
[Elbe, Magdeburg]

Quantified Reasoning About Edits to Feature Models

FOSD 2025 — March 25–28 — Köthen

Elias Kuiter[1], Thomas Thüm[2], Gunter Saake[1]

University of Magdeburg[1], TU Braunschweig[2]

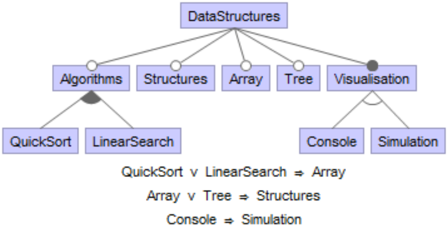
Quantified Reasoning About Edits to Feature Models

Implementierungstechniken für Software-Produktlinien

Übung 10: Analyse von Produktlinien

1. **Feature-Modell-Analyse**

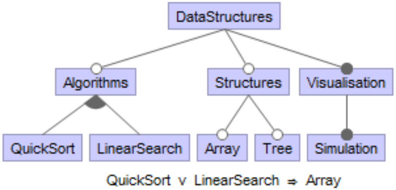
   Gegeben sei das folgende Feature-Modell FM.



2. **Evolution von Feature-Modellen**

   (a) Welche semantischen Änderungen an Feature-Modellen können vorgenommen werden?

   (b) Gegeben sei das folgende Feature-Modell FM'. Welche Änderung gegenüber dem obigen Modell FM wurden vorgenommen? Was bringen diese Änderungen?



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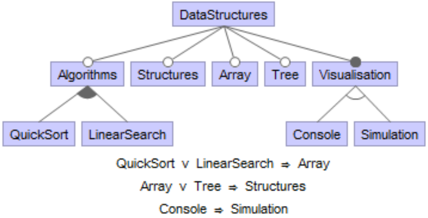

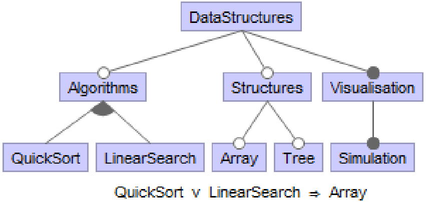

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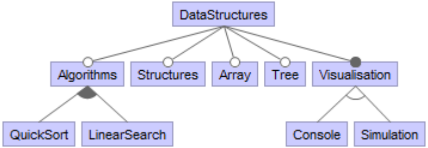
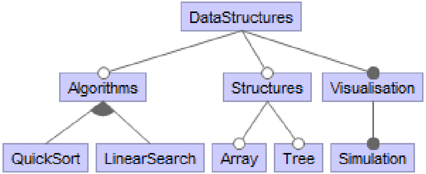


QuickSort ∨ LinearSearch ⇒ Array

Array ∨ Tree ⇒ Structures

Console ⇒ Simulation



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What Happens to the Configuration Space?

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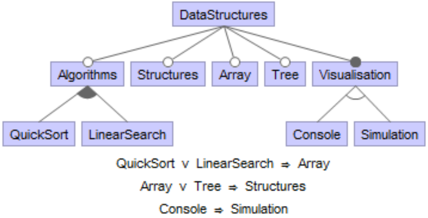

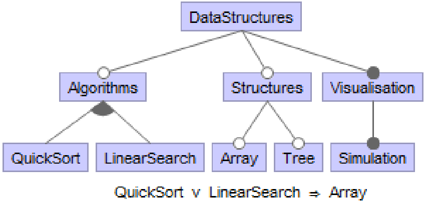

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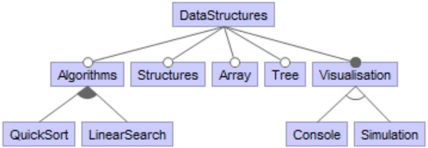

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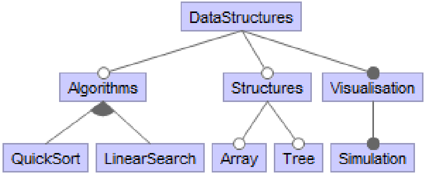
$\stackrel{?}{=}$



