Reverse Engineering Feature Models.

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What are feature models?

Feature models describe the common and variable characteristics of products in a product line.

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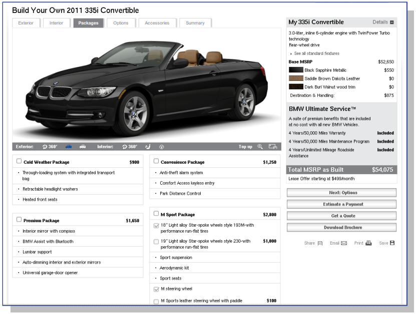

Car configurator.

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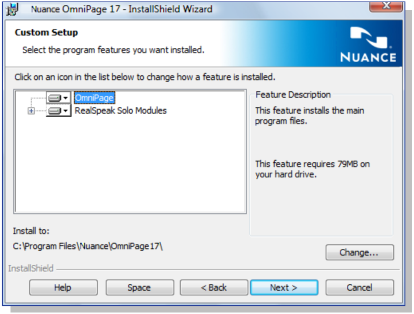
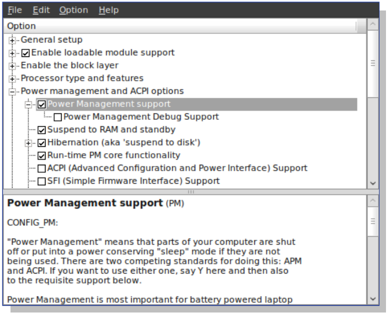


Installation wizards.

What are feature models?

Feature models describe the common and variable characteristics of products in a product line.



Linux kernel configurator.

What are feature models?

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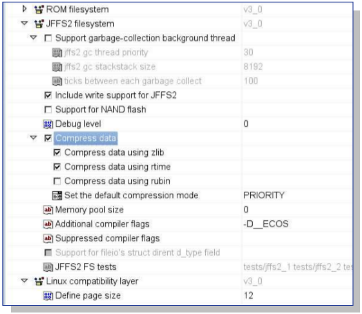

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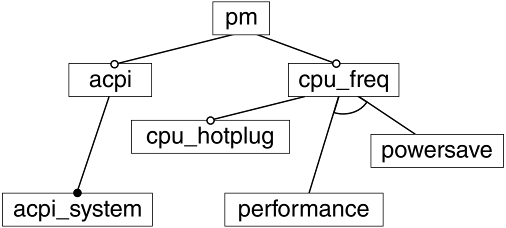
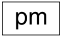


$\text{powersave} \wedge \text{acpi} \rightarrow \text{cpu\_hotplug}$

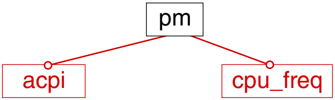
FODA feature model [Kang et al. 1990]

Feature model syntax.



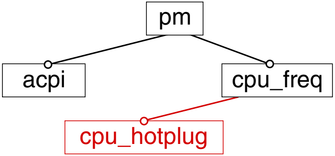
Root feature.

Feature model syntax.



Optional features.

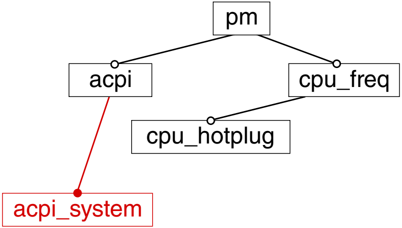
Feature model syntax.



Child features / feature hierarchy.

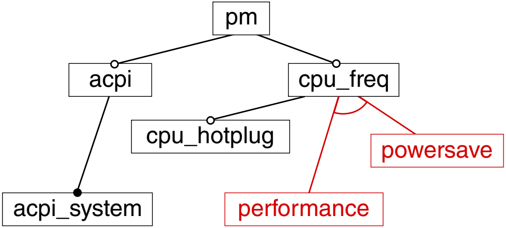
In feature models, *child* $\rightarrow$ *parent*

Feature model syntax.



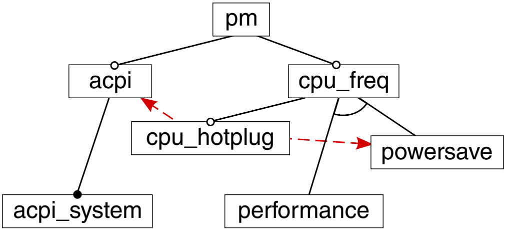
Mandatory feature.

