

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.

What are feature models?

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

The screenshot displays a web-based car configurator for a 2011 BMW 335i Convertible. The main area features a 3D rendering of the car. To the right, a 'My 335i Convertible' summary box lists the base MSRP at \$52,650 and a total MSRP of \$54,073. Below the car image, various optional packages are listed with their respective prices:

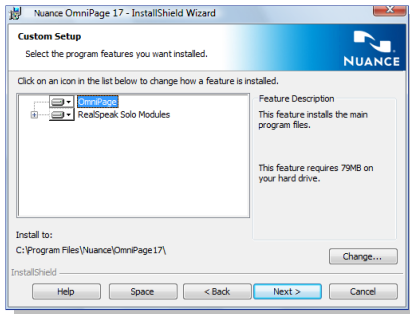
- Cold Weather Package** (\$99): Thaw-aiding system with integrated transport bag, Retractable headlight washers, Heated front seats.
- Convenience Package** (\$1,250): Anti-theft alarm system, Comfort Access keyless entry, Park Distance Control.
- Performance Package** (\$1,656): Motor noise with suspension, BMW Assist with Bluetooth, Leather interior, Auto-dimming interior and exterior mirrors, Universal garage door opener.
- M Sport Package** (\$2,000): 17" Light alloy (the grille wheels style 1039) with performance run-flat tires.
- M Sport Package** (\$1,990): 17" Light alloy (the grille wheels style 220) with performance run-flat tires, Sport suspension, Aerodynamic kit, Sport seats, M Sport leather steering wheel with paddle.

The right-hand side also includes a 'BMW Ultimate Service' section with three included services: 4 years/50,000 miles warranty, 4 years/50,000 miles maintenance program, and 4 years/50,000 miles roadside assistance. A 'Total MSRP as Built' of \$54,073 is shown, with a note that lease offers are being calculated. At the bottom, there are buttons for 'Start Options', 'Estimate a Payment', 'Get a Quote', and 'Download Brochure', along with a navigation bar for 'Home', 'Contact Us', 'Print', and 'Save'.

Car configurator.

What are feature models?

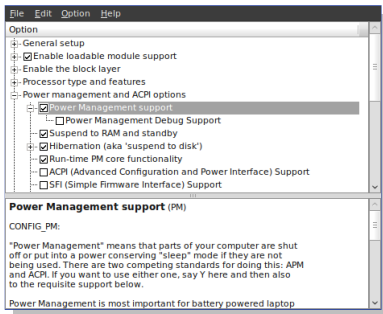
Feature models describe the common and variable characteristics of products in a product line.



Installation wizards.

What are feature models?

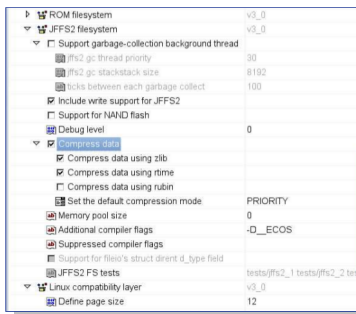
Feature models describe the common and variable characteristics of products in a product line.



Linux kernel configurator.

What are feature models?

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



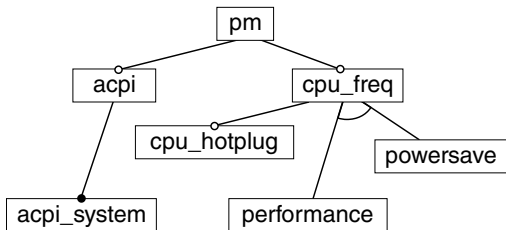
The image shows a screenshot of the eCos kernel configurator interface. It displays a tree view of feature models for the ROM and JFFS2 filesystems. The JFFS2 filesystem section is expanded, showing various configuration options such as garbage collection background thread, thread priority, stack size, and write support. The 'Compress data' option is highlighted in blue.

| | |
|---|----------------------------------|
| ROM filesystem | v3_0 |
| JFFS2 filesystem | v3_0 |
| Support garbage-collection background thread | |
| jffs2 gc thread priority | 30 |
| jffs2 gc stacksize size | 8192 |
| ticks between each garbage collect | 100 |
| <input checked="" type="checkbox"/> Include write support for JFFS2 | |
| <input type="checkbox"/> Support for NAND flash | |
| Debug level | 0 |
| <input checked="" type="checkbox"/> Compress data | |
| <input checked="" type="checkbox"/> Compress data using zlib | |
| <input checked="" type="checkbox"/> Compress data using rtme | |
| <input type="checkbox"/> Compress data using rubin | |
| Set the default compression mode | PRIORITY |
| Memory pool size | 0 |
| Additional compiler flags | -D_ECOS |
| Suppressed compiler flags | |
| Support for fileio's struct dirent d_type field | |
| JFFS2 FS tests | tests/jffs2_1 tests/jffs2_2 test |
| Linux compatibility layer | v3_0 |
| Define page size | 12 |

eCos kernel configurator.

