	22	16	-5	2	1	-1
10	6	12	18	-1	-2	2	8
14	10	6	15	-1	2	-1	-16
-2	-6	3	3	-5	9	-6	-1
-6	1	3	3	5	7	2	0
-6	-7	16	-2	8	2	5	1
-2	-6	0	-5	7	-5	-4	1

1 decomposition level

2.2 Lossless approach: principle

Res. 0

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8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

11	22	-13	-1	-1	-9	-2	-4
10	13	4	-7	-5	2	1	-1
-5	6	9	-12	-1	-2	2	8
-5	5	-1	4	-1	2	-1	-16
-2	-6	3	3	-5	9	-6	-1
-6	1	3	3	5	7	2	0
-6	-7	16	-2	8	2	5	1
-2	-6	0	-5	7	-5	-4	1

2 decomposition levels

2.2 Lossless approach: principle

Res. 0

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

11	22	-13	-1	-1	-9	-2	-4
10	13	4	-7	-5	2	1	-1
-5	6	9	-12	-1	-2	2	8
-5	5	-1	4	-1	2	-1	-16
-2	-6	3	3	-5	9	-6	-1
-6	1	3	3	5	7	2	0
-6	-7	16	-2	8	2	5	1
-2	-6	0	-5	7	-5	-4	1

2 decomposition levels

2.2 Lossless approach: principle

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2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

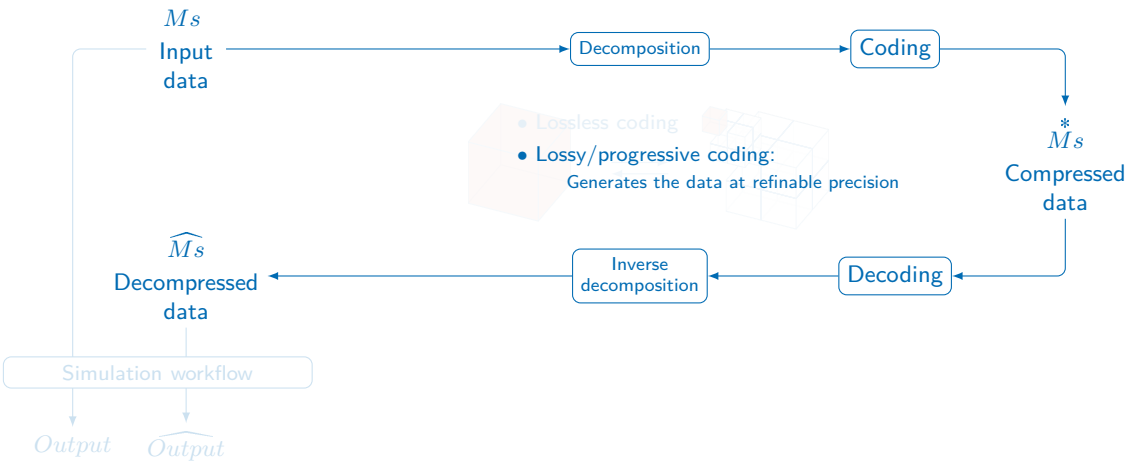
11	22
10	13

11	22	-13	-1	-1	-9	-2	-4
10	13	4	-7	-5	2	1	-1
-5	6	9	-12	-1	-2	2	8
-5	5	-1	4	-1	2	-1	-16
-2	-6	3	3	-5	9	-6	-1
-6	1	3	3	5	7	2	0
-6	-7	16	-2	8	2	5	1
-2	-6	0	-5	7	-5	-4	1

2 decomposition levels

Subbands coding
with generic lossless methods

2.2 Coding step



- Lossless coding
- Lossy/progressive coding:
  Generates the data at refinable precision

2.2 Lossy/progressive approach

5 MSB_Z

Res. 0

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

11	22	-13	-1	-1	-9	-2	-4
10	13	4	-7	-5	2	1	-1
-5	6	9	-12	-1	-2	2	8
-5	5	-1	4	-1	2	-1	-16
-2	-6	3	3	-5	9	-6	-1
-6	1	3	3	5	7	2	0
-6	-7	16	-2	8	2	5	1
-2	-6	0	-5	7	-5	-4	1

		11
Most Significant Bit	4	0
	3	1
5 MSB_Z	2	0
	1	1
Least Significant Bit	0	1

2.2 Lossy/progressive approach

5 MSB_Z

Res. 0

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

10	22	-12	0	0	-8	-2	-4
10	12	4	-6	-4	2	0	0
-4	6	8	-12	0	-2	2	8
-4	4	0	4	0	2	0	-16
-2	-6	2	2	-4	8	-6	0
-6	0	2	2	4	6	2	0
-6	-6	16	-2	8	2	4	0
-2	-6	0	-4	6	-4	-4	0

Most Significant Bit 4

3

4 MSB_Z 2

1

Least Significant Bit 0

10
0
1
0
1
1

2.2 Lossy/progressive approach

Res. 0

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

10	22	-12	0	0	-8	-2	-4
10	12	4	-6	-4	2	0	0
-4	6	8	-12	0	-2	2	8
-4	4	0	4	0	2	0	-16
-2	-6	2	2	-4	8	-6	0
-6	0	2	2	4	6	2	0
-6	-6	16	-2	8	2	4	0
-2	-6	0	-4	6	-4	-4	0

Most Significant Bit 4

3

4 MSB_Z 2

1

Least Significant Bit 0

10
0
1
0
1
1

2.2 Lossy/progressive approach

Res. 0

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

8	20	-12	0	0	-8	0	-4
8	12	4	-4	-4	0	0	0
-4	4	8	-12	0	0	0	8
-4	4	0	4	0	0	0	-16
0	-4	0	0	-4	8	-4	0
-4	0	0	0	4	4	0	0
-4	-4	16	0	8	0	4	0
0	-4	0	-4	4	-4	-4	0

Most Significant Bit 4

3 MSB_Z 3

2

1

Least Significant Bit 0

8
0
1
0
1
1

2.2 Lossy/progressive approach

Res. 0

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

8	20	-12	0	0	-8	0	-4
8	12	4	-4	-4	0	0	0
-4	4	8	-12	0	0	0	8
-4	4	0	4	0	0	0	-16
0	-4	0	0	-4	8	-4	0
-4	0	0	0	4	4	0	0
-4	-4	16	0	8	0	4	0
0	-4	0	-4	4	-4	-4	0

Most Significant Bit 4

3 MSB_Z 3

2

1

Least Significant Bit 0

8
0
1
0
1
1

2.2 Lossy/progressive approach

Res. 0

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

8	16	-8	0	0	-8	0	0
8	8	0	0	0	0	0	0
0	0	8	-8	0	0	0	8
0	0	0	0	0	0	0	-16
0	0	0	0	0	8	0	0
0	0	0	0	0	0	0	0
0	0	16	0	8	0	0	0
0	0	0	0	0	0	0	0

Most Significant Bit 4

3

2 MSB_Z 2

1

Least Significant Bit 0

8
0
1
0
1
1

2.2 Lossy/progressive approach

Res. 0

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

8	16	-8	0	0	-8	0	0
8	8	0	0	0	0	0	0
0	0	8	-8	0	0	0	8
0	0	0	0	0	0	0	-16
0	0	0	0	0	8	0	0
0	0	0	0	0	0	0	0
0	0	16	0	8	0	0	0
0	0	0	0	0	0	0	0

Most Significant Bit 4

3

2 MSB_Z

1

Least Significant Bit 0

8
0
1
0
1
1

2.2 Lossy/progressive approach

Res. 0

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

Sig	Sig	Sig	0	0	Sig	0	0
Sig	Sig	0	0	0	0	0	0
0	0	Sig	Sig	0	0	0	Sig
0	0	0	0	0	0	0	Sig
0	0	0	0	0	Sig	0	0
0	0	0	0	0	0	0	0
0	0	Sig	0	0	0	0	0
0	0	0	0	0	0	0	0

Progressive coding - Zerotree:

- EZW (Shapiro, 1993)
- SPIHT (Said and Pearlman, 1996)

2.2 Lossy/progressive approach

Res. 0

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

Sig	Sig	Sig		0	Sig		
Sig	Sig		0	0	0		
		Sig	Sig			0	Sig
	0	0				0	Sig
				0	Sig	0	0
				0	0	0	0
		Sig	0	0	0		
		0	0	0	0		

Progressive coding - Zerotree:

- EZW (Shapiro, 1993)
- SPIHT (Said and Pearlman, 1996)

2.2 Lossy/progressive approach

Res. 0

5 MSB$_Z$

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB$_Z$

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB$_Z$

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB$_Z$

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

Res. -1

4	13	21	28
5	22	22	16
10	6	12	18
14	10	6	15

Res. -2

11	22
10	13

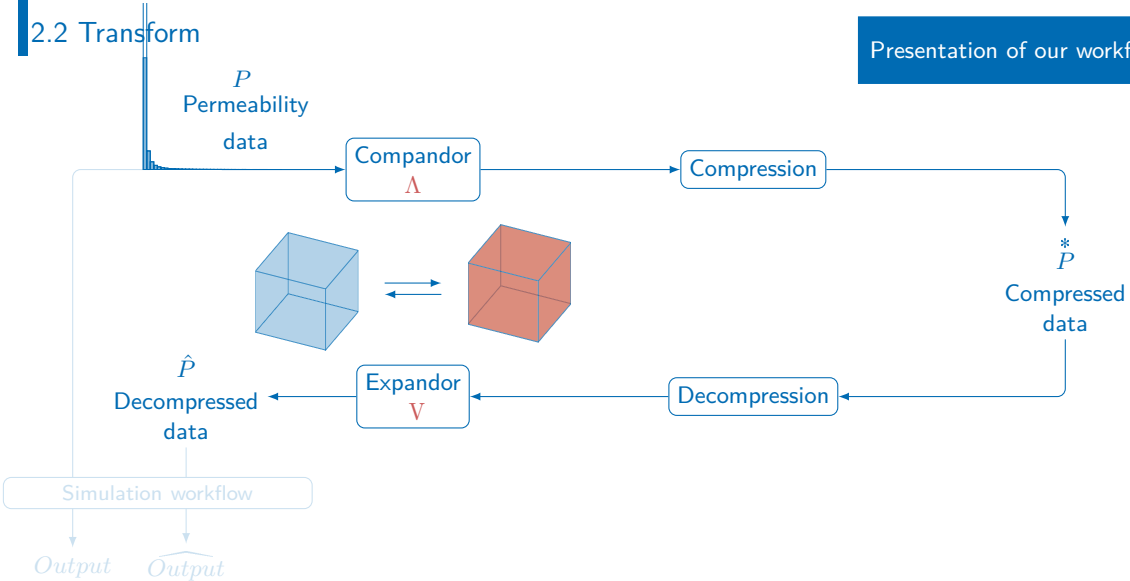
Sig	Sig	Sig	Ztr	0	Sig		
Sig	Sig	Ztr	0	0	0		
Ztr	Ztr	Sig	Sig			0	Sig
Ztr	0	0	Ztr			0	Sig
				0	Sig	0	0
				0	0	0	0
		Sig	0	0	0		
		0	0	0	0		

Progressive coding - Zerotree:

- EZW (Shapiro, 1993)
- SPIHT (Said and Pearlman, 1996)

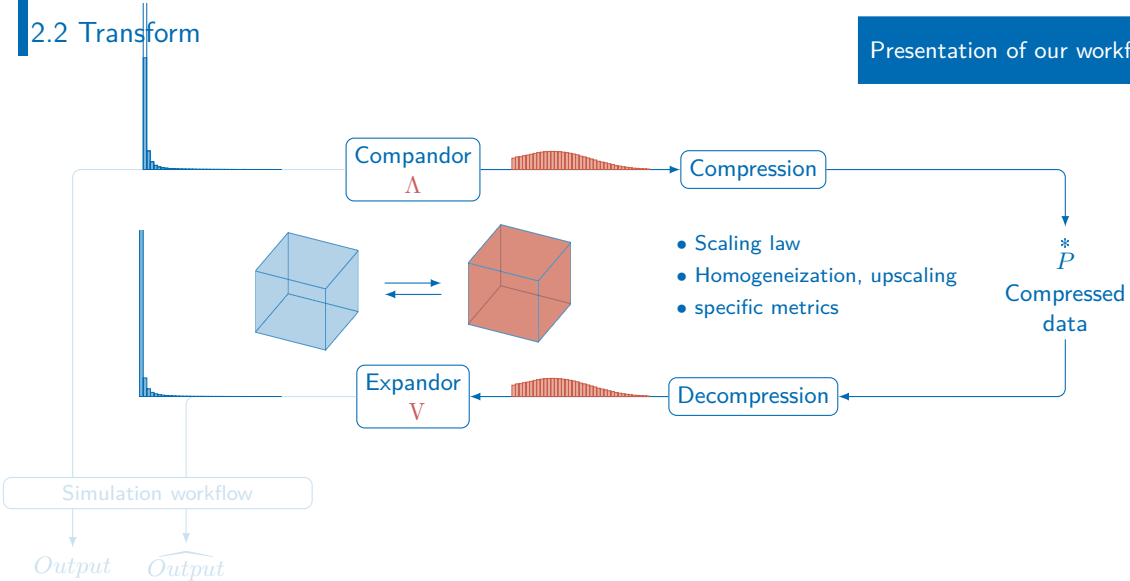
2.2 Transform

Presentation of our workflow



2.2 Transform

Presentation of our workflow



- Scaling law
- Homogeneization, upscaling
- specific metrics

2.2 Transform

Compandor

$$\Lambda_{nbits}(P) = round\left(\frac{\lambda(P) - \lambda(\min P)}{\lambda(\max P) - \lambda(\min P)} \times (2^{nbits} - 1)\right),$$

$$with \quad \lambda(P) = \log(P + 1),$$

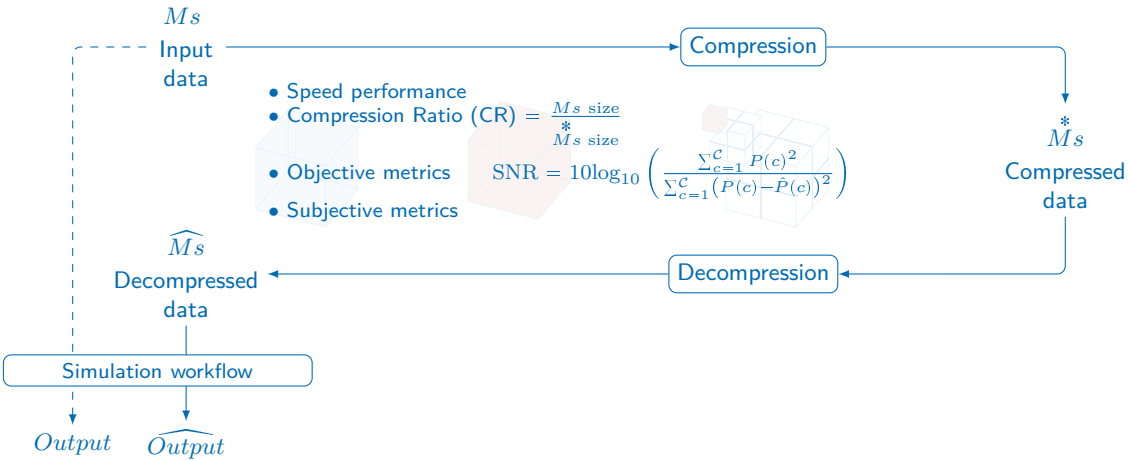
Expandor

$$\hat{P} = \mathrm{V}_{nbits}(\Lambda_{nbits}(P)) = \Upsilon\left(\frac{\Lambda_{nbits}(P)}{(2^{nbits} - 1)} \times (\lambda(\max P) - \lambda(\min P)) + \lambda(\min P)\right),$$

