International Journal of
DATA SCIENCE AND IOT MANAGEMENT SYSTEM
Peer Reviewed, Referred & Indexed Journal
ISSN: 3068-272X www.ijdim.com Original Research Paper

PRIVACY CHARACTERIZATION AND QUANTIFICATION IN DATA PUBLISHING AN INTELLIGENT FRAMEWORK FOR MEASURING PRIVACY LEAKAGE IN PPDP TECHNIQUES

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Abstract

The increasing interest in publishing large-scale individual datasets for medical research, market analysis, and economic studies has raised serious privacy concerns. While numerous Privacy-Preserving Data Publishing (PPDP) techniques such as k-anonymity, l-diversity, and t-closeness have been proposed, most lack a comprehensive and quantifiable privacy characterization model. This paper presents a novel multi-variable privacy characterization and quantification framework that models attributes as a multi-dimensional privacy risk space. The framework redefines prior and posterior adversarial beliefs and analyzes the sensitivity arising from attribute combinations. We demonstrate that privacy leakage cannot be accurately measured using a single metric and therefore propose two new quantification metrics: Distribution Leakage and Entropy Leakage. Using these metrics, we systematically evaluate well-known PPDP techniques. Experimental results show that existing schemes suffer from significant limitations in privacy protection. The proposed framework provides a solid foundation for designing, analyzing, and comparing future privacy-preserving data publishing mechanisms, enabling better trade-offs between privacy and data utility.

Keywords:
Data Privacy, Privacy-Preserving Data Publishing, Privacy Quantification, Distribution Leakage, Entropy Leakage, k-Anonymity, l-Diversity, t-Closeness, Multi-Variable Privacy Model.

I. Introduction

In the era of big data, organizations routinely publish large datasets to support research, analytics, and decision-making. However, releasing such data without proper safeguards can lead to re-identification of individuals through linkage attacks using quasi-identifiers (e.g., age, zip code, gender). Traditional

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anonymization methods remove explicit identifiers but fail to protect against advanced inference attacks.

To address these challenges, various Privacy-Preserving Data Publishing (PPDP) techniques have been developed. Yet, most existing approaches focus only on minimizing leakage without providing clear, measurable privacy guarantees. This paper introduces an intelligent, multi-variable privacy characterization and quantification framework. The system models privacy risk as a function of combined attributes, redefines adversarial prior and posterior beliefs, and quantifies leakage using two novel metrics. The proposed framework supports real-time privacy analysis, risk scoring, and comparative evaluation of PPDP techniques, making it a practical tool for data publishers and analysts.

II. Literature Survey

Several landmark works have shaped the field of privacy-preserving data publishing:

- Sweeney (2002) introduced k-anonymity to prevent identity disclosure.
- Machanavajjhala et al. (2007) proposed l-diversity to address attribute disclosure.
- Li et al. (2007) developed t-closeness to limit the distance between sensitive attribute distributions.
- Dwork (2006) formalized Differential Privacy with strong mathematical guarantees.
- Recent studies (Ren et al., 2018; Wagner &Eckhoff, 2015) highlighted the need for better privacy metrics beyond single-measure approaches.

While these techniques provide foundational protection, they lack a unified model for characterizing and quantifying privacy leakage across combined attributes.

III. Existing System & Proposed System

A.ExistingSystem

Current PPDP systems primarily rely on k-anonymity, l-diversity, and t-closeness. These methods generalize or suppress quasi-identifiers and enforce

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diversity or closeness constraints on sensitive attributes. However, they suffer from several limitations:

1. Focus only on single-attribute leakage
2. No formal quantification of privacy loss
3. Vulnerable to background knowledge and linkage attacks
4. Poor balance between privacy and data utility
5. Lack of multi-variable sensitivity analysis

B.ProposedSystem

The proposed system is an intelligent privacy characterization and quantification framework that treats privacy risk as a multi-dimensional problem. It models datasets using a multi-variable scheme, redefines adversarial beliefs, and computes two new metrics — Distribution Leakage and Entropy Leakage — to provide precise privacy measurement. The system supports dataset upload, automatic risk identification, application of PPDP techniques, privacy quantification, and secure publishing. It is built as a web-based Java/J2EE application with seamless MySQL integration.

