An Empirical Study of Boosting Spectrum-based Fault Localization via PageRank

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Motivation

Key Insight**：** *to enhance the existing SBFL techniques by additionally considering how to differentiate tests (i.e., the other dimension in program spectra),*

How to differentiate program entities → How to differentiate tests

t1
(cover 100)

t2
(cover 1)

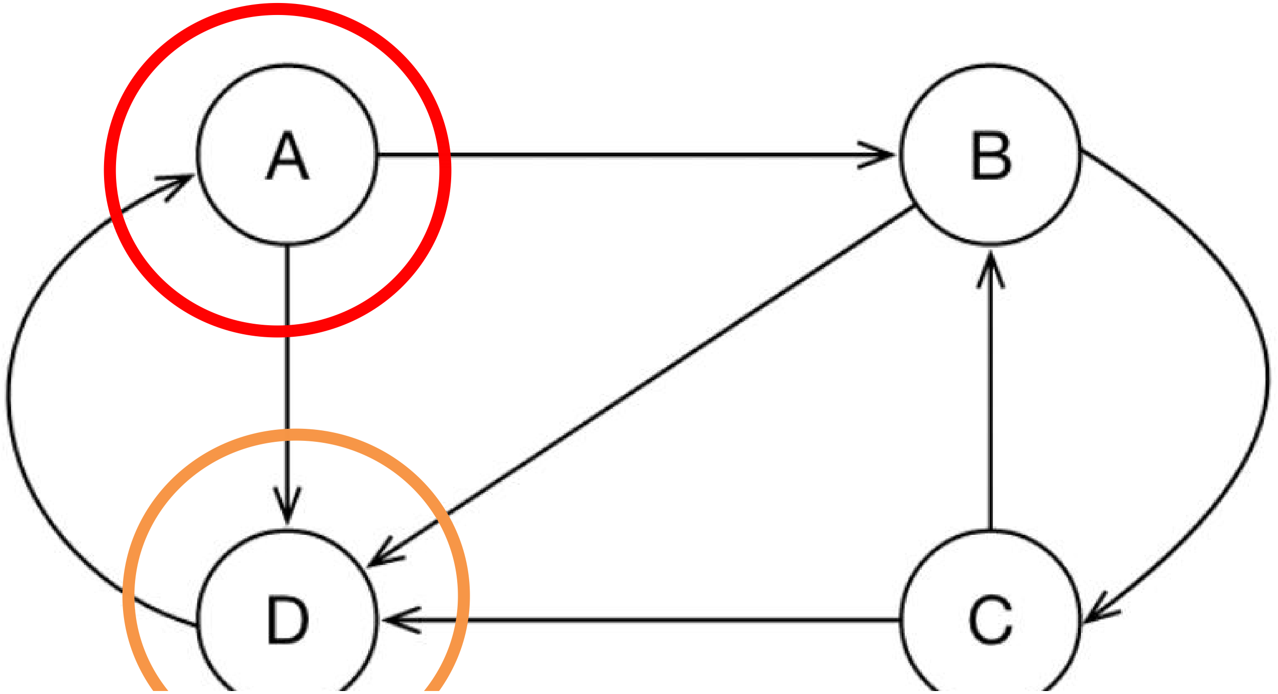
SBFL

$\mathcal{T}$	c_1	c_2	$\cdots$	c_M	e
t_1	$\mathcal{A}_{11}$	$\mathcal{A}_{12}$	$\cdots$	$\mathcal{A}_{1M}$	e_1
t_2	$\mathcal{A}_{21}$	$\mathcal{A}_{22}$	$\cdots$	$\mathcal{A}_{2M}$	e_2
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
t_N	$\mathcal{A}_{N1}$	$\mathcal{A}_{N2}$	$\cdots$	$\mathcal{A}_{NM}$	e_N

Figure 1: An example spectrum.