$$with \quad \Upsilon(P) = \exp(P) - 1.$$

$Output$ $\widehat{Output}$

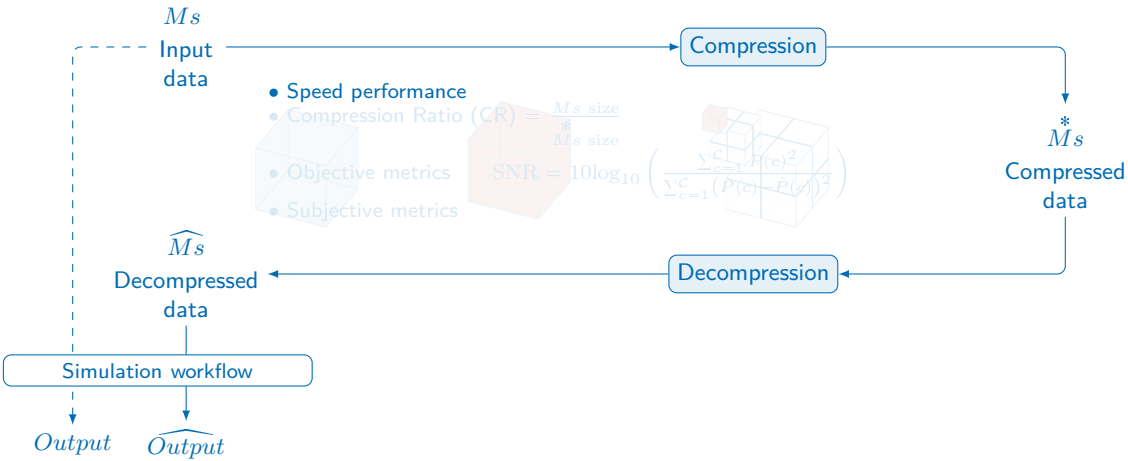
2.2 Evaluation criteria



- Speed performance
- Compression Ratio (CR) $= \frac{Ms \text{ size}}{\overset{*}{Ms} \text{ size}}$
- Objective metrics
- Subjective metrics

$$\mathrm{SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{\mathcal{C}} P(c)^2}{\sum_{c=1}^{\mathcal{C}} \left(P(c)-\hat{P}(c)\right)^2}\right)$$

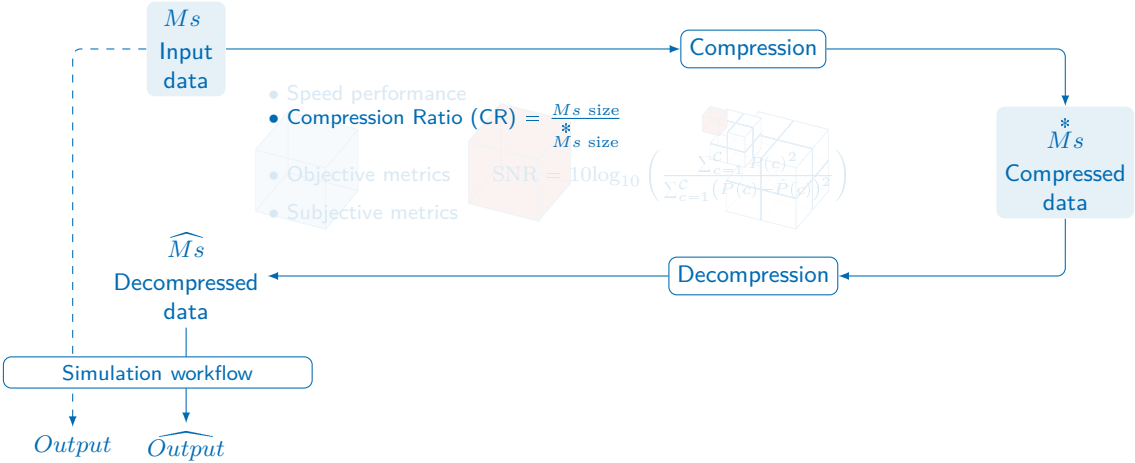
2.2 Evaluation criteria



- Speed performance
- Compression Ratio (CR) $= \frac{Ms \text{ size}}{\overset{*}{Ms} \text{ size}}$
- Objective metrics
- Subjective metrics

$$\mathrm{SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{C} P(c)^2}{\sum_{c=1}^{C} \left(\widehat{P}(c) - P(c)\right)^2}\right)$$

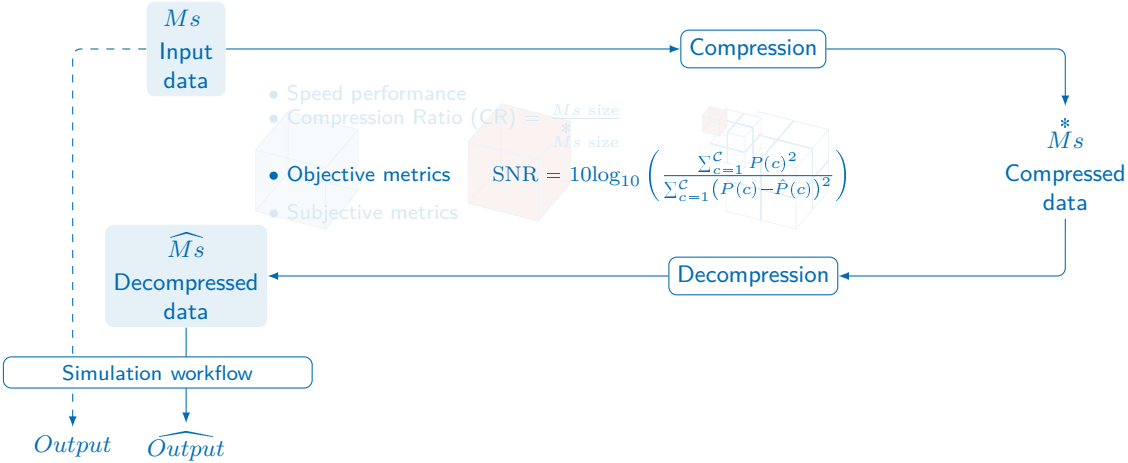
2.2 Evaluation criteria



- Speed performance
- Compression Ratio (CR) $= \frac{Ms \text{ size}}{\overset{*}{Ms} \text{ size}}$
- Objective metrics
- Subjective metrics

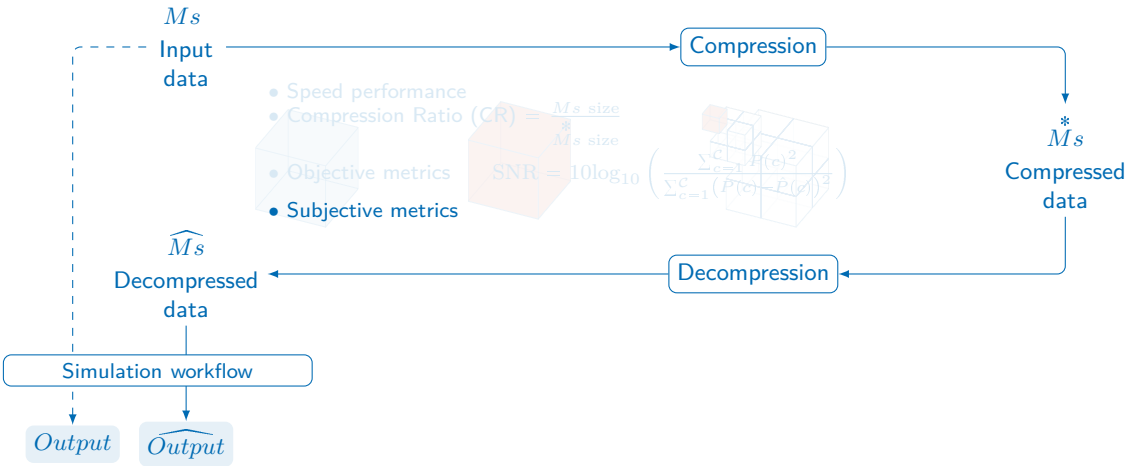
$$\mathrm{SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{C} P(c)^2}{\sum_{c=1}^{C}\left(\overset{*}{P}(c) - P(c)\right)^2}\right)$$

2.2 Evaluation criteria



- Speed performance
- Compression Ratio (CR) $= \frac{Ms \text{ size}}{\overset{*}{Ms} \text{ size}}$
- Objective metrics $\quad \mathrm{SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{\mathcal{C}} P(c)^2}{\sum_{c=1}^{\mathcal{C}} \left(P(c)-\hat{P}(c)\right)^2}\right)$
- Subjective metrics

2.2 Evaluation criteria

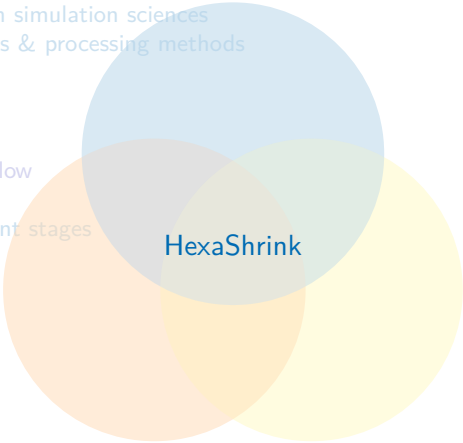


1. Introduction
   Context: Growing data in simulation sciences
   Geological volume meshes & processing methods
   Problematic
   State of the art

2. Presentation of our workflow
   Complete workflow
   Description of the different stages

3. Experimentations
   Coding
   Simulation
   Going further

4. Conclusion & perspectives



Is our method relevant for:

- Compression
- Visualization
- Simulation

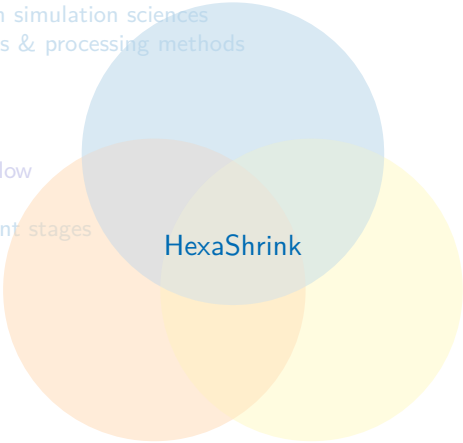
... ?

1. Introduction
   Context: Growing data in simulation sciences
   Geological volume meshes & processing methods
   Problematic
   State of the art

2. Presentation of our workflow
   Complete workflow
   Description of the different stages

3. Experimentations
   Coding
   Simulation
   Going further

4. Conclusion & perspectives

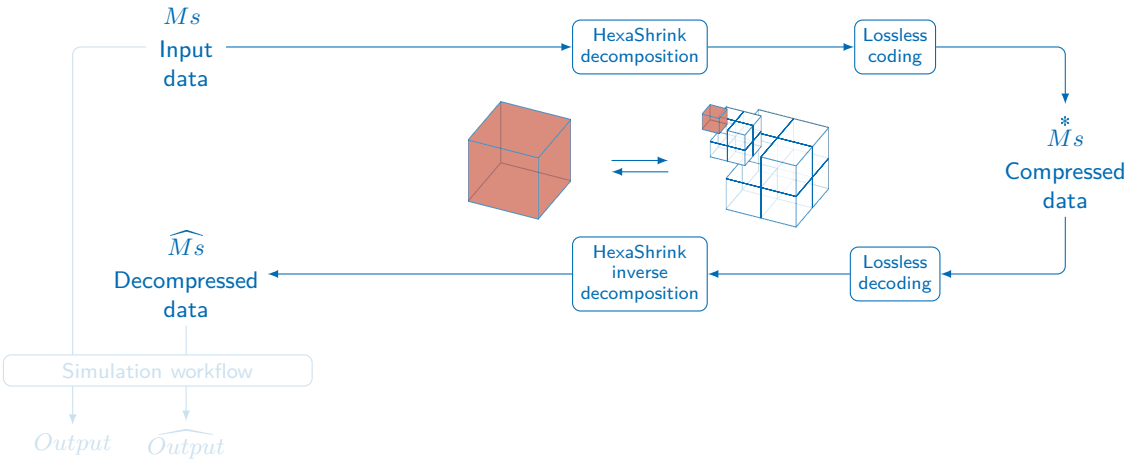


Is our method relevant for:

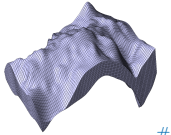
- Compression
- Visualization
- Simulation

... ?

