FAST PATTERN MATCHING IN 3D IMAGES ON GPUS

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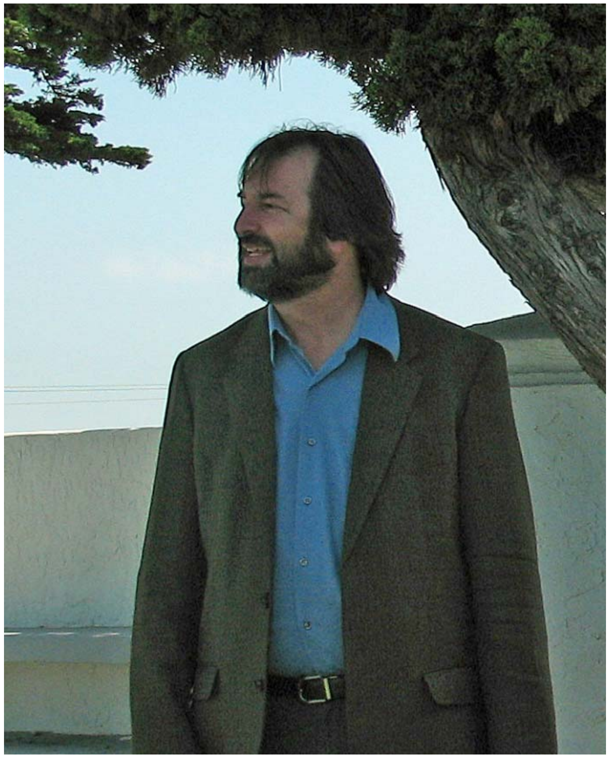
ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΟΝΙΚΗΣ

In Memory of Dennis M. Healy, Jr.



July 2007
Contributed by Mary Healy Hambric

Outline

- LCCs : local correlation coefficients
  - application requirements
  - computational challenges
  - recent progress
- Fast LCC
  - Algorithmic acceleration
  - Architectural acceleration (on GPUs)
- Building blocks
  - In image processing and information processing
- Conclusion

Fast Convolution or Correlation

Convolution (Correlation) Theorem

$$F(h * g) = F(h) \cdot F(g)$$

$$h * g = F^{-1}(\, F(h) \cdot F(g)\,)$$

Discrete Version

Equally spaced sampling

Periodic convolution : padding otherwise

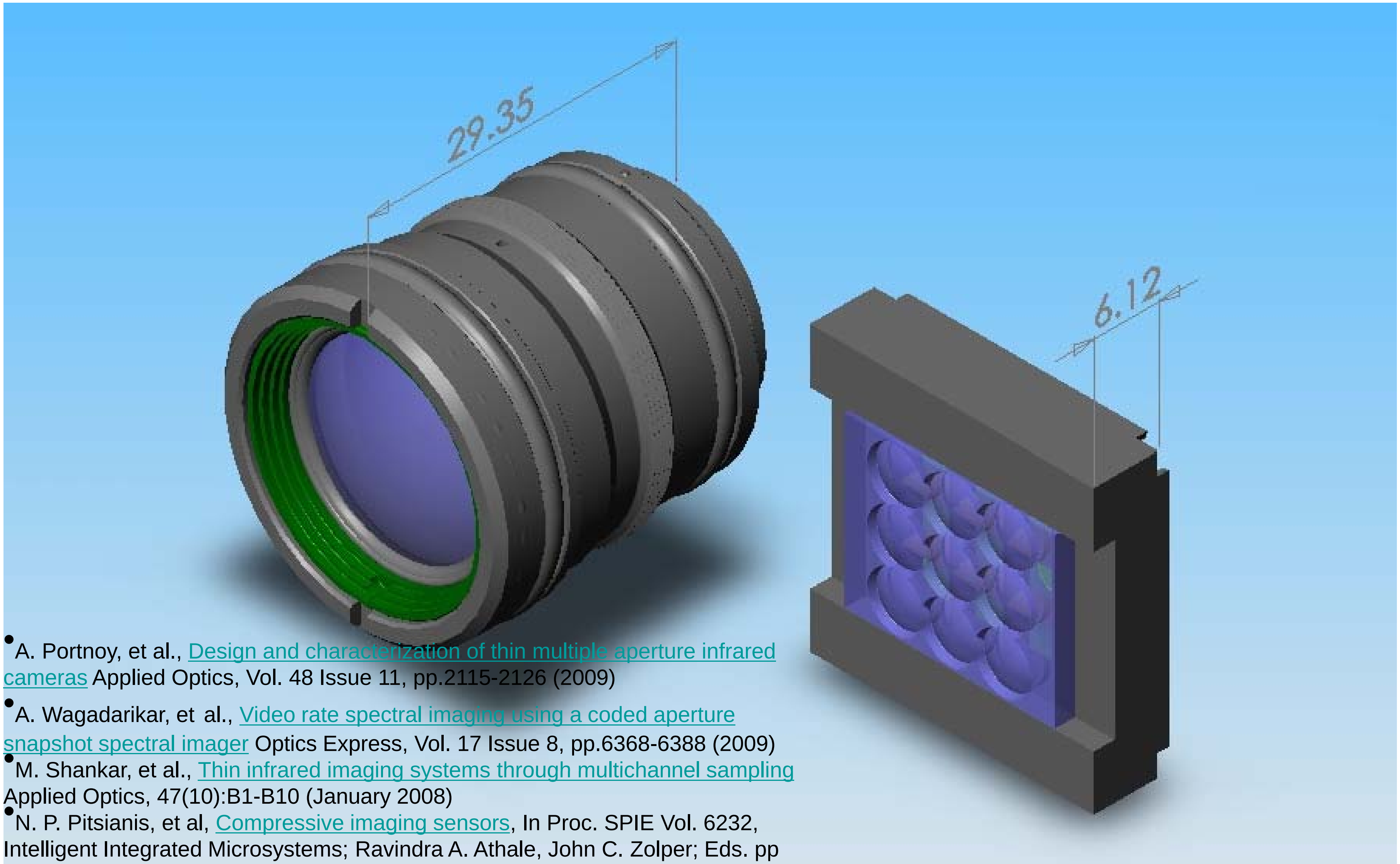
FFT : O(N log(N))

