The 19th Pacific Conference on Computer Graphics and Applications
(Pacific Graphics 2011) will be held on September 21 to 23, 2011 in Kaohsiung, Taiwan.

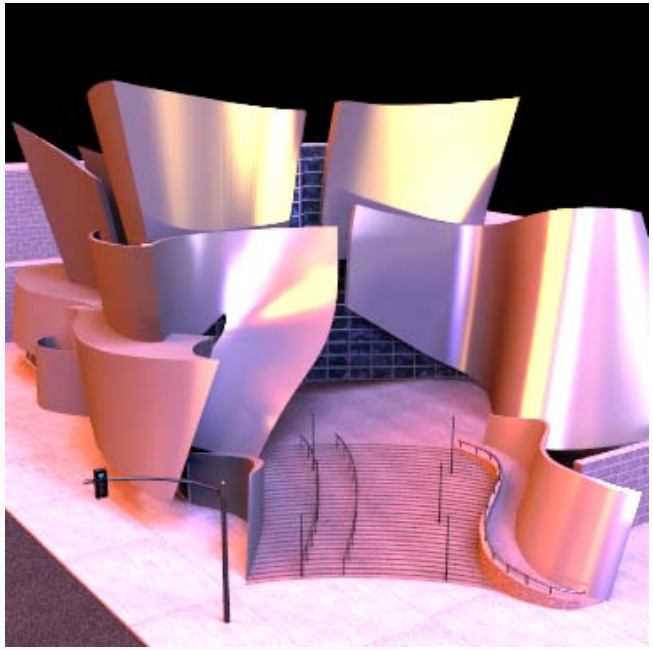
Improving Performance and Accuracy of Local PCA

V. Gassenbauer, J. Křivánek, K. Bouatouch,
C. Bouville, M. Ribardière

University of Rennes 1, France, and
Charles University, Czech Republic

Objective

Precomputed Radiance Transfer (PRT)



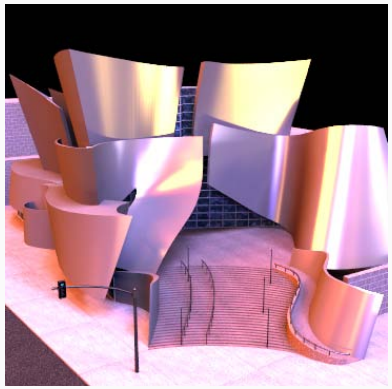
Bidirectional Texture Function (BTF) compression

Image courtesy of Hongzhi Wu

- **Need to compress large data set**

Precomputed Radiance Transfer

- **Relighting as a matrix-vector multiply**



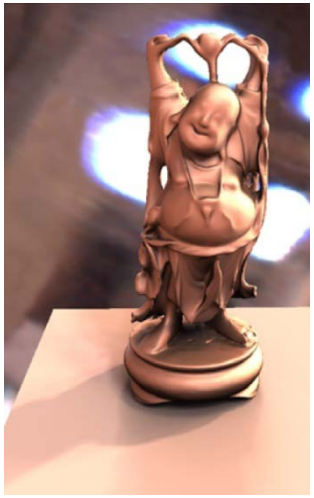
$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_4 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix} \cdot \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_M \end{bmatrix}$$

- **Matrix $T(x,\omega_i)$ - Billions of elements**
  - Infeasible multiplication
  - Compression (wavelet, **Local PCA**)

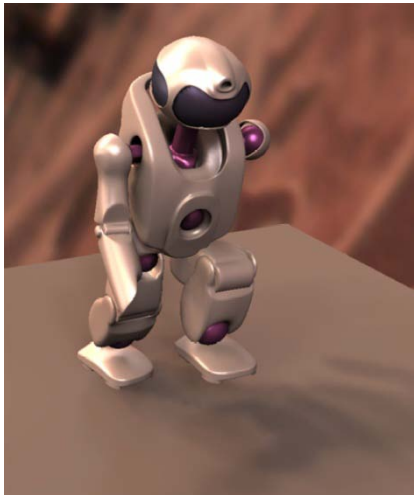
Related Work

- **Precomputation-based rendering**

[Sloan et al. 02,03]
Low-freq shadows,
inter-reflections



[Liu et al. 04],
[Huang et al. 10]
High-freq shadows,
inter-reflections

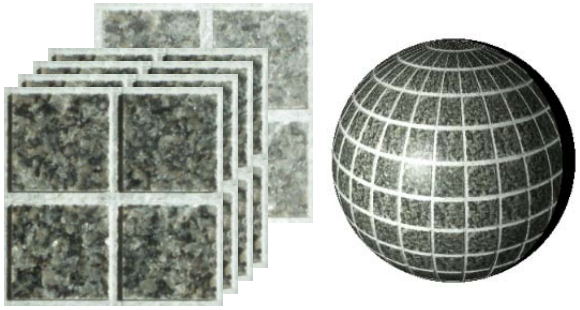


[Xu et al. 08]
Dynamic scene,
BRDF editing

- Still use slow and inaccurate LPCA !

