Sanitizing and Minimizing Databases for Software Application Test Outsourcing

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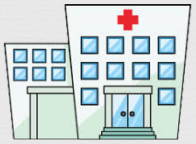
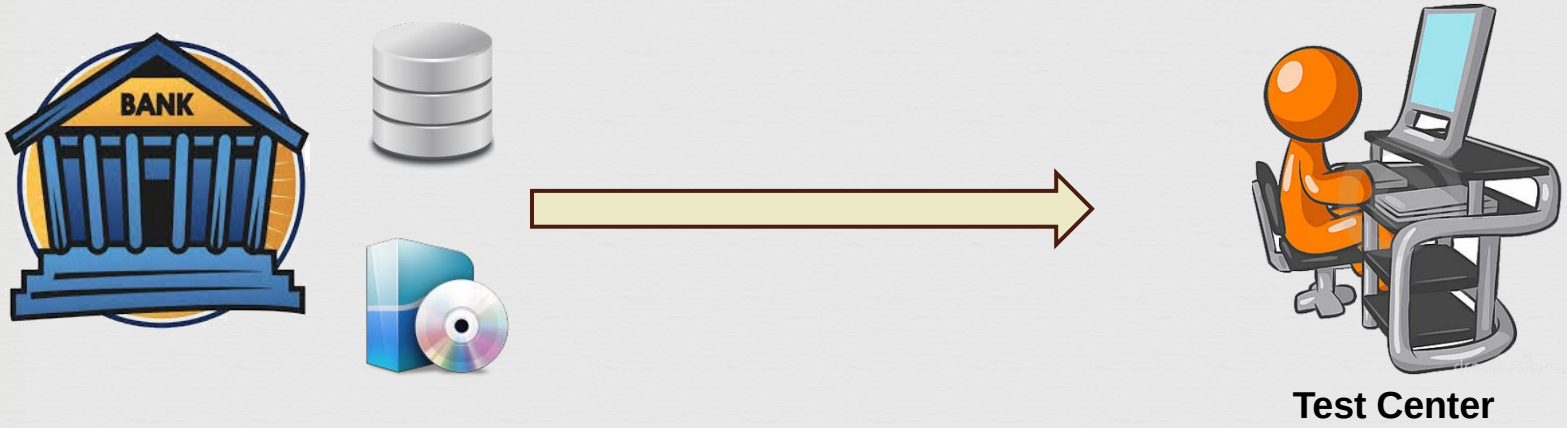
Motivation

- Database-Centric Applications (DCA)



Motivation



- Expected outsourcing market in 2020: $50B vs. $30B in 2010
- State of the art: clean room testing and fake data generation

Clean Room Testing

Generate Fake Data

Original table

Age	Gender	# of Children	Nationality
51	M	1	Chinese
29	F	3	American
46	M	1	Japanese
9	F	0	American
…	…	…	…

Anonymized table (Naïve version)

Age	Gender	# of Children	Nationality
61	M	3	Chinese
8	F	2	Chinese
33	F	0	Japanese
29	M	1	American
…	…	…	…

- Type and value restriction
- Semantic connections between data
- Program behavior

```
if (nationality == “Japanese” && age > 40) {
        f(disease);
}
```

Our work

- We focus on balancing the following four dimensions:

Privacy	**Data minimization**
Semantic correctness	**Testing coverage**

PISTIS - Protecting and mInimizing databases for Software TestIng taSks

- Program analysis
- Weight-based k-clustering algorithm
- Compute centroid objects
- Associative rule mining

