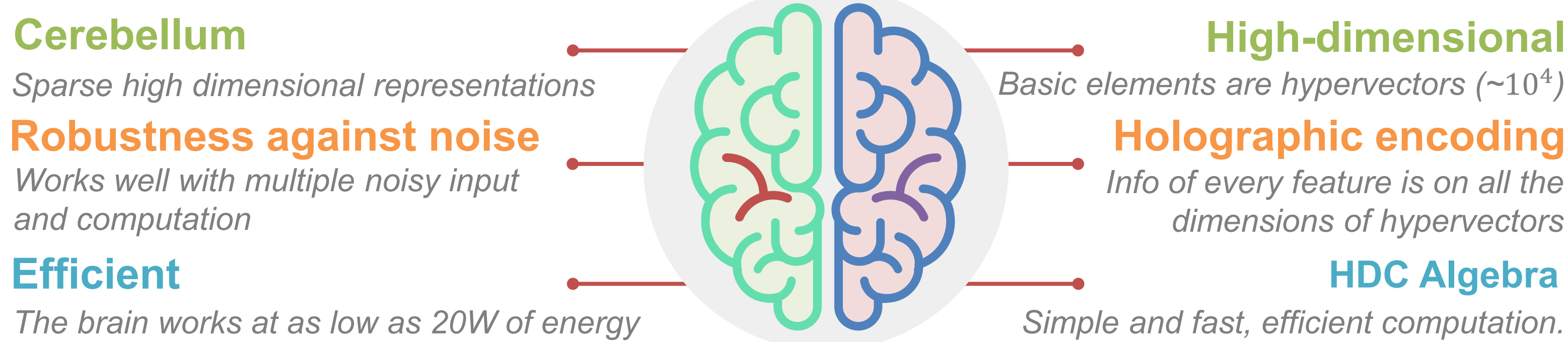


Scalable Edge-Based Hyperdimensional Classification with Brain-Like Neural Adaptation

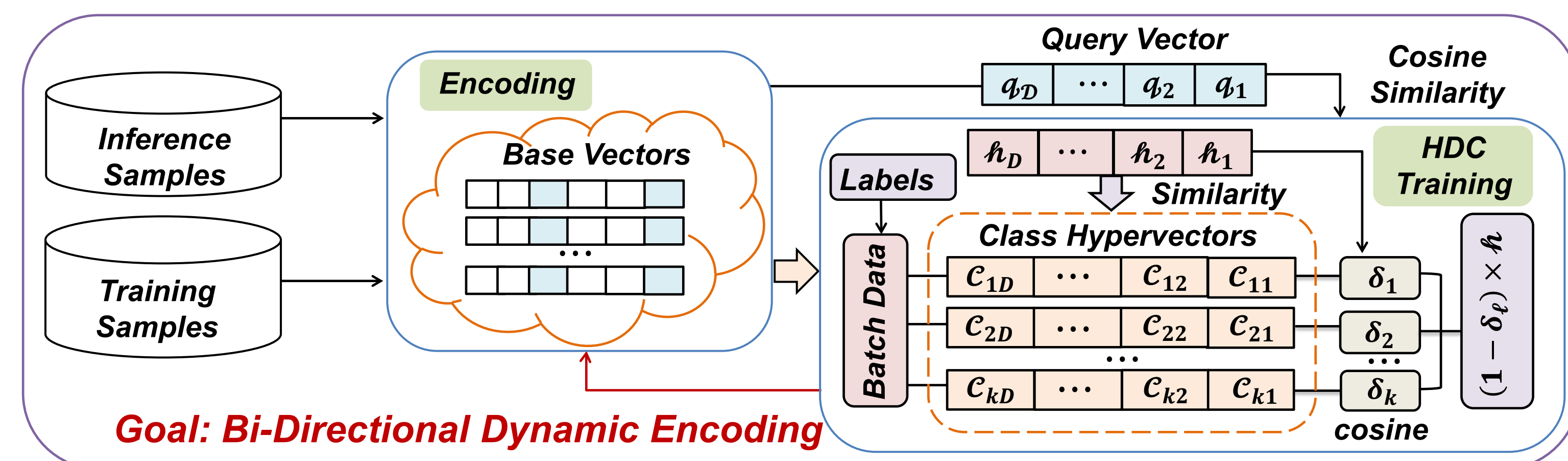
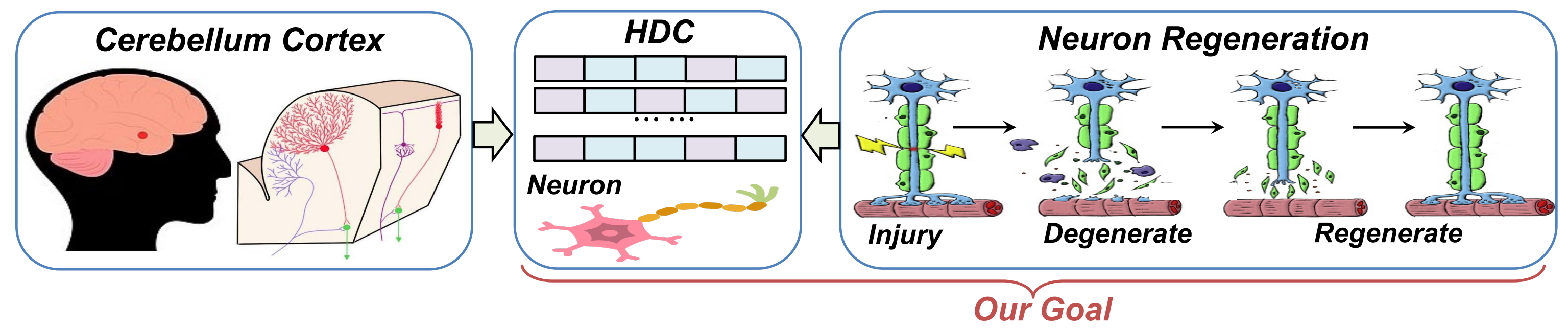
Junyao Wang, Mohammad Abdullah Al Faruque
University of California, Irvine