Local Correlation Coefficients (LCCs)

- Calculating the LCCs of a prototype-pattern with all patches in a large image
  - A basic operation in image registration, object classification and recognition, target identification and tracking
  - Statistically robust to local changes and noise

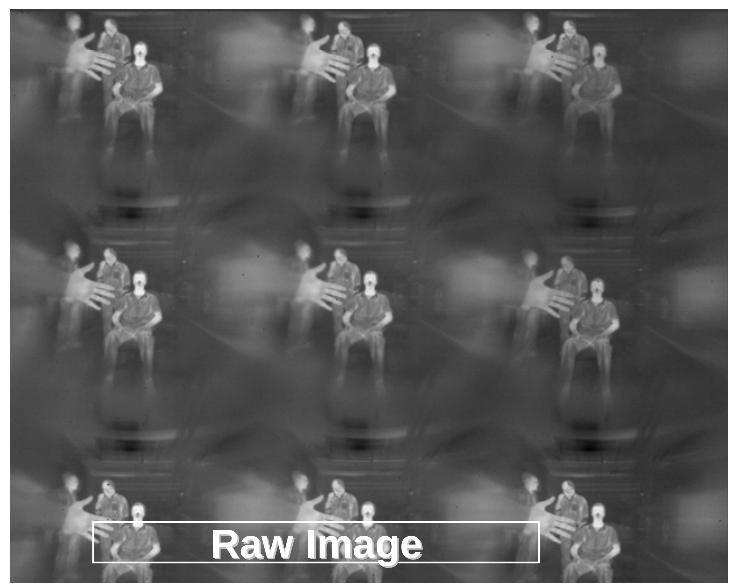
- Fast calculation of LCCs without compromising integrity
  - in many situations, rapid computation of LCCs was based on relaxed linearized conditions, to avoid local translation in mean and normalization in variance
  - "Fast LCC with ***local*** zero-mean translation and unit-variance normalization", Sun & Pitsianis 2008

Applications: MONTAGE

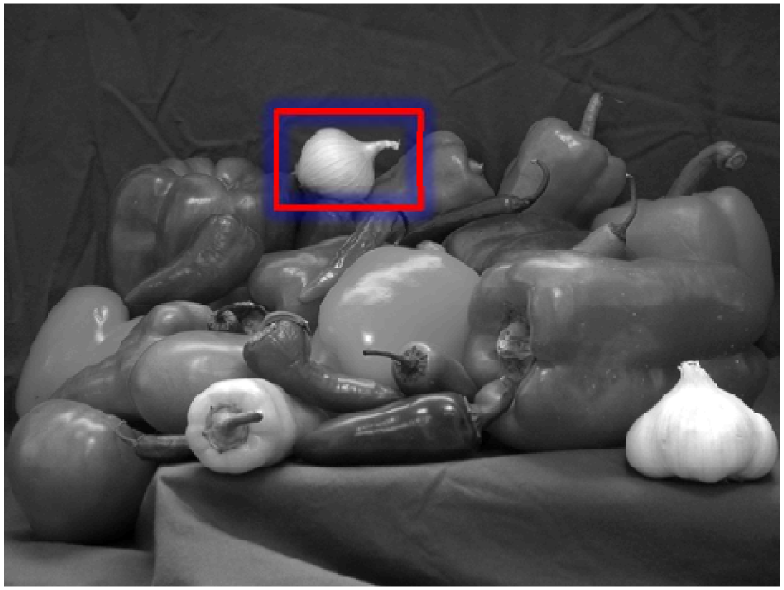


- A. Portnoy, et al., Design and characterization of thin multiple aperture infrared cameras Applied Optics, Vol. 48 Issue 11, pp.2115-2126 (2009)
- A. Wagadarikar, et al., Video rate spectral imaging using a coded aperture snapshot spectral imager Optics Express, Vol. 17 Issue 8, pp.6368-6388 (2009)
- M. Shankar, et al., Thin infrared imaging systems through multichannel sampling Applied Optics, 47(10):B1-B10 (January 2008)
- N. P. Pitsianis, et al, Compressive imaging sensors, In Proc. SPIE Vol. 6232, Intelligent Integrated Microsystems; Ravindra A. Athale, John C. Zolper; Eds. pp 43-51, May 2006