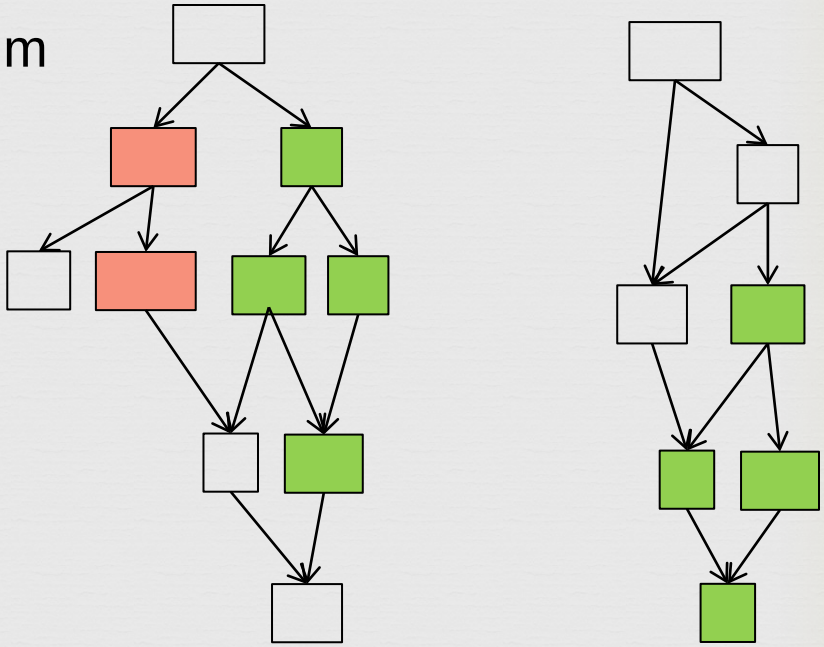
PISTIS - Program analysis

- Program analysis

Nationality	Age
…	…
…	…

Original table

- Weight-based k-clustering algorithm
- Compute centroid objects
- Associative rule mining

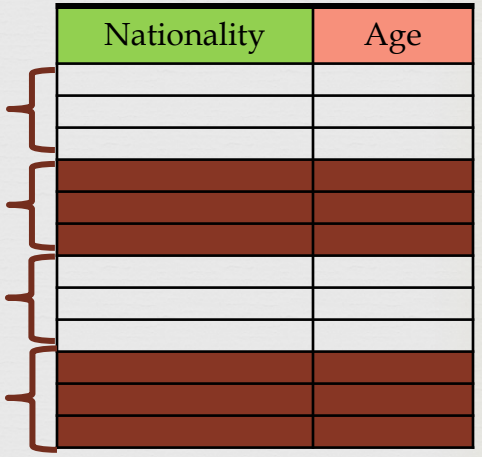


CFGs

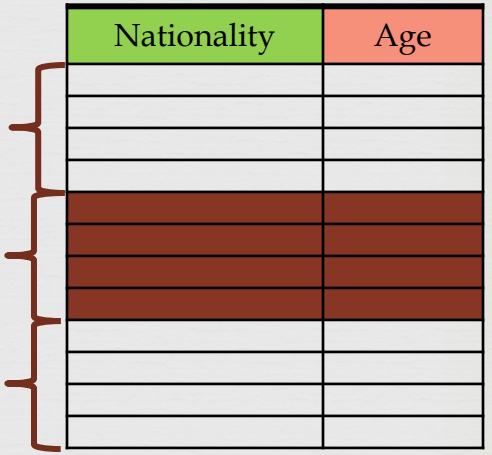
PISTIS - Weight-based k-clustering algorithm

- Program analysis
- Weight-based k-clustering algorithm
- Compute centroid objects
- Associative rule mining

