[Magdeburger Dom]

Towards Effective and Efficient Feature-Model Analysis of Evolving System Software

SPLC 2025 — September 1–5 — A Coruña, Spain

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University of Magdeburg[1] (TU Braunschweig[2])

Motivation

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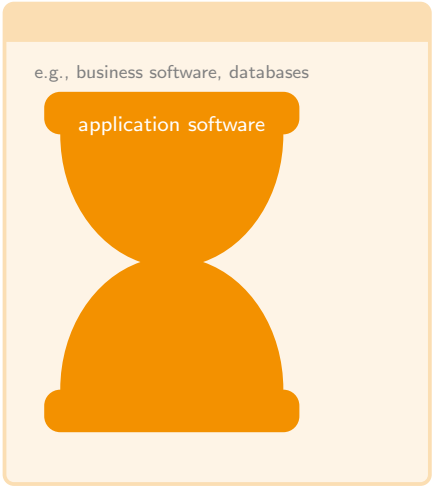
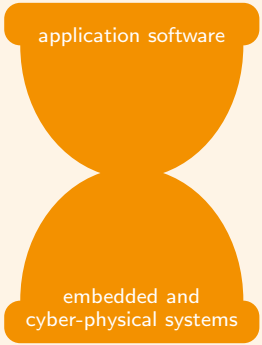


Motivation

e.g., business software, databases



e.g., cars, internet of things

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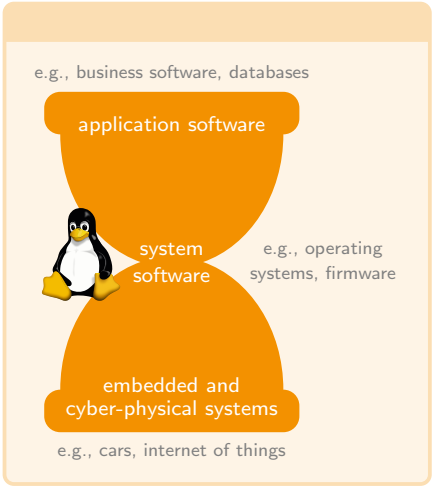
e.g., business software, databases
application software
system software
e.g., operating systems, firmware
embedded and cyber-physical systems
e.g., cars, internet of things

Motivation

Variability in System Software

e.g., business software, databases

application software

system software

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System Software | Safety | Security | Variability

Motivation

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Variability in Space

- **product lines** for mass customization
  (in system software: Linux, BusyBox, . . .)

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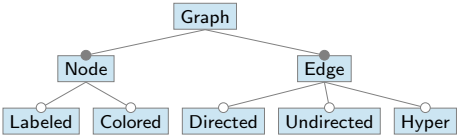
- **feature models** to describe variability
  (in system software: `KConfig` language)

System Software | Safety | Security | Variability

Variability in Space



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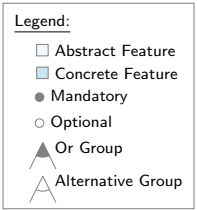

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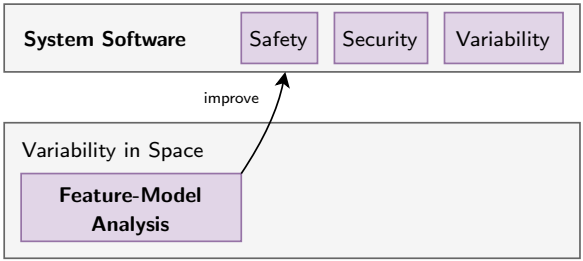
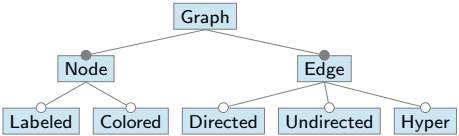
Variability in Space

- **product lines** for mass customization
  (in system software: Linux, BusyBox, . . .)
- **feature models** to describe variability
  (in system software: `KConfig` language)
- **automated analyses** with formulas





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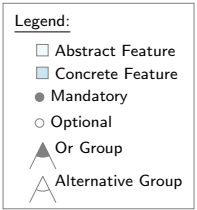