3.1 Lossless approach

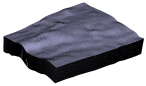


3.1 Our benchmark



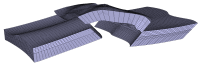
#1

~~faults~~
93,600 cells
4.62 MB



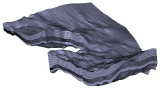
#2

~~faults~~
1,000,000 cells
42.46 MB



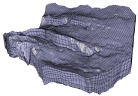
#3

faults
36,816 cells
1.46 MB



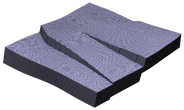
#4

faults
210,000 cells
7.88 MB



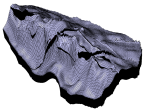
#5

faults
450,576 cells
22.73 MB



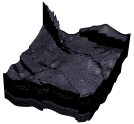
#6

faults
524,288 cells
64.27 MB



#7

faults
6,577,325 cells
274.57 MB



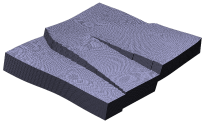
#8

faults
13,947,600 cells
580.94 MB

3.1 Lossless approach: compression performance

(Bouard et al., 2018)

On mesh#6



Features		Compression ratio			
Faults	File Size	Level	gzip (1992)	bzip2 (1996)	LZMA (1998)
Yes	64.27 MB	none	1.88	2.25	3.04
		1	2.70	3.17	3.71
		2–6	2.84–2.86	3.39–3.42	3.90–3.93

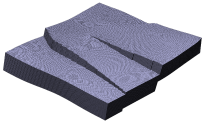
Observations:

- Lossless coders provide good performance
- HexaShrink improves further compression rate
- Less significant improvements above two levels

3.1 Lossless approach: compression performance

(Bouard et al., 2018)

On mesh#6



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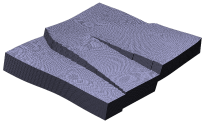

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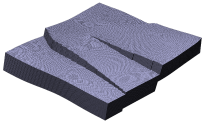

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- HexaShrink improves further compression rate
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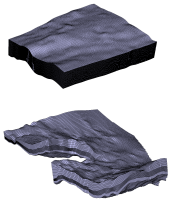
3.1 Lossless approach: compression performance

(Bouard et al., 2018)

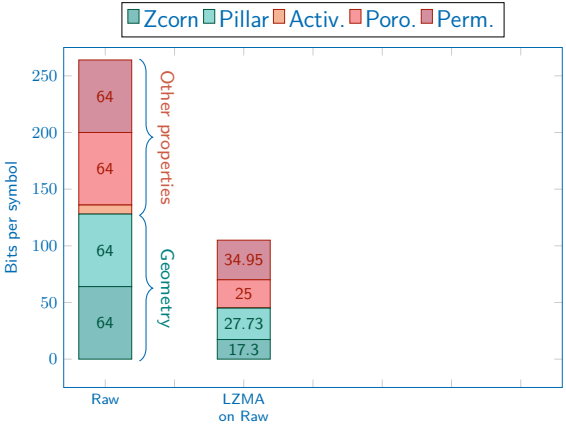
On all meshes

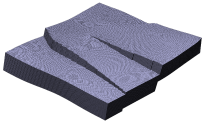


Mesh	Features		Compression ratio			
	Faults	File Size	Level	gzip (1992)	bzip2 (1996)	LZMA (1998)
1	No	4.62 MB	none	3.73	4.98	6.43
			1	5.62	6.07	7.52
			2–4	5.67	6.12–6.13	7.42–7.44
2	No	42.46 MB	none	3.23	8.41	10.12
			1	6.49	10.82	11.81
			2–6	7.48–7.58	12.75–13.03	13.35
3	Yes	1.46 MB	none	2.67	2.99	3.63
			1	3.88	4.70	5.24
			2–4	4.03–4.05	4.92–4.93	5.47–5.48
4	Yes	7.88 MB	none	1.83	1.89	2.21
			1	2.64	3.06	3.48
			2–4	2.76	3.22–3.23	3.64–3.65
5	Yes	22.73 MB	none	2.46	2.55	3.33
			1	3.14	2.83	3.71
			2–4	3.25–3.26	2.91–2.92	3.80–3.81
6	Yes	64.27 MB	none	1.88	2.25	3.04
			1	2.70	3.17	3.71
			2–6	2.84–2.86	3.39–3.42	3.90–3.93
7	Yes	274.57 MB	none	2.31	2.25	3.04
			1	3.31	3.53	4.44
			2–6	4.14–4.24	4.48–4.68	5.54–5.73
8	Yes	580.94 MB	none	3.20	5.98	12.52
			1	5.42	7.07	8.90
			2–7	5.80–6.72	7.63–10.12	9.05–10.23

3.1 Lossless approach: compression performance

In-depth analysis for *LZMA* (Bouard et al., 2018)





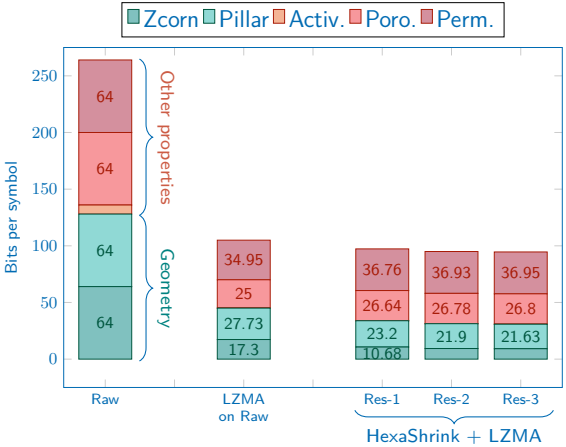
LZMA efficiency on all components

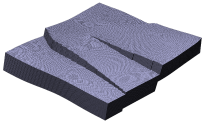
With Hexashrink decomposition:

- Geometry
  - Method efficiency
- Other properties

3.1 Lossless approach: compression performance

In-depth analysis for *LZMA* (Bouard et al., 2018)





LZMA efficiency on all components

With Hexashrink decomposition:

- Geometry
  - Method efficiency
- Other properties
  - Limits

3.1 Lossless approach: compression performance

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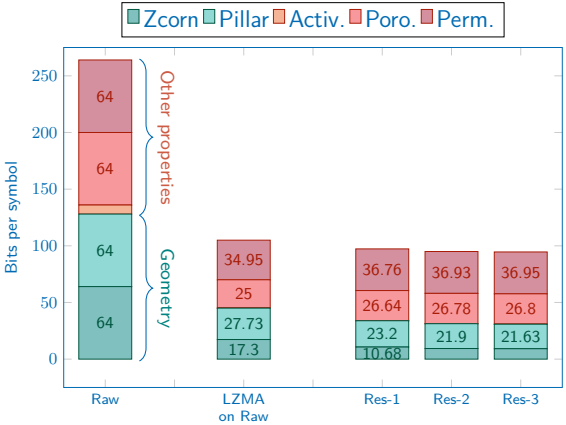
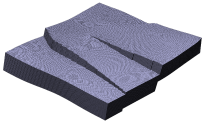




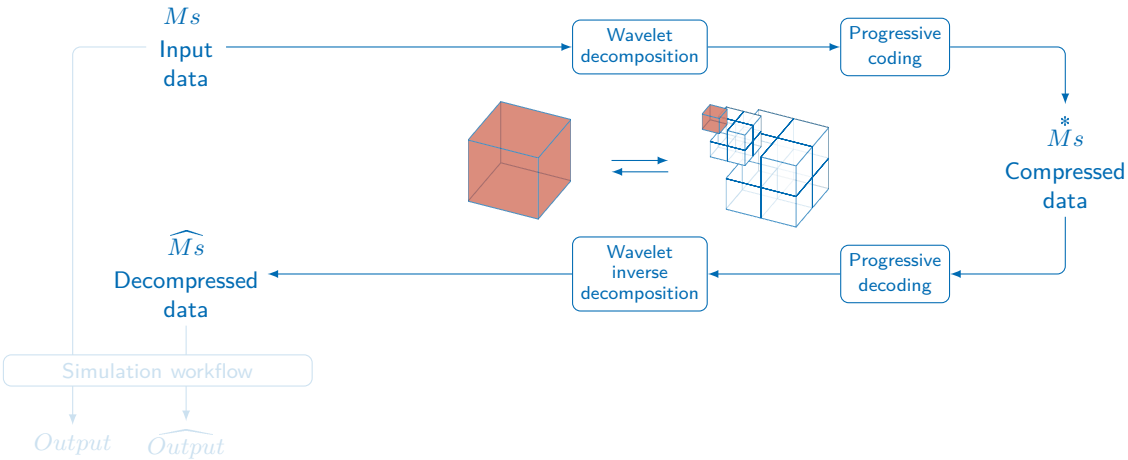
LZMA efficiency on all components

With Hexashrink decomposition:

- Geometry
- Other properties

Go toward refinable precision...

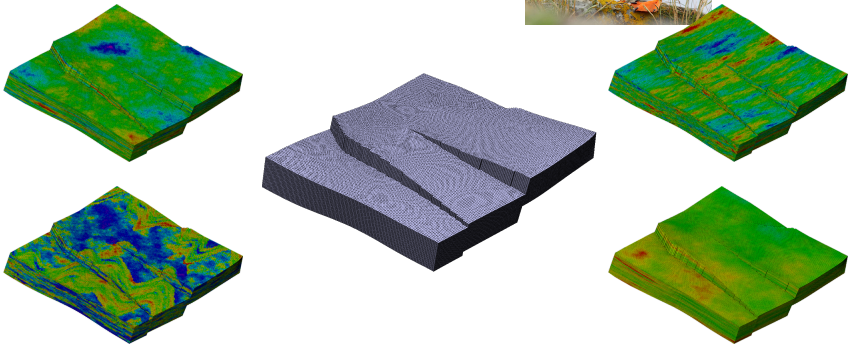
3.1 Lossy/progressive approach



3.1 Lossy/progressive approach on Lundi

...on properties:

Four environnements,
inspired by SPE10 (Christie and Blunt, 2001)



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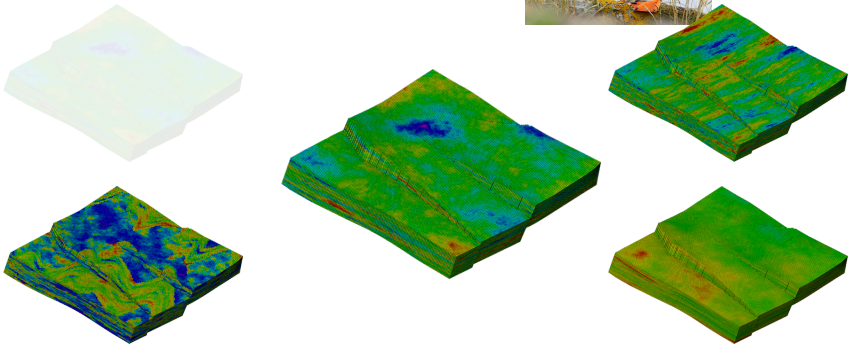
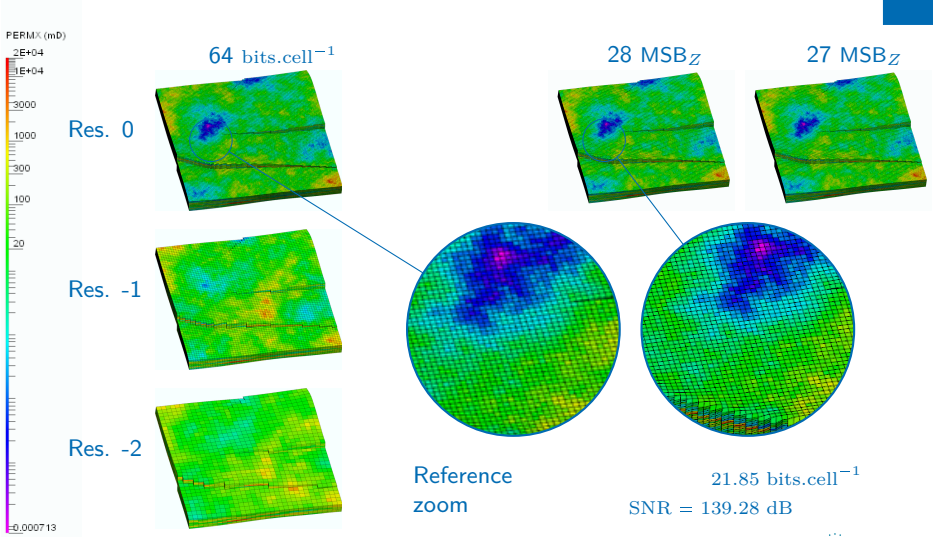


3.1 Lossy/progressive approach: visual results



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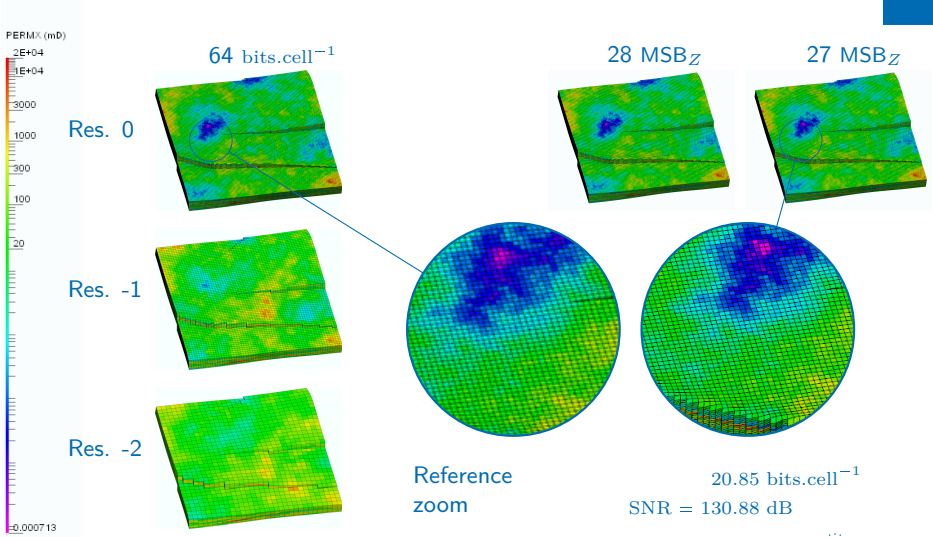

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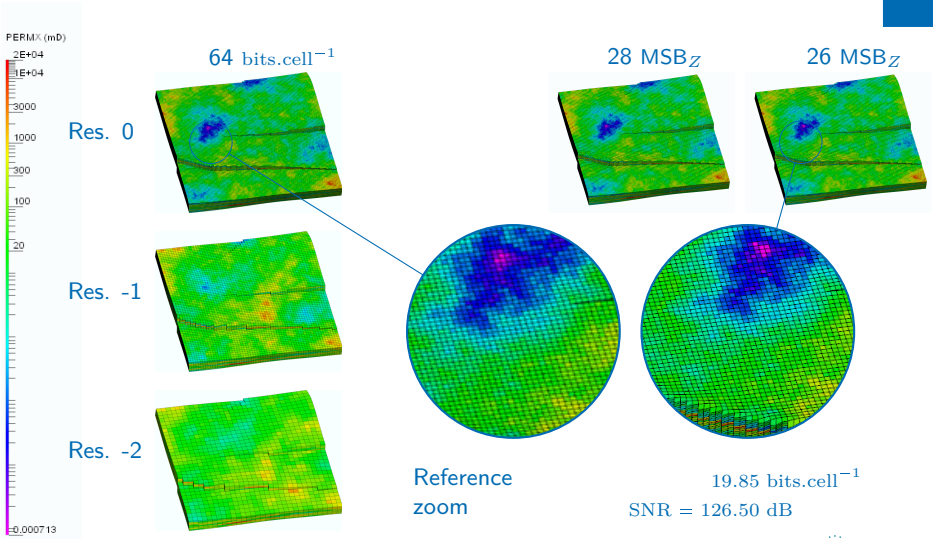