K=4

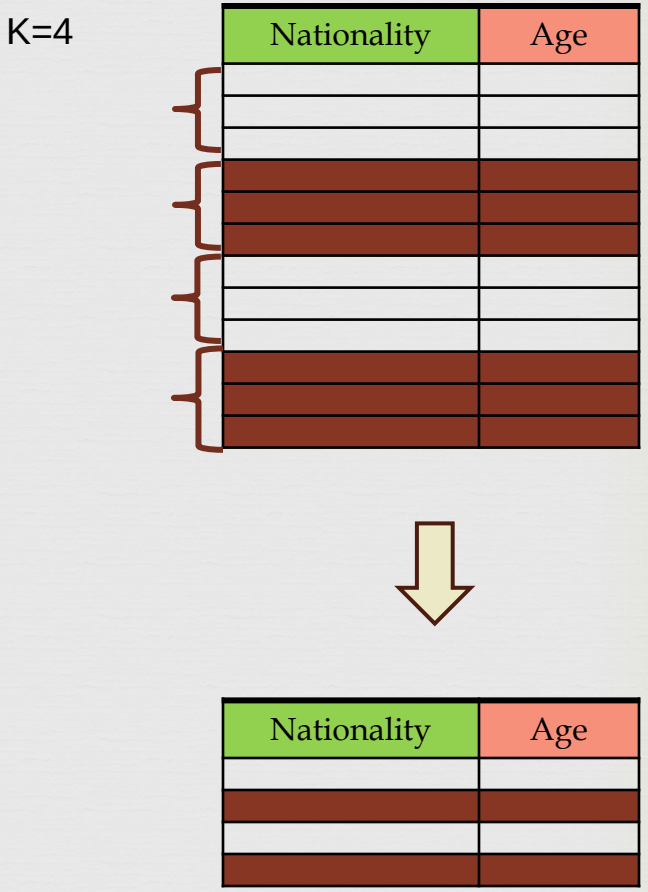


K=3



PISTIS - Compute centroid objects

- Program analysis
- Weight-based k-clustering algorithm
- Compute centroid objects
- Associative rule mining



PISTIS - Compute centroid objects

- Program analysis
- Weight-based k-clustering algorithm
- Compute centroid objects
- Associative rule mining

Original table

“pregnant ==true -> gender == female”

PISTIS - Protecting and mInimizing databases for Software TestIng taSks

- Program analysis – – – – – – – – **Test coverage**
- Weight-based k-clustering algorithm
- Compute centroid objects

