Performance Evaluation of Full Search Equivalent Pattern Matching Algorithms

Wanli Ouyang, Federico Tombari,
Stefano Mattoccia, Luigi Di Stefano, and Wai-Kuen Cham

Outline

- Introduction
- Evaluation of Full Search Equivalent Algorithms
- Conclusion and contribution

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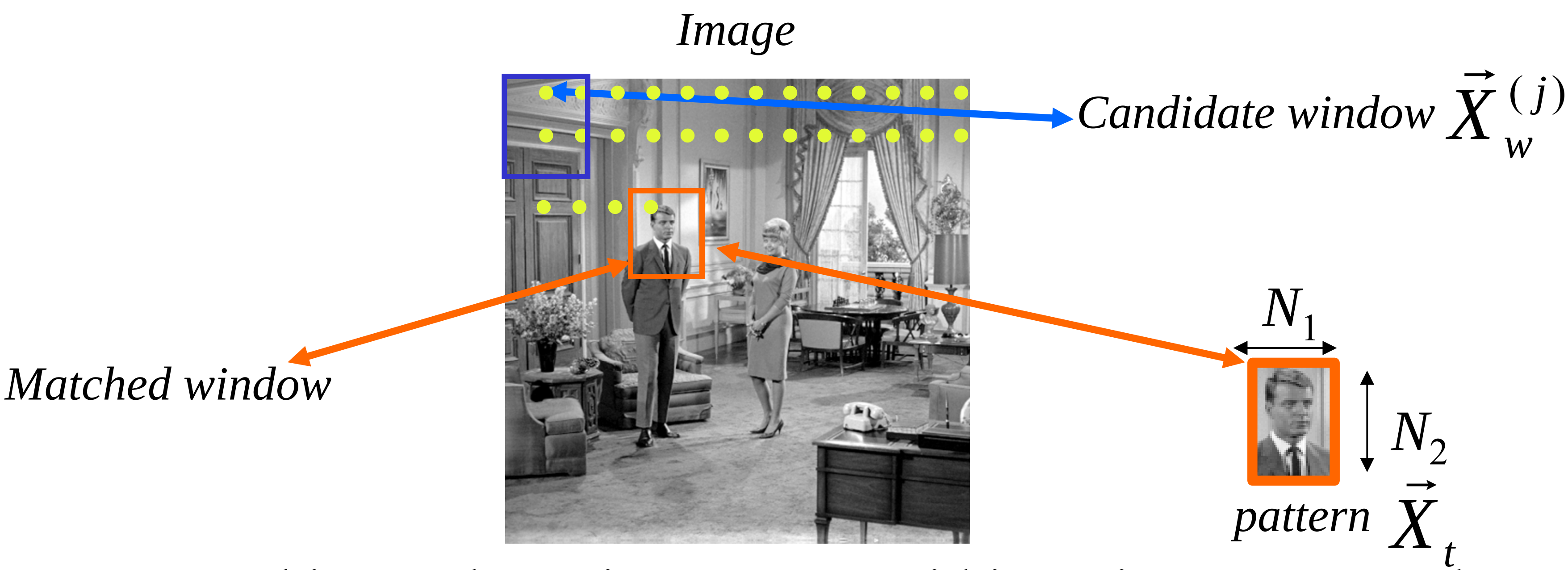
- **Introduction**
  - **Pattern matching and app.**
  - Full search equvialent algorithms
- Evaluation of Full Search Equivalent Algorithms
- Conclusion and contribution

Pattern (or Template) Matching



Pattern matching seeks a given pattern within an image. For each candidate window, the distance between window and pattern is calculated:

$$d(\vec{X}_t, \vec{X}_w^{(j)}), \quad e.g. \| \vec{X}_t - \vec{X}_w^{(j)} \|_2^2$$

The smaller is the distance, the more similar is the window to the pattern. In practice: $d(\vec{X}_t, \vec{X}_w^{(j)}) \le T$ ==> match!

Application: Pattern (or Template) Matching

- Image based rendering, image compression, object detection, **super resolution**, texture synthesis, block matching in motion estimation, **image denoising**, road/path tracking, mouth tracking, **wide baseline image matching** and action recognition …

W. Freeman, T. Jones, and E. Pasztor. Example-based superresolution. *IEEE Computer Graphics and Applications*, 22(2):56–65, Mar./Apr 2002.

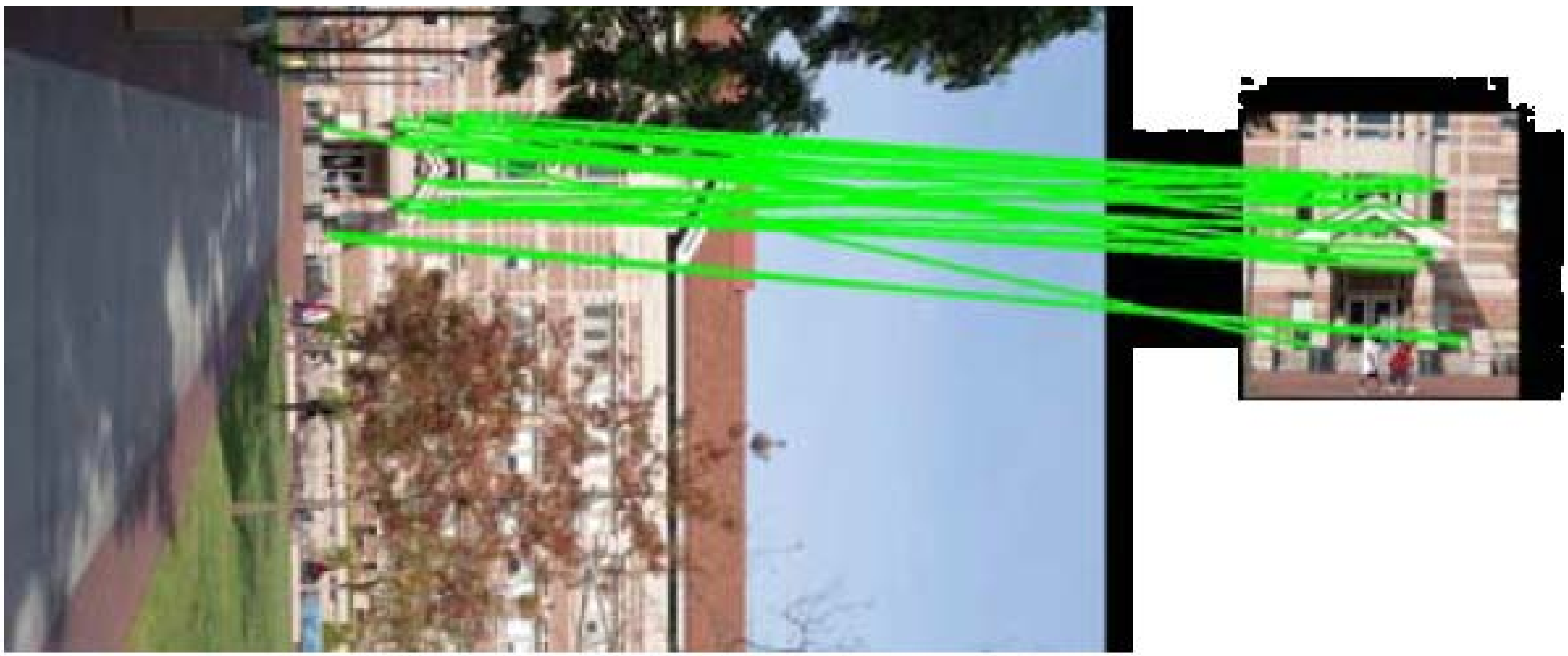
A. Buades, B. Coll, and J.-M. Morel. A non-local algorithm for image denoising. In *CVPR*, volume 2, pages 60– 65, Jun. 2005.

