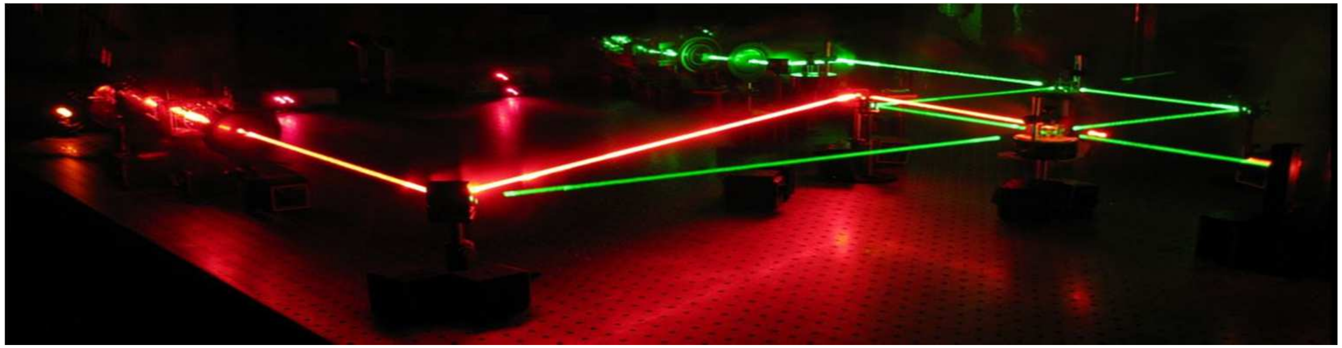

Digital Holography Compression

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Outline

- Context

- Phase-shifting digital holography
- Data representations

- Overview of holographic data compression
- Separable and non-separable Vector Lifting Schemes
- Open access database

- Concluding remarks

Context

Context

- **High interests for 3D video**
  - Expectation of greatly enhanced user experience
  - 3D video widely perceived as one of the next major advancement in video technology

- **Shortcomings**
  - Current stereo/multi-view solutions only exploit limited depth cues
  - Inherent vergence – accommodation conflict

Context

- **Holography:**
  - Invented by Dennis Gabor in 1948

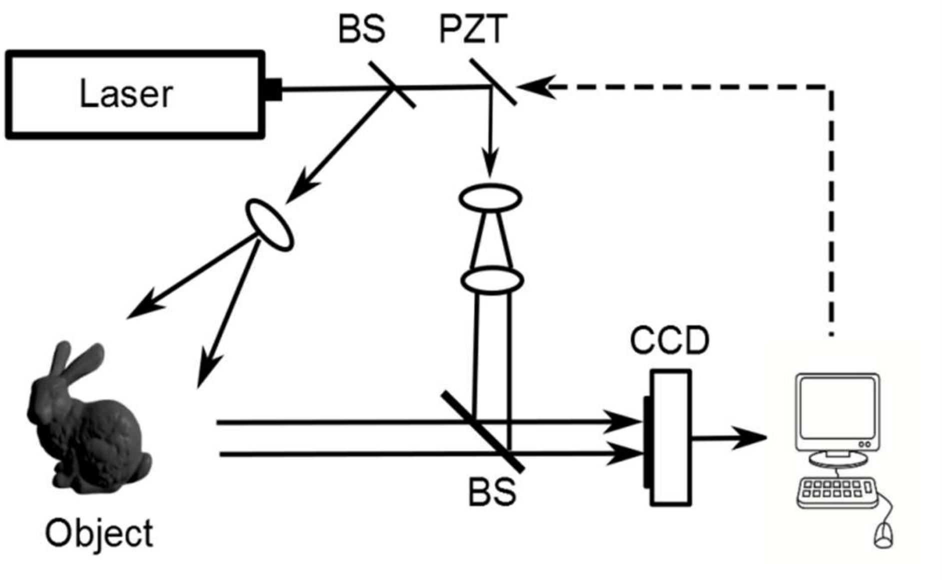
Optically recording information of the wavefront emanating from a 3D object

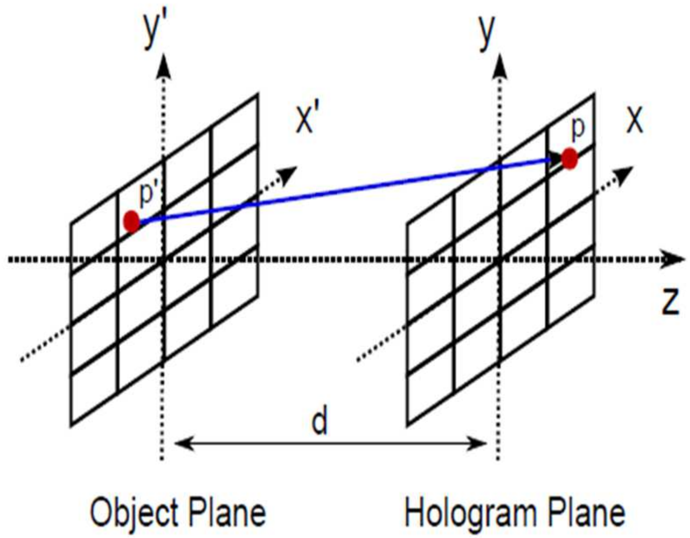
Subsequently make possible the rendering of three-dimensional views of this object by reconstructing the corresponding wavefront

- **The ultimate 3D experience**
  - Continuous head motion parallax
  - Natural eye vergence and accommodation
  - Other important depth-cues: perspective, occlusions, lighting, shadings and defocus blur.

