PASA: A Principled Embedding-Space Watermarking Approach for LLM-Generated Text under Semantic-Invariant Attacks

Zhenxin Ai[1], Haiyun He[1*] [1]The Hong Kong University of Science and Technology (Guangzhou)

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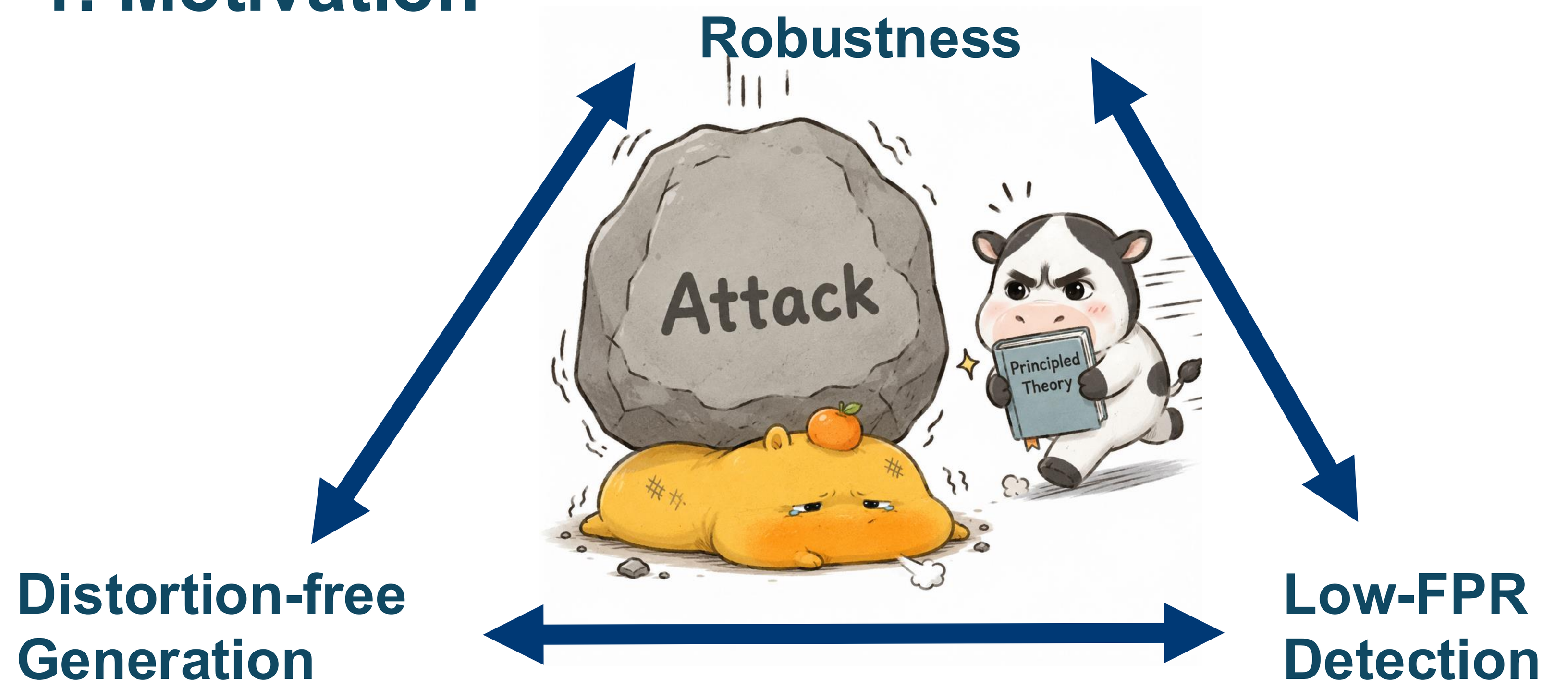
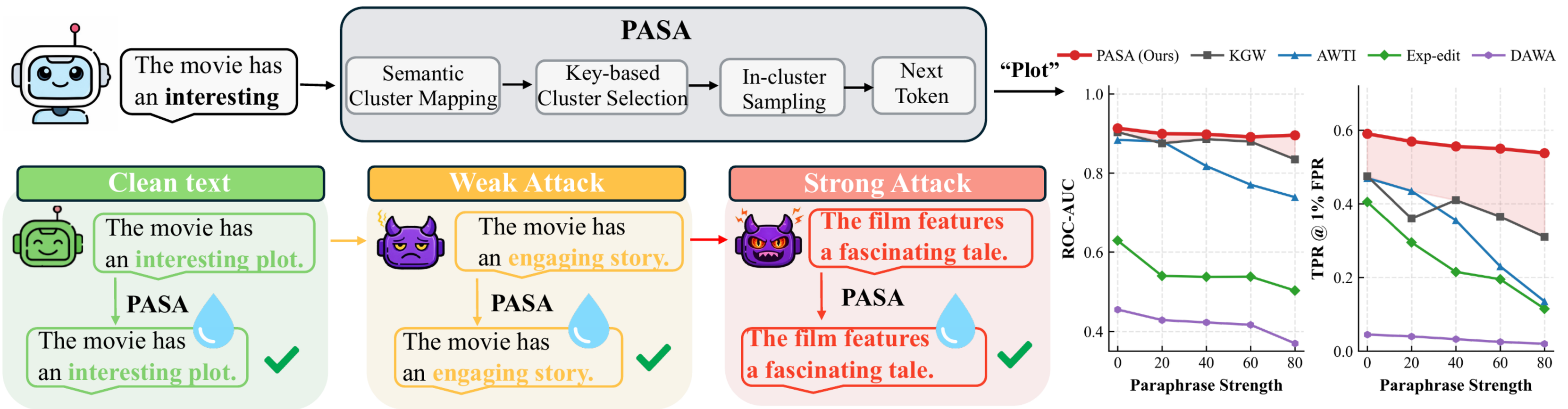
Introduction

