



Technische
Universität
Braunschweig



On Language Levels for Feature Modeling Notations

Thomas Thüm, Christoph Seidl, Ina Schaefer
MODEVAR, September 10, 2019

Part I

The Need for Variability Modeling



The Situation 110 Years Ago: Ford Model T



„Any customer can have a car painted any color that he wants so long as it is black.“

— Henry Ford, 1909

Today: Every Second Car has a Unique Configuration



Constraints Among Features are Challenging

Configuration Assistant.

» Show instructions

Your most recent action requires your configuration to be adjusted.

Your choice

+ Enhanced Bluetooth telephone with USB & Voice Control

Price

+ £ 350.00

Adding

+ BMW Navigation

£ 0.00

Removing

- Enhanced Bluetooth with wireless charging

- £ 395.00

- Navigation system Professional

£ 0.00

- WiFi hotspot preparation

£ 0.00

- Media package - Professional

- £ 900.00

- Online Entertainment

£ 0.00

- Microsoft Office 365

- £ 150.00

Constraints Among Features are Challenging

Configuration Assistant.

» Show instructions

Your most recent action requires your configuration to be adjusted.

Your choice

+ Enhanced Bluetooth telephone with USB & Voice Control

Price

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A car without Microsoft Office 365?!?

Removing

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£ 0.00

- Microsoft Office 365

- £ 150.00

Constraints Among Features are Challenging

Display

14.0" FHD (1920x1080), LED backlight, 300 nits, 16:9 aspect ratio, 700:1 contrast ratio, 72% gamut, 170° viewing angle, IPS, Touch

SELECTED

14.0" WQHD (2560x1440), LED backlight, 300 nits, 16:9 aspect ratio, 700:1 contrast ratio, 72% gamut, 170° viewing angle, IPS, Touch

+ £91.20

14.0" HDR WQHD (2560x1440) with Dolby Vision™, LED backlight, 500 nits, 16:9 aspect ratio, 1500:1 contrast ratio, 100% gamut, 170° viewing angle, IPS, Touch

+ £159.60

Please note this display is only available with WWAN/mobile broadband.

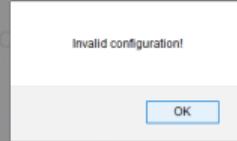
Constraints Among Features are Challenging

Display

14.0" FHD (1920x1080), LED backlight, 300 nits, 16:9 aspect ratio, 700:1 contrast ratio, 72% gamut, 170° viewing angle, IPS, Touch

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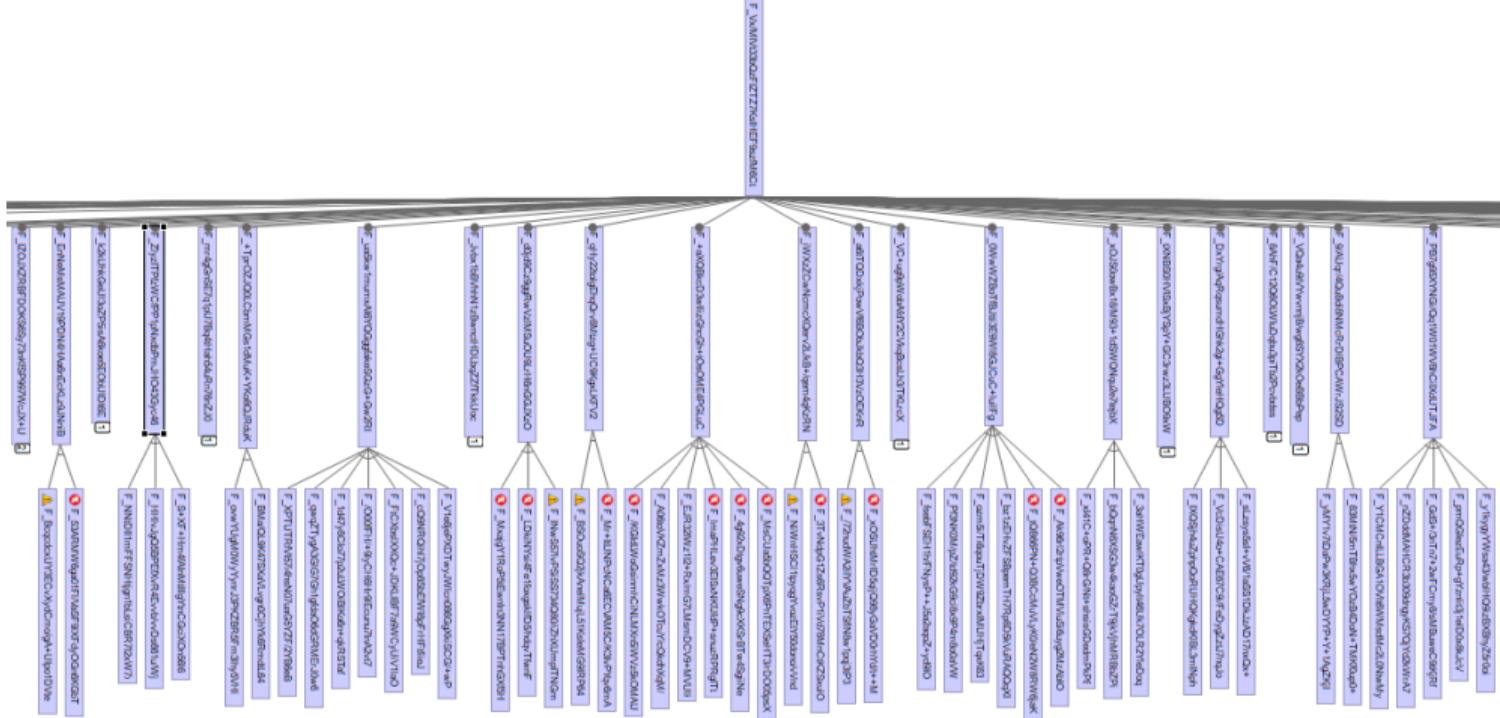


