4th IEEE Int'l Workshop on Mobile Vision, 2014

Cascade of Box (CABOX) Filters for Fast Scale Space Approximation

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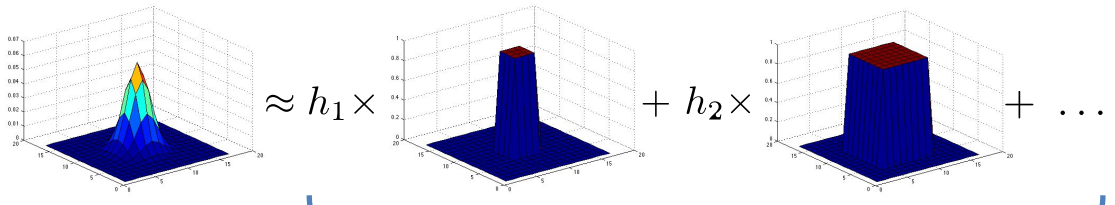
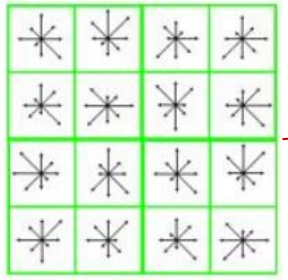


Outline

- Motivation
- Approximate Scale Space with Box Filters
- Simulation Results
- Conclusion & Future Work

Mobile Visual Search Scenarios and Problems

- Technology: key point based Image Search
  - Scale and rotation invariant key points that can be matched up in query:

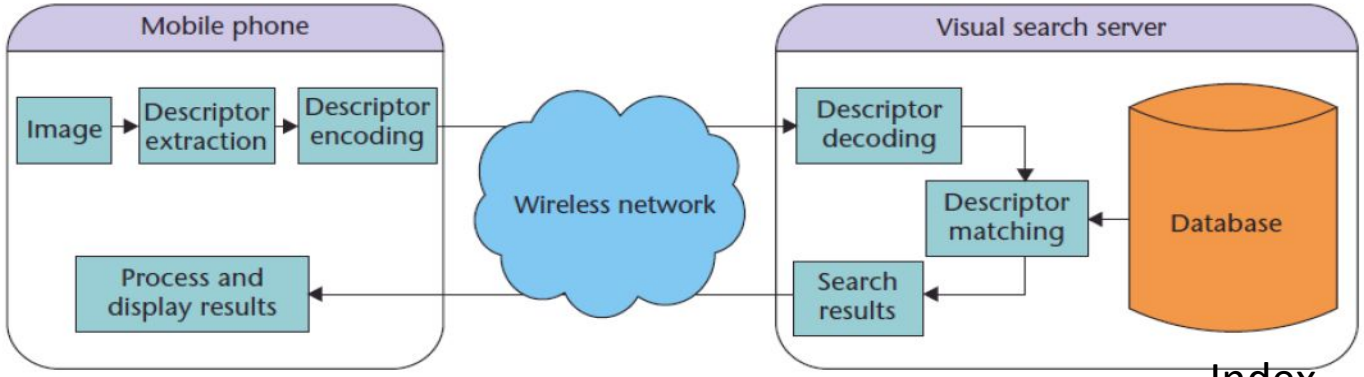


- Applications:
  - Mobile Query by Capture, Augmented Reality

- **What is wrong** by sending images/raw features over the channel ?

MPEG-7 Compact Descriptor for Visual Search (CDVS)

- MPEG CDVS Standardization Scope
  - –Front-end: image feature capture and compression
  - –Server Back-end: image feature indexing and query processing



- Objectives/Challenges:
  - –**Real-time**: front end real time performance, e.g, 640x480 @30fps
  - –**Compression**: Low bit rate over the air, achieving 100 X compression w.r.t to sending images, or 10X compression of the raw features.
  - –**Matching Accuracy**: >95% accuracy in pair-wise matching (verification) and >90% precision in identification
  - –**Indexing/Search Efficiency**: real time backend response from BIGDATA (100m) visual repository

SIFT Patent and Detection Speed

- SIFT Patent
  - SIFT patent was licensed to an unknown party, and the un-certainty of its licensing policy puts MPEG CDVS in jeopardy
  - Need to circumvent the key claims of the patent – DoG filtering
- Complexity Reduction:
  - The SIFT detection is computationally heavy
  - For mobile application deployment and especially for AR type applications, where visual queries are generated at much faster pace, the complexity need to be significantly reduced for mobile computing platform.

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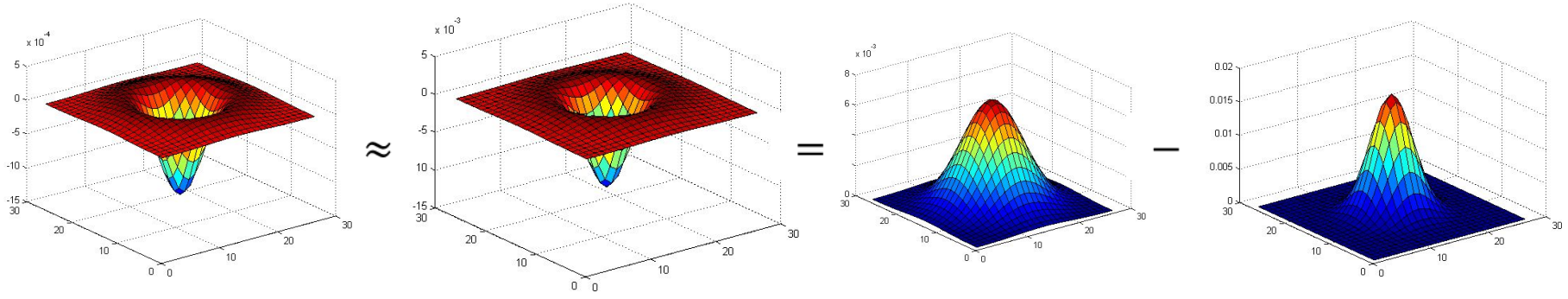
Blob detection: Difference of Gaussians (DoG)