Related Work

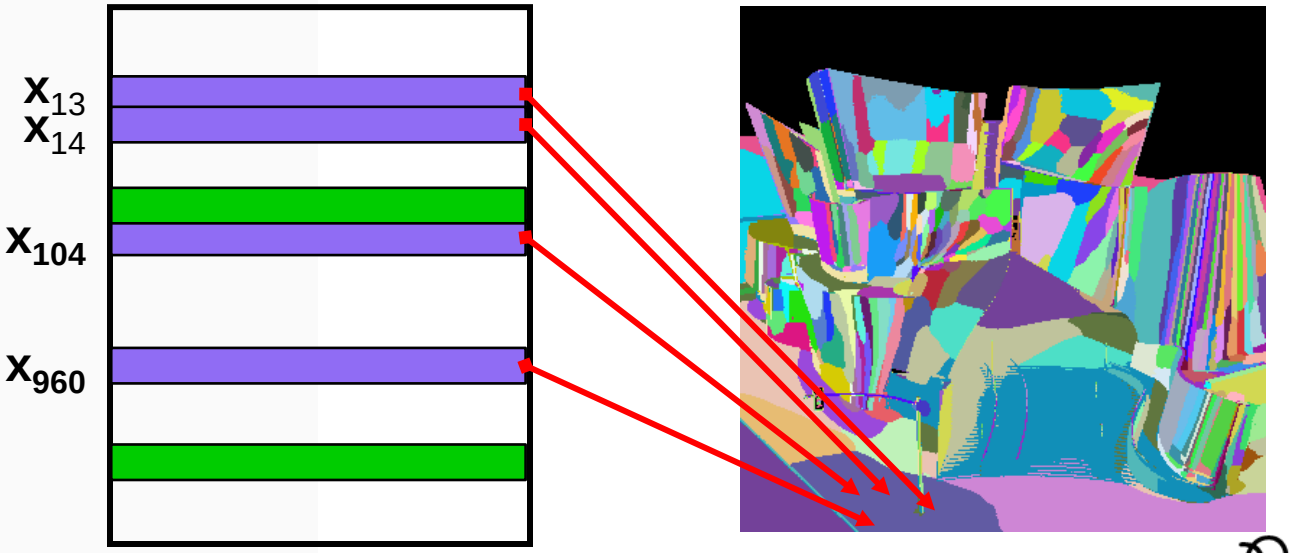
- **BTF compression**
  - [Müller et al. 03], [Filip et al. 09]



- **Simpler LPCA: *k*-means problem**
  - Better performance
    [Phillips 02], [Elkan 03], [Hamerly10]
  - Better accuracy
    [Arthur et al. 07], [Kanugo et al. 02]

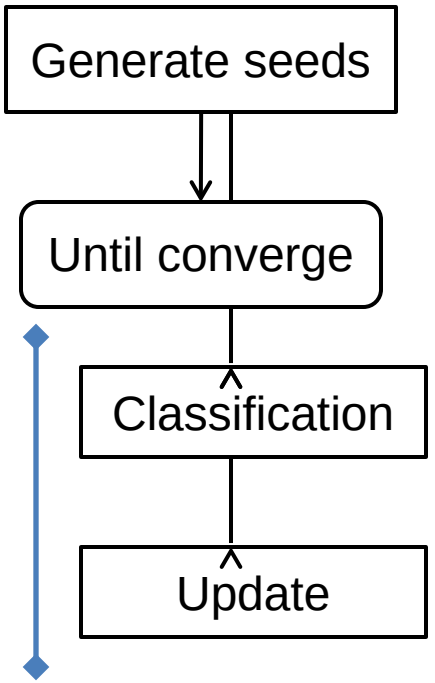
Compression Problem

- **Input**
  - High-dimensional points (rows of **T**)
  - Number of clusters *k*
- **Output**
  - Find *k* clusters – i.e. low-dimensional subspaces



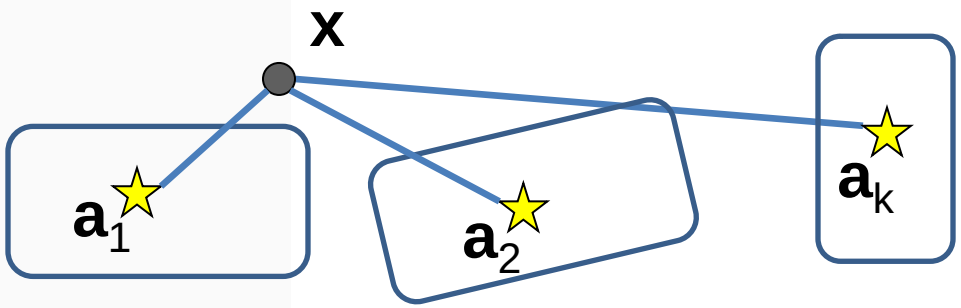
LPCA – The Algorithm

- **Guess *k* clusters (i.e. subs.)**
  - Initialize by randomly selected centers
- **Repeat until convergence**
  - Assign each point to the nearest cluster
  - Update PCA in the cluster

