VITAL: Variability Improvement Analysis of Software Product Line Infrastructure

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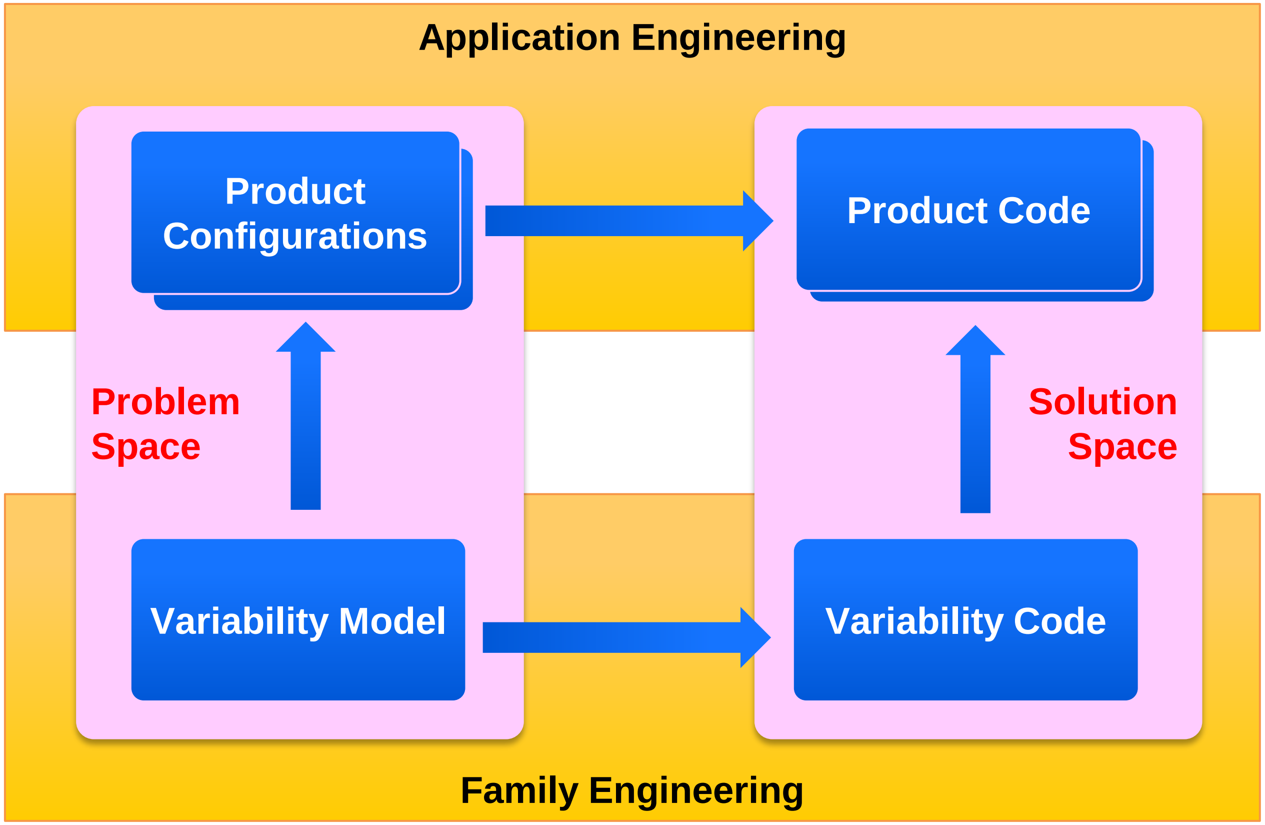
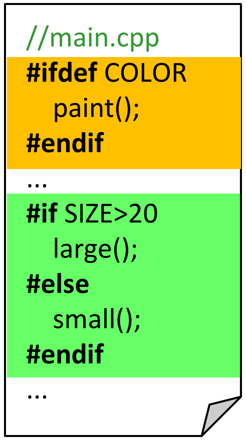
Context