Feature model syntax.



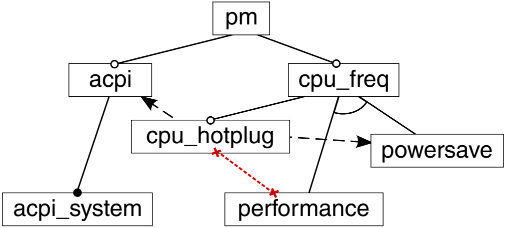
XOR-*group.*

Feature model syntax.



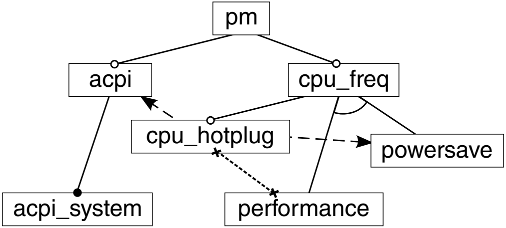
Implies edges.

Feature model syntax.



Excludes edges.

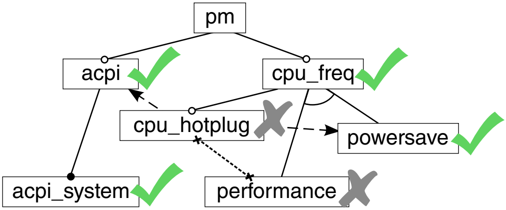
Feature model syntax.



$$\textbf{powersave} \wedge \textbf{acpi} \rightarrow \textbf{cpu\_hotplug}$$

Additional cross-tree constraints.

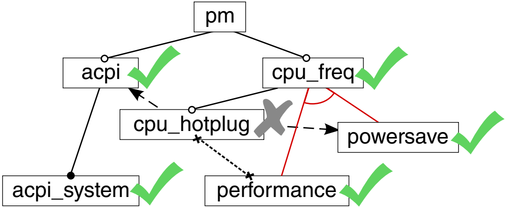
Legal configurations.



{ pm, acpi, acpi_system, cpu_freq, powersave }

Valid Configuration.

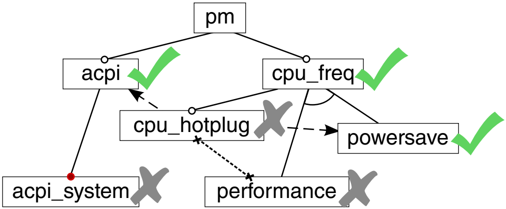
Legal configurations.



{ pm, acpi, acpi_system, cpu_freq, powersave, performance }

Invalid Configuration: violates XOR-group.

Legal configurations.



{ pm, acpi, cpu_freq, powersave }

Invalid Configuration: violates mandatory feature.

Why reverse-engineer a feature model?

- Many product lines manage variability in an ad-hoc manner.
  e.g. FreeBSD, vim, Mplayer, etc.
- For these systems, features and dependencies are hidden in documentation, code and build system.
- Feature models make features and dependencies explicit.
- Feature models are well-understood with tool support (e.g. configurators) and automated analysis.

FreeBSD.

Configuring FreeBSD:

```
# IPI_PREEMPTION relies on the PREEMPTION option

# Mandatory:
Device apic                # I/O apic

# Optional:
options MPTABLE_FORCE_HTT #enable HTT CPUs ...
options IPI_PREEMPTION
```

Code:

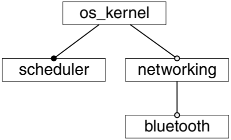
```
MODULE_DEPEND(at91_twi, iicbus, …);
#ifdef A … #endif
```

Features and dependencies are scattered through code and documentation.

Reverse-engineering steps.

```
#ifdef A
   #ifndef B
       #error ...
    #endif
#endif
```

scheduler $\leftrightarrow$ os_kernel
networking $\rightarrow$ os_kernel
bluetooth $\rightarrow$ networking



bluetooth is a network driver.

Descriptions

Codebase

Feature names

Feature Model

Dependencies

Reverse-engineering steps.