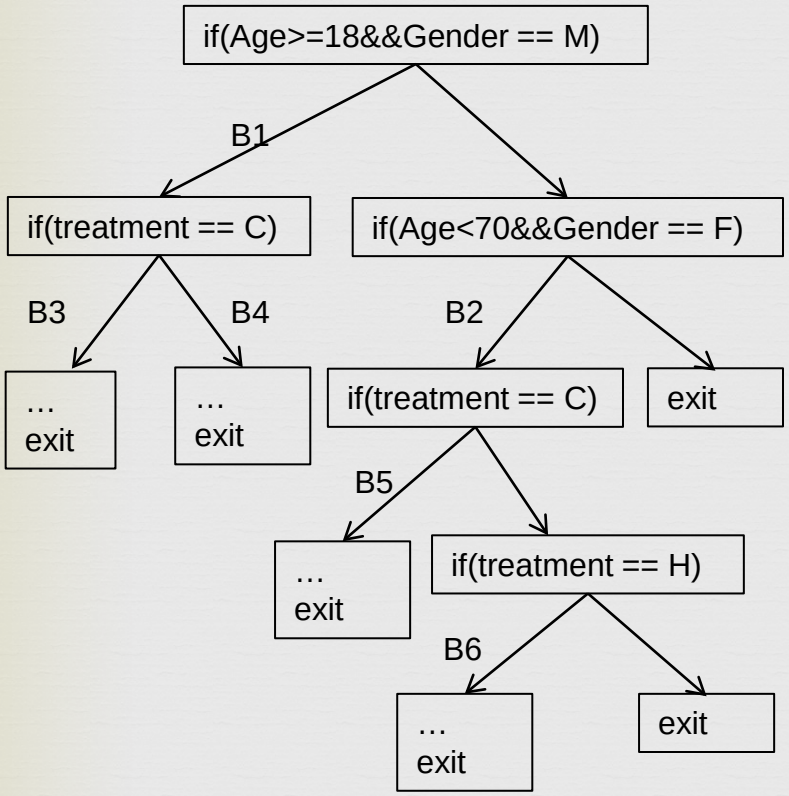
Data minimization

Privacy

- Associative rule mining – – – – – – – – **Semantic correctness**

PISTIS allows us to meet all four goals

An example

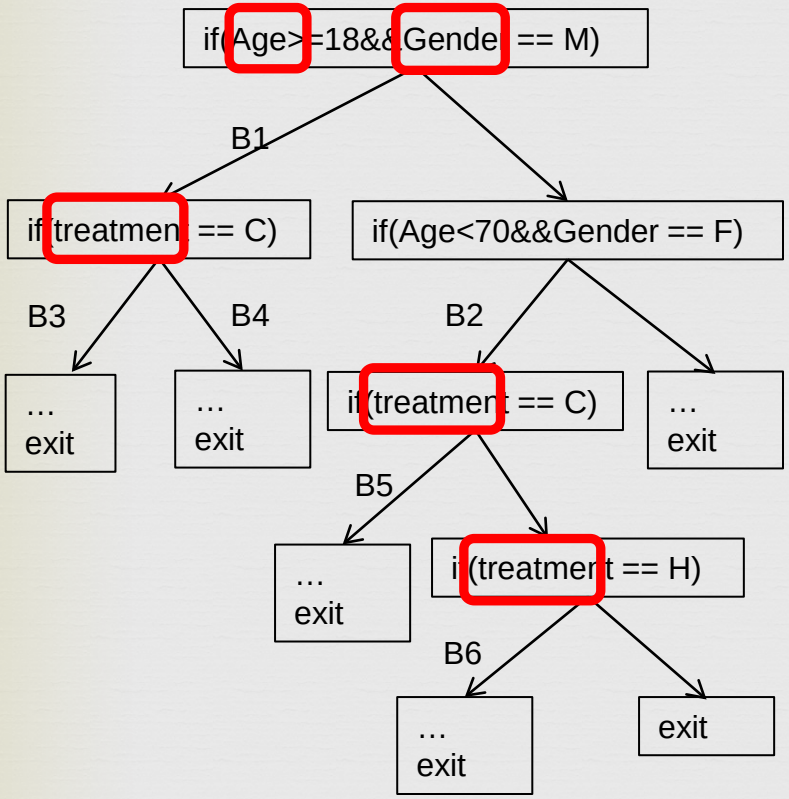


Original table

Age	State	Gender	Treatment	Branch
42	OH	M	Vasectomy	B1,B4
47	OH	F	Hysterectomy	B2,B6
51	VA	F	Chemotherapy	B2,B5
55	VA	M	Chemotherapy	B1,B3
62	OH	M	Chemotherapy	B1,B3
67	CA	F	Hysterectomy	B2,B6
30	OH	M	Vasectomy	B1,B4
31	CA	F	Chemotherapy	B2,B5
35	OH	F	Hysterectomy	B2,B6

Attribute Ranking

- Step 1: compute attribute weights



Original table

Age	State	Gender	Treatment
…	…	…	…

Attribute Weights

Age	5
Gender	5
Treatment	4
State	0

Data Normalization

- Step 2: translate the original data table into a normalized table
  - Numerical attributes

Age	State	Gender	Treatment
42	OH	M	Vasectomy
47	OH	F	Hysterectomy
51	VA	F	Chemotherapy
55	VA	M	Chemotherapy
62	OH	M	Chemotherapy
67	CA	F	Hysterectomy
30	OH	M	Vasectomy
31	CA	F	Chemotherapy
35	OH	F	Hysterectomy

Age
42
47
51
55
62
67
30
31
35

Age (normalized)
0.63
0.7
0.76
0.82
0.93
1
0.45
0.46
0.52

Data Normalization

- Categorical attributes

Age	State	Gender	Treatment
42	OH	M	Vasectomy
47	OH	F	Hysterectomy
51	VA	F	Chemotherapy
55	VA	M	Chemotherapy
62	OH	M	Chemotherapy
67	CA	F	Hysterectomy
30	OH	M	Vasectomy
31	CA	F	Chemotherapy
35	OH	F	Hysterectomy