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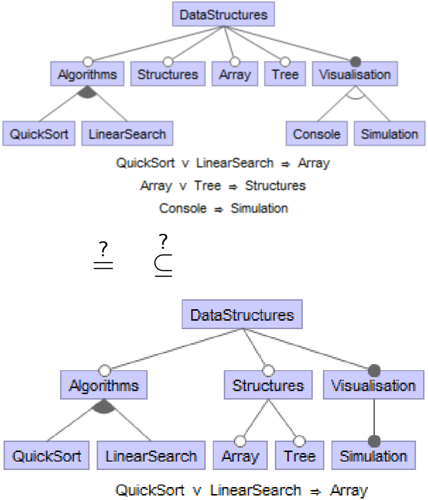

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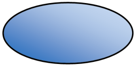
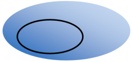
No Products Deleted	 Refactoring	 Generalization
Products Deleted		

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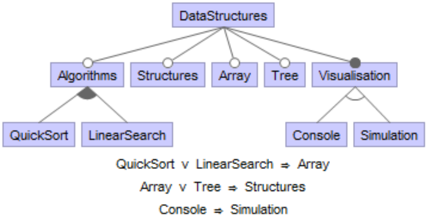
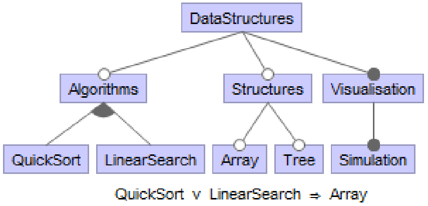


$\stackrel{?}{=}$ $\stackrel{?}{\subseteq}$ $\stackrel{?}{\supseteq}$



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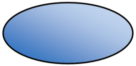
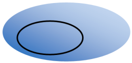
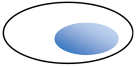
No Products Deleted	 Refactoring	 Generalization
Products Deleted	 Specialization	

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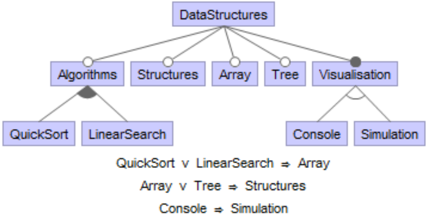

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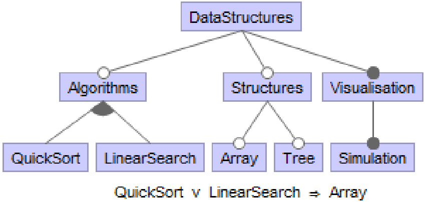

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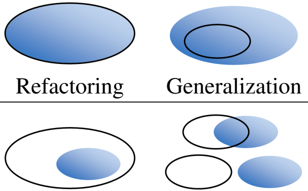

	No Products Added	Products Added
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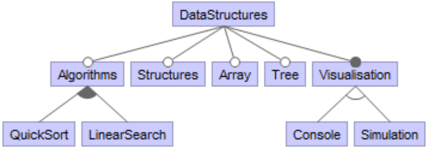

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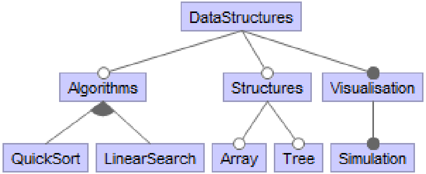

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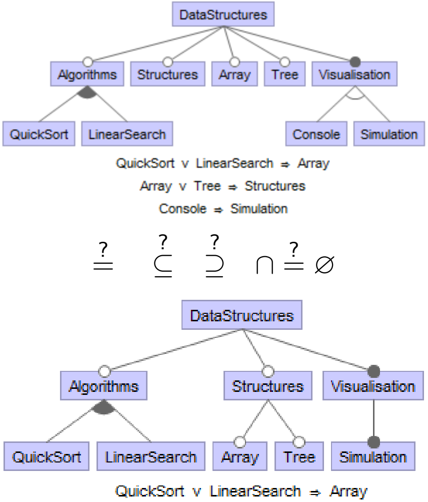
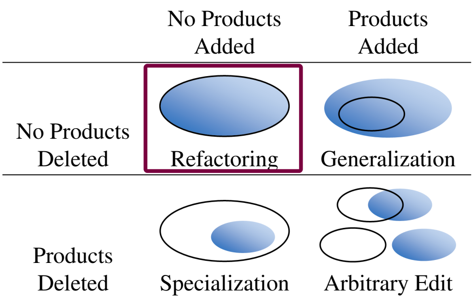


Feature-Model Edits [Thüm et al. '09]