Phase-shifting digital holography

Phase-Shifting Digital Hologram





BS: beam splitters
PZT: piezoelectric transducer mirror

Phase-Shifting Digital Hologram

- **Generation of Fresnel holograms based on Fourier transform**
  - Object wave at the hologram plane

$$U(x,y) = \int\int A(x',y')\exp[i\pi\frac{(x'-x)^2+(y'-y)^2}{\lambda d}]dx'dy'$$

$$U(x,y) = exp[i\frac{\pi}{\lambda d}(x^2+y^2)]\mathscr{F}\{A(x',y')\exp[i\frac{\pi}{\lambda d}(x')^2+(y')^2]\}$$

  - The captured intensity of the interference patterns

$$I_H(x,y;\phi) = |U_R(x,y;\phi)+U(x,y)|^2 \qquad U_R(x,y;\phi) = |A_R(x,y)|\exp(i\phi), \qquad \phi = 0, \frac{\pi}{2}, \pi$$

Complex amplitude of the reference wave

  - Reconstruction: object wavefront at the hologram plane

$$U(x,y) = \frac{1-i}{4U_R^*}\{I_H(x,y;0) - I_H(x,y;\frac{\pi}{2}) + i[I_H(x,y;\frac{\pi}{2}) - I_H(x,y;\pi)]\}$$

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Data representations

Intensity-based representation

- **Intensity of the interference patterns**
  - Real-valued interference patterns which are captured (or computer-simulated) on the sensor

$$I_H(x,y;\phi) = |U_R(x,y;\phi) + U(x,y)|^2 \qquad \phi \in \{o, \tfrac{\pi}{2}, \pi\}$$

- **Shifted distance information**
  - Two channels – difference of intensities - are sufficient to reconstruct the complex field

$$U(x,y) = \frac{1-i}{4U_R^*}\{I_H(x,y;0) - I_H(x,y;\frac{\pi}{2}) + i[I_H(x,y;\frac{\pi}{2}) - I_H(x,y;\pi)]\}$$

$$D_1 = 2A_R A cos(0-\varphi) - 2A_R A cos(\frac{\pi}{2}-\varphi)$$

$$D_2 = 2A_R A cos(\frac{\pi}{2}-\varphi) - 2A_R A cos(\pi-\varphi)$$

Complex wavefield representation

- **Complex amplitude values of the wavefield**
- **Real-imaginary**

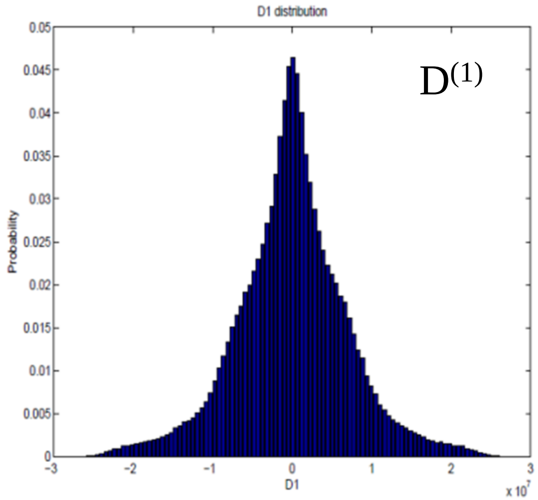
$$\widehat{U_O}(x,y) = real(\widehat{U_O}(x,y)) + i \cdot imag(\widehat{U_O}(x,y))$$

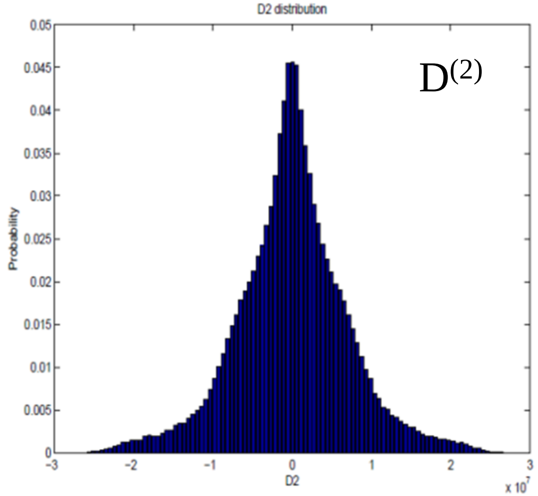
- **Amplitude-phase information**

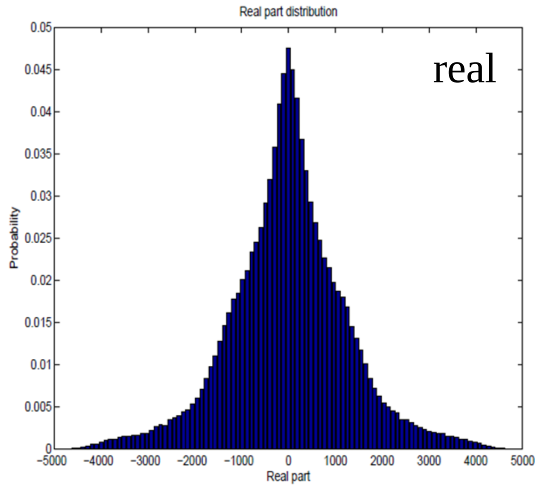
$$\widehat{U_O}(x,y) = \widehat{A_O}(x,y)\exp(i\widehat{\varphi_O}(x,y))$$

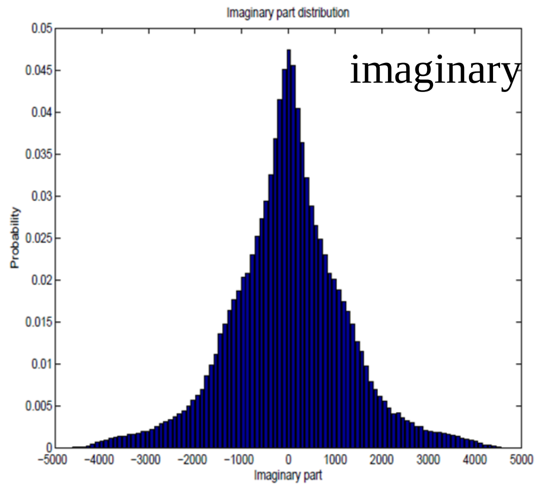
Histograms

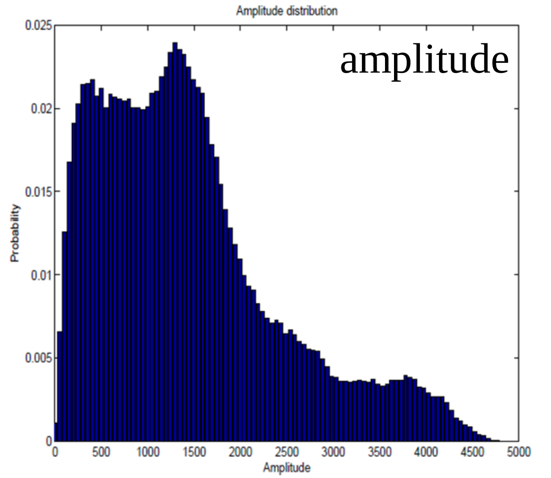
Shifted distance	Real-imaginary	Amplitude-phase