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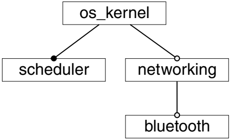

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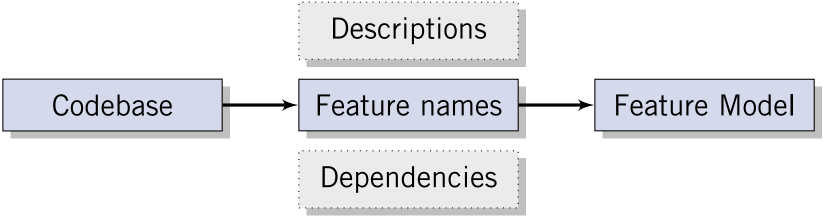

Feature names are needed to build a feature model.

Reverse-engineering steps.

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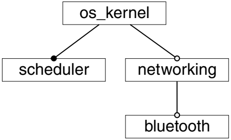

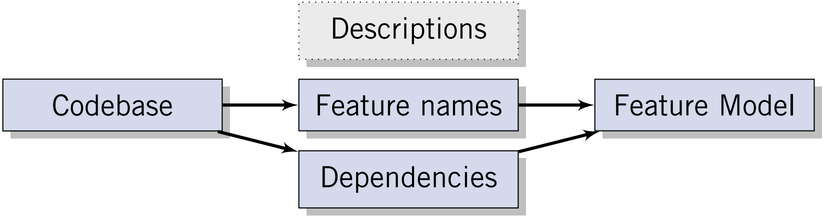

Let's first try to reverse-engineer a feature model using just names and dependencies.

Using just names and dependencies.

Given these features:

$$\{\text{os\_kernel}, \text{scheduler}, \text{networking}, \text{bluetooth}\}$$

…and these dependencies:

1. $(\text{bluetooth} \vee \text{networking} \vee \text{scheduler} \rightarrow \text{os\_kernel})$
2. $\wedge\ (\text{os\_kernel} \rightarrow \text{scheduler})$
3. $\wedge\ (\text{bluetooth} \rightarrow \text{networking})$

- What are the legal configurations of features?
- What is the feature model that describes these legal configurations?

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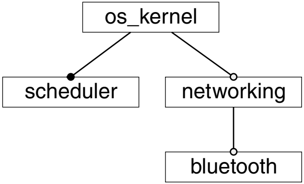
Many possible models.



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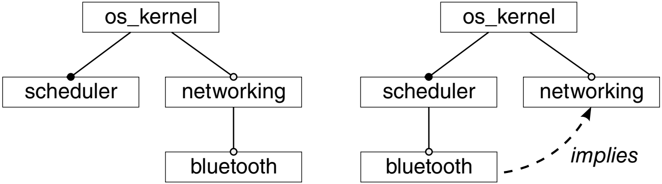

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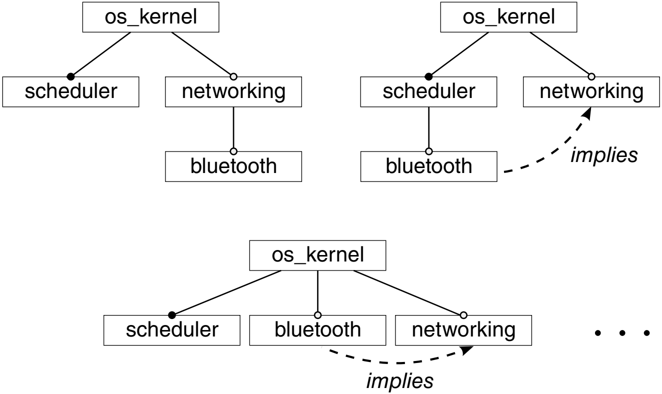

- All these models are refactorings.
- All describe the same features and dependencies.
- We need domain knowledge to identify the best model.

Reverse-engineering steps.

