Pixel-Based Hyperparameter Selection for Feature-Based Image Registration

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Outline

- What is image registration?
  - General principle
  - Standard approaches
- Problem: choice of the hyperparameters
- Our approach
- Experimental results

What is image registration?

Find the geometric transformation that aligns a source image and a target image

Source image S

find $\mathbf{p}$ such that:

$$\mathcal{W}(\cdot;\mathbf{p})$$

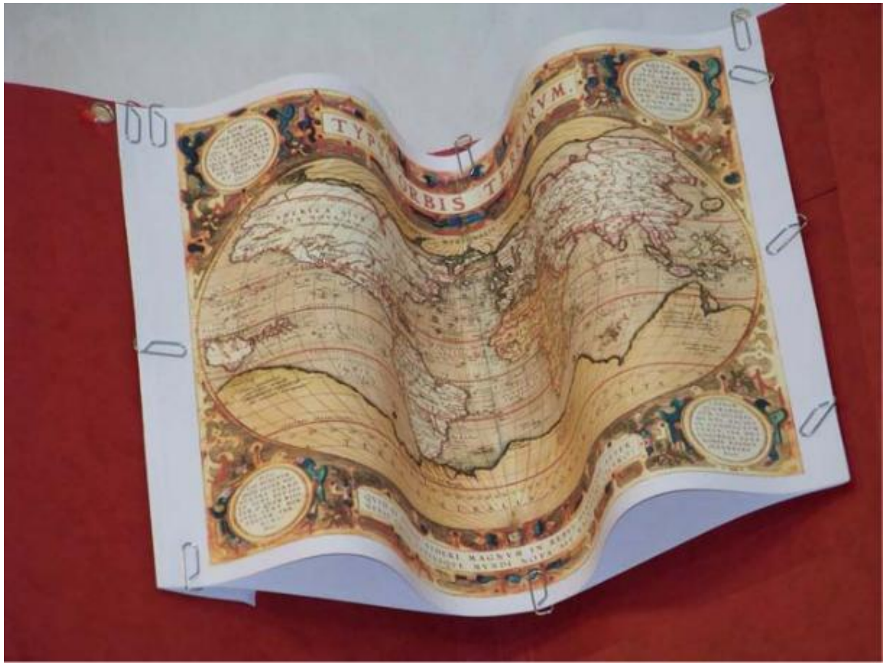
Target image T

Two standard approaches

- The feature-based approach
- The direct approach (photometric approach)