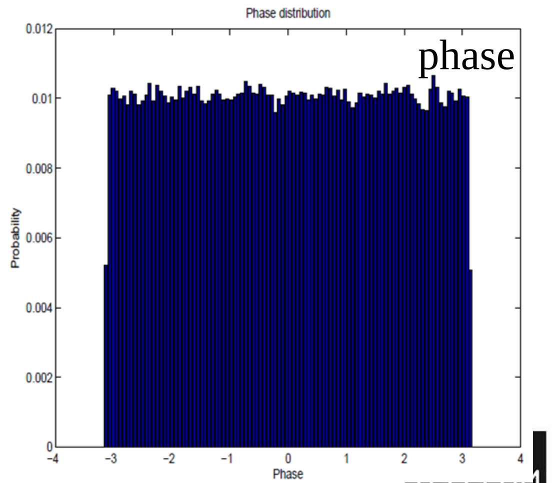












Comparative study

- **Quantization**
  - Uniform scalar quantization (USQ)
  - Adaptive scalar quantization (Lloyd Max) (ASQ)
  - Vector quantization (LBG) (VQ)

Number of bit	PSNR of Girl						PSNR of Bunny					
	Am,Ph			D1,D2			Am,Ph			D1,D2		
	USQ	ASQ	VQ	USQ	ASQ	VQ	USQ	ASQ	VQ	USQ	ASQ	VQ
2	26.01	25.82	27.64	19.71	26.71	29.56	18.77	19.36	22.39	15.65	22.81	23.38
3	35.67	35.73	36.36	31.63	34.53	37.36	28.28	28.69	29.17	25.38	29.71	30.52
4	43.32	43.61	42.90	40.36	42.51	45.15	34.83	35.26	35.46	32.33	36.23	37.54
5	48.09	48.16	49.12	47.07	49.35	52.47	40.82	41.11	41.58	38.51	41.85	44.07

Overview of holographic data compression

Quantization-based methods

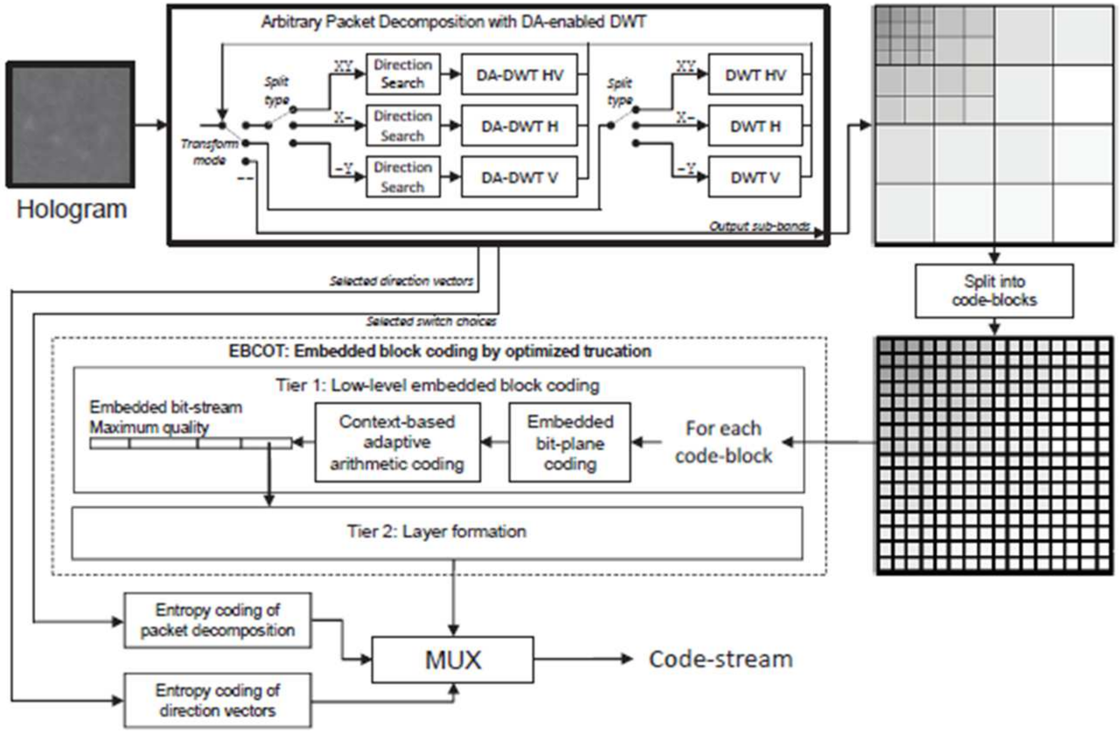
- **Quantization of interference patterns**
  - G. A. Mills and I. Yamaguchi. Effects of quantization in phase-shifting digital holography. Applied Optics, 2005.
- **Non-uniform quantization**
  - A. E. Shortt, T. J. Naughton and B. Javidi, ‘A companding approach for nonuniform quantization of digital holograms of three-dimensional objects,” Optics Express 2006.
- **Histogram-based**
  - A.E. Shortt, T.J. Naughton, and B. Javidi. Histogram approaches for lossy compression of digital holograms of three-dimensional objects. IEEE Transactions on, Image Processing, June 2007.