LoG DoG Gaussian 2 Gaussian 1



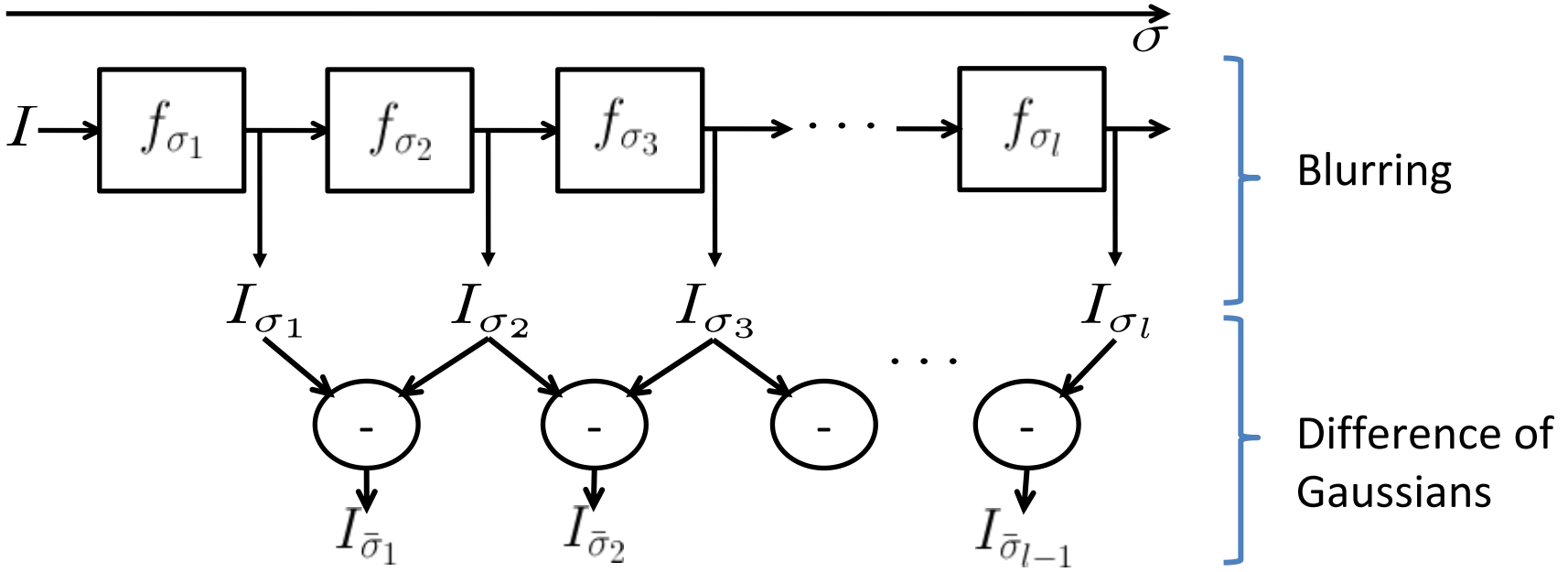
L_σ D_σ g_{σ_2} g_{σ_1}

- Convolving the filter with an image in an efficient manner:

$$I * L_\sigma \approx I * \underbrace{(g_{\sigma_2} - g_{\sigma_1})}_{D\sigma} = (I * g_{\sigma_2}) - (I * g_{\sigma_1})$$

- We can exploit the separability property of the Gaussian filter!
- Requires O(2N) multiplications and O(2N) additions per pixel!

Difference of Gaussians pipeline

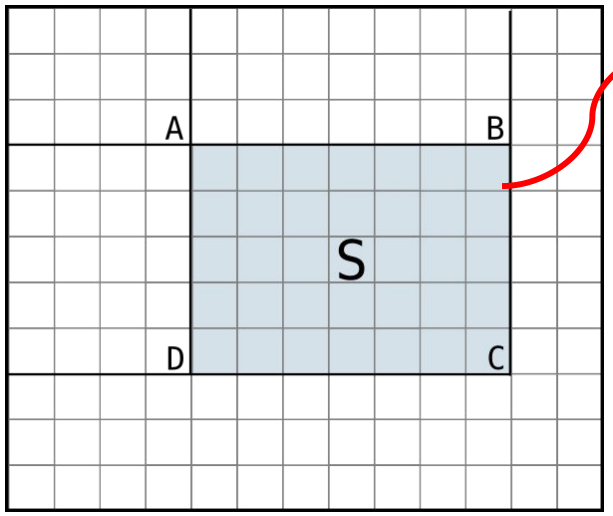


$$\bar{\sigma} = \sqrt{\frac{\sigma_a^2 + \sigma_b^2}{2}}$$

LoG $\bar{\sigma}$s calculated from the Gaussian parameters and σ_a σ_b

Can we speed up this process even further?

Gaussian kernel approximation using Box filters

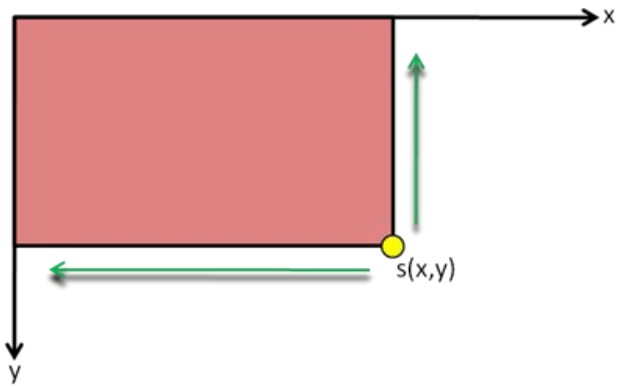


Box Filter

For a given pixel, the box filter computes the average over the rectangle (A,B,C,D).