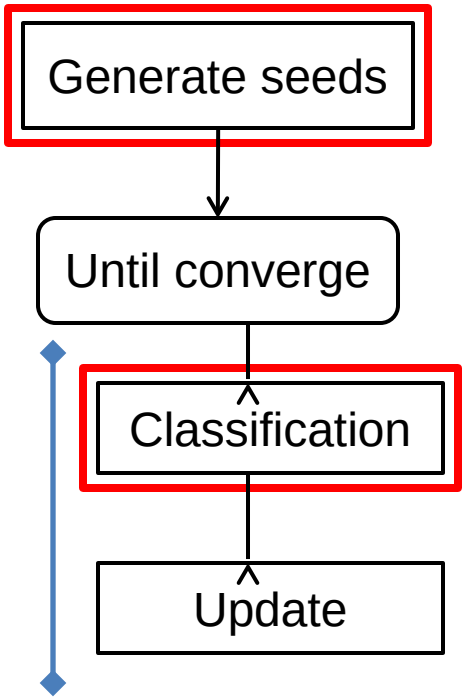


Motivation

- **Inefficient**
  - For each point compute distance to all clusters $\mathbf{a}_i$

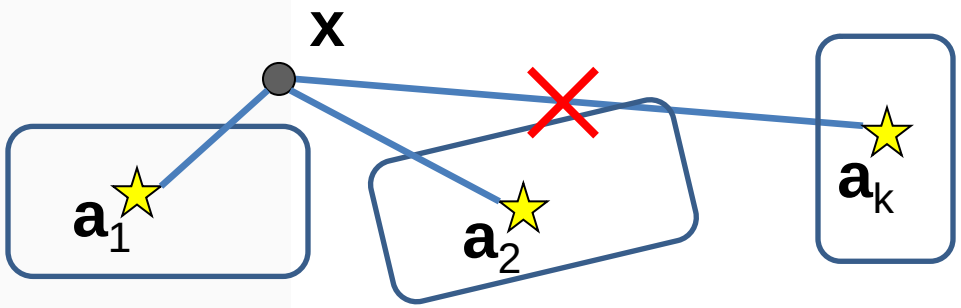


- **Inaccurate**
  - Prone to get stuck in a local optimum

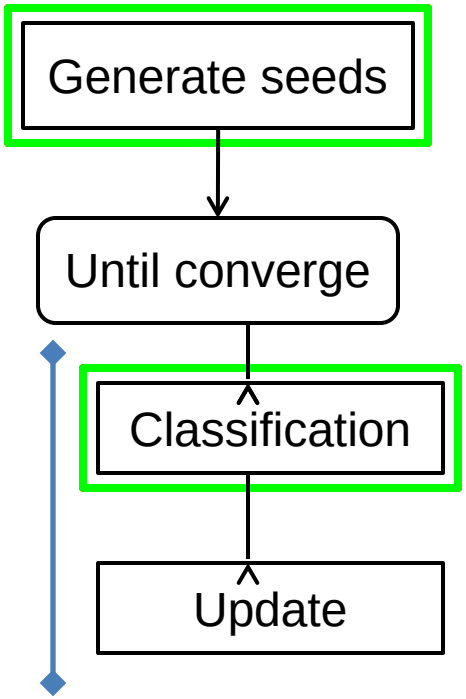


Our Contribution

- ~~Inefficient~~
  - For each point compute distance to all clusters $\mathbf{a}_i$
  - SortCluster LPCA (SC-LPCA)



- ~~Inaccurate~~
  - Prone to get stuck in a local optimum
  - SortMeans++

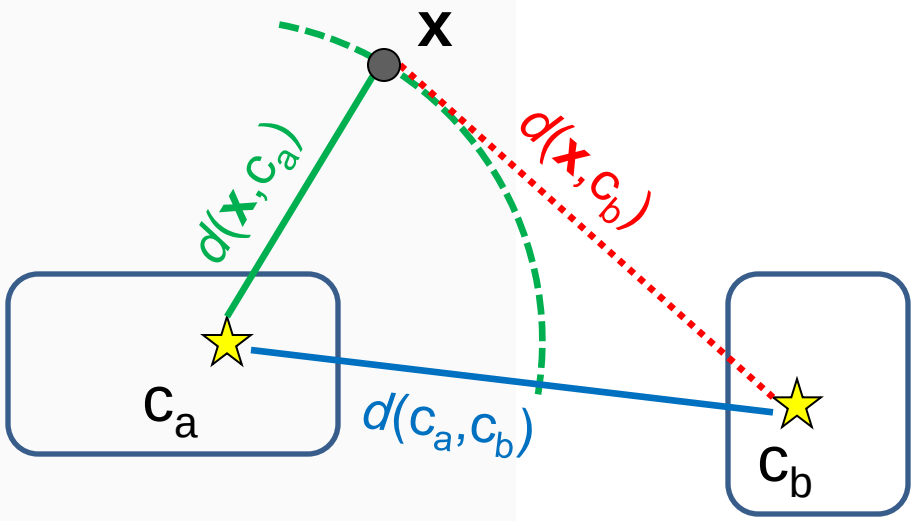


Outline

- **Improving Performance**
  - SortCluster-LPCA (SC-LPCA)
- **Improving Accuracy**
  - SortMeans++
- **Results**