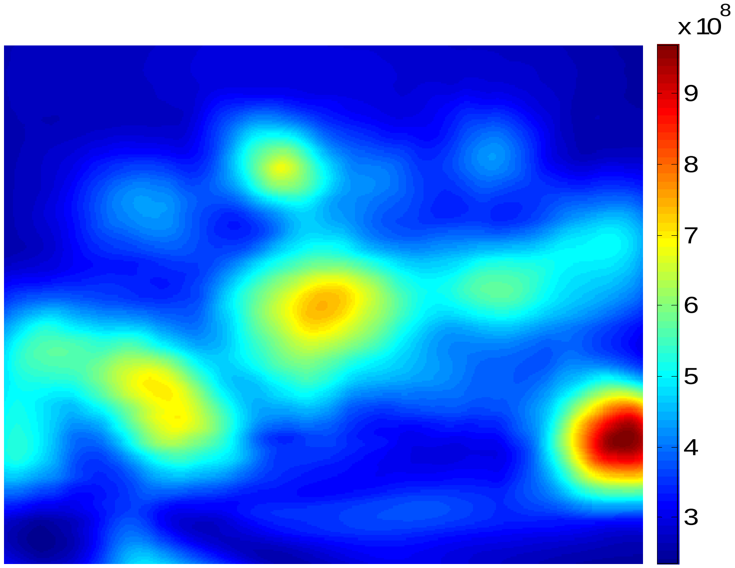
Sub-pixel Image Registration



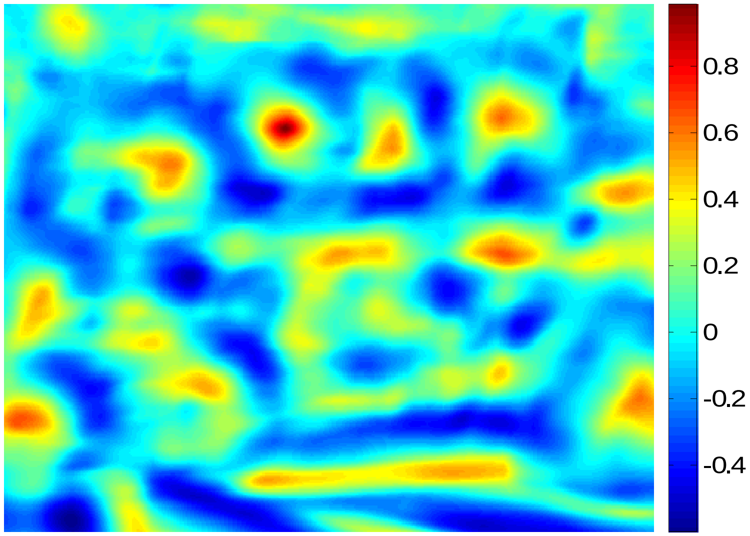
Template Matching



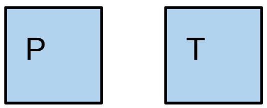
Without Local Normalization



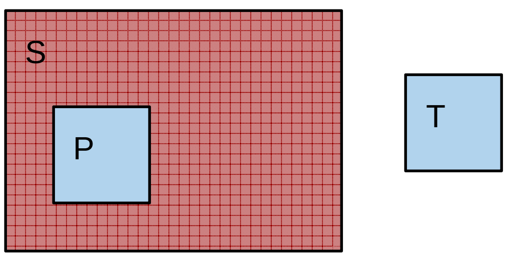
With Local Normalization



Local Correlation Coefficients

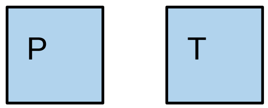


$$corr(P,T) = \sum_{(x,y)} P(x,y) \cdot T(x,y)$$

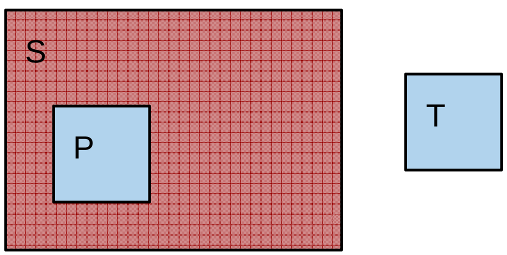


$$corr(S,T)_{(u,v)} = \sum_{(x,y)} S(x,y;u,v) \cdot T(x,y)$$

Normalized Local Correlation Coefficients



$$c(P,T) = \sum_{(x,y)} \frac{P(x,y)-\mu_P}{\sigma_P} \cdot \frac{T(x,y)-\mu_T}{\sigma_T}$$



$$c(S,T)_{(u,v)} = \sum_{(x,y)} \frac{S(x,y;u,v)-\mu_{S_{(u,v)}}}{\sigma_{S_{(u,v)}}} \cdot \frac{T(x,y)-\mu_T}{\sigma_T}$$

$$\mu_T = \frac{1}{N_T} \sum_{(x,y)} T(x,y), \quad \sigma_T^2 = \frac{1}{N_T} \sum_{(x,y)} (T(x,y)-\mu_T)^2$$

X. Sun, N. P. Pitsianis, and P. Bientinesi, Fast computation of local correlation coefficients Proc. SPIE 7074, 707405 (2008)

Algorithmic Acceleration

1. **Reformulation in term of convolutions**
2. **Use of Fourier transform identities**

Reformulation in Terms of Convolutions

$$\sum_{x,y}[S(x,y;u,v)-\mu_S(u,v)]\,T(x,y) = \{S*T\}(u,v)-\frac{1}{N_T}\{S*B_T\}(u,v)\cdot\{B_S*T\}(u,v)$$