The feature-based approach

Source image S

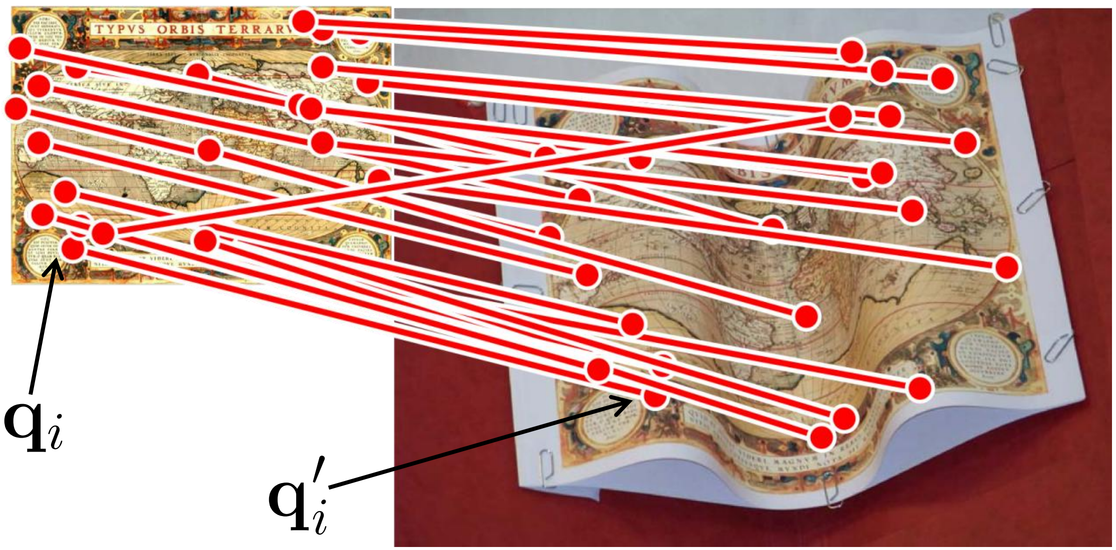


Target image T

The feature-based approach

Extracting point correspondences

$$\{\mathbf{q}_i \leftrightarrow \mathbf{q}'_i\}_{i=1}^{n}$$

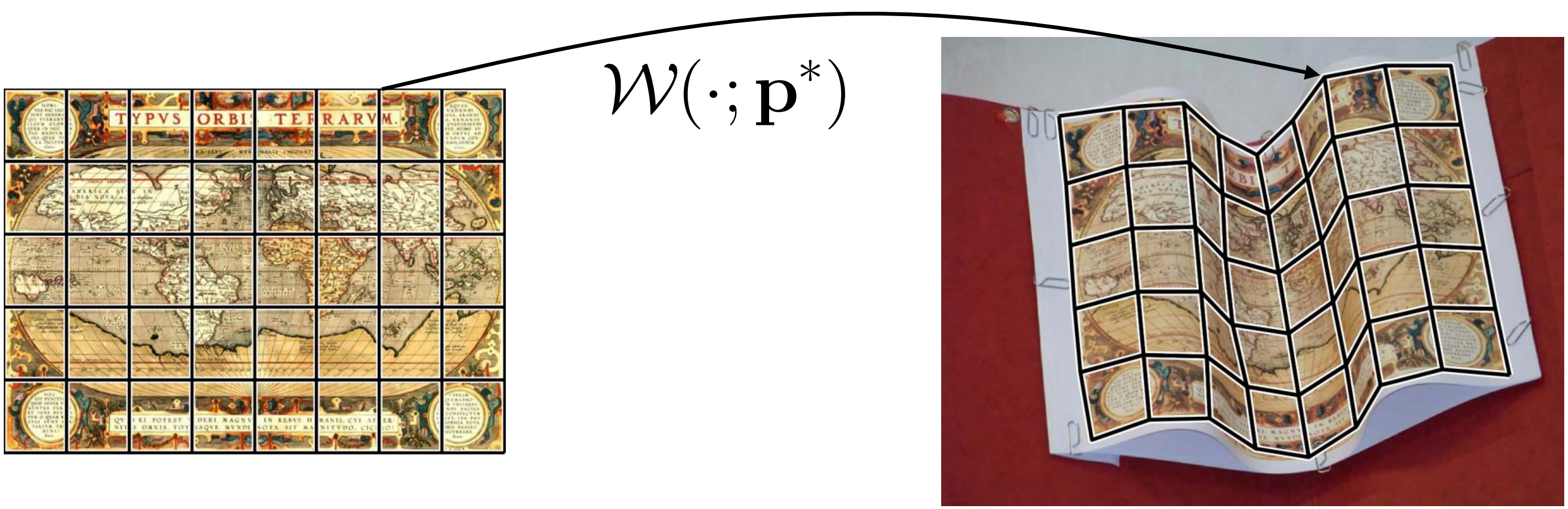


[Methods: SIFT, SURF, …]

The feature-based approach

The parameters **p*** of the transformation are computed from the point correspondences

$$\mathbf{p}^* = \arg\min_{\mathbf{p}} \sum_{i=1}^{n} \|\mathcal{W}(\mathbf{q}_i; \mathbf{p}) - \mathbf{q}'_i\|^2$$



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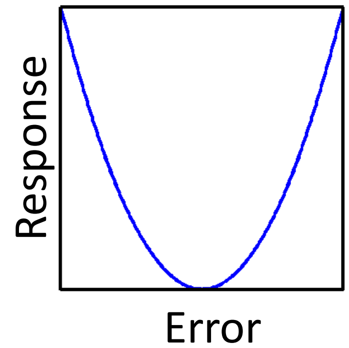
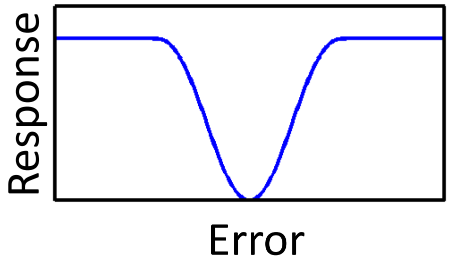
The feature-based approach