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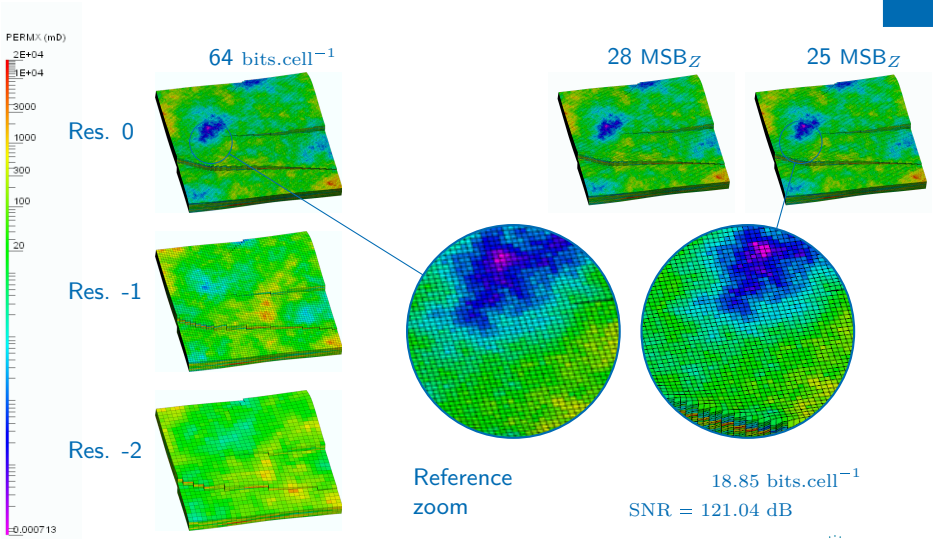

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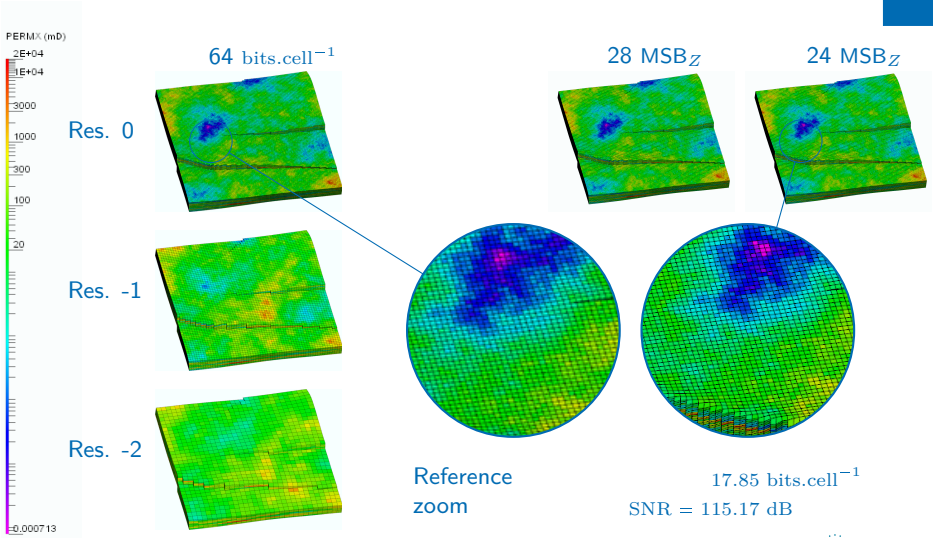

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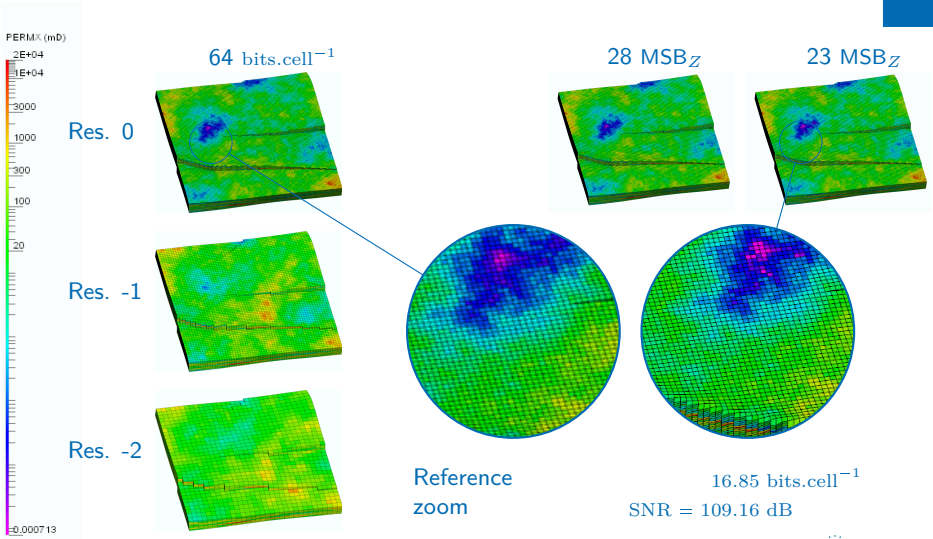

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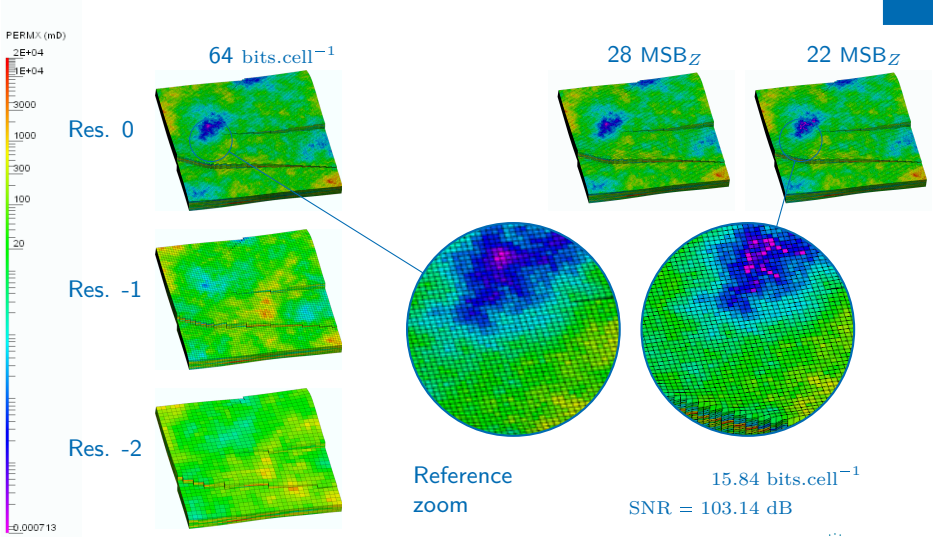

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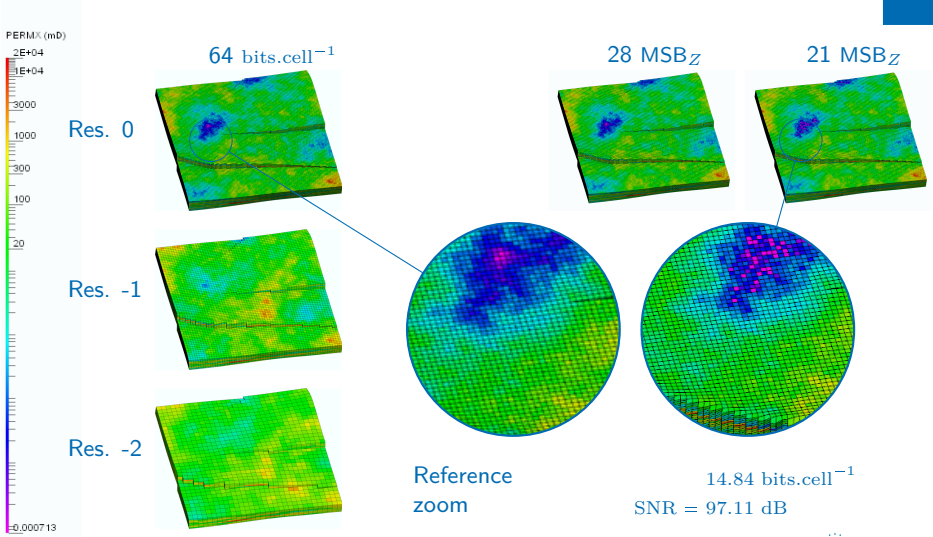

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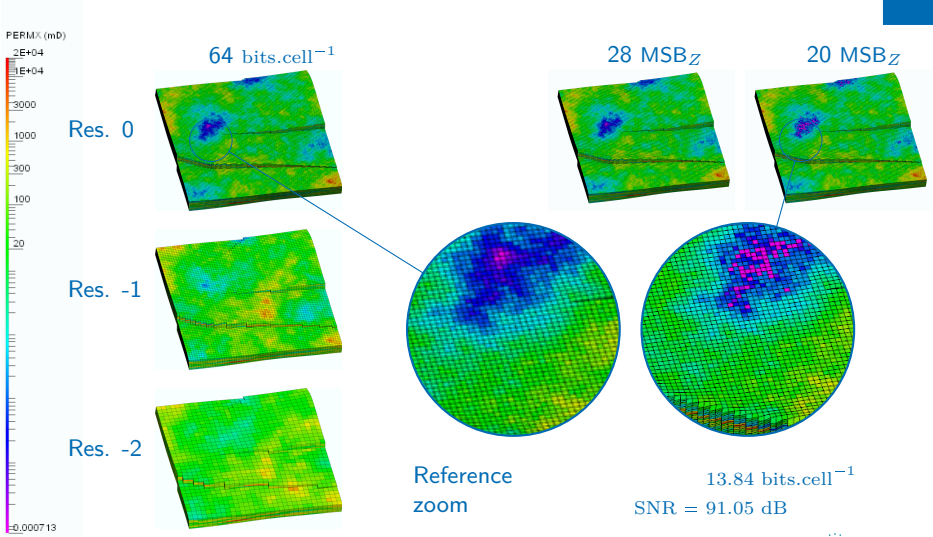

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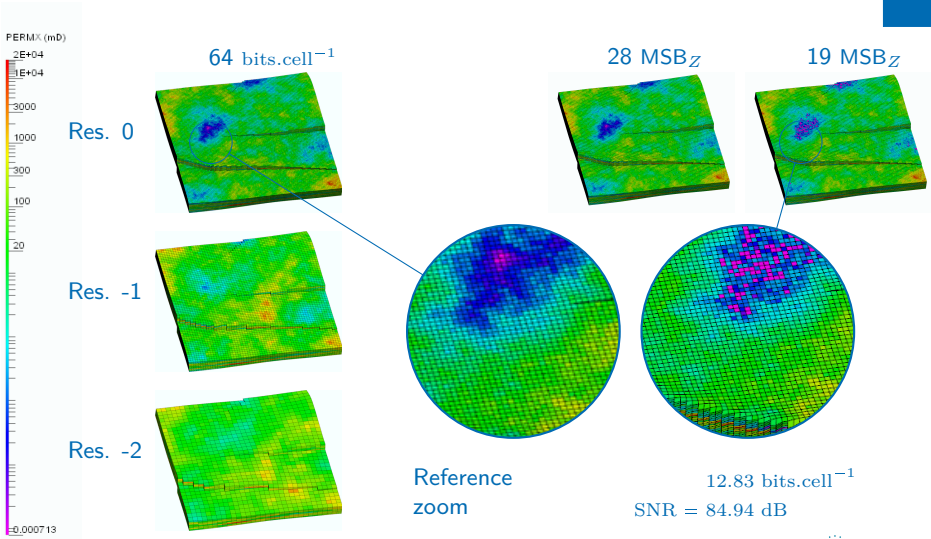
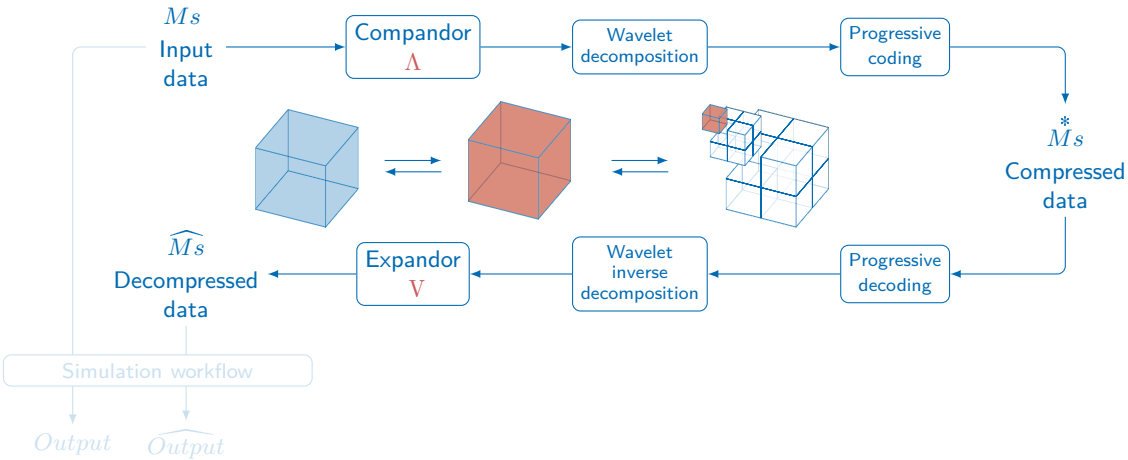