Q. Wang and S. You. Real-time image matching based on multiple view kernel projection. In *CVPR*, 2007.

Wide baseline image matching

Cited **5** times on Google Scholar

[PDF] **Real-time image matching based on multiple view kernel projection**
Q Wang, S You - IEEE Conference on Computer Vision and Pattern ..., 2007 - cs.ualberta.ca
Abstract This paper proposes a novel **matching** method for **real- time** finding the correspondences among different images containing the same object. The method utilizes an efficient **Kernel Projection** scheme to descript the **image** patch around a detected feature point. In order to achieve **...**
Cited by 5 - Related articles - View as HTML - All 4 versions



Q. Wang and S. You. Real-time image matching based on multiple view kernel projection. In *CVPR*, 2007.

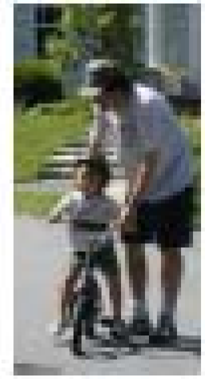
Image denoising

Cited **218 times** on Google Scholar

[PDF] A non-local algorithm for image denoising
A Buades, B Coll, J Morel - ... Society Conference on Computer Vision and ..., 2005 - Citeseer
We propose **a** new measure, the method noise, to evalu- ate and compare the performance of digital **image** denois- ing methods. We first compute and analyze this method noise for **a** wide class of **denoising algorithms**, namely the local smoothing filters. Second, we propose **a ...**
Cited by 218 - Related articles - View as HTML - BL Direct - All 13 versions

A. Buades, B. Coll, and J.-M. Morel. A non-local algorithm for image denoising. In *CVPR*, volume 2, pages 60– 65, Jun. 2005.

Super resolution



[Example-based super-resolution]
WT Freeman, TR Jones, EC ... - IEEE Computer ..., 2002 - doi.ieeecomputersociety.org
Polygon-based representations of 3D objects offer resolution independence over a wide range of scales. With this approach, object boundaries remain sharp when we zoom in on an object until very close range, where faceting appears due to finite polygon size (see Figure 1). **...**
Cited by 398 - Related articles - BL Direct - All 11 versions

Cited **398** times on Google Scholar

W. Freeman, T. Jones, and E. Pasztor. Example-based superresolution. *IEEE Computer Graphics and Applications*, 22(2):56–65, Mar./Apr 2002.

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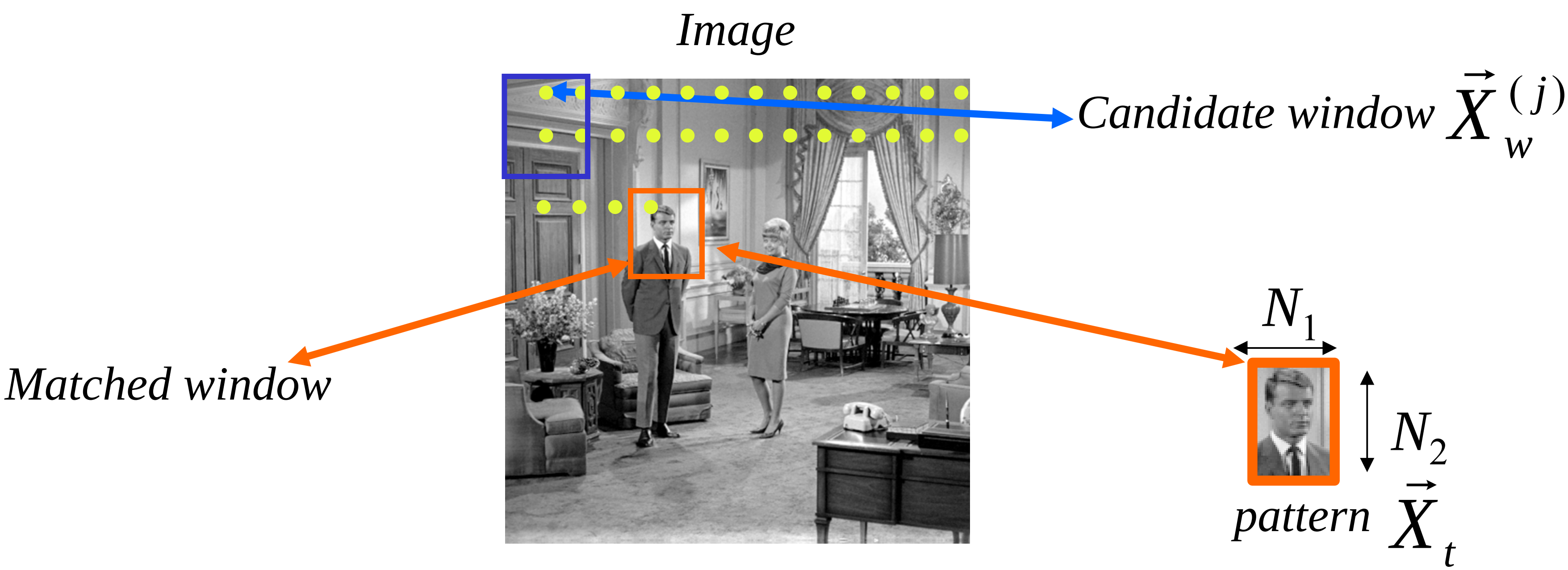
Full search (Exhaustive search)



Evaluate $d(\vec{X}_t, \vec{X}_w^{(j)})$ for every candidate window

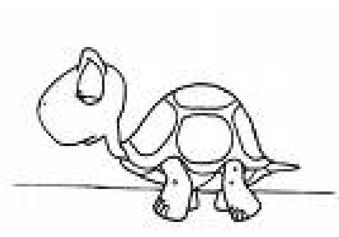
Slow, bench mark

Full search equivalent algorithms: same result, faster

Full search equivalent pattern matching using lower bound

Pattern *Candidate window*

$$d(\vec{X}_t, \vec{X}_w^{(j)}) \le T$$ ==> match!



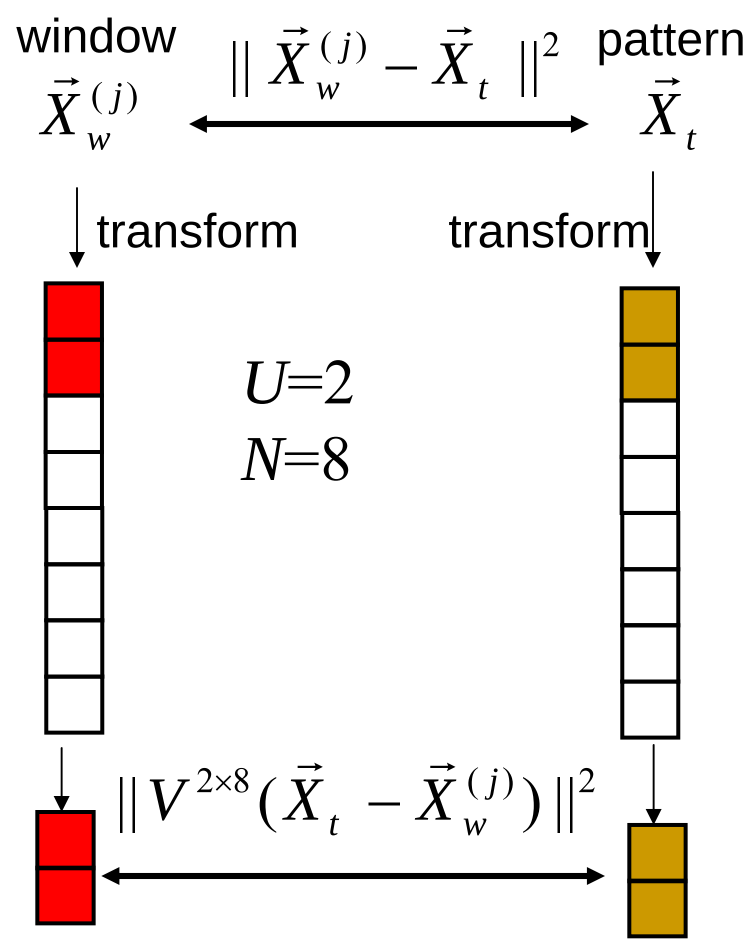
$$d(\vec{X}_t, \vec{X}_w^{(j)}) \ge f_{low}(\vec{X}_t, \vec{X}_w^{(j)})$$

$$f_{low}(\vec{X}_t, \vec{X}_w^{(j)}) > T$$

=> $d(\vec{X}_t, \vec{X}_w^{(j)}) > T$ => Mismatch!

