# Person Re-Identification by Manifold Ranking

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## 1 Introduction


Given a set of gallery images at Location B, who is the target?


**Problem:**
Re-identify a person at different locations and time.

**Existing learning-to-rank methods are not scalable:**

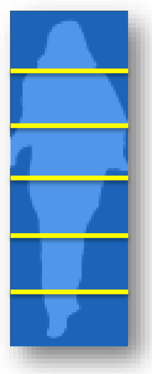
- The learning process requires exhaustive supervision on pairwise individual correspondence between camera pair.
- The value of unlabelled gallery instances is generally overlooked.

**Contributions:**

- Investigate the importance of using unlabelled gallery data for rank diffusion.
- Systematically formulate and validate manifold ranking models [3, 4].
- Performance significantly boosted by manifold ranking (14% performance gain at rank-1 matching rate)

## 2 Re-id by Manifold Ranking (MRank)

**Step 1. Feature extraction**



2784-dimensional feature vector:
RGB
YCbCr
HSV
Gabor
Schmid

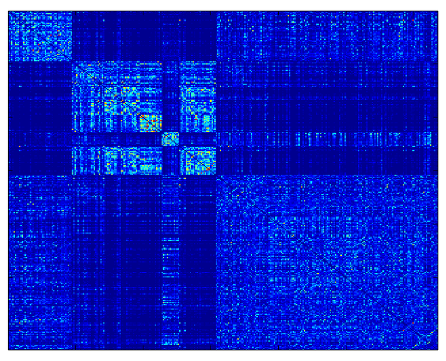
$$\mathbf{x} = (x_1, \ldots, x_d)^\top \in \mathbb{R}^d$$

**Step 2. Compute pairwise affinity, *A*, between all *n* gallery images and probe**

$$A \in \mathbb{R}^{(n+1)\times(n+1)}$$
$$A_{ij} = \exp\left(-\mathrm{dist}^2(\mathbf{x}_i, \mathbf{x}_j)/\sigma^2\right)$$

**Step 3. Estimate graph Laplacian**

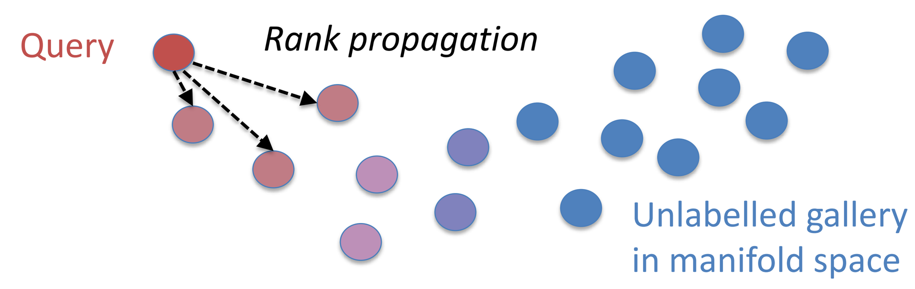
Normalised:
$$L_n = I - D^{-1/2} A D^{-1/2}$$
Unnormalised:
$$L_u = D - A$$
where $D_{ii} = \sum_j A_{ij}$