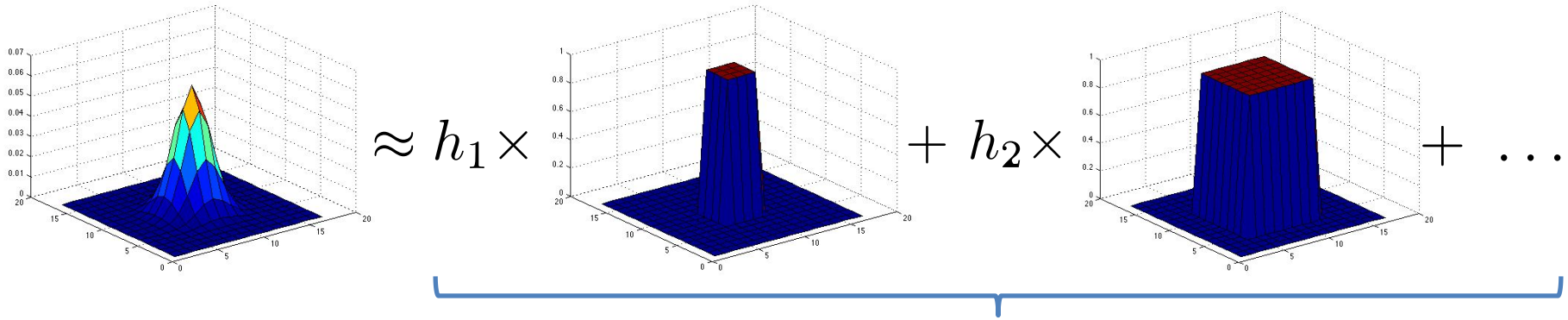
$$S = In(C) + In(A) - In(D) - In(B)$$

Requires only 4 additions and 1 multiplication!



Integral Image: A table whose entries hold the sum of the pixels from the origin to the point (x, y).

CABOX: Gaussian kernel approximation using Box filters



Gaussian Filter g_σ

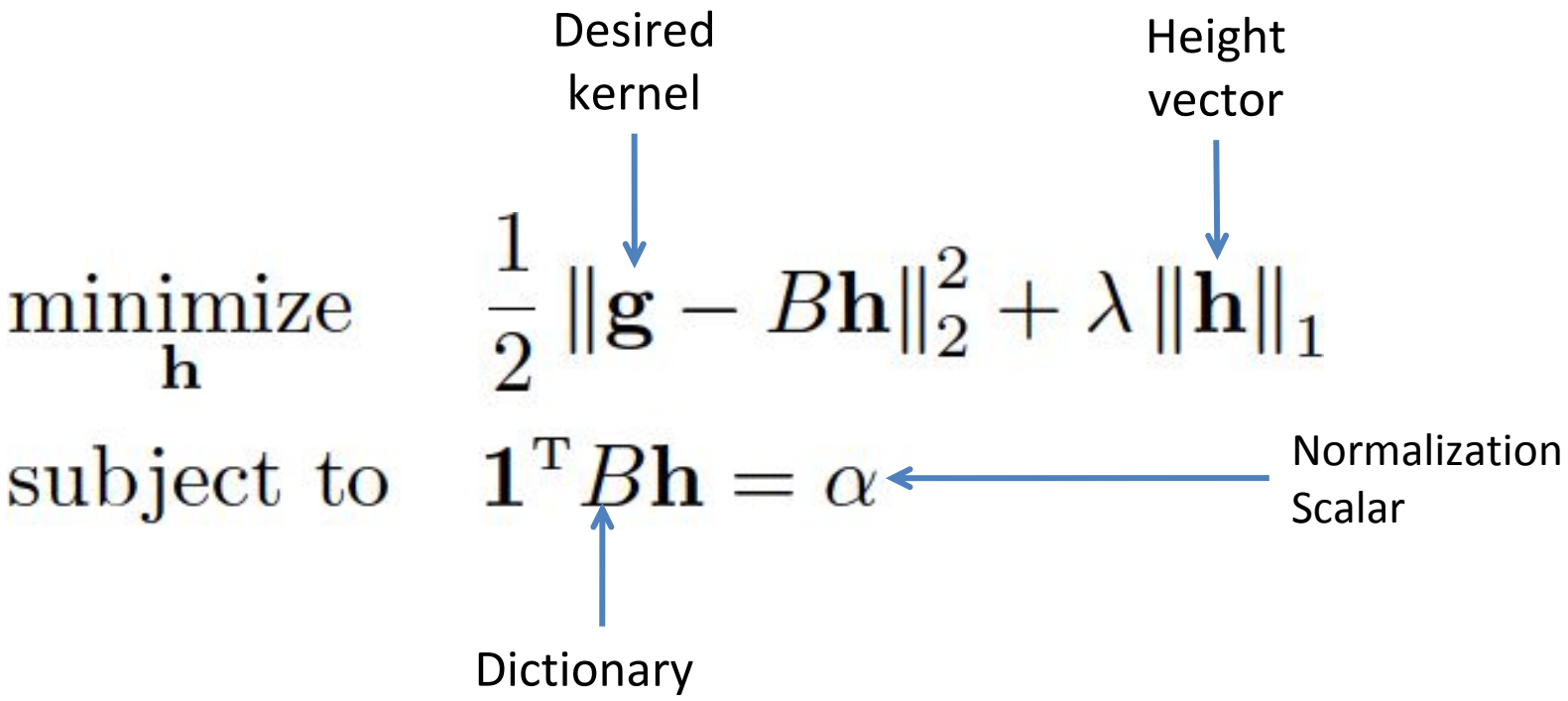
Box Filters b_σ

We need to find a coarse approximation of the Gaussian kernel using a set of k box filters.

- We can use integral images for fast convolution
- Complexity can be reduced if we use a few box filters
  - O(k) multiplications and O(4k) additions, where k is the number of box filters used.