$$\{S*T\}(u,v) = \sum_{(x,y)} S(x,y;u,v)\,T(x,y)$$

$$\{S*B_T\}(u,v) = N_T\,\mu_S(u,v)$$

$$\{B_S*T\}(u,v) = \sum_{(x,y)} B_S(x,y;u,v)\,T(x,y)$$

$$\sigma_S = \sqrt{S^2 * B_T - N_T\mu_S^2}$$

Fast LCC in the Fourier Domain

A. $F(B_T)$, $F(B_S)$, $F(T)$, $F^{-1}(F(T) \cdot F(B_S))$
% pre-calculated

B. $F(S + i \cdot S^2)$
% to obtain $F(S)$, $F(S^2)$

C. $F^{-1}(F(S) \cdot F(B_T) + i \cdot F(S^2) \cdot F(B_T))$
% to obtain $S * B_T$ and $S^2 * B_T$

D. $F^{-1}(F(S) \cdot F(T))$
% to obtain $S * T$.

2.5 FFTs per image

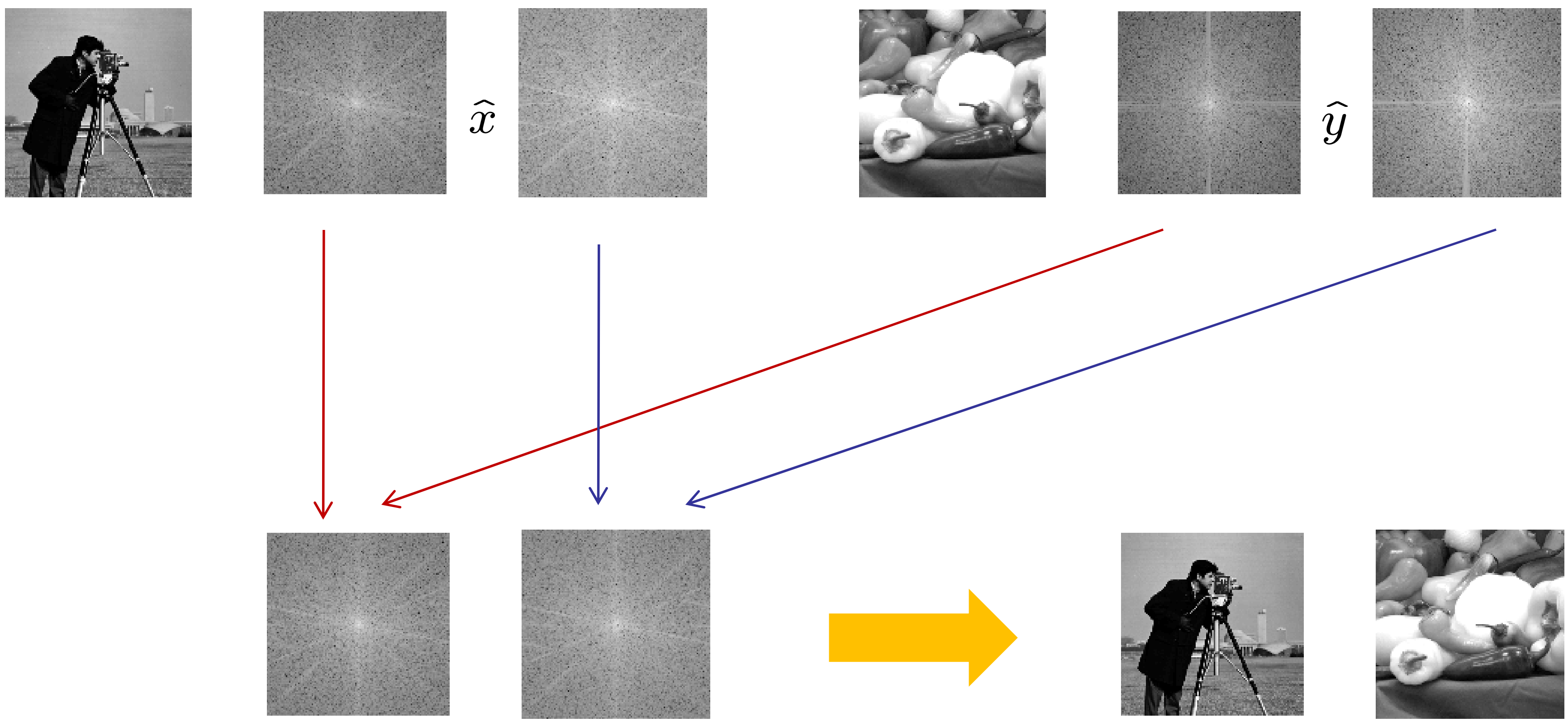
DFT Identity with real data : Two by one

Let $\widehat{z} = F(x + i\, y)$ then

$$
\begin{aligned}
2\,\widehat{x} &= (I+J)\widehat{z}_{\mathrm{R}} + i(I-J)\widehat{z}_{\mathrm{I}} \\
2\,\widehat{y} &= (I+J)\widehat{z}_{\mathrm{I}} - i(I-J)\widehat{z}_{\mathrm{R}}
\end{aligned}
$$