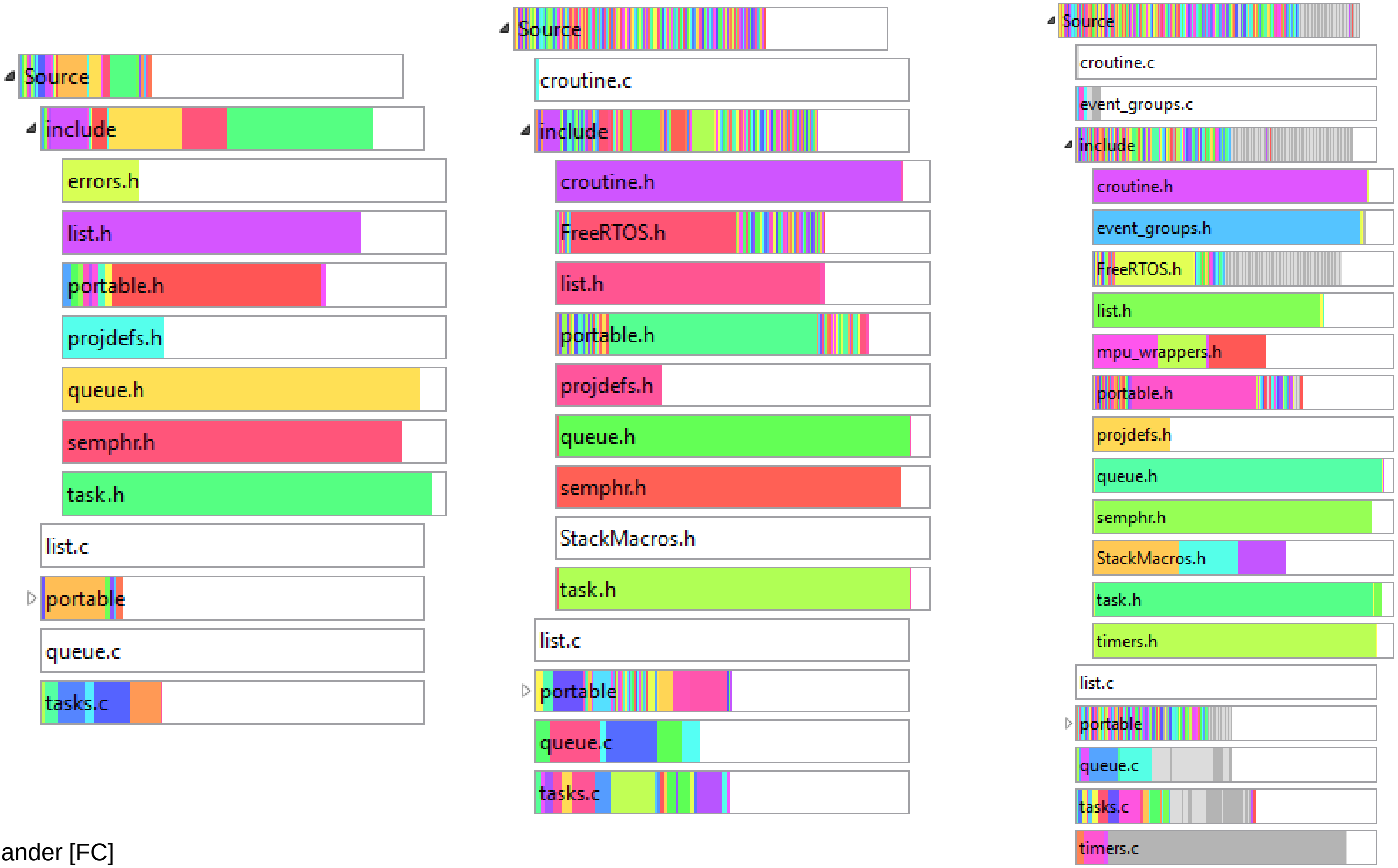

Application Engineering
Product Configurations
Product Code
Problem Space
Solution Space
Variability Model
Variability Code
Family Engineering

An Example of Product Line Evolution

FreeRTOS	v2.4 (2004.07)	v5.2 (2009.03)	v8.0 (2014.02)
# Vars	21	156	296
# VPs	52	503	1088
Var Code Size	627 LOC	3480 LOC	9461 LOC
# Var Files	19	108	172



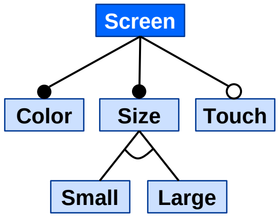
```
//main.cpp
#ifdef COLOR
   paint();
#endif
...
#if SIZE>20
   large();
#else
   small();
#endif
...
```



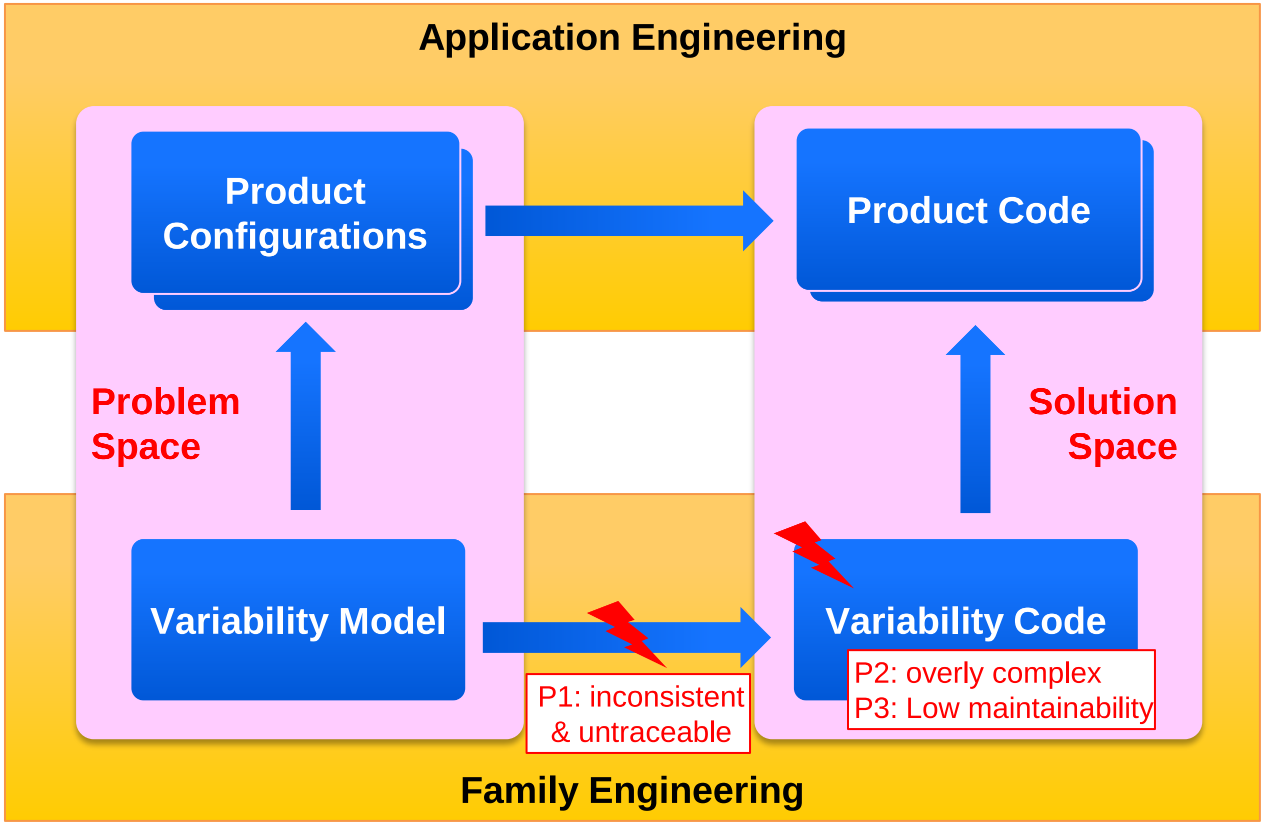
visualized by Feature Commander [FC]

Problem

- variability code erosion
  - ❖ Variability code becomes hard to understand and maintain



