Improvements for Spectrum-based Fault Localization in Spreadsheets

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Outline

1. Motivation
2. Fault Localization in Spreadsheets
3. Improvements for SFL
4. Evaluation
5. Conclusion

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Motivation

Spreadsheets are . . .

- used privately and in corporate environment
- used for critical computations and decisions[1]
- faulty! (~88 % of all spreadsheets)[2]

Quality assurance in spreadsheets:

- Fault detection, localization, repair

1 James Kwak. The Importance of Excel. The Baseline Scenario. @. Feb. 9, 2013. URL: http://baselinescenario.com/2013/02/09/the-importance-of-excel/ (visited on 03/31/2015)

2 Raymond R. Panko. “Spreadsheet Errors: What We Know. What We Think We Can Do”. In: Proceedings of the European Spreadsheet Risks Interest Group (EuSpRIG). 2000, pp. 7–17. URL: http://arxiv.org/abs/0802.3457 (visited on 04/08/2014)

Example - Bonus Calculation

	A	B	C	D	E
1		**Hours**	**Salary**	**Bonus**	**Sum**
2	Jones	17	272	26	298
3	Smith	13	208	0	208
4	Rogers	20	320	40	360
5	**Total**		800	66	866

	A	B	C	D	E
1		**Hours**	**Salary**	**Bonus**	**Sum**
2	Jones	17	=B2*16	=IF(B2>15; C3 /8;0)	=SUM(C2:D2)
3	Smith	13	=B3*16	=IF(B3>15; C3 /8;0)	=SUM(C3:D3)
4	Rogers	20	=B4*16	=IF(B4>15; C4 /8;0)	=SUM(C4:D4)
5	**Total**		=SUM(C2:C4)	=SUM(D2:D4)	=SUM(E2:E4)

Figure: Faulty bonus calculation

Example - Bonus Calculation

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4	Rogers	20	=B4*16	=IF(B4>15; C4 /8;0)	=SUM(C4:D4)
5	Total		*=SUM(C2:C4)*	*=SUM(D2:D4)*	*=SUM(E2:E4)*

Figure: `D2` is faulty (26 instead of 34)

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Spectrum-based Fault Localization I

Goal: Find root cause of unexpected spreadsheet behavior

- Trace-based (as opposed to model-based)
  - Analyze cell dependencies
  - Return fault likelihoods for each cell
- Process:
  1. Testing Decisions
  2. Analyze dependencies (CONEs)
  3. Compute fault likelihood (similarity coefficient)

Spectrum-based Fault Localization II

1. **Testing Decisions** (TD)
   - User provided
   - Judging the value of cells
     - Expected (✓) $= TD^+$
     - Unexpected (✗) $= TD^-$

	A	B	C	D	E
1		Hours	Salary	Bonus	Sum
2	Jones	17	272	26	298
3	Smith	13	208	0	✓ 208
4	Rogers	20	320	40	360
5	Total		✓ 800	66	✗ 866

Spectrum-based Fault Localization III

2. Create CONEs from the testing decisions

- CONE(c) = Set of cells containing c and all cells referenced by c
    - directly (in formula) and
    - indirectly (recursive)
- CONE(E5) = {E5,E2,E3,E4,D2,D3,D4,C2,C3,C4}

	A	B	C	D	E
1		Hours	Salary	Bonus	Sum
2	Jones	17	272	26	298
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4	Rogers	20	320	40	360
5	Total		***800***	***66***	✗ ***866***

Spectrum-based Fault Localization IV

3. Similarity coefficient correlates

   - No. TD^{+} and the
   - No. TD^{-} a cell contributes to

Using the **Ochiai**[1] coefficient:

	A	B	C	D	E
1		Hours	Salary	Bonus	Sum
2	Jones	17	0.7	1	1
3	Smith	13	0.6	0.7	0.7
4	Rogers	20	0.7	1	1
5	Total		0	0	1

Rank	Cells
1.	D2,E2,D4,E4,E5
2.	C2,D3,E3,C4
3.	C3

1 R. Abreu, P. Zoeteweij, and A.J.C. van Gemund. "An Evaluation of Similarity Coefficients for Software Fault Localization". In: 12th Pacific Rim International Symposium on Dependable Computing, 2006. PRDC '06. Dec. 2006, pp. 39–46. DOI: 10.1109/PRDC.2006.18

SFL Properties

Advantages

- Fast
- Low user requirement
- Intuitive cell ranking

	A	B	C	D	E
1		Hours	Salary	Bonus	Sum
2	Jones	17	272	26	298
3	Smith	13	208	0	✓ 208
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	A	B	C	D	E
1		Hours	Salary	Bonus	Sum
2	Jones	17	0.7	1	1
3	Smith	13	0.6	0.7	0.7
4	Rogers	20	0.7	1	1
5	Total		0	0	1