Transform-based methods

- **Wavelets**
  - A.E. Shortt, T.J. Naughton, and B. Javidi. Compression of digital holograms of three-dimensional objects using wavelets. Opt. Express, Apr 2006.
- **Fresnelets + SPIHT**
  - E. Darakis and J.J. Soraghan. Use of fresnelets for phase-shifting digital hologram compression. IEEE Transactions on Image Processing, 2006.
- **Gabor/Morlet wavelets with selected view point**
  - K. Viswanathan, P. Gioia, and L. Morin, Wavelet compression of digital holograms: towards a view-dependent framework, SPIE 2013.
  - K. Viswanathan, P. Gioia, and L. Morin. Morlet wavelet transformed holograms for numerical adaptive view-based reconstruction, SPIE 2014.

Transform-based methods

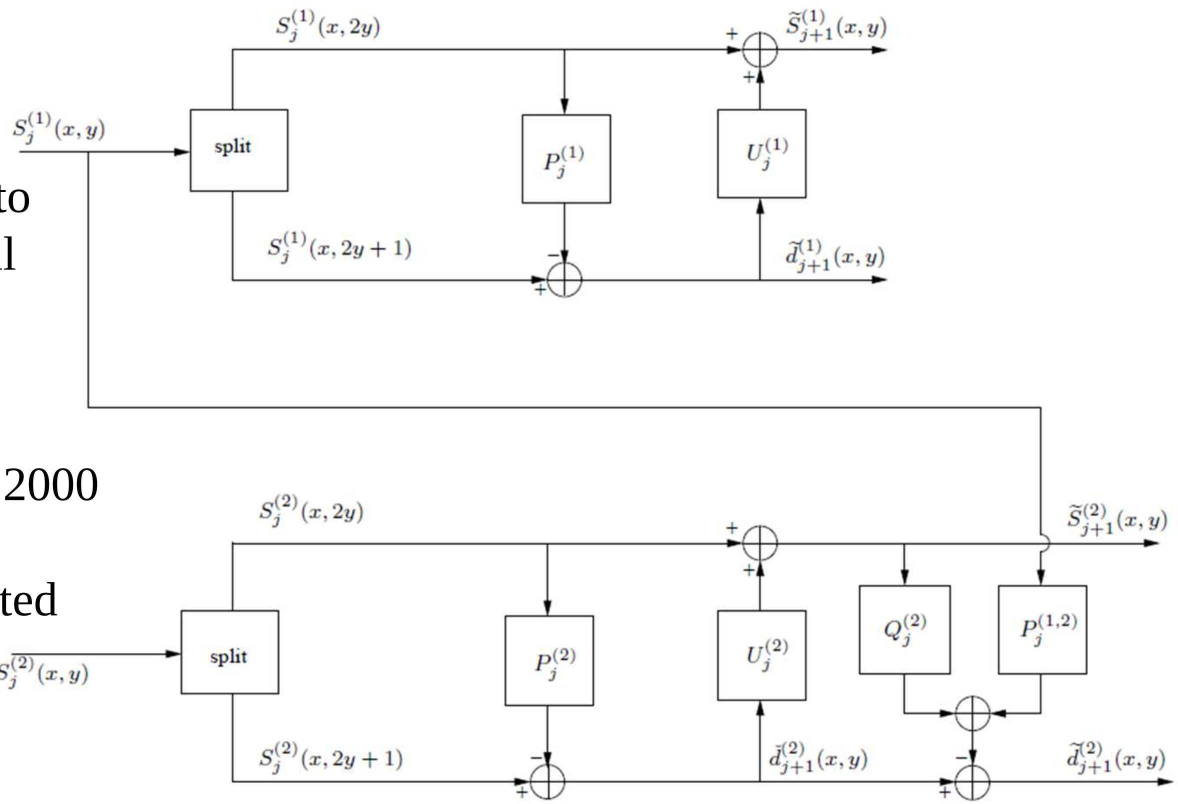
- **JPEG2000-based with arbitrary packet decomposition and directional wavelet transforms**
  - D. Blinder et al. Wavelet coding of off-axis holographic images, SPIE 2013.
  - D. Blinder et al. JPEG 2000-based compression of fringe patterns for digital holographic microscopy, Optical Engineering, 2014



Separable and non-separable Vector Lifting Schemes

Separable Vector Lifting Scheme

- **Joint compact representation of two channels**
  - On the lines and columns
  - Over *J* resolution levels
  - Prediction weights are optimized to minimize the variance of the detail signal (filter length=2)

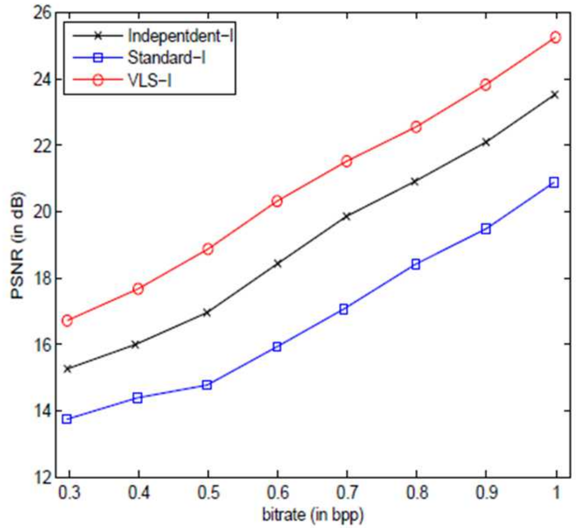


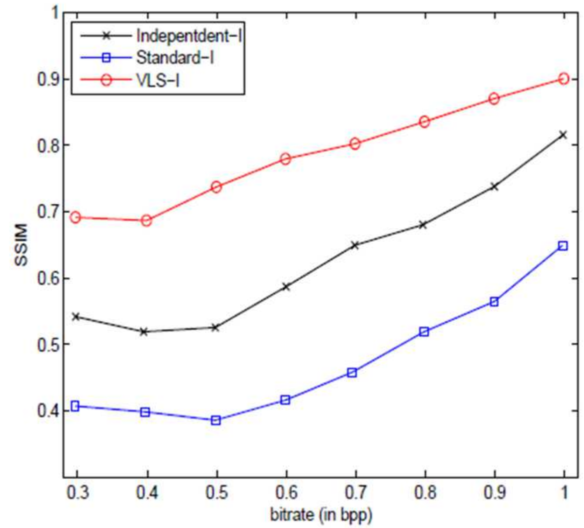
  - Coefficients encoded using JPEG 2000 (EBCOT)
  - Prediction filters are also transmitted

Y. Xing, M. Kaaniche, B. Pesquet-Popescu and F. Dufaux, Vector lifting scheme for phase-shifting holographic data compression, Optical Engineering 53(11), May 2014.