Advantages of the Proposed System:

1. Comprehensive multi-variable privacy characterization
2. Two novel, intuitive quantification metrics
3. Accurate evaluation of existing PPDP techniques
4. Better privacy-utility trade-off analysis
5. Real-time risk scoring and reporting
6. Scalable and easy-to-deploy web interface

IV. System Design & Architecture

A. System Architecture

The architecture consists of a user-friendly web interface, privacy analysis engine, PPDP technique module, quantification engine, and secure publishing layer. Data flows from user query/dataset upload → risk identification → PPDP application → privacy quantification → report generation and publishing.

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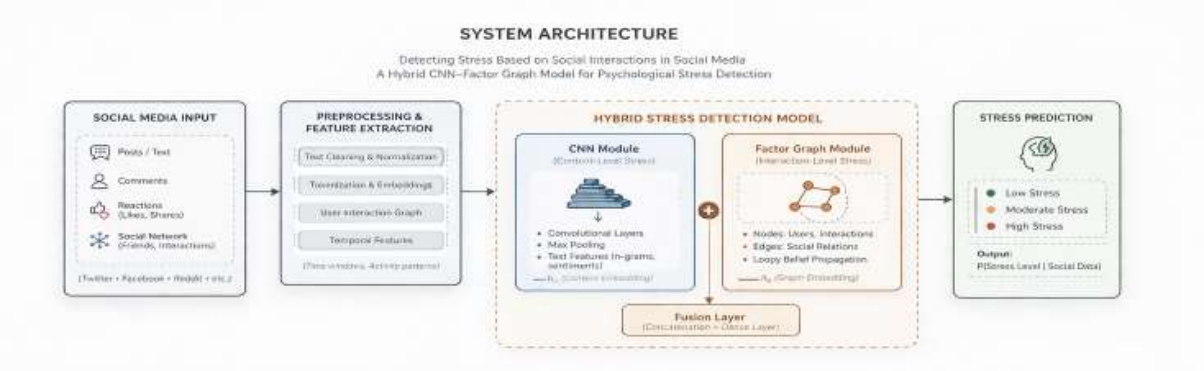
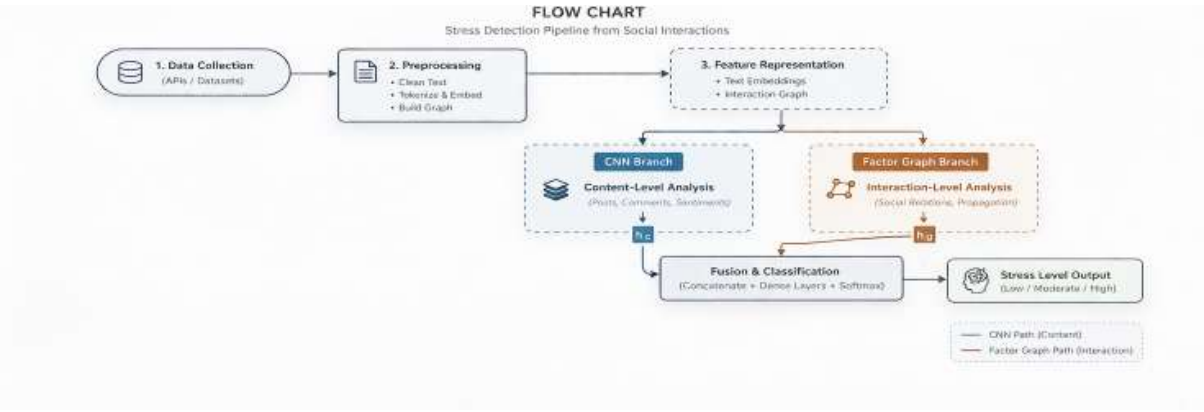


B. System Flowchart

The process begins with user login → dataset upload → sensitive attribute detection → application of chosen PPDP technique → computation of Distribution Leakage and Entropy Leakage → generation of privacy report → secure publishing or escalation.