Example (U<<N):

$$\| \vec{X}_t - \vec{X}_w^{(j)} \|^2 \ge \| V^{U \times N} (\vec{X}_t - \vec{X}_w^{(j)}) \|^2 > T$$

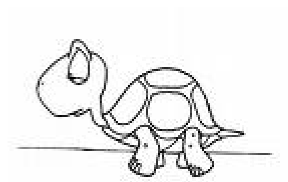


Full search equivalent pattern matching using lower bound

$$\left\| \begin{bmatrix} x_{w,0} - x_{t,0} \\ x_{w,1} - x_{t,1} \\ x_{w,2} - x_{t,2} \\ x_{w,3} - x_{t,3} \\ x_{w,4} - x_{t,4} \\ x_{w,5} - x_{t,5} \\ x_{w,6} - x_{t,6} \\ x_{w,7} - x_{t,7} \end{bmatrix} \right\|^2$$

window $\vec{X}_w^{(j)}$ $\quad \| \vec{X}_w^{(j)} - \vec{X}_t \|^2 \quad$ pattern $\vec{X}_t$

transform $\qquad$ transform



U=2

N=8

$$\left\| \begin{bmatrix} y_{w,0} - y_{t,0} \\ y_{w,0} - y_{t,0} \end{bmatrix} \right\|^2$$

$$\| V^{2\times 8} (\vec{X}_t - \vec{X}_w^{(j)}) \|^2$$

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Y. Hel-Or and H. Hel-Or. Real time pattern matching using projection kernels. *TPAMI,* 27(9):1430–1445, Sept. 2005.
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W. Ouyang and W. Cham. Fast algorithm for Walsh Hadamard transform on sliding windows. *TPAMI,* 32(1):165–171, Jan. 2010.

Full search equivalent pattern matching using lower bound

Pattern　　*Candidate window*

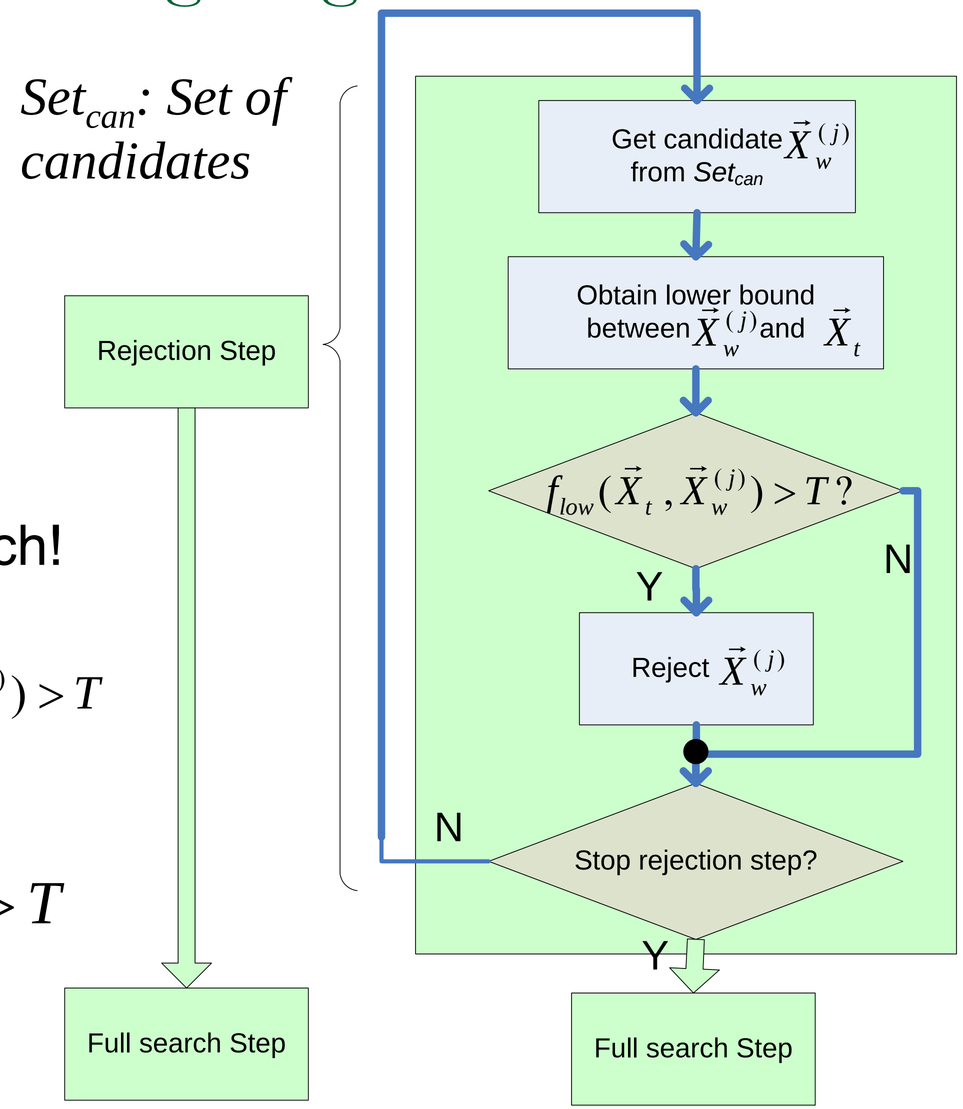
$$d(\vec{X}_t, \vec{X}_w^{(j)}) \le T \quad ==> \quad \text{match!}$$

Mismatch!

$$\left.\begin{array}{l} d(\vec{X}_t, \vec{X}_w^{(j)}) \ge f_{low}(\vec{X}_t, \vec{X}_w^{(j)}) \\ f_{low}(\vec{X}_t, \vec{X}_w^{(j)}) > T \end{array}\right\} => d(\vec{X}_t, \vec{X}_w^{(j)}) > T$$

Example (U<<N):

$$\| \vec{X}_t - \vec{X}_w^{(j)} \|^2 \ge \| V^{U \times N} (\vec{X}_t - \vec{X}_w^{(j)}) \|^2 > T$$



Recent algorithms

- 1. Alkhansari's Low Resolution Pruning (LRP) algorithm;
- 2. Hel-Or and Hel-Or's projection based algorithm (PWHT) using Walsh-Hadamard Transform (WHT);
- 3. Ben-Artzi and Hel-Ors' projection based algorithm using GCK algorithm (PGCK);
- 4. Tombari *et al.* Increasing Dissimilarity Approximation (IDA) algorithm;
- 5. Our algorithm using fast WHT (FWHT).

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2. Y. Hel-Or and H. Hel-Or. Real time pattern matching using projection kernels. *TPAMI,* 27(9):1430–1445, Sept. 2005.

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  - **The “story”**
  - Experimental results
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Pattern matching evaluation – the story

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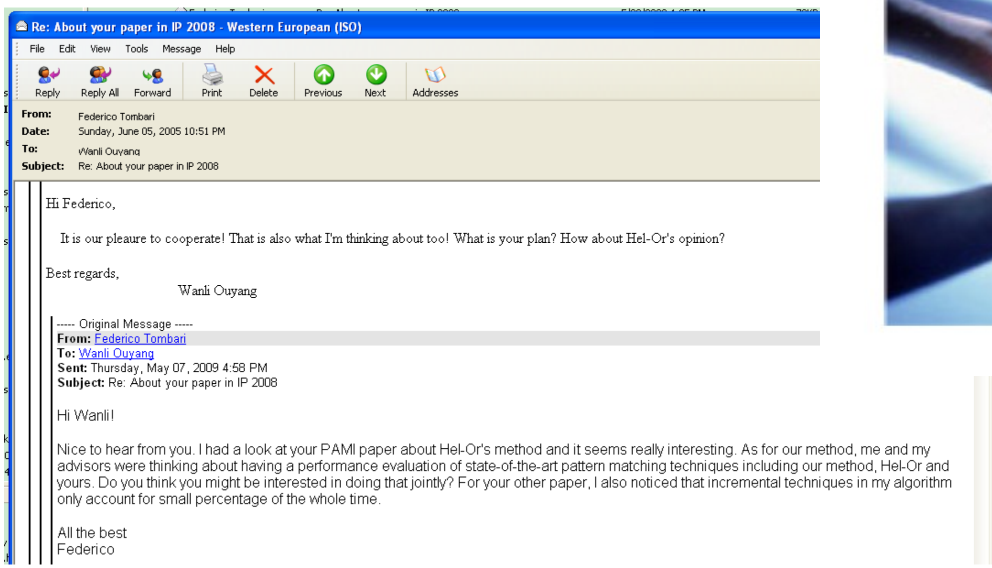
The story



Re: About your paper in IP 2008 - Western European (ISO)

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Reply Reply All Forward Print Delete Previous Next Addresses

From: Federico Tombari
Date: Sunday, June 05, 2005 10:51 PM
To: Wanli Ouyang
Subject: Re: About your paper in IP 2008

Hi Federico,

It is our pleaure to cooperate! That is also what I'm thinking about too! What is your plan? How about Hel-Or's opinion?