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+ £91.20

SELECTED

Variability Models as Central Knowledge Database

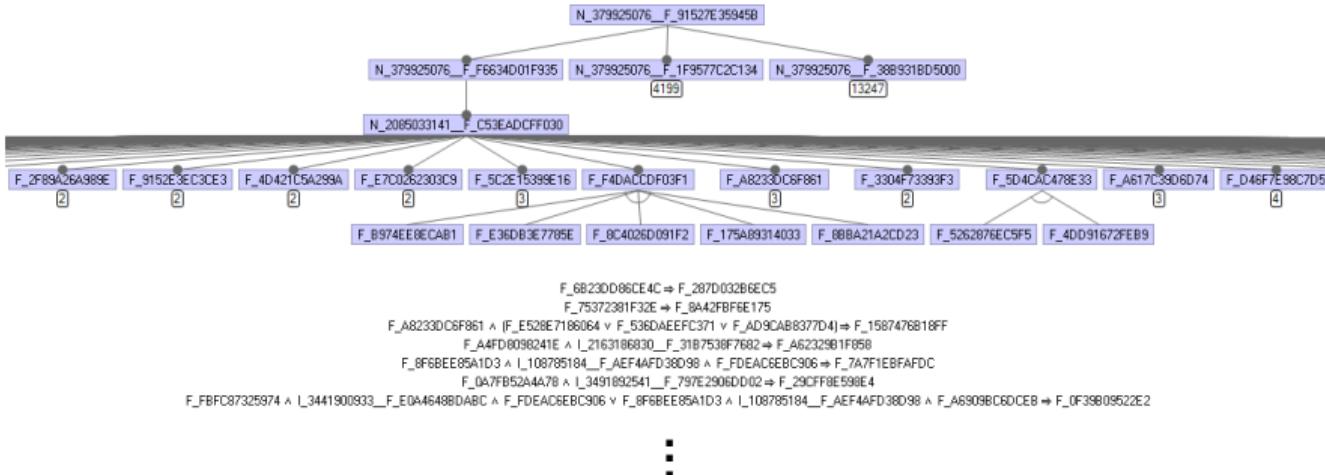


Part II

The Need for Variability Analyses

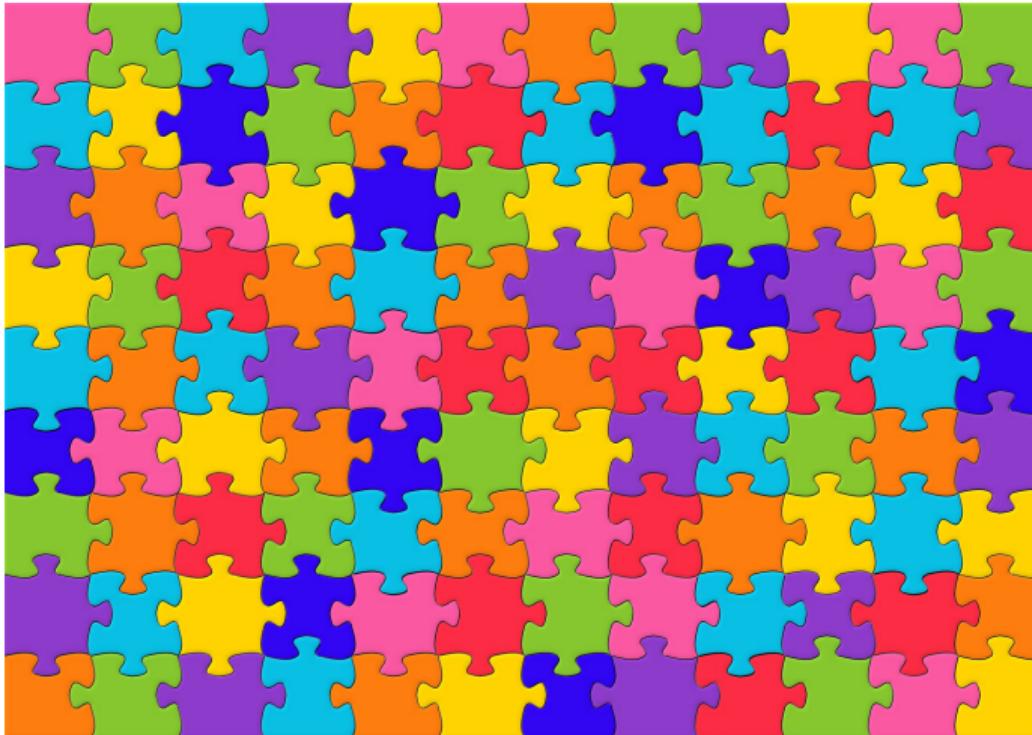


Real-World Variability Modeling

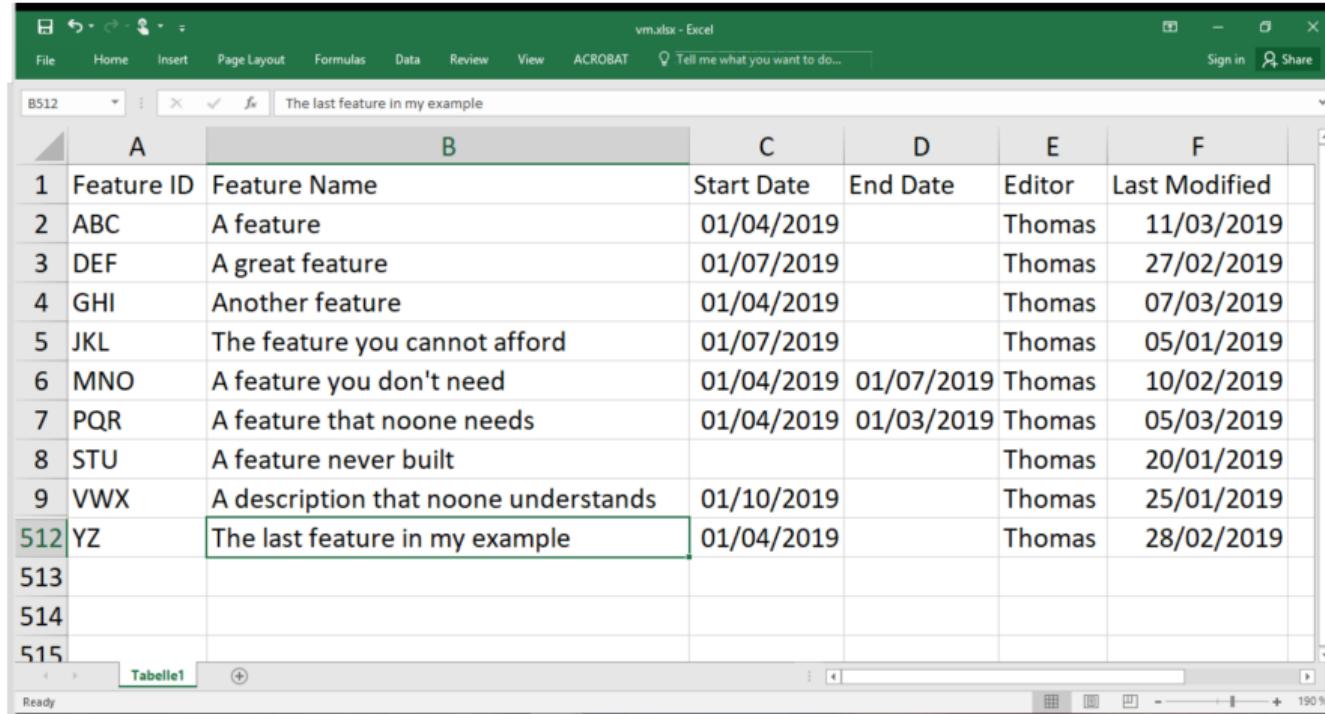


- Thousands of features and constraints, increases over time
- No modularity or information hiding
- Temporal elements
- Typically not modeled with feature models

One Product Line Specified with Different "Languages"