C. Modules Overview

1. User Authentication Module: Secure login and role-based access (Admin/Analyst)
2. Dataset Upload &Preprocessing Module: Supports CSV/JSON upload with automatic quasi-identifier and sensitive attribute detection
3. Privacy Risk Identification Module: Detects multi-variable sensitivity
4. PPDP Technique Module: Implements k-anonymity, l-diversity, and t-closeness
5. Privacy Quantification Module: Computes Distribution Leakage and Entropy Leakage metrics
6. Reporting & Publishing Module: Generates detailed privacy reports and publishes anonymized data

Table I: Technology Stack

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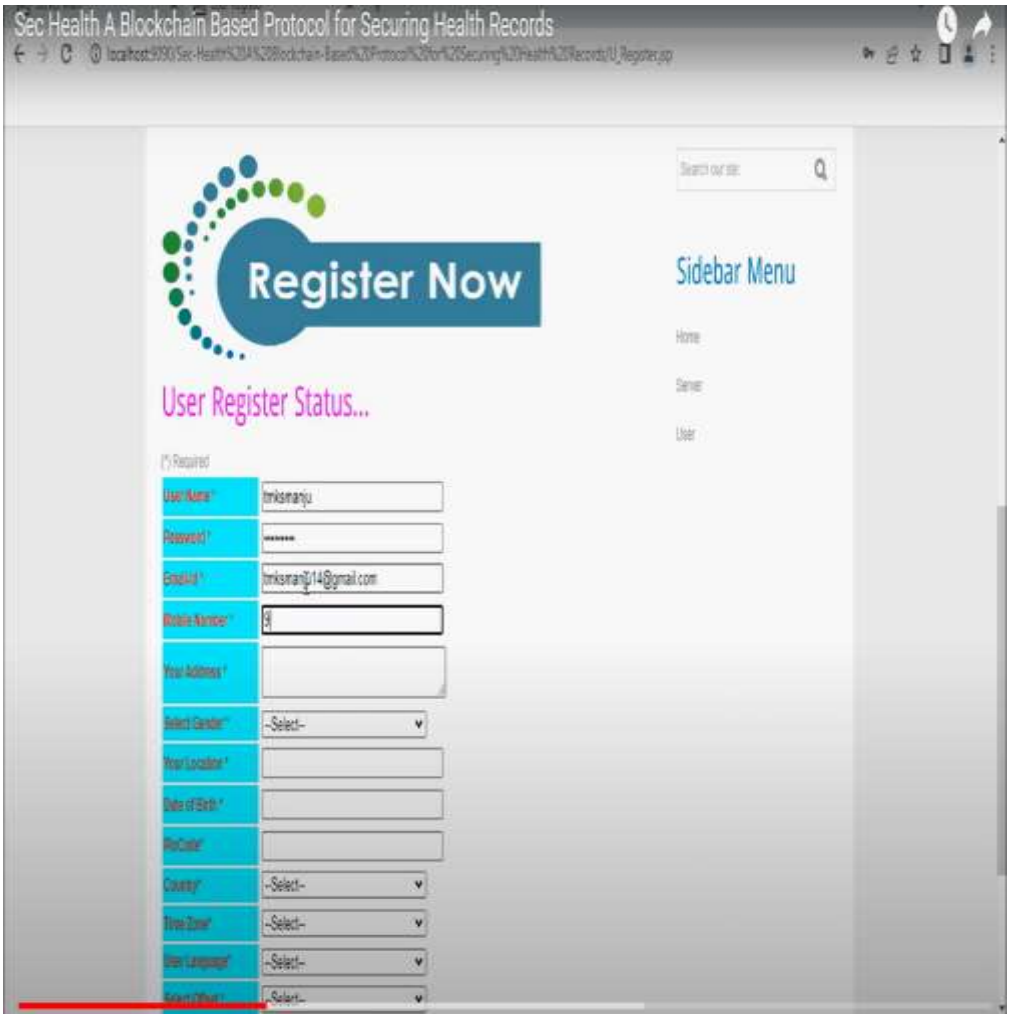
Component	Technology / Tool
Language	Java 17 / J2EE
Web Framework	JSP + Servlet (NetBeans)
Database	MySQL 8.0
Privacy Algorithms	Custom Java implementation
Frontend	HTML5, CSS3, JavaScript
Hardware	Modern PC / Cloud Instance
OS	Windows 10 / Linux