Feature model


Application Engineering

Product Configurations

Product Code

Problem Space

Solution Space

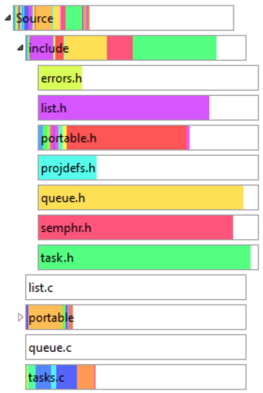
Variability Model

Variability Code

P1: inconsistent & untraceable

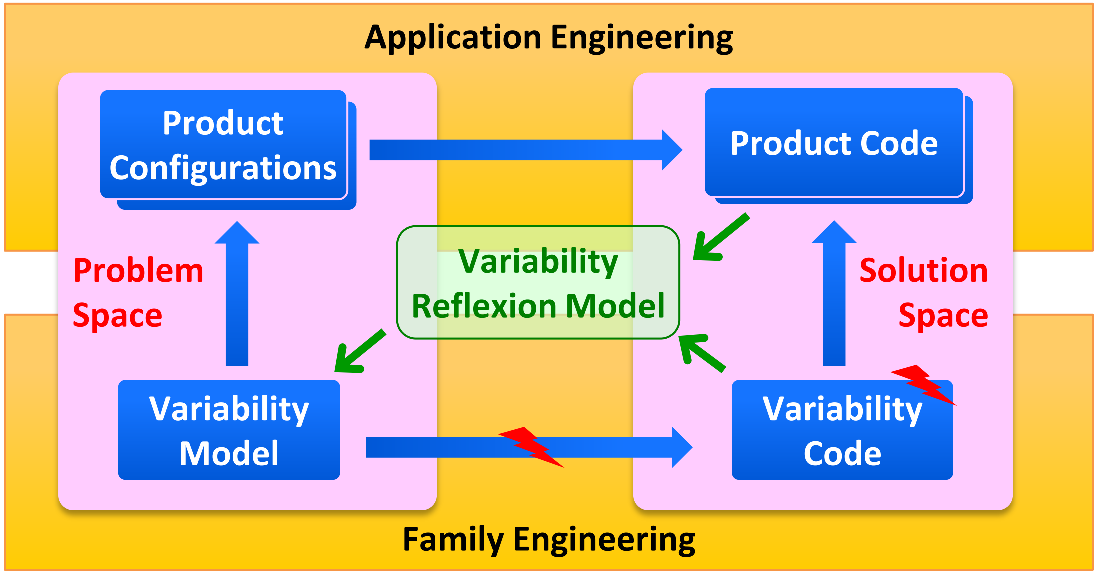
P2: overly complex
P3: Low maintainability

Family Engineering



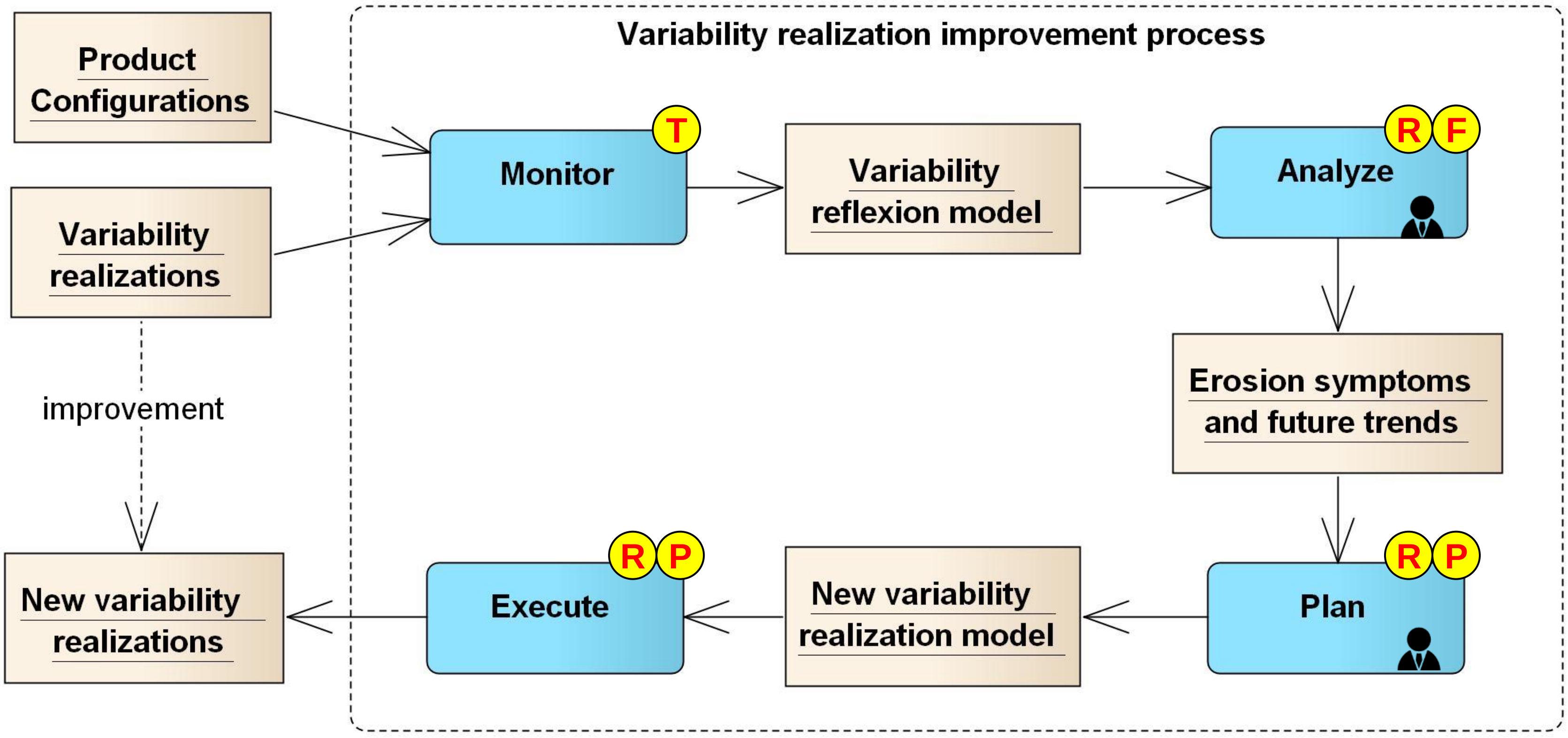
Solution Idea

- VITAL: Variability Improvement Analysis
  - Automated extraction of variability reflexion model
    - Analyzing C Preprocessor Code
    - Extracting variability code elements and their interdependencies
  - Identifying variability code erosion symptoms
  - Further countermeasures against variability code erosion