Issues

- Multiple fault interference
- Low rank of the faulty cell
  - Oracle mistakes
  - Coincidental correctness
- Large Ties
  - Lack of prioritization
  - Difficult to compare

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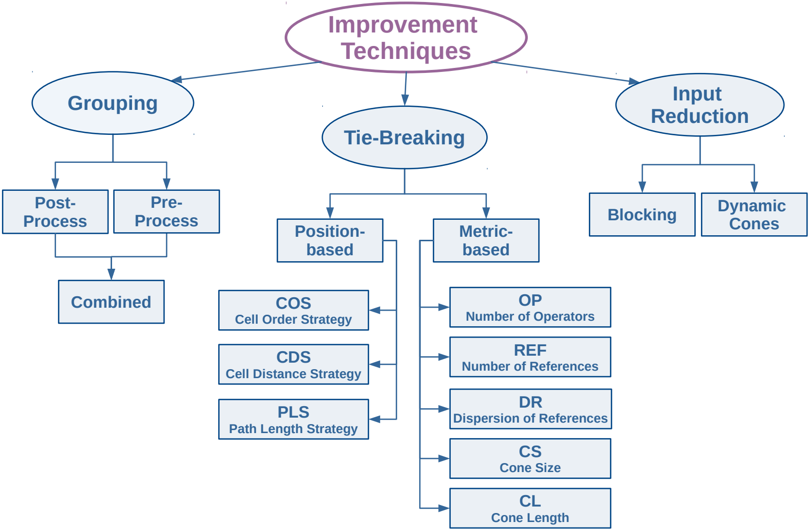
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Tie-Breaking
Input Reduction
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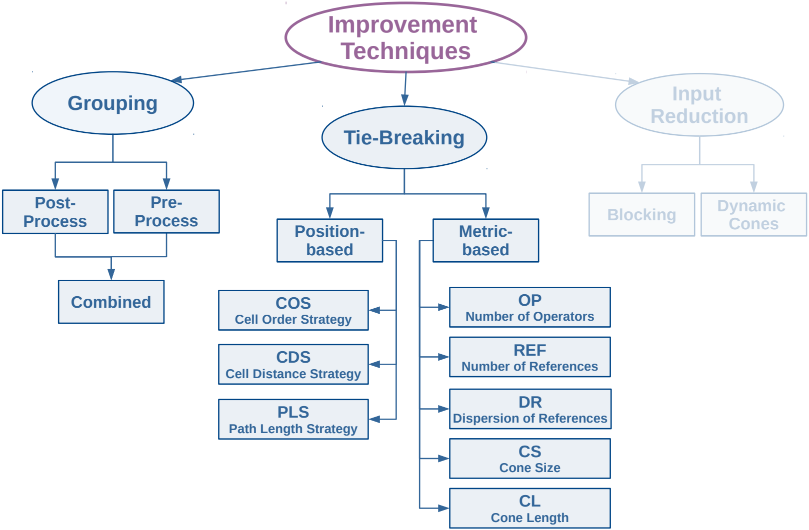
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Grouping I

Goal: Group cell areas with duplicate formulas to a single unit

- Formulas must be identical in `R1C1`

	1	2	3	4	5
1		Hours	Salary	Bonus	Sum
2	Jones	17	=RC[-1]*16	=IF(RC[-2]>15; R[1]C[-1] /8;0)	=SUM(RC[-2]:RC[-1])
3	Smith	13	=RC[-1]*16	=IF(RC[-2]>15; RC[-1] /8;0)	=SUM(RC[-2]:RC[-1])
4	Rogers	20	=RC[-1]*16	=IF(RC[-2]>15; RC[-1] /8;0)	=SUM(RC[-2]:RC[-1])
5	Total		=SUM(R[-3]C:R[-1]C)	=SUM(R[-3]C:R[-1]C)	=SUM(R[-3]C:R[-1]C)

Figure: Four groups with the faulty cell isolated

- Post- vs. Pre-Processing

Grouping II

- **Post-Process** Grouping
  - Analyze spreadsheet after SFL is applied
  - Groupable cells must have the same similiarity coefficient
- **Pre-Process** Grouping
  - Analyze spreadsheet before SFL is applied
  - Copy testing decisions to all cells in group
  - Cells can only be grouped if they work on the same type of data

Pre-Process Grouping Example

Type-safe group is an area containing

- Constants of the same type (i.e. int, string, . . .)
- Formula cells
    - Share the same formula **and**
    - All references share same type

	1	2	3	4	5
1		Hours	Salary	Bonus	Sum
2	Jones	17	=RC[-1]*16	=IF(RC[-2]>15; R[1]C[-1] /8;0)	=SUM(RC[-2]:RC[-1])
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4	Rogers	20	=RC[-1]*16	=IF(RC[-2]>15; RC[-1] /8;0)	=SUM(RC[-2]:RC[-1])
5	Total		*=SUM(R[-3]C:R[-1]C)*	*=SUM(R[-3]C:R[-1]C)*	*=SUM(R[-3]C:R[-1]C)*

Figure: Three groups, isolating the row with the faulty cell D2.