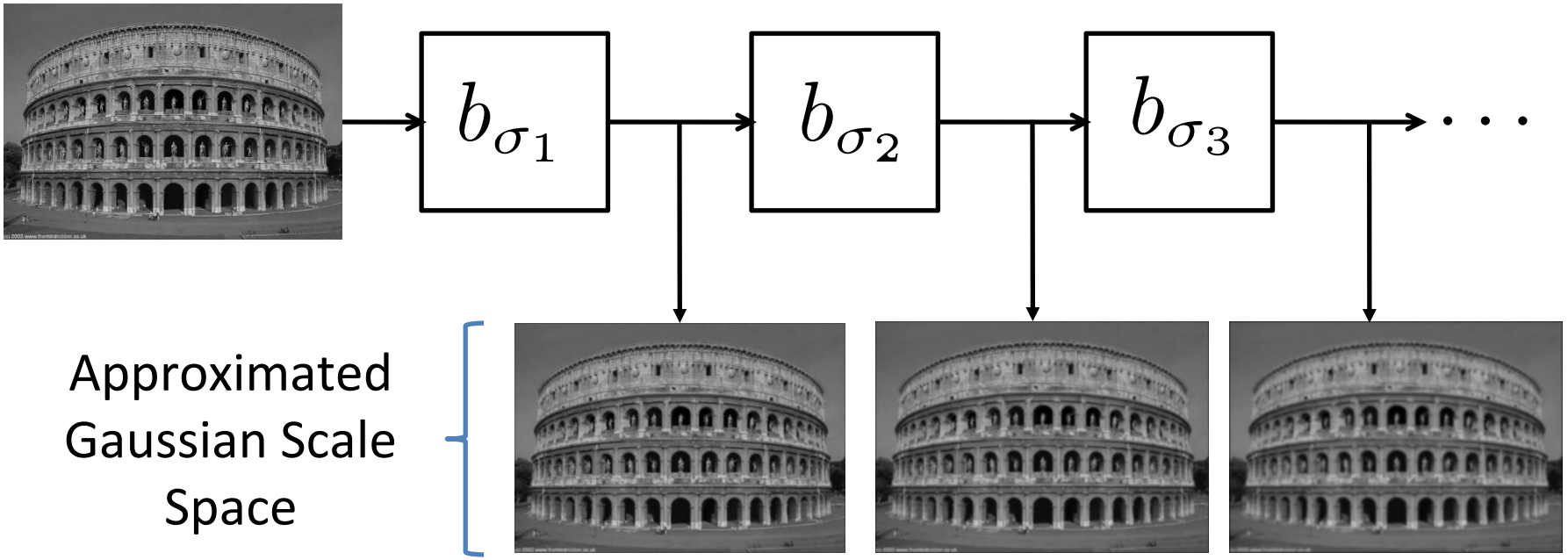
CABOX design

We can approximate a Gaussian kernel with a set of box filters by solving the following problem:



CABOX: Gaussian kernel approximation using Box filters

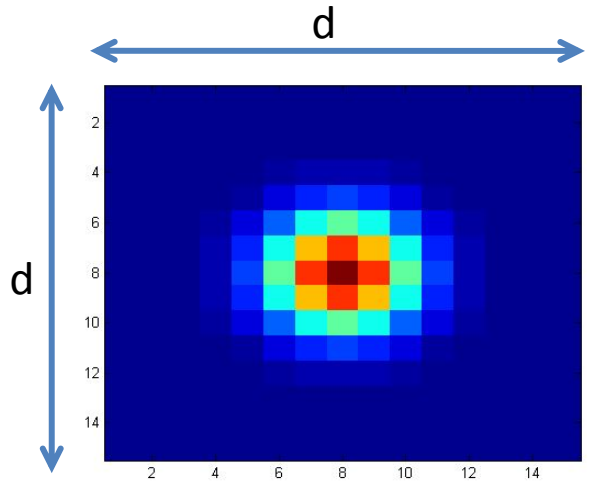
We can then plug in our approximations in the scale space pipeline.



In essence, we are doing the following approximation:

$$I * L_\sigma \approx (I * g_{\sigma_2}) - (I * g_{\sigma_1}) \approx (I * b_{\sigma_2}) - (I * b_{\sigma_1})$$

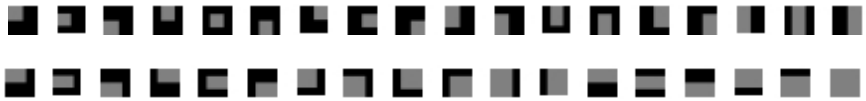
What Box filters to use for the approximation?



The size of the Gaussian kernel is calculated with the following formula:

$$d = 2\lceil 4\sigma \rceil + 1$$

Extended Dictionary: All possible rectangles with minimum size of 2.



Concentric Squares Dictionary.

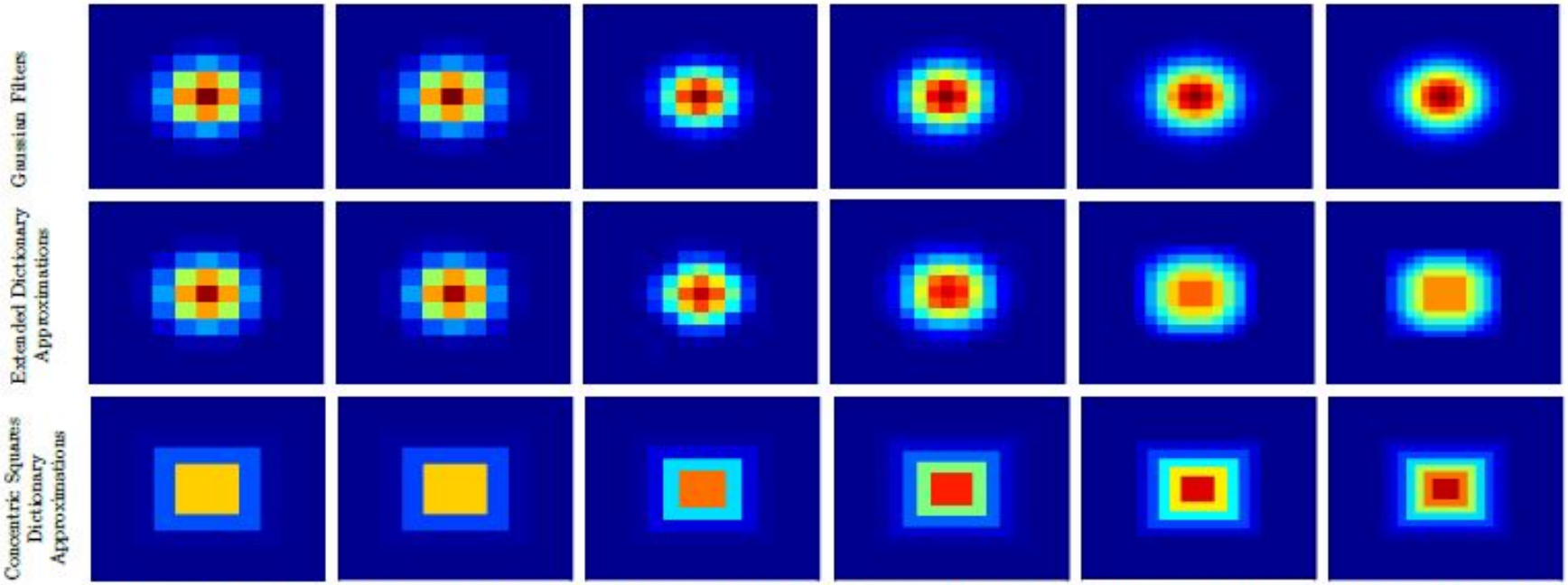
The dictionary will affect the number of boxes used when solving the optimization problem.