Variability Realization Improvement Process

Main contribution in **Monitor** and **Analyze**



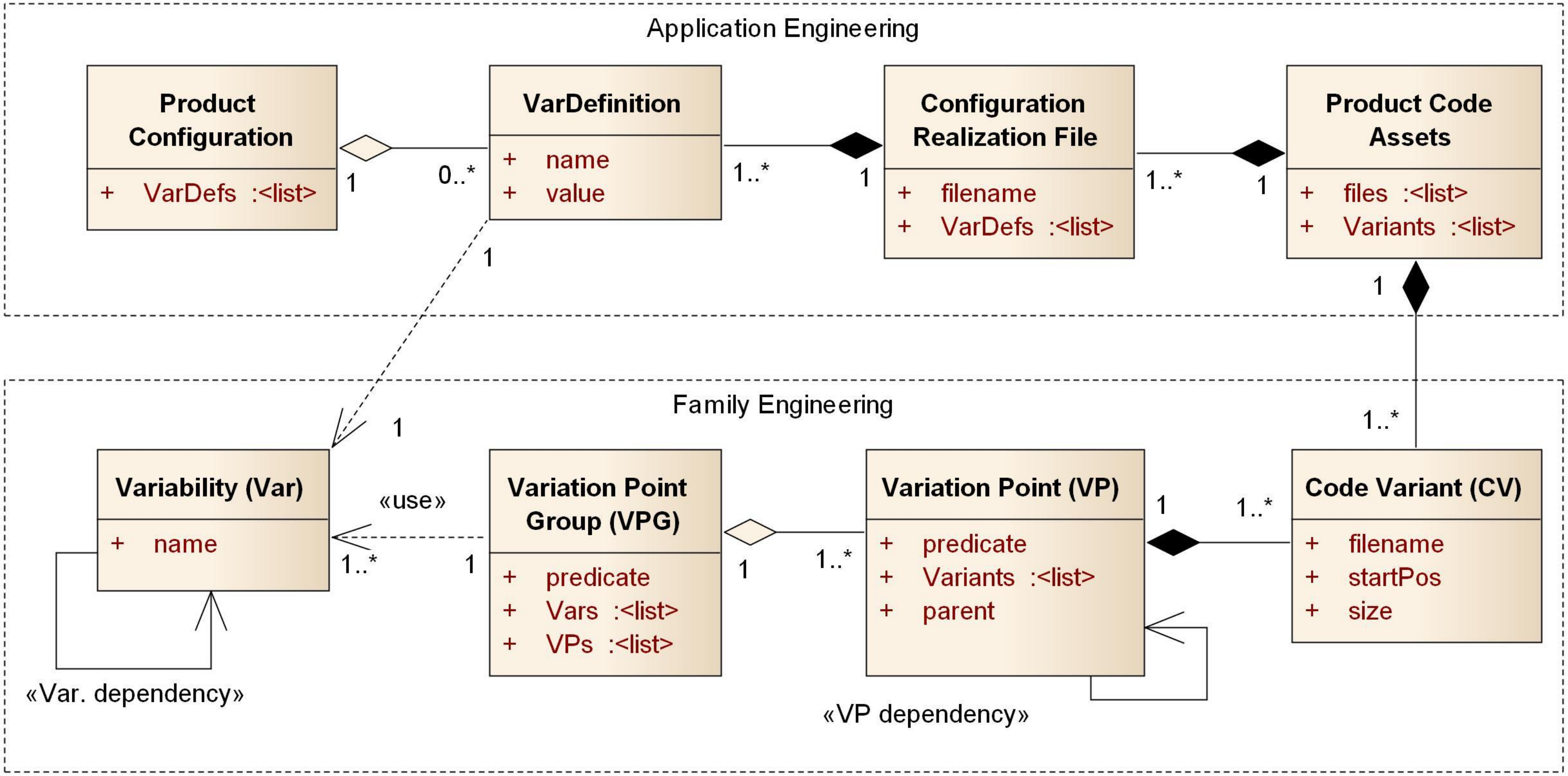
Variability realization improvement process
Product Configurations
Variability realizations
improvement
New variability realizations
Monitor
T
Variability reflexion model
Analyze
R
F
Erosion symptoms and future trends
Plan
R
P
New variability realization model
Execute
R
P

Legend: T Tolerance R Removal F Forecasting P Prevention 👤 domain experts

Challenges	Tactics	Description	Type
Current erosion	**Tolerance**	To understand (eroded) variability realizations without changing anything.	analytical
	Removal	To identify and fix eroded elements in existing variability realizations.	reactive
Future erosion	**Forecasting**	To predict future erosion trend and their likely consequences.	analytical
	Prevention	To avoid erosion in future variability realizations.	proactive