Tie Breaking I

Goal: Rank faulty cell higher than non-faulty cells

- Position- vs. Metric-based Tie-Breaking
- **Position-based** TB measures distances / path lengths between cells
  - **COS** (Cell Order Strategy):
    Euclidean distance from top-left corner `A1`
  - **CDS** (Cell Distance Strategy):
    Euclidean distance from nearest TD^{-}
  - **PLS** (Path Length Strategy):
    Number of cell references to reach TD^{-}

Tie Breaking II

- **Metric-based** TB analyzes formulas, using heuristics to find fault likelihood
  - **OP, REF**: Number of Operators / References
  - **DR** (Dispersion of References): Referenced cells/areas where coordinates do not overlap with the referencing cell → higher fault likelihood

	A	B	C	D	E
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4	Rogers	20	=B4*16	=IF(B4>15; C4 /8;0)	=SUM(C4:D4)
5	Total		=SUM(C2:C4)	=SUM(D2:D4)	=SUM(E2:E4)

  - **CS, CL** (Cone Size/Length): Number of cells needed to compute the cell value

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Measuring Success I

Compare position of faulty cell in the ranking for SFL alone and with our strategies

- Worst Case Scenario
  - Faulty cell c_f is reached last in the tie

$$\text{RELRANK}_{\text{worst}} = \frac{|\{c \in \text{CELLS} : SC(c) \geq SC(c_f)\}|}{|C_F \subseteq \text{CELLS}|}$$

  - C_F = Formula cells in the Spreadsheet
  - SC = Similarity Coefficient
  - Used for cumulative histogram
  - Emphasizes even small improvements

Measuring Success II

- Average Case Scenario
  - User inspects half of the equally ranked, non-faulty cells before reaching the faulty cell
  - Comparison to “pure chance”
  - Risk analysis with Impact

$$\mathit{Impact} = \textsc{RelRank}_{\text{avg}}^{\mathit{before}} - \textsc{RelRank}_{\text{avg}}^{\mathit{after}}$$

- positive Impact: fault is ranked in the first half of the tie
- negative Impact: fault is ranked in the second half

Evaluation Corpora

1. EUSES: many, diverse, real spreadsheets
2. INFO: student submissions for an Excel course
3. BURNETT: user study with two small spreadsheets

Feature	EUSES	INFO	BURNETT
Spreadsheet size	diverse	large	small
TD origin	injected	injected	authentic
Fault origin	injected	authentic	injected
Grouping	★★	★★★	-
Tie-Breaking	★	★★	★

Grouping Strategies (INFO)

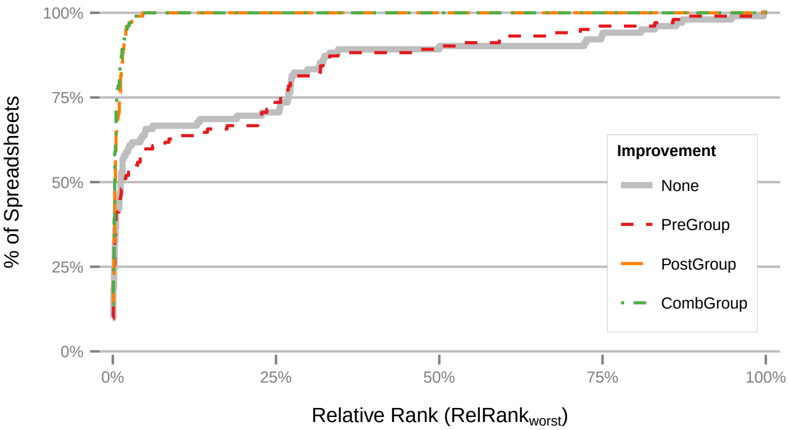


Figure: Cumulative Histogram for the RELRANK$_{\text{worst}}$ in INFO

Grouping Strategies (EUSES)