1. Motivation



2. Core Contributions



Overview of PASA and its robustness comparison under paraphrasing attacks.

1. **Semantic-Space Watermarking:** Watermarking over latent **semantic clusters**.
2. **Principled Trade-off:** Minimize **miss-detection** under **FA** and **distortion constraints**.

$$\min \beta_1^f \quad \text{s.t.} \quad \sup_Q \beta_0^f \le \alpha,\ D(P_{X^T}, Q_{X^T}) \le \epsilon$$

3. **Robust Low-FPR Detection:** **Stronger robustness** against **replacement** and **paraphrasing** attacks.

Method: PASA

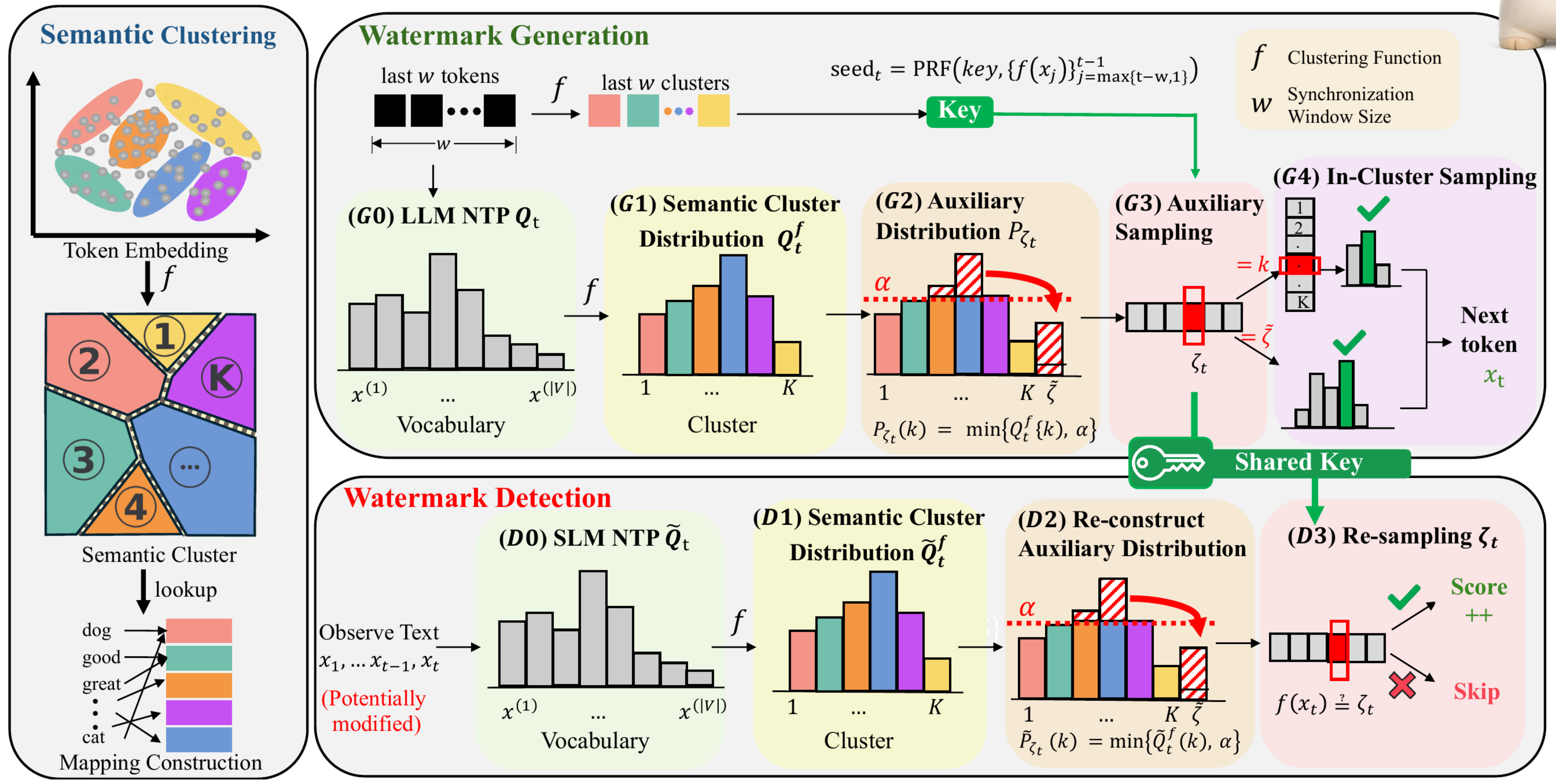


Illustration of the detailed PASA pipeline, including semantic cluster mapping, watermark generation, and watermark detection.

Semantic-Level Watermarking

Map tokens into semantic clusters to make watermark *signals stable under paraphrasing*.

$$f: \mathcal{V} \to [K],\ Q_t^f(k) = \sum_{x: f(x)=k} Q_t(x)$$

Watermarking Generation

Auxiliary variable is sampled using *a secret-key PRF*.

Next token is sampled inside the selected semantic cluster.

