Sample Spaces and Feature Models: There and Back Again

Krzysztof Czarnecki[1] Steven She[1] Andrzej Wąsowski[2]

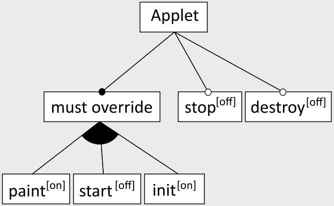
[1]University of Waterloo, Canada

[2]IT University of Copenhagen, Denmark

Software Product Line Conference 2008

Overview

Feature Models



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Feature Model with Soft Constraints

Sample Spaces

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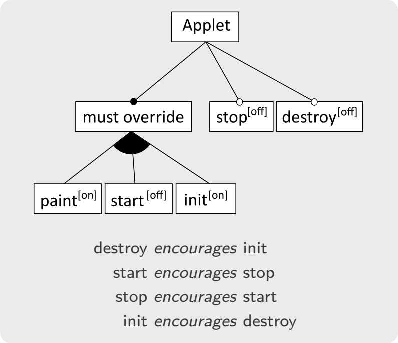

Feature Model with Soft Constraints

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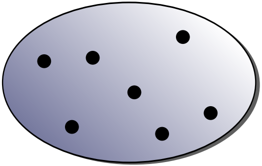

Sample Set of Configurations

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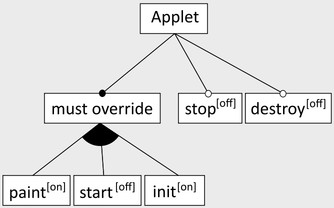

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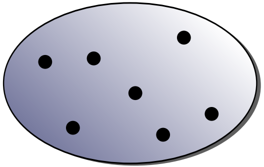

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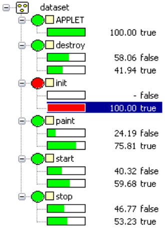
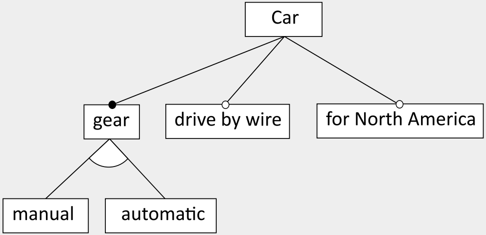


Configuration

Outline

Outline

Basic Feature Models



drive by wire $\rightarrow$ automatic

Feature Models...

- represent commonality and variability in a product line.
- describe a set of *legal configurations*.
- **But**... existing feature models can not express *preference* among legal configurations.

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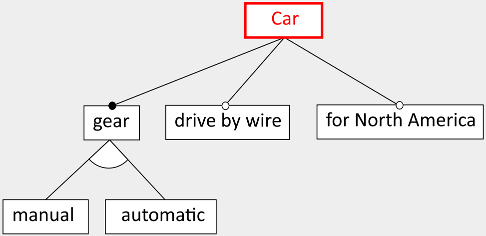

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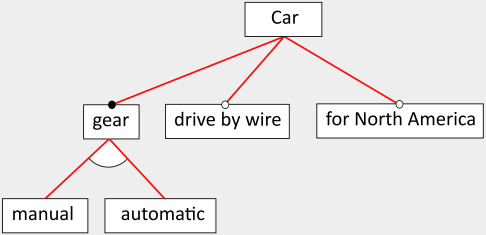

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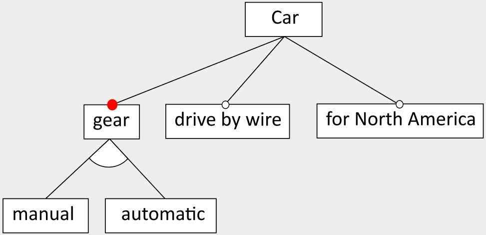

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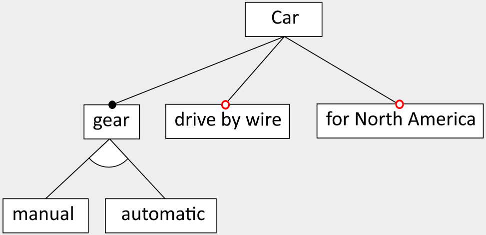