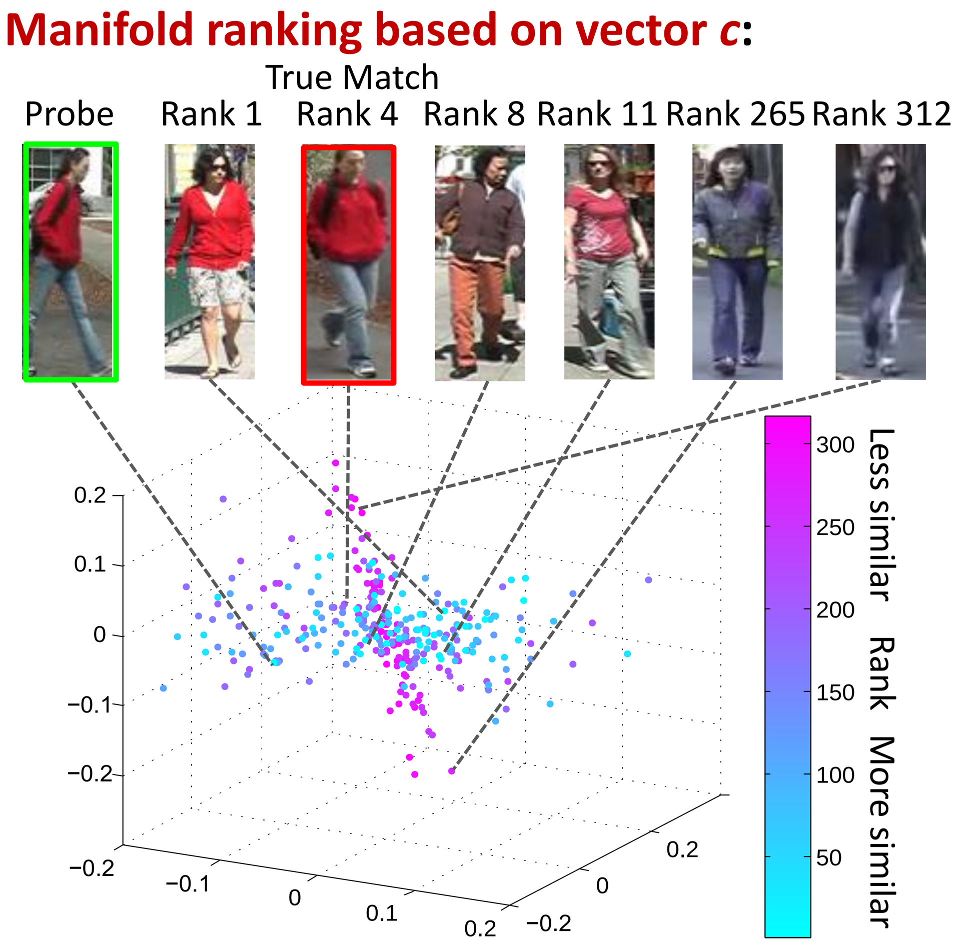
**Step 4. Manifold ranking**

$$\text{MRank}-L_n: \quad \mathbf{c} = (\beta I + L_n)^{-1}\mathbf{y}$$
$$\text{MRank}-L_u: \quad \mathbf{c} = \left[(\beta I + L_u)^{-1}\right]^m \mathbf{y}$$

where
$\mathbf{c}$ is the final ranking score vector
$\mathbf{y} = (y_1, \ldots, y_{n+1})^\top \quad y_i = 1$ if $\mathbf{x}_i$ is a query
$\beta \geq 0 \quad m \geq 0$




**Manifold ranking based on vector *c*:**




## 3 MRank vs. Conventional Methods without Manifold Ranking

**Datasets:**


**Highlights:**

- Performance is measured using matching rate at rank-*r* = the expectation of finding the correct match in the top *r* matches
- MRank can be initialised with supervised distance metrics, denoted as MRank-$L_u$ (*dist*) and MRank-$L_n$ (*dist*) for unnormalised and normalised Laplacians
- A relative improvement of **14%** at rank-1 recognition rate over the state-of-the-art learning to rank methods (RankSVM [1] and PRDC [2]).