Best regards,
Wanli Ouyang

----- Original Message -----
From: Federico Tombari
To: Wanli Ouyang
Sent: Thursday, May 07, 2009 4:58 PM
Subject: Re: About your paper in IP 2008

Hi Wanli!

Nice to hear from you. I had a look at your PAMI paper about Hel-Or's method and it seems really interesting. As for our method, me and my advisors were thinking about having a performance evaluation of state-of-the-art pattern matching techniques including our method, Hel-Or and yours. Do you think you might be interested in doing that jointly? For your other paper, I also noticed that incremental techniques in my algorithm only account for small percentage of the whole time.

All the best
Federico

Federico Tombari

Univ. Bologna
[bə'ləunjə]
博洛尼亚大学

Stefano Mattoccia

- Dr. Tombari: I and my advisor were thinking about having a performance evaluation of state-of-the-art pattern matching techniques. Do you think you might be interested?
- We: It is our pleasure! That is what we are thinking about too!

Agreement

- Five full search equivalent.
- The Fast Fourier Transform (FFT) approach for pattern matching in OpenCV is used for comparison.
- SSD and SAD are used as dissimilarity measure.

$$\boxed{d(\vec{X}_t, \vec{X}_w^{(j)}) \le T}$$

- Aim:
  - Outline the most efficient algorithm(s) for pattern matching on datasets having different disturbance factors.
  - The datasets and code for the algorithms will be put online.
  - A benchmark against which future algorithms can be assessed.
  - The analysis for these algorithms can inspire new fast algorithms.

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Algorithms evaluated

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Datasets

300 image-pattern pairs for each dataset

Dataset	Image size	J	Pattern size	N
$Scale1-1$	160×120	19200	16×16	256
$Scale2-1$	320×240	76800	16×16	256
$Scale2-2$	320×240	76800	32×32	1024
$Scale3-1$	640×480	307200	16×16	256
$Scale3-2$	640×480	307200	32×32	1024
$Scale3-3$	640×480	307200	64×64	4096
$Scale4-1$	1280×960	1228800	16×16	256
$Scale4-2$	1280×960	1228800	32×32	1024
$Scale4-3$	1280×960	1228800	64×64	4096
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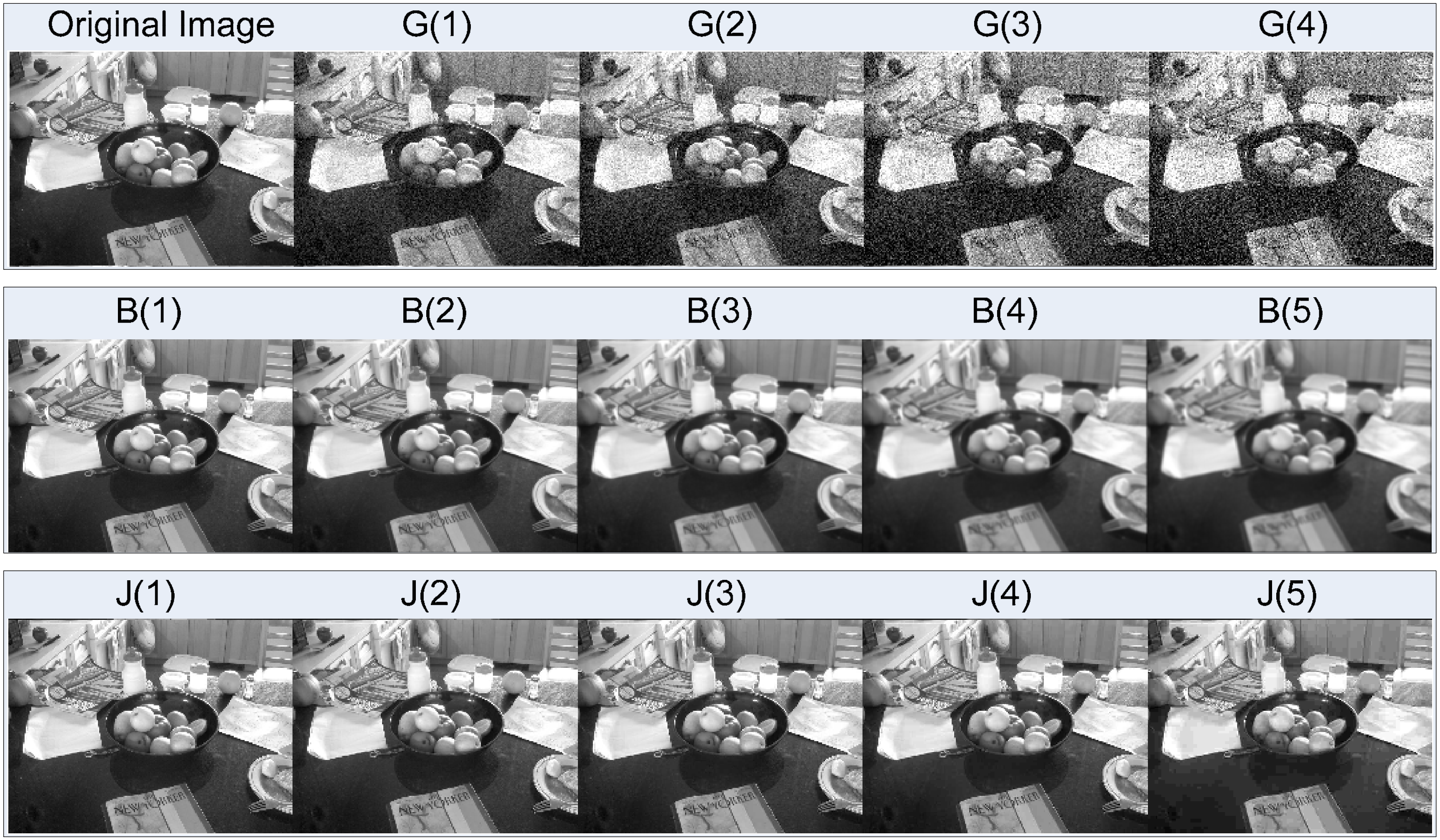
Distortion



PSNR for 512X512 “couple”

G: 23.0, 20.1, 17.2, 15.6 — Gaussian noise

B: 39.60, 35.23, 33.42, 31.75 28.05 — Gaussian blur

J: 27.46, 26.90, 25.04, 23.83, 23.18 — JPEG

Measures

- Execution time

Environment	CPU	Memory size
$Env1$	Intel core 2 (6400) 2.13GHz	3G
$Env2$	Intel Pentium 4 2.8GHz	1G
$Env3$	Intel Xeon 3GHz	2G
$Env4$	AMD	

- Number of operations. Computational analysis is provided for IDA, PGCK and FWHT.

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Time speed-ups over Full Search (No noise, SSD)

$$\frac{Time_{FS}}{Time_{PGCK}}$$

Larger => faster

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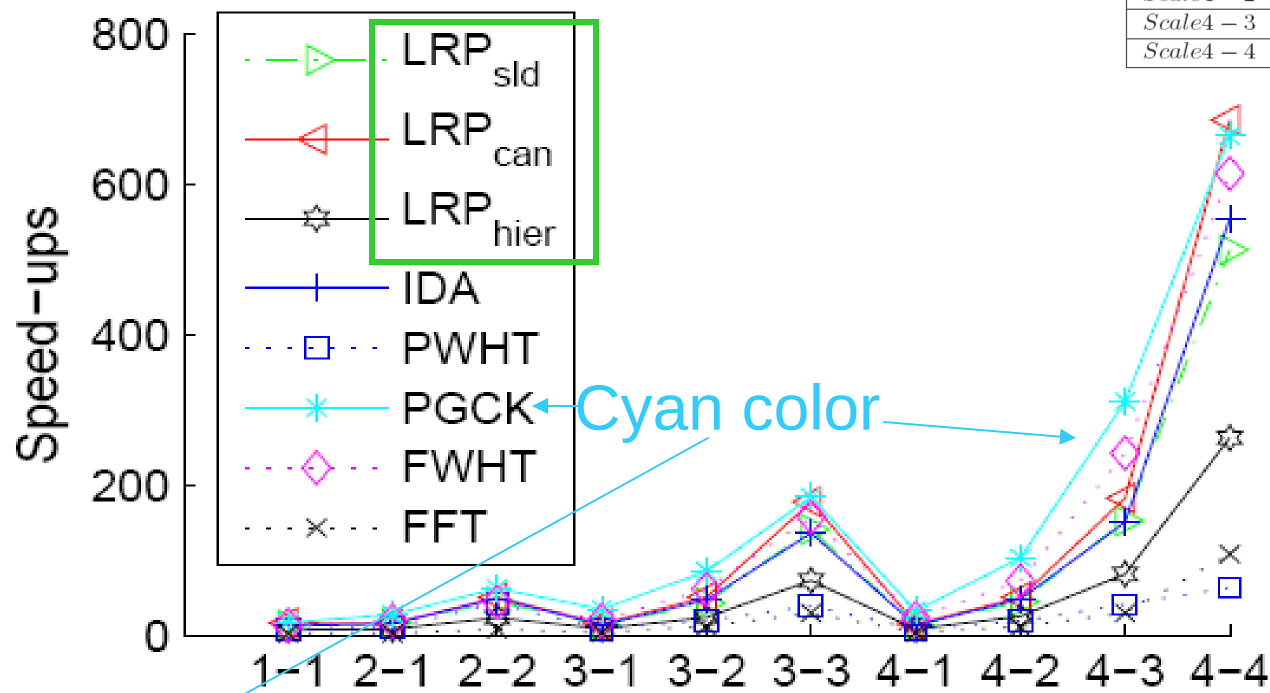