Approximation results

$$\text{residual} = \|\mathbf{g} - B\mathbf{h}\|_2$$

	Concentric Squares		Extended	
σ	Num. of Boxes	Residual	Num. of Boxes	Residual
1.249000	3	0.0554	43	0.0068
1.226270	3	0.0578	21	0.0067
1.545008	4	0.0358	42	0.0146
1.946588	6	0.0248	36	0.0087
2.452547	5	0.0192	16	0.0169
3.090016	8	0.0142	18	0.0163

The influence of the used dictionary determines not only the quality of the approximation but also the number of boxes required.

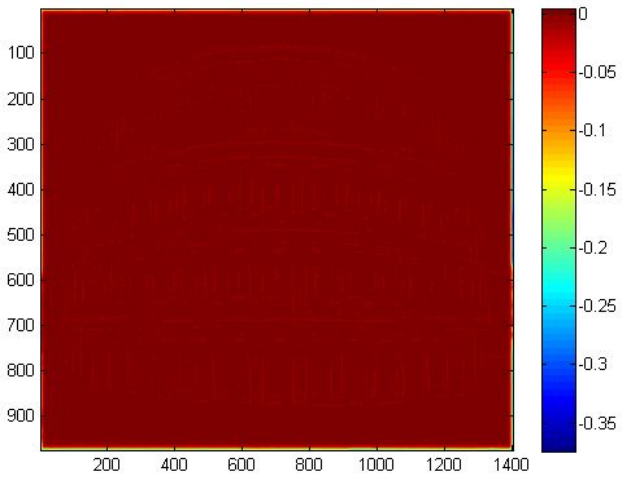


(a) $\sigma = 1.249000$ (b) $\sigma = 1.226270$ (c) $\sigma = 1.545008$ (d) $\sigma = 1.946588$ (e) $\sigma = 2.452547$ (f) $\sigma = 3.090016$

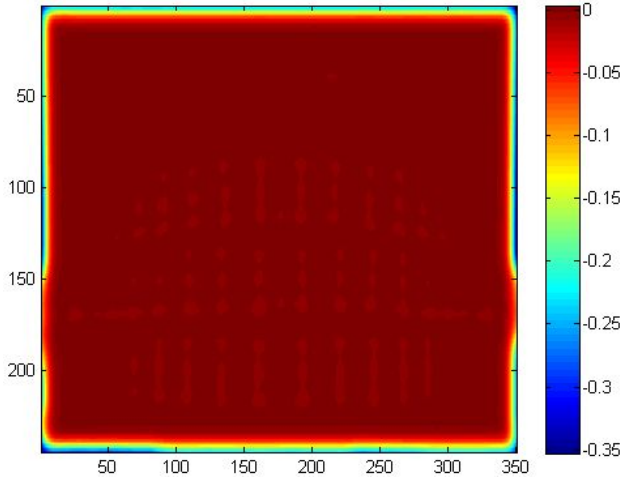
Gaussian Scale Space experiments

	Colosseum	Oxford Bldg.	Zürich
			
MSE	0.0045	0.0015	0.0063
Octaves	5	6	5
Scales	6	6	6

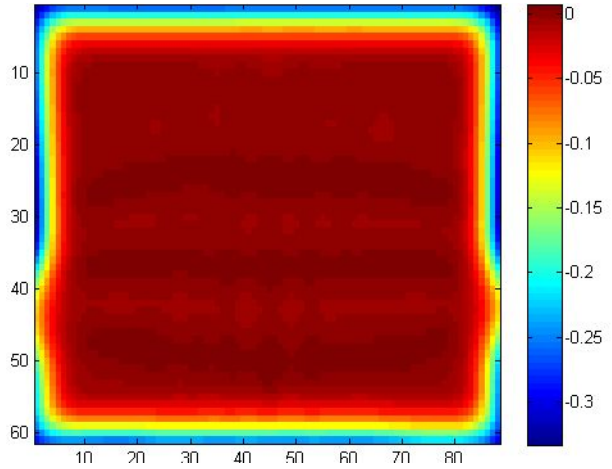
The Mean Square Error (MSE) of our approximation method across all octaves and scales is minimal, considering that the pixel intensities are in the range of 0 to 1.