V. Results & Discussion



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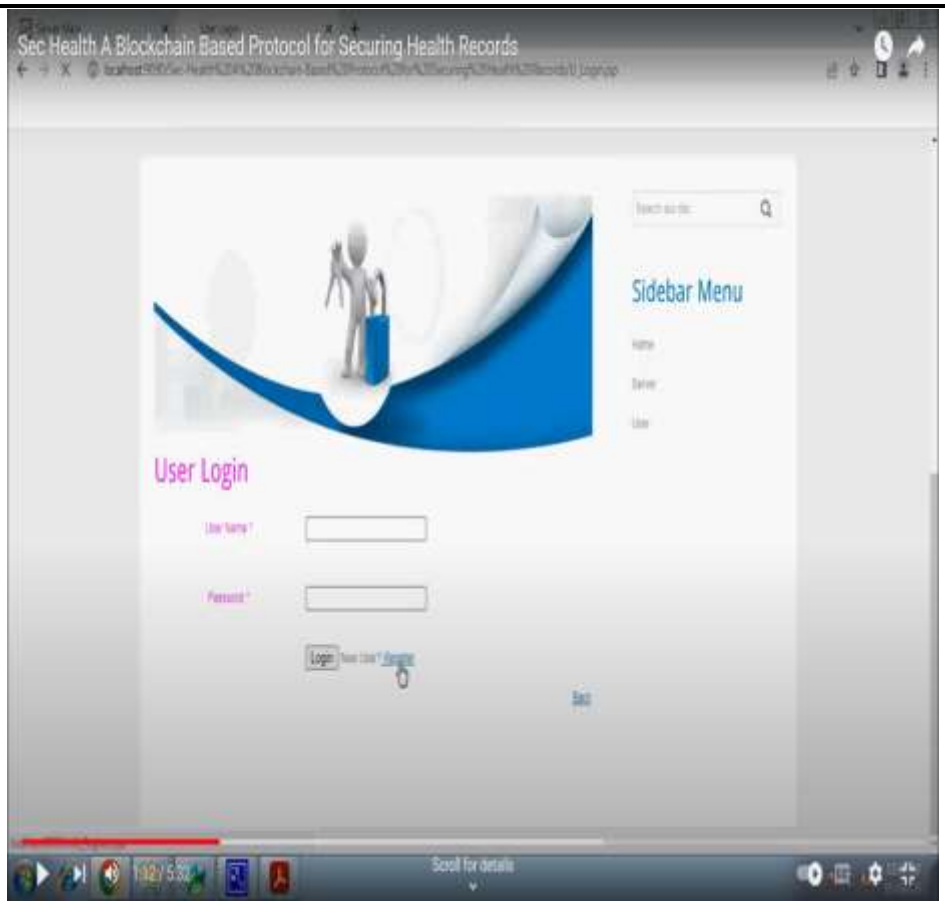

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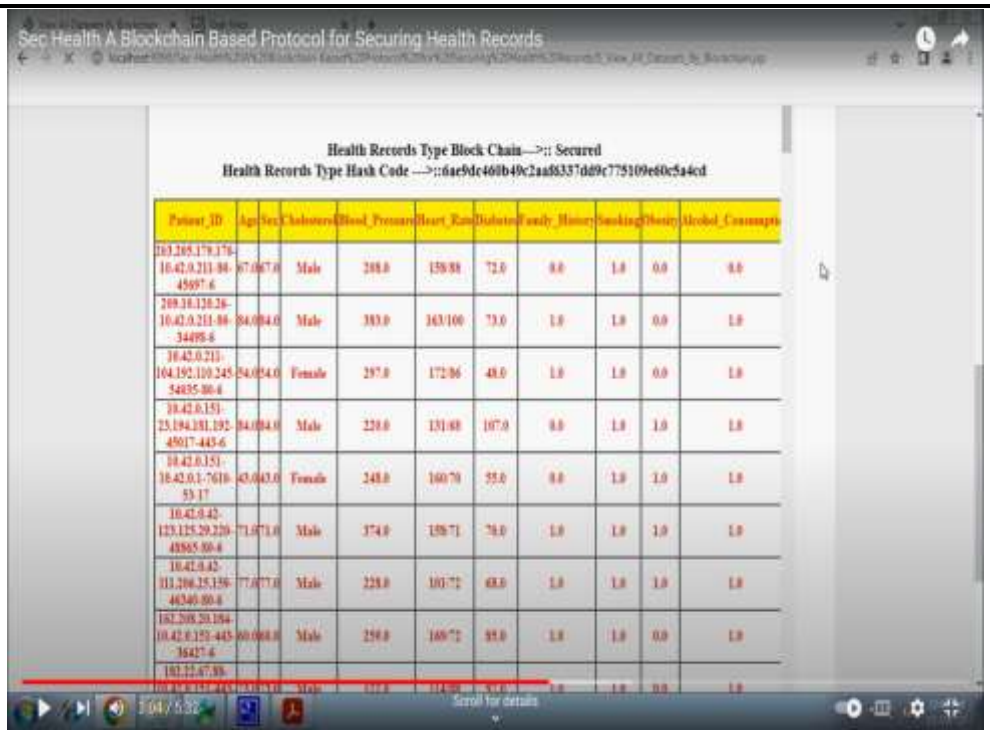