State
OH
OH
VA
VA
OH
CA
OH
CA
OH

OH	VA	CA
1	0	0
1	0	0
0	1	0
0	1	0
1	0	0
0	0	1
1	0	0
0	0	1
1	0	0

Data Normalization

Normalized table

Age (Normalized)	OH	VA	CA	Female	Male	Hysterectomy	Vasectomy	Chemotherapy
0.63	1	0	0	0	1	0	1	0
0.7	1	0	0	1	0	1	0	0
0.76	0	1	0	1	0	0	0	1
0.82	0	1	0	0	1	0	0	1
0.93	1	0	0	0	1	0	0	1
1	0	0	1	1	0	1	0	0
0.45	1	0	0	0	1	0	1	0
0.46	0	0	1	1	0	0	0	1
0.52	1	0	0	1	0	1	0	0

Clustering

- Step 3: apply weighted k-means clustering

Attribute Weights

Age	5
Gender	5
Treatment	4
State	0

Clustered table, k=3

Age (Normalized)	OH	VA	CA	Female	Male	Hysterectomy	Vasectomy	Chemotherapy
0.63	1	0	0	0	1	0	1	0
0.7	1	0	0	1	0	1	0	0
0.76	0	1	0	1	0	0	0	1
0.82	0	1	0	0	1	0	0	1
0.93	1	0	0	0	1	0	0	1
1	0	0	1	1	0	1	0	0
0.45	1	0	0	0	1	0	1	0
0.46	0	0	1	1	0	0	0	1
0.52	1	0	0	1	0	1	0	0

Computing centroid

- Step 4: compute the centroid records

0.63	1	0	0	0	1	0	1	0
0.7	1	0	0	1	0	1	0	0
0.76	0	1	0	1	0	0	0	1

0.7	0.67	0.33	0	0.67	0.33	0.33	0.33	0.33

Computing centroid

- Step 4: compute the centroid records

0.63	1	0	0	0	1	0	1	0
0.7	1	0	0	1	0	1	0	0
0.76	0	1	0	1	0	0	0	1

0.7	0.67	0.33	0	0.67	0.33	0.33	0.33	0.33

Centroid table

Age (Normalized)	OH	VA	CA	Female	Male	Hysterectomy	Vasectomy	Chemotherapy
0.7	0.67	0.33	0	0.67	0.33	0.33	0.33	0.33
0.92	0.33	0.33	0.33	0.33	0.67	0	0.33	0.67
0.48	0.67	0	0.33	0.67	0.33	0.33	0.33	0.33

Anonymized table

- Step 5: generate real anonymized table

Age (Normalized)	OH	VA	CA	Female	Male	Hysterectomy	Vasectomy	Chemotherapy
0.7	0.67	0.33	0	0.67	0.33	0.33	0.33	0.33

Age	State	Gender	Treatment
47	OH	F	Vasectomy

Anonymized table

Age	State	Gender	Treatment
47	OH	F	Vasectomy
61	VA	M	Chemotherapy
32	OH	F	Hysterectomy

Associative rule

- Step 6: generate and apply associative rule

Original table

Age	State	Gender	Treatment
42	OH	M	Vasectomy
47	OH	F	Hysterectomy
51	VA	F	Chemotherapy
55	VA	M	Chemotherapy
62	OH	M	Chemotherapy
67	CA	F	Hysterectomy
30	OH	M	Vasectomy
31	CA	F	Chemotherapy
35	OH	F	Hysterectomy

"Vasectomy->male"

Anonymized table

Age	State	Gender	Treatment
47	OH	F	Vasectomy
61	VA	M	Chemotherapy
32	OH	F	Hysterectomy

Anonymized table with correction

Age	State	Gender	Treatment
47	OH	M	Vasectomy
61	VA	M	Chemotherapy
32	OH	F	Hysterectomy

Branch Coverage

Original table

Age	State	Gender	Treatment	Branch
42	OH	M	Vasectomy	B1,B4
47	OH	F	Hysterectomy	B2,B6
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35	OH	F	Hysterectomy	B2,B6