$\mathcal{T}$	c_1	c_2	c_3	c_4	c_5	e
t_1	1	0	1	1	0	✓
t_2	0	1	1	1	1	✗
t_3	1	0	1	0	0	✗
t_4	0	1	0	0	1	✓
t_5	1	0	0	1	1	✓

PageRank



$$\vec{x} = d \cdot \boldsymbol{P}\vec{x} + (1-d)\cdot\vec{v} \quad \mathbf{k}$$

$$PR_i = \sum_{\forall j, j \to i} \frac{PR_j}{\text{Outbound Link Num of Node } j} \qquad (1)$$

Method-level Aggregation

```
class Code{
  static int m1(int x) {
    int y = Math.abs(x);
    if ( y % 2 == 1)
      int s = 1;//buggy
    else
      int s = 1;
    return s;
  }


  static int m2(int x) {
    int s = x + 1;
    return s;
  }
}
```

```
public void t1() {
  int a = Code.m1(-2);
  int b = Code.m2(a);
  assertEquals(2, b);
}
public void t2() {
  int a = Code.m1(2);
  assertEquals(1, a);
}
public void t3() {
  int a = Code.m1(3);
  int b = Code.m2(a);
  assertEquals(0, c);
}
public void t4() {
  int a = Code.m2(5);
  assertEquals(6, a);
}
```