HDC Introduction



- **Binding (+):** Element-wise addition, i.e., $\mathcal{H}_{bundle} = \mathcal{H}_1 + \mathcal{H}_2$, $\delta(\mathcal{H}_{bundle}, \mathcal{H}_1) \gg 0$, $\delta(\mathcal{H}_{bundle}, \mathcal{H}_3) \approx 0$
- **Bundling:** Element-wise multiplication, i.e., $\mathcal{H}_{bind} = \mathcal{H}_1 * \mathcal{H}_2$, $\delta(\mathcal{H}_{bind}, \mathcal{H}_1) \approx 0$, $\delta(\mathcal{H}_{bind}, \mathcal{H}_2) \approx 0$
- **Reasoning:** measuring the similarity of hypervectors, e.g., cosine similarity $\delta(\mathcal{H}_1, \mathcal{H}_2) = \frac{\mathcal{H}_1 \cdot \mathcal{H}_2}{\|\mathcal{H}_1\| \cdot \|\mathcal{H}_2\|}$

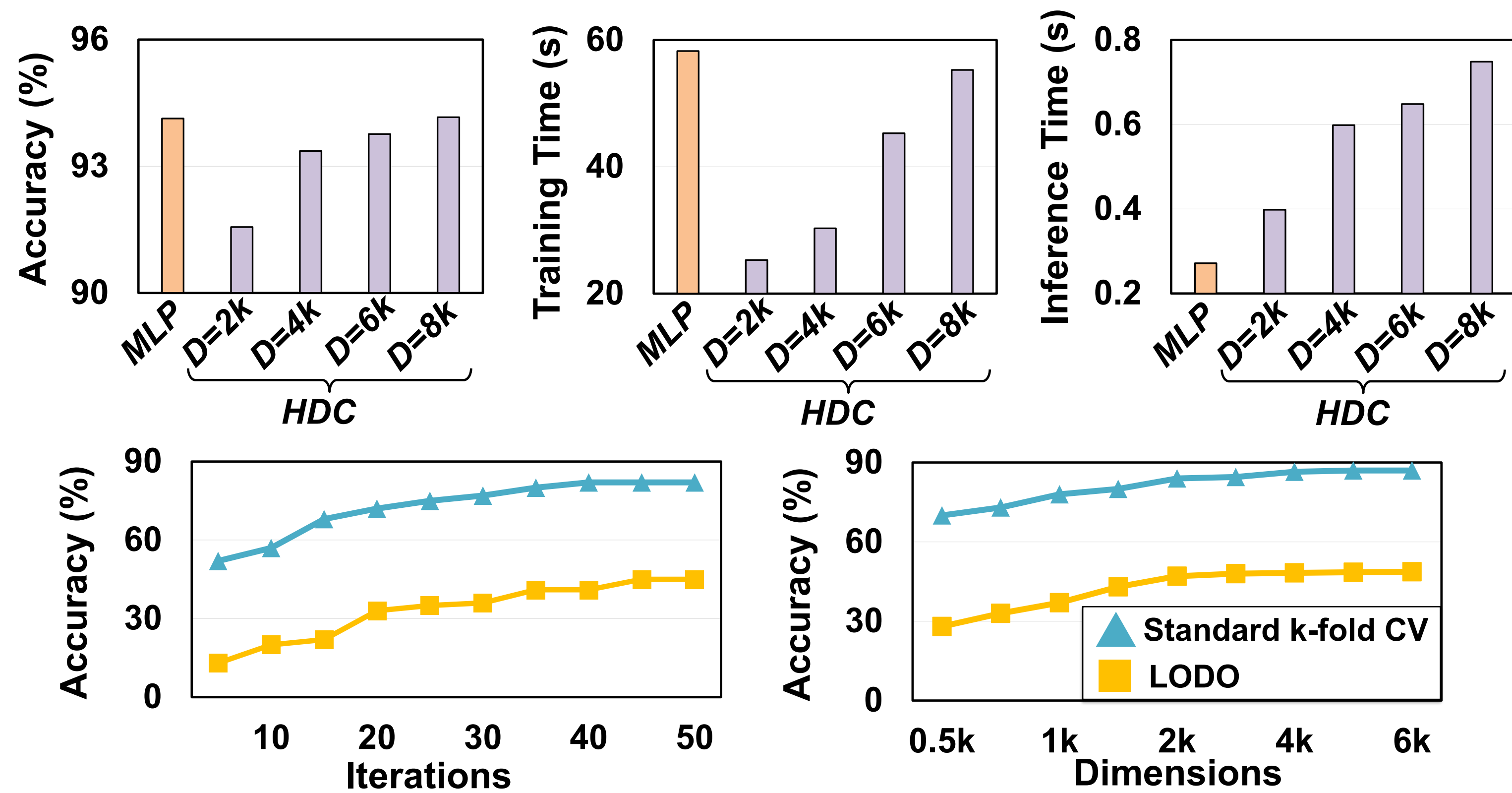
Motivation: Dynamic Neural Regeneration



- **Neurons in human brains:**
 - Dynamically regenerate all the time
 - Provide useful functionalities when accessing new information.

Can we support a similar behavior as brain neural regeneration?