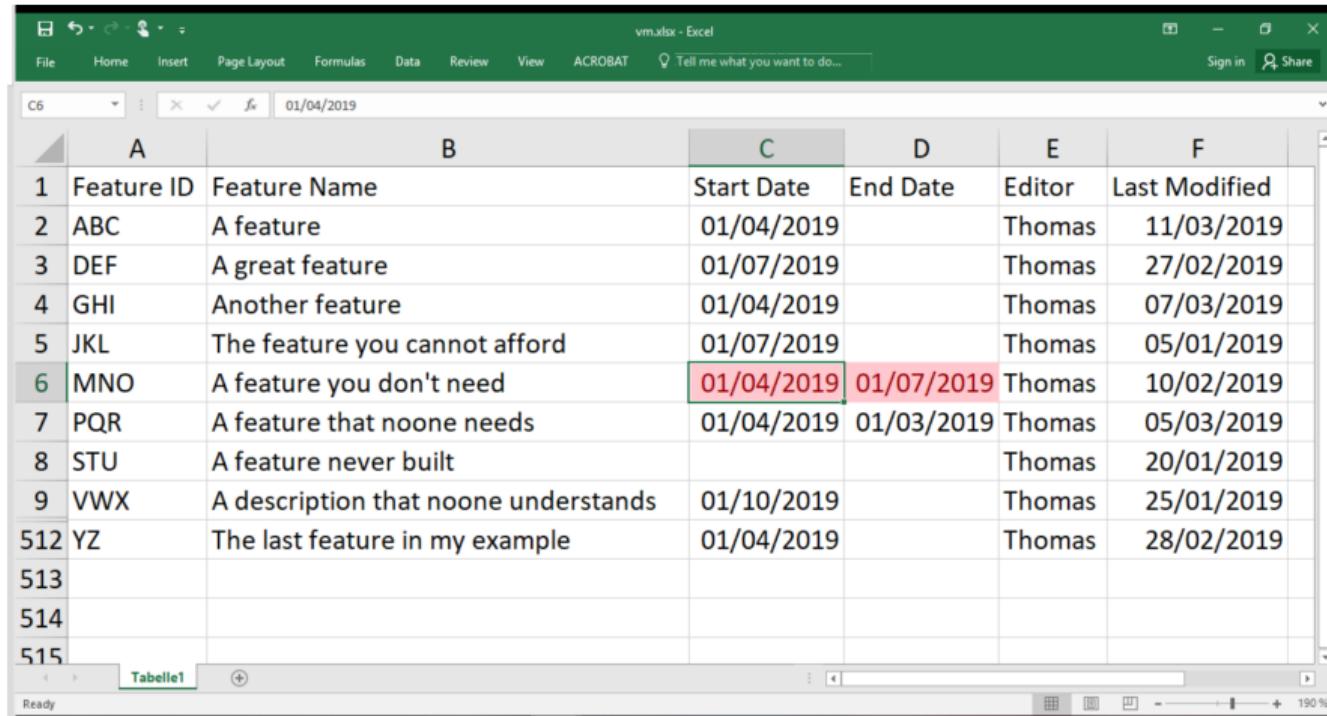
Variability Modeling par Excellence



The screenshot shows a Microsoft Excel spreadsheet titled "vm.xlsx - Excel". The table has columns labeled A through F. Column A contains row numbers from 1 to 15. Column B contains feature names, and column C contains start dates. Columns D, E, and F contain end dates, editors, and last modified dates respectively. Row 15 is highlighted in green and contains the text "The last feature in my example".

	A	B	C	D	E	F
1	Feature ID	Feature Name	Start Date	End Date	Editor	Last Modified
2	ABC	A feature	01/04/2019		Thomas	11/03/2019
3	DEF	A great feature	01/07/2019		Thomas	27/02/2019
4	GHI	Another feature	01/04/2019		Thomas	07/03/2019
5	JKL	The feature you cannot afford	01/07/2019		Thomas	05/01/2019
6	MNO	A feature you don't need	01/04/2019	01/07/2019	Thomas	10/02/2019
7	PQR	A feature that noone needs	01/04/2019	01/03/2019	Thomas	05/03/2019
8	STU	A feature never built			Thomas	20/01/2019
9	VWX	A description that noone understands	01/10/2019		Thomas	25/01/2019
512	YZ	The last feature in my example	01/04/2019		Thomas	28/02/2019
513						
514						
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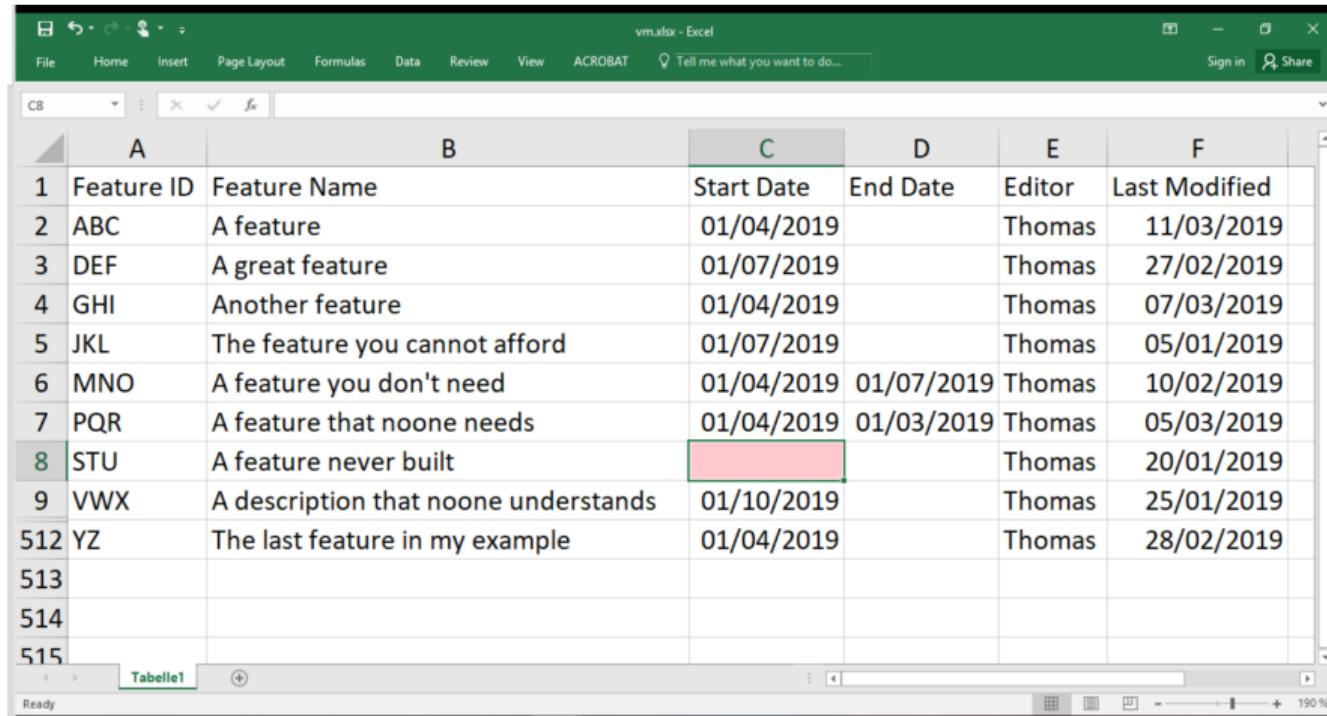
Variability Modeling par Excellence



The screenshot shows a Microsoft Excel spreadsheet titled "vm.xlsx - Excel". The table has columns A through F. Column A contains Feature IDs (e.g., 1, ABC, DEF, GHI, JKL, MNO, PQR, STU, VWX, YZ). Column B contains Feature Names. Columns C and D represent dates: Start Date and End Date. Column E lists Editors, and Column F lists Last Modified dates. Row 6 is highlighted with a green background.

