S C I E N C E ▪ P A S S I O N ▪ T E C H N O L O G Y

Qualitative deviation models vs. quantitative models for fault localization in spreadsheets

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FWF Der Wissenschaftsfonds.

DFG Deutsche Forschungsgemeinschaft

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Spreadsheet Errors

JPMorganChase

~ 300 million EUR damage

Spreadsheet Errors

Paper published by Reinhart & Rogoff

Many governments used it for decisions

Immense loss of reputation

	A	B	I	J	K	L	M
2			Real GDP growth				
3			Debt/GDP				
4	Country	Coverage	30 or less	30 to 60	60 to 90	90 or above	30 or less
26			3,7	3,0	3,5	1,7	5,5
27	Minimum		1,6	0,3	1,3	-1,8	0,8
28	Maximum		5,4	4,9	10,2	3,6	13,3
29							
30	US	1946-2009	n.a.	3,4	3,3	-2,0	n.a.
31	UK	1946-2009	n.a.	2,4	2,5	2,4	n.a.
32	Sweden	1946-2009	3,6	2,9	2,7	n.a.	6,3
33	Spain	1946-2009	1,5	3,4	4,2	n.a.	9,9
34	Portugal	1952-2009	4,8	2,5	0,3	n.a.	7,9
35	New Zealand	1948-2009	2,5	2,9	3,9	-7,9	2,6
36	Netherlands	1956-2009	4,1	2,7	1,1	n.a.	6,4
37	Norway	1947-2009	3,4	5,1	n.a.	n.a.	5,4
38	Japan	1946-2009	7,0	4,0	1,0	0,7	7,0
39	Italy	1951-2009	5,4	2,1	1,8	1,0	5,6
40	Ireland	1948-2009	4,4	4,5	4,0	2,4	2,9
41	Greece	1970-2009	4,0	0,3	2,7	2,9	13,3
42	Germany	1946-2009	3,9	0,9	n.a.	n.a.	3,2
43	France	1946-2022	4,9	2,7	3,0	n.a.	5,2
44	Finland	1946-2023	3,8	2,4	5,5	n.a.	7,0
45	Denmark	1946-2024	3,5	1,7	2,4	n.a.	5,6
46	Canada	1946-2025	1,9	3,6	4,1	n.a.	2,2
47	Belgium	1946-2026	n.a.	4,2	3,1	2,6	n.a.
48	Austria	1946-2027	5,2	3,3	-3,8	n.a.	5,7
49	Australia	1946-2028	3,2	4,9	4,0	n.a.	5,9
50							
51			4,1	2,8	2,8	=AVERAGE(L30:L44)	
52							

Running Example

= D4 / D2

	A	B	C	D
1	Item	1st Qtr	2nd Qtr	Total
2	Units Sold	1000	1500	2500
3	ASP/Unit	$ 20	$ 21	$ 20,6
4	Sales Revenue	$ 20.000	$ 31.500	$ 51.500
5	Expenses	$ 5.000	$ 6.000	$ 5.000
6	Operating Income	$ 15.000	$ 25.500	$ 46.500
7	Op Income in %	75,0 %	81,0 %	90,3 %

Should be 78.6%

This is a simplified version of the homework/Budgetone spreadsheet from the EUSES Spreadsheet Corpus