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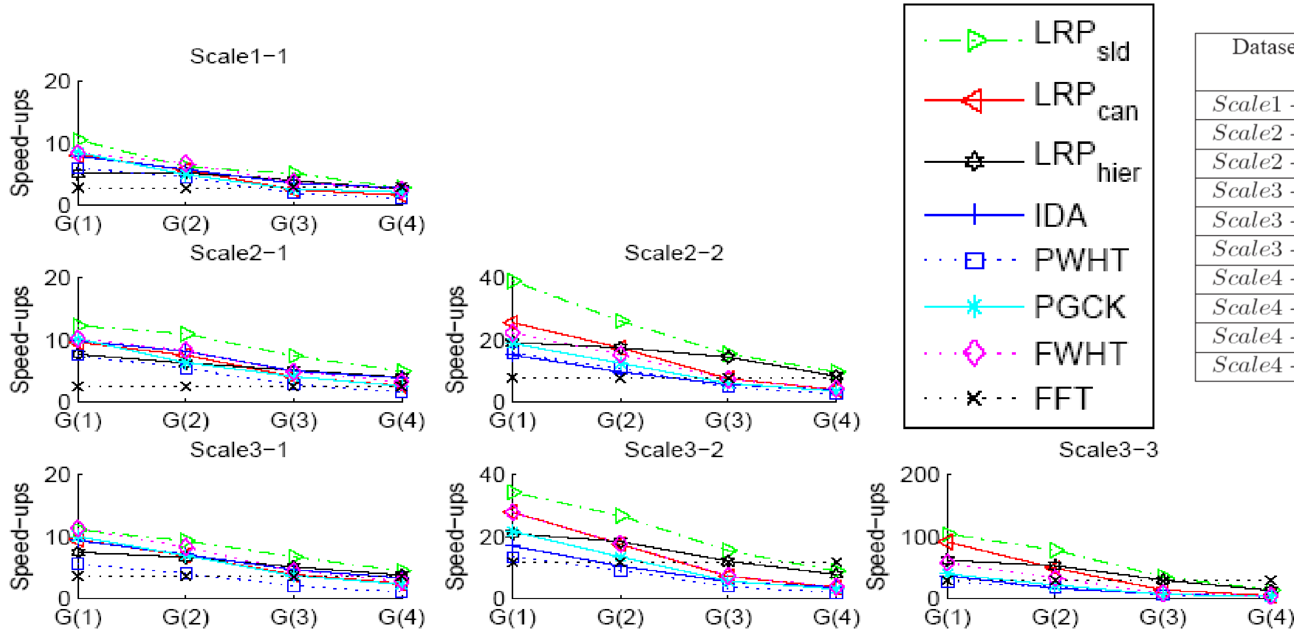
Time speed-ups over Full Search (Gaussian, SSD)



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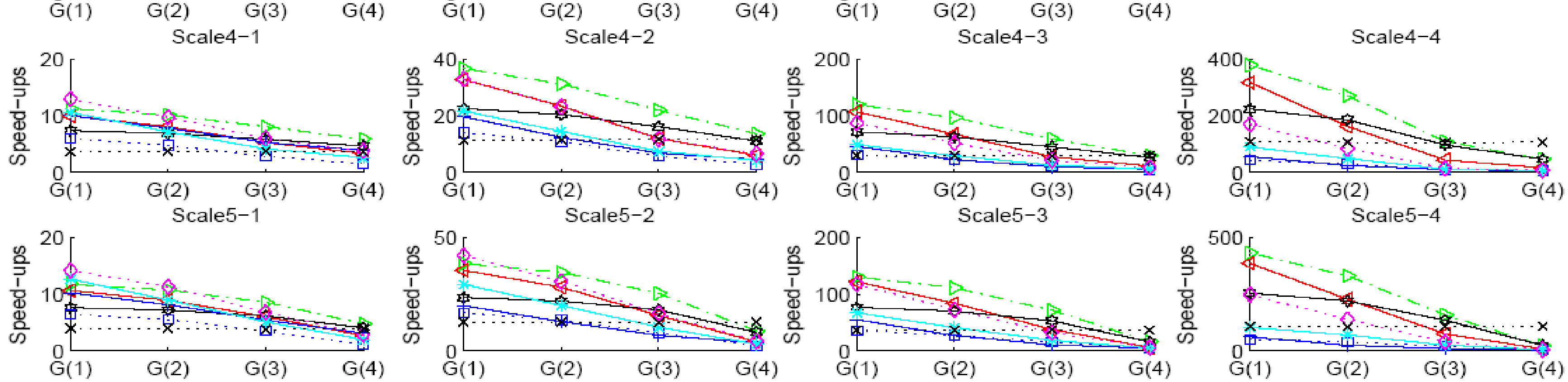