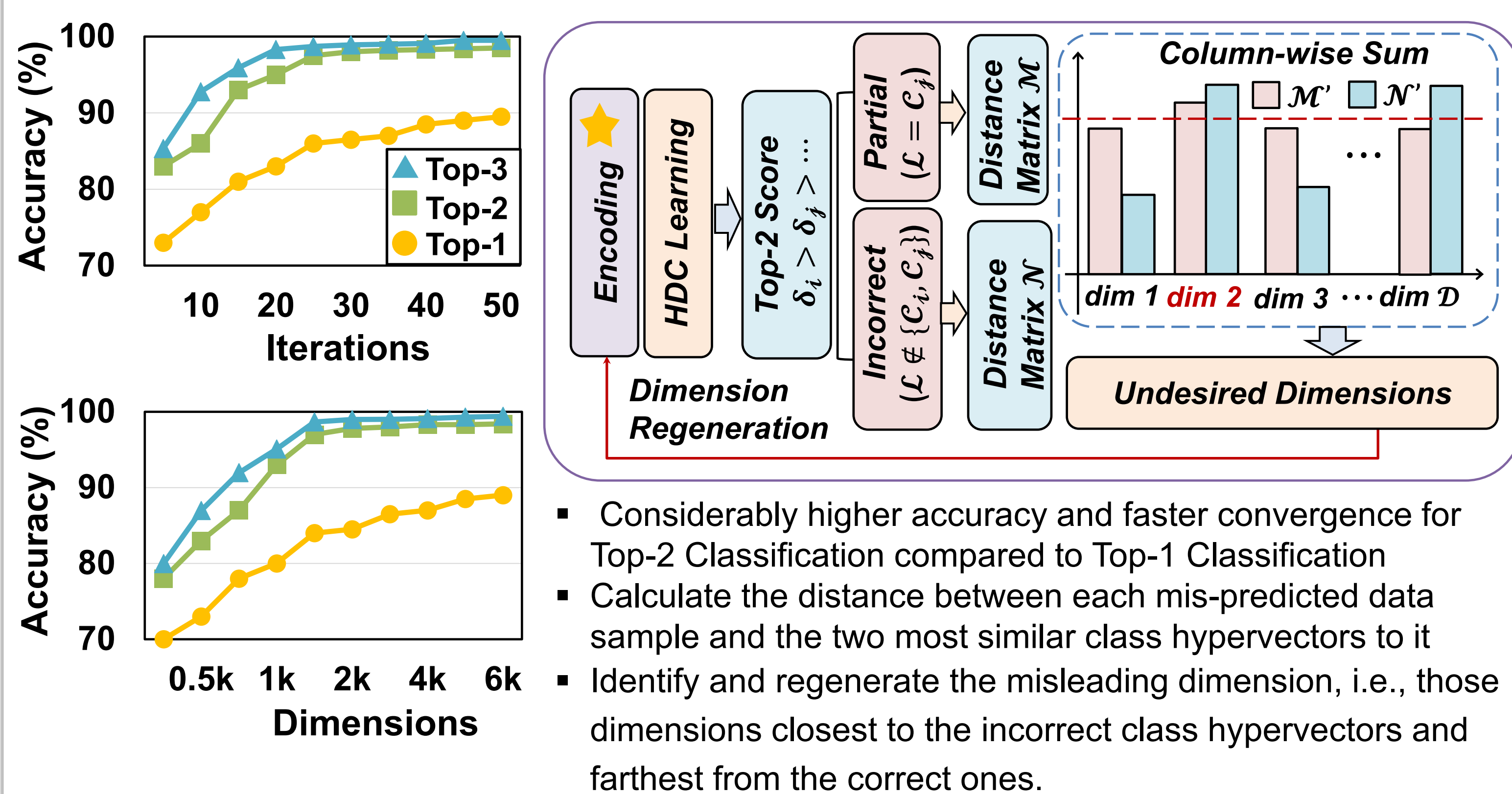
Problem: Undesired Dimensions



- **Are all the dimensions "useful"?**
 - Can we lower the dimensionality without sacrificing accuracy?
- **Are all the dimensions "good"?**
 - Are there any dimensions misleading the results?
- **Are all the dimensions "unbiased"?**