	A	B	C	D	E	F
1	Feature ID	Feature Name	Start Date	End Date	Editor	Last Modified
2	ABC	A feature	01/04/2019		Thomas	11/03/2019
3	DEF	A great feature	01/07/2019		Thomas	27/02/2019
4	GHI	Another feature	01/04/2019		Thomas	07/03/2019
5	JKL	The feature you cannot afford	01/07/2019		Thomas	05/01/2019
6	MNO	A feature you don't need	01/04/2019	01/07/2019	Thomas	10/02/2019
7	PQR	A feature that noone needs	01/04/2019	01/03/2019	Thomas	05/03/2019
8	STU	A feature never built			Thomas	20/01/2019
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512	YZ	The last feature in my example	01/04/2019		Thomas	28/02/2019
513						
514						
515						

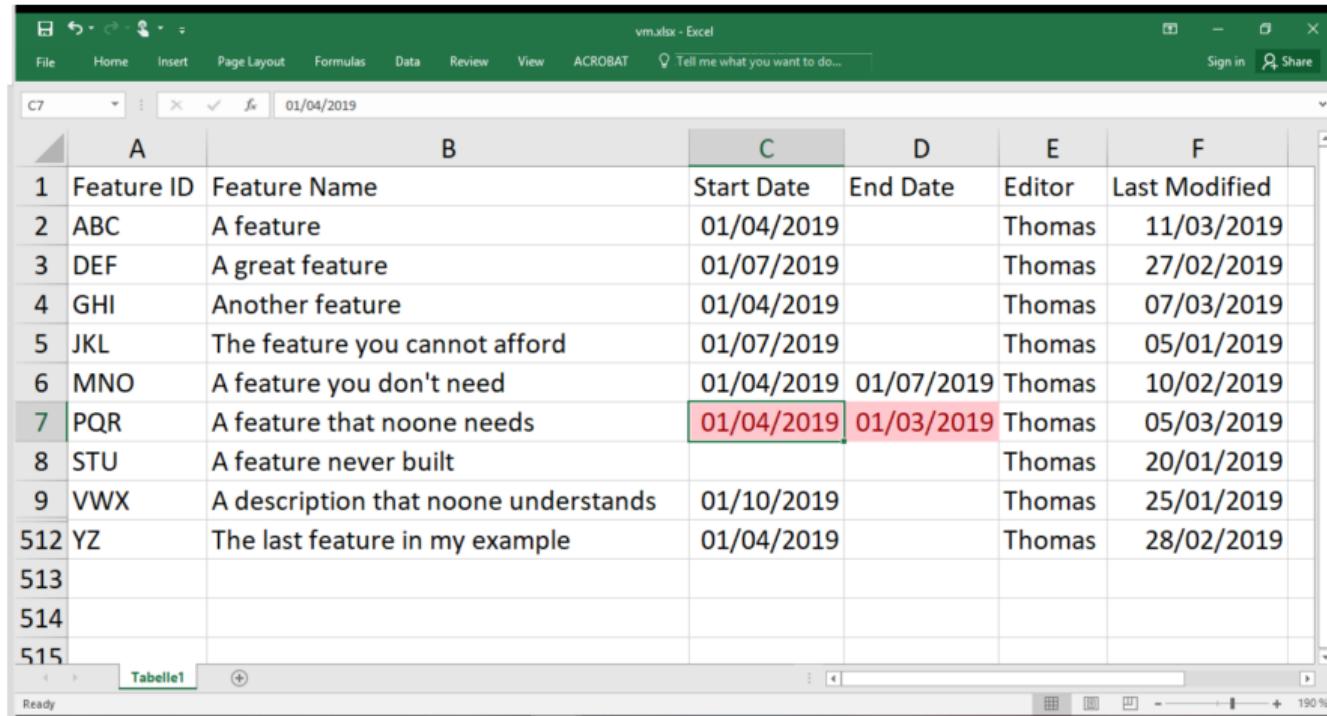
Variability Modeling par Excellence



The screenshot shows a Microsoft Excel spreadsheet titled "vm.xlsx - Excel". The table has columns labeled A, B, C, D, E, and F. Column A contains Feature IDs (1 through 515). Column B contains Feature Names. Column C contains Start Dates. Column D contains End Dates. Column E contains Editors. Column F contains Last Modified dates. Row 8 is highlighted with a pink background.

	A	B	C	D	E	F
1	Feature ID	Feature Name	Start Date	End Date	Editor	Last Modified
2	ABC	A feature	01/04/2019		Thomas	11/03/2019
3	DEF	A great feature	01/07/2019		Thomas	27/02/2019
4	GHI	Another feature	01/04/2019		Thomas	07/03/2019
5	JKL	The feature you cannot afford	01/07/2019		Thomas	05/01/2019
6	MNO	A feature you don't need	01/04/2019	01/07/2019	Thomas	10/02/2019
7	PQR	A feature that noone needs	01/04/2019	01/03/2019	Thomas	05/03/2019
8	STU	A feature never built			Thomas	20/01/2019
9	VWX	A description that noone understands	01/10/2019		Thomas	25/01/2019
512	YZ	The last feature in my example	01/04/2019		Thomas	28/02/2019
513						
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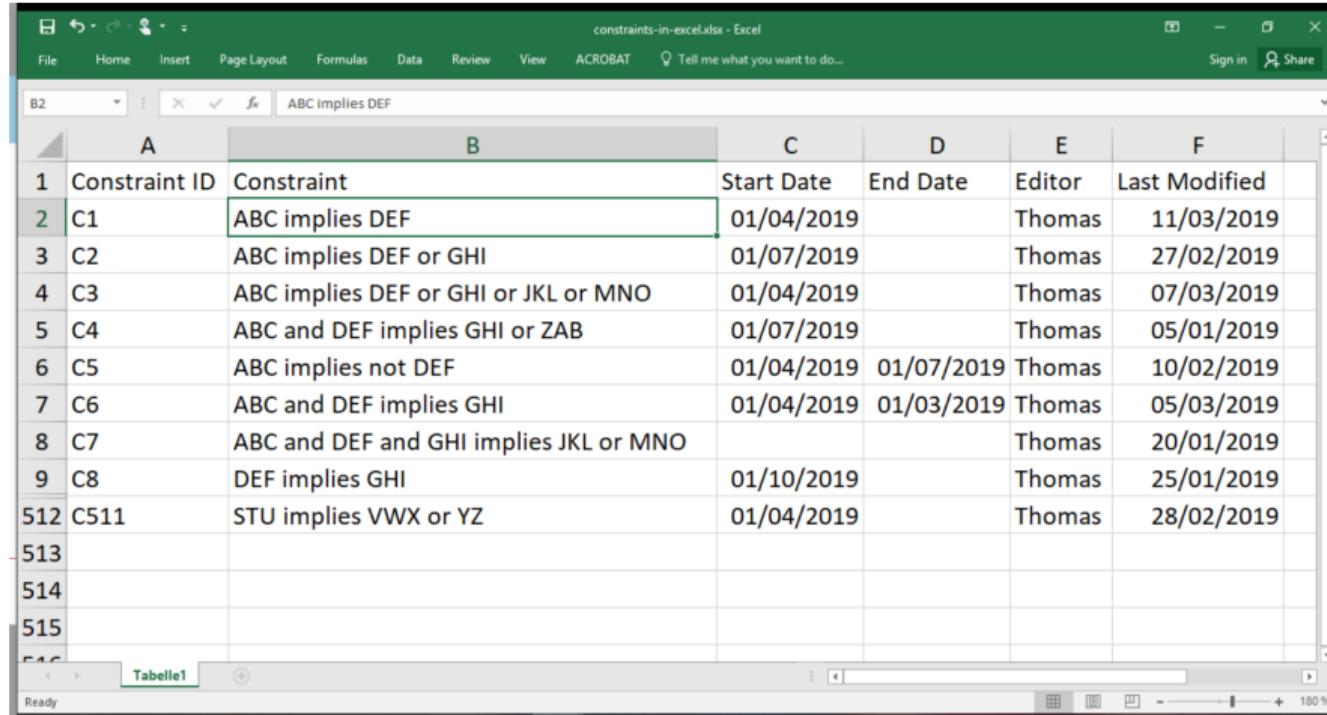
Variability Modeling par Excellence