| Method | i-LIDS ($p = 50$) | | | | | VIPeR ($p = 316$) | | | | | GRID ($p = 900$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | r = 1 | r = 5 | r = 10 | r = 15 | r = 20 | r = 1 | r = 5 | r = 10 | r = 15 | r = 20 | r = 1 | r = 5 | r = 10 | r = 15 | r = 20 |
| $\ell_1$-norm | 29.60 | **54.80** | 67.60 | 74.60 | 81.00 | **9.43** | **20.03** | **27.06** | **30.95** | **34.68** | 4.40 | 11.68 | 16.24 | 19.12 | 24.80 |
| MRank-$L_n$ ($\ell_1$-norm) | **31.40** | 54.40 | **68.40** | 75.60 | **83.60** | 8.48 | 18.70 | 24.40 | 28.83 | 32.66 | **7.12** | 12.32 | 17.68 | 20.64 | **25.36** |
| MRank-$L_u$ ($\ell_1$-norm) | 30.60 | 53.40 | 68.20 | **76.00** | 82.80 | 8.35 | 17.06 | 22.47 | 26.33 | 30.76 | 6.00 | **13.28** | **17.92** | **21.12** | 24.00 |
| $\ell_2$-norm | 28.20 | 54.00 | 66.20 | 72.40 | 79.40 | 10.95 | 23.92 | 31.39 | 38.86 | **44.11** | 4.88 | 14.24 | 20.32 | 22.40 | 26.24 |
| MRank-$L_n$ ($\ell_2$-norm) | **31.40** | 55.60 | **67.60** | **77.40** | **82.20** | **11.42** | **24.27** | **33.73** | **38.92** | **44.11** | **5.76** | 14.96 | **21.76** | **25.12** | **30.96** |
| MRank-$L_u$ ($\ell_2$-norm) | 31.00 | **56.00** | 67.40 | 77.00 | 81.20 | 10.57 | 24.24 | 33.42 | 38.83 | 43.42 | **5.76** | **15.44** | 21.28 | 24.96 | 28.40 |
| RankSVM [1] | 42.60 | 67.60 | 78.80 | 86.00 | 92.00 | 14.87 | 37.12 | 50.19 | 58.48 | 65.66 | 10.24 | 24.56 | 33.28 | 39.44 | 43.68 |
| MRank-$L_n$ (RankSVM) | **42.80** | **70.40** | **81.80** | 86.40 | **92.40** | 19.27 | 42.41 | 55.00 | 63.86 | 70.06 | **12.24** | **27.84** | 36.32 | **42.24** | **46.56** |
| MRank-$L_u$ (RankSVM) | 41.80 | 69.60 | 81.40 | **87.00** | 91.40 | **19.34** | **42.47** | **55.51** | **64.11** | **70.44** | 11.44 | 27.60 | **36.40** | **42.24** | 46.24 |
| PRDC [2] | 44.80 | 68.00 | 77.60 | 84.20 | 88.20 | 16.01 | 37.09 | 51.27 | 59.43 | 65.95 | 9.68 | 22.00 | 32.96 | 38.96 | 44.32 |
| MRank-$L_n$ (PRDC) | 47.80 | **71.60** | **80.60** | 85.00 | **90.60** | **19.37** | **42.78** | **54.78** | **63.77** | **69.62** | 10.88 | 24.96 | **35.84** | 41.44 | 46.40 |
| MRank-$L_u$ (PRDC) | **49.00** | 70.60 | **80.60** | **85.60** | **90.60** | 18.45 | 41.74 | 53.67 | 62.72 | 69.27 | **11.12** | **26.08** | 35.76 | **41.76** | **46.56** |

*$L_u$ = Unnormalised Laplacian; $L_n$ = normalised Laplacian; r = rank; p = number of person in a test set*

## 4 $L_u$ vs. $L_n$

Fig.(a)

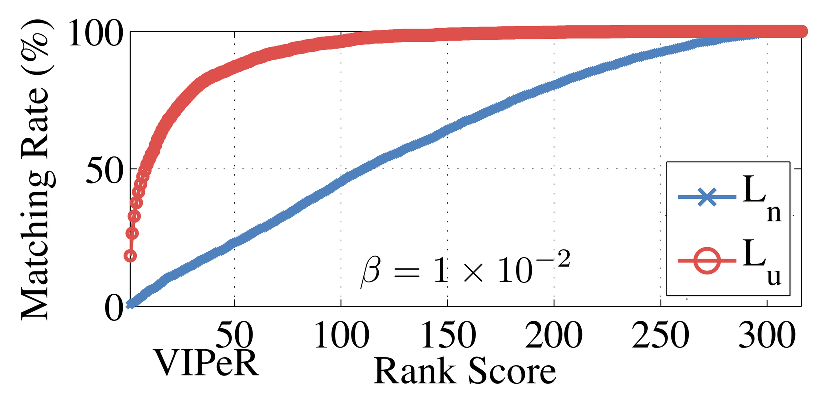
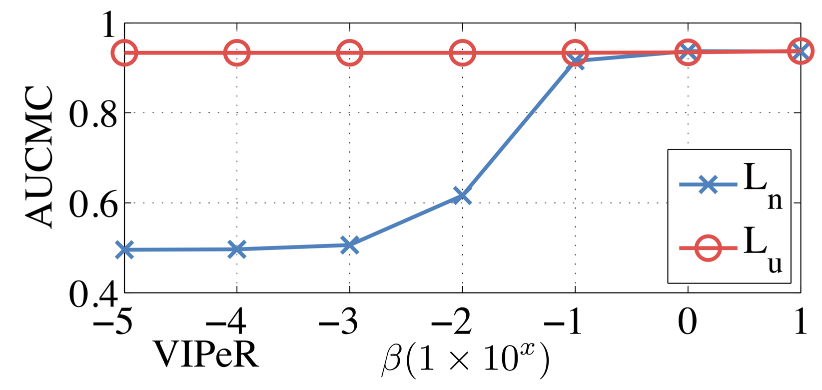