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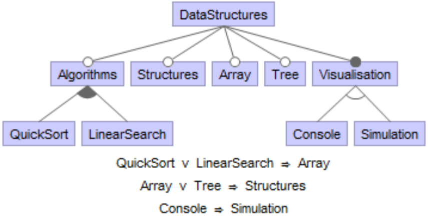

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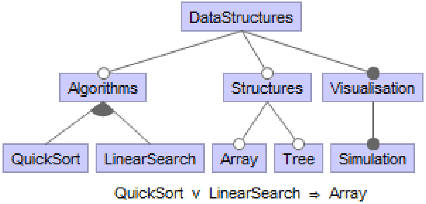

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- **goal**: compare versions of a feature model
- **use cases**: e.g., to avoid unintentional changes, understand patterns in evolution, or support continuous integration ⇒ **quality assurance**

Quantified Reasoning About Edits to Feature Models

SAT-Based: Simplified Reasoning [Thüm et al. '09]

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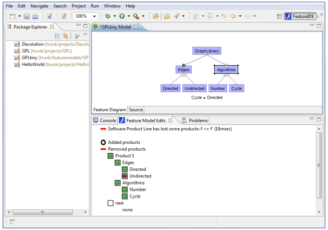

Formal tool demonstration tomorrow at 4:30pm
Available open source at `http://www.fosd.de/featureide`

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Weaknesses

let's see . . .

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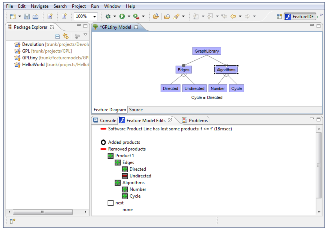

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Remarks on Significance (Only 1 Day Old)

Tobias Heß in Home Office

"Hey Thomas,

I have good news!

I checked every commit in the history of Busybox, Fiasco, Soletta, uclibc, Toybox, and FinancialServices.

We can significantly simplify your classification algorithm, as 100 % of the changes are arbitrary edits:"

The New Algorithm

```
String classify(FM f, FM g) {
    return "Arbitrary Edit";
}
```

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Weaknesses

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Weaknesses

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- no empirical evaluation

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Weaknesses

- all nontrivial edits are arbitrary
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implemented in FeatureIDE

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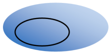
Improving SAT-Based Reasoning



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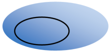
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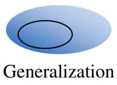

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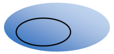

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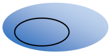

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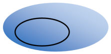

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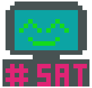

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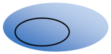

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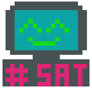

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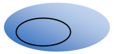

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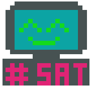

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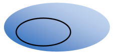

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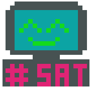

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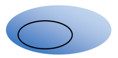

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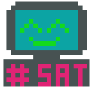

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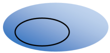

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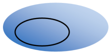

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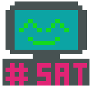

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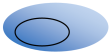

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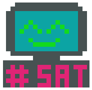

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- measure inadvertent **variability growth**
- **reify differences** to explore them and lift analyses

- compare to **SAT-based reasoning** [Thüm et al. '09]
- and to **BDD-based differencing** [Acher et al. '12]
- and to **syntactic differencing** [Dintzner et al. '18]
- evaluate on models + investigate their **evolution**

Eliminate Tseitin and Negation

$$\frac{\#\mathrm{SAT}(\theta_T(\phi \land \neg\psi))}{\#\mathrm{SAT}(\theta_T(\phi))} = 1 - \frac{\#\mathrm{SAT}(\theta_D(\phi \land \psi))}{\#\mathrm{SAT}(\theta_D(\phi))}$$

Total Vs. Partial Tseitin Transformation

- **total**: abbreviate every subformula
  $\Rightarrow$ negation in $\mathcal{O}(1)$, greenuces transform effort
- **partial**: abbreviate only selected subformulas
  $\Rightarrow$ introduces fewer auxiliary variables

Projected Model Counting (#∃SAT)

$$\frac{\#\exists\mathrm{SAT}(\theta_T(\phi \land \bigwedge_{v \in V_\psi \setminus V_\phi}(v \leftrightarrow \mathrm{def}(v)) \land \neg\psi), V_\pi)}{\#\exists\mathrm{SAT}(\theta_T(\phi), V_\pi)}$$

where $V_\pi = (V_\phi \setminus V_\psi) \cup \mathrm{aux}$ [Sundermann et al. '24]