$$X_t \sim \frac{Q_t(x)\mathbf{1}\{f(x) = \zeta_t\}}{Q_t^f(\zeta_t)}$$

Watermark Detection

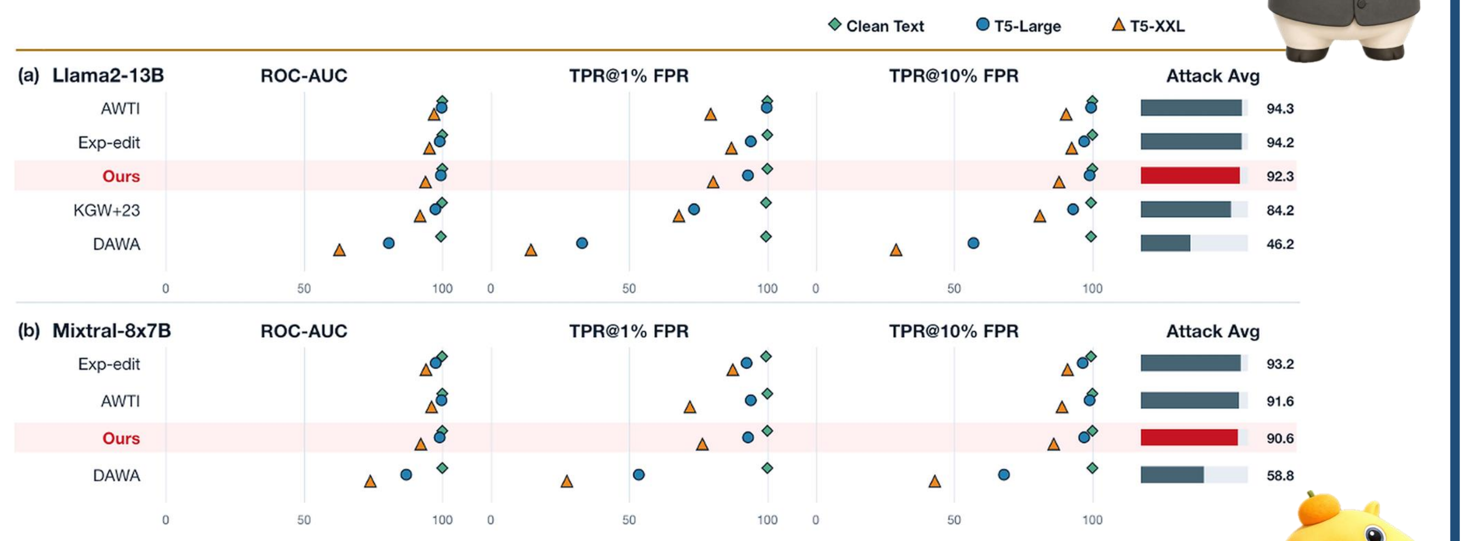
Secret-key replay verifies watermark evidence via semantic-cluster matches.

$$S = \sum_{t=1}^{T} \mathbf{1}[f(x_t) = \hat{\delta}_t],$$

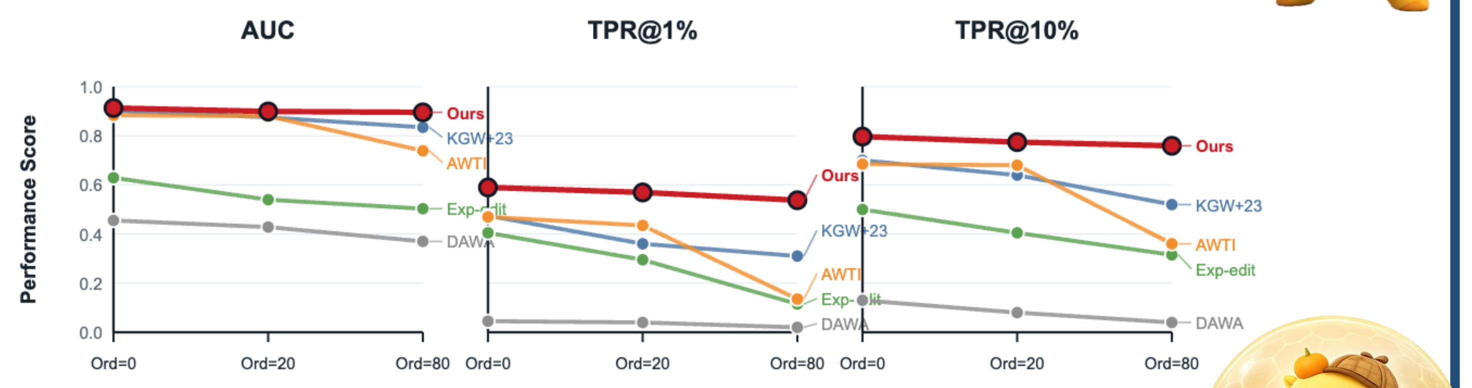
$$S \ge \tau \Rightarrow \text{Watermarked.}$$