Fig. 2: Example Code Snippet for Method-level Aggregation

Implement

PRFL+

$PRFL_{MA}$

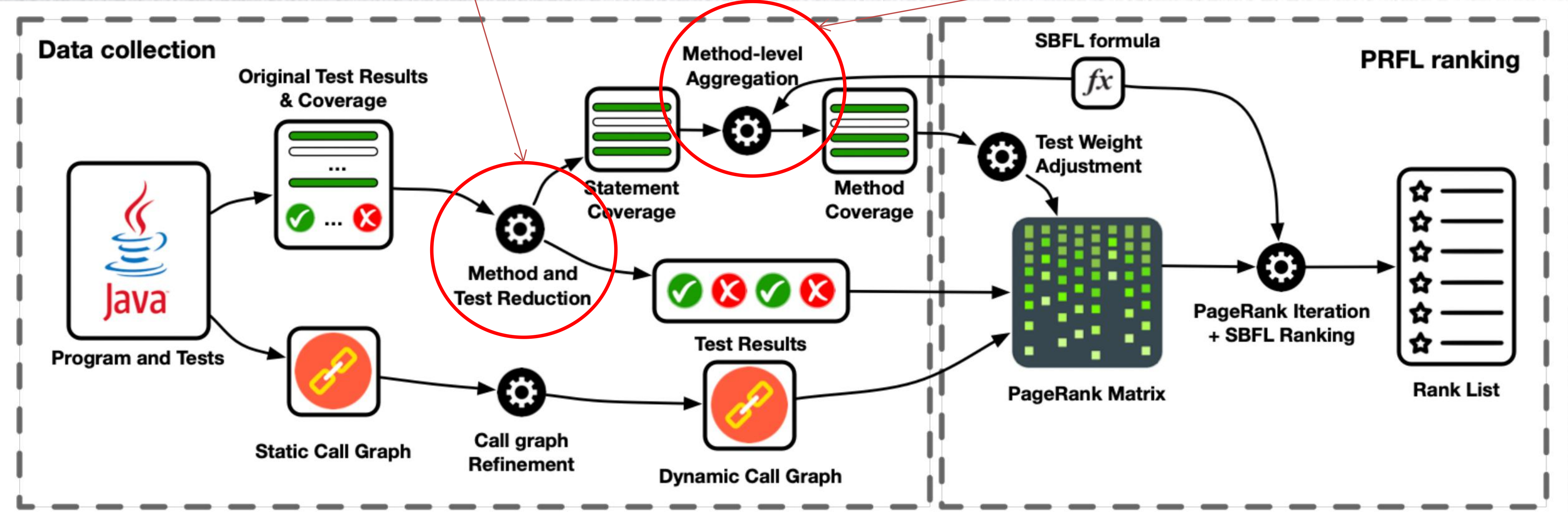


Fig. 5: Framework of the Proposed Approach

Dataset: Defects4J and Bugs.jar

Evaluation Metrics: AWE and Top-N

Implement

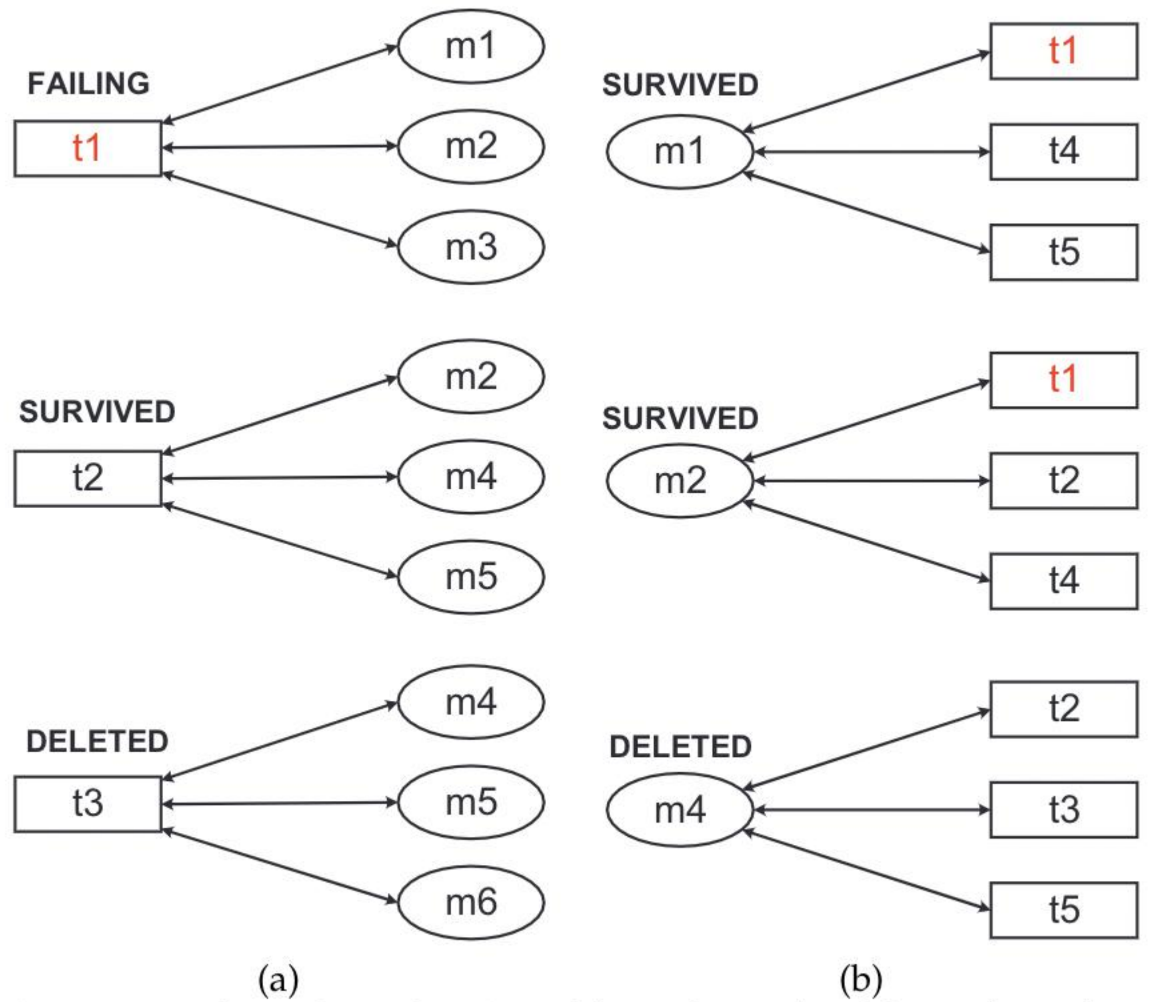


Fig. 6: Test-based Reduction (a) and Method-based Reduction (b)