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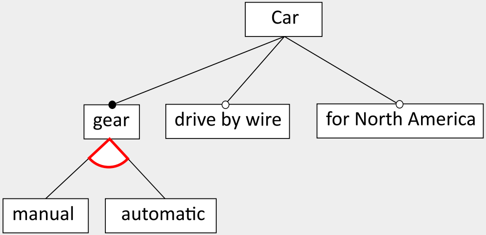

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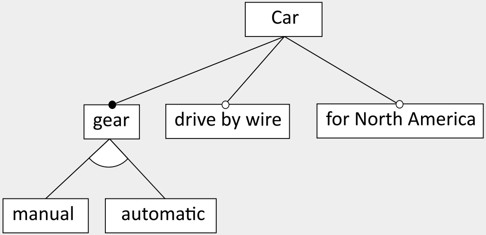

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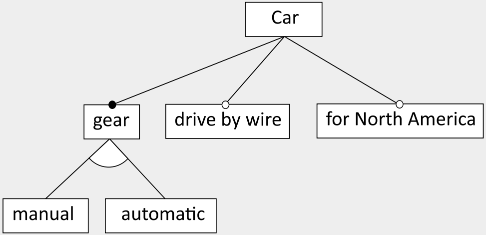

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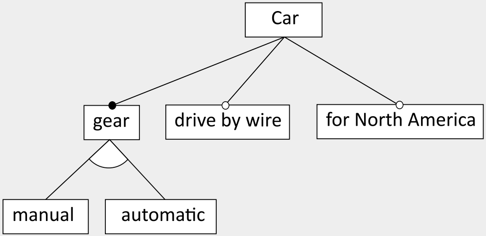
Probabilistic Feature Models (PFMs)



drive by wire $\longrightarrow$ automatic

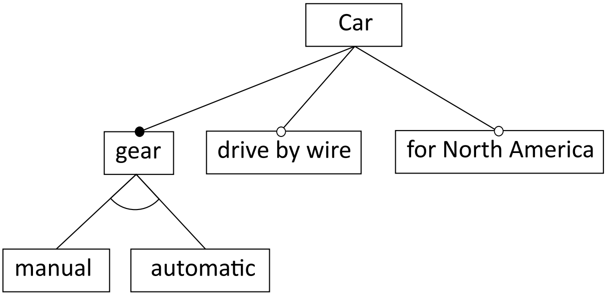
automatic *given* gear [20%]

automatic *given* North America [80%]

Probabilistic Feature Models add **soft constraints**.

...a constraint that should be satisfied by most configurations, but some may violate it.

Interactive Configuration



drive by wire	$\rightarrow$	automatic	
automatic	*given*	gear	[20%]
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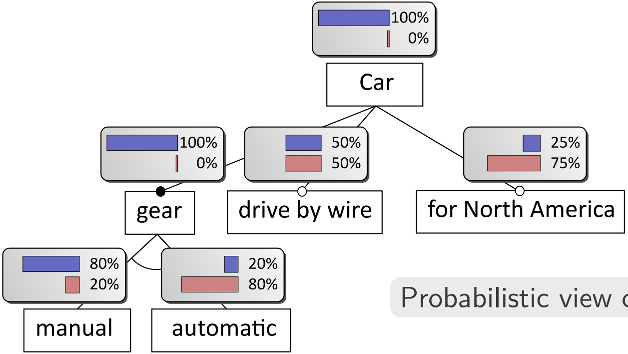
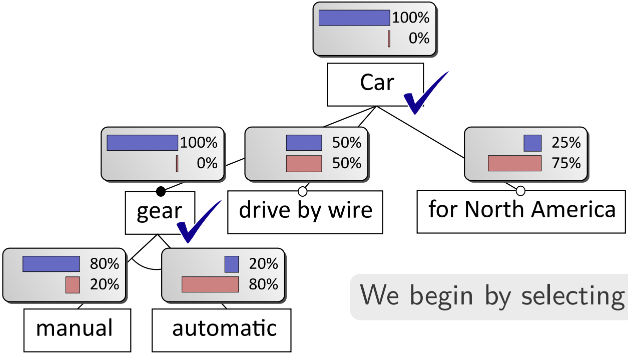