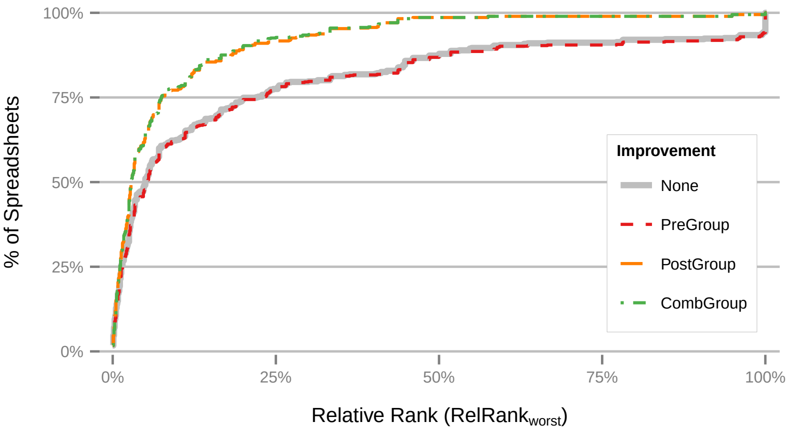


Figure: Cumulative Histogram for the RELRANK$_{\text{worst}}$ in EUSES

Impact Analysis

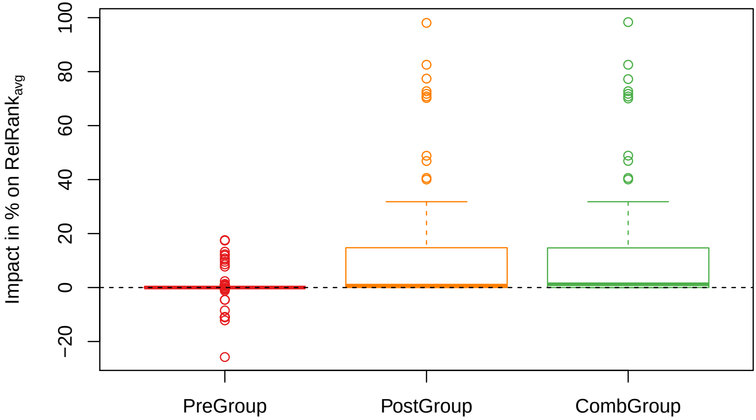
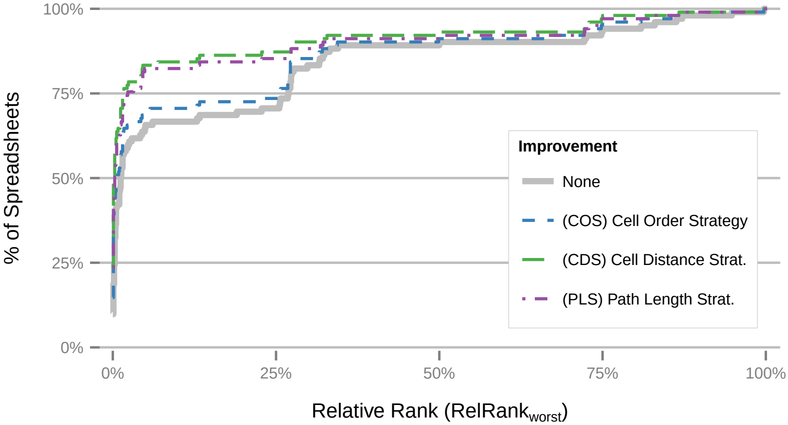


Figure: Boxplot on the Impact on the INFO corpus

Position-based Tie-Breaking



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Metric-based Tie-Breaking (OP, REF, DR)