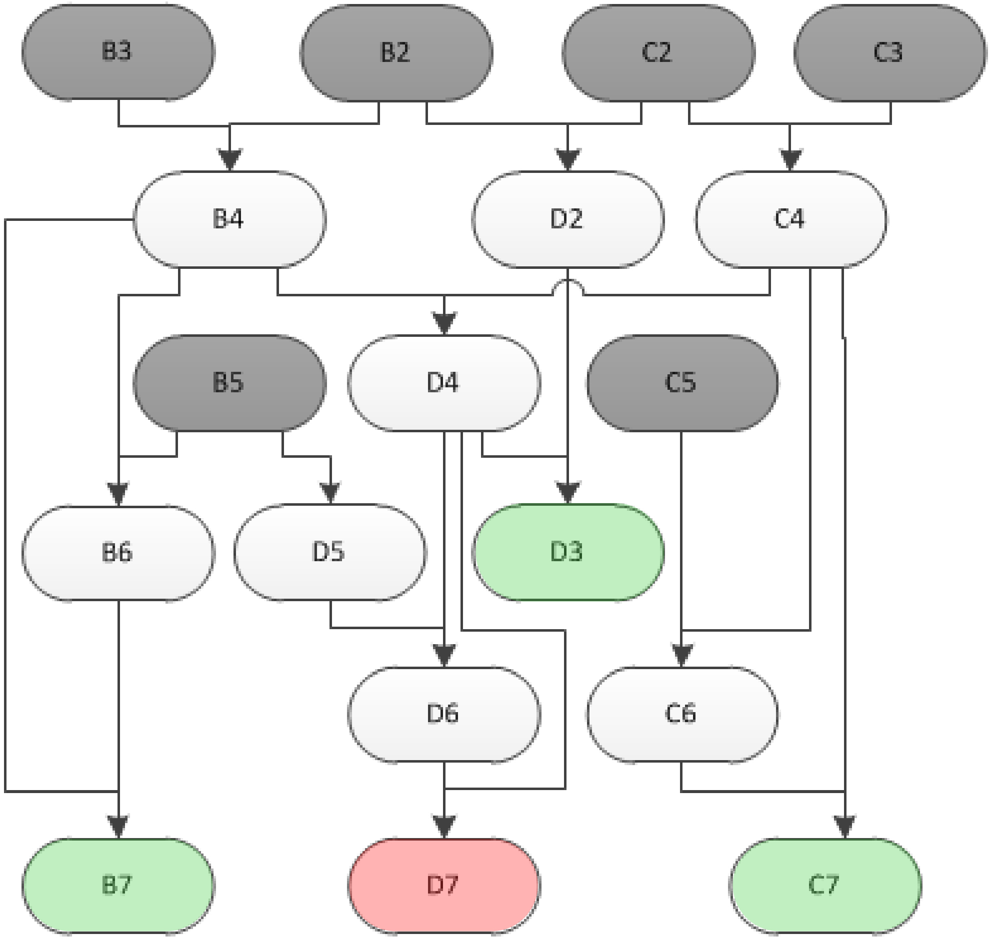
Running Example – Formula View

	A	B	C	D
1	**Item**	**1st Qtr**	**2nd Qtr**	**Total**
2	**Units Sold**	1000	1500	=SUM(B2:C2)
3	**ASP/Unit**	20	21	=D4/D2
4	**Sales Revenue**	=B3*B2	=C3*C2	=SUM(B4:C4)
5	**Expenses**	5000	6000	=SUM(B5:B5)
6	**Operating Income**	=B4-B5	=C4-C5	=D4-D5
7	**Op Income in %**	=B6/B4	=C6/C4	=D6/D4

This is a simplified version of the homework/Budgetone spreadsheet from the EUSES Spreadsheet Corpus

Running Example – Dependency Graph

	A	B	C	D
1	**Item**	**1st Qtr**	**2nd Qtr**	**Total**
2	**Units Sold**	1000	1500	=SUM(B2:C2)
3	**ASP/Unit**	20	21	=D4/D2
4	**Sales Revenue**	=B3*B2	=C3*C2	=SUM(B4:C4)
5	**Expenses**	5000	6000	=SUM(B5:B5)
6	**Operating Income**	=B4-B5	=C4-C5	=D4-D5
7	**Op Income in %**	=B6/B4	=C6/C4	=D6/D4



This is a simplified version of the homework/Budgetone spreadsheet from the EUSES Spreadsheet Corpus

Model-Based (Software) Debugging

Spreadsheet + Expect. Output → Conversion → Constraints (Model) → Solve → Diagnoses

	B	C	D
1	**1st Qtr**	**2nd Qtr**	**Total**
2	1000	1500	=SUM(B2:C2)
3	20	21	=D4/D2
4	=B3*B2	=C3*C2	=SUM(B4:C4)
5	5000	6000	=SUM(B5:B5)
6	=B4-B5	=C4-C5	=D4-D5
7	=B6/B4	=C6/C4	=D6/D4