Accelerated *k*-means

- **Δ-inequality [Phillips 02]**



If $d(c_a,c_b) \geq 2d(\mathbf{x},c_a)$

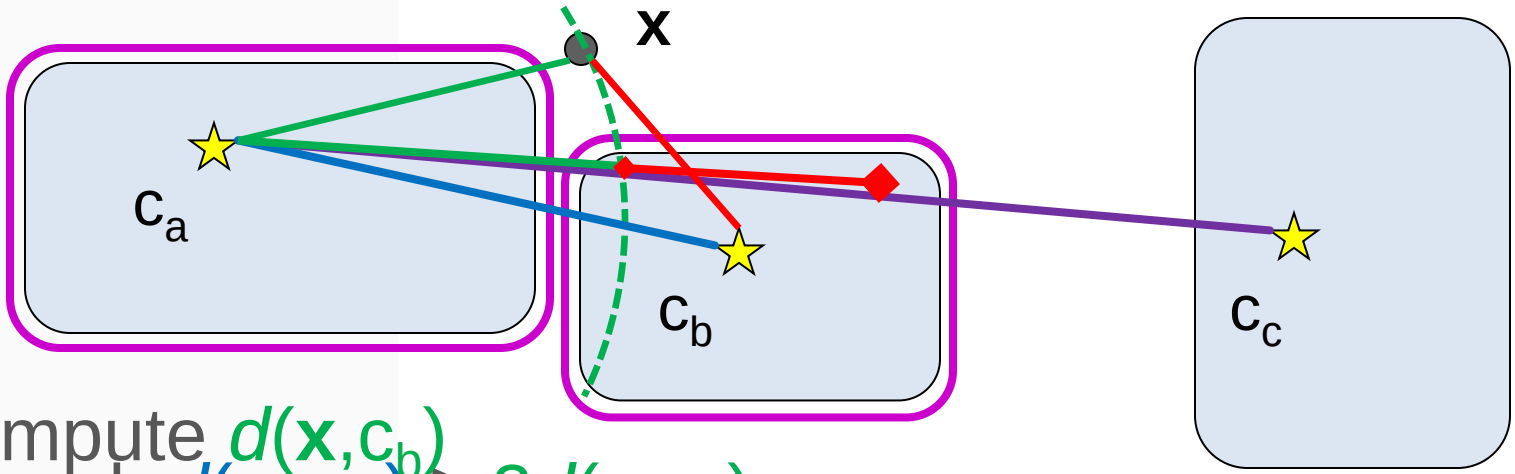
$\rightarrow d(\mathbf{x},c_b) \geq d(\mathbf{x},c_a)$

$\rightarrow d(\mathbf{x},c_b)$ not necessary to compute !

How does it work ?