- Variants
  - Robustness





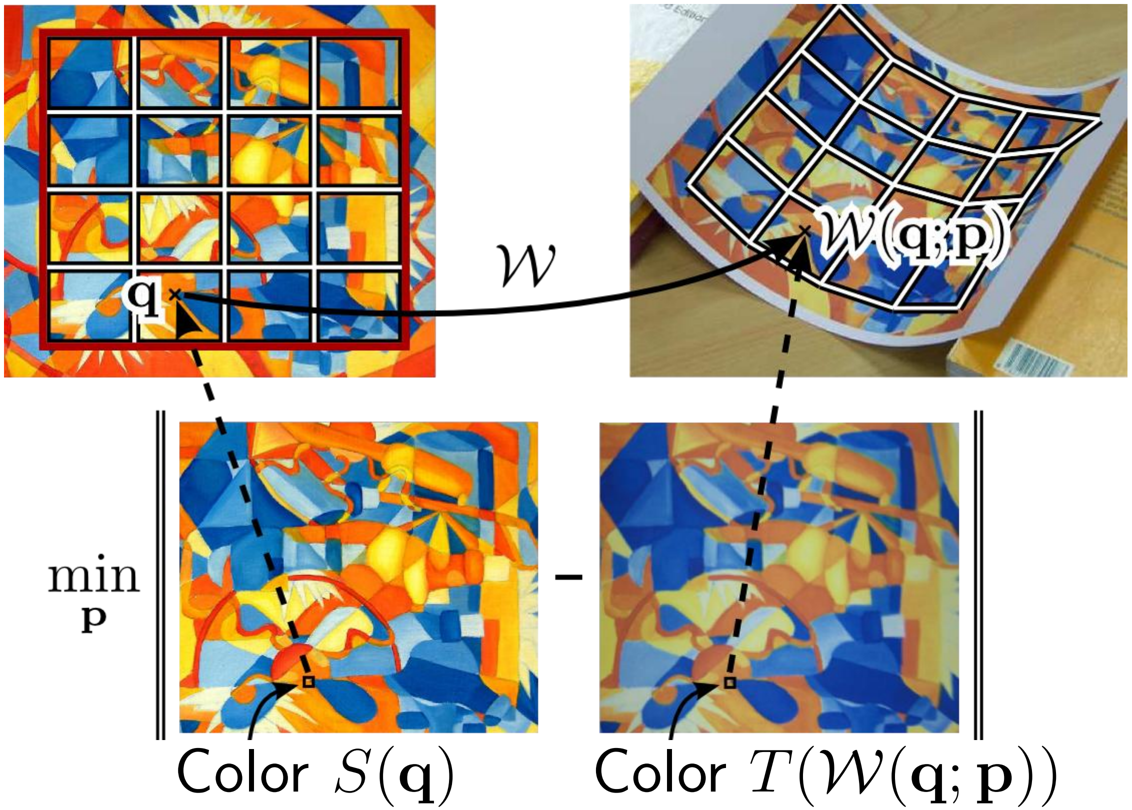
$$\min_{\mathbf{p}} \sum_{i=1}^{n} \rho\left(\mathcal{W}(\mathbf{q}_i; \mathbf{p}) - \mathbf{q}'_i; \gamma\right)$$

  - Regularization

$$\min_{\mathbf{p}} \sum_{i=1}^{n} \rho\left(\mathcal{W}(\mathbf{q}_i; \mathbf{p}) - \mathbf{q}'_i; \gamma\right) + \lambda \sum_{i=1}^{2} \int_{\Omega} \left\| \frac{\partial^2 \mathcal{W}^i}{\partial \mathbf{q}^2}(\mathbf{q}; \mathbf{p}) \right\|^2 \mathrm{d}\mathbf{q}$$

The direct approach

$$\mathbf{p}^* = \arg\min_{\mathbf{p}} \sum_{\mathbf{q}\in\mathfrak{R}} \|S(\mathbf{q}) - T(\mathcal{W}(\mathbf{q};\mathbf{p}))\|^2$$



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Problem: the hyperparameters

- What are the hyperparameters?

$$\min_{\mathbf{p}} \sum_{i=1}^{n} \rho\left(\mathcal{W}(\mathbf{q}_i;\mathbf{p}) - \mathbf{q}'_i;\gamma\right) + \lambda\mathcal{R}(\mathbf{p})$$

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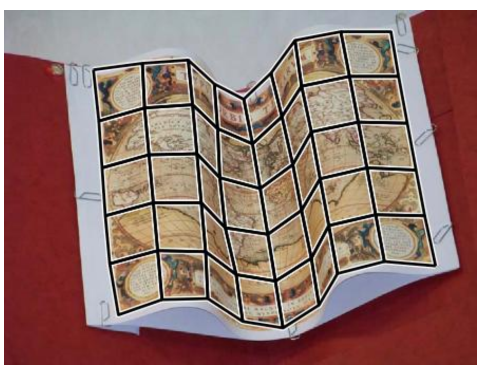
The hyperparameters

Determining the hyperparameters is mandatory!