Should be 78,6%

AB(D2) $\vee$ *behavior(D2)*
AB(D3) $\vee$ *behavior(D3)*
AB(B4) $\vee$ *behavior(B4)*
…

Test case:
D7 == 0,786
B7 == 0,750
…

For single faults:
SUM(AB(D2),AB(D3),…)==1

- Single Fault:
  - {D5}
  - {D6}
  - {D7}
- Double Fault:
  - {D3,D4}
  - …

All models are automatically derived from a faulty spreadsheet and also contain the fault!

[AHP14] Abreu, Hofer, Perez, Wotawa: "Using constraints to diagnose faulty spreadsheets." *Software Quality Journal, pp. 1–26,* 2014.

Models for a Spreadsheet's Behavior

Value-based

D2 = B2 + C2

D3 = D4 / D2

Dependency-based

$ok(B2) \land ok(C2) \rightarrow ok(D2)$

$ok(D4) \land ok(D2) \rightarrow ok(D3)$

	A	B	C	D
1	**Item**	**1st Qtr**	**2nd Qtr**	**Total**
2	**Units Sold**	1000	1500	=SUM(B2:C2)
3	**ASP/Unit**	20	21	=D4/D2
4	**Sales Revenue**	=B3*B2	=C3*C2	=SUM(B4:C4)
5	**Expenses**	5000	6000	=SUM(B5:B5)
6	**Operating Income**	=B4-B5	=C4-C5	=D4-D5
7	**Op Income in %**	=B6/B4	=C6/C4	=D6/D4

Models for a Spreadsheet's Behavior

Value-based

D2 = B2 + C2

D3 = D4 / D2

- + exact, few diagnoses
- – computation time
- – Reals: lacking support

Dependency-based

$ok(B2) \wedge ok(C2) \rightarrow ok(D2)$

$ok(D4) \wedge ok(D2) \rightarrow ok(D3)$

- + fast
- + only Boolean
- – many diagnoses

Models for a Spreadsheet's Behavior

Value-based

D2 = B2 + C2

D3 = D4 / D2

Dependency-based

$ok(B2) \wedge ok(C2) \rightarrow ok(D2)$

$ok(D4) \wedge ok(D2) \rightarrow ok(D3)$

Comparison-based

$eq(B2) \wedge eq(C2) \rightarrow eq(D2)$

$gt(B2) \wedge eq(C2) \rightarrow gt(D2)$

…

	A	B	C	D
1	**Item**	**1st Qtr**	**2nd Qtr**	**Total**
2	**Units Sold**	1000	1500	=SUM(B2:C2)
3	**ASP/Unit**	20	21	=D4/D2
4	**Sales Revenue**	=B3*B2	=C3*C2	=SUM(B4:C4)
5	**Expenses**	5000	6000	=SUM(B5:B5)
6	**Operating Income**	=B4-B5	=C4-C5	=D4-D5
7	**Op Income in %**	=B6/B4	=C6/C4	=D6/D4

Comparison-based Modeling

in1 + in2 = out

in1 * in2 = out

ABNORMAL	in1	in2	out
False	=	=	=
False	<	=	<
False	=	<	<
False	<	<	<
False	>	=	>
False	=	>	>
False	>	>	>
False	<	>	?
False	>	<	?
True	**?**	**?**	**?**

in1 - in2 = out

in1 / in2 = out

ABNORMAL	in1	in2	out
False	=	=	=
False	<	=	<
False	=	<	>
False	<	<	?
False	>	=	>
False	=	>	<
False	>	>	?
False	<	>	<
False	>	<	>
True	**?**	**?**	**?**