We know: potentially nearest cluster to **x**

We know: Distances of other cluster w.r.t. c_a



Compute $d(\mathbf{x},c_b)$

Check $d(c_a,c_b) \geq 2d(\mathbf{x},c_a)$

Compute $d(\mathbf{x},c_a)$

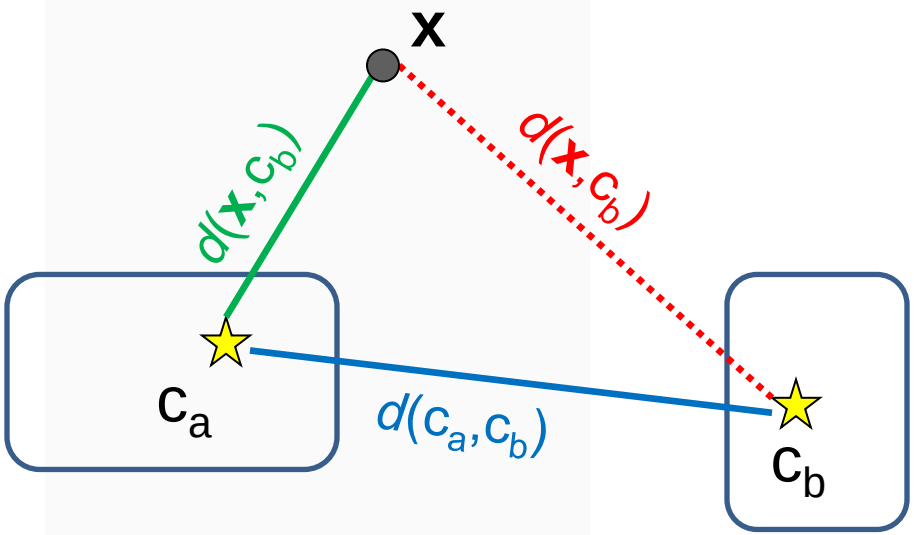
c_b becomes a new nearest cluster

Check $d(c_a,c_c) \geq d(\mathbf{x},c_a)+d(\mathbf{x},c_b)$

Our Contribution: From *k*-means t

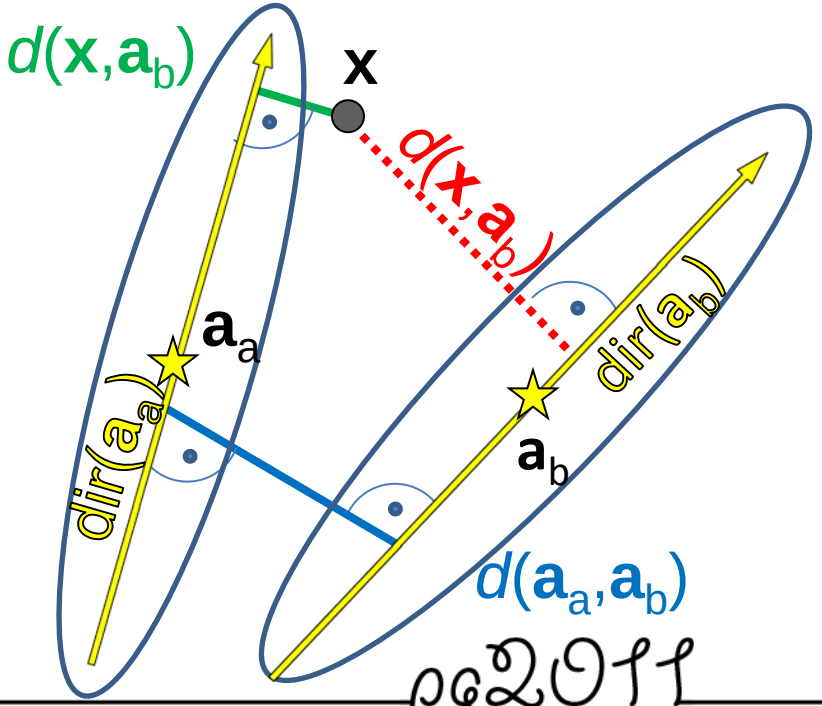
k-means

Piecewise reconstruction



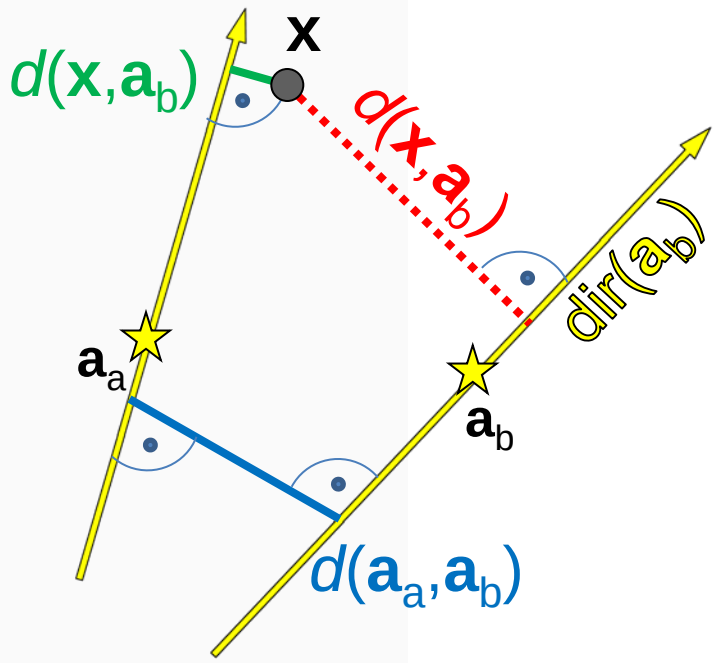
LPCA

Piecewise reconstruction in low-dimensional subspaces



Δ-inequality for LPCA

- **Distance between subspaces**
  - $d(\mathbf{a}_a,\mathbf{a}_b) = \inf\{\|p - q\| ; p \text{ in } \mathbf{a}_a, q \text{ in } \mathbf{a}_b\}$



- Δ-inequality for subspaces

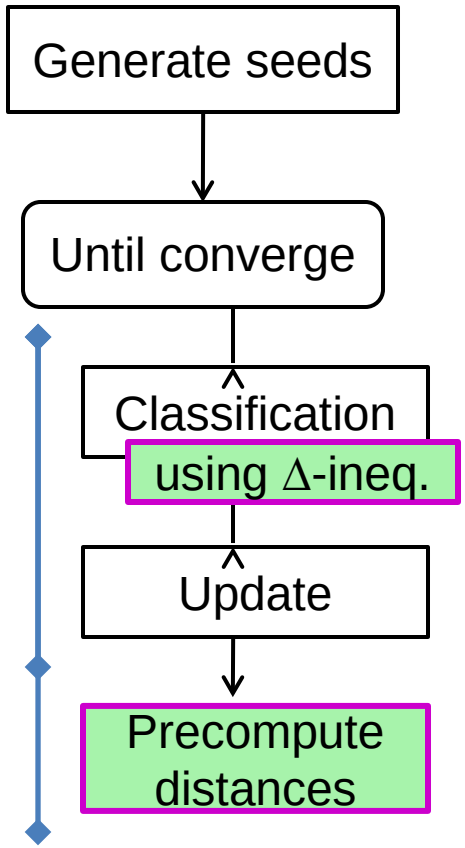
If $d(\mathbf{a}_a,\mathbf{a}_b) \geq 2d(\mathbf{x},\mathbf{a}_b)$

$\rightarrow d(\mathbf{x},\mathbf{a}_b) \geq d(\mathbf{x},\mathbf{a}_b)$

$\rightarrow d(\mathbf{x},\mathbf{a}_b)$ not necessary to compute !