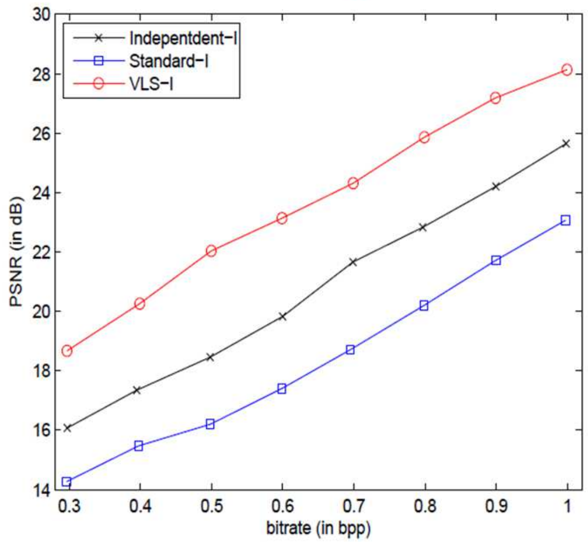
Experimental Results

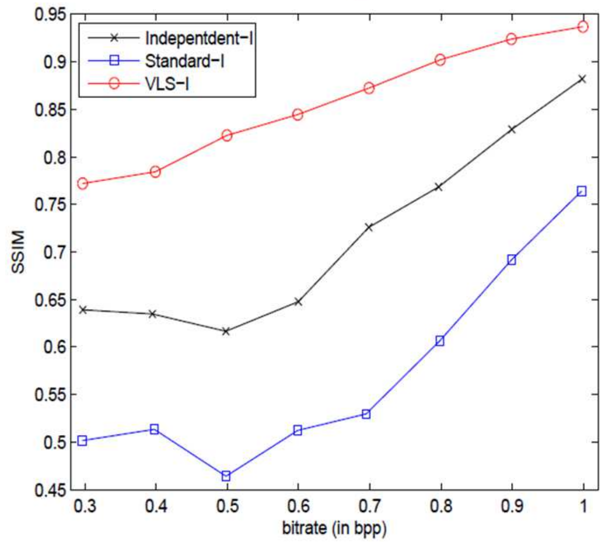
Luigi-1





Bunny-1





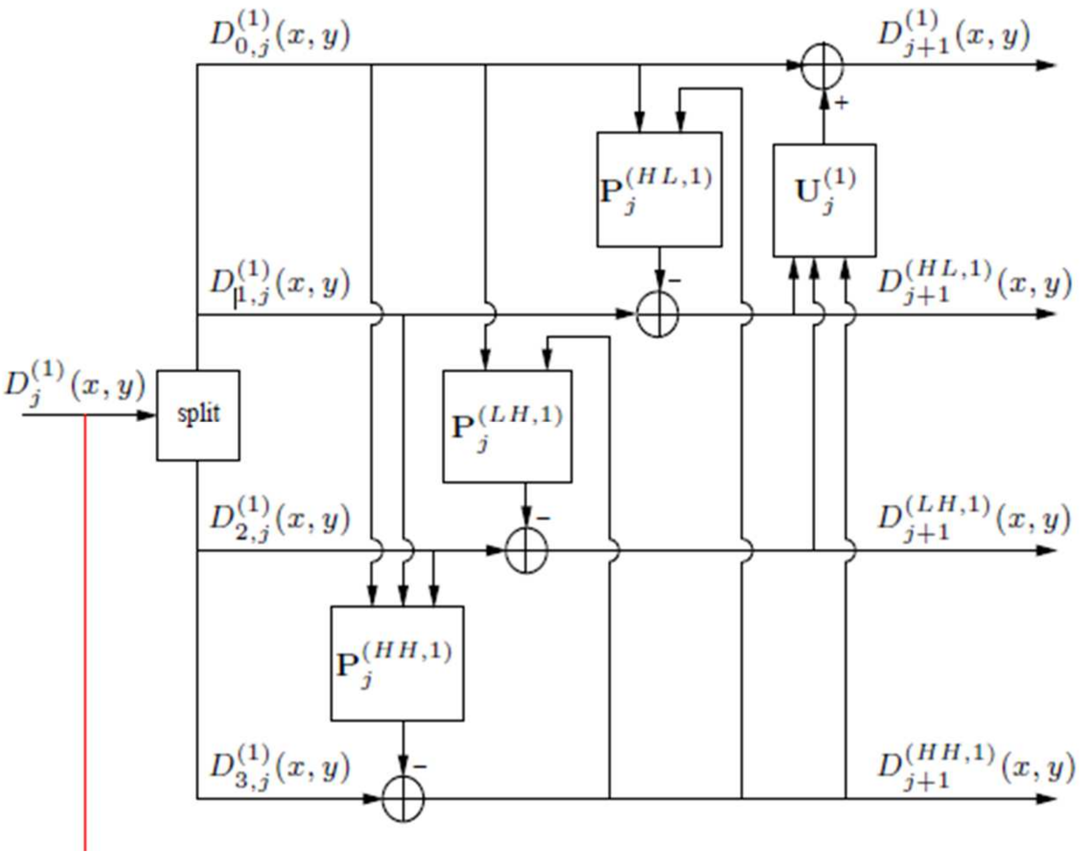
Non-separable Vector Lifting Scheme

- The data to be encoded present some isotropic structures
- Non-separable VLS (NS-VLS)
  - Simultaneously exploit the correlation between the two channels, as well as their 2D wave characteristics

Y. Xing, M. Kaaniche, B. Pesquet-Popescu and F. Dufaux, Adaptive non separable vector lifting scheme for digital holographic data compression, Applied Optics, 2015.