Probabilistic view of the PFM.

drive by wire	$\rightarrow$	automatic	
automatic	*given*	gear	[20%]
automatic	*given*	North America	[80%]

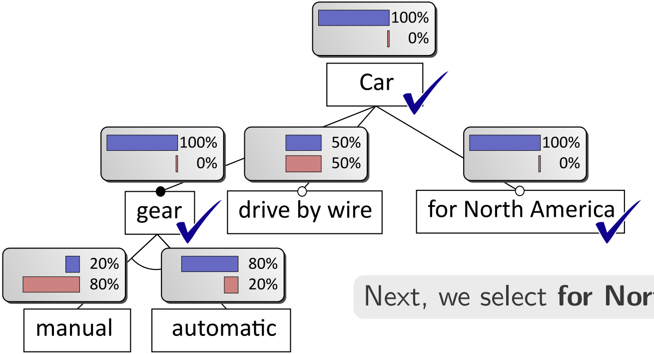
Interactive Configuration



We begin by selecting **Car** and **Gear**.

drive by wire	$\longrightarrow$	automatic	
automatic	*given*	gear	[20%]
automatic	*given*	North America	[80%]

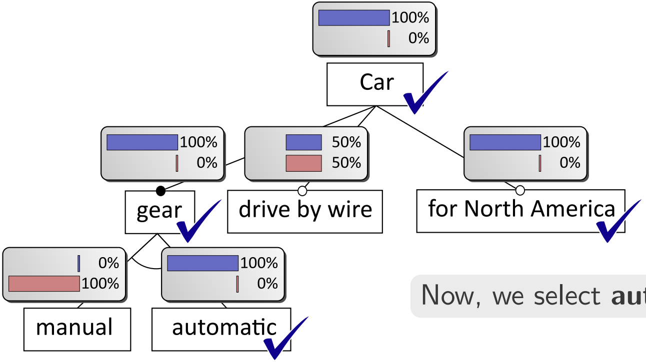
Interactive Configuration



Next, we select **for North America**.

drive by wire	$\longrightarrow$	automatic	
automatic	*given*	gear	[20%]
automatic	*given*	North America	[80%]

Interactive Configuration

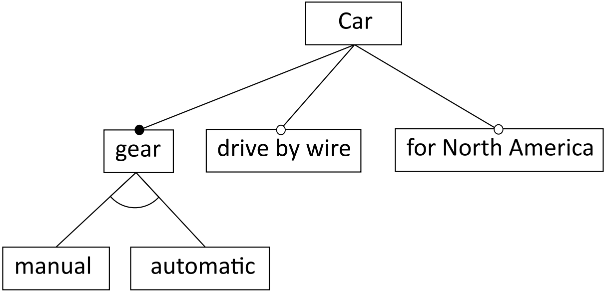


Now, we select **automatic**.

drive by wire	$\rightarrow$	automatic	
automatic	*given*	gear	[20%]
automatic	*given*	North America	[80%]

Outline

Semantics of Basic Feature Models

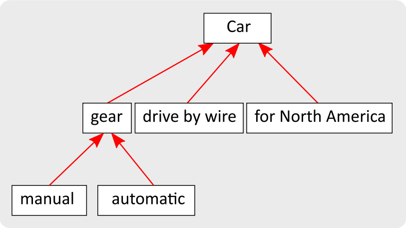


$$\text{drive by wire} \quad \rightarrow \quad \text{automatic}$$

The semantics of a basic feature model...

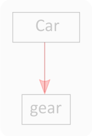
is defined as a conjunction of it's *hard constraints* as a **propositional formula**.

