Parallelized Incremental PCA for Online Data Visualization

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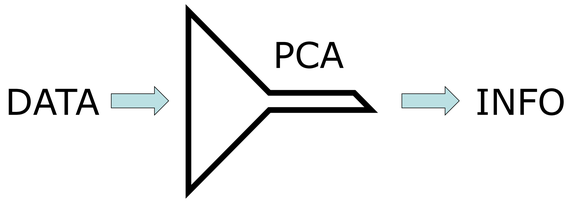
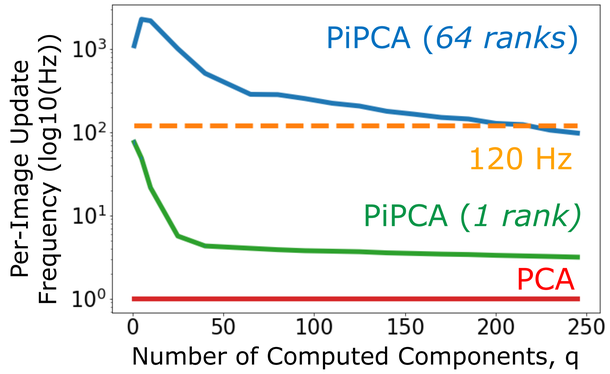
Introduction

Principal component analysis (PCA) is a lightweight exploratory data analysis technique that isolates the most significant modes of variation within a dataset.

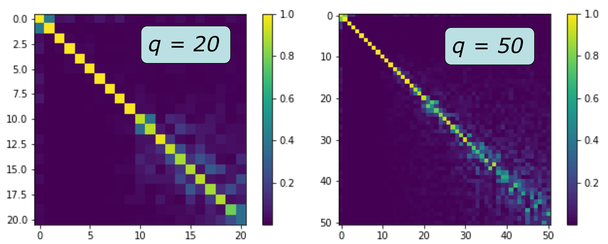


***Objective*:** Implement an online **PCA** plugin for the existing LCLS framework *'btx'* to be used for hit-detection, denoising, and real-time data exploration.

Results



PiPCA update frequency **exceeds** the 120Hz image arrival window for q < ~200 (amortized per-image update) when running over 64 ranks.



Confusion Matrix of $\boldsymbol{U}_q$ calculated using PiPCA and PCA

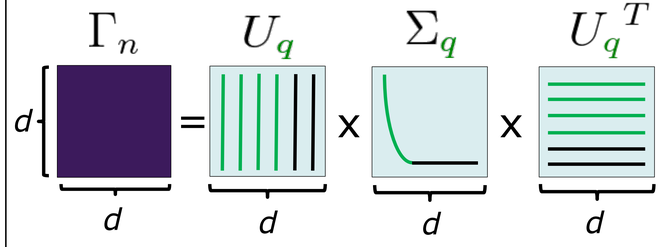
PiPCA accurately calculates and updates the first q / 2 principal axes and values, maintaining comparable explained variance to lossless PCA.

PCA

Given a *(d x n)* dataset $\boldsymbol{X}$ with *d* features and *n* samples, PCA finds the rank-*q* < *d* basis $\boldsymbol{U}_q$ that minimizes the **compression loss**:

$$L_n(\boldsymbol{U}_q) = \frac{1}{n}\|\boldsymbol{X} - \boldsymbol{U}_q\boldsymbol{U}_q^T\boldsymbol{X}\|_F^2$$

$\boldsymbol{U}_q$ and its corresponding $\boldsymbol{\Sigma}_q$ are formed from the *q* most significant eigenvectors and eigenvalues of the sample covariance matrix $\boldsymbol{\Gamma}_n = \boldsymbol{X}\boldsymbol{X}^T / (n-1)$:

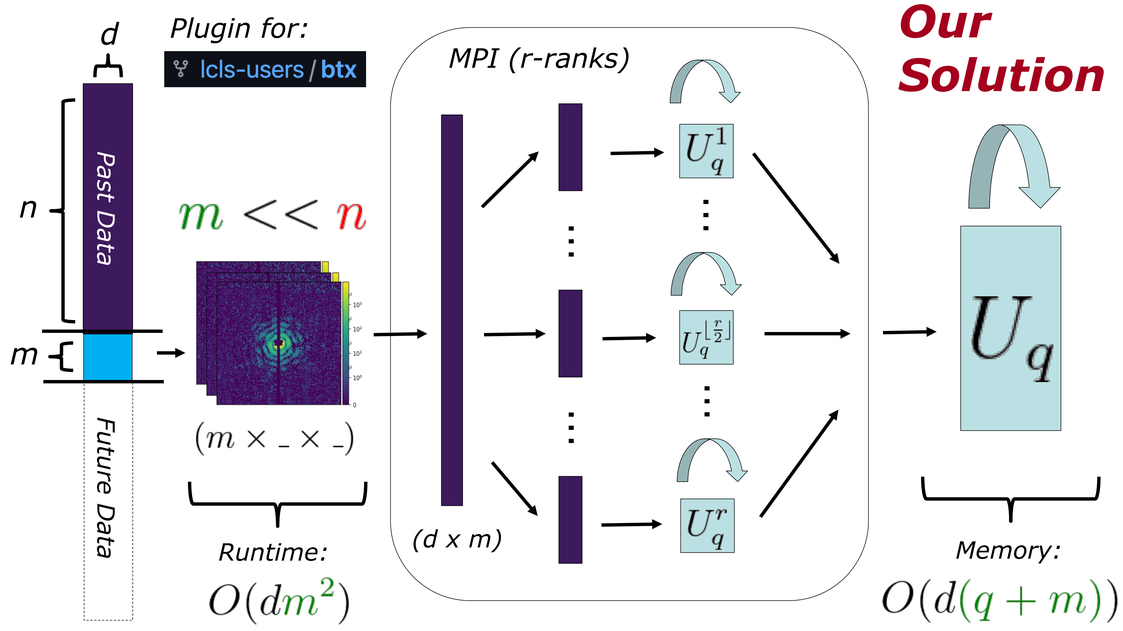


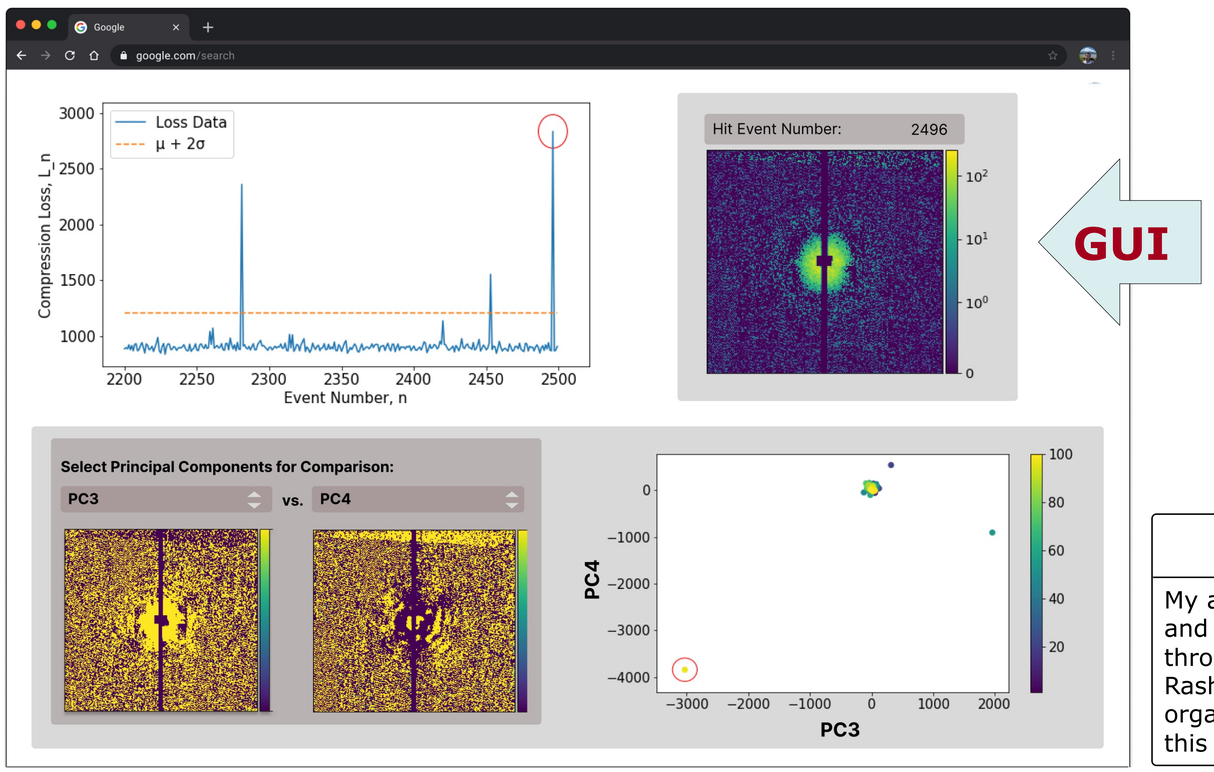
Runtime & Memory Complexity:

$O(dn^2) \sim 1e12$

Scaling Problem

Parallelized Incremental PCA (PiPCA)





Future Enhancements

Areas of enhancement and exploration include:

- Adaptive tuning of *r, q,* and *m.*
- Implementation of an interactive **GUI** for real-time data visualization.
- Research into interfacing with GPU, instead of CPU, clusters.
- Further performance improvements, including:
  - data cropping and masking
  - smart model training (pausing model updates within a stability window).

Acknowledgments

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