What are feature models?

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



$\text{powersave} \wedge \text{acpi} \rightarrow \text{cpu_hotplug}$

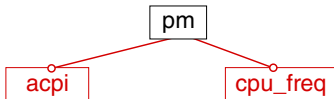
FODA feature model [Kang et al. 1990]

Feature model syntax.

pm

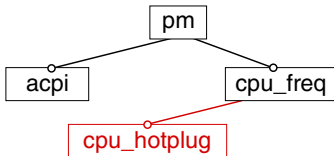
Root feature.

Feature model syntax.



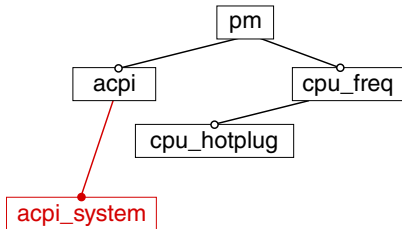
Optional features.

Feature model syntax.



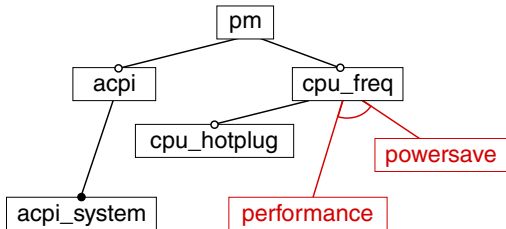
Child features / feature hierarchy.
In feature models, *child* → *parent*

Feature model syntax.



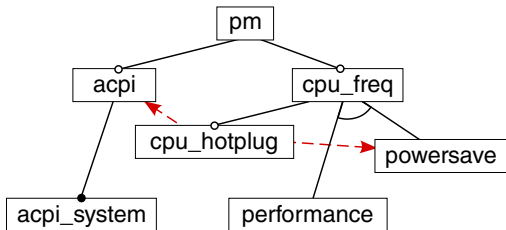
Mandatory feature.

Feature model syntax.



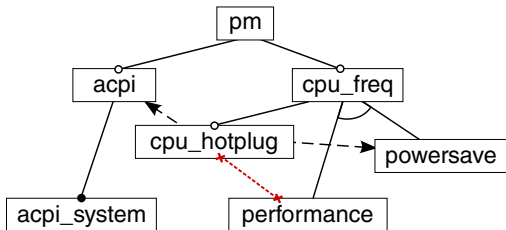
XOR-group.

Feature model syntax.



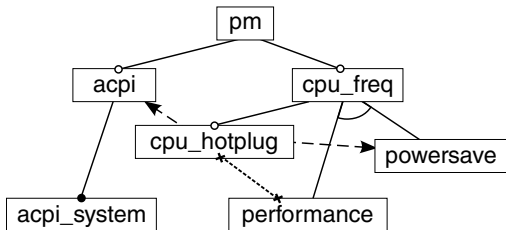
Implies edges.

Feature model syntax.



Excludes edges.

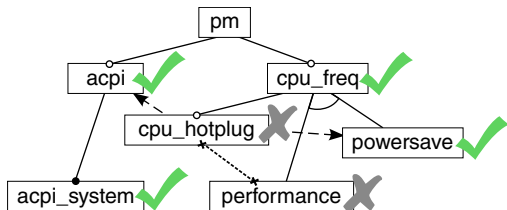
Feature model syntax.



$\text{powersave} \wedge \text{acpi} \rightarrow \text{cpu_hotplug}$

Additional cross-tree constraints.

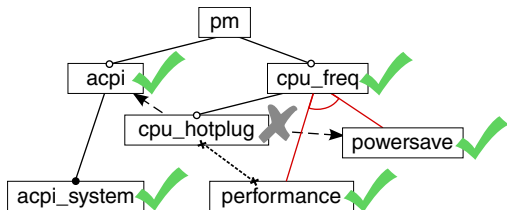
Legal configurations.



{ pm, acpi, acpi_system, cpu_freq, powersave }

Valid Configuration.