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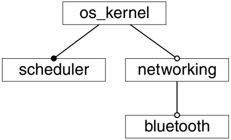
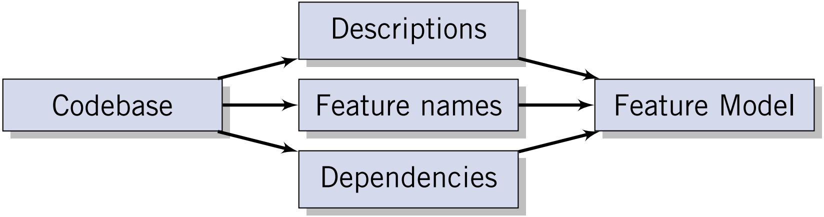
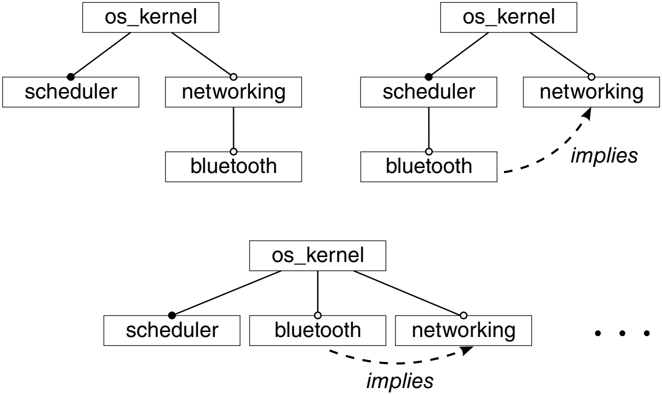


bluetooth is a network driver.



Leverage both names and descriptions for additional domain knowledge.

Many possible models.



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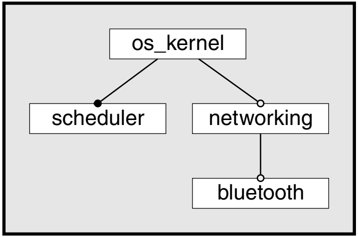

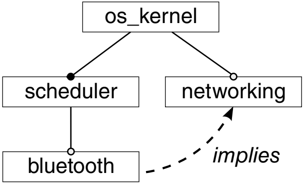

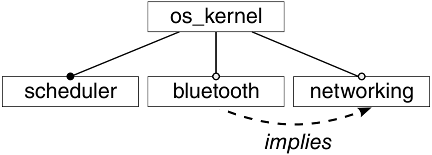

. . .

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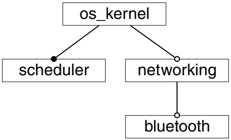

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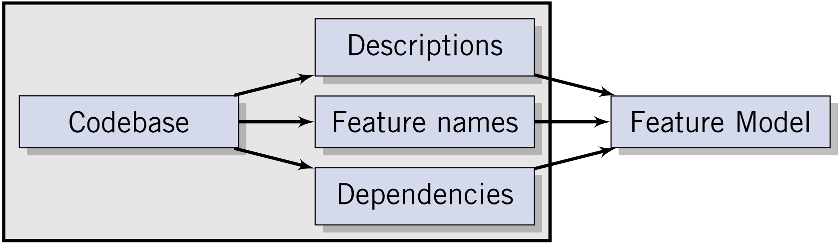

We rely on existing and ongoing work to extract necessary input from code and documentation. [Berger et al. 2010]

Reverse-engineering steps.

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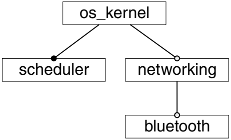

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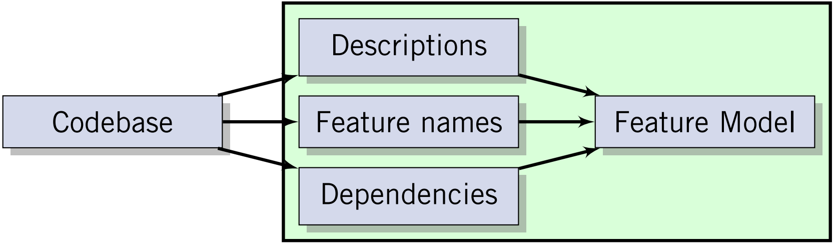


This work uses feature names, descriptions and dependencies to build a feature model.

Goal.

Provide support for reverse-engineering a large-scale feature model from existing project artifacts.

- A project (e.g. FreeBSD) could benefit from a FM for configuration and analysis.
- Many possible FMs describe the same features and dependencies—exponential!
- Our work provides assistance for building feature hierarchy by significantly reducing choices for the model builder.
- Other FM elements, such as groups, are detected automatically.

Outline.