Our SortCluster-LPCA

- **When assigning $\mathbf{x}$**
  - Start from $\mathbf{a}_j$
  - Proceed $\mathbf{a}_i$ in increasing order of distances w.r.t. $\mathbf{a}_j$
  - Check Δ-inequality
- **For all $\mathbf{a}_i$ precompute**
  - Distances to each others
  - Ordering



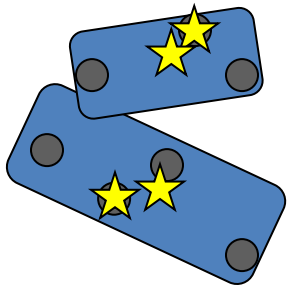
Outline

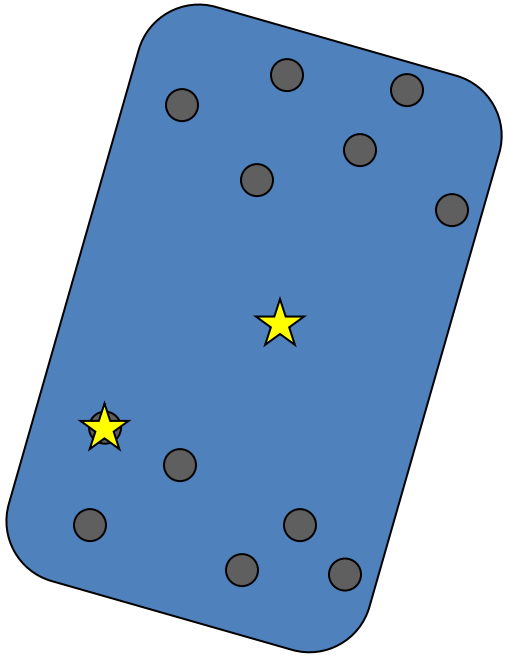
- **Improving Performance**
  - SortCluster-LPCA (SC-LPCA)
- **Improving Accuracy**
  - SortMeans++
- **Results**

LPCA Accuracy

- LPCA prone to stuck in local optimum

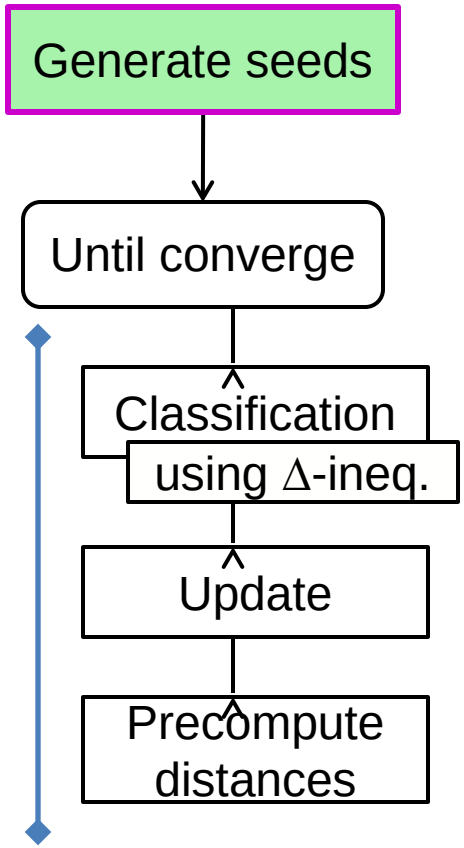
- Observation
  - Error comes from poor selections of cluster centers