Main Experiments

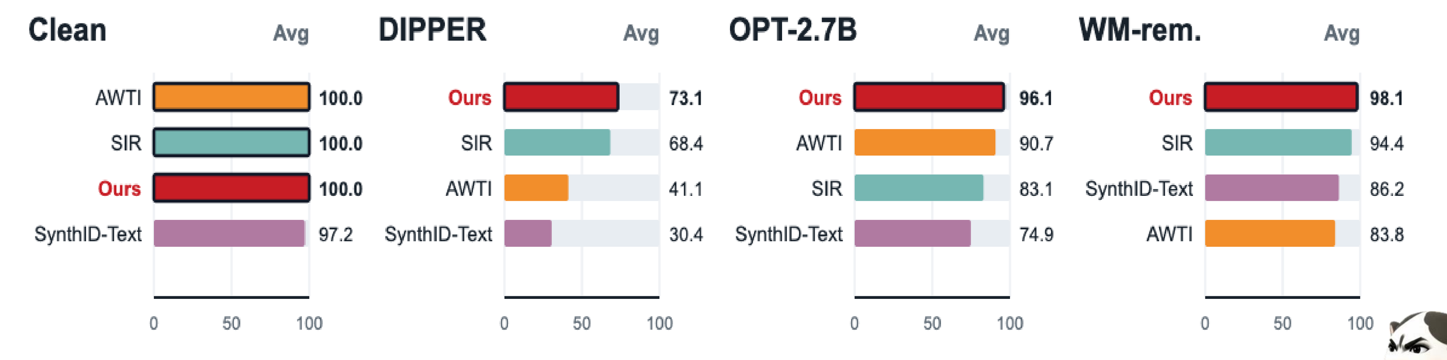
Detection Performance



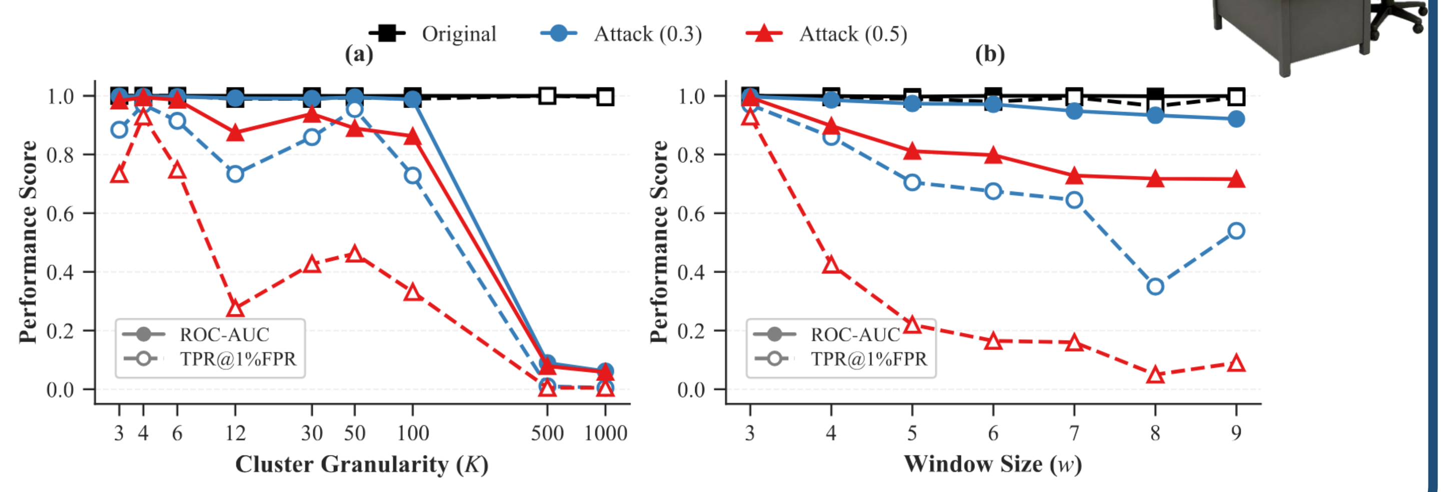
Robustness under Semantic-Invariant Attacks



More Attacks



Ablation Study



Email: zhenxinai@hkust-gz.edu.cn
Paper: https://arxiv.org/abs/2605.10977 Project Page: https://ai-kunkun.github.io/PASA_page/