$$x + i\, y = F^{-1}(\widehat{x} + i\, \widehat{y})$$

Illustration of Two-by-One identity



$$\widehat{x} + i\ \widehat{y}$$

$$x + i\ y = F^{-1}(\widehat{x} + i\ \widehat{y})$$

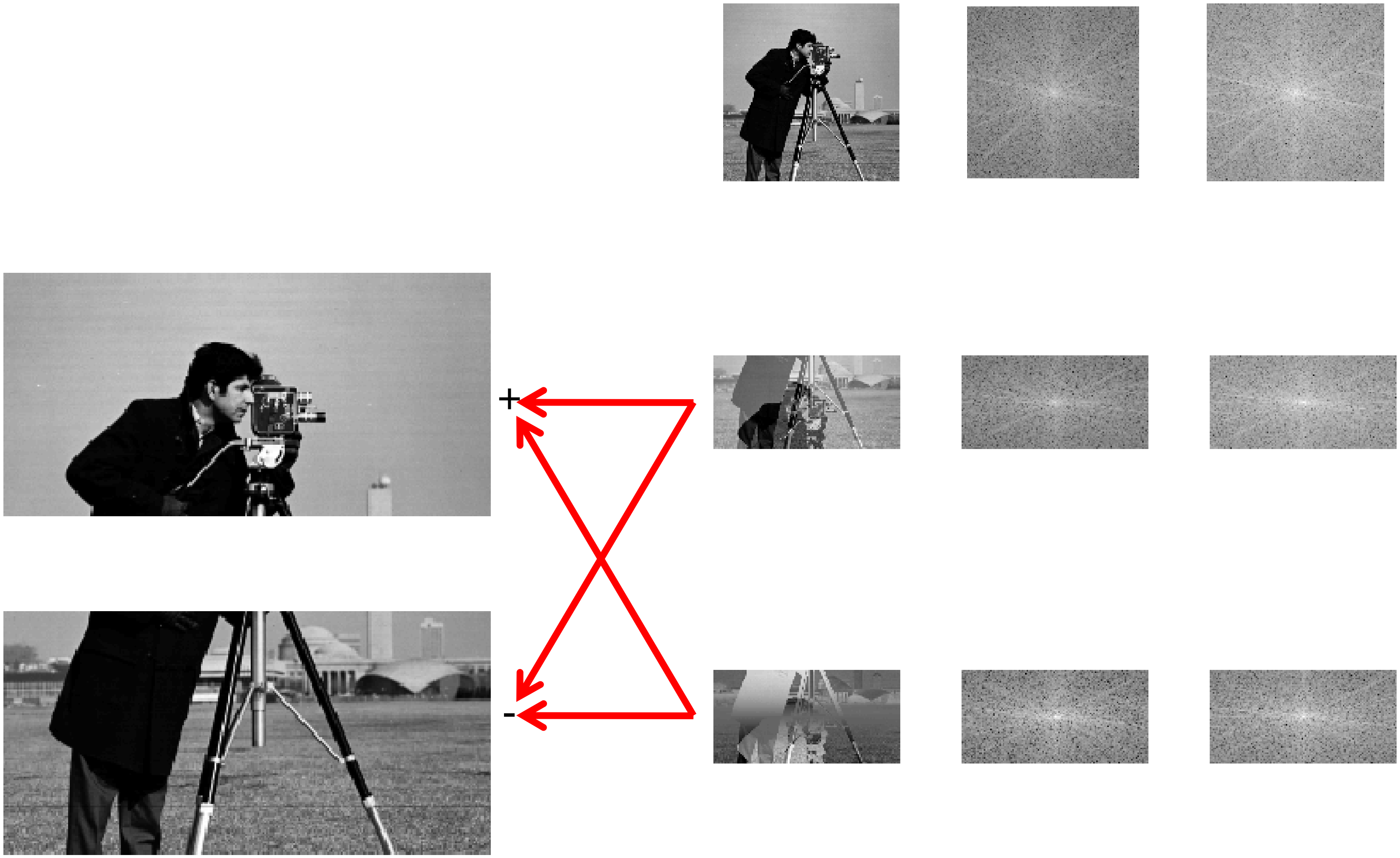
DFT Identity : One-by-Half

$$w = \omega_n^{(0:\frac{n}{2}-1)}$$

$$\begin{bmatrix} \hat{x}_{\mathsf{T}} \\ \hat{x}_{\mathsf{B}} \end{bmatrix} = \begin{bmatrix} F x_{\mathsf{E}} + w \odot F x_{\mathsf{O}} \\ F x_{\mathsf{E}} - w \odot F x_{\mathsf{O}} \end{bmatrix}$$

$$\begin{bmatrix} x_{\mathsf{T}} \\ x_{\mathsf{B}} \end{bmatrix} = \begin{bmatrix} F^{-1} \hat{x}_{\mathsf{E}} + \bar{w} \odot F^{-1} \hat{x}_{\mathsf{O}} \\ F^{-1} \hat{x}_{\mathsf{E}} - \bar{w} \odot F^{-1} \hat{x}_{\mathsf{O}} \end{bmatrix}$$

Illustration of One-by-Half



Architectural Acceleration

1. Necessary complement of fast algorithms in real-time image processing or massive data processing

2. The use of GPUs in particular
   - omnipresent in desktops, laptops
   - a prototype of parallel architecture
     - many-core
     - memory hierarchy
     - bandwidth
     - programming model
     - 3D image processing