Non-Clausal Slicing

$$\pi_1 = \exists(V_\phi \setminus V_\psi)\ \theta_D \quad \longrightarrow \quad \pi_1 = \exists(V_\phi \setminus V_\psi)$$

Implementation – Meet Two Enthusiastic Researchers (and Their Tools)

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renowned feature-model historian
studies evolution for a living

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- extracts **feature-model histories**
- extends KConfigReader, KClause (+ ConfigFix)
- reproducible + fully automated

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clausy 🎅 [/ekuiter/clausy]

- transforms feature models **into CNF**
- competes with Z3 in performance
- supports diffing (slicing planned)

Conclusion

	No Products Added	Products Added
No Products Deleted	Refactoring	Generalization
Products Deleted	Specialization	Arbitrary Edit

Improving SAT-Based Reasoning

ψ generalizes ϕ iff $\neg\mathsf{SAT}(\theta_D(\phi \wedge \neg\psi))$

ψ generalizes ϕ iff $\neg\mathsf{SAT}(\theta_T(\phi \wedge \neg\psi))$

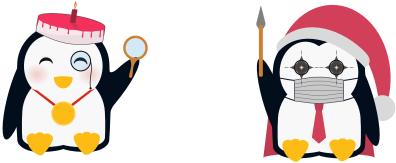
Introducing #SAT-Based Reasoning

the degree of removed configurations is

$$\text{(none) } 0 \leq \frac{\#\mathsf{SAT}(\theta_T(\pi_1\ \phi \wedge \pi_2\ \psi))}{\#\mathsf{SAT}(\theta_T(\pi_1\ \phi))} \leq 1 \text{ (all)}$$

e.g., $\pi_1 = \exists(V_\phi \setminus V_\psi)\ \theta_D$ removed f's

e.g., $\pi_2 = \bigwedge_{v \in V_\psi \setminus V_\phi} (v \leftrightarrow \mathsf{def}(v))\ \ \wedge \neg$ added f's



/ekuiter/torte 🍰 /ekuiter/clausy 🎅

🐧 Disclaimer: No penguins were AI-generated in the making of this presentation. All were returned to TikZpingus, their natural habitat.

Inadvertent Variability Reduction – The Use Case

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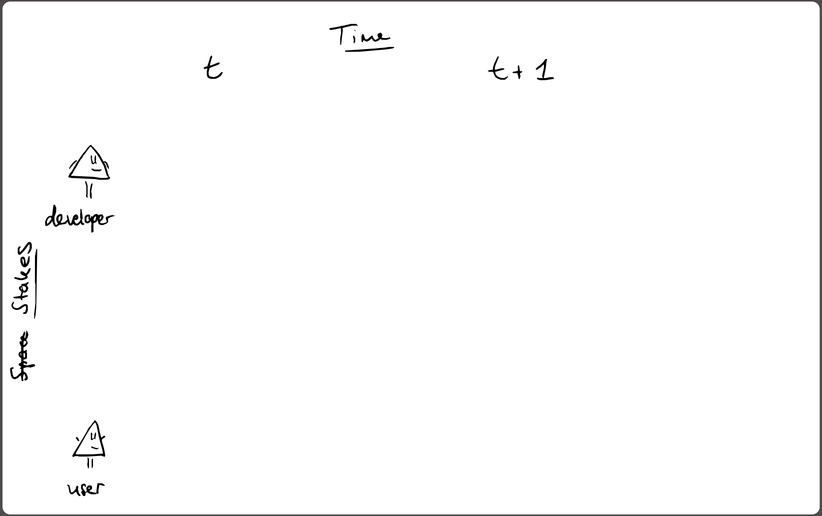
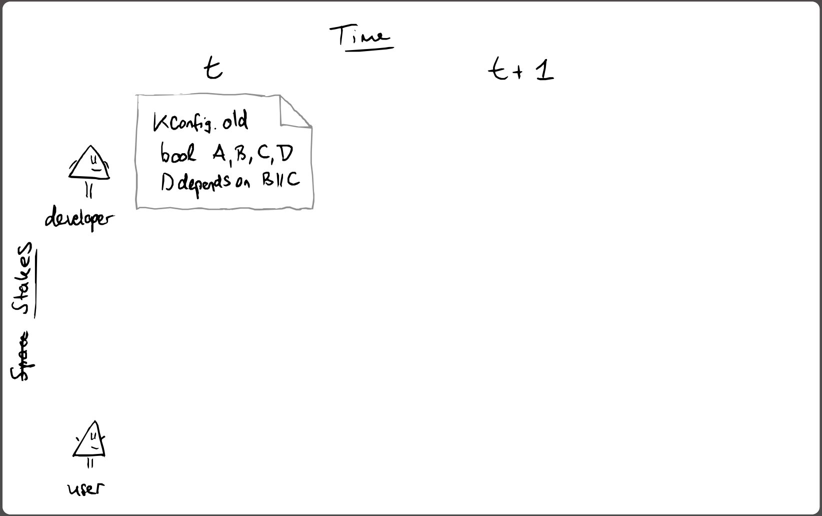
Time