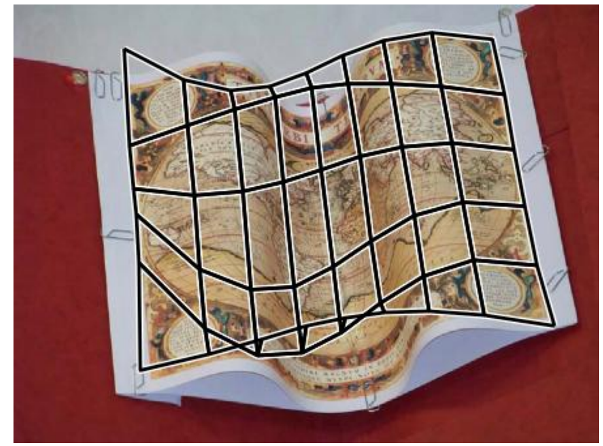
Source image

Target image

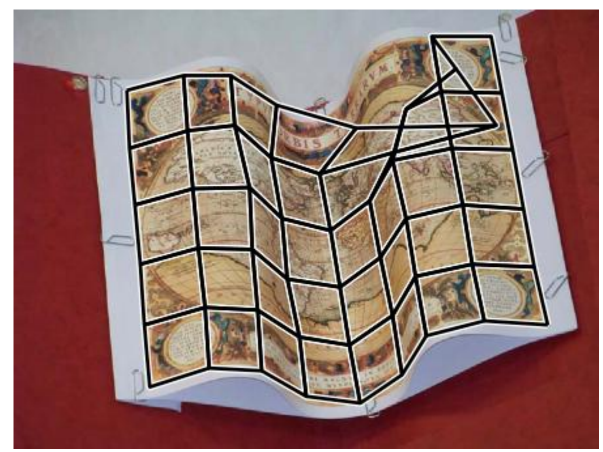


Number of control points

Not enough



Too much

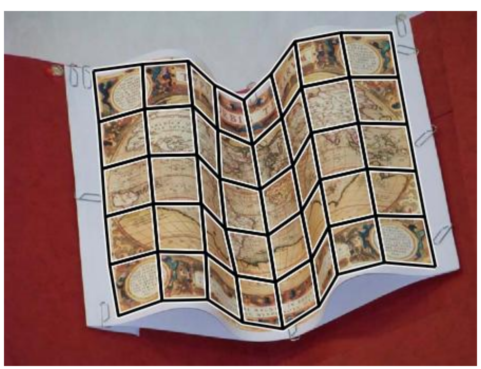


The hyperparameters

Determining the hyperparameters is mandatory!

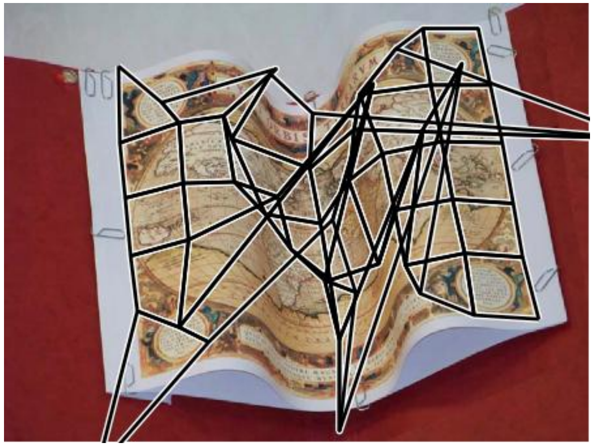
Source image

Target image



M-estimator threshold

Too low



Too high

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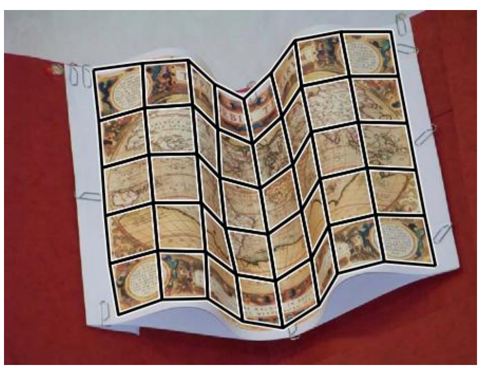
The hyperparameters

Determining the hyperparameters is mandatory!

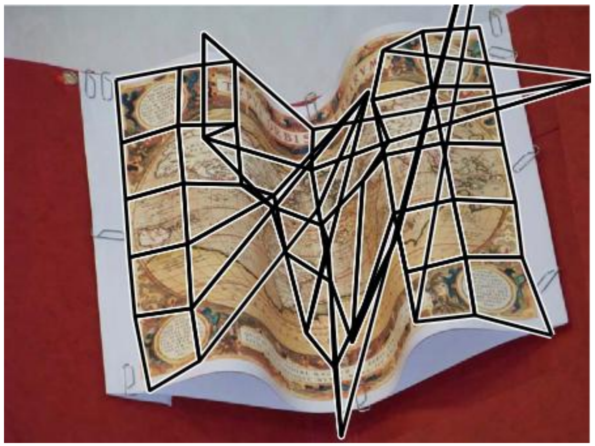
Source image

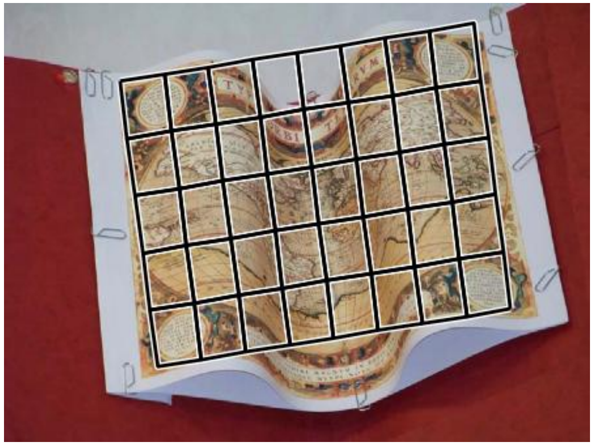
Target image



Regularization parameter

Too low





Too high

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Determining the hyperparameters

- How can we determine the hyperparameters?