3.1 Compandor effect: visual results



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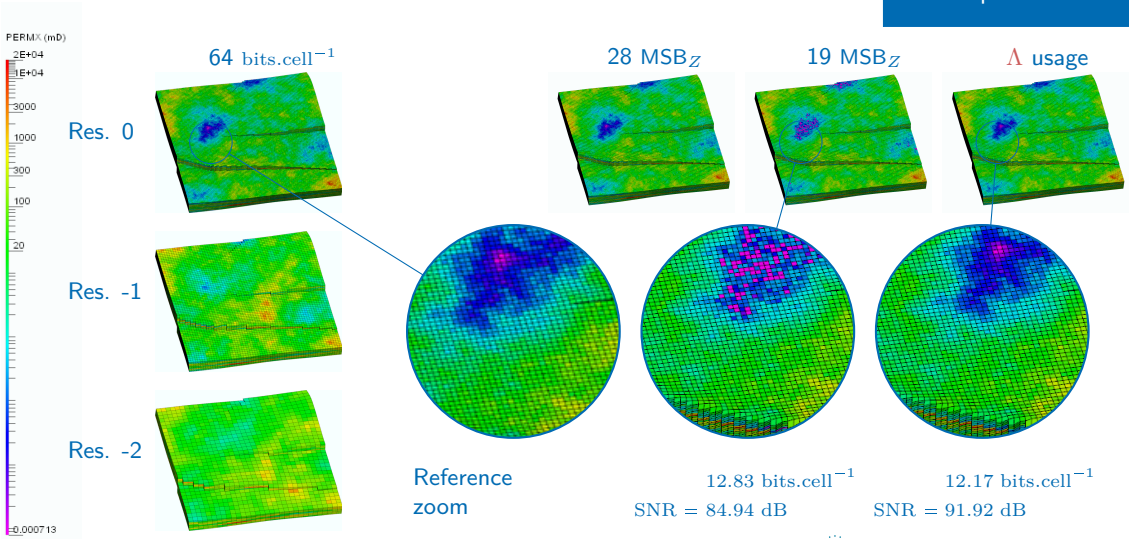
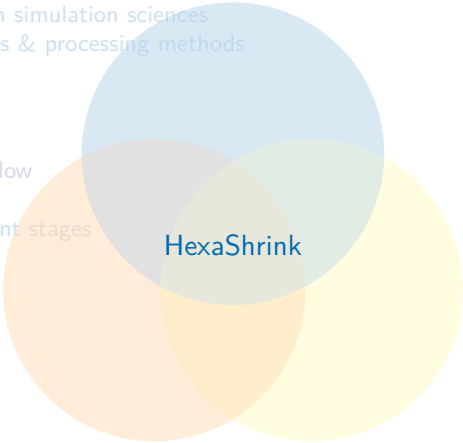


1. Introduction
   Context: Growing data in simulation sciences
   Geological volume meshes & processing methods
   Problematic
   State of the art

2. Presentation of our workflow
   Complete workflow
   Description of the different stages

3. Experimentations
   Coding
   Simulation
   Going further

4. Conclusion & perspectives



Is our method relevant for:

- ☑ Compression
- ☑ Visualization
- ☐ Simulation

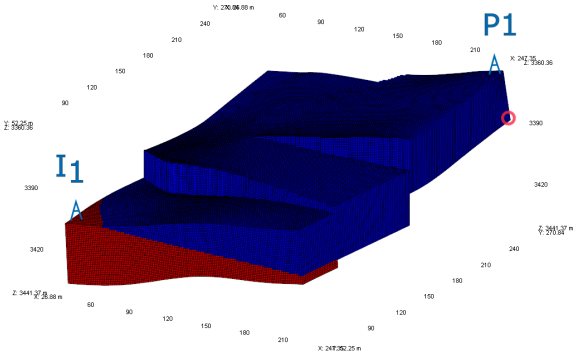
... ?

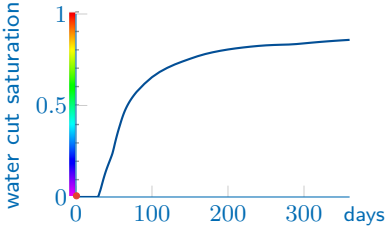
3.2 Simulation: principle & outcomes

$$\frac{\partial}{\partial t}(\phi\rho S_w) - \sum_{i=1}^{3}\frac{\partial}{\partial x_i}(K\frac{K_{rw}}{\mu_w}\rho_w\frac{\partial}{\partial x_i}(P_w - \rho w g Z)) + \rho_w Q_w = 0$$

Partial differential equations resolution,

$$\frac{\partial}{\partial t}(\phi\rho S_o) - \sum_{i=1}^{3}\frac{\partial}{\partial x_i}(K\frac{K_{ro}}{\mu_o}\rho_o\frac{\partial}{\partial x_i}(P_o - \rho o g Z)) + \rho_o Q_w = 0$$





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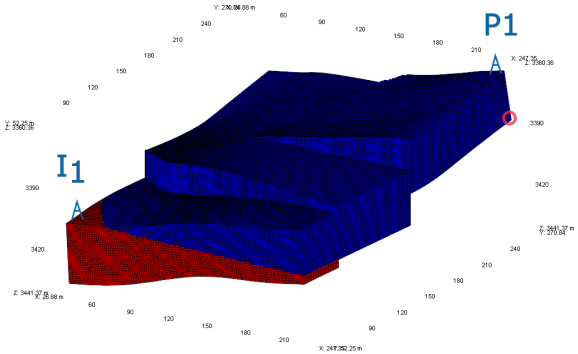
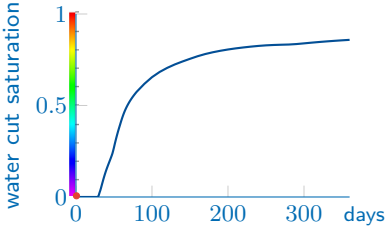
Partial differential equations resolution,

$$\frac{\partial}{\partial t}(\phi\rho S_o) - \sum_{i=1}^{3}\frac{\partial}{\partial x_i}(K\frac{K_{ro}}{\mu_o}\rho_o\frac{\partial}{\partial x_i}(P_o - \rho o g Z)) + \rho_o Q_w = 0$$





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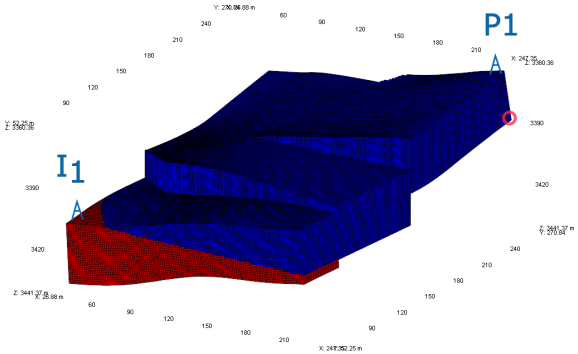
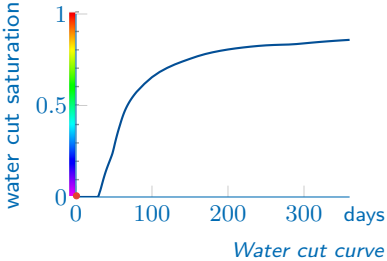
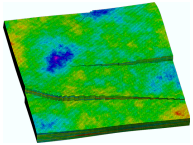
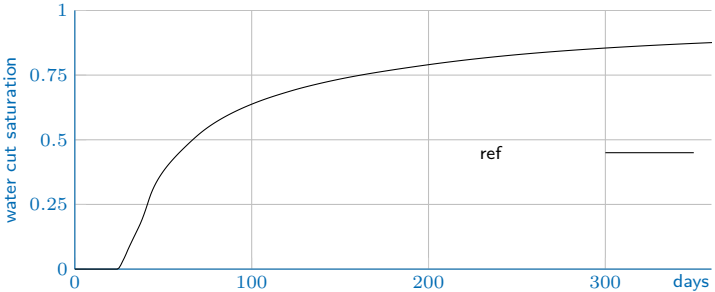




3.2 Simulation: fidelity wrt resolution level (HexaShrink)

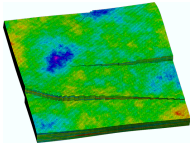
Raw

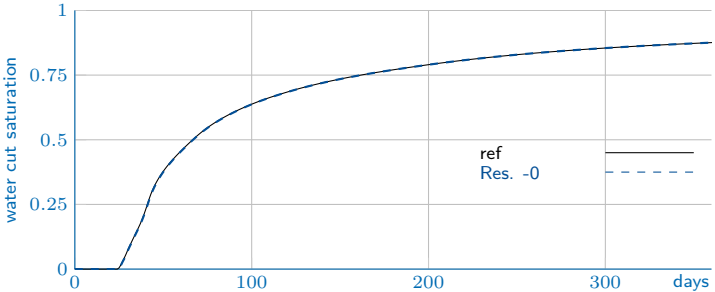




3.2 Simulation: fidelity wrt resolution level (HexaShrink)

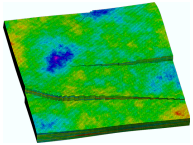
Res. -0
≈ 72 hours



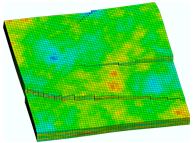


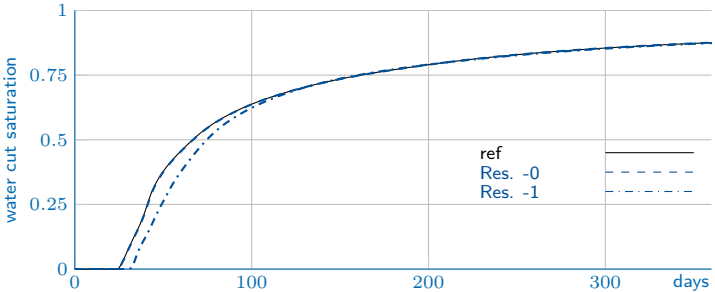
3.2 Simulation: fidelity wrt resolution level (HexaShrink)