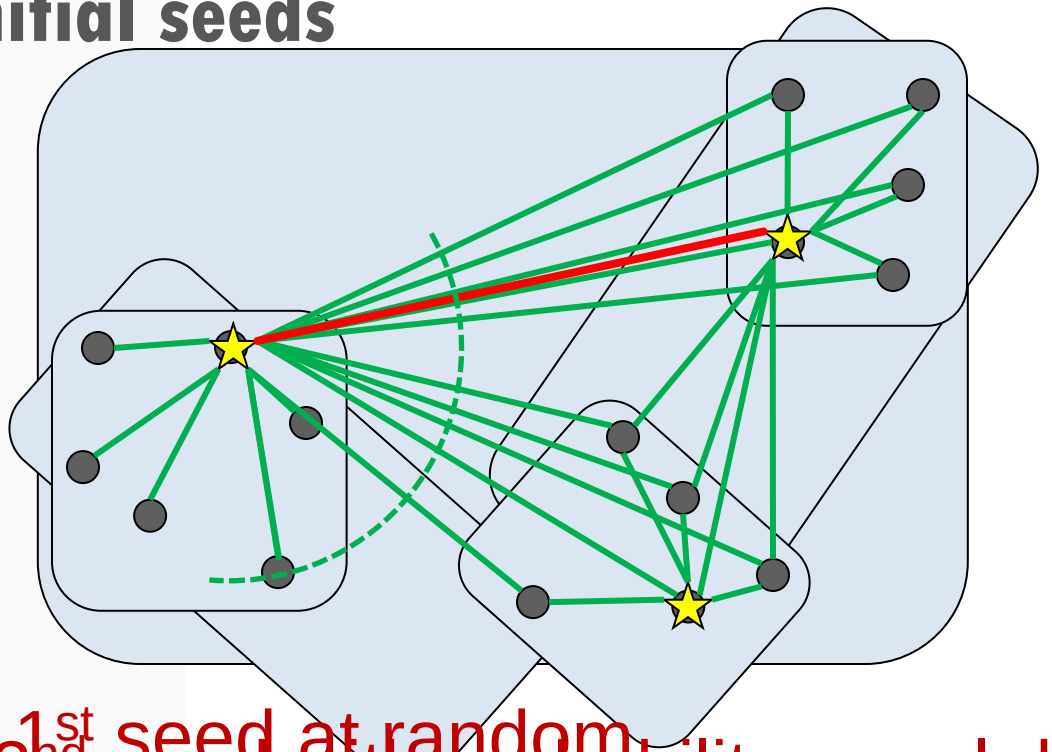
Generation of Seeds

- **Some heuristic**
  - Farthest first [Hochbaum et al. 85]
  - Sum based [Hašan et al. 06]
  - *k*-means++ [Arthur and Vassil. 07]
  - …
- ***Our approach:* SortMeans++**
  - Based on *k*-means++
  - Faster



Our SortMeans++

- Select initial seeds



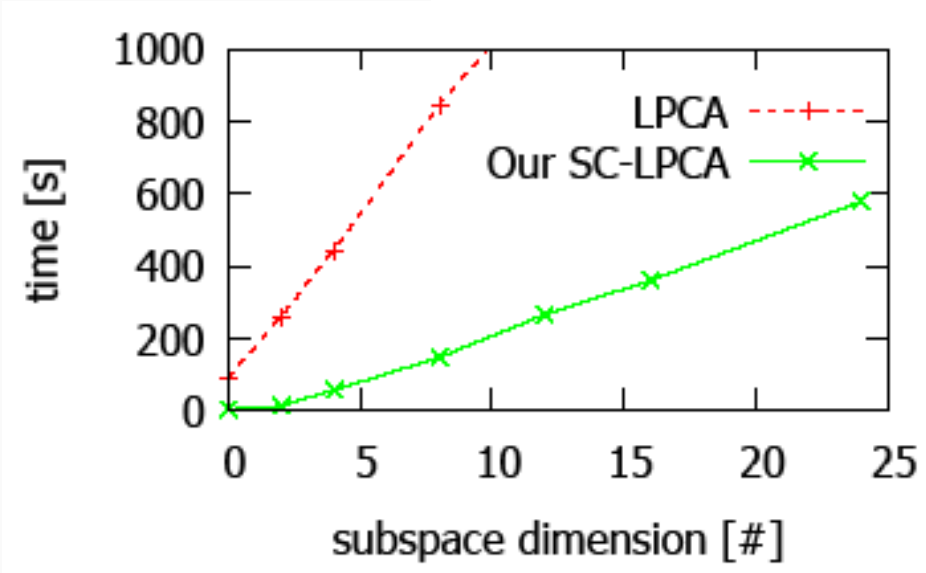
Select 1st seed at random
Take 2nd seed with probability equal distances
Recluster using A-inequality
Take 3rd seed with probability equal distances
Recluster …

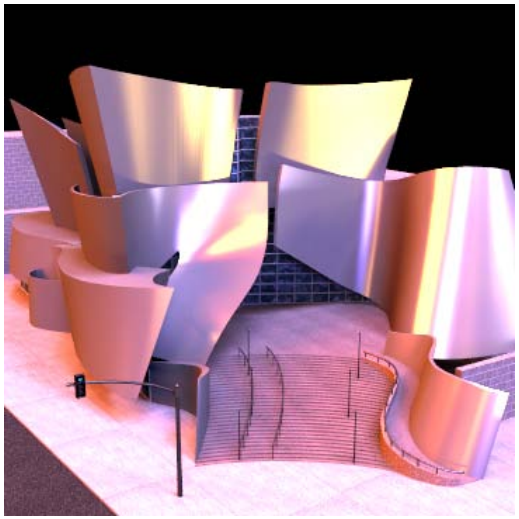
Outline

- **Improving Performance**
  - SortCluster-LPCA (SC-LPCA)
- **Improving Accuracy**
  - SortMeans++
- **Results**

Results

- **Evaluate method with different parameters**
  - Scalability with the subspace dimension