$$\min_{\mathbf{p},\lambda,\gamma,\ldots} \sum_{i=1}^{n} \rho\left(\mathcal{W}(\mathbf{q}_i;\mathbf{p}) - \mathbf{q}'_i;\gamma\right) + \lambda\mathcal{R}(\mathbf{p})$$

Determining the hyperparameters

- Classical approach

$$\lambda^\star, \gamma^\star, \ldots = \arg \min_{\lambda, \gamma, \ldots} \mathcal{C}(\lambda, \gamma, \ldots)$$

$$\min_{\mathbf{p}} \sum_{i=1}^{n} \rho \left(\mathcal{W}(\mathbf{q}_i; \mathbf{p}) - \mathbf{q}'_i; \gamma^\star \right) + \lambda^\star \mathcal{R}(\mathbf{p})$$

Cross Validation

- A common approach : Cross Validation
  - Measures the ability of « generalizing the data »
  - Divide the dataset into a training set and test set

- Drawbacks
  - Computation time
  - Only use the data of the problem (here, the point correspondences)

Other criteria

- Mallow's Cp
- Akaike Information Criterion (AIC)
- Bayesian Information Criterion (BIC)
- Minimum Description Length (MDL)
- …

- Always the same problem: only use the point correspondences

Our approach

- Use **all** the available information:
  - The point correspondences
  - *And* the pixel colors

- Point correspondences: training set

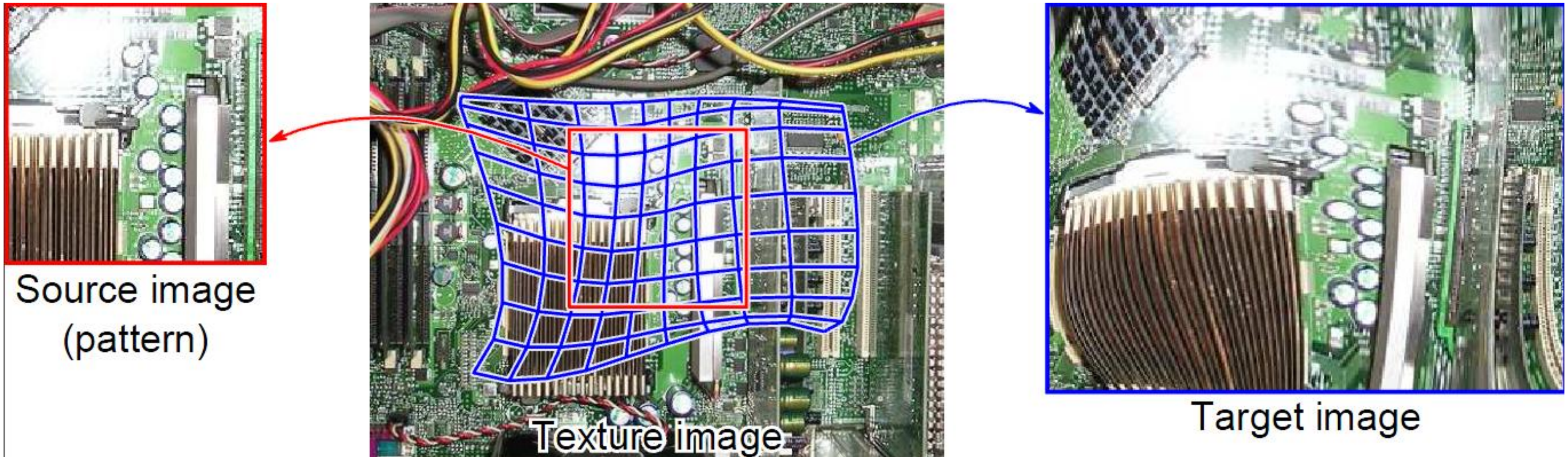
- Colors: test set

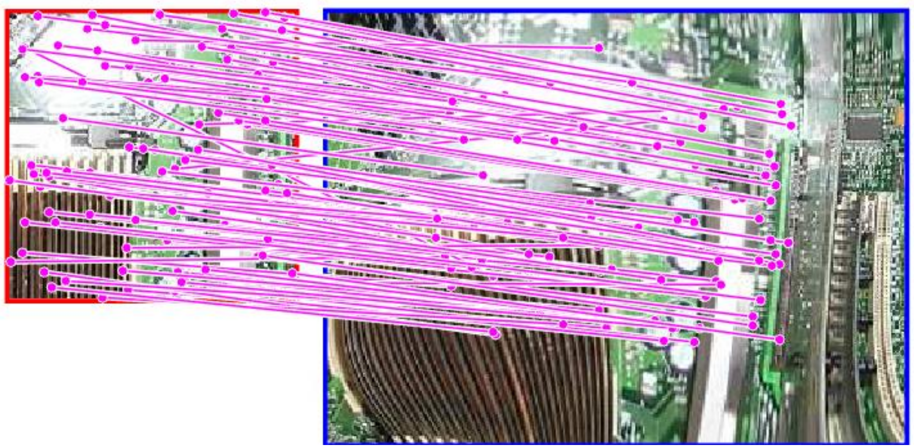
Our approach

$$\mathcal{C}(\lambda, \gamma, \ldots) = \frac{1}{|\mathfrak{R}|} \sum_{i=1}^{n} \|\mathcal{S}(\mathbf{q}) - \mathcal{T}(\mathcal{W}(\mathbf{q}; \mathbf{p}_{\lambda,\gamma,\ldots}))\|^2$$