~~Space~~ Stakes

Inadvertent Variability Reduction – The Use Case



Inadvertent Variability Reduction – The Use Case



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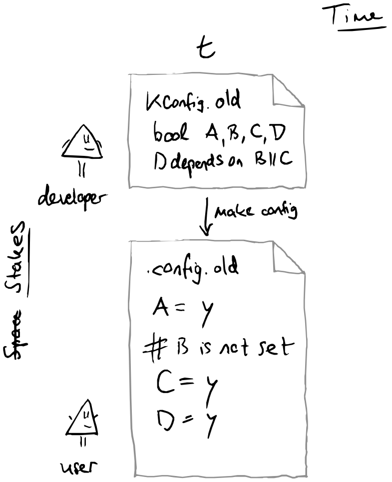

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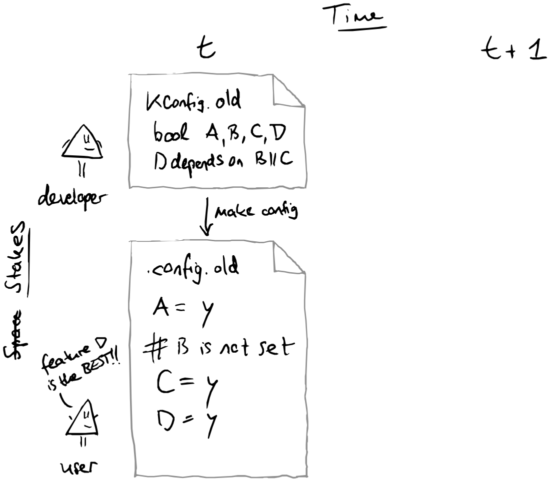

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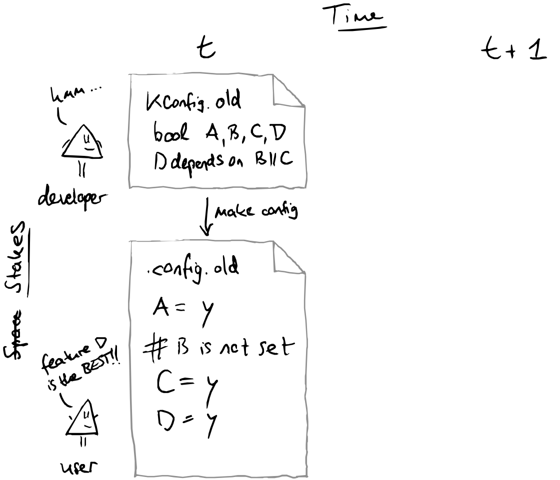

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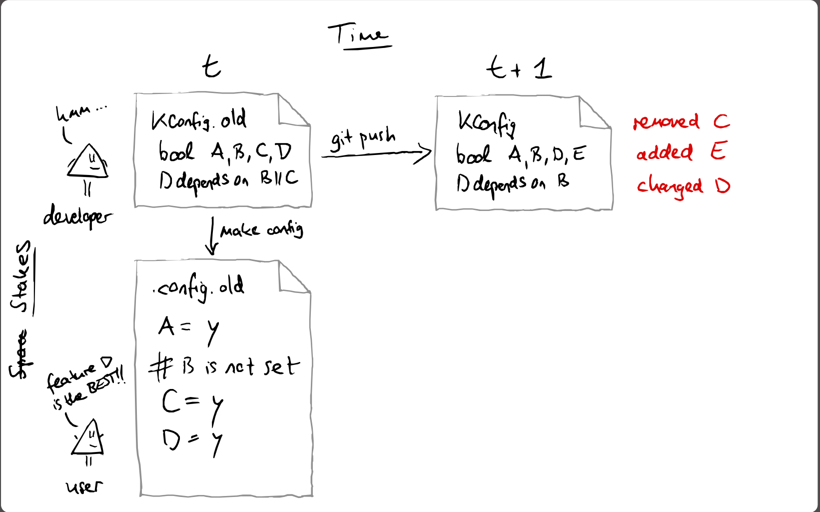