Fig. (b)

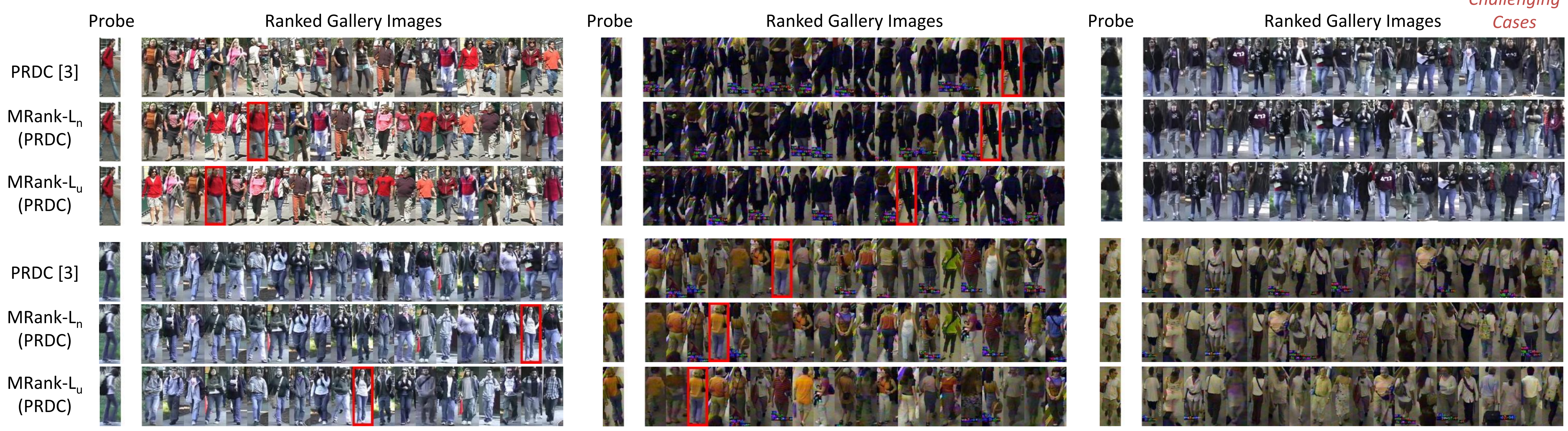



β is an important parameter that controls the convergence of manifold ranking.
Fig. (a) Matching rate curves with $\beta = 10^{-2}$
Fig. (b) Area under the curve with β varied from $10^{-5}$ to 10.

** Unnormalised Laplacian, $L_u$, is less sensitive to β in comparison to normalised Laplacian, $L_n$.*

## 5 Examples

The leftmost image is the probe. The true match within the ordered gallery candidates is highlighted with red border.
MRank gains better retrieval results as compared to PRDC [2] without manifold ranking. (And higher visual consistency at top ranks).




[1] B. Prosser, W. Zheng, S. Gong, and T. Xiang, “Person re-identification by support vector ranking,” in BMVC, 2010
[2] W. Zheng, S. Gong, and T. Xiang, “Re-identification by relative distance comparison,” TPAMI, 2012
[3] D. Zhou, J. Weston, A. Gretton, O. Bousquet, and B. Scholkopf, “Ranking on data manifolds,” in NIPS, 2004
[4] X. Zhou, M. Belkin, and N. Srebro, “An iterated graph Laplacian approach for ranking on manifolds,” in SIGKDD, 2011

**Dataset and Source Code:**
http://personal.ie.cuhk.edu.hk/~ccloy/