Res. -0
≈ 72 hours



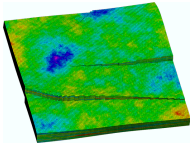
Res. -1
≈ 4 hours



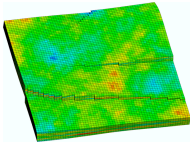


3.2 Simulation: fidelity wrt resolution level (HexaShrink)

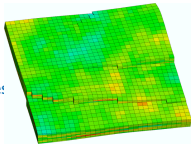
Res. -0
≈ 72 hours

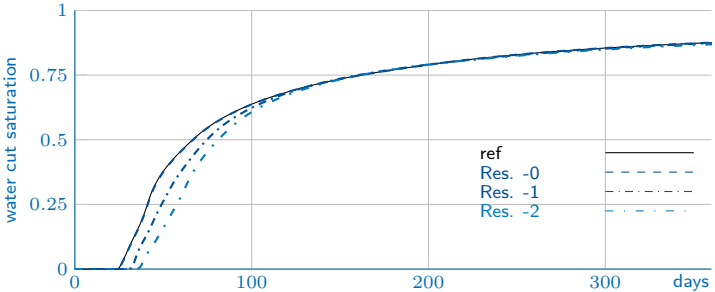


Res. -1
≈ 4 hours



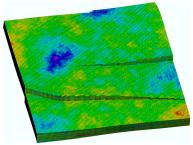
Res. -2
≈ 20 minutes





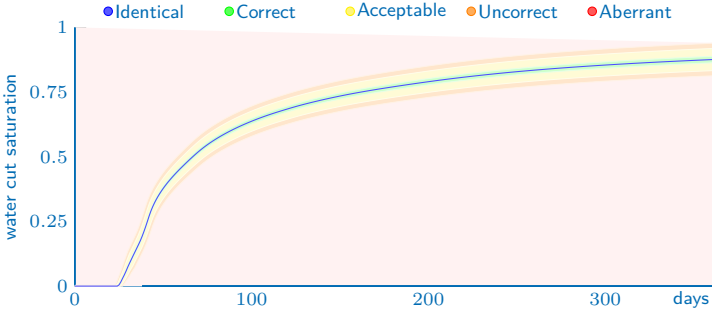
3.2 Simulation: subjective evaluation

Res. -0



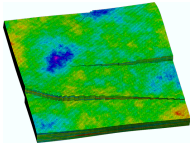
Res. -1

Res. -2



3.2 Simulation: fidelity wrt refinable precision

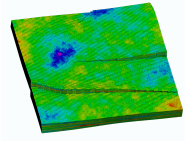
Res. 0



Res. -1

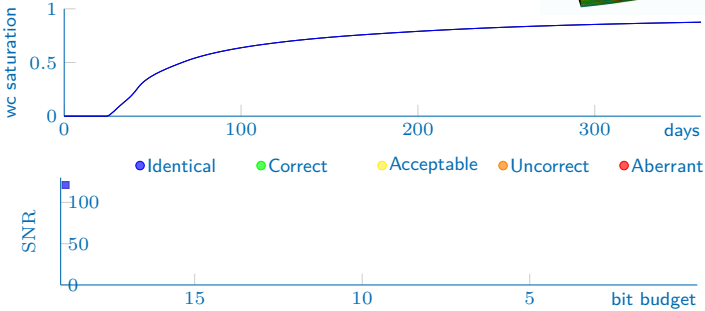
Res. -2

25 MSB_Z



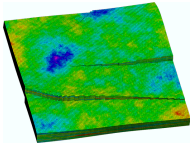
$18.85\ \mathrm{bits.cell}^{-1}$

$\mathrm{SNR} = 121.04\ \mathrm{dB}$



3.2 Simulation: fidelity wrt refinable precision

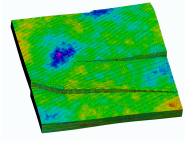
Res. 0



Res. -1

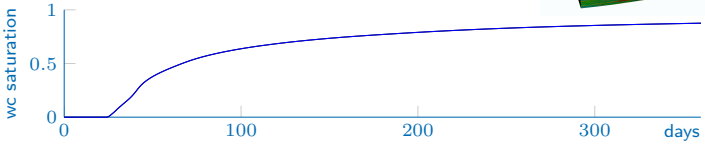
Res. -2

23 MSB_Z

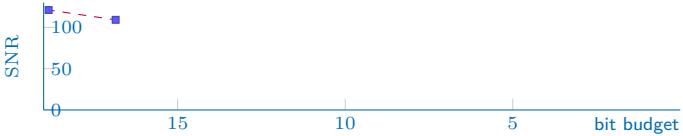


$16.85\ \mathrm{bits.cell}^{-1}$

$\mathrm{SNR} = 109.16\ \mathrm{dB}$

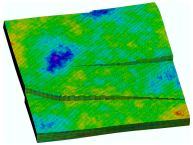


Identical Correct Acceptable Uncorrect Aberrant



3.2 Simulation: fidelity wrt refinable precision

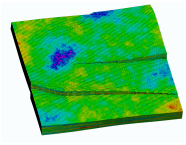
Res. 0



Res. -1

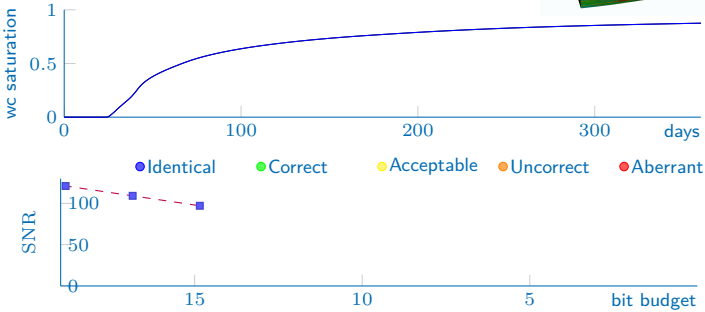
Res. -2

21 MSB_Z



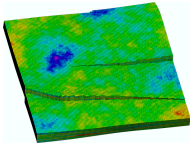
$14.84\ \mathrm{bits.cell}^{-1}$

$\mathrm{SNR} = 97.11\ \mathrm{dB}$



3.2 Simulation: fidelity wrt refinable precision

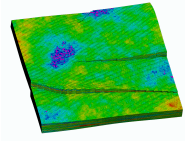
Res. 0



Res. -1

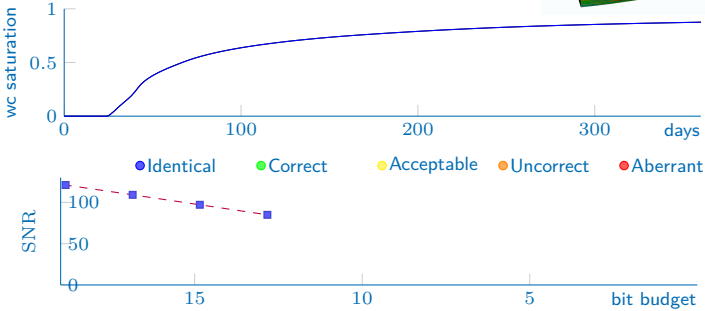
Res. -2

19 MSB_Z



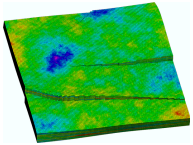
$12.83\ \text{bits.cell}^{-1}$

$\text{SNR} = 84.94\ \text{dB}$



3.2 Simulation: fidelity wrt refinable precision

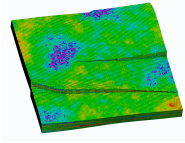
Res. 0



Res. -1

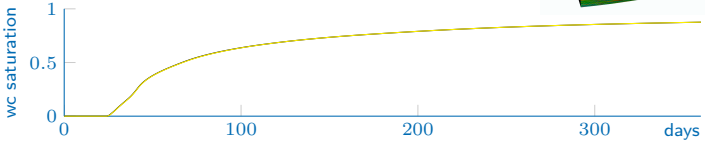
Res. -2

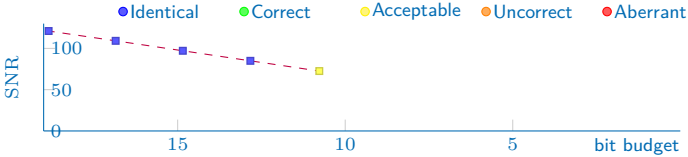
17 MSB_Z



$10.77\ \mathrm{bits.cell}^{-1}$

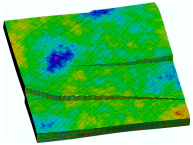
$\mathrm{SNR} = 72.54\ \mathrm{dB}$





3.2 Simulation: fidelity wrt refinable precision

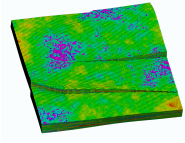
Res. 0



Res. -1

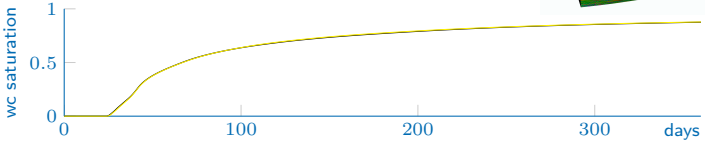
Res. -2

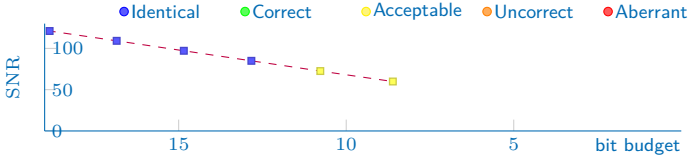
15 MSB_Z



$8.60\ \mathrm{bits.cell}^{-1}$

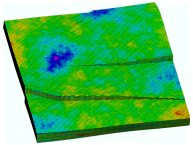
$\mathrm{SNR} = 59.89\ \mathrm{dB}$





3.2 Simulation: fidelity wrt refinable precision

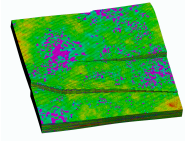
Res. 0



Res. -1

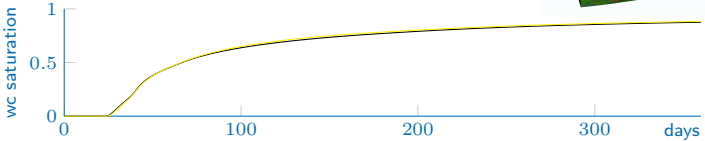
Res. -2

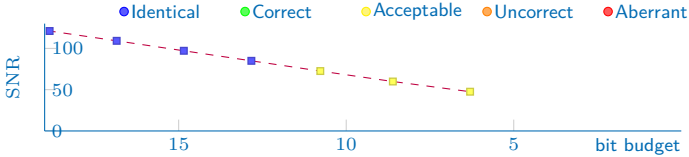
13 MSB_Z



$6.30\ \mathrm{bits.cell}^{-1}$

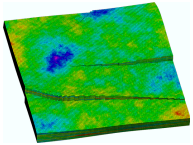
$\mathrm{SNR} = 47.54\ \mathrm{dB}$





3.2 Simulation: fidelity wrt refinable precision

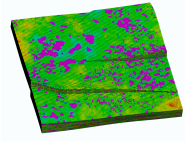
Res. 0



Res. -1

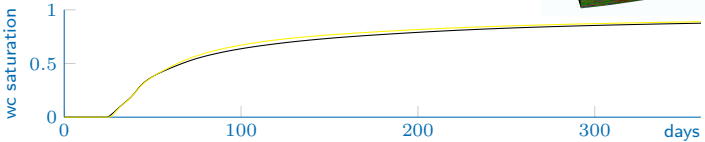
Res. -2

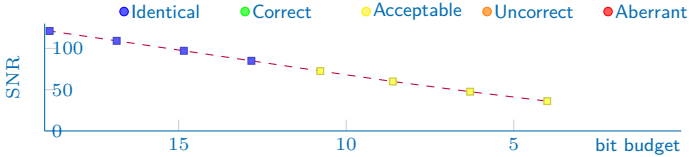
11 MSB_Z



$4.00\ \mathrm{bits.cell}^{-1}$

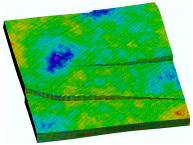
$\mathrm{SNR} = 36.10\ \mathrm{dB}$





3.2 Simulation: fidelity wrt refinable precision

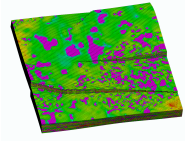
Res. 0



Res. -1

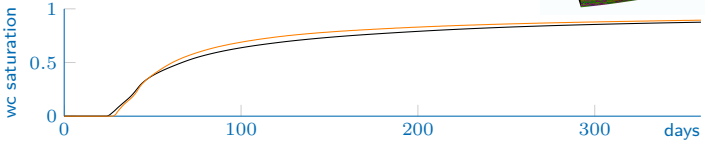
Res. -2

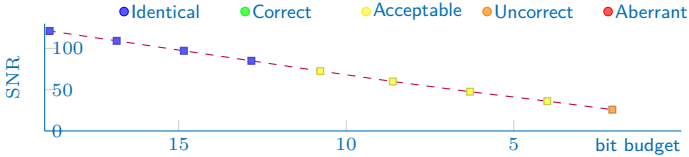
9 MSB_Z



$2.05\ \mathrm{bits.cell}^{-1}$

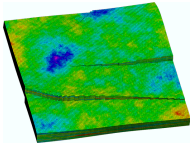
$\mathrm{SNR} = 25.82\ \mathrm{dB}$





3.2 Simulation: fidelity wrt refinable precision

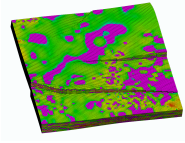
Res. 0



Res. -1

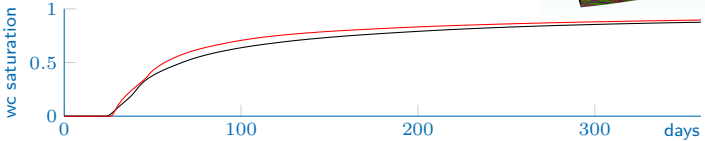
Res. -2

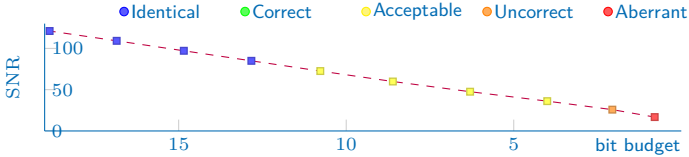
7 MSB_Z



$0.79\ \mathrm{bits.cell}^{-1}$

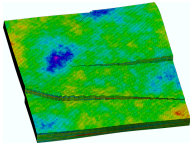
$\mathrm{SNR} = 16.91\ \mathrm{dB}$





3.2 Simulation: fidelity wrt refinable precision

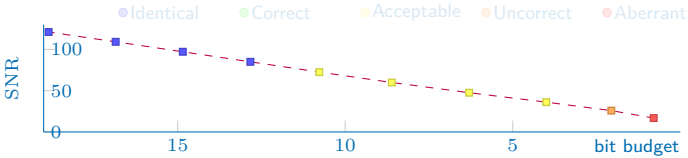
Res. 0



Res. -1

Res. -2

Is SNR suitable for simulation?

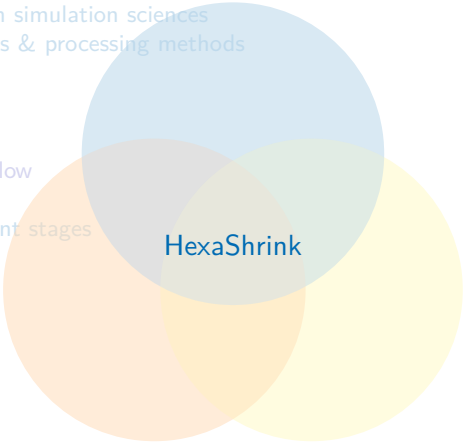


1. Introduction
   Context: Growing data in simulation sciences
   Geological volume meshes & processing methods
   Problematic
   State of the art

2. Presentation of our workflow
   Complete workflow
   Description of the different stages

3. Experimentations
   Coding
   Simulation
   Going further

4. Conclusion & perspectives



Is our method relevant for:

- ☑ Compression
- ☑ Visualization
- ☐ Simulation

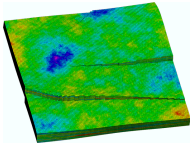
... ?

3.3 Going further: is SNR suitable for simulation?

Experimentations

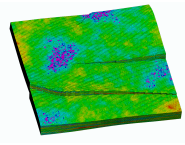
$$\mathrm{SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{C} P(c)^2}{\sum_{c=1}^{C}\left(P(c)-\hat{P}(c)\right)^2}\right)$$

Res. 0



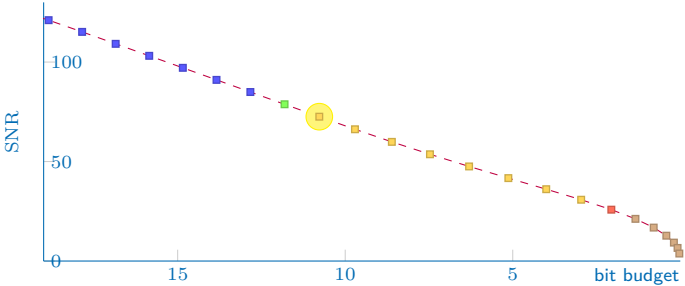
$10.77\ \mathrm{bits.cell}^{-1}$

$\mathrm{SNR} = 72.54\ \mathrm{dB}$



Res. -1

Res. -2

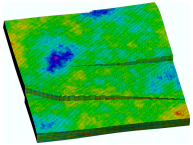


3.3 Going further: is SNR suitable for simulation?

Experimentations

$$\mathrm{SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{C} P(c)^2}{\sum_{c=1}^{C}\left(P(c)-\hat{P}(c)\right)^2}\right)$$

Res. 0

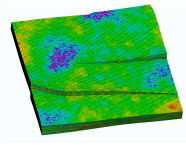


Res. -1

Res. -2

10.77 bits.cell^{-1}

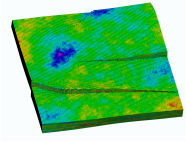
$\mathrm{SNR} = 72.54$ dB

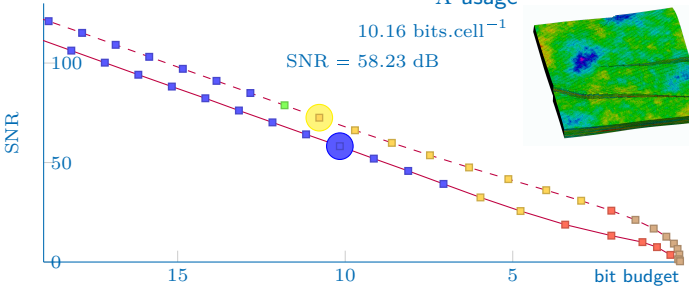


Λ usage

10.16 bits.cell^{-1}

$\mathrm{SNR} = 58.23$ dB



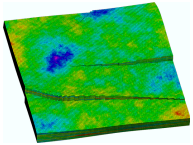


3.3 Going further: is SNR suitable for simulation?

Experimentations

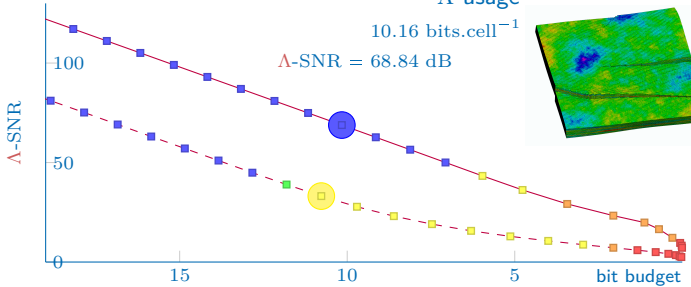
$$\Lambda\text{-SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{\mathcal{C}} \Lambda_{P(c)}^2}{\sum_{c=1}^{\mathcal{C}} \left(\Lambda_{P(c)} - \Lambda_{\hat{P}(c)}\right)^2}\right)$$

Res. 0



Res. -1

Res. -2

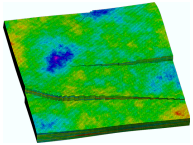


3.3 Going further: is SNR suitable for simulation?

Experimentations

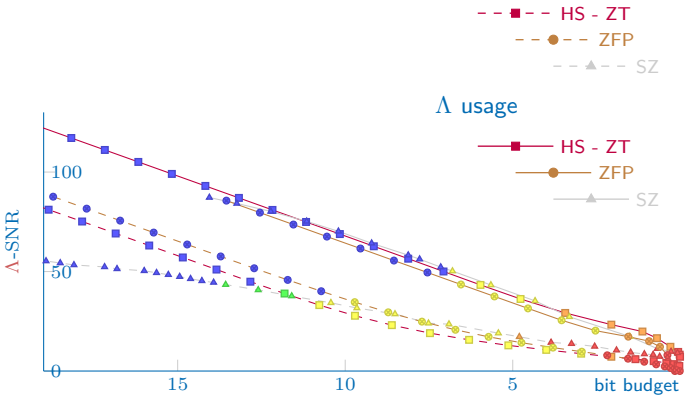
$$\Lambda\text{-SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{\mathcal{C}} \Lambda_{P(c)}^2}{\sum_{c=1}^{\mathcal{C}} \left(\Lambda_{P(c)} - \Lambda_{\hat{P}(c)}\right)^2}\right)$$