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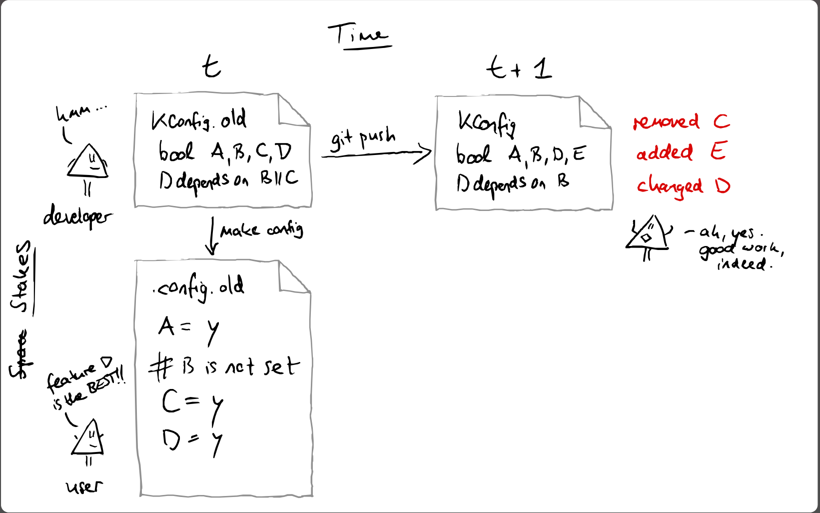

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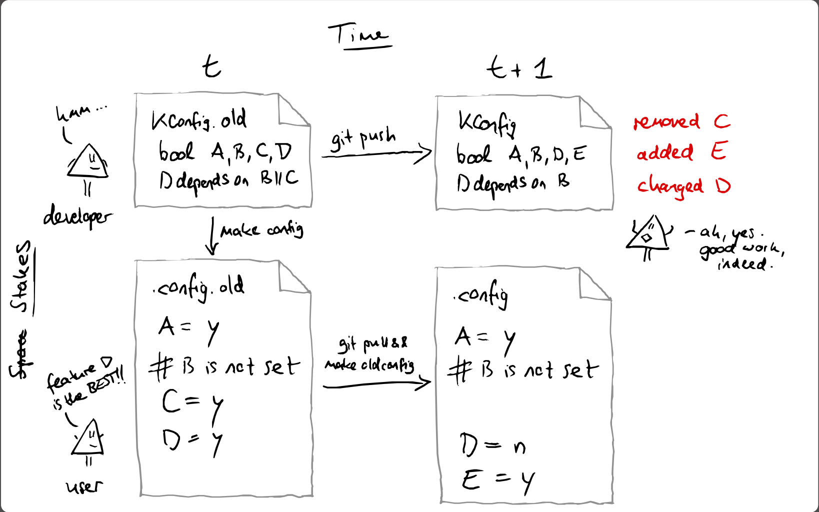

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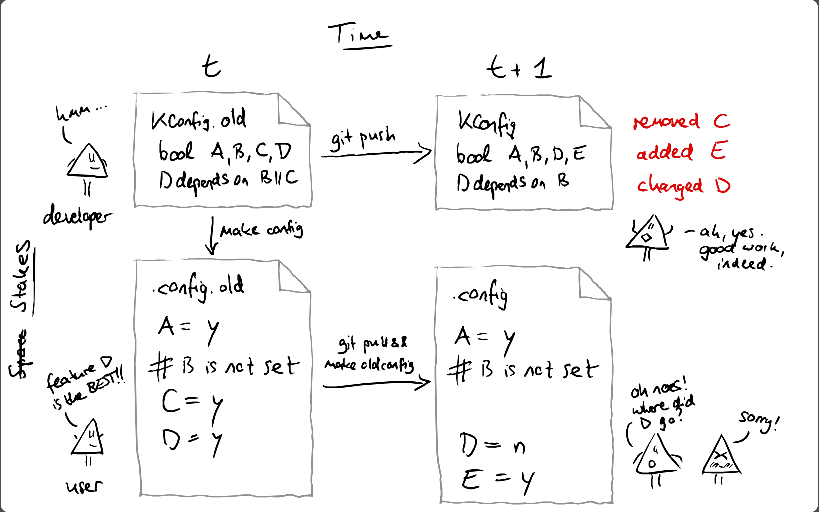