The screenshot shows an Excel spreadsheet with the following data:

	A	B	C	D	E	F
1	Feature ID	Feature Name	Start Date	End Date	Editor	Last Modified
2	ABC	A feature	01/04/2019		Thomas	11/03/2019
3	DEF	A great feature	01/07/2019		Thomas	27/02/2019
4	GHI	Another feature	01/04/2019		Thomas	07/03/2019
5	JKL	The feature you cannot afford	01/07/2019		Thomas	05/01/2019
6	MNO	A feature you don't need	01/04/2019	01/07/2019	Thomas	10/02/2019
7	PQR	A feature that noone needs	01/04/2019	01/03/2019	Thomas	05/03/2019
8	STU	A feature never built			Thomas	20/01/2019
9	VWX	A description that noone understands	01/10/2019		Thomas	25/01/2019
512	YZ	The last feature in my example	01/04/2019		Thomas	28/02/2019
513						
514						
515						

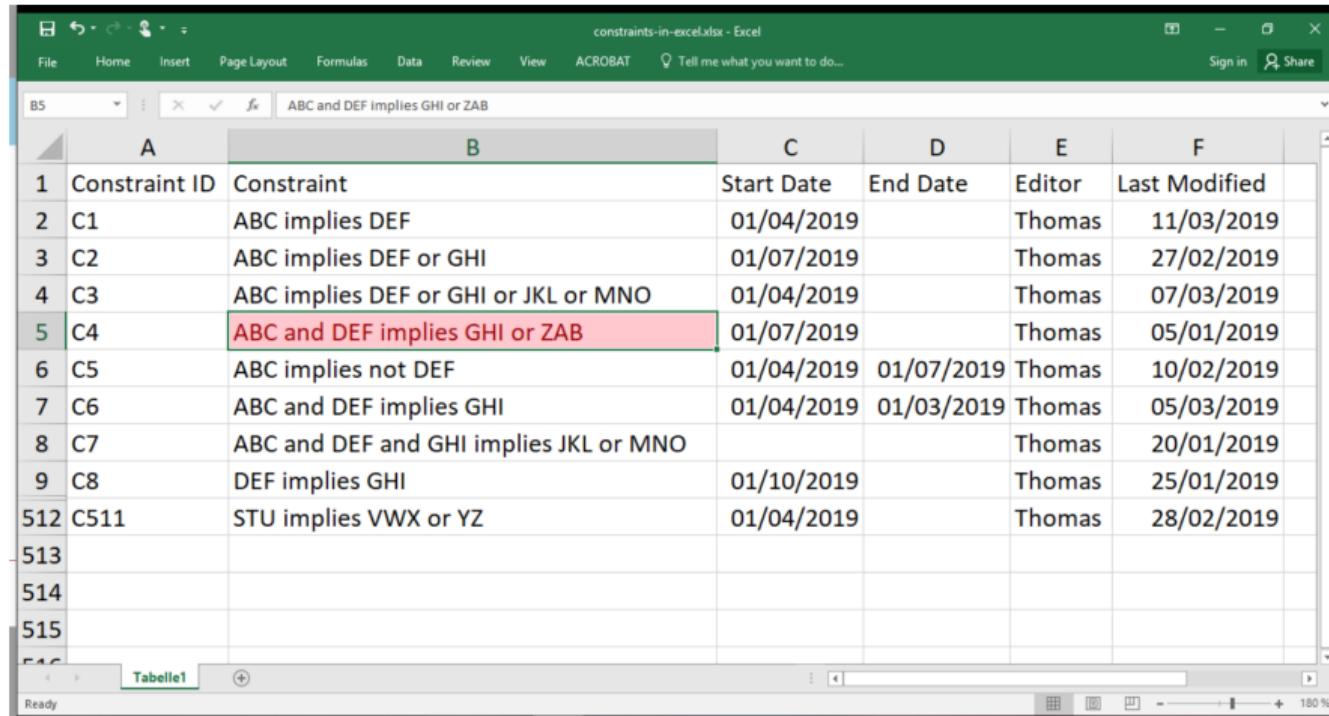
Variability Modeling par Excellence



The screenshot shows a Microsoft Excel spreadsheet titled "constraints-in-excel.xlsx - Excel". The table has columns labeled A through F. Column A contains constraint IDs, column B contains the constraint descriptions, and columns C through F contain metadata like start date, end date, editor, and last modified date.

	A	B	C	D	E	F
1	Constraint ID	Constraint	Start Date	End Date	Editor	Last Modified
2	C1	ABC implies DEF	01/04/2019		Thomas	11/03/2019
3	C2	ABC implies DEF or GHI	01/07/2019		Thomas	27/02/2019
4	C3	ABC implies DEF or GHI or JKL or MNO	01/04/2019		Thomas	07/03/2019
5	C4	ABC and DEF implies GHI or ZAB	01/07/2019		Thomas	05/01/2019
6	C5	ABC implies not DEF	01/04/2019	01/07/2019	Thomas	10/02/2019
7	C6	ABC and DEF implies GHI	01/04/2019	01/03/2019	Thomas	05/03/2019
8	C7	ABC and DEF and GHI implies JKL or MNO			Thomas	20/01/2019
9	C8	DEF implies GHI	01/10/2019		Thomas	25/01/2019
512	C511	STU implies VWX or YZ	01/04/2019		Thomas	28/02/2019
513						
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515						
516						

Variability Modeling par Excellence



	A	B	C	D	E	F
1	Constraint ID	Constraint	Start Date	End Date	Editor	Last Modified
2	C1	ABC implies DEF	01/04/2019		Thomas	11/03/2019
3	C2	ABC implies DEF or GHI	01/07/2019		Thomas	27/02/2019
4	C3	ABC implies DEF or GHI or JKL or MNO	01/04/2019		Thomas	07/03/2019
5	C4	ABC and DEF implies GHI or ZAB	01/07/2019		Thomas	05/01/2019
6	C5	ABC implies not DEF	01/04/2019	01/07/2019	Thomas	10/02/2019
7	C6	ABC and DEF implies GHI	01/04/2019	01/03/2019	Thomas	05/03/2019
8	C7	ABC and DEF and GHI implies JKL or MNO			Thomas	20/01/2019
9	C8	DEF implies GHI	01/10/2019		Thomas	25/01/2019
512	C511	STU implies VWX or YZ	01/04/2019		Thomas	28/02/2019
513						
514						
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516						

Clone-and-Own of Variability Models

The screenshot shows a Microsoft Excel spreadsheet titled "Variability - Feature". The data is organized into columns: Feature ID, Feature Name, Start Date, End Date, Editor, and Last Modified. The rows contain various feature entries, such as ABC, DEF, GHI, JKL, MNO, PQR, STU, VWX, and YZ. The cell containing "YZ" is highlighted in green, indicating it is the last feature in the example.

Feature ID	Feature Name	Start Date	End Date	Editor	Last Modified
1	ABC	01/04/2019		Thomas	11/03/2019
2	DEF	01/07/2019		Thomas	27/02/2019
3	GHI	01/04/2019		Thomas	07/03/2019
4	JKL	01/07/2019		Thomas	05/01/2019
5	MNO	01/04/2019	01/07/2019	Thomas	10/02/2019
6	PQR	01/04/2019	01/03/2019	Thomas	05/03/2019
7	STU	A feature never built		Thomas	20/01/2019
8	VWX	A description that noone understands	01/10/2019	Thomas	25/01/2019
9	YZ	The last feature in my example	01/04/2019	Thomas	28/02/2019

The screenshot shows a Microsoft Excel spreadsheet titled "Variability - Constraint". The data is organized into columns: Constraint ID, Constraint, Start Date, End Date, Editor, and Last Modified. The rows contain various constraint entries, such as C1 through C8, and C511. The cell containing "YZ" is highlighted in green, indicating it is the last constraint in the example.