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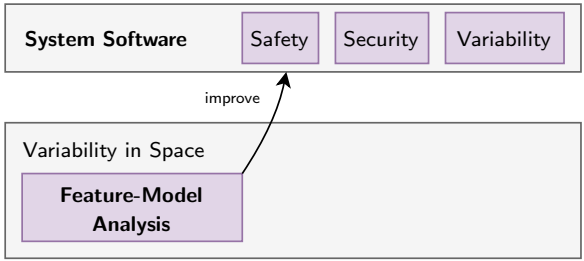
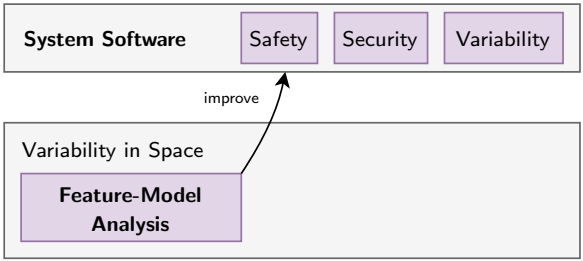

System Software
Safety
Security
Variability
improve
Variability in Space
Feature-Model Analysis

Motivation

Variability in Time

- most software **evolves** over time



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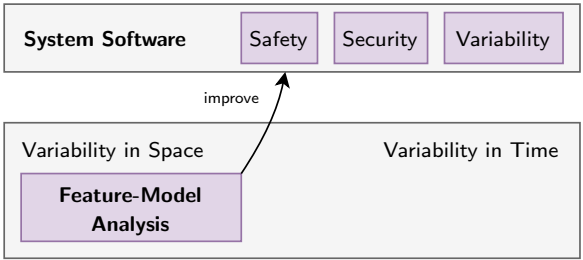
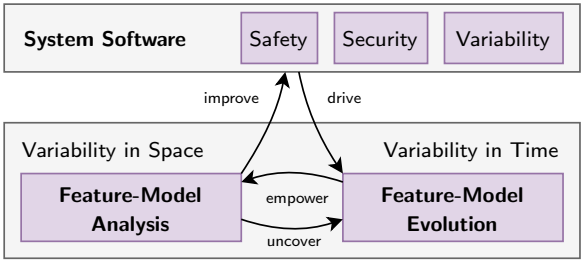
- so do product lines
  (long-term, open histories in system software)



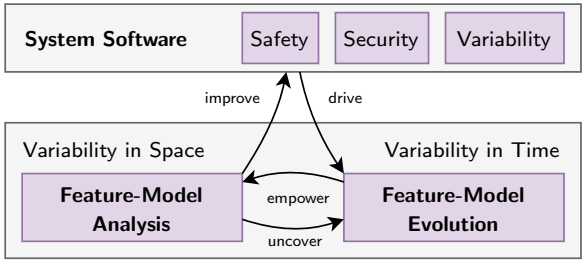
Motivation

Variability in Time

- most software **evolves** over time
- so do product lines
  (long-term, open histories in system software)
- symbiosis: variability in space ⇆ time
  (many field configurations in system software)



Effective and Efficient Feature-Model Analyses for Evolving System Software



Effective and Efficient Feature-Model Analyses for Evolving System Software

Challenge:

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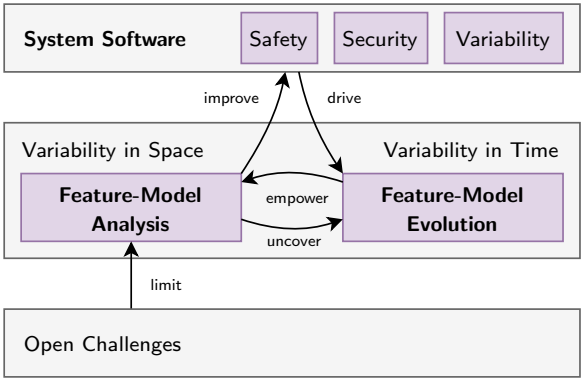

Effective and Efficient Feature-Model Analyses for Evolving System Software

Challenge: Effectiveness

- **mandatory** computation steps

⇒ may impact **correctness** + **accuracy**

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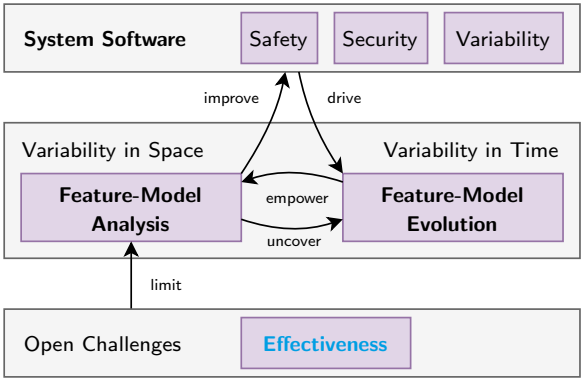