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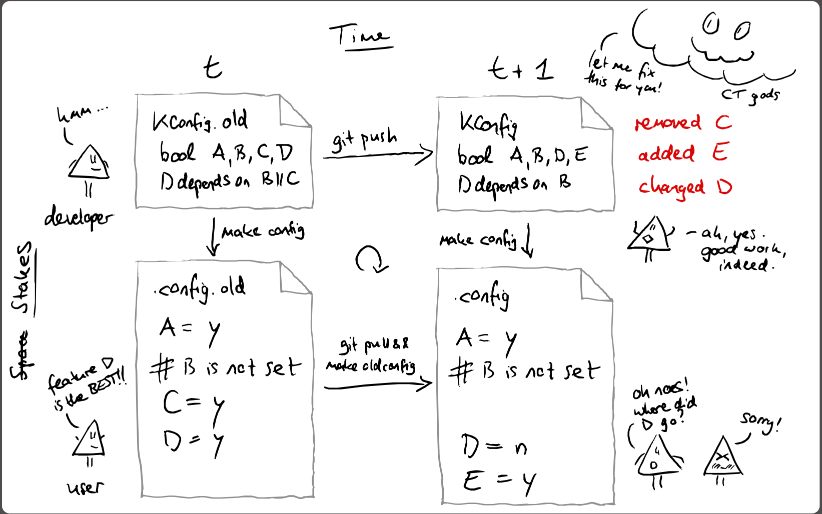

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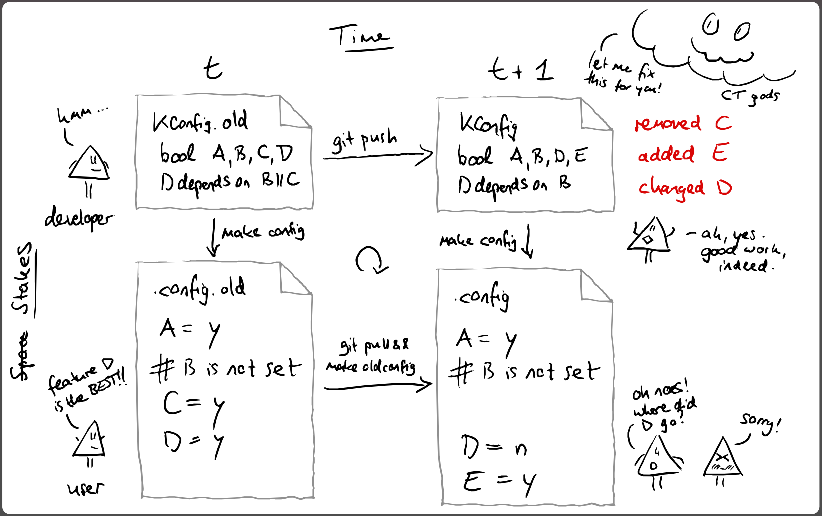
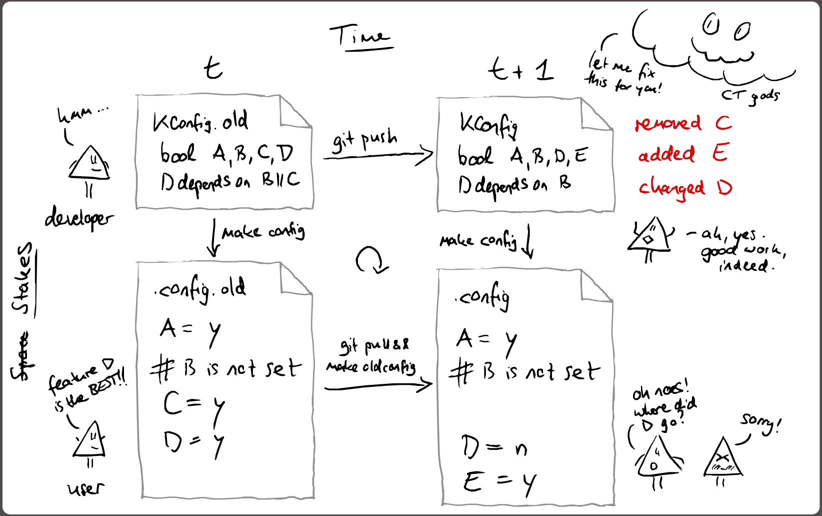


Assuming . . .