Constraint ID	Constraint	Start Date	End Date	Editor	Last Modified	
1	C1	ABC Implies DEF	01/04/2019	Thomas	11/03/2019	
2	C2	ABC implies DEF or GHI	01/07/2019	Thomas	27/02/2019	
3	C3	ABC implies DEF or GHI or JKL or MNO	01/04/2019	Thomas	07/03/2019	
4	C4	ABC and DEF implies GHI or ZAB	03/07/2019	Thomas	05/01/2019	
5	C5	ABC implies not DEF	01/04/2019	01/07/2019	Thomas	10/02/2019
6	C6	ABC and DEF implies GHI	01/04/2019	01/03/2019	Thomas	05/03/2019
7	C7	ABC and DEF and GHI implies JKL or MNO		Thomas	20/01/2019	
8	C8	DEF implies GHI	01/10/2019	Thomas	25/01/2019	
512	C511	STU implies VWX or YZ	01/04/2019	Thomas	28/02/2019	

Thomas Thüm | On Language Levels for Feature Modeling Notations | Slide 12

Clone-and-Own of Variability Models

The screenshot shows a Microsoft Excel spreadsheet titled "variability - Best". The table has columns A through F. Row 1 contains the headers: Feature ID, Feature Name, Start Date, End Date, Editor, and Last Modified. Rows 2 through 9 contain data entries. Row 12 is highlighted in green and contains the text "The last feature in my example".

A	B	C	D	E	F
1	Feature ID	Feature Name	Start Date	End Date	Editor
2	ABC	A feature	01/04/2019		Thomas
3	DEF	A great feature	01/07/2019		Thomas
4	GHI	Another feature	01/04/2019		Thomas
5	JKL	The feature you cannot afford	01/07/2019		Thomas
6	MNO	A feature you don't need	01/04/2019	01/07/2019	Thomas
7	PQR	A feature that noone needs	01/04/2019	01/03/2019	Thomas
8	STU	A feature never built			Thomas
9	VWX	A description that noone understands	01/10/2019		Thomas
512	YZ	The last feature in my example	01/04/2019		Thomas
513					
514					
515					

The screenshot shows a Microsoft Excel spreadsheet titled "variability - Best". The table has columns A through F. Row 1 contains the headers: Feature ID, Feature Name, Start Date, End Date, Editor, and Last Modified. Rows 2 through 9 contain data entries. Row 12 is highlighted in green and contains the text "The last feature in my example".

A	B	C	D	E	F
1	Feature ID	Feature Name	Start Date	End Date	Editor
2	ABC	A feature	01/04/2019		Thomas
3	DEF	A great feature	01/07/2019		Thomas
4	GHI	Another feature	01/04/2019		Thomas
5	The feature you cannot afford	01/07/2019		Thomas	
6	MNO	A feature you don't need	01/04/2019	01/07/2019	Thomas
7	PQR	A feature that noone needs	01/04/2019	01/03/2019	Thomas
8	STU	A feature never built			Thomas
9	VWX	A description that noone understands	01/10/2019		Thomas
512	YZ	The last feature in my example	01/04/2019		Thomas
513					
514					
515					

The screenshot shows a Microsoft Excel spreadsheet titled "constraints-in-excelate - Best". The table has columns A through F. Row 1 contains the headers: Constraint ID, Constraint, Start Date, End Date, Editor, and Last Modified. Rows 2 through 9 contain data entries. Row 12 is highlighted in green and contains the text "ABC implies DEF".

A	B	C	D	E	F
1	Constraint ID	Constraint	Start Date	End Date	Editor
2	C1	ABC implies DEF	01/04/2019		Thomas
3	C2	ABC implies DEF or GHI	01/07/2019		Thomas
4	C3	ABC implies DEF or GHI or JKL or MNO	01/04/2019		Thomas
5	C4	ABC and DEF implies GHI or ZAB	01/07/2019		Thomas
6	C5	ABC implies not DEF	01/04/2019	01/07/2019	Thomas
7	C6	ABC and DEF implies GHI	01/04/2019	01/03/2019	Thomas
8	C7	ABC and DEF and GHI implies JKL or MNO			Thomas
9	C8	DEF implies GHI	01/10/2019		Thomas
512	C511	STU implies VWX or YZ	01/04/2019		Thomas
513					
514					
515					

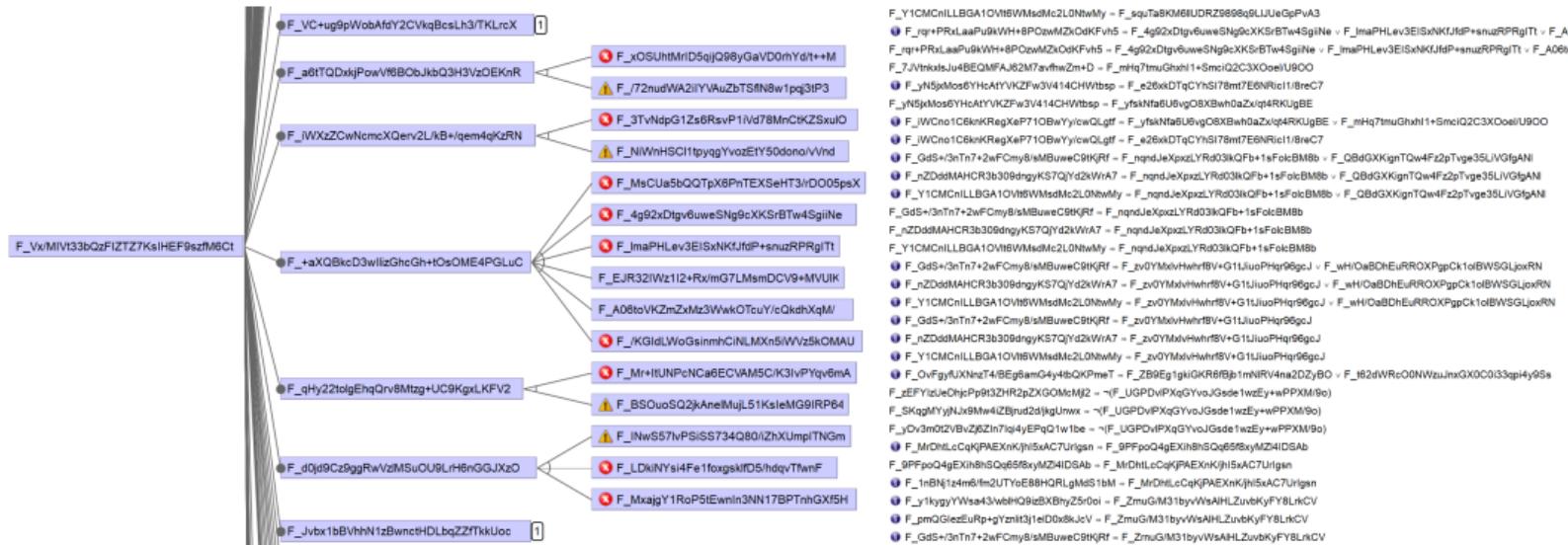
The screenshot shows a Microsoft Excel spreadsheet titled "constraints-in-excelate - Best". The table has columns A through F. Row 1 contains the headers: Constraint ID, Constraint, Start Date, End Date, Editor, and Last Modified. Rows 2 through 9 contain data entries. Row 12 is highlighted in green and contains the text "ABC implies DEF".