Effective and Efficient Feature-Model Analyses for Evolving System Software

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Challenge: Efficiency

- **large and complex** feature models

⇒ may impact **scalability** + **performance**

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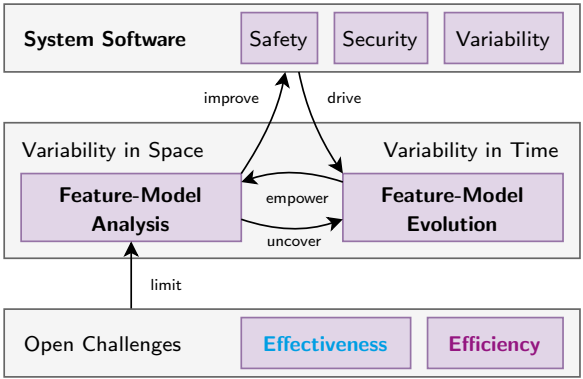

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- **mandatory** computation steps

⇒ may impact **correctness** + **accuracy**

Challenge: Efficiency

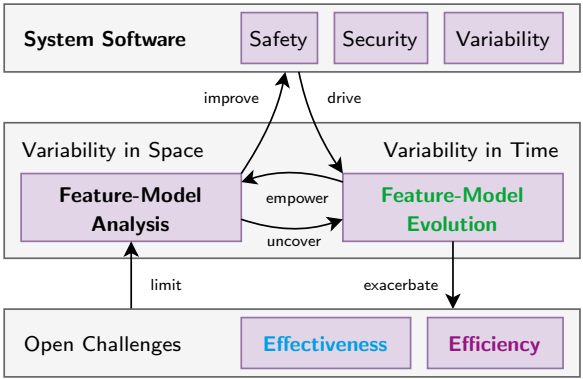
- **large and complex** feature models

⇒ may impact **scalability** + **performance**

Challenge: Evolution

- variability **grows**, languages **evolve**

⇒ may impact **feasibility**



Analysis Pipeline [Kuiter et al. '24, Sundermann et al. '24]

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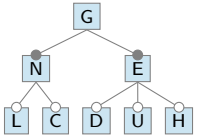
Feature Model



$\neg(D \wedge U)$
$H \rightarrow U$
$D \nLeftrightarrow (U \wedge H)$

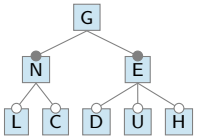
Analysis Pipeline [Kuiter et al. '24, Sundermann et al. '24]

Model

ask

interactive

Feature Model



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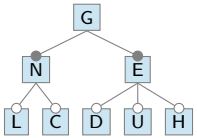
Core Feature F?

#Configurations?

Analysis Pipeline [Kuiter et al. '24, Sundermann et al. '24]

Model → (ask: interactive) • → (extract: automated) • Formula

Feature Model



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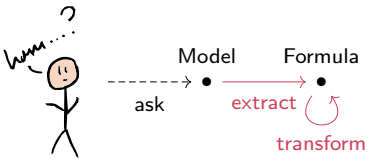
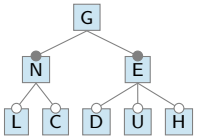


interactive

automated

Feature Model



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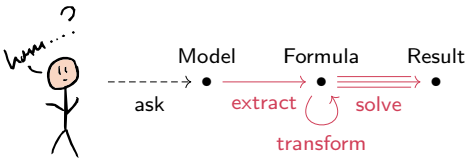

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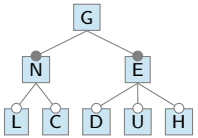

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Core Feature F?

$SAT(\Phi \wedge \neg F)$

Core Features

$\{G, N, E\}$

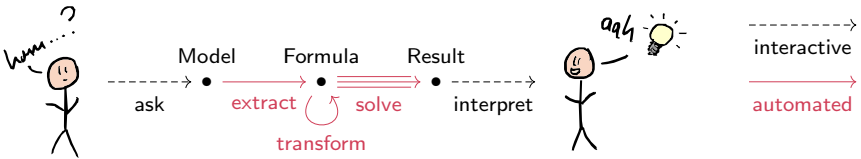
#Configurations?