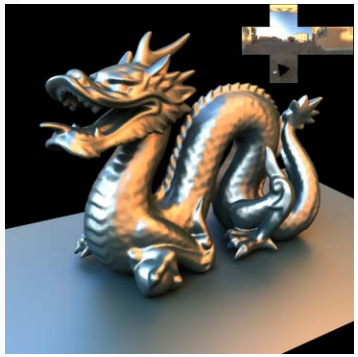


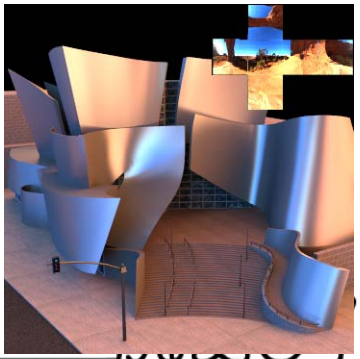
  - More than 5x speed-up

Overall Performance

- Did several iterations of (SC)LPCA up to 24 basis

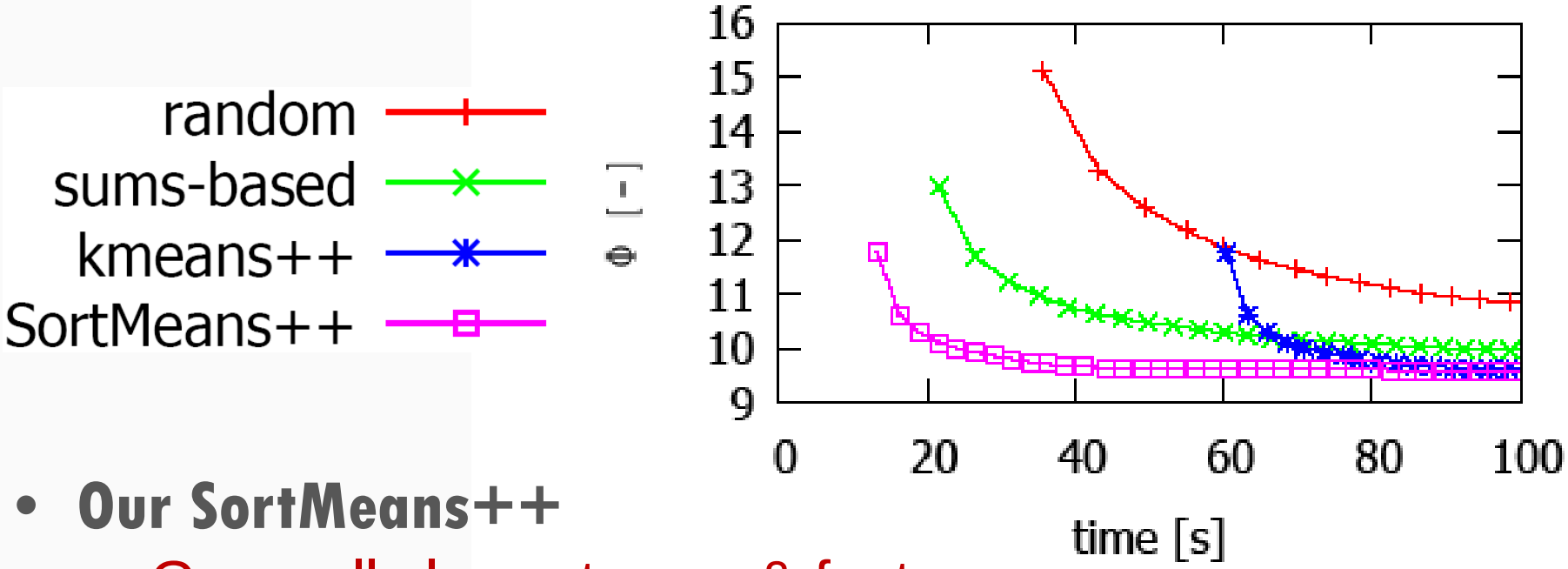
Model	Vertices [#]	LPCA	SC-LPCA	Speed Up	PRT
Horse	67.6k	3h 48m	11m	20.3x	22.5 s
Dragon	57.5k	3h 1m	28m	6.4x	25.5 s
Buddha	85.2k	4h 38m	50m	5.6x	31.6 s
Disney	106.3k	5h 50m	1h 8m	5.1x	46.5 s



Improving Accuracy

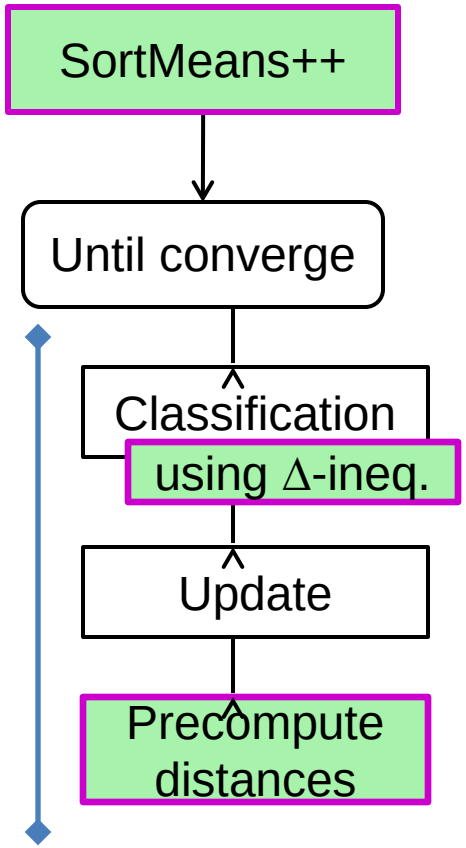
- **Latency and accuracy of seeding algs:**



- **Our SortMeans++**
  - Generally lowest error & fast
  - Improve performance of SC-LPCA !

Conclusion

- **SC-LPCA (accelerated LPCA)**
  - Avoid unnecessary distance comp.
  - Speed-up of 5 to 20 on our PRT data
  - Without changing output !
- **Improve accuracy (SortMeans++)**
  - More accurate data approximation
- **Future work**
  - Test on other CG data
  - GPU acceleration



BTF Compression

- Try several data sets



- SC-LPCA speed-up of about only 1.5x
  - Reason: Small number of subspaces

The End

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  - European Community
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Thank You for your attention