Res. 0



Res. -1

Res. -2

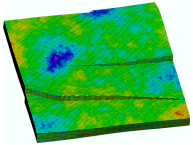


3.3 Going further: is SNR suitable for simulation?

Experimentations

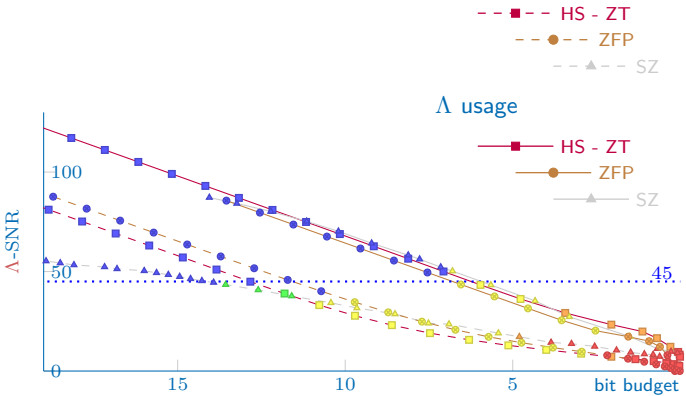
$$\Lambda\text{-SNR} = 10\log_{10}\left(\frac{\sum_{c=1}^{\mathcal{C}} \Lambda_{P(c)}^2}{\sum_{c=1}^{\mathcal{C}} \left(\Lambda_{P(c)} - \Lambda_{\hat{P}(c)}\right)^2}\right)$$

Res. 0



Res. -1

Res. -2



3.3 Going further: How to find the right precision?

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

1 MSB_Z

0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	8	8	0	0
0	0	0	0	-8	-8	0	0
0	0	0	0	0	0	-8	8
0	0	0	0	0	0	-8	8

11	22	-13	-1	-1	-9	-2	-4
10	13	4	-7	-5	2	1	-1
-5	6	9	-12	-1	-2	2	8
-5	5	-1	4	-1	2	-1	-16
-2	-6	3	3	-5	9	-6	-1
-6	1	3	3	5	7	2	0
-6	-7	16	-2	8	2	5	1
-2	-6	0	-5	7	-5	-4	1

3.3 Going further: How to find the right precision?

Experimentations

5 $MSB_{\mathbb{Z}}$

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 $MSB_{\mathbb{Z}}$

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 $MSB_{\mathbb{Z}}$

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 $MSB_{\mathbb{Z}}$

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

1 $MSB_{\mathbb{Z}}$

0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	8	8	0	0
0	0	0	0	-8	-8	0	0
0	0	0	0	0	0	-8	8
0	0	0	0	0	0	-8	8

0	16	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-16
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	16	0	0	0	0	0
0	0	0	0	0	0	0	0

3.3 Going further: How to find the right precision?

Experimentations

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

1 MSB_Z

0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	8	8	0	0
0	0	0	0	-8	-8	0	0
0	0	0	0	0	0	-8	8
0	0	0	0	0	0	-8	8

0	16	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-16
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	16	0	0	0	0	0
0	0	0	0	0	0	0	0

0	Sig	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	Sig
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	Sig	0	0	0	0	0
0	0	0	0	0	0	0	0

Symbols number:

$$\text{nSig}(1) = 3$$

3.3 Going further: How to find the right precision?

5 MSB$_Z$

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB$_Z$

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB$_Z$

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB$_Z$

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

1 MSB$_Z$

0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	8	8	0	0
0	0	0	0	-8	-8	0	0
0	0	0	0	0	0	-8	8
0	0	0	0	0	0	-8	8

0	16	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-16
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	16	0	0	0	0	0
0	0	0	0	0	0	0	0

0	Sig	Ztr	Ztr				
0	Ztr	Ztr	0				
Ztr	Ztr					0	0
Ztr	0					0	Sig
		Sig	0				
		0	0				

Symbols number:

$$\begin{aligned} \mathrm{nSig}(1) &= 3 \\ \mathrm{nZtr}(1) &= 7 \\ + \quad \mathrm{n0}(1) &= 10 \\ = \quad \mathrm{nZ}(1) &= 17 \end{aligned}$$

3.3 Going further: How to find the right precision?

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

1 MSB_Z

0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	8	8	0	0
0	0	0	0	-8	-8	0	0
0	0	0	0	0	0	-8	8
0	0	0	0	0	0	-8	8

8	16	-8	0	0	-8	0	0
8	8	0	0	0	0	0	0
0	0	8	-8	0	0	0	8
0	0	0	0	0	0	0	-16
0	0	0	0	0	8	0	0
0	0	0	0	0	0	0	0
0	0	16	0	8	0	0	0
0	0	0	0	0	0	0	0

Sig	Sig	Sig	Ztr	0	Sig		
Sig	Sig	Ztr	0	0	0		
Ztr	Ztr	Sig	Sig			0	Sig
Ztr	0	0	Ztr			0	Sig
				0	Sig	0	0
				0	0	0	0
		Sig	0	0	0		
		0	0	0	0		

Symbols number:

$$\begin{aligned} nSig(2) &= 12 \\ nZtr(2) &= 6 \\ + \quad n0(2) &= 22 \\ = \quad nZ(2) &= 28 \end{aligned}$$

3.3 Going further: How to find the right precision?

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

1 MSB_Z

0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	8	8	0	0
0	0	0	0	-8	-8	0	0
0	0	0	0	0	0	-8	8
0	0	0	0	0	0	-8	8

8	20	-12	0	0	-8	0	-4
8	12	4	-4	-4	0	0	0
-4	4	8	-12	0	0	0	8
-4	4	0	4	0	0	0	-16
0	-4	0	0	-4	8	-4	0
-4	0	0	0	4	4	0	0
-4	-4	16	0	8	0	4	0
0	-4	0	-4	4	-4	-4	0

Sig	Sig	Sig	0	0	Sig	0	Sig
Sig	Sig	Sig	Sig	Sig	0	0	0
Sig	Sig	Sig	Sig	0	0	0	Sig
Sig	Sig	0	Sig	0	0	0	Sig
0	Sig	0	0	Sig	Sig	Sig	0
Sig	0	0	0	Sig	Sig	0	0
Sig	Sig	Sig	0	Sig	0	Sig	0
0	Sig	0	Sig	Sig	Sig	Sig	0

Symbols number:

$$nSig(3) = 36$$

$$\begin{aligned} & nZtr(3) &= 0 \\ + \quad & n0(3) &= 27 \\ = \quad & nZ(3) &= 27 \end{aligned}$$

3.3 Going further: How to find the right precision?

5 MSB_Z

2	5	8	12	20	25	27	31
6	4	9	22	20	19	25	28
1	3	25	20	24	22	17	18
4	11	21	23	20	20	14	15
8	5	2	3	22	18	21	13
10	15	8	11	4	5	22	15
15	12	7	8	4	7	5	20
13	17	15	11	6	5	9	25

4 MSB_Z

0	4	6	12	16	21	25	30
4	3	8	22	17	16	24	27
0	3	24	21	22	21	16	18
3	11	21	24	19	20	14	16
6	4	2	3	19	17	20	14
8	14	9	12	3	5	22	16
14	13	7	10	4	8	4	20
13	18	16	13	6	6	10	26

3 MSB_Z

0	0	2	10	12	20	25	31
0	0	6	22	16	16	27	29
0	1	23	21	20	20	14	18
1	11	21	23	20	20	14	18
0	0	0	3	17	15	18	14
3	11	7	11	3	5	22	18
10	12	5	9	3	9	2	18
12	18	17	13	5	7	10	26

2 MSB_Z

0	0	0	12	2	14	18	30
0	4	4	24	6	10	22	26
0	2	22	22	16	16	12	20
2	10	22	22	16	16	12	20
0	0	0	6	8	8	8	8
0	12	6	14	0	0	16	16
6	14	4	8	0	10	0	16
14	22	16	12	2	6	8	24

1 MSB_Z

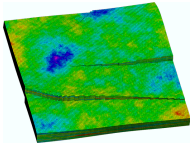
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	16	16	16	16
0	0	0	0	8	8	0	0
0	0	0	0	-8	-8	0	0
0	0	0	0	0	0	-8	8
0	0	0	0	0	0	-8	8

$$\text{ZT activity}(i) = \frac{\mathrm{nS}(i) - \mathrm{nS}(i+1) + \mathrm{nZ}(i) - \mathrm{nZ}(i+1)}{\mathcal{C}}$$