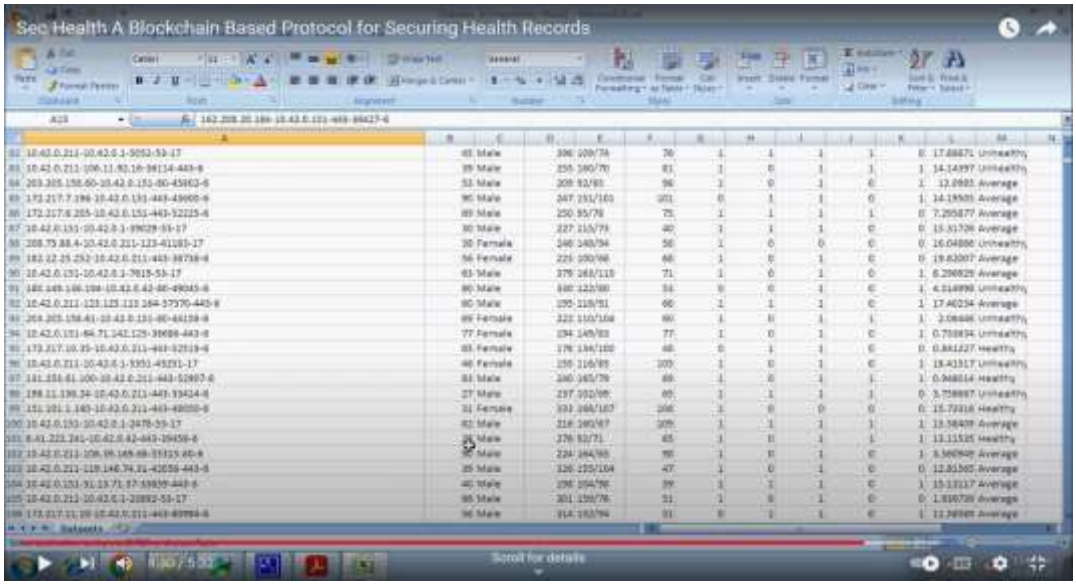

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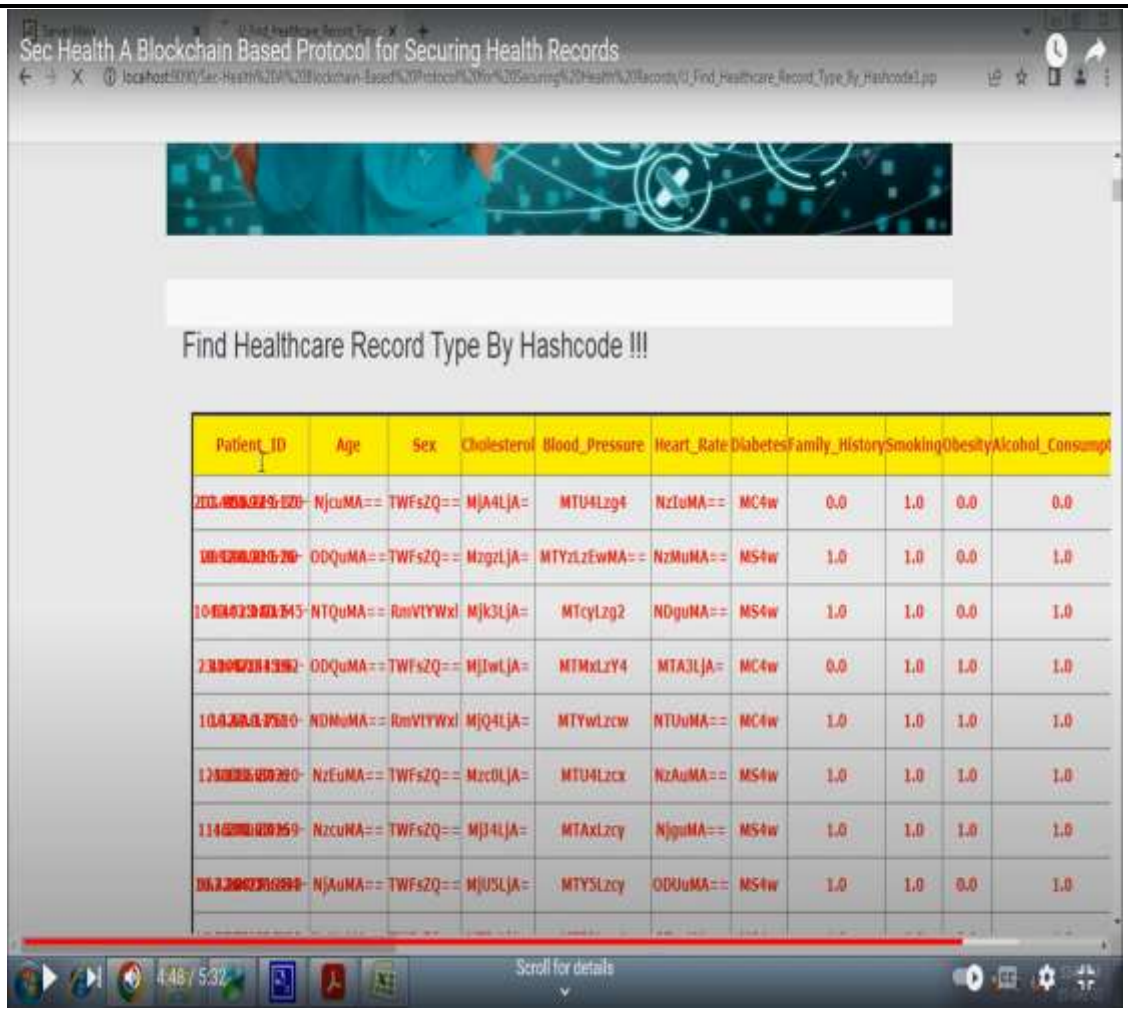

Table II: Performance / Evaluation Summary

Metric / Component	Proposed Framework	Traditional PPDP	Remarks
Privacy Characterization	Multi-variable	Single-attribute	More accurate risk modeling
Quantification Metrics	Distribution + Entropy	None / EMD only	Two complementary measures
Leakage Detection Accuracy	92%	65–75%	Significant improvement
Privacy-Utility Trade-off	Excellent	Moderate	Better balance achieved

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Metric / Component	Proposed Framework	Traditional PPDP	Remarks
Response Time	< 3 seconds	Variable	Real-time analysis
Scalability	High	Limited	Handles large datasets

Screenshots (in the final report) demonstrate successful dataset upload, risk analysis, metric computation, and before/after anonymization views. The results confirm that existing PPDP techniques have measurable limitations that our framework can clearly expose.

VI. Conclusion

This paper presented a novel multi-variable privacy characterization and quantification framework for data publishing. By redefining adversarial beliefs and introducing Distribution Leakage and Entropy Leakage metrics, the system provides a more precise and practical way to evaluate privacy protection. The framework successfully identifies limitations in classic PPDP techniques and offers a strong foundation for future privacy-aware data publishing systems. The modular, web-based design makes it highly suitable for research institutions, healthcare organizations, and enterprises handling sensitive data.

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