RQ1: PRFL's Overall Effectiveness and Efficiency

TABLE 5: Results of SBFL and PRFL on All Defects4J Faults

	Tech	Top-1		Top-3		Top-5		AWE		
		S	P	S	P	S	P	S	P	Impr.
Chart	Tarantula	7	12	20	21	22	24	14.92	13.63	8.63%
	SBI	7	11	20	21	22	24	14.92	13.63	8.63%
	Ochiai	6	11	17	20	19	24	11.83	10.21	13.66%
	Jaccard	6	11	17	20	20	24	12.12	10.60	12.54%
	Ochiai2	6	12	17	21	21	24	12.15	11.40	6.17%
	Kulczynski	6	11	17	20	20	24	12.12	10.60	12.54%
	Dstar2	5	10	16	21	19	24	13.65	9.83	28.03%
	Op2	5	7	14	17	16	20	66.19	61.37	7.29%
Overall	Tarantula	75	98	181	205	229	251	35.80	28.58	20.18%
	SBI	75	97	181	205	229	251	35.80	28.58	20.17%
	Ochiai	79	110	179	212	230	274	34.66	25.70	25.85%
	Jaccard	76	99	176	204	229	254	35.08	27.83	20.68%
	Ochiai2	75	98	178	207	227	253	35.21	28.25	19.78%
	Kulczynski	76	99	176	204	229	254	35.08	27.83	20.68%
	Dstar2	79	109	177	209	221	269	36.63	27.00	26.30%
	Op2	82	83	172	185	212	231	69.95	62.72	10.34%

Evaluation

TABLE 6: Fault Localization Overheads

Sub	COV	CG	DP	Analysis	Ranking	Total
Chart	35.18	66.71	6.49	1.33	0.01	109.72
Closure	231.73	431.71	888.87	6.61	0.01	1558.94
Lang	23.85	22.26	0.81	0.38	0.01	47.31
Math	268.32	106.21	8.33	1.47	0.01	384.34
Mockito	45.37	38.93	4.30	0.15	0.01	88.76
Time	21.56	25.72	19.39	1.32	0.01	68.00
Avg.	104.33	115.23	154.70	1.87	0.01	376.17

RQ3: Impact of Fault Number

TABLE 9: Overall fault Localization Results on Single-fault and Multi-location-faults of Defects4J

Tech	Single-fault versions									Multi-location-faults versions								
	Top-1		Top-3		Top-5		AWE			Top-1		Top-3		Top-5		AWE		
	S	P	S	P	S	P	S	P	Impr.	S	P	S	P	S	P	S	P	Impr.
Tarantula	58	70	122	135	150	161	30.81	24.20	21.44%	17	28	59	70	79	90	27.28	20.88	23.45%
SBI	58	70	122	135	150	161	30.81	24.20	21.44%	17	27	59	70	79	90	27.28	20.89	23.41%
Ochiai	63	82	128	144	156	178	26.41	19.00	28.06%	16	28	51	68	74	96	26.22	20.43	22.08%
Jaccard	60	73	123	137	153	163	29.42	23.02	21.74%	16	26	53	67	76	91	27.27	20.66	24.26%
Ochiai2	59	71	122	136	151	162	29.83	23.64	20.76%	16	27	56	71	76	91	27.22	20.83	23.47%
Kulczynski	60	73	123	137	153	163	29.42	23.02	21.74%	16	26	53	67	76	91	27.28	20.66	24.27%
Dstar2	64	82	129	146	156	179	26.35	18.81	28.62%	15	27	48	63	65	90	27.19	20.58	24.31%
Op2	68	67	136	142	162	174	24.17	19.75	18.30%	14	16	36	43	50	57	63.98	53.23	16.81%

Column **S** and **P** indicate SBFL and PRFL respectively

RQ4: Comparison of PRFL and Recent Proposed SBFL Technique

TABLE 10: Effectiveness of Ochiai, Multric and PRFL

Tech.	Proj.	Top1	Top3	Top5	AWE
Ochiai	Chart	6	17	19	11.83
	Lang	22	44	56	5.35
	Math	24	60	73	9.25
	Time	6	11	18	22.93
	Mockito	7	18	25	49.91
	Closure	14	29	39	108.70
	Overall	79	179	230	34.66
Multric	Chart	7	18	21	10.88
	Lang	23	47	59	6.9
	Math	21	57	69	25.17
	Time	6	14	14	39.11
	Mockito	6	14	24	48.55
	Closure	17	38	49	134.44
	Overall	80	188	236	44.18
PRFL-Ochiai	Chart	11	20	24	10.21
	Lang	30	50	58	4.76
	Math	33	65	83	6.92
	Time	7	13	18	19.93
	Mockito	9	20	32	36.66
	Closure	20	43	59	75.74
	Overall	110	212	274	25.70