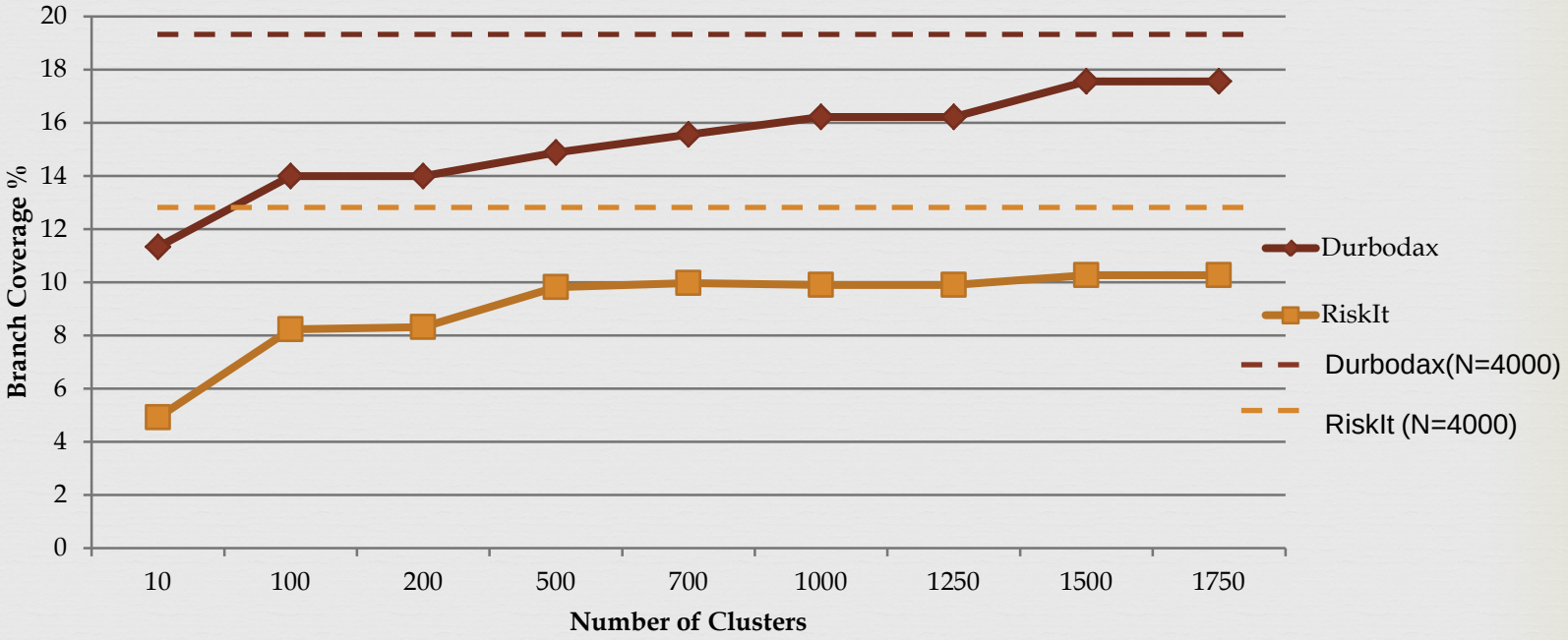
Anonymized table with correction

Age	State	Gender	Treatment	Branch
47	OH	M	Vasectomy	B1, B4
61	VA	M	Chemotherapy	B1, B3
32	OH	F	Hysterectomy	B2, B6