Logical Components of a Basic Feature Model



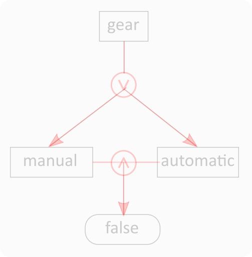
Feature Dependencies

$\wedge$



Mandatory

$\wedge$



Group

$\wedge$ Car

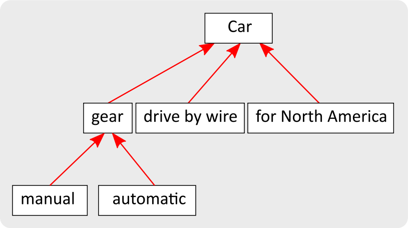
Root

$\wedge\ \phi$

Additional Constraints

This formula denotes a set of *legal configurations*.

Logical Components of a Basic Feature Model



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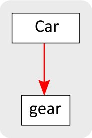

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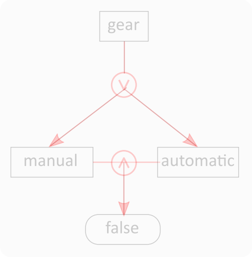

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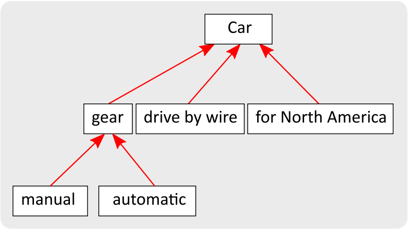

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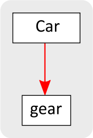

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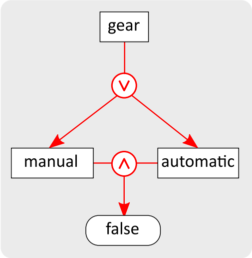

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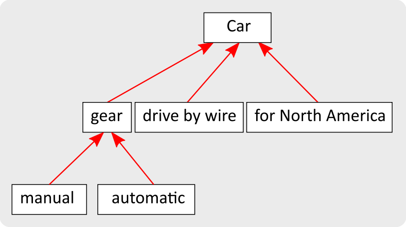

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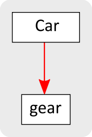

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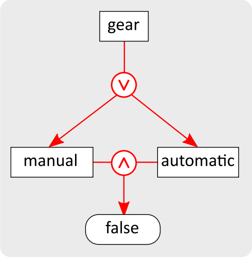

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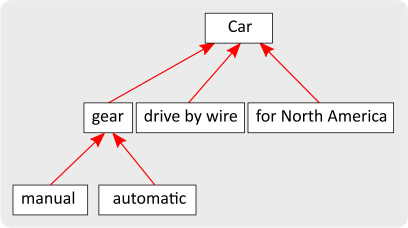

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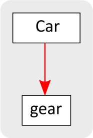

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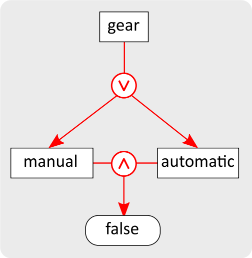

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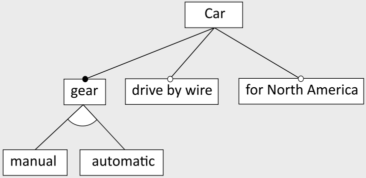
Components of a Probabilistic Feature Model

A probabilistic feature model is...

A basic feature model + *soft constraints*



drive by wire → automatic

+

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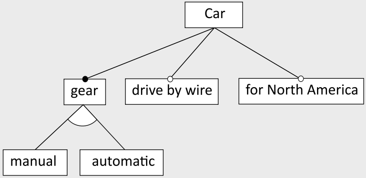
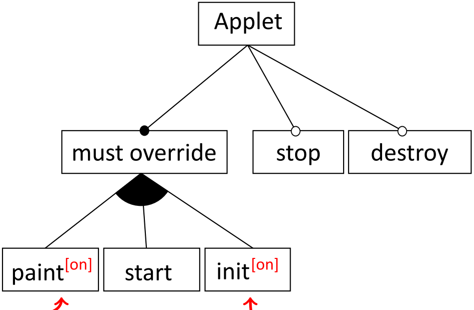