1 Introduction

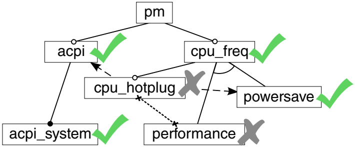
2 Procedures

3 Evaluation

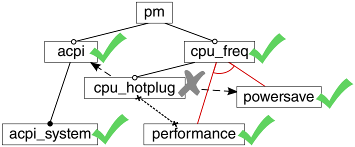
4 Conclusions

Configuration semantics.

The configuration semantics of a feature model is a set of legal configurations.



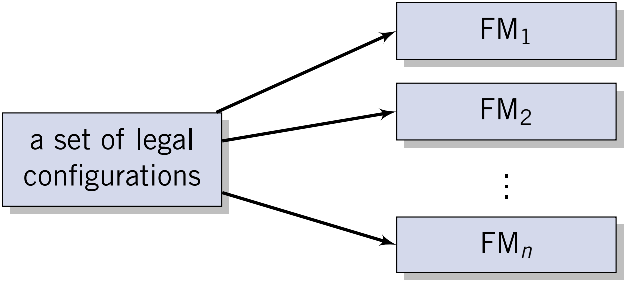
Legal configuration.



Illegal configuration.

Reverse-engineering.

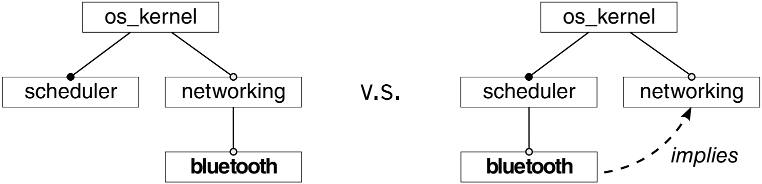
A set of legal configurations can be represented by many *possible feature models.*



- The configuration semantics alone are not enough to identify a unique FM.

Domain semantics.

The domain semantics are the meaning of the features and are reflected in the names and hierarchy.



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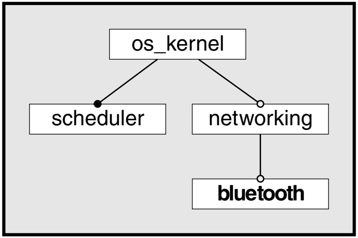
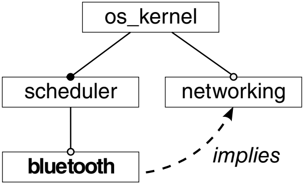


v.s.



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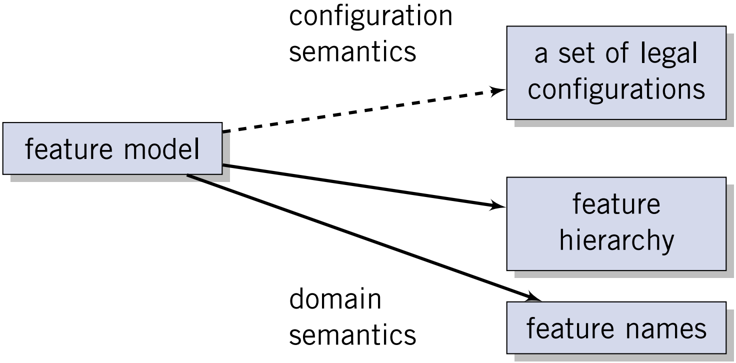
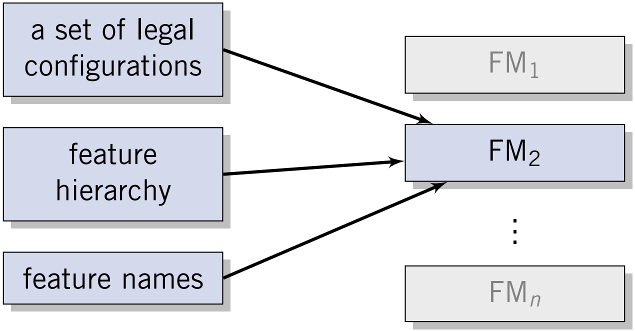
Domain semantics (cont.)