$\#SAT(\Phi)$

#Configurations

8

Analysis Pipeline [Kuiter et al. '24, Sundermann et al. '24]



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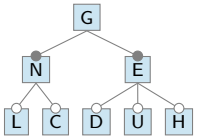

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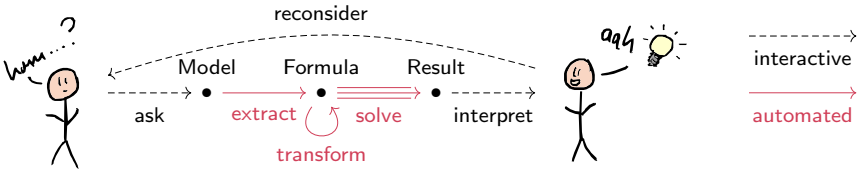

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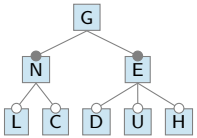

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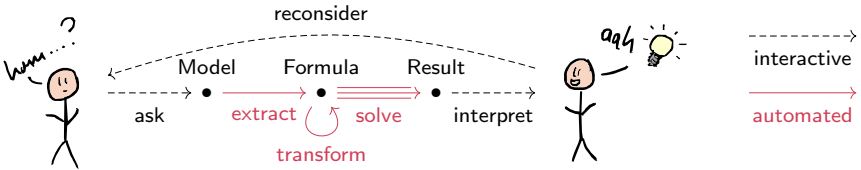

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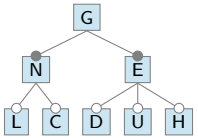

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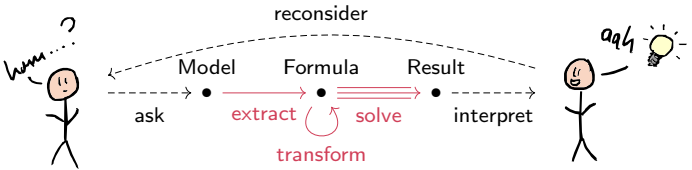
$\Rightarrow$ (#)SAT enables advanced analyses

e.g., core/dead features, sampling, static analysis, verification, ...

Contributions



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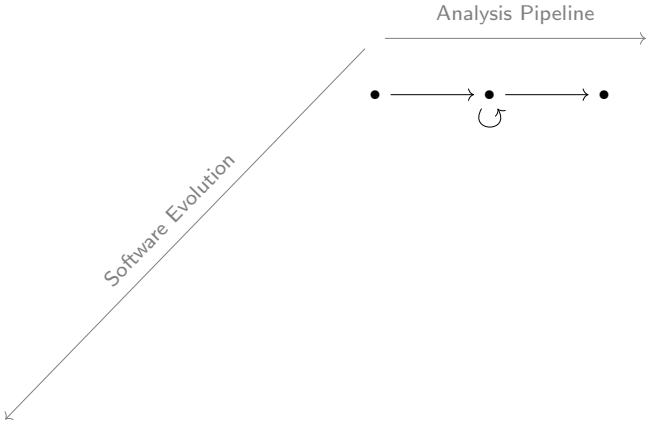

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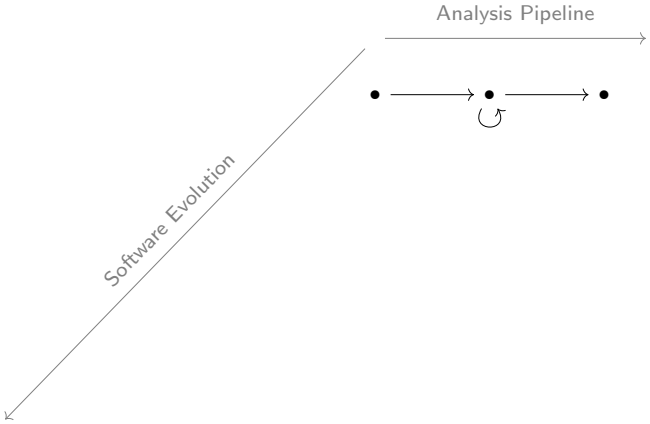
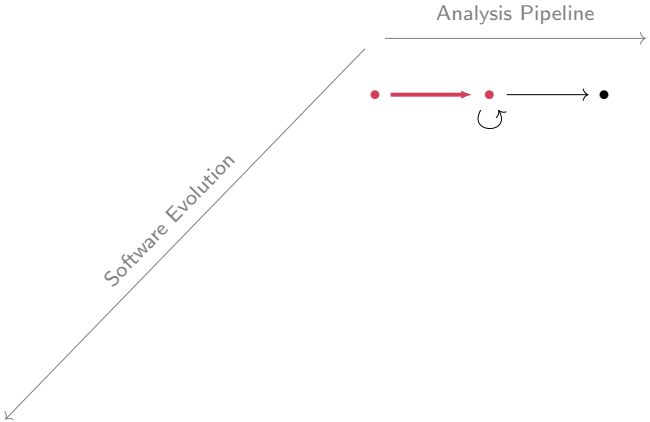