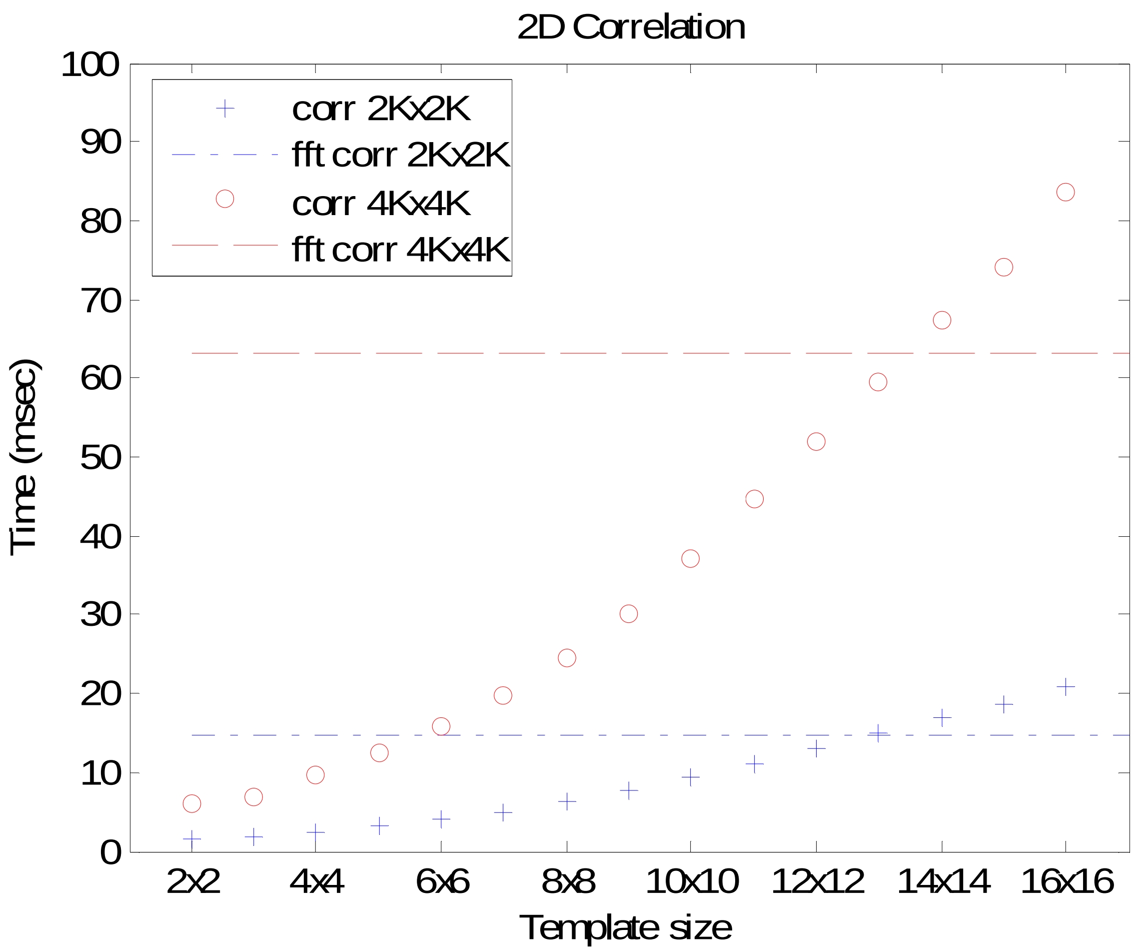
2D Convolution on CPU and GPU

Data Size	Xeon 1 core @ 1.86GHz		C1060 @ 1.35 GHz
	double	float	float
$2K \times 2K$	931	674	14
$4K \times 4K$	4,223	3,210	63