drive by wire $\rightarrow$ automatic

+

Feature Modeling with Soft Constraints

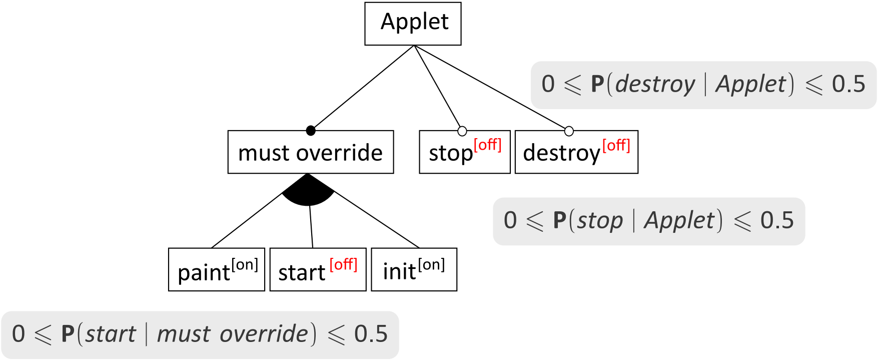


$0.8 \leqslant \mathbf{P}(\mathit{paint} \mid \mathit{must\ override}) \leqslant 1.0$

$0.8 \leqslant \mathbf{P}(\mathit{init} \mid \mathit{must\ override}) \leqslant 1.0$

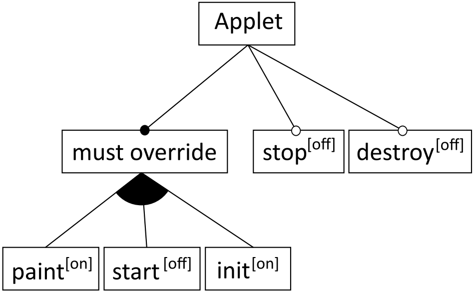
- **On-by-default** if cond. probability between 80% and 100%.

Feature Modeling with Soft Constraints



- **Off-by-default** if cond. probability between 0 and 50%.

Feature Modeling with Soft Constraints



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stop *encourages* start

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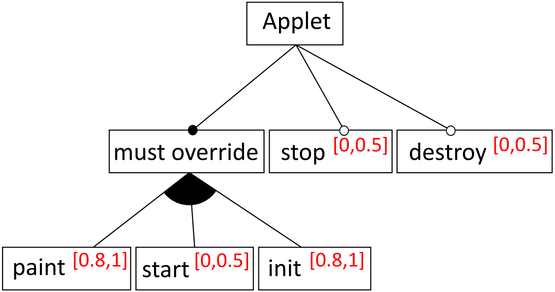

$$
\begin{aligned}
(\text{init} \mid \text{destroy}) &\ [0.8, 1.0] \\
(\text{stop} \mid \text{start}) &\ [0.8, 1.0] \\
(\text{start} \mid \text{stop}) &\ [0.8, 1.0] \\
(\text{destroy} \mid \text{init}) &\ [0.8, 1.0]
\end{aligned}
$$

Joint Probability Distributions

Basic feature models...

specify a set of *legal configurations*.

Probabilistic feature models...

specify a set of *legal joint probability distributions* (JPDs).

A joint probability distribution...

assigns a probability to each *possible configuration*.

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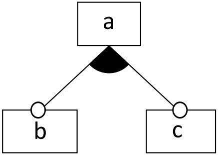
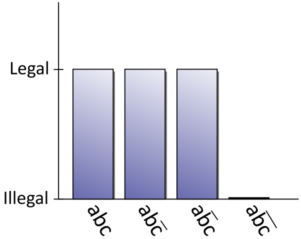


Basic Feature Model



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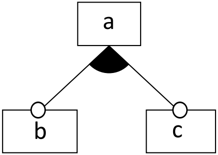