Part I – Analyzing Snapshots

Contributions



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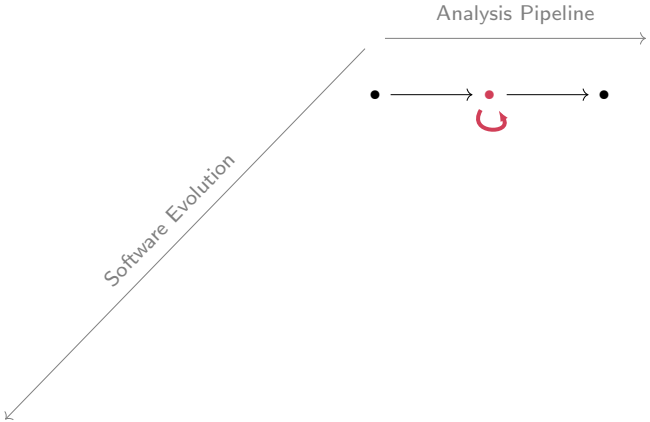
1. **Extracting Feature Models**

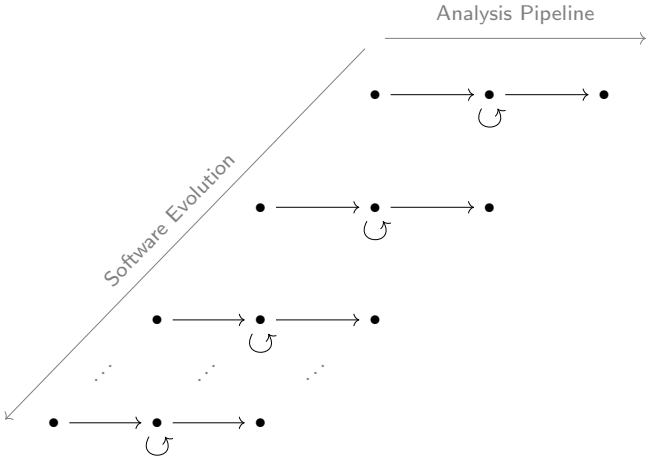
Contributions



Part I – Analyzing Snapshots

1. Extracting Feature Models
2. **Transforming Feature Models**

Contributions



Part I – Analyzing Snapshots

1. Extracting Feature Models
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Part II – Analyzing Evolution

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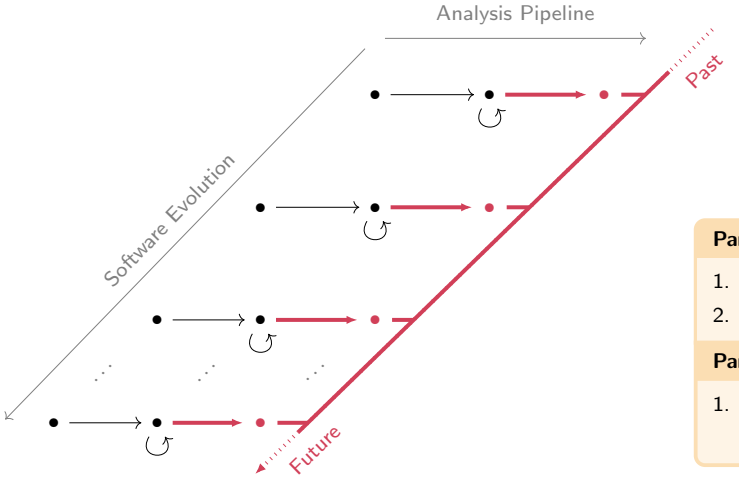