3.3 Going further: How to find the right precision?

Experimentations

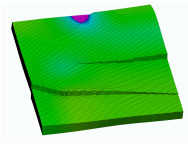
Res. 0

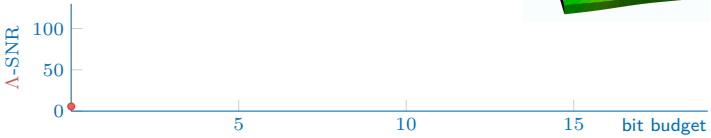


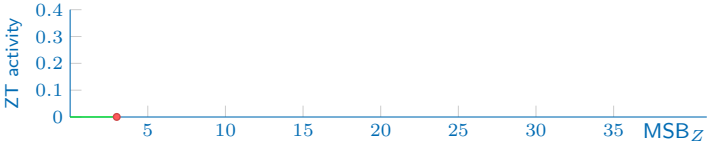
Res. -1

Res. -2

3 MSB_Z



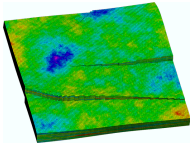




3.3 Going further: How to find the right precision?

Experimentations

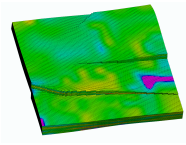
Res. 0

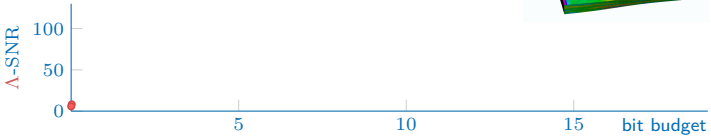


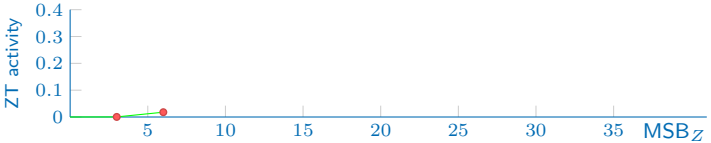
Res. -1

Res. -2

6 MSB_Z



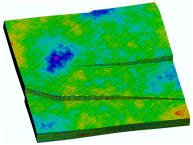




3.3 Going further: How to find the right precision?

Experimentations

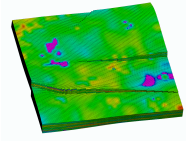
Res. 0

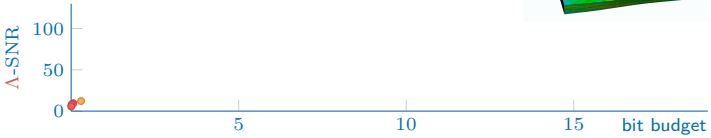


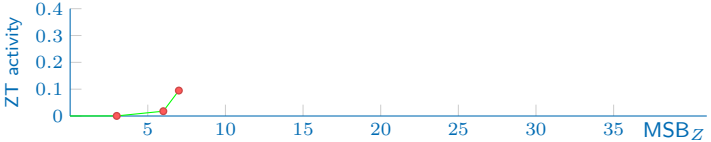
Res. -1

Res. -2

7 MSB_Z

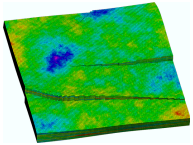






3.3 Going further: How to find the right precision?

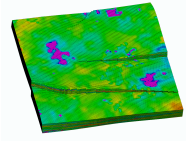
Res. 0

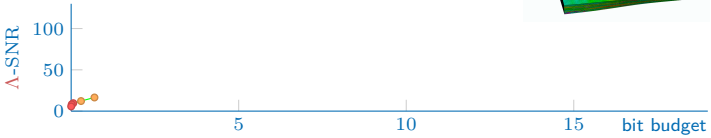


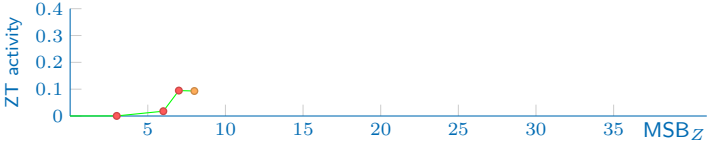
Res. -1

Res. -2

8 MSB$_Z$

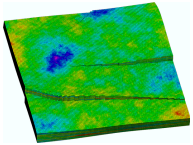






3.3 Going further: How to find the right precision?

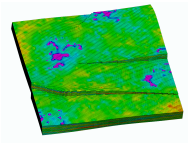
Res. 0

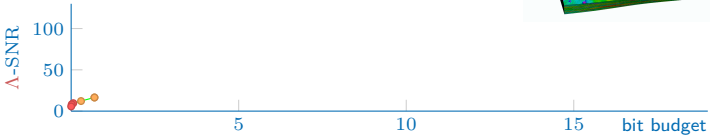


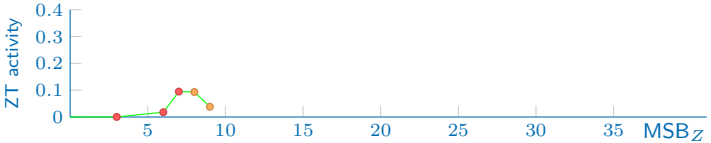
Res. -1

Res. -2

9 MSB_Z

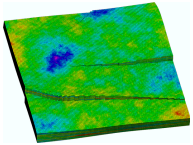






3.3 Going further: How to find the right precision?

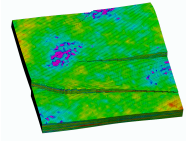
Res. 0

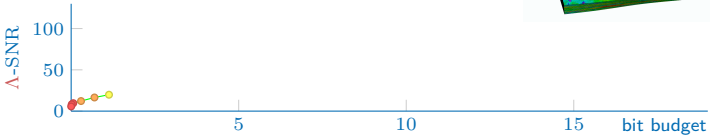


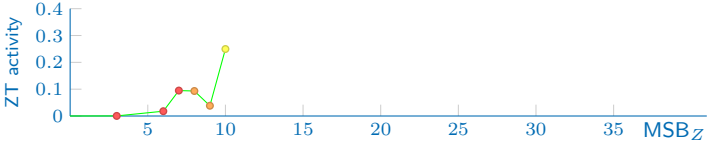
Res. -1

Res. -2

10 MSB_Z



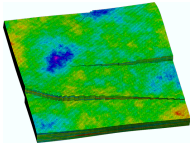




3.3 Going further: How to find the right precision?

Experimentations

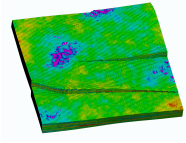
Res. 0

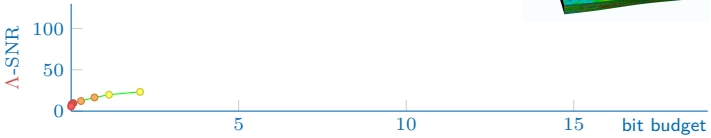


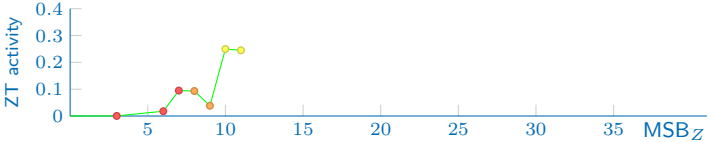
Res. -1

Res. -2

11 MSB_Z



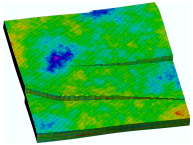




3.3 Going further: How to find the right precision?

Experimentations

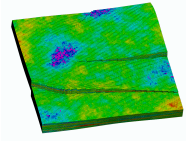
Res. 0

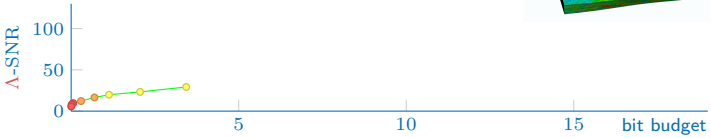


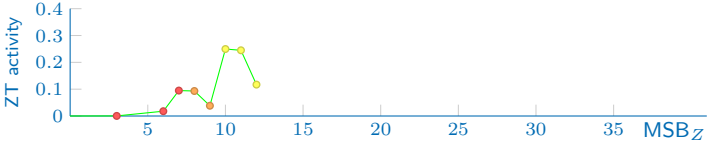
Res. -1

Res. -2

12 MSB_Z

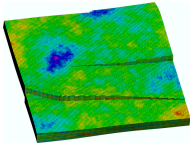






3.3 Going further: How to find the right precision?

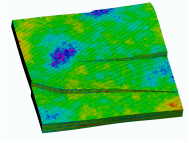
Res. 0

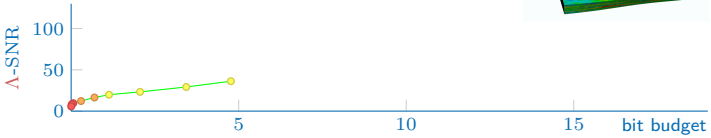


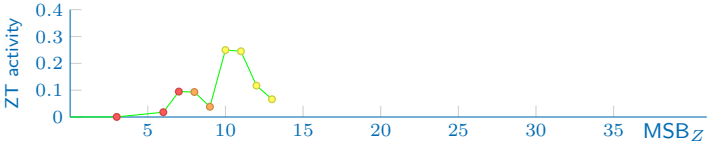
Res. -1

Res. -2

13 MSB_Z



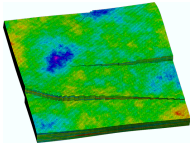




3.3 Going further: How to find the right precision?

Experimentations

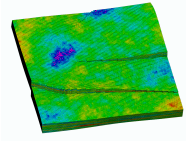
Res. 0

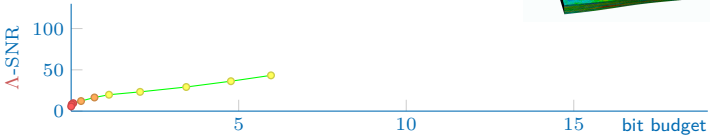


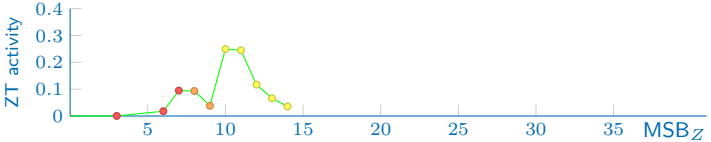
Res. -1

Res. -2

14 MSB_Z

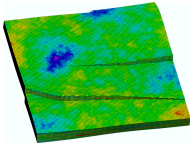






3.3 Going further: How to find the right precision?

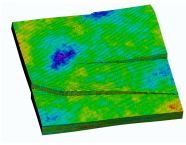
Res. 0

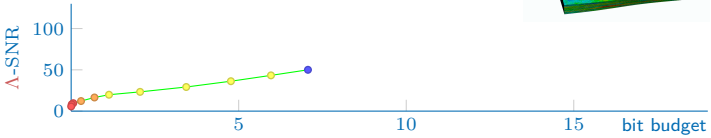


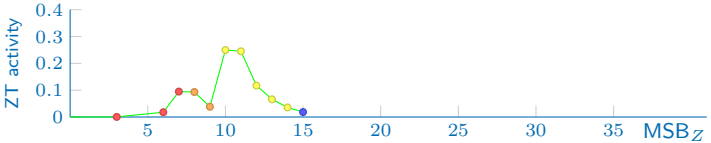
Res. -1

Res. -2

15 MSB_Z

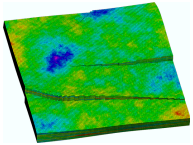






3.3 Going further: How to find the right precision?

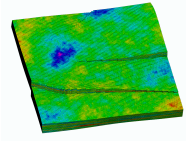
Res. 0

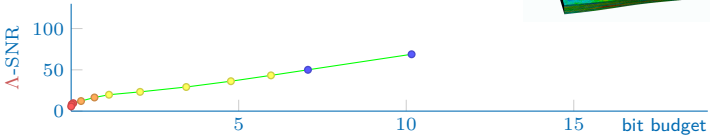


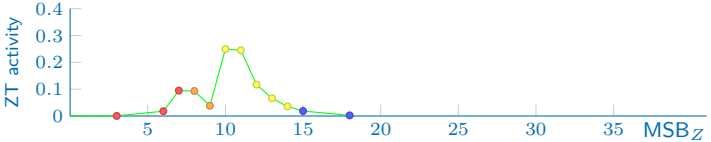
Res. -1

Res. -2

18 MSB_Z



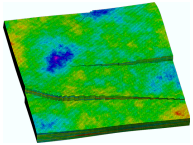




3.3 Going further: How to find the right precision?

Experimentations

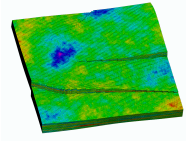
Res. 0

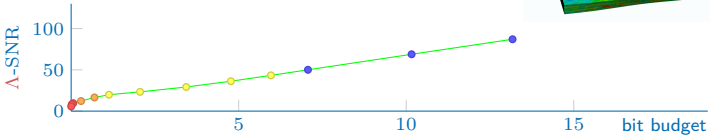


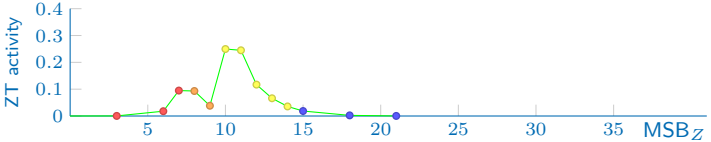
Res. -1

Res. -2

21 MSB_Z







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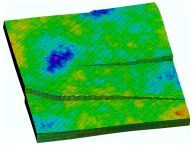
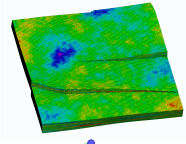
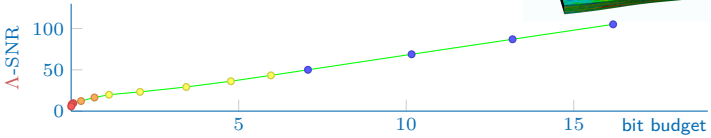


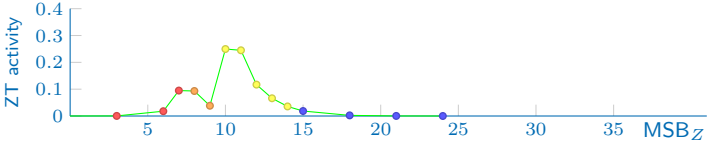
Res. -1

Res. -2

24 MSB_Z







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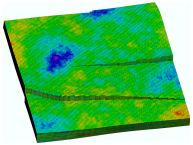
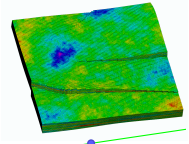
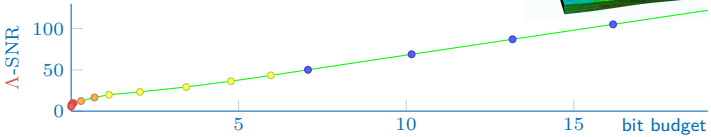


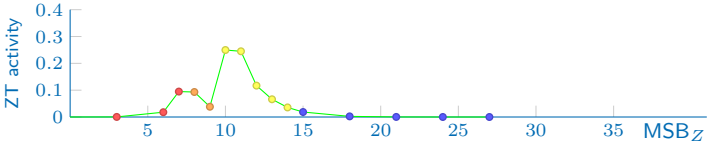
Res. -1

Res. -2

27 MSB_Z







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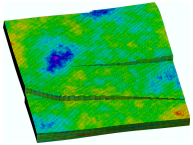

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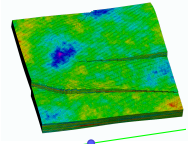
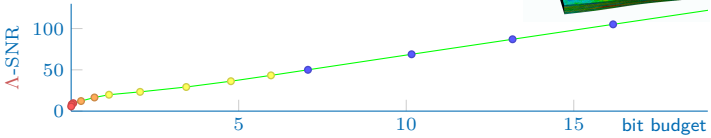
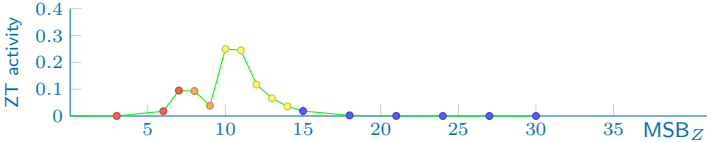
30 MSB_Z







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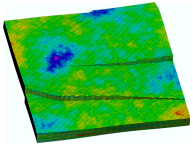

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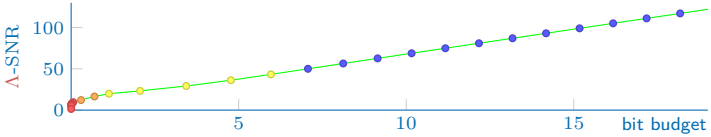
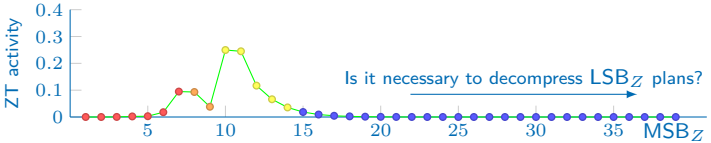


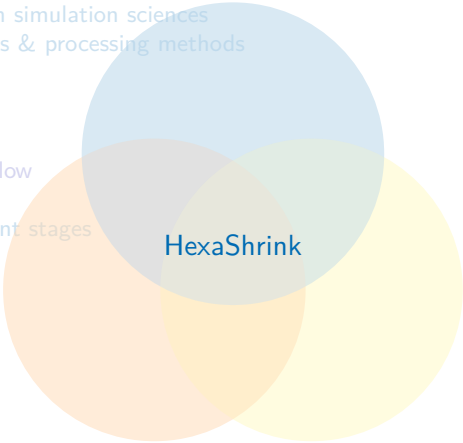


1. Introduction
   Context: Growing data in simulation sciences
   Geological volume meshes & processing methods
   Problematic
   State of the art

2. Presentation of our workflow
   Complete workflow
   Description of the different stages

3. Experimentations
   Coding
   Simulation
   Going further

4. Conclusion & perspectives



Is our method relevant for:

- ✓ Compression
- ✓ Visualization
- ✓ Simulation

... ?

Conclusion & perspectives

Conclusion & perspectives

- Designed complete compression/simulation workflow
- Model shareable LUNDI mesh
  - generates & uses data at refinable resolution and precision
- Obtained nice results
  - ☑ Compression
  - ☑ Visualization
  - ☑ Simulation
- Compandor/Expandor usage
  - Significantly improves results
- New metrics more suitable for simulation
  - Objective evaluation: A-SNR
  - Subjective evaluation
- Some ways to continue to explore
  - ZT activity
  - Anisotropy of geological data

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Publications

Journal paper

Peyrot, J.-L., Duval, L., Payan, F., Bouard, L., Chizat, L., Schneider, S., and Antonini, M. *HexaShrink, an exact scalable framework for hexahedral meshes with attributes and discontinuities: multiresolution rendering and storage of geoscience models*. Computat. Geosci. (May. 2019).

In writing

Bouard, L., Duval, L., Payan, F., Preux, C., and Antonini, M. *Accurate reservoir simulation with refinable precision on petrophysical properties*. Computer & Geosci. (to be submitted, Feb. 2021).

International conferences

81st EAGE Conference and Exhibition (European Association of Geoscientists & Engineers), London. (2019). Bouard, L., Duval, L., Preux, C., Payan, F., and Antonini, M.
Lossless progressive compression of meshes for upscaling and upgridding in reservoir simulation with HexaShrink. Accepted for an oral presentation.

National conferences

CORESA (COmpression et REprésentation des Signaux Audiovisuels), Poitiers. (2018). Bouard, L., Duval, L., Payan, F., and Antonini, M.
Decomposition multi-échelles de maillages 3D hexaédriques dans le domaine des géosciences. Étude des performances en compression sans pertes.

RING meeting (Research for Integrative Numerical Geology), Nancy. (2019) Bouard, L., Duval, L., Preux, C., Payan, F., and Antonini, M.
A lossless to lossy compression of meshes for upscaling and upgridding in reservoir simulation with HexaShrink.

Other communications

LIRIS, Lyon. (June, 2020), Bouard, L., Duval, L., Payan, F., Preux, C., and Antonini, M.
Comparative study of the impact of refinable-precision coding on geoscience simulation data.

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