$$\mathbf{p}^* = \arg\min_{\mathbf{p}} \sum_{\mathbf{q}\in\mathfrak{R}} \|S(\mathbf{q}) - T(\mathcal{W}(\mathbf{q}; \mathbf{p}))\|^2$$

Experimental results





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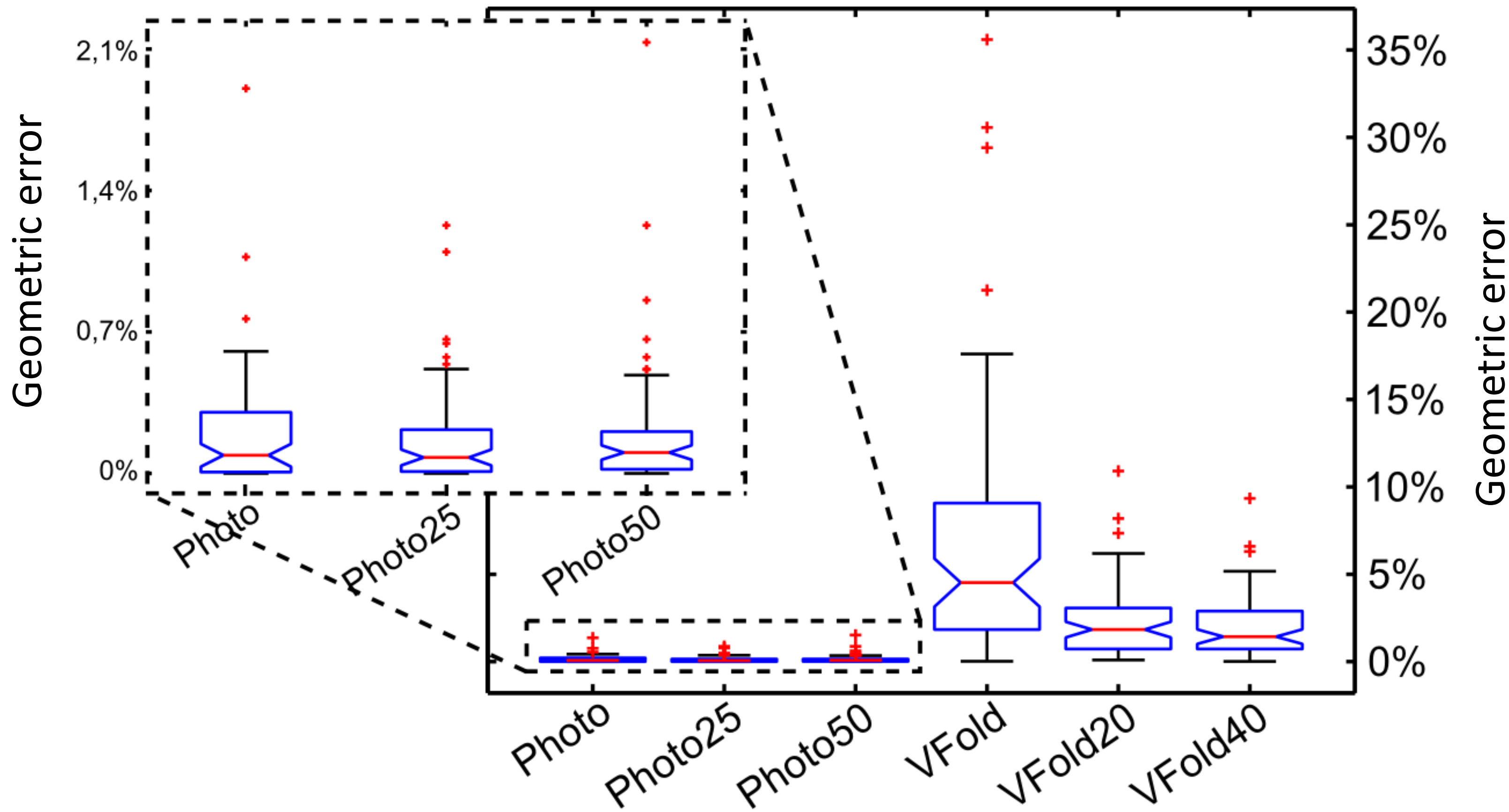
Experimental results

Geometric error (with respect to the ground truth)