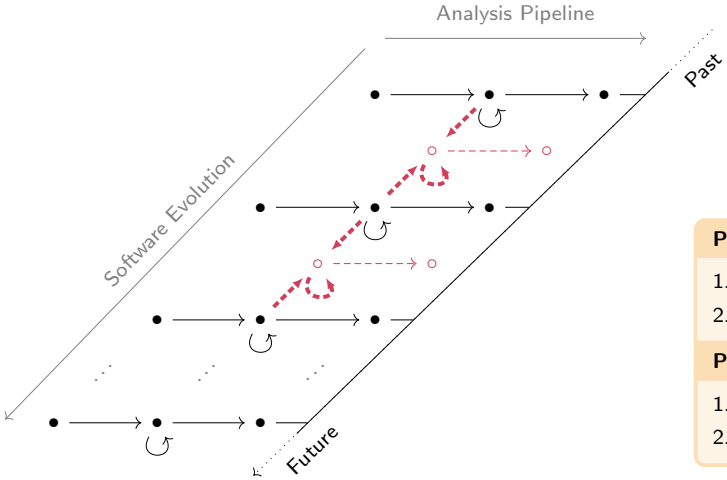
Part I – Analyzing Snapshots

1. Extracting Feature Models
2. Transforming Feature Models

Part II – Analyzing Evolution

1. **Long-Term History**

Contributions



Part I – Analyzing Snapshots

1. Extracting Feature Models
2. Transforming Feature Models

Part II – Analyzing Evolution

1. Long-Term History
2. **Individual Steps**

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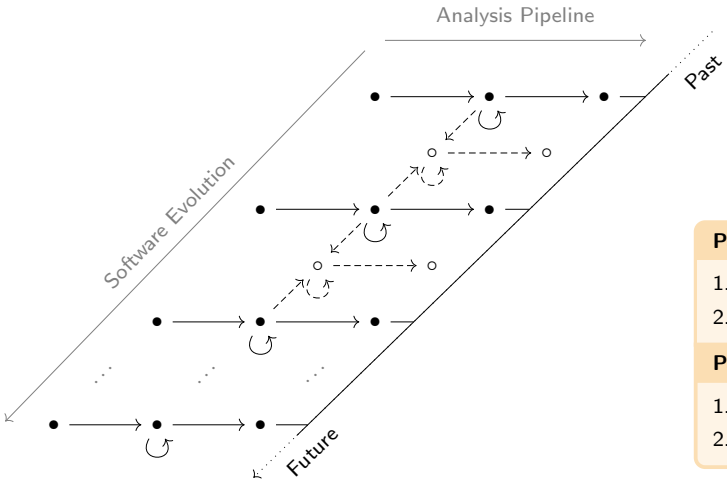

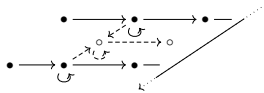

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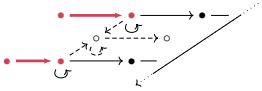

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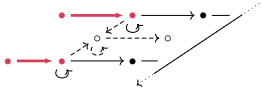

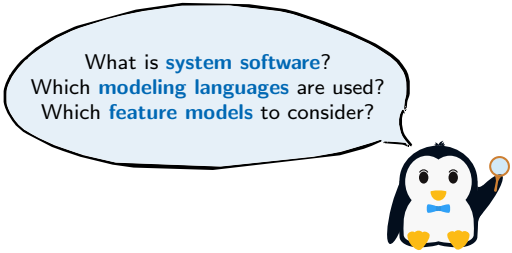

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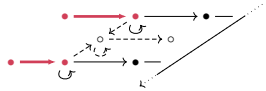

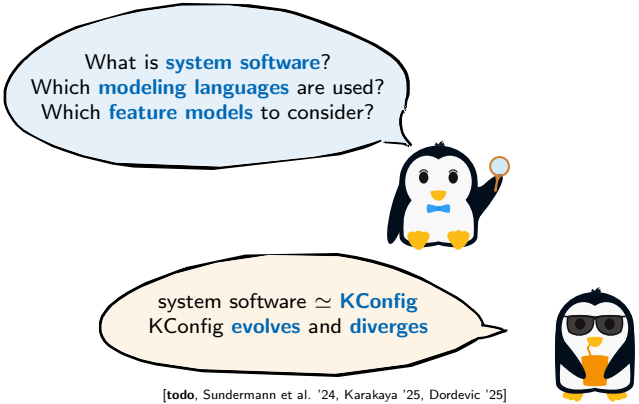

[**todo**, Sundermann et al. '24, Karakaya '25, Dordevic '25]