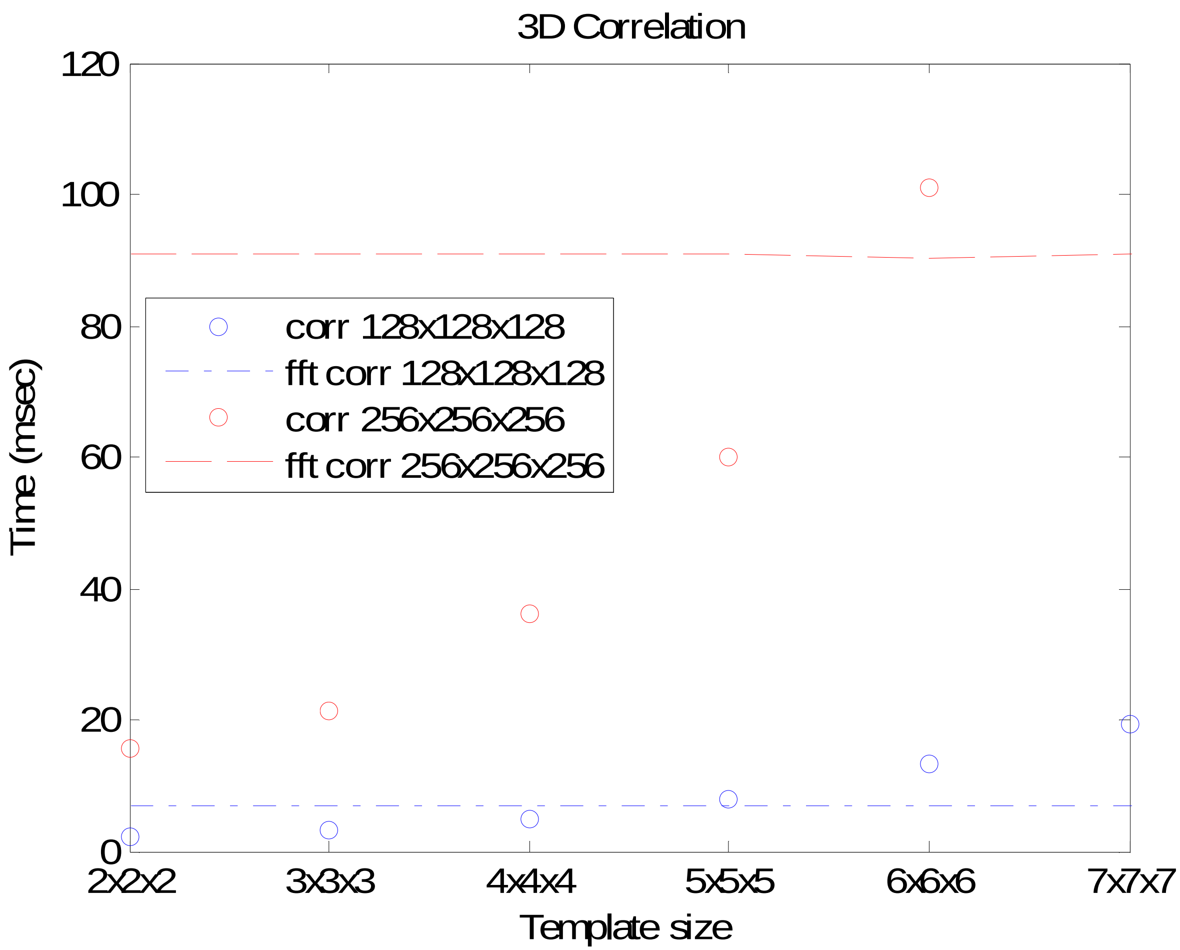
Execution time (**msec)**

FFTW 3.1.2 on Xeon
CUDA SDK 2.3 **CUFFT** on GPU

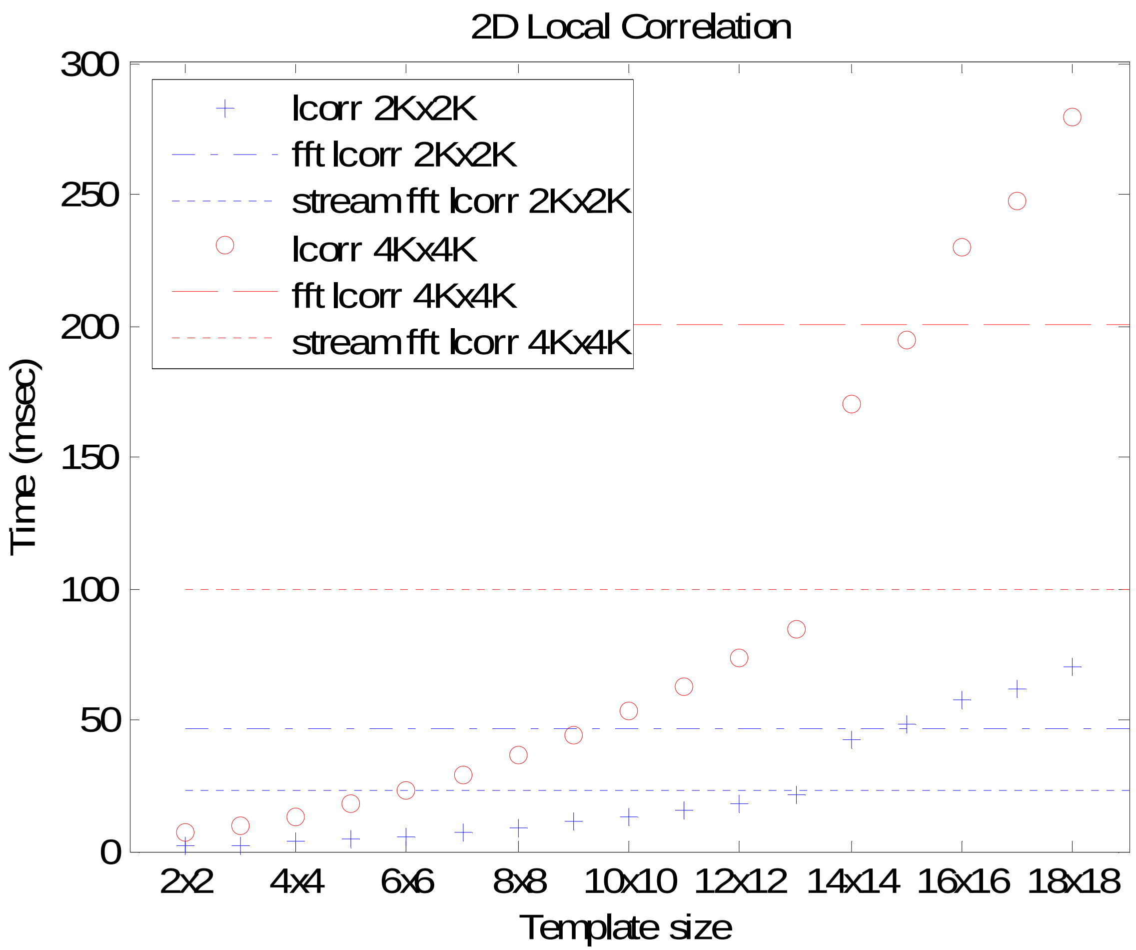
Algorithmic Acceleration of 2D Convolution