Error for Scale=6
Octave=1



Error for Scale=6
Octave=3



Error for Scale=4
Octave=5

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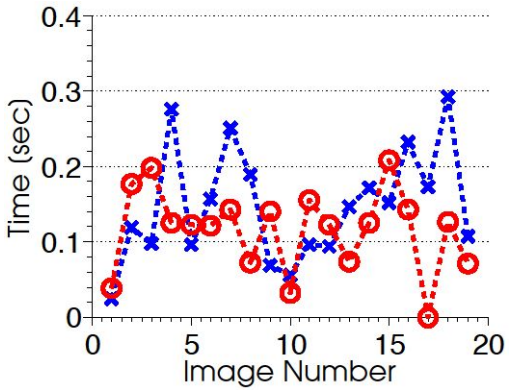
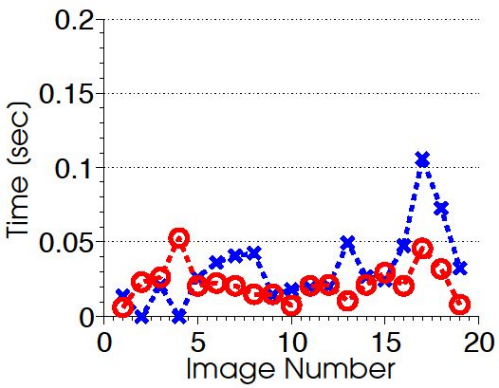
Complexity Reduction

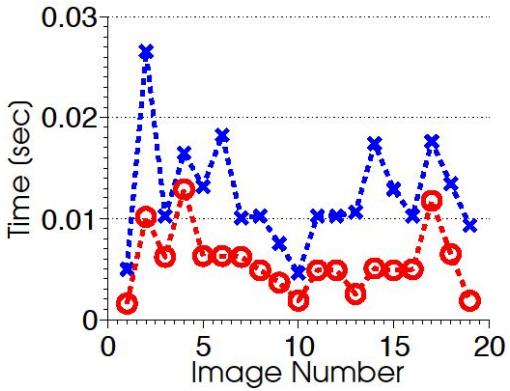
On average CABOX reduced the scale space construction time in approximately 44%.



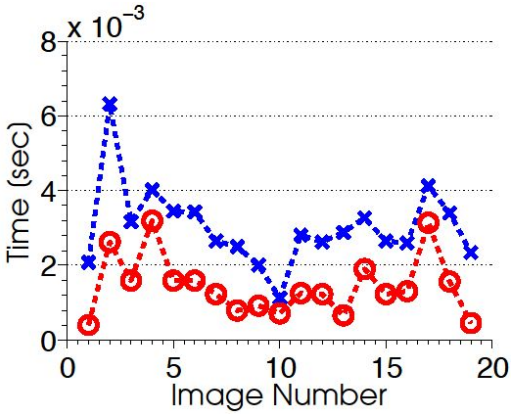
22% reduction time for 1st octave.



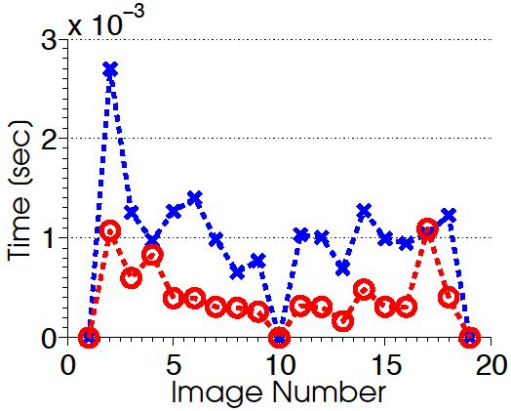
32% reduction time for 2nd octave.



54% reduction time for 3rd octave.



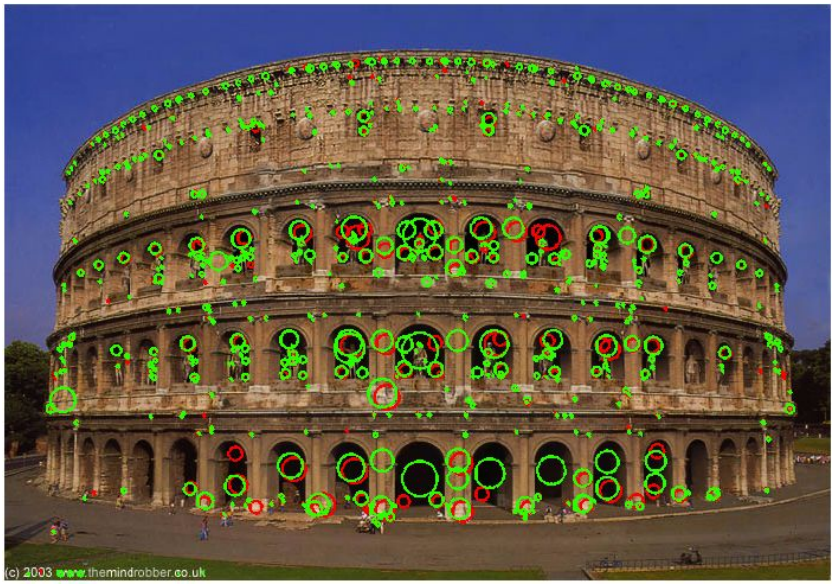
52% reduction time for 4th octave.



59% reduction time for 5th octave.

Gaussian
CABOX

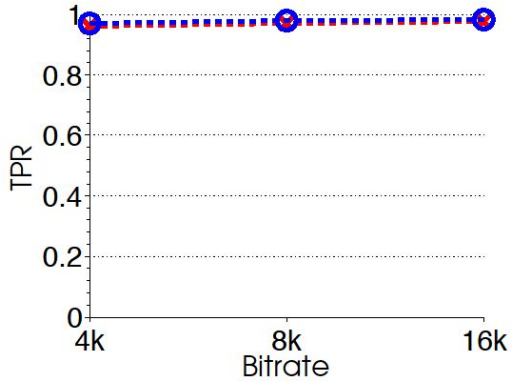
Feature detection repeatability test



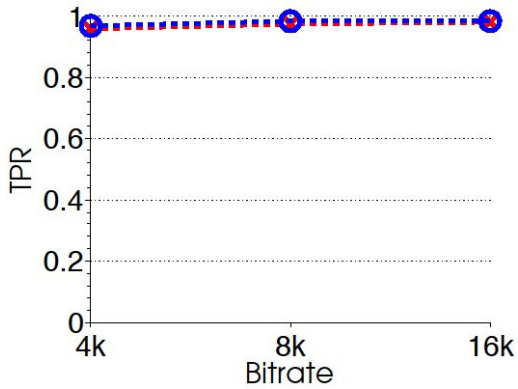
Of those features detected with CABOX (red circles), 89% are also detected by VLFeat (green circles) while the remaining 11% correspond to new features.