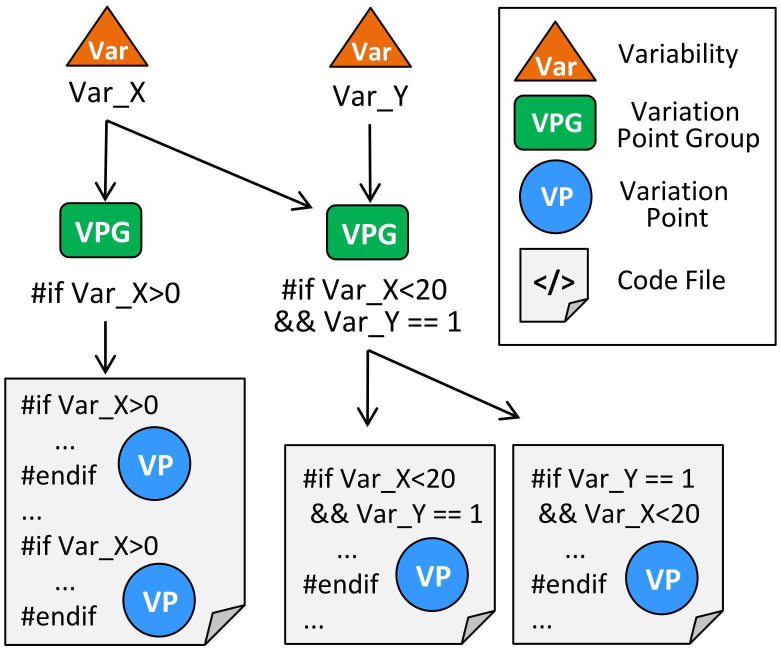
Monitor

- Extracting Variability Reflexion Model



Core of Variability Reflexion Model

- Variability Code Elements
  - Variability (Var)
    - representing a variable feature
  - Variation Point (VP)
    - including Code Variants (CV)
  - **Variation Point Group (VPG)** new
    - a group of VPs with equivalent logic for selecting CVs
    - Mapping problem space and solution space

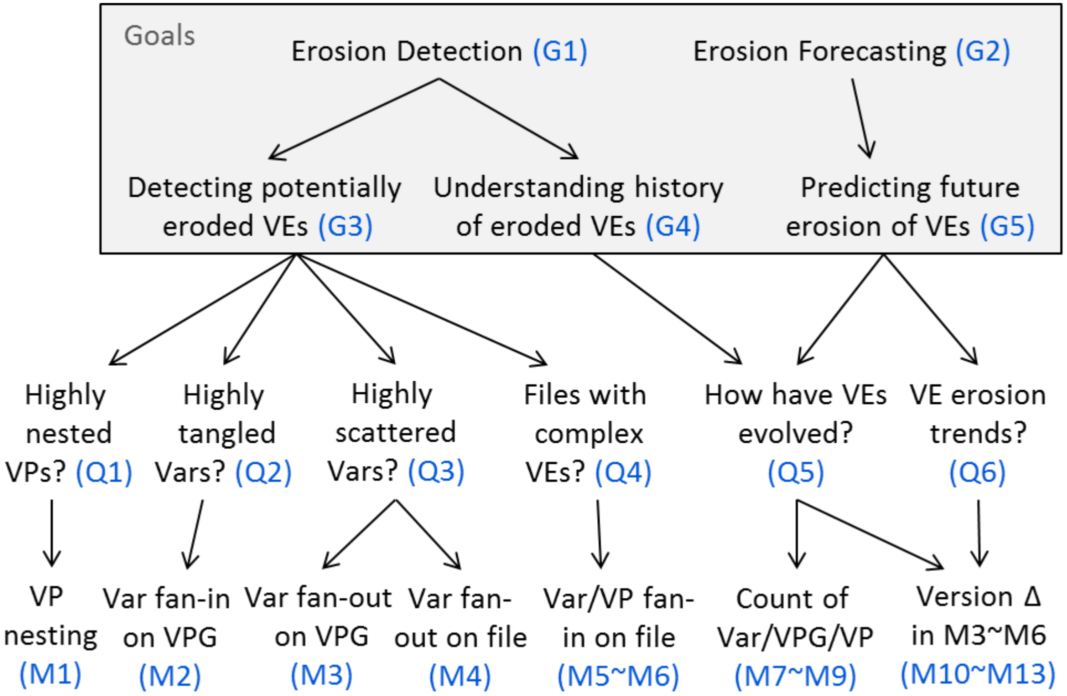


Variability Code using Conditional Compilation

Analyze

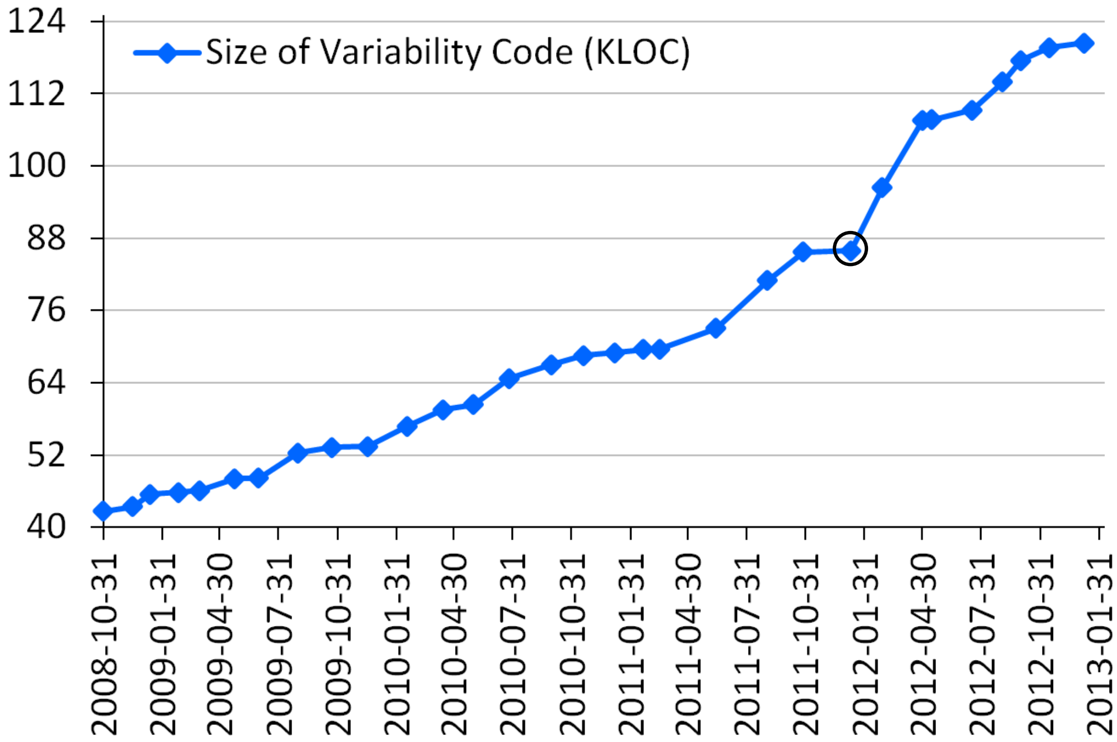
- Erosion Detection and Forecasting

Top-level Goals	Object	Purpose	Focus	Stakeholder	Context
Goal 1	Variability code erosion	Detect	Eroded elements	Product line code maintainer	Variability code using Conditional Compilation
Goal 2		Forecast	Erosion Trends		