Non-separable Vector Lifting Scheme

- **Decomposition of the reference image**

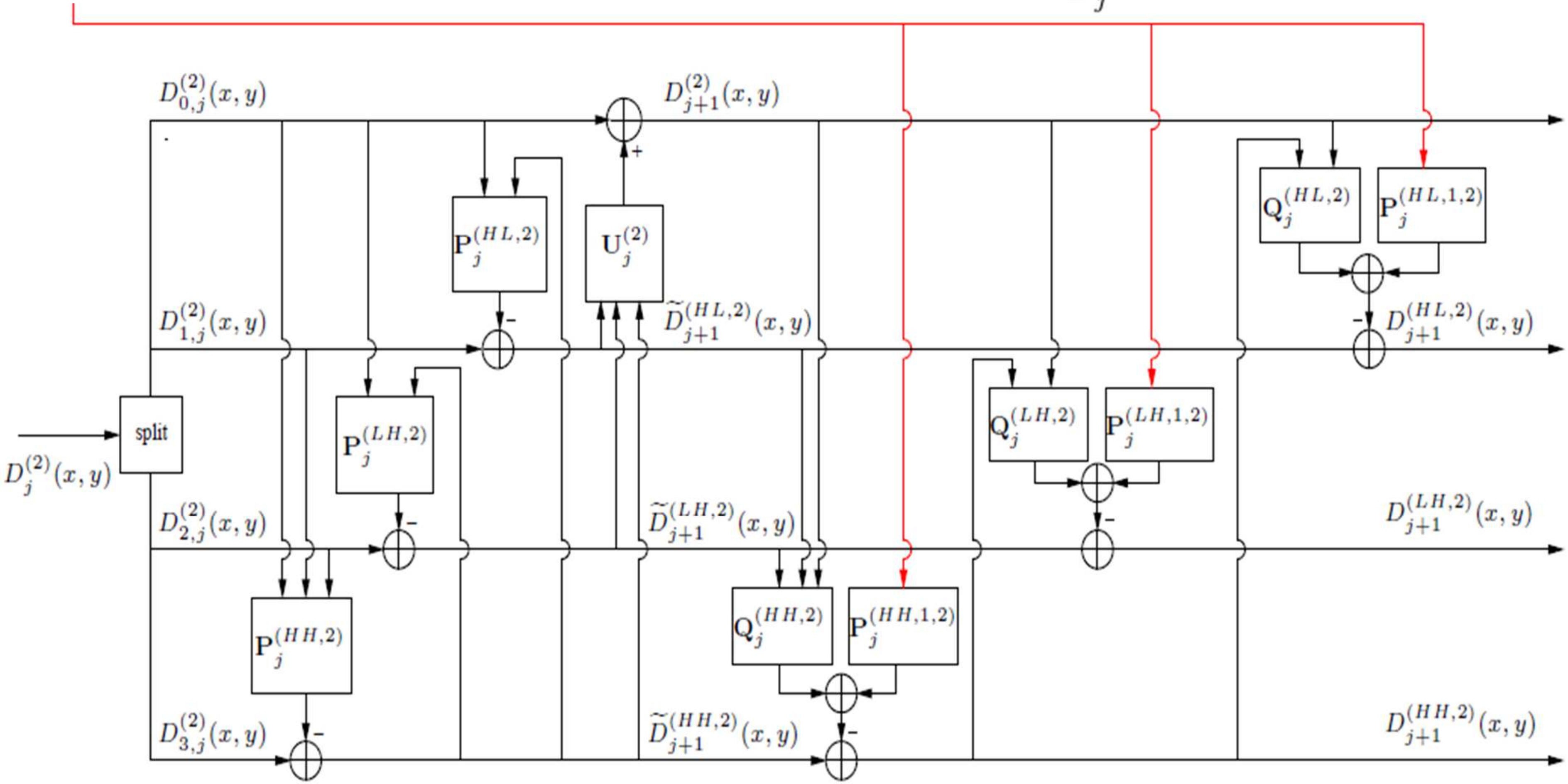


- Three prediction steps and an update step
- One approximation and three detail signals oriented horizontally, vertically, and diagonally

Non-separable Vector Lifting Scheme

- **Decomposition of the target image**

Three hybrid prediction simultaneously exploiting the intra and inter redundancies