A	B	C	D	E	F
1	Constraint ID	Constraint	Start Date	End Date	Editor
2	C1	ABC implies DEF	01/04/2019		Thomas
3	C2	ABC implies DEF or GHI	01/07/2019		Thomas
4	C3	ABC implies DEF or GHI or JKL or MNO	01/04/2019		Thomas
5	C4	ABC and DEF implies GHI or ZAB	01/07/2019		Thomas
6	C5	ABC implies not DEF	01/04/2019	01/07/2019	Thomas
7	C6	ABC and DEF implies GHI	01/04/2019	01/03/2019	Thomas
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513					
514					
515					

Anomalies in Variability Models

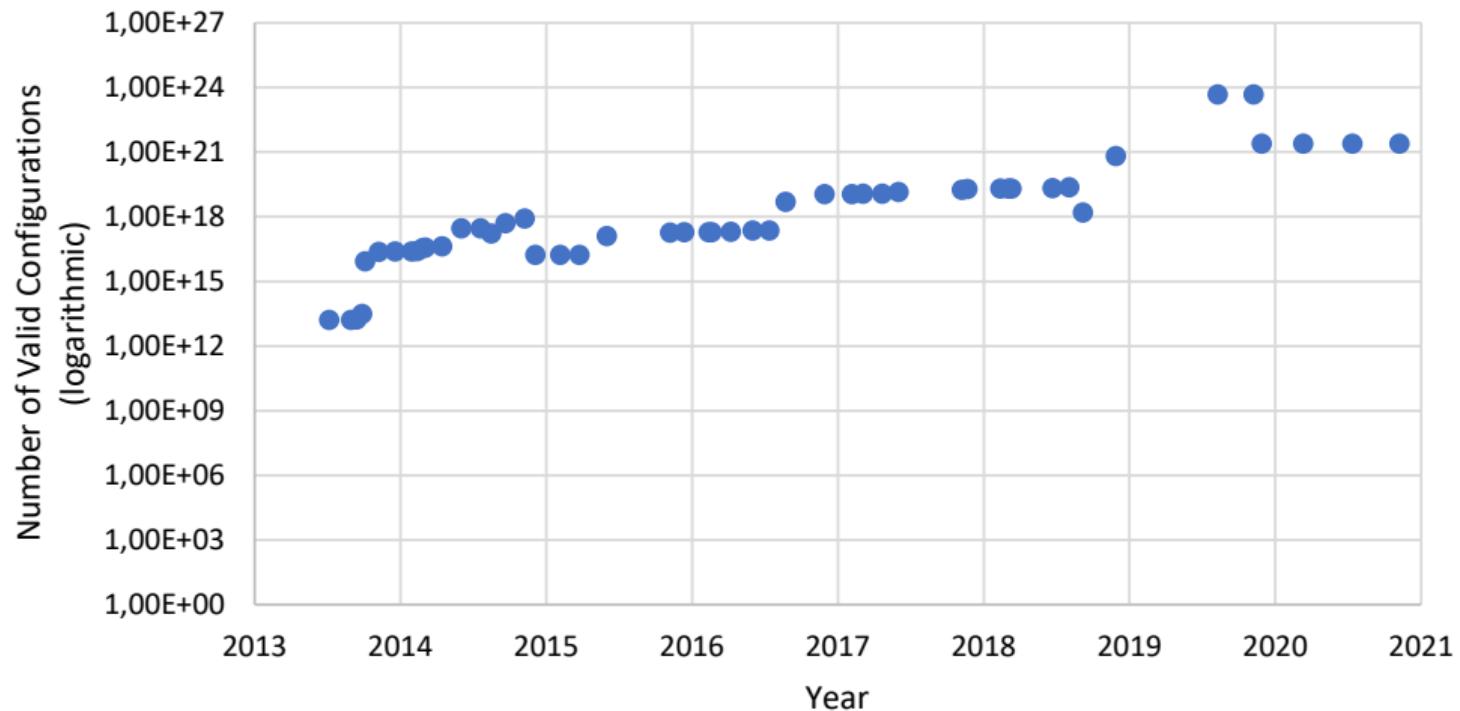


Anomalies in Variability Models



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Configuration Spaces Tend to Grow Over Time