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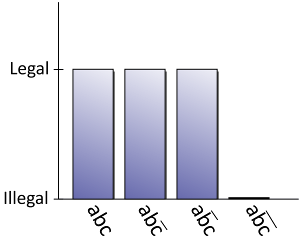
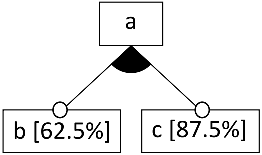
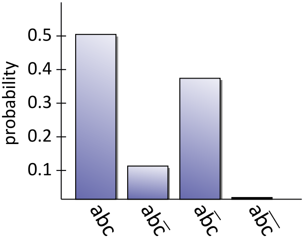




Probabilistic Feature Model



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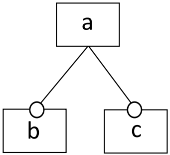
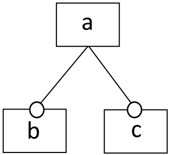
Under-specification in PFMs



a	b	c	$P(a, b, c)$
1	1	1	$p_1 \geqslant 0.0$
1	1	0	$p_2 \geqslant 0.0$
1	0	1	$p_3 \geqslant 0.0$
1	0	0	$p_4 \geqslant 0.0$
0	$\vdots$	$\vdots$	$p_{5\ldots8} = 0$

An *abstract* PFM is *under-specified* and specifies a range of JPDs.

Under-specification in PFMs



c *given* b [80%]

a	b	c	$P(a,b,c)$
1	1	1	$p_1 \geqslant 0.0$
1	1	0	$p_2 = 0.25p_1$
1	0	1	$p_3 \geqslant 0.0$
1	0	0	$p_4 = 1 - 1.25p_1 - p_3$
0	$\vdots$	$\vdots$	$p_{5\ldots8} = 0$

where $1.25p_1 + p_3 \leqslant 1$

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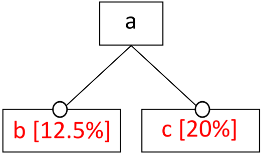
Under-specification in PFMs



c *given* b [80%]

a	b	c	$P(a,b,c)$
1	1	1	$p_1 = 0.1$
1	1	0	$p_2 = 0.025$
1	0	1	$p_3 = 0.1$
1	0	0	$p_4 = 0.775$
0	⋮	⋮	$p_{5\ldots8} = 0$

A *concrete* PFM specifies a single JPD.

Outline

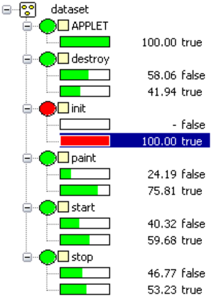
Configuration

Requires a single concrete JPD.

- Abstract PFMs need to be completed.
- *Entropy maximization*.

Probabilistic Inference.

- Relation with *Bayesian Networks*.
- *Most probable explanation* algorithms.
- Adaptive guidance given current state.



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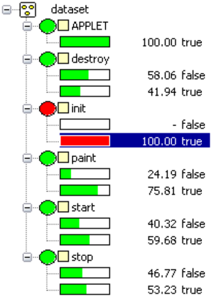
- *Most probable explanation* algorithms.
- Adaptive guidance given current state.



Outline

1. Motivation
2. Probabilistic Feature Models
   - Semantics of Soft Constraints
   - Joint Probability Distributions
3. Configuration
4. Application: Feature Model Mining
   - Mining on Applets
5. Conclusions

Feature Model Mining

Synthesize a feature model that is representative of the variability in a sample set of configurations.

conf	a	b	c	d
1	✓		✓	✓
2	✓	✓		
3	✓		✓	
4	✓	✓	✓	

Sample Set

Feature Model Mining

Synthesize a feature model that is representative of the variability in a sample set of configurations.

conf	a	b	c	d
1	✓		✓	✓
2	✓	✓		
3	✓		✓	
4	✓	✓	✓	

Sample Set

$$
\begin{array}{lr}
c \Rightarrow a & [100\%] \\
\wedge\ b \Rightarrow a & [100\%] \\
\wedge\ d \Rightarrow c & [100\%] \\
\wedge\ a \Rightarrow b \vee c & [100\%] \\
\wedge\ \ldots & \\
\wedge\ a \Rightarrow c & [75\%]
\end{array}
$$