Algorithmic Acceleration of 3D Convolution



GPU Acceleration of 2D LCCs



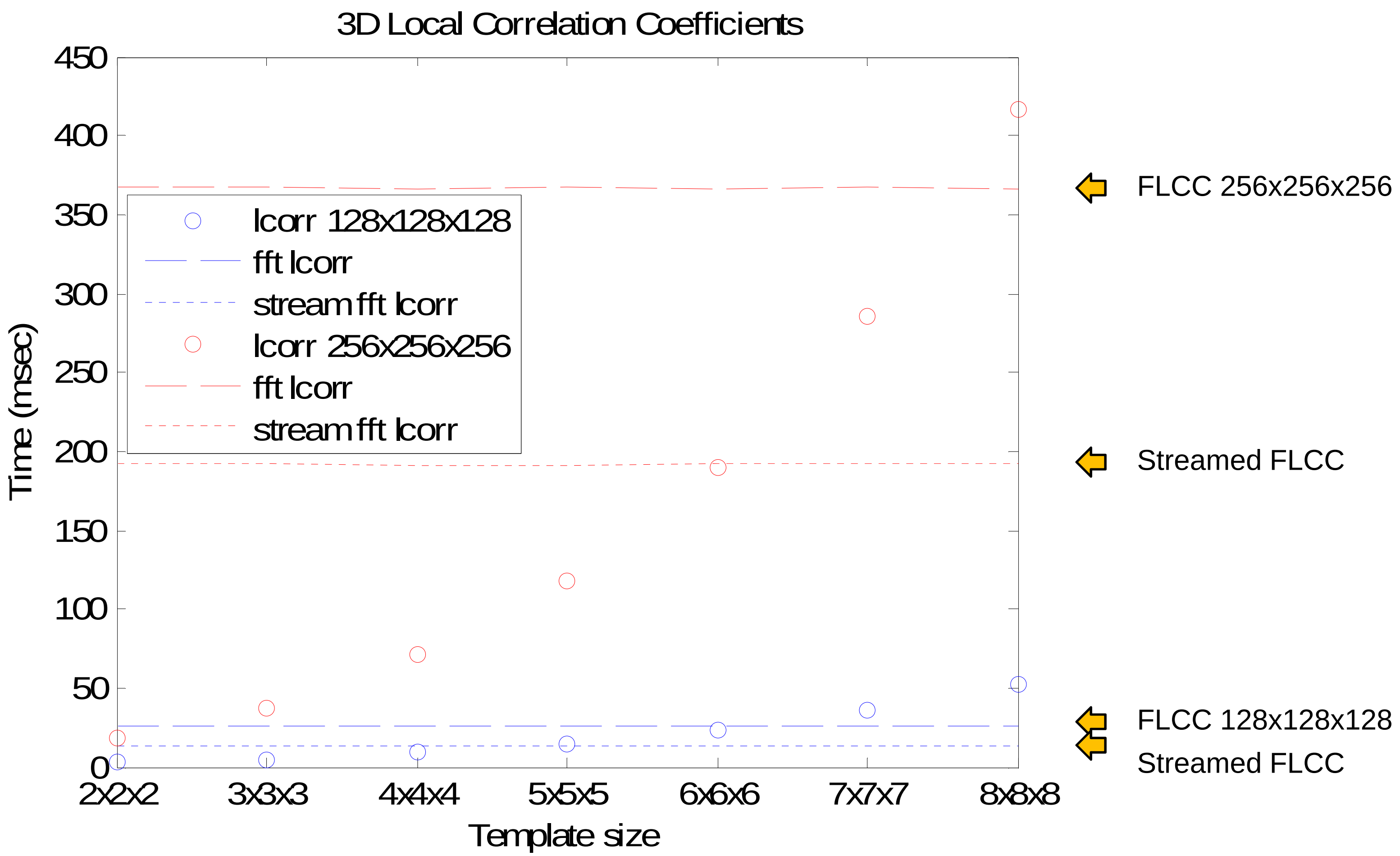
FLCC 4Kx4K

Streamed FLCC 4Kx4K

FLCC 2Kx2K

Streamed FLCC 2Kx2K

GPU Acceleration of 3D LCCs



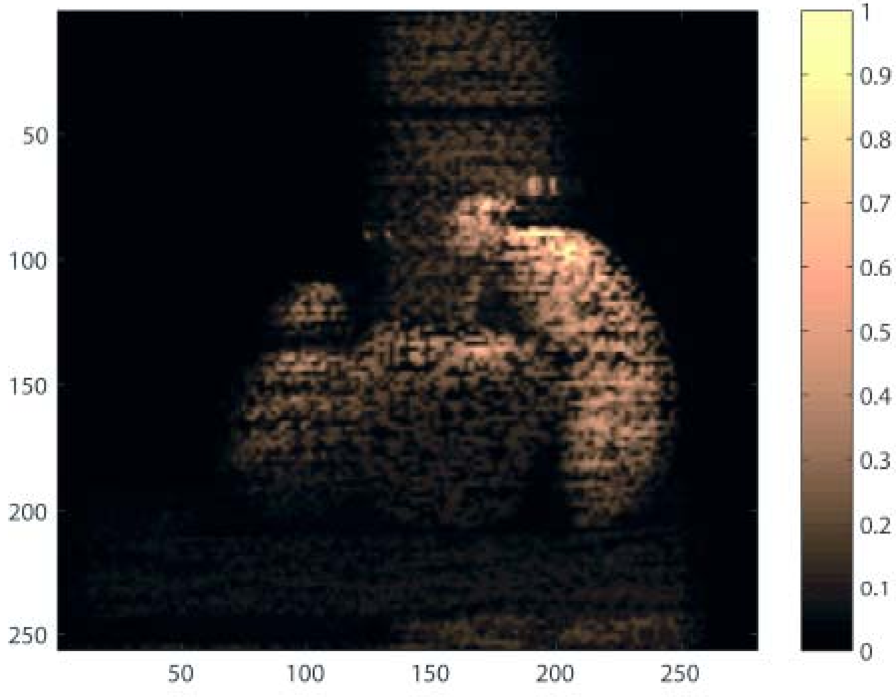
Building Blocks

1. In image processing

2. In data modeling & information processing

Fast Deconvolution with Incomplete Data

Construction of spectral images from coded intensity data

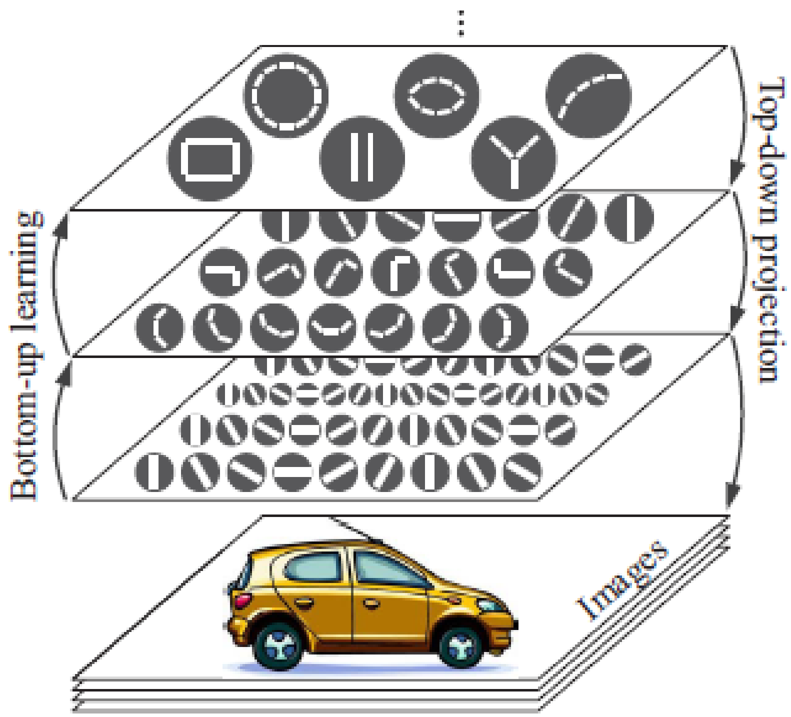


X. Sun and N. P. Pitsianis (2008)

Hierarchical Data Indexing & Fast Feature Matching

Object Feature Extraction in Multiple Layers

- *Simple and densely populated* features at lower layers
- *Complex but sparse* features at higher layers



S. Fidler, G. Berginc, A. Leonardis, Proc IEEE CVPR (2006)

Conclusions

- Convolution/correlation, LCCs important in new and conventional applications
- Reformulation critical in designing fast algorithms without compromising quality
- Joint algorithmic and architectural accelerations
- Efficient implementation of fast algorithms on modern parallel architectures

Acknowledgments

- **FANTOM** : Algorithm-Architecture Co-design
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- AutoGPU
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