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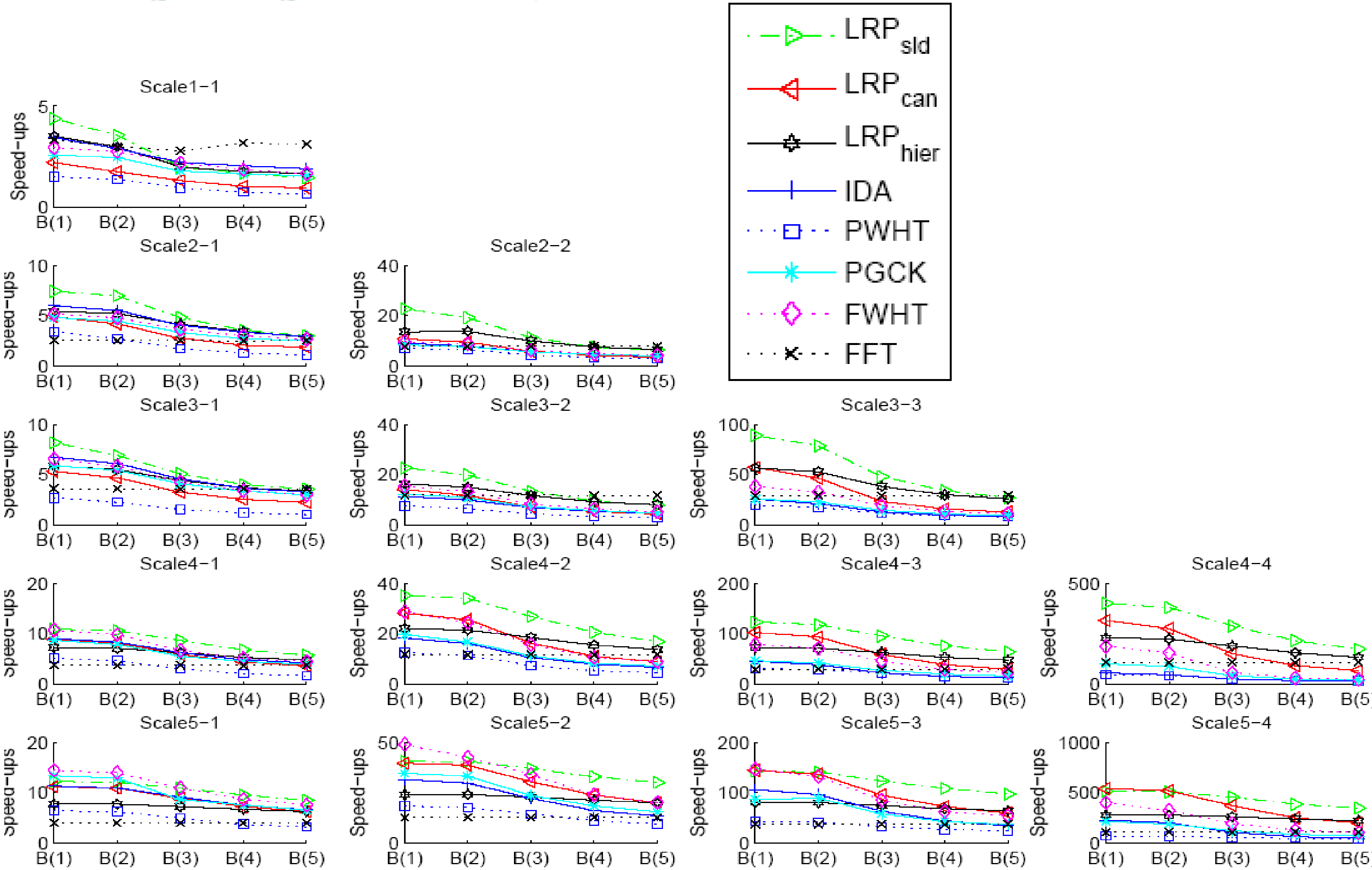
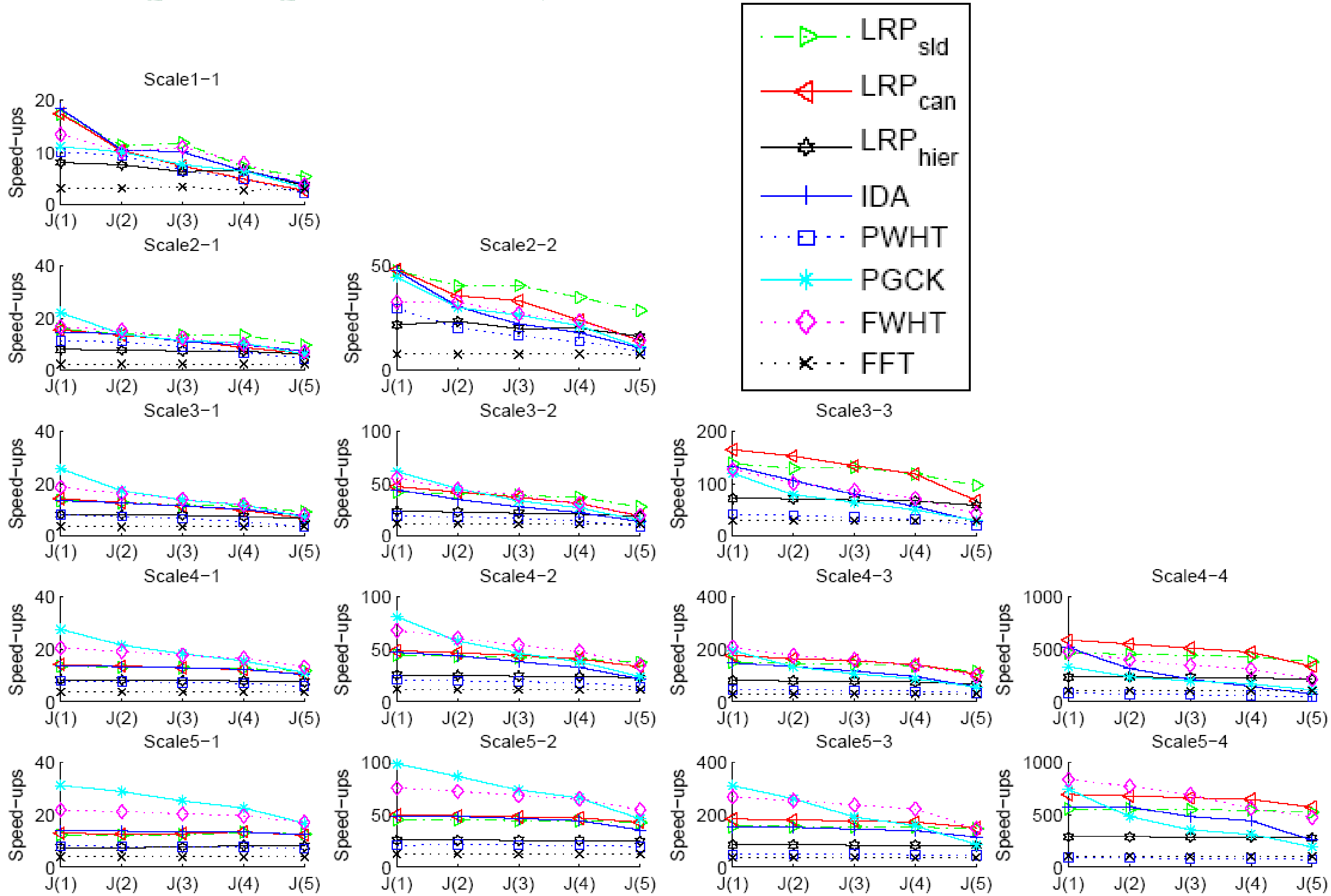
Time speed-ups over FS (blur, SSD)



Time speed-ups over FS (JPEG, SSD)



Short conclusion on execution time SSD

- No noise is added: PGCK is the fastest
- Gaussian noise and blur:
  - FWHT is the fastest when pattern is small, image size is large and noise level is low
  - FFT is the fastest when noise is high
  - LRP_{sld} is the fastest in other cases
  - JPEG:
  - PGCK and FWHT are the fastest when pattern size is small or noise level is small
  - LRP_{can} is the fastest in other cases.

Time speed-ups over FS (No noise, SAD)

$$\frac{Time_{FS}}{Time_{PGCK}}$$

Larger => faster

Dataset	Image size	J	Pattern size	N
$Scale1-1$	160 × 120	19200	16 × 16	256
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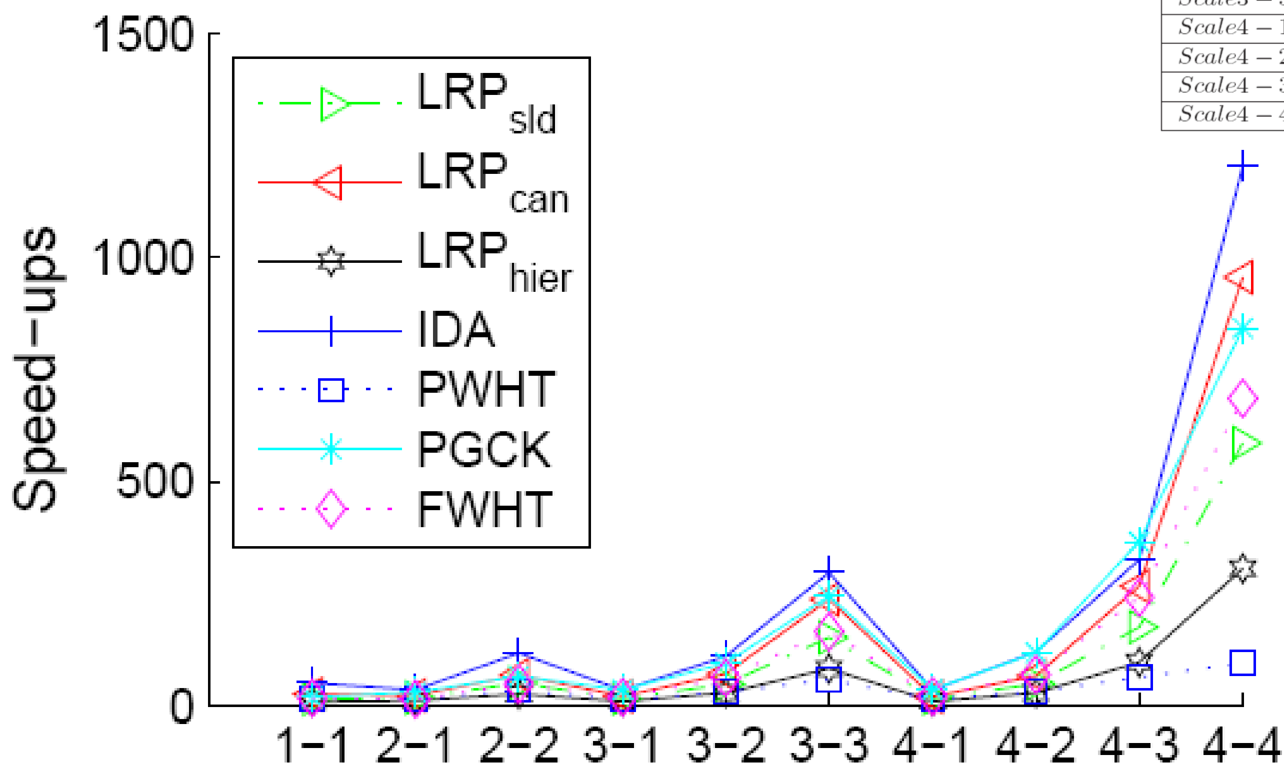