Association Rules

Association Rule Mining

Feature Model Mining

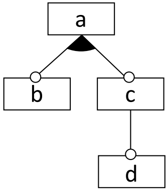
Synthesize a feature model that is representative of the variability in a sample set of configurations.

conf	a	b	c	d
1	✓		✓	✓
2	✓	✓		
3	✓		✓	
4	✓	✓	✓	

Sample Set

$$
\begin{array}{llr}
 & c \Rightarrow a & [100\%] \\
\wedge & b \Rightarrow a & [100\%] \\
\wedge & d \Rightarrow c & [100\%] \\
\wedge & a \Rightarrow b \vee c & [100\%] \\
\wedge & \ldots & \\
\wedge & a \Rightarrow c & [75\%]
\end{array}
$$

Association Rules



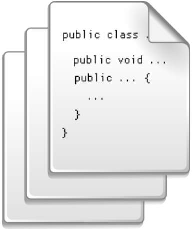
c *given* a [75%]

Feature Model

Association Rule Mining

Feature Model Synthesis
Czarnecki and Wąsowski 2007

Feature Model Mining on Applets



conf	Applet	destroy	paint	init	start	stop
1	✓		✓	✓		
2	✓	✓			✓	✓
3	✓			✓		
⋮						

Applets

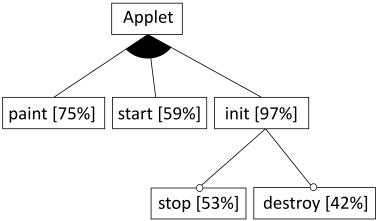
Sample Set

Construct sample set by analysing overridden methods in 64 applets:

`destroy`, `paint`, `init`, `start` and `stop`.

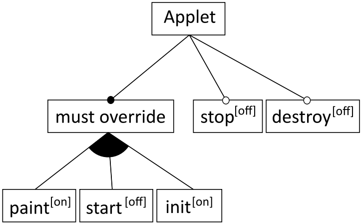
Case Study Results

Mined Feature Model



stop *given* start [84%]
start *given* stop [97%]
paint *given* destroy [88%]
paint *given* stop [88%]
more...

Expert-specified Model



destroy *encourages* init
start *encourages* stop
stop *encourages* start
init *encourages* destroy

Outline

Related Work

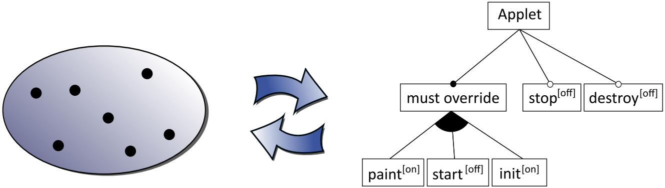
Probabilistic Feature Models.

- Soft Constraints [Czarnecki 2000] [Wada, Suzuki and Oba 2007]
- Feature Models and fuzzy logic [Robak, Pieczyński, 2003]
- i* goal models [Giorgini et al., 2002]

Reverse-engineering models.

- Using concept analysis [Loesch and Ploedereder, 2007]
- Identifying code differences [Jepsen et. al., 2007]

Conclusions

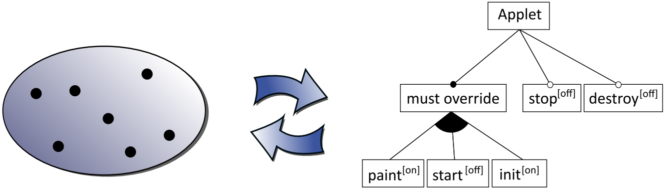


Sample Space   Feature Model with soft constraints

Probabilistic Feature Models.

- Basic feature models extended with *soft constraints*.
- Specifies a set of joint probability distributions.
- Modeling, reverse-engineering, configuration.

Conclusions



Sample Space

Feature Model with soft constraints

Probabilistic Feature Models.

- Basic feature models extended with *soft constraints*.
- Specifies a set of joint probability distributions.
- Modeling, reverse-engineering, configuration.

Questions?