Goals
Erosion Detection (G1)
Erosion Forecasting (G2)
Detecting potentially eroded VEs (G3)
Understanding history of eroded VEs (G4)
Predicting future erosion of VEs (G5)
Highly nested VPs? (Q1)
Highly tangled Vars? (Q2)
Highly scattered Vars? (Q3)
Files with complex VEs? (Q4)
How have VEs evolved? (Q5)
VE erosion trends? (Q6)
VP nesting (M1)
Var fan-in on VPG (M2)
Var fan-out on VPG (M3)
Var fan-out on file (M4)
Var/VP fan-in on file (M5~M6)
Count of Var/VPG/VP (M7~M9)
Version Δ in M3~M6 (M10~M13)

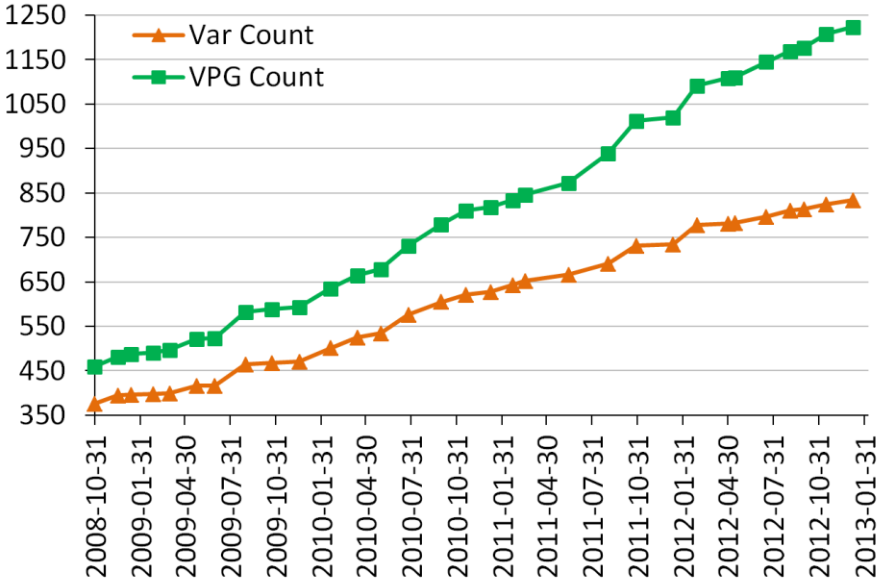
An Industrial Case Study of Erosion Detection and Forecasting [SPLC'13]

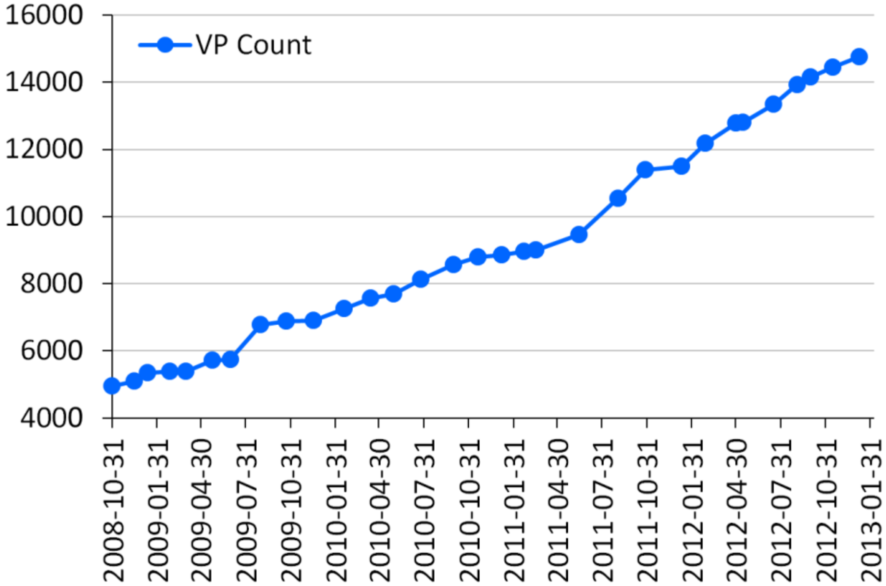
- Danfoss SPL: 31 versions along 4 years
  - Feature modeling was introduced from 2012.01
  - Some automatically generated files are excluded since they are not maintained manually



An Industrial Case Study of Erosion Detection and Forecasting [SPLC'13]

- The last release contains
  - 834 Vars
  - 1223 VPGs
  - 13969 VPs
  - 1322 variability-related files





An Industrial Case Study of Erosion Detection and Forecasting [SPLC'13]

- Detected Erosion Symptoms
  - VP nesting
  - Var Tangling
    - Var Fan-in on VPG
  - Var scattering
    - Var Fan-out on VPG
    - Var Fan-out on File
  - Complex files
    - Var Fan-in on File
    - VP Fan-in on File

Nesting Level	1	2	3	4	5
VP Count	7988	5082	833	64	2

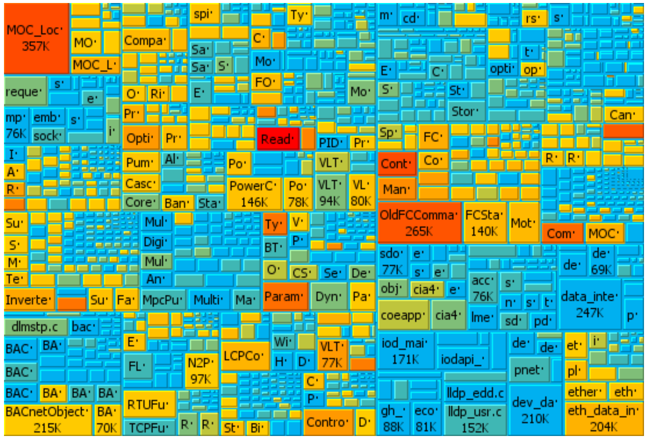
Var Fan-in on VPG	1	2	3	4	7	11
VPG Count	1010	185	22	4	1	1