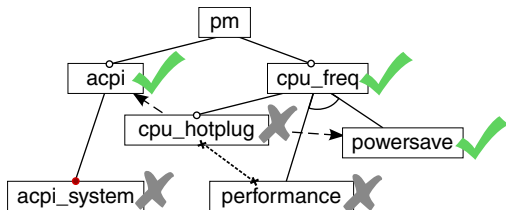
Legal configurations.



{ 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_HTTP #enable HTTP CPUs ...
options IPI_PREEMPTION
```

Code:

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

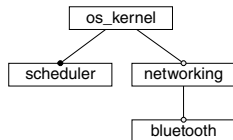
Features and dependencies are scattered through code and documentation.

Reverse-engineering steps.

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

```
scheduler ↔ os_kernel
networking → os_kernel
bluetooth → networking
```

bluetooth is a network driver.



Codebase

Descriptions

Feature names

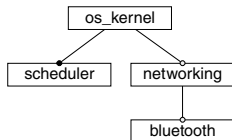
Dependencies

Feature Model

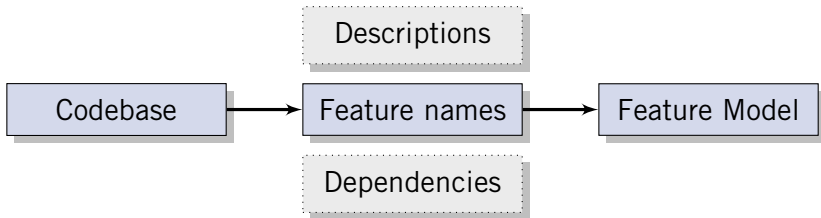
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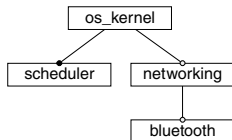


Feature names are needed to build a feature model.

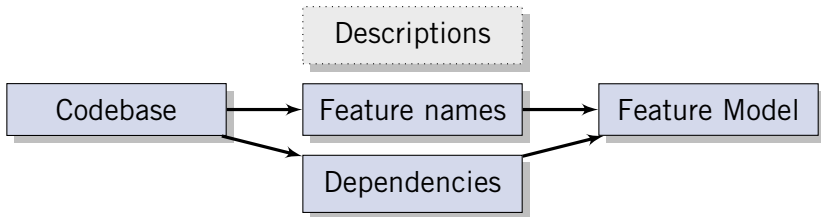
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bluetooth is a network driver.



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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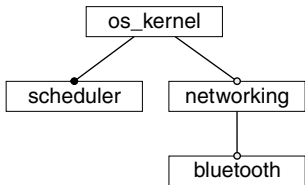
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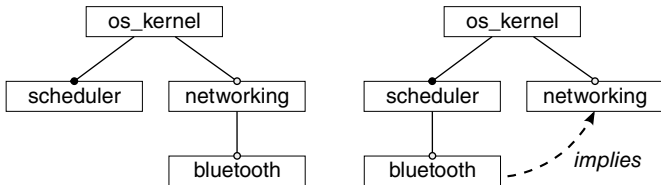
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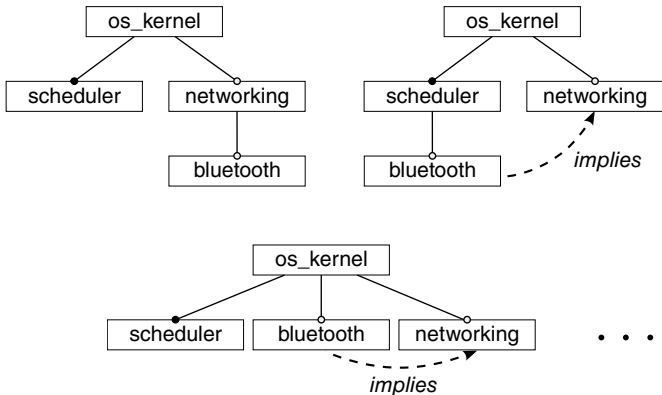
Many possible models.



Many possible models.



Many possible models.

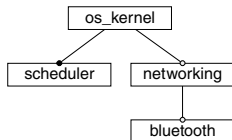


- All these models are refactorings.