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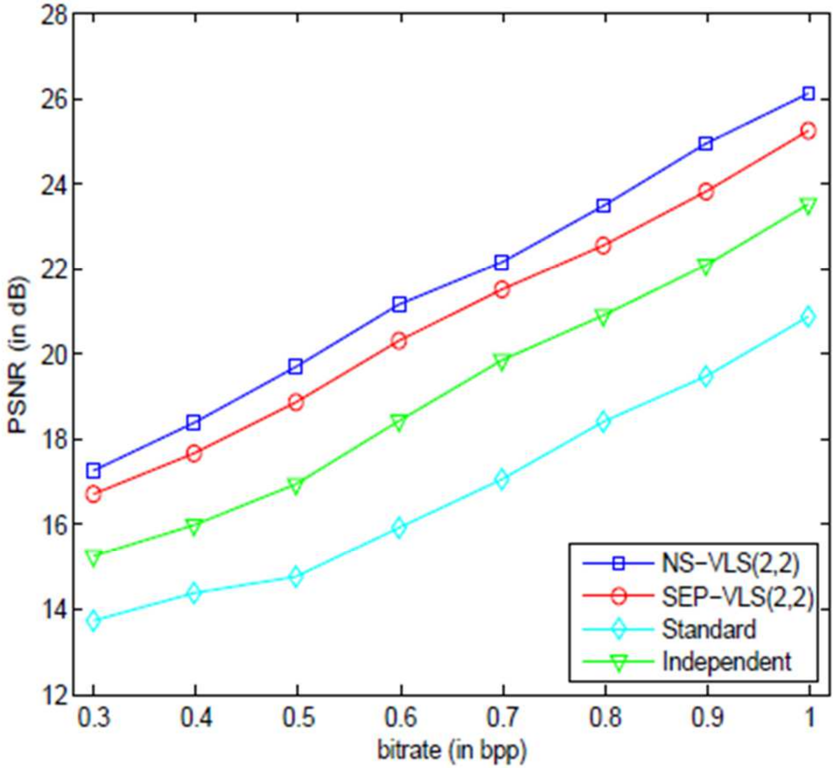
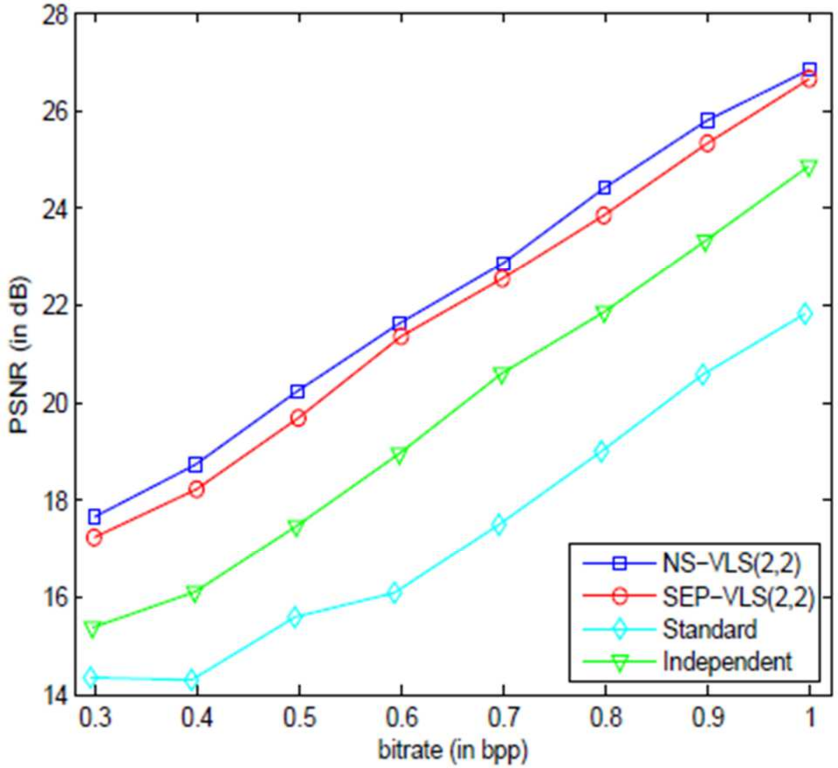
Experimental Results



"Luigi-1"



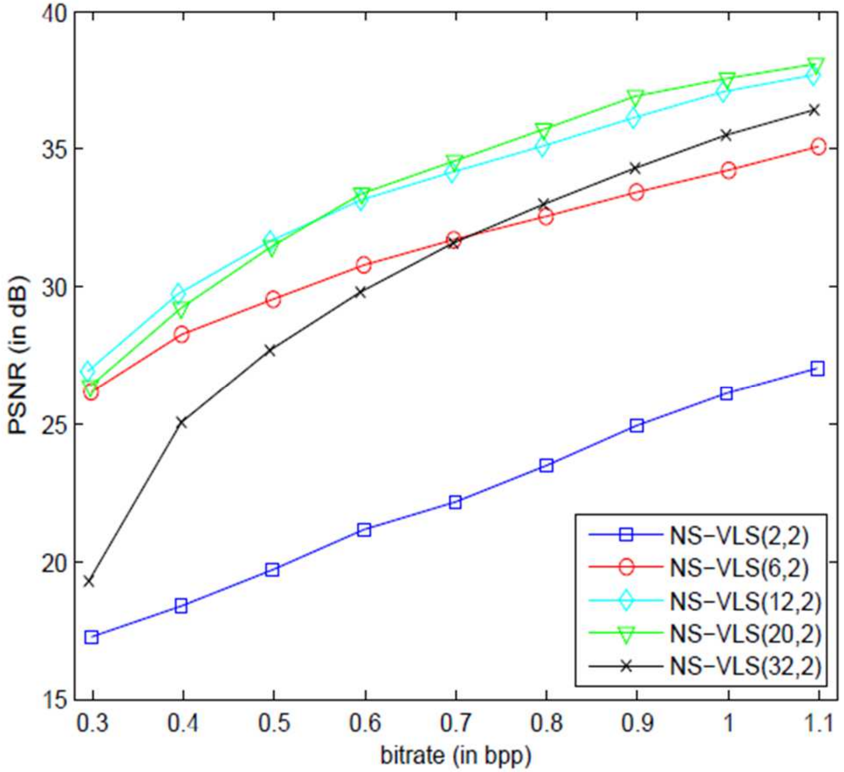
"Luigi-2"