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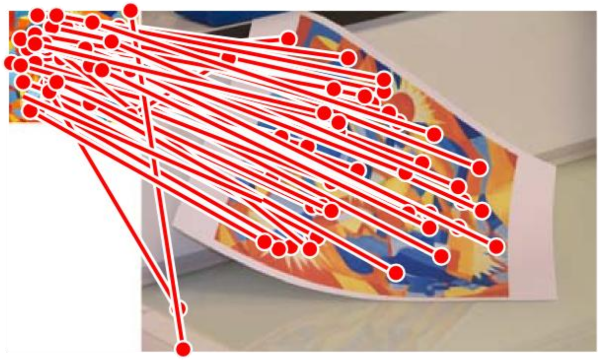
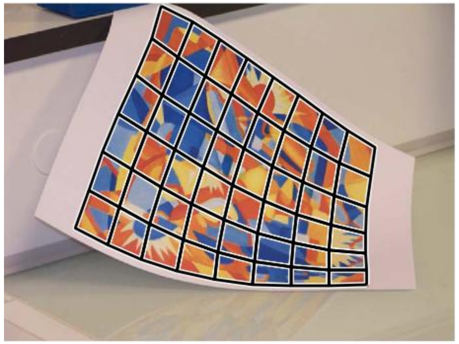
Experimental results

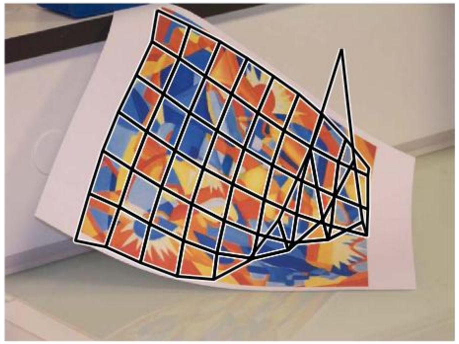
(a) Source image



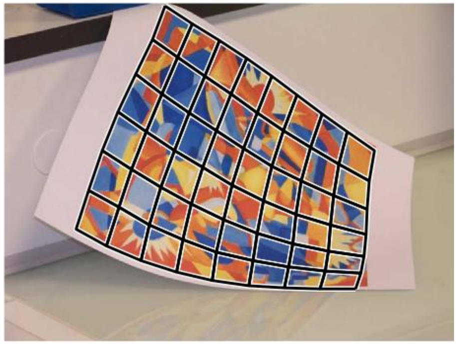
(b) Point correspondences



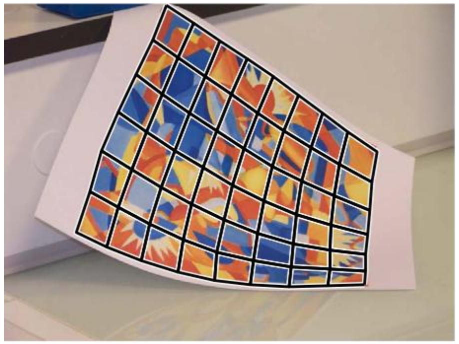
(c) Ground truth warp



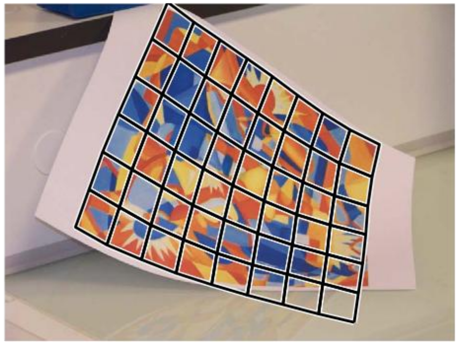
(e) VFold CV



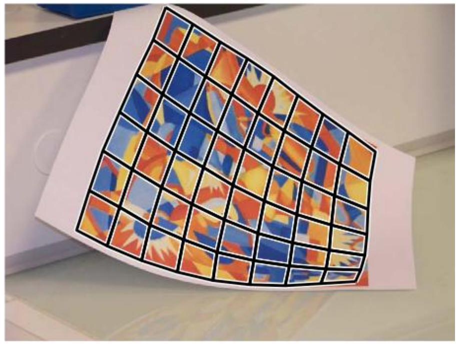
(g) Our criterion



(d) Oracle



(f) VFold CV (threshold = 20%)

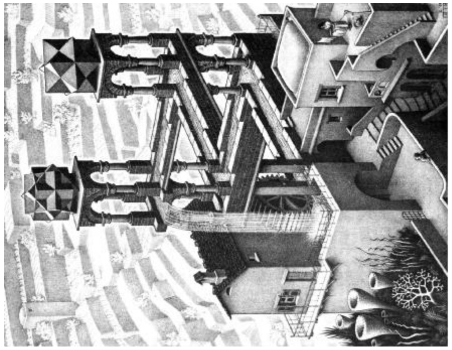


(h) Our criterion (threshold = 25%)