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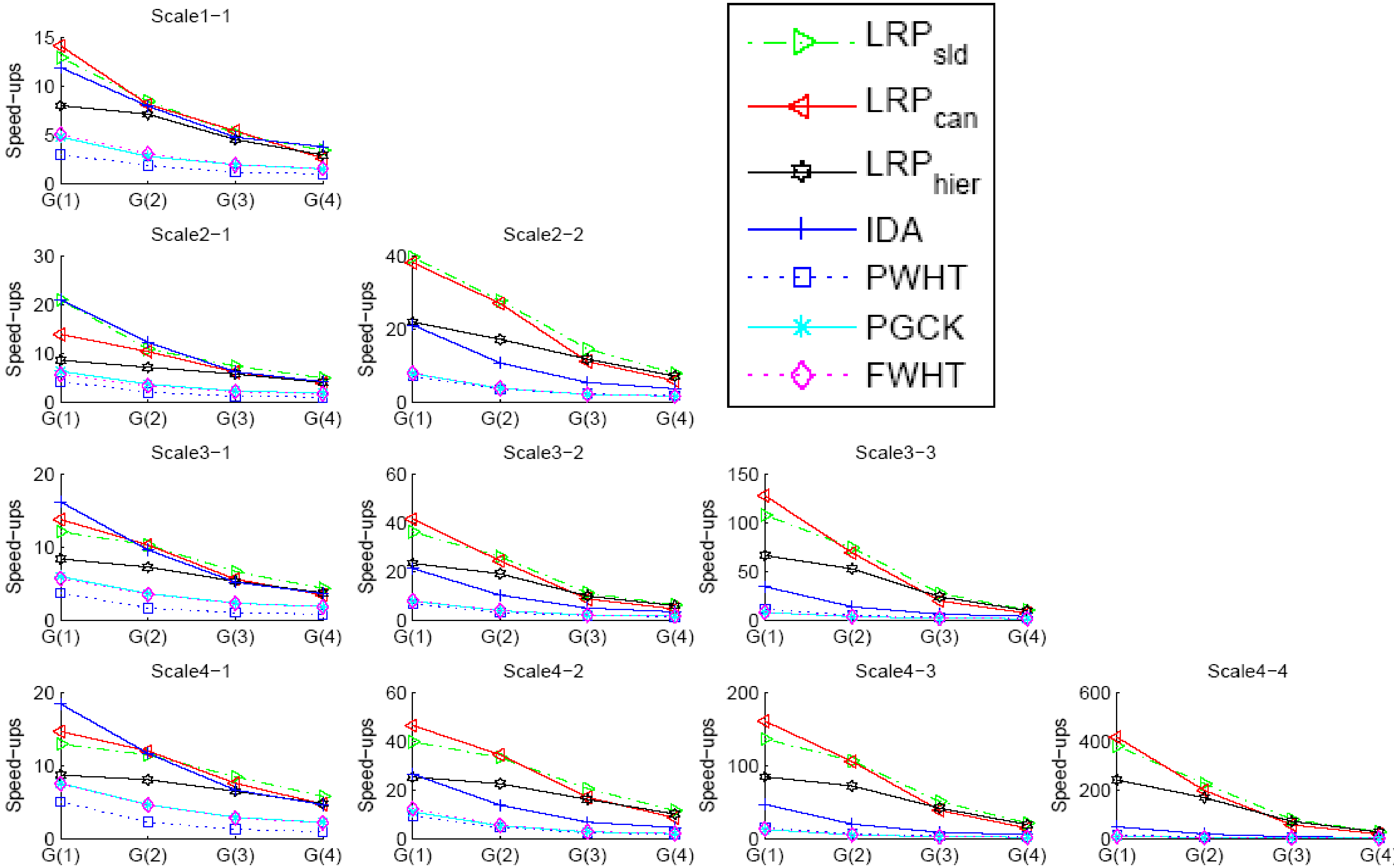
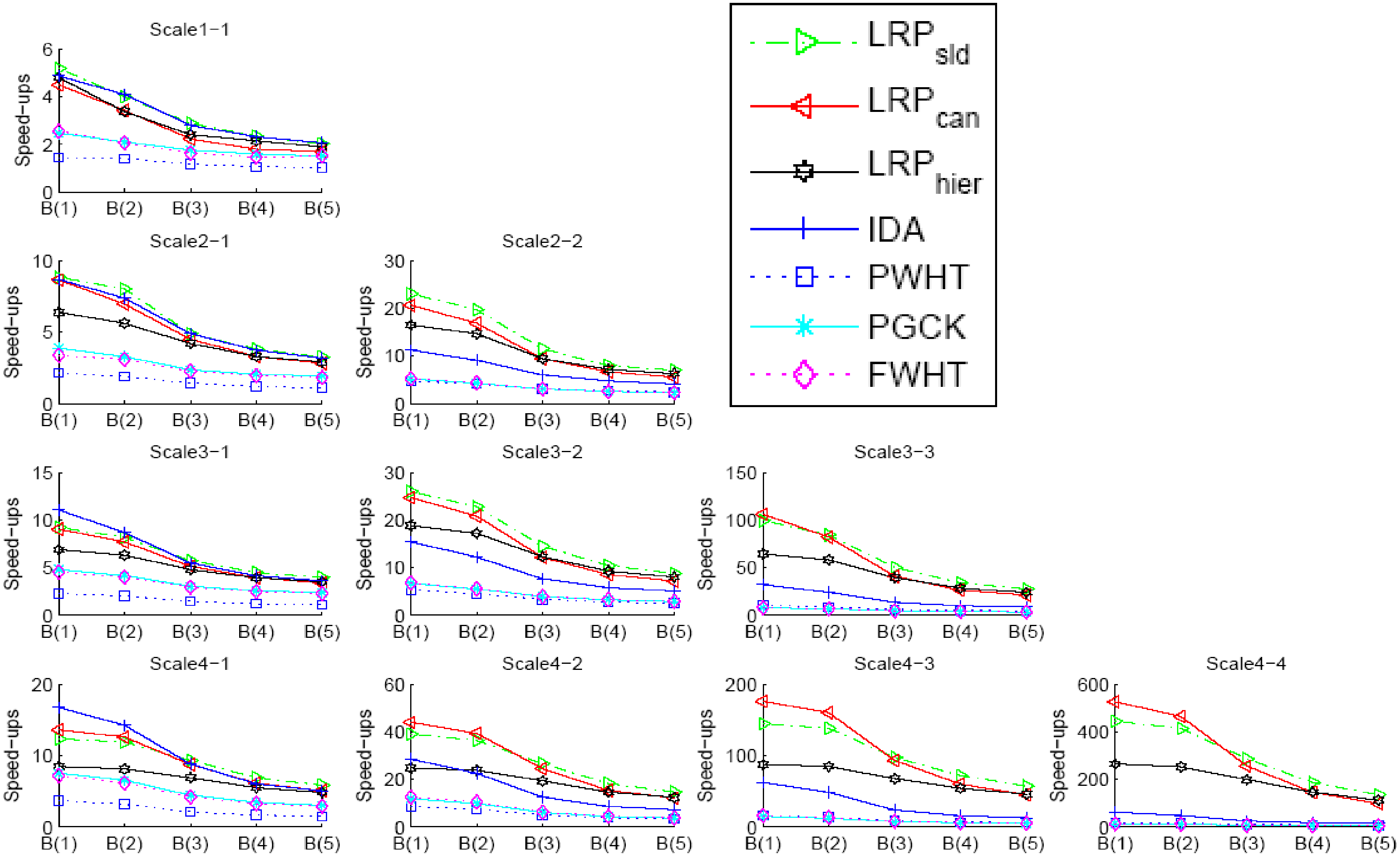
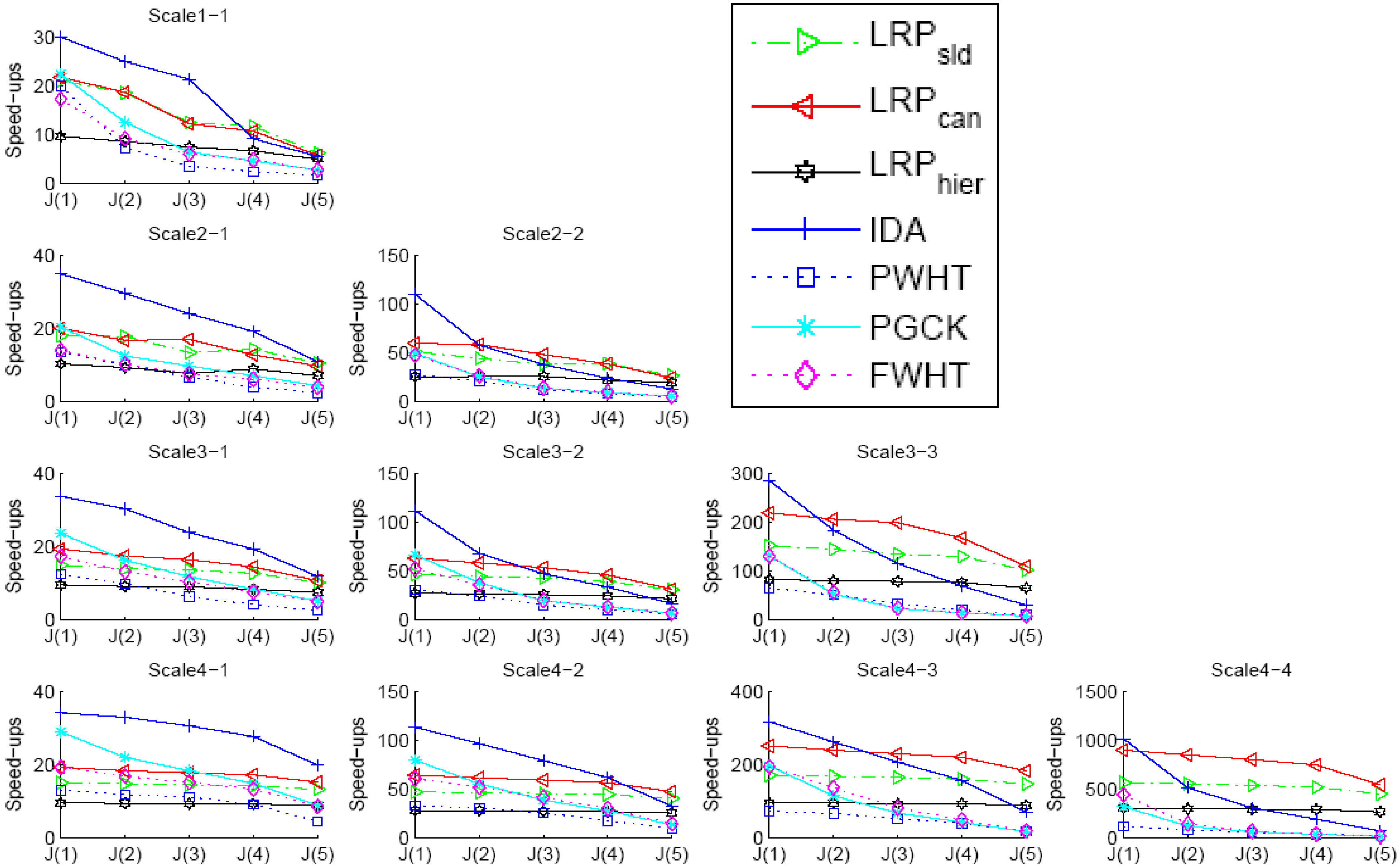
Time speed-ups over FS (Gaussian noise, SAD)