Experiment

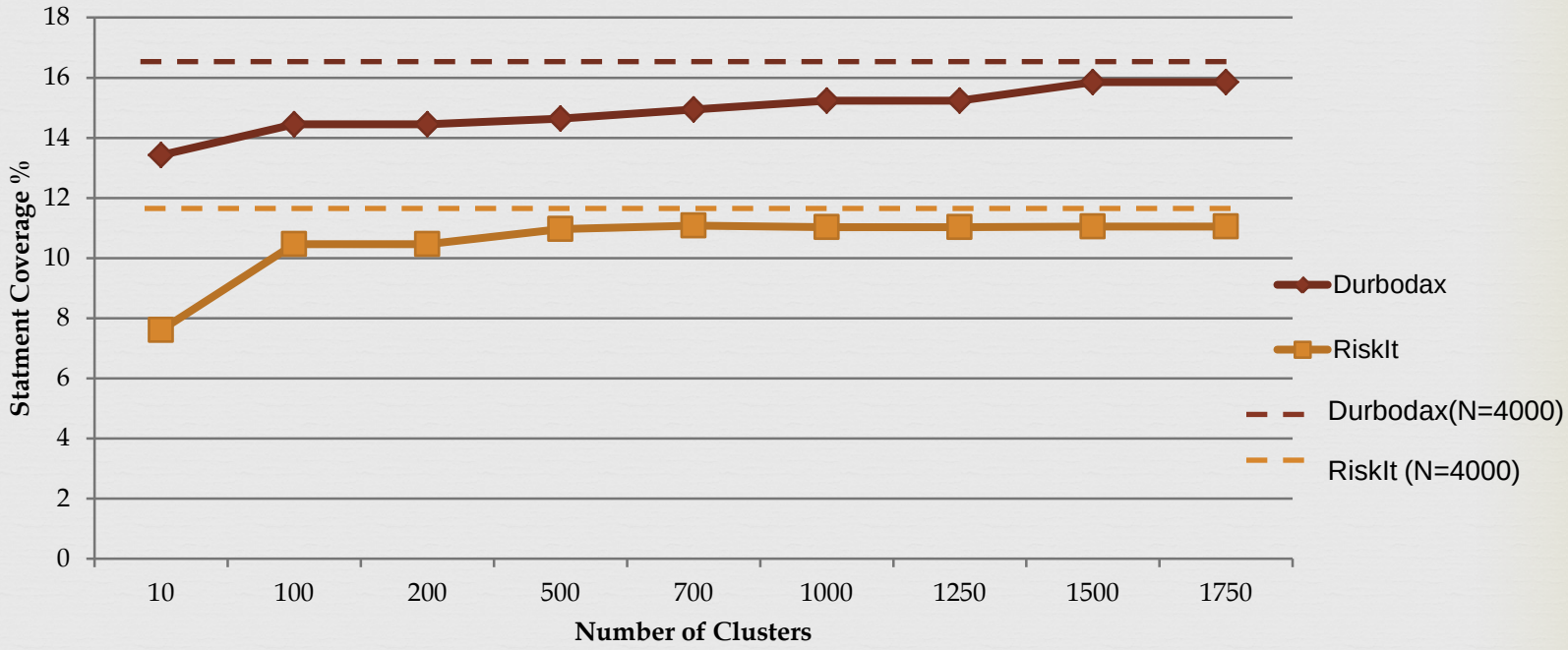
- We evaluated PISTIS on two open-source Java applications, DurboDax and RiskIt
  - DurboDax: 27 tables and 114 attributes
  - RiskIt: 14 tables and 57 attributes
  - Randomly select 4000 records
  - Branch coverage are 19.3% and 13% respectively.

Branch coverage



Branch coverage on the number of clusters for subject applications

Statement coverage



Statement coverage on the number of clusters for subject applications

Disclosure rate

- To evaluate privacy level
- Similarity matrix
- Disclosure rate: the average of all cells in the similarity matrix

Similarity matrix

Age	State	Gender	Treatment
42	OH	M	Vasectomy
47	OH	F	Hysterectomy
51	VA	F	Chemotherapy
55	VA	M	Chemotherapy
62	OH	M	Chemotherapy
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Original table

Age	State	Gender	Treatment
47	OH	M	Vasectomy
61	VA	M	Chemotherapy
32	OH	F	Hysterectomy