 - Distribution Shift: when training and testing data come from different data distribution
 - Are there dimensions specifically contribute to the domain-specific information?

The encoder is static: Never updated during the entire training phase!

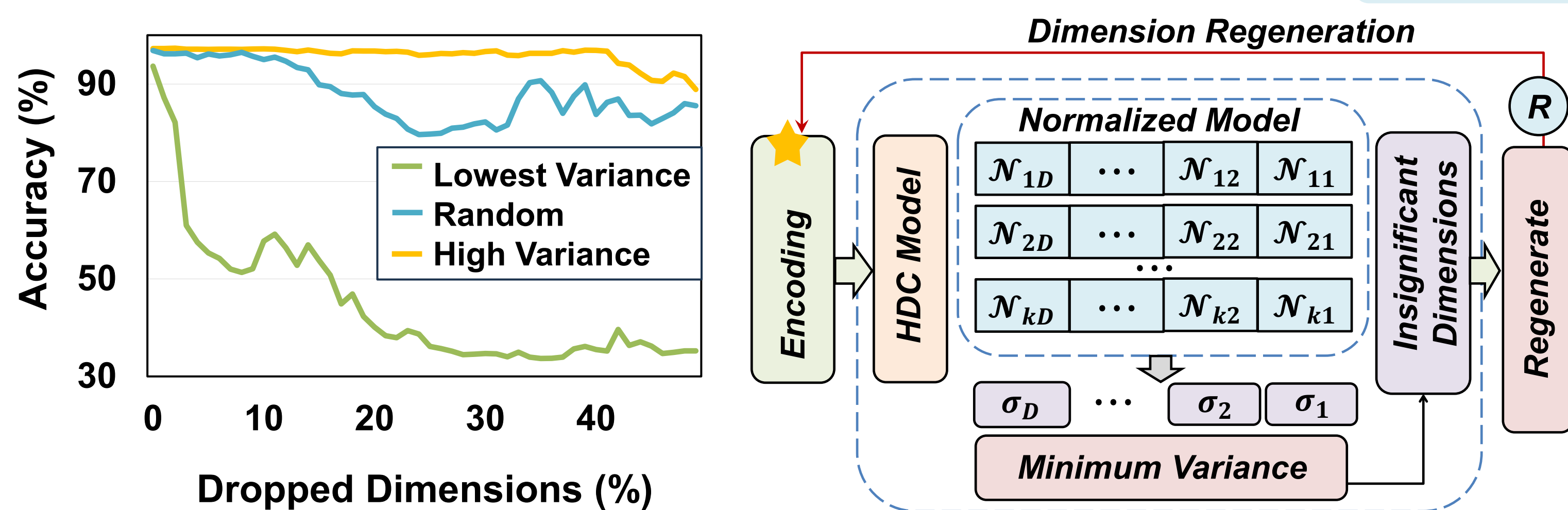
Work II*: Regenerating Misleading Dimensions DAC'23