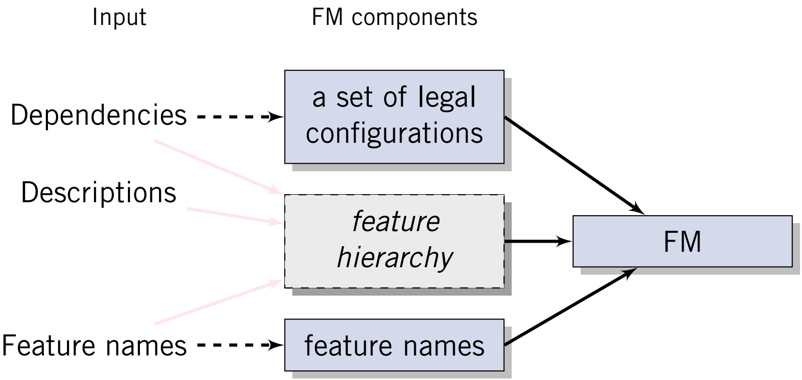


Reverse-engineering II.

Given a set of legal configurations, feature names and a hierarchy, a precise FM can be reverse-engineered.

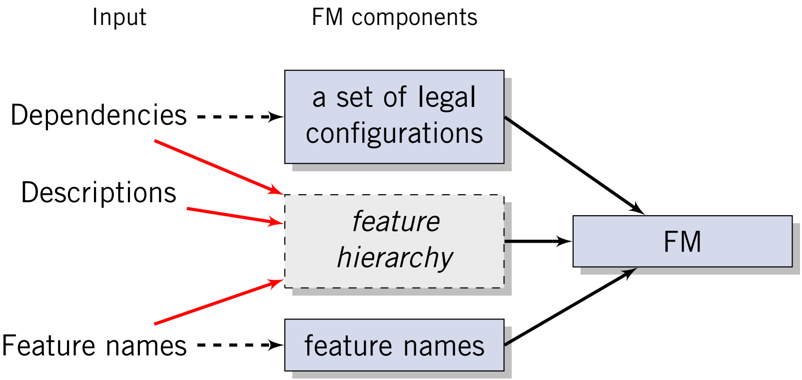


Reverse-engineering II (cont.)



- When reverse-engineering a FM, the feature hierarchy doesn't exist yet.

Reverse-engineering II (cont.)



- We can build the feature hierarchy using dependencies, names and descriptions.

Building the feature hierarchy.

1. Determine a parent for every feature:
   - We use the names and descriptions to propose a hierarchy that reflects domain semantics.
   - An interactive, tool-assisted procedure.
   - Given a feature, rank choices for its parent by similarity.
2. A child must imply its parent:
   - The meaning of the hierarchy in a feature model.
   - Generate an implication graph from dependencies.

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Feature similarity.

Feature names and descriptions	
os_kernel	Operating system.
scheduler	I/O scheduling.
networking	Networking drivers.
ethernet	Type of local area networking.

Selecting a parent for:

bluetooth, a network driver.

Feature similarity.

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Implication graph.

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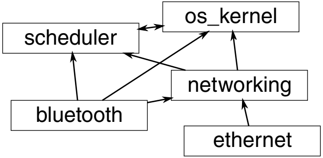

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- ethernet is not shown—not a choice for parent.
- Implications significantly reduce the number of choices.
- But, in a practical setting, dependencies may be incomplete.

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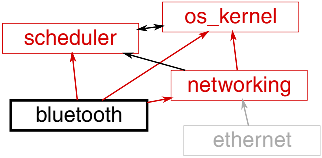

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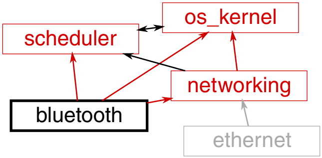

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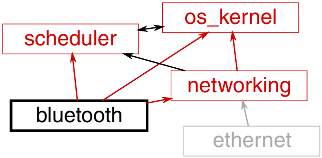
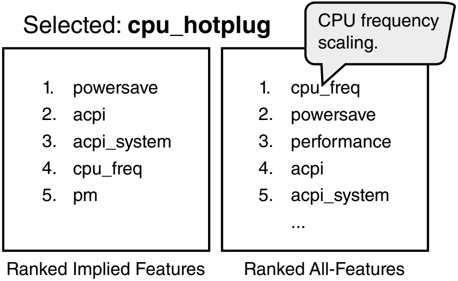


Selecting a parent for:

bluetooth, a network driver.