- users are uniform over configurations
- updates are non-interactive
- users expect choices to be preserved

Inadvertent Variability Reduction – The Use Case



Assuming . . .

- users are uniform over configurations
- updates are non-interactive
- users expect choices to be preserved

. . . how many of our users are negatively impacted by an update?

⇒ decision-making

⇒ understanding configuration spaces

Inadvertent Variability Reduction – The Math

cfg loss = ______________________________

Inadvertent Variability Reduction – The Math

$$\text{cfg loss} = \frac{\phi \qquad \land \neg \psi}{\phi}$$

Inadvertent Variability Reduction – The Math

$$\text{cfg loss} = \frac{\#SAT(\phi \land \neg\psi)}{\#SAT(\phi)}$$

Inadvertent Variability Reduction – The Math

$$\text{cfg loss} = \frac{\#SAT(\Theta_T(\quad \phi \quad \wedge \neg \psi))}{\#SAT(\Theta_T(\quad \phi))}$$

Inadvertent Variability Reduction – The Math

$$\text{cfg loss} = \frac{\#SAT(\Theta_T(\exists v_\phi \setminus v_\psi \, \Theta_D(\phi) \qquad \wedge \neg \psi))}{\#SAT(\Theta_T(\exists v_\phi \setminus v_\psi \, \Theta_D(\phi)))}$$

Inadvertent Variability Reduction – The Math

$$\text{cfg loss} = \frac{\#SAT\left(\Theta_T\left(\exists V_\phi \setminus V_\psi\, \Theta_D(\phi) \wedge \bigwedge_{v \in V_\psi \setminus V_\phi} (v \leftrightarrow def(v)) \wedge \neg \psi\right)\right)}{\#SAT\left(\Theta_T\left(\exists V_\phi \setminus V_\psi\, \Theta_D(\phi)\right)\right)}$$

Inadvertent Variability Reduction – The Math

$$\text{cfg loss} = \frac{\#SAT\left(\Theta_T\left(\exists V_\phi \setminus V_\psi\, \Theta_D(\phi) \wedge \bigwedge_{v \in V_\psi \setminus V_\phi} (v \leftrightarrow def(v)) \wedge \neg \psi\right)\right)}{\#SAT\left(\Theta_T\left(\exists V_\phi \setminus V_\psi\, \Theta_D(\phi)\right)\right)}$$

a clever combination of distributive and Tseitin transformation, #SAT, and slicing

Inadvertent Variability Reduction – The Math

$$\text{cfg loss} = \frac{\#SAT\left(\Theta_T\left(\exists V_\Phi \setminus V_\Psi\, \Theta_D(\Phi) \wedge \bigwedge_{v \in V_\Psi \setminus V_\Phi} (v \leftrightarrow def(v)) \wedge \neg \Psi\right)\right)}{\#SAT\left(\Theta_T\left(\exists V_\Phi \setminus V_\Psi\, \Theta_D(\Phi)\right)\right)}$$

a clever combination of distributive and Tseitin transformation, #SAT, and slicing

---

$$\#SAT\left(\Theta_T\left(\left(\exists V_\Phi \setminus V_\Psi \left(\Theta_D(\Phi)\right) \wedge \bigwedge_{v \in V_\Psi \setminus V_\Phi} (v \leftrightarrow def(v))\right) \circ \Psi\right)\right)$$

$$= \#\exists SAT\left(\Theta_T\left(\left(\Phi \wedge \bigwedge_{v \in V_\Psi \setminus V_\Phi} (v \leftrightarrow def(v))\right) \circ \Psi\right), V_\Phi \setminus V_\Psi \cup aux\right)$$

instead of #SAT and slicing (e.g., FeatureIDE), we can also use #∃SAT (e.g., pd4)

negation can also be avoided when using $1 - \#SAT(x)$

Removed Features
Added Features
Share of Features
Year
Removed Constraints
Added Constraints
Share of Constraints
Year
left_diff_kind=weak
Removed Products
Added Products
Share of Products
Year
diff_kind=bottom-strong
diff_kind=top-strong
left_diff_kind=weak