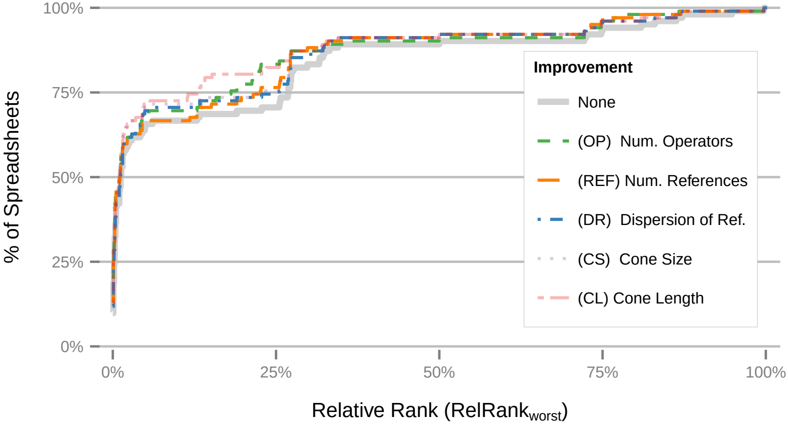
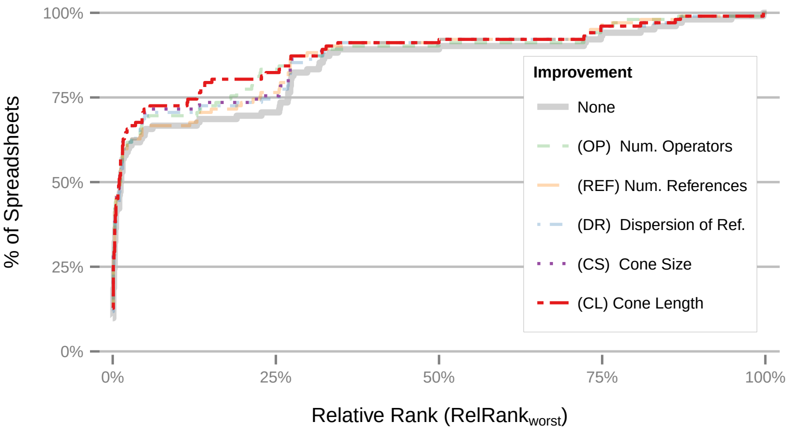


Figure: Cumulative Histogram for the RELRANK$_{worst}$ in INFO

Metric-based Tie-Breaking (CS, CL)



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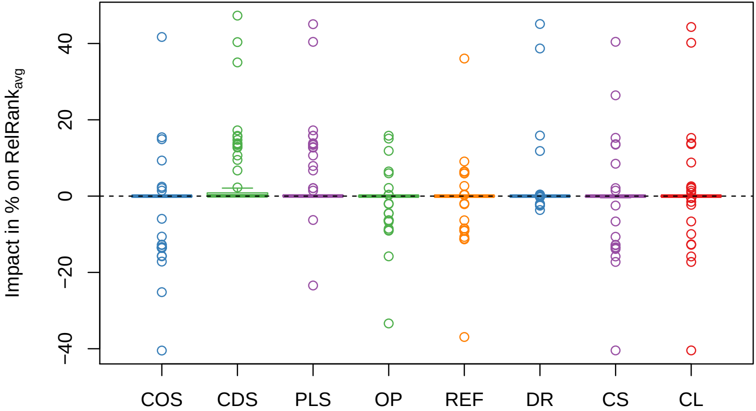
Tie-Breaking Impact



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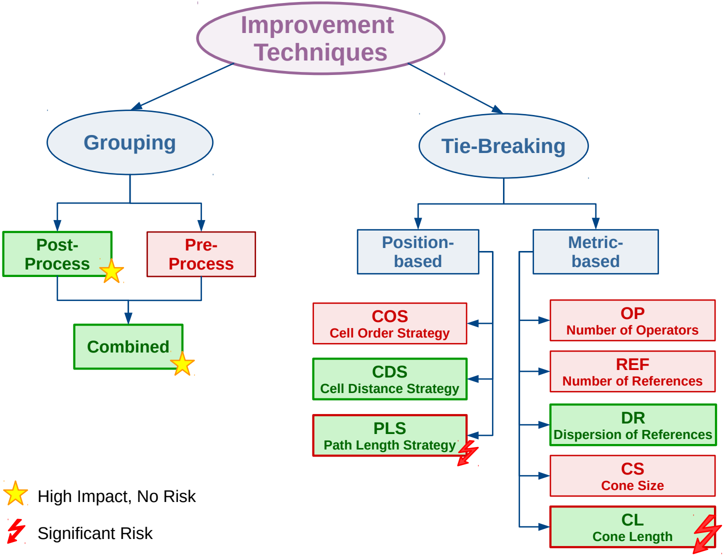
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Cone Length
High Impact, No Risk
Significant Risk

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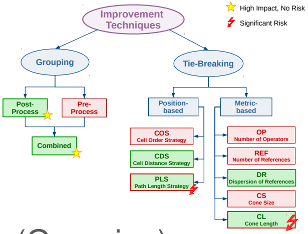

- SFL issues (e.g. large ties)
- Improvement techniques
  - Realistic representation of the tie (Grouping)
  - Rank faulty cell high within tie (Tie-Breaking)
    - Correlation to TDs (CDS)
    - Specialized metrics offer lower risk (DR)
  - Need authentic faults/TDs to evaluate
    - Structural properties influence result
    - 2 new, publicly available spreadsheet corpora[1]
- Future Work
  - Improving Pre-Process Grouping
  - Combination of techniques

1 `spreadsheets.ist.tugraz.at`