Practical Realization with Minion 1

```
MINION 3
# Modeling the domain = > <
# Values: 0 < / 1 = / 2 >

**VARIABLES**
DISCRETE Sheet1_F4{0..2}
DISCRETE Sheet1_F3{0..2}
DISCRETE tmp3{0..2}
DISCRETE Sheet1_H3{0..2}
DISCRETE Sheet1_B4{0..2}
DISCRETE Sheet1_D6{0..2}
DISCRETE Sheet1_B3{0..2}
DISCRETE Sheet1_D5{0..2}
DISCRETE Sheet1_D4{0..2}
DISCRETE Sheet1_D3{0..2}
DISCRETE Sheet1_F5{0..2}
DISCRETE tmp0{0..2}
DISCRETE Sheet1_B8{0..2}
DISCRETE Sheet1_B7{0..2}
DISCRETE Sheet1_B6{0..2}
DISCRETE Sheet1_B5{0..2}
DISCRETE tmp9{0..2}
BOOL ab[8]
```

```
**TUPLELIST**
plusMultFunction 40 4
0 1 1 1
0 2 1 2
0 1 2 2
0 2 2 2
0 0 1 0
0 1 0 0
0 0 0 0
0 0 2 0
0 0 2 1
0 0 2 2
0 2 0 0
0 2 0 1
0 2 0 2
1 0 0 0
1 0 0 1
1 0 0 2
1 1 0 0
1 1 0 1
1 1 0 2
1 2 0 0
1 2 0 1
1 2 0 2
1 0 1 0
1 0 1 1
1 0 1 2
1 0 2 0
1 0 2 1
1 0 2 2
1 1 1 0
```

```
minusDivFunction 40 4
0 1 1 1
0 2 1 2
0 1 2 0
0 2 2 0
0 2 2 1
0 2 2 2
0 0 1 0
0 1 0 2
0 0 0 0
0 0 0 1
0 0 0 2
0 0 2 0
0 2 0 2
1 0 0 0
1 0 0 1
1 0 0 2
1 1 0 0
1 1 0 1
1 1 0 2
1 2 0 0
1 2 0 1
1 2 0 2
1 0 1 0
1 0 1 1
1 0 1 2
1 0 2 0
1 0 2 1
1 0 2 2
1 1 1 0
```