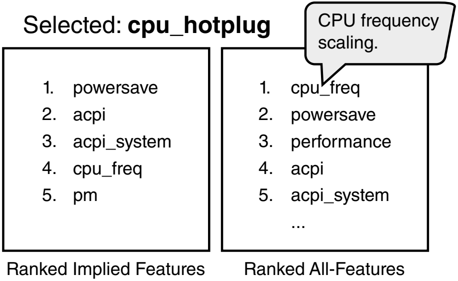
- ethernet is not shown—not a choice for parent.
- Implications significantly reduce the number of choices.
- But, in a practical setting, dependencies may be incomplete.

Two lists: RIFs and RAFs.



- **Ranked Implied Features (RIFs)**
  implied features sorted by similarity to the selected feature.
- **Ranked All-Features (RAFs)**
  all features sorted by similarity to the selected feature.

Two lists: RIFs and RAFs.



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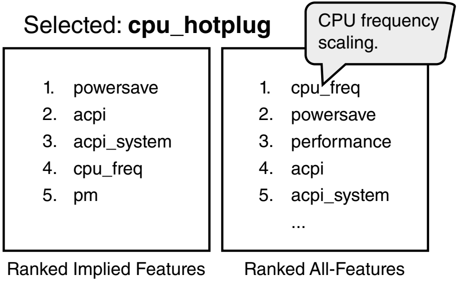

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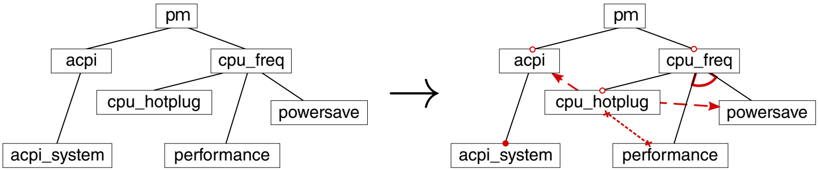
  implied features sorted by similarity to the selected feature.
- **Ranked All-Features (RAFs)**
  all features sorted by similarity to the selected feature.

Other FM constructs.



- User selects a parent for every feature.
- Once a hierarchy is built, other constructs, such as mandatory features and groups, are automatically detected.
- If feature groups overlap, user selects groups to retain.

Outline.

1 Introduction

2 Procedures

3 Evaluation

4 Conclusions

Evaluation questions.

Our similarity measure should reduce the number of choices to only a few when determining a parent for a feature.

1. How many features have their reference parents ranked in the top 5 of our RIFs?
   - Evaluated on complete and incomplete input.

2. How many features are needed for finding 75% of reference parents using the RAFs?

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Evaluation subjects.

Complete input:

- Reference feature models: Linux and eCos.
- Linux has roughly 5000 features; eCos 1200 features.

Incomplete input:

- A portion of FreeBSD.
- Domain analysis to create reference model of 90 features.
- Extracted input dependencies by analyzing preprocessor usage, documentation, etc.
- Simulated incomplete input on Linux and eCos by randomly removing dependencies and words.

Evaluation results for RIFs.

1. How many features have their reference parents ranked in the top 5 of our RIFs?
   - Linux: 76% of features, eCos: 79% of features.
   - Ignoring root features, 90% for Linux and 81% for eCos.
   - For incomplete descriptions, At least 50% of words needed for good results (roughly 10 words in Linux).

Evaluation results for RAFs.

2. How many features are needed for finding 75% of reference parents using the RAFs?
   - Linux: 3% of features, eCos: 6% of features.
   - For incomplete descriptions, 50% of words needed for good results.

More details in paper.

Outline.

Related work.

- Past work looked at only dependencies and didn't deal with multiple possible models.

  [CW 2007]

- Other works have applied textual similarity metrics, but don't take dependencies into account.

  [Alves et al. 2008, Niu et al. 2008]

- Past work attempts to create models automatically and not interactively.

Conclusions.

Future Work.

- Further develop the extraction of dependencies from a codebase.
- Integrate techniques into an existing FM editor.

Conclusions.

- Our procedure deals with incomplete input.
- Combine the use of dependencies and textual similarity.
- Problem requires domain knowledge—tool-assisted.
- Provide empirical data on how effective this technique is on three projects: Linux, eCos and FreeBSD.