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.

**DATA** → **PCA** → **INFO**

**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

**Runtime & Memory Complexity:**

\[ O(dn^2) \sim 10^{12} \]

**Scaling Problem**

Parallelized Incremental PCA (PiPCA)

Given a \((d \times n)\) dataset \(X\) with \(d\) features and \(n\) samples, PCA finds the rank-\(q < d\) basis \(U_q\) that minimizes the **compression loss**:

\[ L_q(U_q) = \frac{1}{2n} \| X - U_q U_q^T X \|_F^2 \]

\(U_q\) and its corresponding \(\Sigma_q\) are formed from the \(q\) most significant eigenvectors and eigenvalues of the sample covariance matrix \(R = XX^T / (n-1)\):

\[ \Gamma_n = U_q \Sigma_q U_q^T \]

**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).

**Our Solution**

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

**Confusion Matrix of** \(U_q\) **calculated using PiPCA and PCA**

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

**Confusion Matrix of** \(U_q\) **calculated using PiPCA and PCA**

**Future Data**

\[ m << n \]

**Memory:**

\[ O(d(q + m)) \]

**Runtime:**

\[ O(dm^2) \]

**Our Solution**

**Future Data**

\[ m << n \]

**Memory:**

\[ O(d(q + m)) \]

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\[ O(dm^2) \]

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