RQ5: Comparison of PRFL, MBFL and the integrated approach

TABLE 11: Overall Results of the Comparison of PRFL, MBFL and Their Combination

Tech.	Proj.	Top 1	Top 3	Top 5	AWE
Metallaxis	Chart	7	19	22	11.88
	Lang	31	55	60	3.12
	Math	19	69	84	6.77
	Time	6	11	15	18.20
	Mockito	9	19	27	52.42
	Overall	72	173	208	15.40
PR-MBFL	Chart	8	20	21	18.16
	Lang	24	48	57	4.22
	Math	20	55	68	10.53
	Time	4	9	12	18.52
	Mockito	6	13	25	52.58
	Overall	62	145	183	17.33
MB-hy-avg	Chart	7	15	22	14.00
	Lang	31	54	60	3.38
	Math	24	63	80	7.24
	Time	7	12	14	18.17
	Mockito	9	20	27	56.05
	Overall	78	164	203	16.47
PRFL	Chart	11	20	24	10.21
	Lang	30	50	58	4.76
	Math	33	65	83	6.92
	Time	7	13	18	19.93
	Mockito	9	20	32	36.66
	Overall	90	168	215	13.08

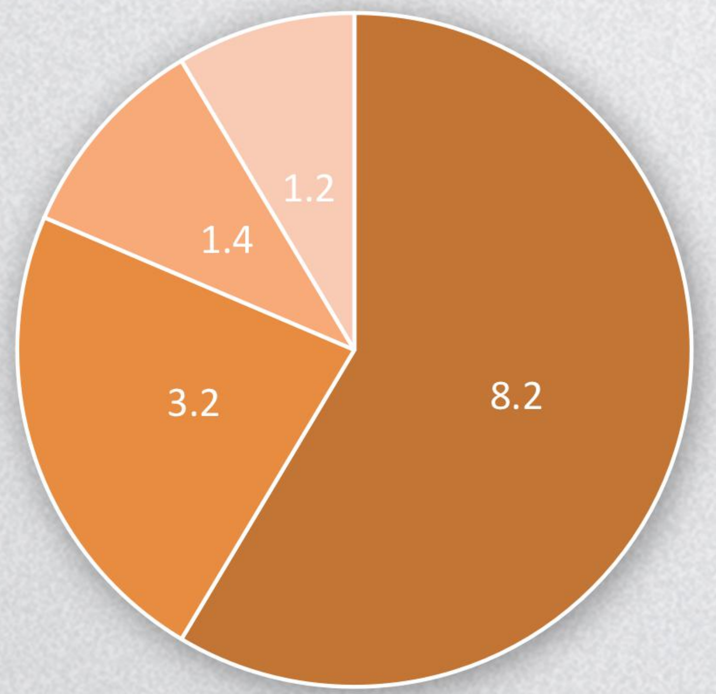
RQ6: Comparison of the constrained PageRank and other link analysis algorithms

TABLE 12: Overall Results of the Comparison of Link Analysis Algorithms

	Tech	STPR				PRFL			
		Top1	Top3	Top5	AWE	Top1	Top3	Top5	AWE
Overall	Tarantula	63	135	171	50.45	98	204	251	28.58
	SBI	63	135	171	50.45	97	204	251	28.58
	Ochiai	62	130	160	48.11	110	211	274	25.70
	Jaccard	62	128	160	53.00	99	203	254	27.83
	Ochiai2	61	134	164	50.72	98	206	253	28.25
	Kulczynski	62	128	160	53.00	99	203	254	27.83
	Dstar2	61	126	157	53.29	109	208	269	27.00
	Op2	62	122	160	58.38	83	184	231	62.72

	Tech	HITS				SALSA			
		Top1	Top3	Top5	AWE	Top1	Top3	Top5	AWE
Overall	Tarantula	72	174	222	31.26	21	81	101	118.65
	SBI	72	174	222	31.26	21	81	101	118.65
	Ochiai	81	189	239	28.03	21	81	101	118.65
	Jaccard	74	178	226	30.65	21	81	101	118.65
	Ochiai2	74	178	225	31.04	21	81	101	118.65
	Kulczynski	74	178	226	30.65	21	81	101	118.65
	Dstar2	81	186	235	28.83	21	81	101	118.65
	Op2	72	161	198	62.33	21	81	101	118.65

Results



- **The experimental results showed that PRFL and $PRFL_{MA}$ outperforms existing state-of-the-art SBFL techniques significantly with low overhead.**

THANK YOU FOR YOUR LISTENING.

谢谢您的聆听