End-End MPEG TM Pairwise matching experiment

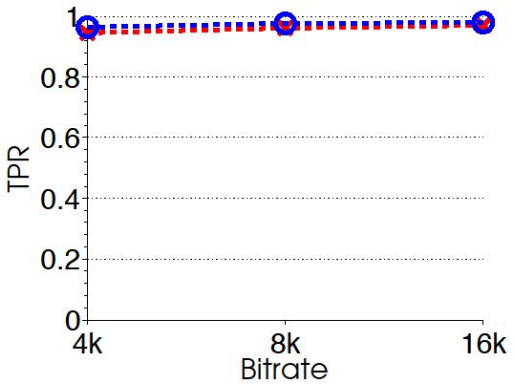
Replacing DoG with CABOX, has minimum effects on the image matching accuracy



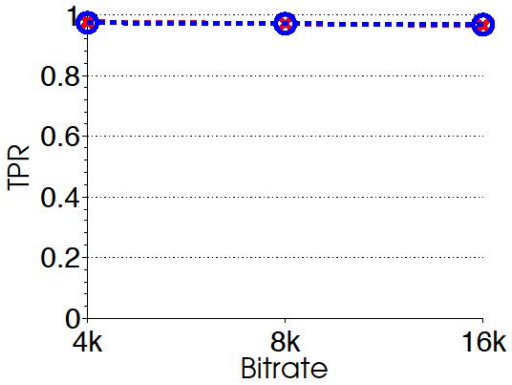
Dataset 1



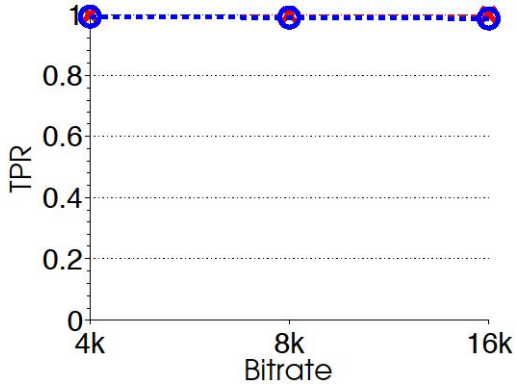
Dataset 2



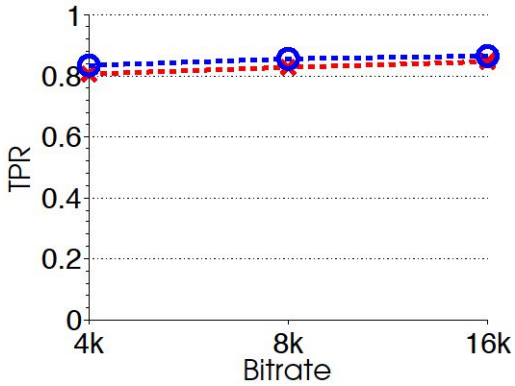
Dataset 3



Dataset 4



Dataset 5



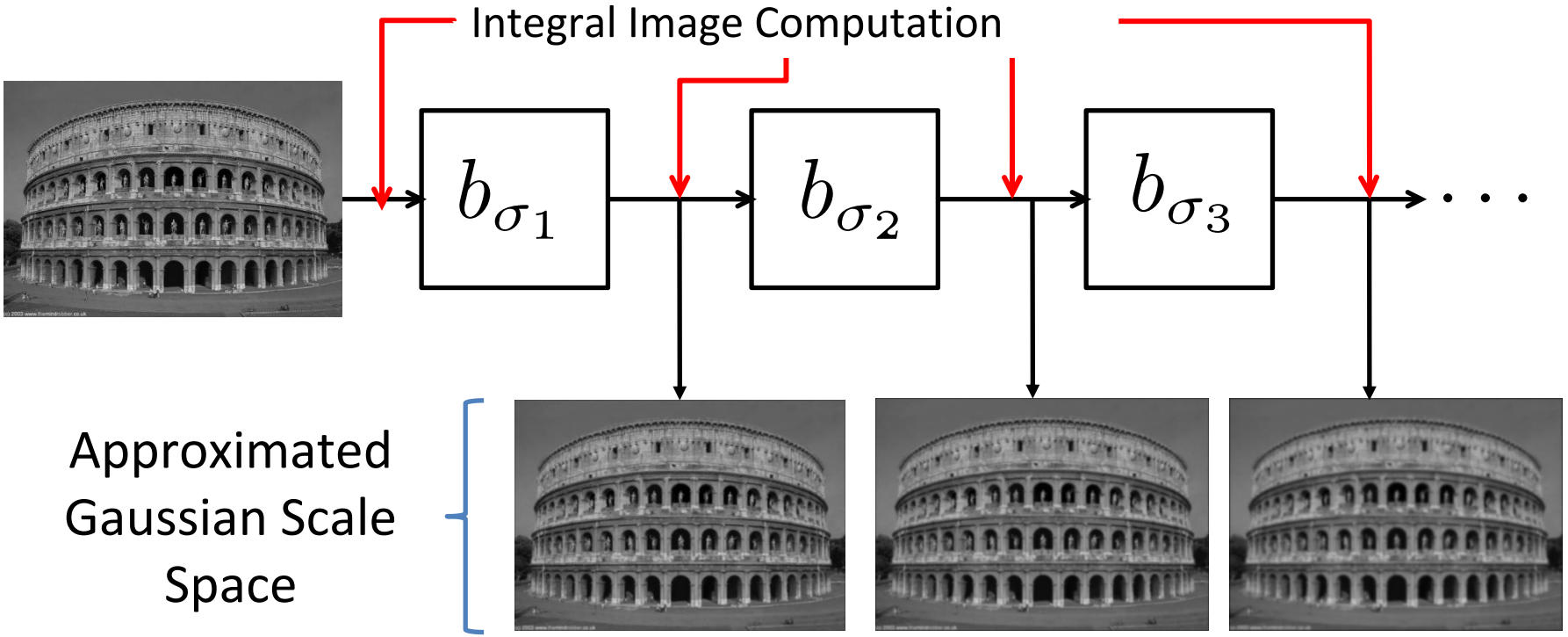
Dataset 6

Gaussian
CABOX

Summary & Future Work

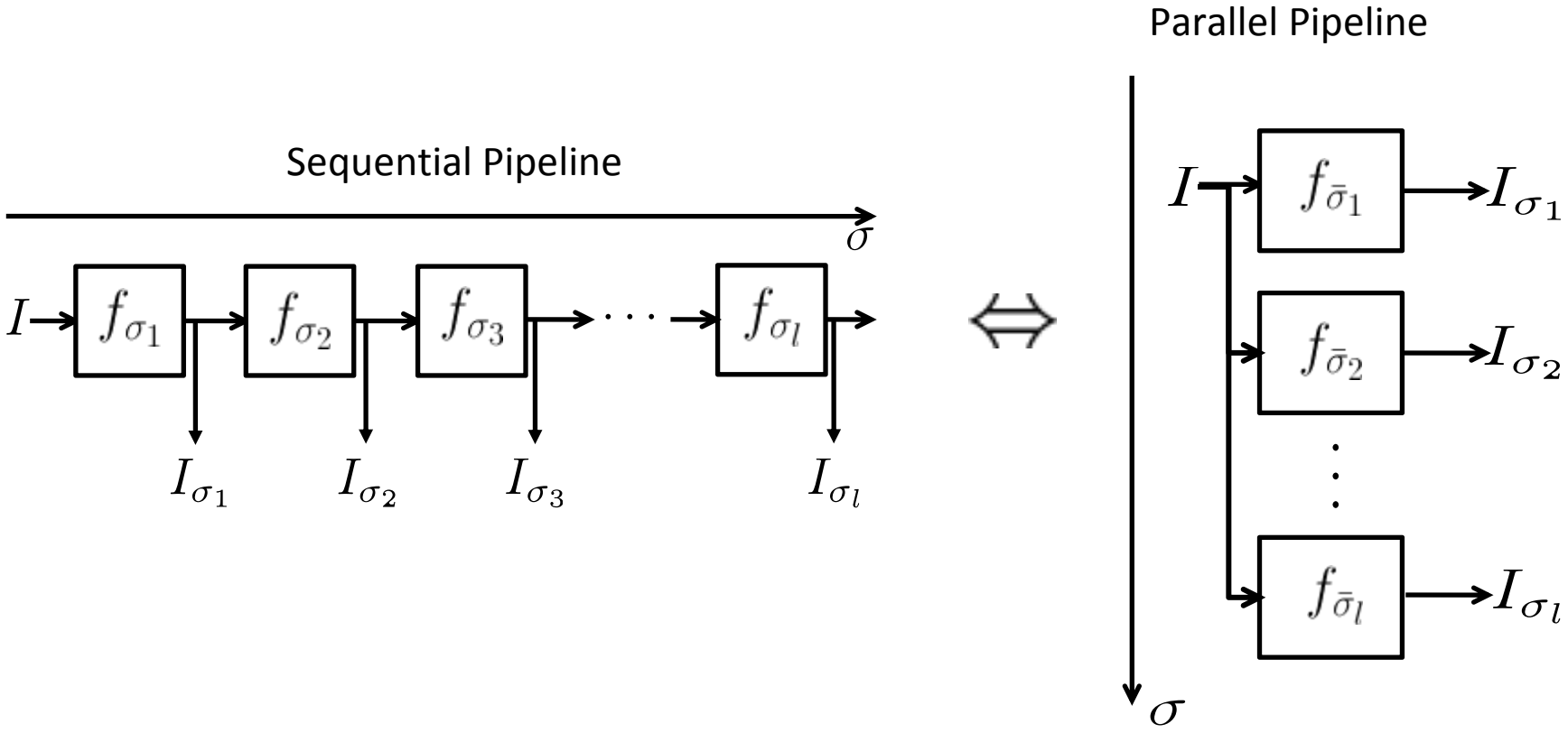
- We presented an integral domain box filter approximation of scale space which is fast
- The accuracy of scale space approximation is achieved by solving the sparsity constrained filter approximation