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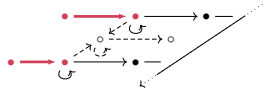

What is **system software**?
Which **modeling languages** are used?
Which **feature models** to consider?

system software $\simeq$ **KConfig**
KConfig **evolves** and **diverges**

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LKC, KConfigLib, Standalone, ... $\Rightarrow$ not unified

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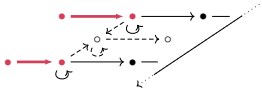

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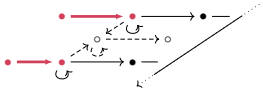

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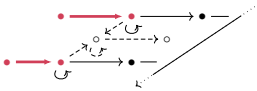

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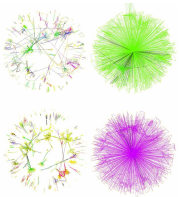

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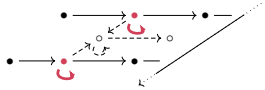
3 extractors, **full histories**, hierarchies, UVL, . . .

Analyzing Snapshots – Transforming Feature Models



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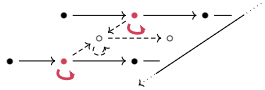

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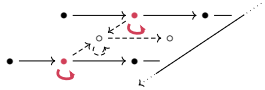

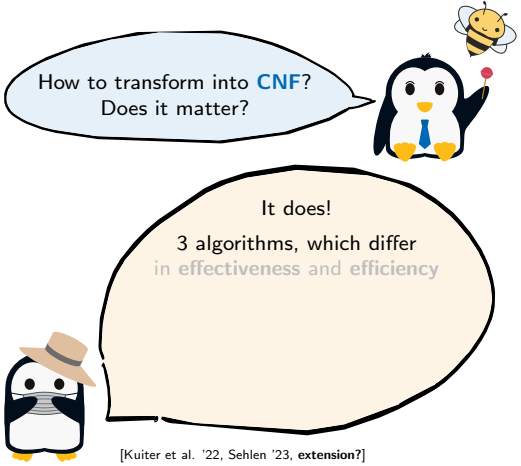

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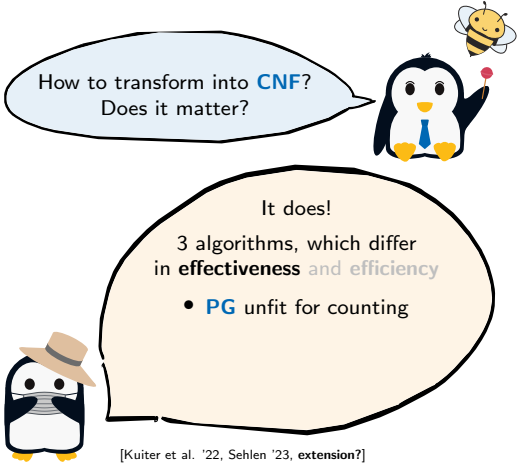

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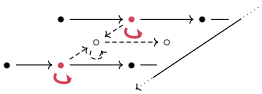

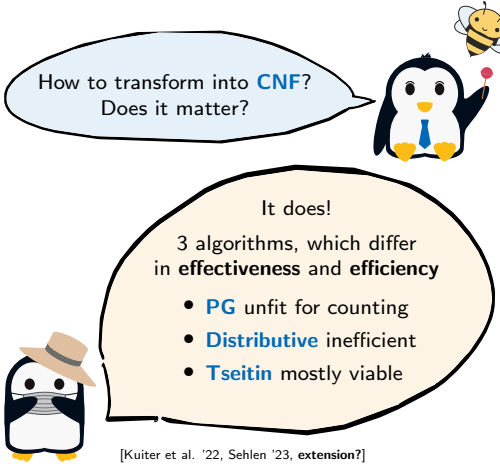

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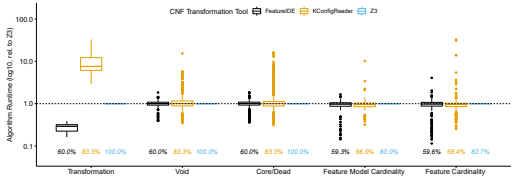
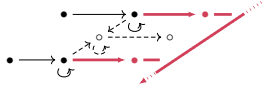