Experimental Results

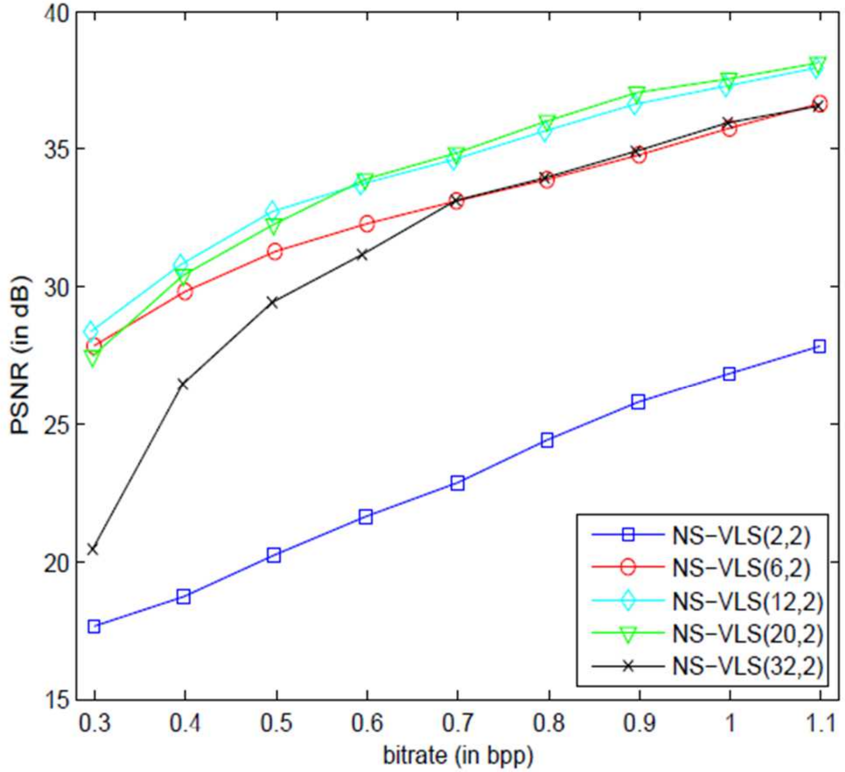
- **Bjontegaard metric of different encoding schemes**
  - The average PSNR, SSIM and bitrate saving gains of NS-VLS(2,2) with respect to SEP-VLS(2,2) using Bjontegaard metric

Objects	bitrate saving (in %)	PSNR gain (in dB)	bitrate saving (in %)	SSIM gain
Bunny-1	-4.79	0.40	2.98	-0.004
Bunny-2	-9.33	0.62	4.20	-0.014
Luigi-1	-10.30	0.80	-9.59	0.026
Luigi-2	-5.26	0.43	-7.75	0.022
Girl	-3.13	0.30	-10.79	0.018
Teapot	-9.92	0.69	0.05	-0.0002

Experimental Results



"Luigi-1"



"Luigi-2"

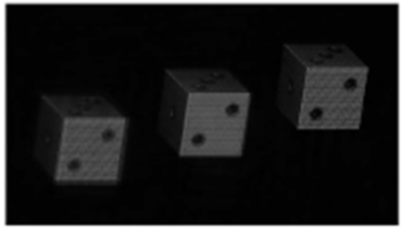
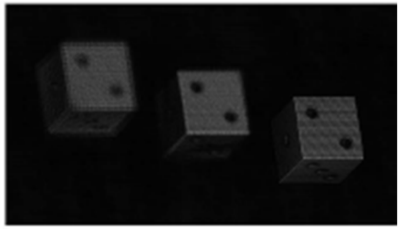
Open access database

Database with various content and data representations

- **Standard reference (computer-generated) holograms to enable researchers to evaluate and compare different codecs**
  - http://www.erc-interfere.eu/

Name	Description of hologram	Dimensions	Pixel size	Wavelength
2D Dice	2D image of a dice	1920x1080	8 μm	633 nm
3D Cat	model of a cat	8192x8192	2 μm	633 nm
3D Venus	model of a buste of Venus	1920x1080	8 μm	633 nm
2D Multi	multiple 2D dice images placed at different depths	1920x1080	8 μm	633 nm
3D Multi	multiple 3D dices placed at different depths	1920x1080	8 μm	633 nm



D. Blinder et al. Open Access Database for Experimental Validations of Holographic Compression Engines, QoMEX’2015, Messinia, Greece, May 2015.

Concluding remarks

Concluding remarks

- **Further investigations**
  1. **Experiments on a wider parameter space**
  2. **More complex scenes**
  3. **Better quality assessment methodology**

- **Open issue:**
  1. **Compress/transmit the hologram, or rather**
  2. **Transmit a representation of the 3D scene and compute the hologram at the display end**

Further reading

- Y. Xing, M. Kaaniche, B. Pesquet-Popescu and F. Dufaux, Vector lifting scheme for phase-shifting holographic data compression, Optical Engineering, 2014.
- Y. Xing, M. Kaaniche, B. Pesquet-Popescu and F. Dufaux, Adaptive non separable vector lifting scheme for digital holographic data compression, Applied Optics, 2015.
- D. Blinder, A. Ahar, A. Symeonidou, Y. Xing, T. Bruylants, C. Schretter, B. Pesquet-Popescu, F. Dufaux, A. Munteanu, P. Schelkens, Open Access Database for Experimental Validations of Holographic Compression Engines, QoMEX'2015, Messinia, Greece, May 2015.
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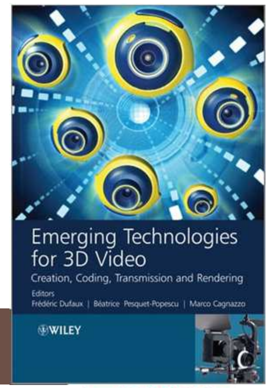

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- A.E. Shortt, T.J. Naughton, and B. Javidi. Histogram approaches for lossy compression of digital holograms of three-dimensional objects. IEEE Transactions on, Image Processing, June 2007.
- A. E. Shortt, T. J. Naughton and B. Javidi, “Compression of digital holograms of three-dimensional objects using wavelets,” Optics Express 14(7), 2625–2630 (2006).
- E. Darakis and J. Soraghan, “Use of fresnelets for phase-shifting digital hologram compression,” IEEE Transactions on Image Processing 15(12), 3804–3811 (2006).
- K. Viswanathan, P. Gioia, and L. Morin, Wavelet compression of digital holograms: towards a view-dependent framework, Proc. SPIE Applications of Digital Image Processing XXXVI, 2013.
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- D. Blinder, T. Bruylants, H. Ottevaere, A. Munteanu, and P. Schelkens, “JPEG 2000-based compression of fringe patterns for digital holographic microscopy,” Optical Engineering, vol. 53, no. 12, p. 123102, 2014.

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Any questions ?

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