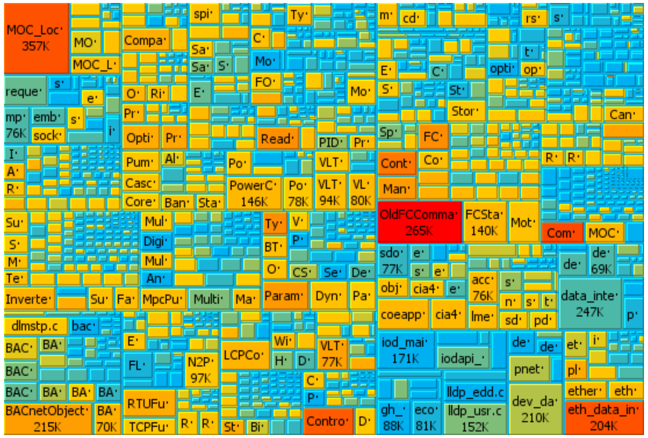
Var Fan-out on VPG	1	2	3~5	6~9	13~18
Variability Count	548	188	70	23	5

Var Fan-out on Files	1	2	3~10	11~46	54~144
Variability Count	247	191	278	105	13

Var Fan-in on File	1	2~3	4~10	11~49	54~118
File Count	679	316	229	89	9

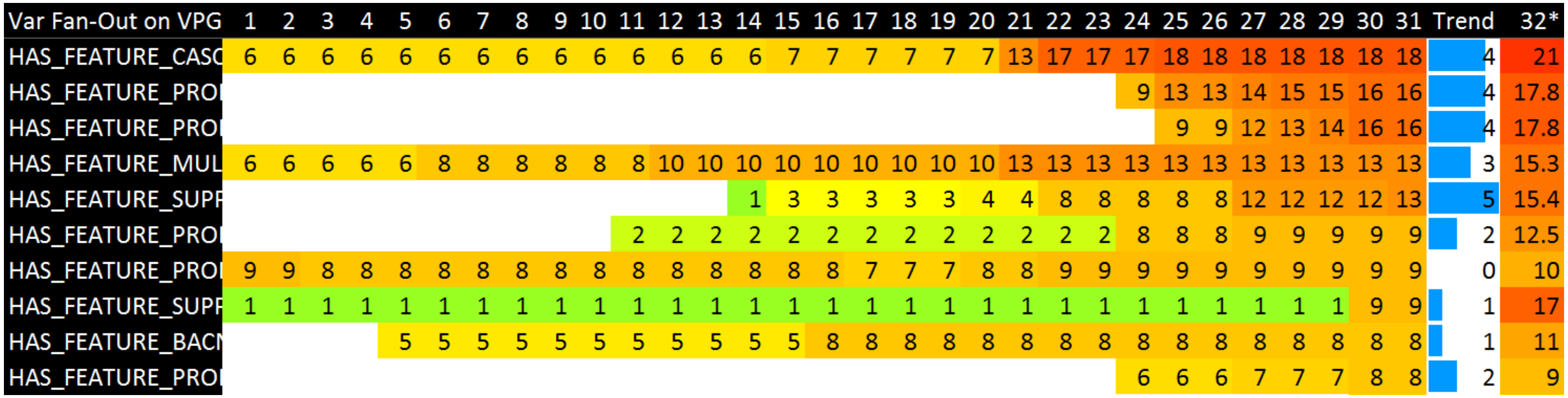
VP Fan-in on File	1	2~3	4~10	11~50	51~407
File Count	385	291	326	273	47





An Industrial Case Study of Erosion Detection and Forecasting [SPLC'13]