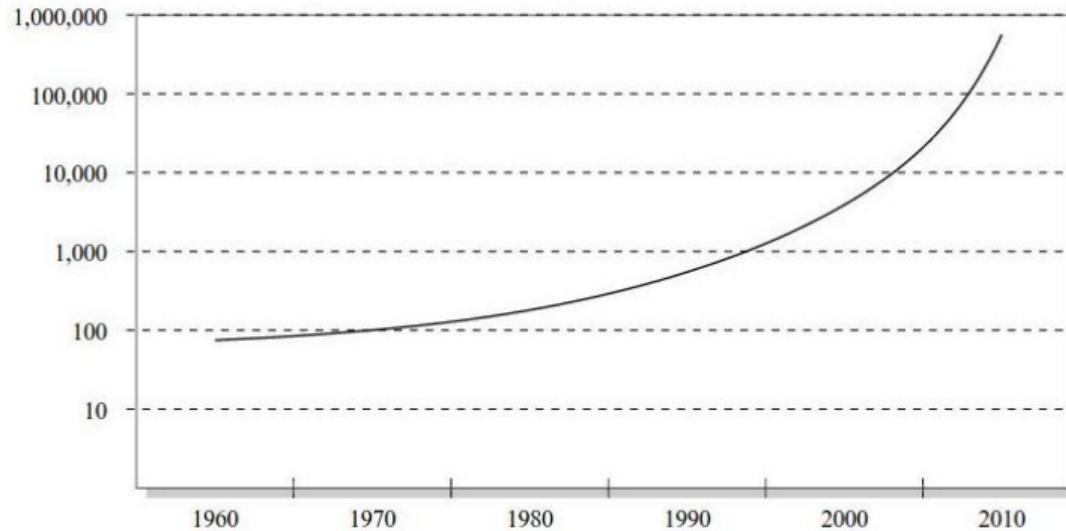


Part III

Criteria for Language Design

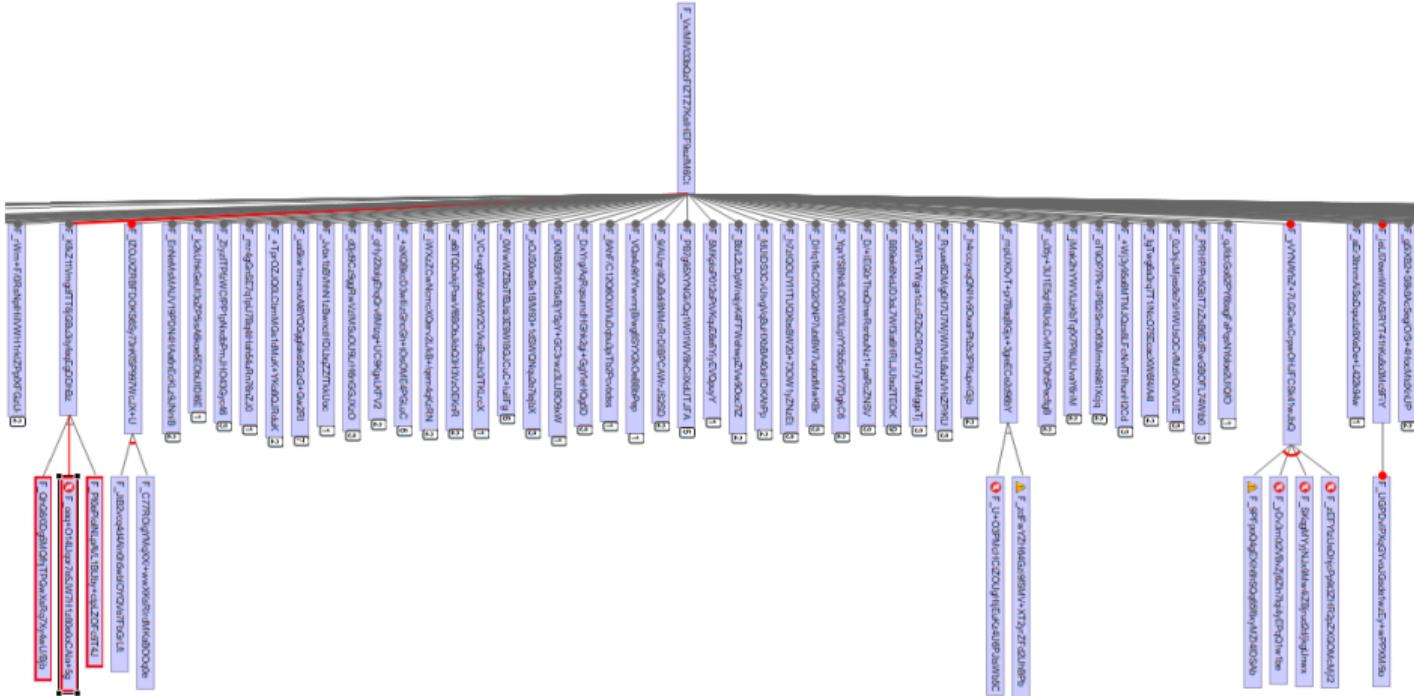


Why to Use SAT Solvers for Variability Analysis?



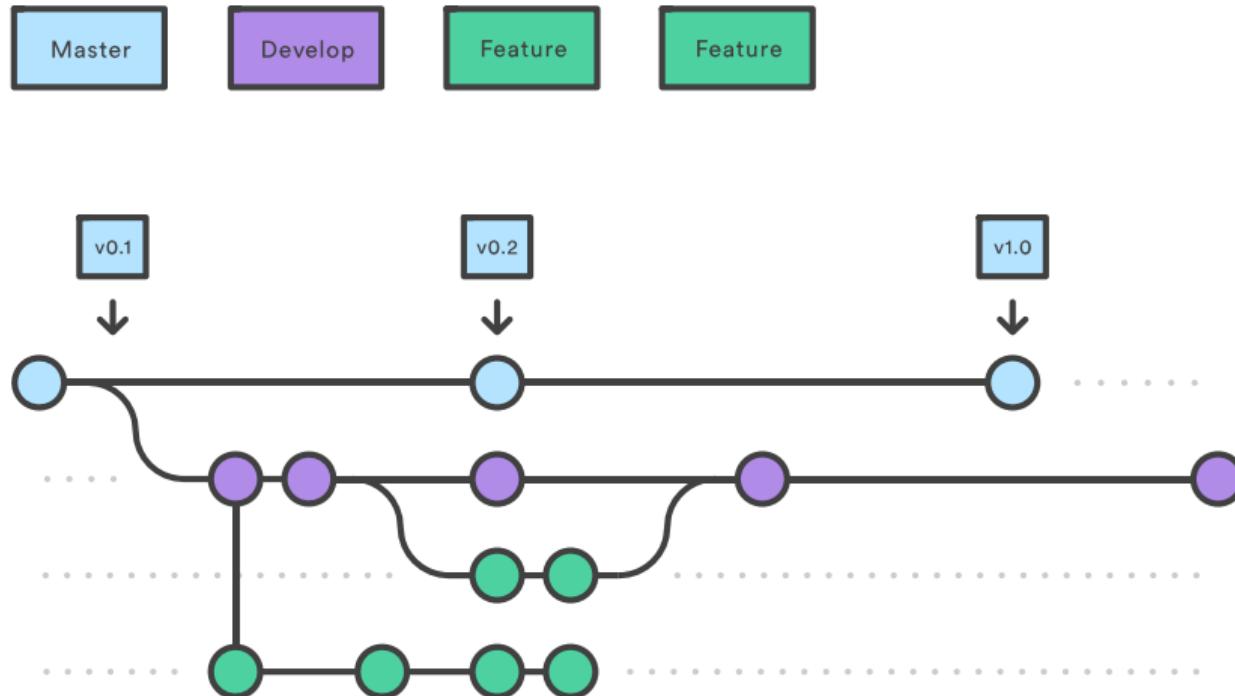
number of variables of a typical, practical SAT instance
that can be solved by the best solvers in that decade

Missing Analyses for Feature Attributes



Thomas Thüm | On Language Levels for Feature Modeling Notations | Slide 17

Industry Demands for Modularity and Branching



Language Levels for Feature Modeling Notations

Major Levels: expressiveness aligns with solver classes

- propositional logic: SAT, binary decision diagram (BDD), #SAT, ...
- first-order logic: satisfiable modulo theory (SMT), constraint satisfaction problem (CSP)?, ...
- more needed? answer set programming (ASP)? pseudo-boolean satisfiability (PB-SAT)? ...

Language Levels for Feature Modeling Notations

Major Levels: expressiveness aligns with solver classes

- propositional logic: SAT, binary decision diagram (BDD), #SAT, ...
- first-order logic: satisfiable modulo theory (SMT), constraint satisfaction problem (CSP)?, ...
- more needed? answer set programming (ASP)? pseudo-boolean satisfiability (PB-SAT)? ...

Minor Levels: differing expressiveness within major levels

- align with expressiveness of state-of-the-art languages
- meet requirements from typical application domains
- example: supported tree and cross-tree constraints

Language Levels for Feature Modeling Notations

Major Levels: expressiveness aligns with solver classes

- propositional logic: SAT, binary decision diagram (BDD), #SAT, ...
- first-order logic: satisfiable modulo theory (SMT), constraint satisfaction problem (CSP)?, ...
- more needed? answer set programming (ASP)? pseudo-boolean satisfiability (PB-SAT)? ...

Minor Levels: differing expressiveness within major levels

- align with expressiveness of state-of-the-art languages
- meet requirements from typical application domains
- example: supported tree and cross-tree constraints

Orthogonal Levels: independent of expressiveness

- Modularity with feature-model interfaces or slicing
- Feature versions and temporal validity with hyper and temporal feature models

Part I

- The Situation 110 Years Ago: Ford Model T
- Today: Every Second Car has a Unique Configuration
- Constraints Among Features are Challenging
- Variability Models as Central Knowledge Database

Part II

- **Real-World Variability Modeling**
- **One Product Line Specified with Different "Languages"**
- **Variability Modeling par Excellence**
- **Clone-and-Own of Variability Models**
- **Anomalies in Variability Models**
- **Configuration Spaces Tend to Grow Over Time**

Part III

- Why to Use SAT Solvers for Variability Analysis?
- Missing Analyses for Feature Attributes
- Industry Demands for Modularity and Branching
- Language Levels for Feature Modeling Notations

On Language Levels for Feature Modeling Notations

Part I

Part II

Part III