- Integration into the MPEG CDVS Test Model verified the robustness and efficiency of the proposed solution
- Future Work:
  - Develop Parallel CABOX filtering for even faster solution

Further Speed-up: Parallel CABOX



- Computation of integral image at every scale level!
- Approximation error propagates along the pipeline!

Parallel CABOX

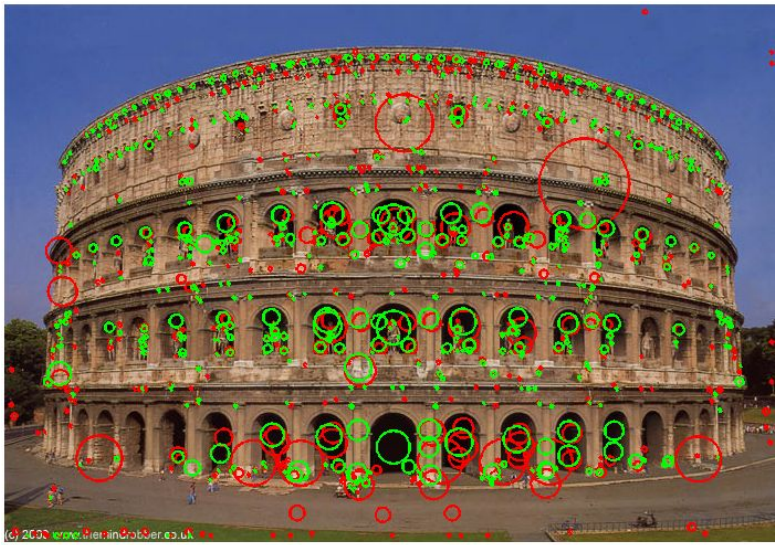


Filters used in the Parallel pipeline are computed using the following formula:

$$\bar{\sigma}_i = \sqrt{\sigma_i^2 + \bar{\sigma}_{i-1}^2}$$

$$\bar{\sigma}_1 = \sigma_1$$

Parallel CABOX Detection Repeatability



Of those features detected with Parallel CABOX (red circles), 72% are also detected by VLFeat (green circles) while the remaining 28% correspond to new features.