Time speed-ups over FS (Blur, SAD)



Time speed-ups over FS (JPEG, SAD)



Short conclusion on execution time SAD

- No noise is added: PGCK and IDA are the fastest
- Gaussian noise and blur:
  - IDA is the fastest in execution time when pattern size is 16x16 while LRP_{sld} is the fastest in larger pattern sizes
- JPEG:
  - LRP_{can} is the fastest for large pattern size and high noise while IDA is the fastest in other cases.
- PWHT, PGCK and FWHT are inefficient in the presence of noises.

Outline

- Introduction
- Evaluation of Full Search Equivalent Algorithms
- **Conclusion and Contribution**

Conclusion

- When no noise is added, PGCK is the fastest in most cases.
- When the three kinds of noises are added, experimental results on both execution time and number of operations have shown that LRP is the fastest in most cases. This nicely agrees with the theoretical analysis developed in Theorem 1.

G. Ben-Artz, H. Hel-Or, and Y. Hel-Or. The Gray-code filter kernels. *TPAMI,* 29(3):382– 393, Mar. 2007.

M. G. Alkhansari. A fast globally optimal algorithm for template matching using low-resolution pruning. *TIP*, 10(4):526–533, Apr 2001.

Contribution

- A unified framework for describing the algorithms evaluated in this paper. Under this framework, we give a theorem that reveals why LRP outperforms other evaluated algorithms.
- The computational analysis of IDA, PWHT, PGCK and FWHT under the framework of pattern matching, which is not provided in previous literature. Based on this analysis, we propose a new termination strategy for fast full-search equivalent pattern matching algorithms and two more efficient formulations of LRP.
- A quantitative performance evaluation of state-of-the-art FS-equivalent pattern matching algorithms based on a very large dataset. This allows us to identify the best performing methods under a number of typical nuisances found in real-world applications. Moreover, the datasets, methodology and results used in our evaluation provide a reference framework for testing future pattern matching algorithms.

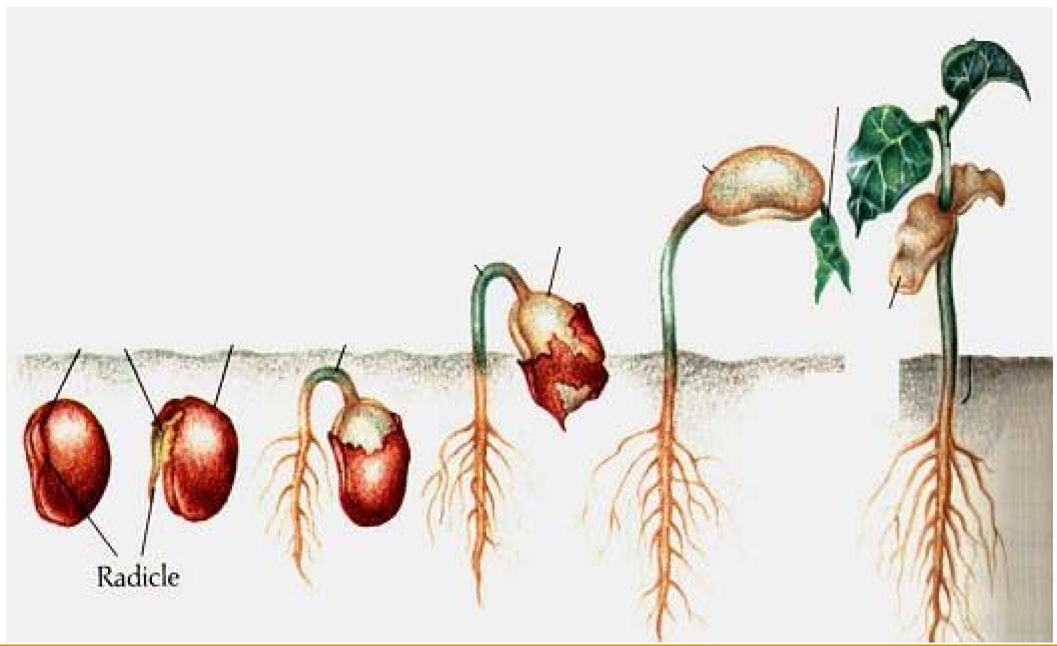
Future …

- ‘My heart will go on’ by Céline Dion
- The cooperation story will go on …

From seeds to fruits





Faster algorithms are being developed...

- Thanks !