Analyzing Evolution – Long-Term History

Case Study: Linux Kernel



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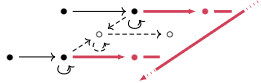

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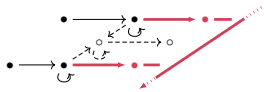

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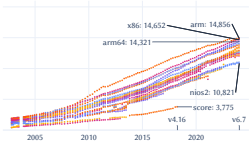

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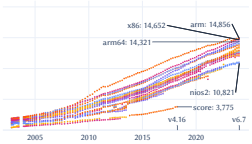

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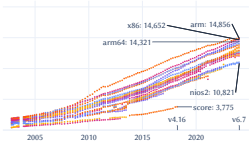

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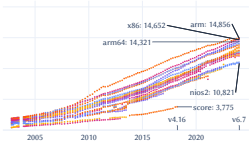

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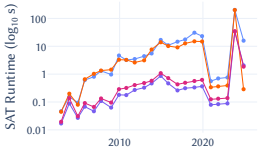

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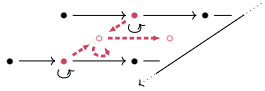
every year, SAT solvers **slow down** by 13%–29%

Analyzing Evolution – Individual Steps



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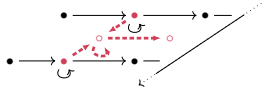

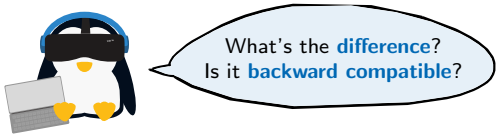

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Is it **backward compatible**?

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for measuring inadvertent

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[**todo**, see FOSD '25]

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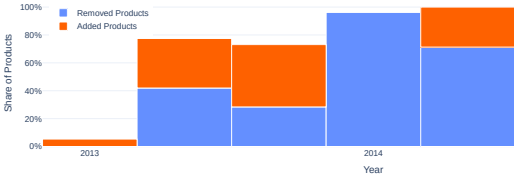


Timeline and Novelty

Chapter	Papers
Motivation + Analysis Pipeline	**VaMoS '24**, **SPLC '25**
Analyzing Snapshots – Extracting Feature Models	2 planned
Analyzing Snapshots – Transforming Feature Models	**ASE '22** + 1?
Analyzing Evolution – Long-Term History	**TOSEM '25** + 1 submitted
Analyzing Evolution – Individual Steps	1 planned

Batory '05

SPLC'17 test of time award

but: CNF is mandatory, yet often overlooked

She et al. '10

VaMoS'20 MIP award

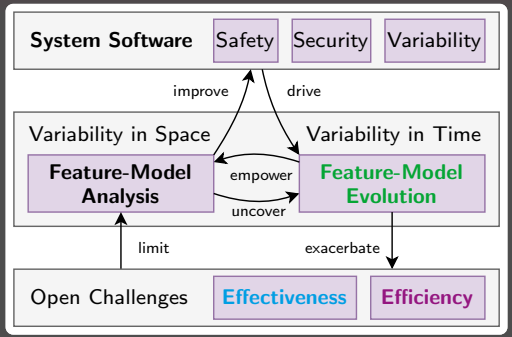
but: configurability not well-defined, inconsistently reported

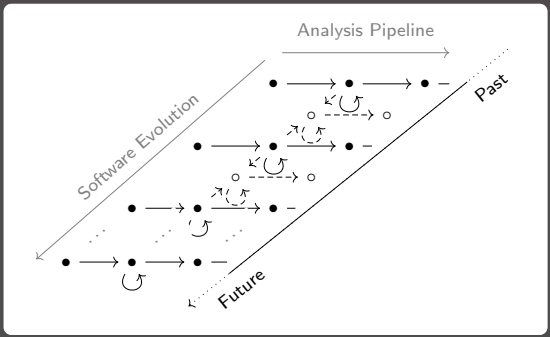
Thüm et al. '09

SPLC'23 MIP award

but: current differencing impractical and coarse-grained

Conclusion





Thank you for listening!