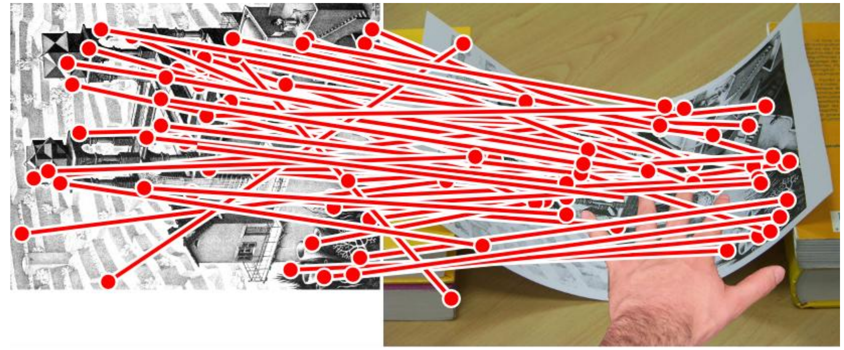
Experimental results

Criterion	Geometric error
VCV	1,852%
VCV (robust)	0,675%
Our criterion	0,190%
Our criterion (robust)	0,197%

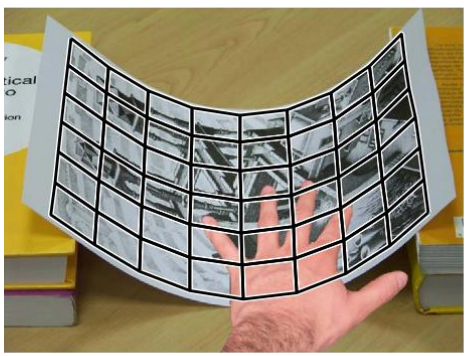
Experimental results



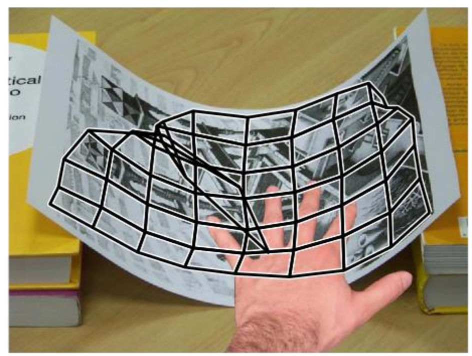
(a) Source image



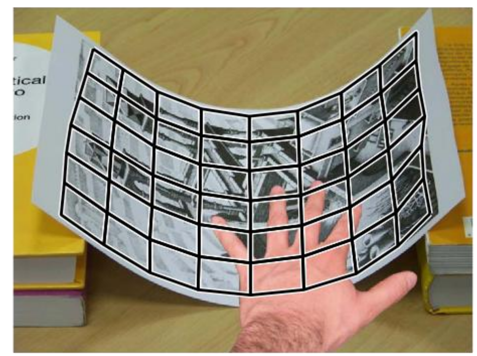
(b) Point correspondences



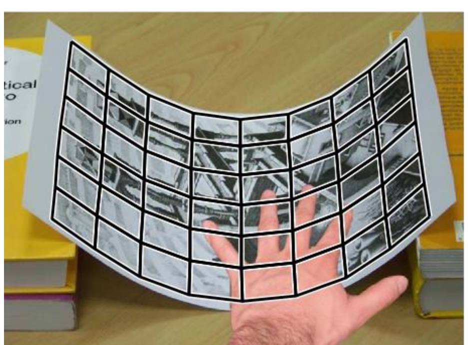
(c) Ground truth warp



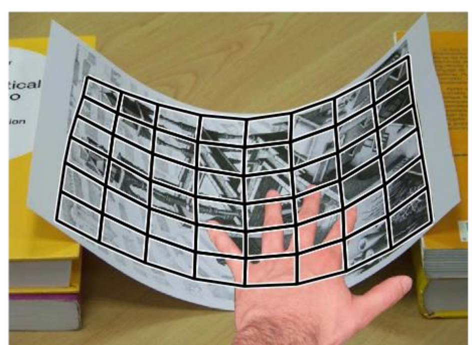
(e) VFold CV



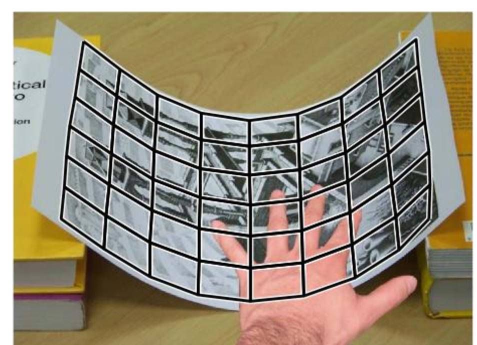
(g) Our criterion



(d) Oracle



(f) VFold CV (threshold = 20%)



(h) Our criterion (threshold = 25%)

Conclusion

- Importance of the hyperparameters and of their selection
- New criterion that uses all the available information
  - May be seen as a combination of the feature-based and the direct approaches to image registration
- What's next?
  - How can we optimize the proposed criterion?

Thank you!