- Considerably higher accuracy and faster convergence for Top-2 Classification compared to Top-1 Classification
- Calculate the distance between each mis-predicted data sample and the two most similar class hypervectors to it
- Identify and regenerate the misleading dimension, i.e., those dimensions closest to the incorrect class hypervectors and farthest from the correct ones.

* Junyao Wang, Sitao Huang, Mohsen Imani, DistHD: A Learner-Aware Dynamic Encoding Method for Hyperdimensional Classification, 60th Annual Design Automation Conference (DAC), 2023

Work I*: Regenerating Insignificant Dimensions DAC'23

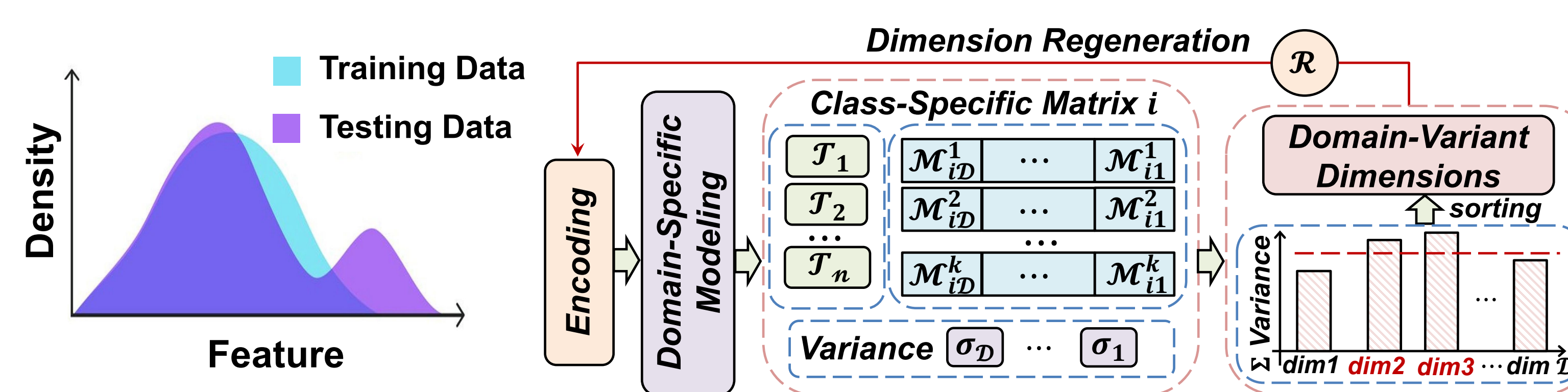


(a) Impact of Dimension Reduction (b) Identifying Insignificant Dimensions

- An effective classifier has a strong capability to distinguish patterns, i.e., a testing sample has very differentiated similarity scores to each class.
- Dimensions with similar values store common information across classes, hence playing minimal roles in the classification.
- We regenerate these insignificant dimensions to reduce the unnecessary computations involved and improve the inference efficiency.

* Junyao Wang, Hanning Chen, Mariam Issa, Sitao Huang, Mohsen Imani, Late Breaking Results: Scalable and Efficient Hyperdimensional Computing for Network Intrusion Detection, 60th Annual Design Automation Conference (DAC), 2023.

Work III*: Regenerating Biased Dimensions ICCAD'23



- **Distribution Shift:** A fundamental problem in data-driven ML
 - The excellent relies heavily on the critical assumption that the training and inference data come from the same distribution, but this can be easily violated in reality.
- **Domain Generalization:** extract domain-invariant features across known domains
- Domain Specific Models → Class-Specific Aggregation → Domain-Variant Filter → Dimension Regeneration → Model Ensemble
- Regenerate dimensions that highly correlated to domain-specific information

* Junyao Wang, Luke Chen, Mohammad Abdullah Al Faruque, DOMINO: Domain-Invariant Hyperdimensional Classification for Multi-Sensor Time Series Data, IEEE/ACM International Conference on Computer-Aided Design (ICCAD), 2023.