Practical Realization with Minion 2

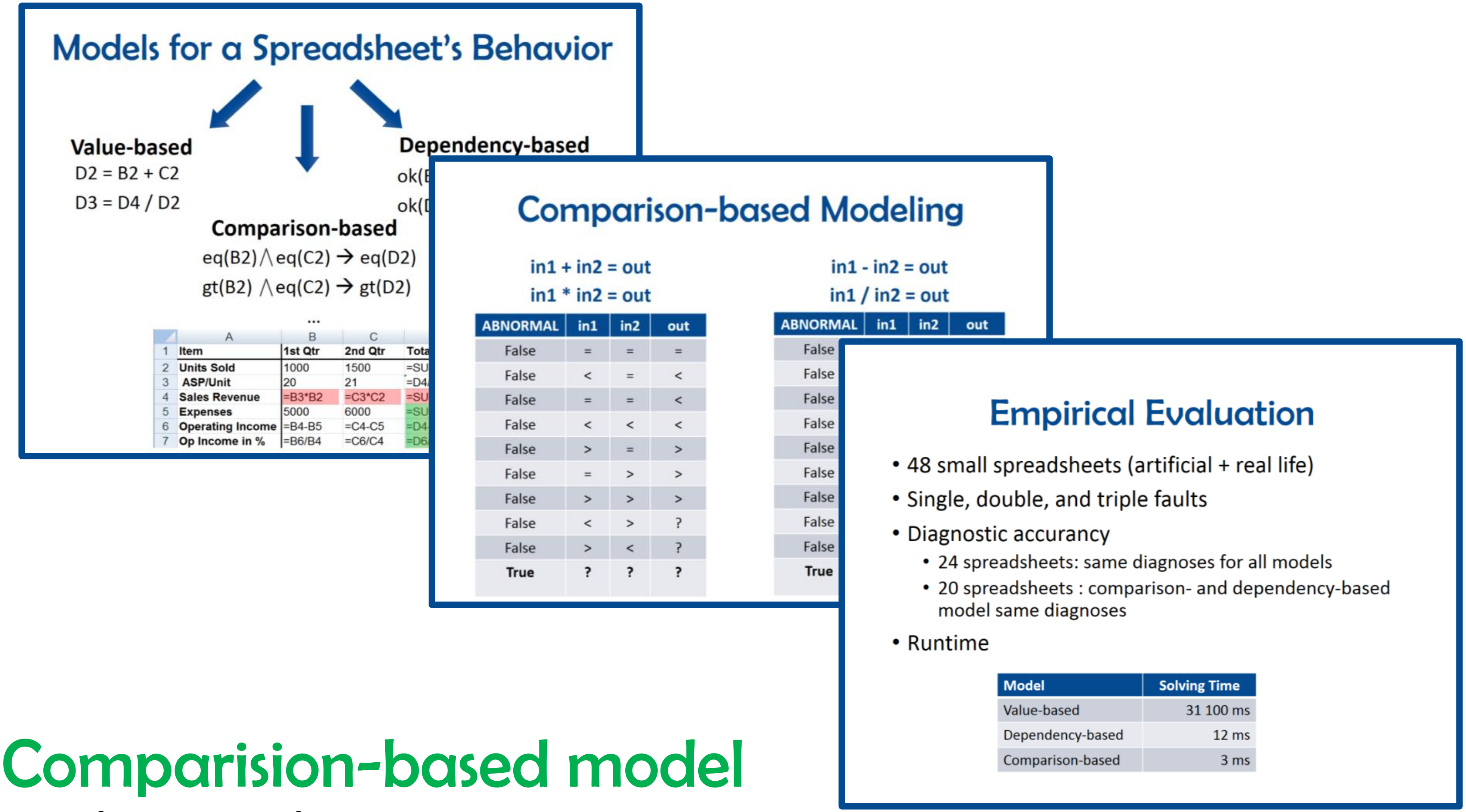
```
**SEARCH**
VARORDER [ab]
PRINT [ab]

**CONSTRAINTS**
# System description
table([ab[4],Sheet1_D4,Sheet1_D5,Sheet1_F4], plusMultFunction)
table([ab[1],Sheet1_D3,Sheet1_D4,Sheet1_F3], plusMultFunction)
table([ab[3],Sheet1_B4,Sheet1_B6,Sheet1_D4], plusMultFunction)
table([ab[5],Sheet1_B7,Sheet1_B8,Sheet1_D5], plusMultFunction)
table([ab[6],Sheet1_D5,Sheet1_D6,Sheet1_F5], plusMultFunction)
table([ab[7],Sheet1_B8,Sheet1_B6,tmp9], plusMultFunction)
table([ab[0],Sheet1_B3,Sheet1_B4,tmp0], plusMultFunction)
table([ab[7],tmp9,Sheet1_B4,Sheet1_D6], plusMultFunction)
table([ab[2],Sheet1_F3,Sheet1_F4,tmp3], minusDivFunction)
table([ab[2],tmp3,Sheet1_F5,Sheet1_H3], minusDivFunction)
table([ab[0],tmp0,Sheet1_B5,Sheet1_D3], plusMultFunction)

# TEST CASE / Observations
eq(Sheet1_B8,1)
eq(Sheet1_B7,1)
eq(Sheet1_B6,1)
eq(Sheet1_H3,0)
eq(Sheet1_B3,1)
eq(Sheet1_B4,1)
eq(Sheet1_B5,1)

#SIZE OF SOLUTION
watchsumgeq(ab,1)
watchsumleq(ab,1)
**EOF**
```

Empirical Evaluation

- 48 small spreadsheets (artificial + real life)
- Single, double, and triple faults
- Diagnostic accurancy
  - 24 spreadsheets: same diagnoses for all models
  - 20 spreadsheets : comparison- and dependency-based model same diagnoses
- Runtime

Model	Solving Time
Value-based	31 100 ms
Dependency-based	12 ms
Comparison-based	3 ms

Summary and Conclusion



Comparision-based model

- Short solving time
- Good diagnostic accurancy

→ **Useful in practice**