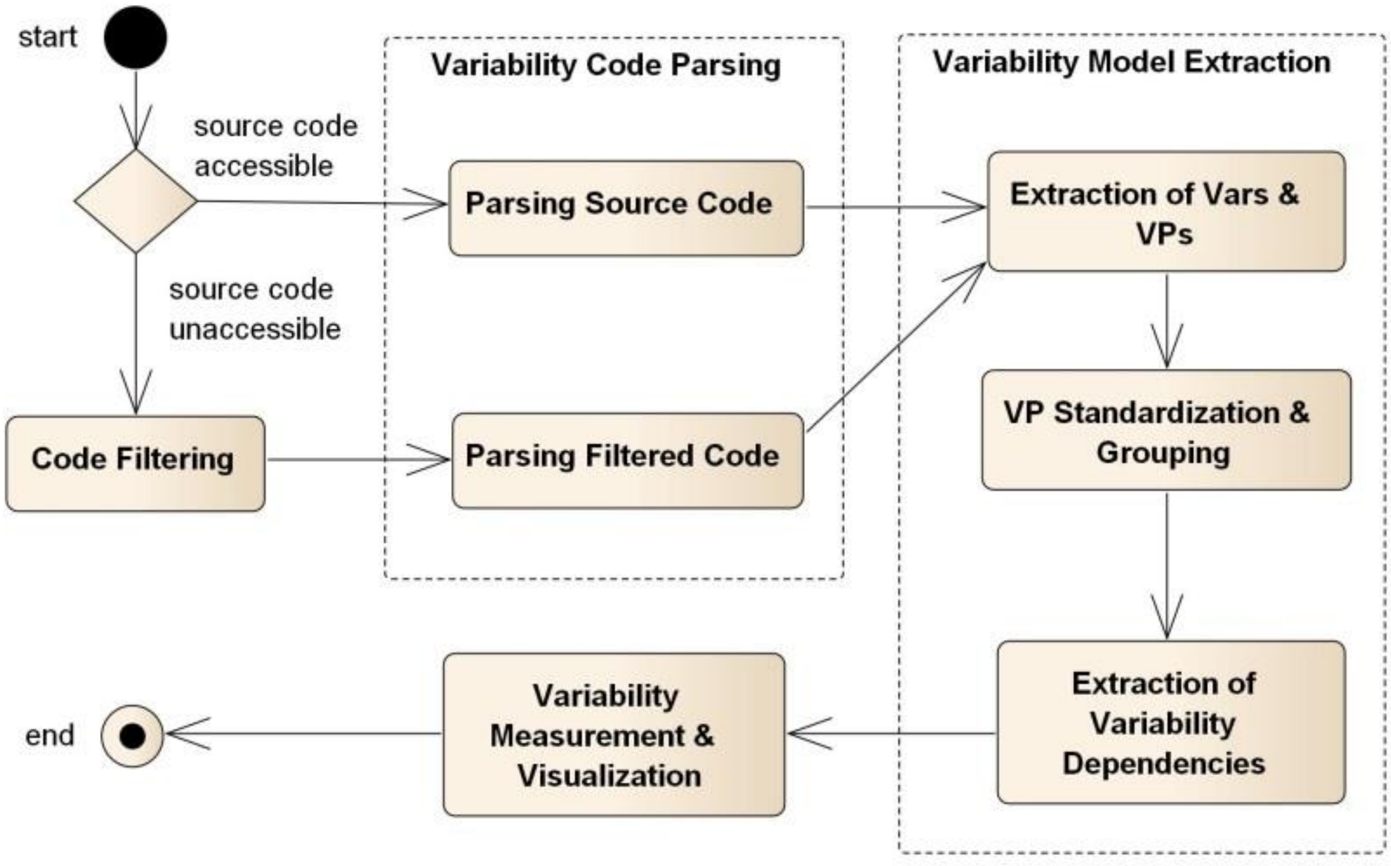
- Erosion Forecasting
  - ❖ e.g., predicting erosion trend of Var scattering on VPGs (Var Fan-Out on VPG)
  - ❖ Trend := #rises - #falls, indicating probability of future increase of Var fan-out on VPG
    - ➢ E.g., trend of 1st Var = count(7-6, 13-7, 17-13, 18-17) - 0 = Count(1, 6, 4, 1) = 4
  - ❖ Predicted value (version 32) := base value (version 31) + Avg(positive Δs)
    - ➢ E.g., predicted value of 1st Var = 18+ Avg(1, 6, 4, 1) = 18+3 = 21



Var Fan-Out on VPG	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Trend	32*
HAS_FEATURE_CASC	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	13	17	17	17	18	18	18	18	18	18	18	4	21
HAS_FEATURE_PRO																								9	13	13	14	15	15	16	16	4	17.8
HAS_FEATURE_PRO																									9	9	12	13	14	16	16	4	17.8
HAS_FEATURE_MUL	6	6	6	6	6	8	8	8	8	8	8	10	10	10	10	10	10	10	10	10	13	13	13	13	13	13	13	13	13	13	13	3	15.3
HAS_FEATURE_SUPP														1	3	3	3	3	3	4	4	8	8	8	8	8	12	12	12	12	13	5	15.4
HAS_FEATURE_PRO											2	2	2	2	2	2	2	2	2	2	2	2	2	8	8	8	9	9	9	9	9	2	12.5
HAS_FEATURE_PRO	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	8	8	9	9	9	9	9	9	9	9	9	9	0	10
HAS_FEATURE_SUPP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9	9	1	17
HAS_FEATURE_BAC					5	5	5	5	5	5	5	5	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	1	11
HAS_FEATURE_PRO																								6	6	6	7	7	7	8	8	2	9

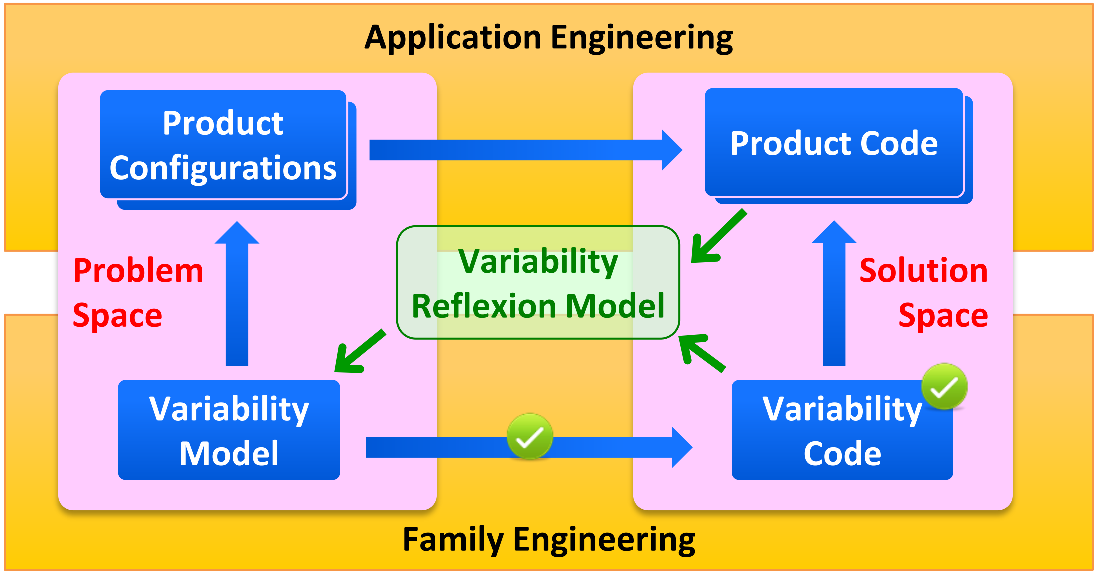
VITAL Tool Support

- For variability realization analysis and improvement



Conclusion

- **VITAL** approach can improve Variability code maintainability
  - Erosion Tolerance: done
    - variability reflexion model extraction
  - Erosion Removal
    - erosion detection done
    - erosion fixing not validated
  - Erosion Forecasting: done
  - Erosion Prevention: not validated



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