Anonymized table

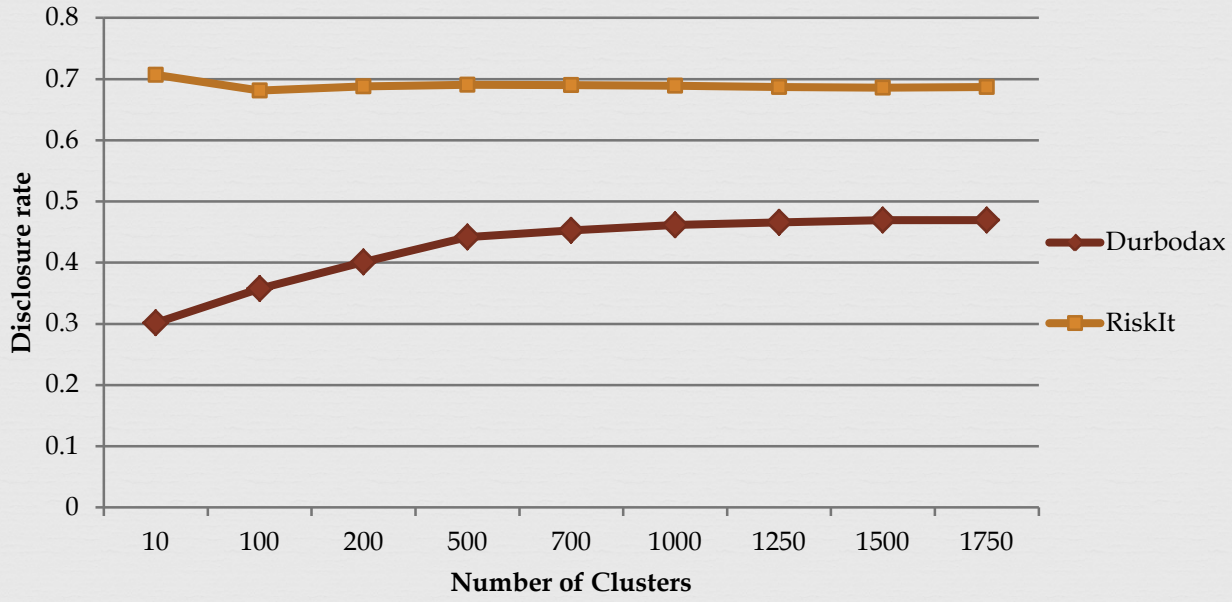
$$\frac{0 + 1 + 1 + 1}{4} = 0.75$$

- Similarity matrix

	Record 1	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Record 8	Record 9
C1	0.75	0.25	0	0.25	0.5	0	0	0	0.25
C2	0.25	0	0.5	0.75	0.5	0	0.25	0.25	0
C3	0.25	0.75	0.25	0	0.25	0.5	0.25	0.25	0.75

Disclosure rate

- We compute the disclosure rate as the average of all cells in the similarity matrix



Disclosure rate on the number of clusters for subject applications

Summary

Our work

- We focus on balancing the following four dimensions:

Privacy	**Data minimization**
Semantic correctness	**Testing coverage**

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PISTIS - Protecting and mInimizing databases for Software TestIng taSks

- Program analysis ------- **Test coverage**
- Weight-based k-clustering algorithm — **Data minimization**
- Compute centroid objects — **Privacy**
- Associative rule mining ------- **Semantic correctness**

PISTIS allows us to meet all four goals

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Running example

- Step 4: maps the table back to the original attributes

Age (Normalized)	OH	VA	CA	Female	Male	Hysterectomy	Vasectomy	Chemotherapy
0.7	0.67	0.33	0	0.67	0.33	0.33	0.33	0.33

Age	State	Gender	Treatment
47	OH	F	Vasectomy

Age	State	Gender	Treatment
47	OH	F	Vasectomy
61	VA	M	Chemotherapy
32	OH	F	Hysterectomy

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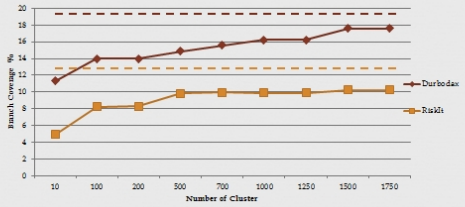
Branch coverage



Branch coverage on the number of clusters for subject applications

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