- All describe the same features and dependencies.
- We need domain knowledge to identify the best model.

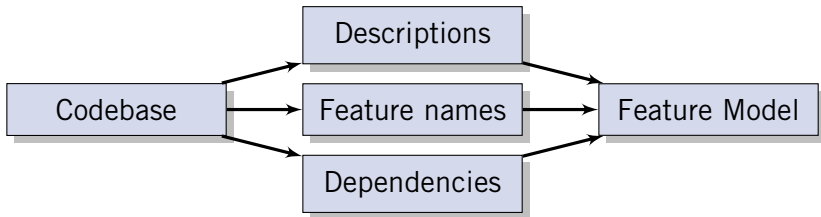
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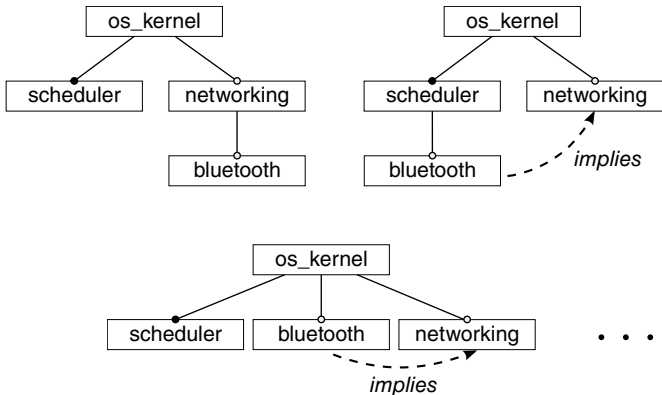


bluetooth is a network driver.



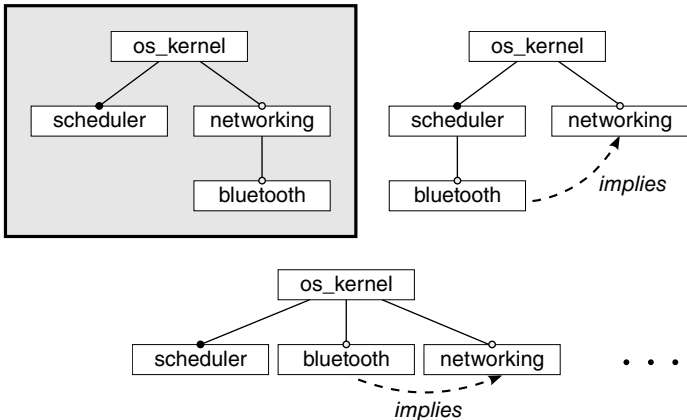
Leverage both names and descriptions for additional domain knowledge.

Many possible models.



`bluetooth` is a network driver.

Many possible models.

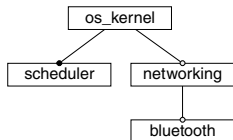


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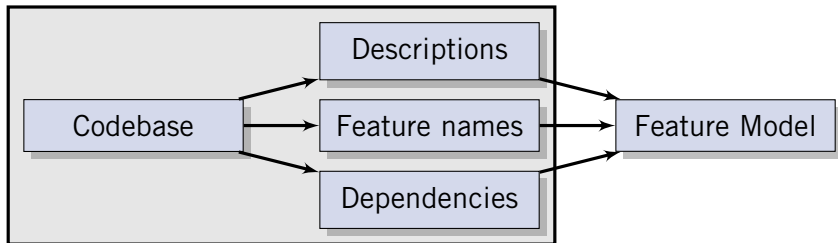
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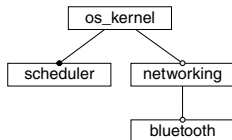


We rely on existing and ongoing work to extract necessary input from code and documentation. [Berger et al. 2010]

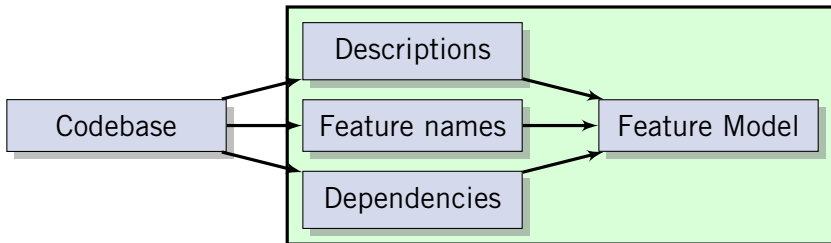
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This work uses feature names, descriptions and dependencies to build a feature model.

Goal.

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

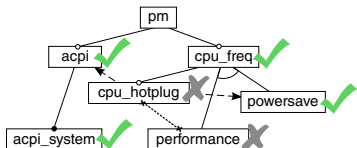
- A project (e.g. FreeBSD) could benefit from a FM for configuration and analysis.
- Many possible FMs describe the same features and dependencies—exponential!
- Our work provides assistance for building feature hierarchy by significantly reducing choices for the model builder.
- Other FM elements, such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

Outline.

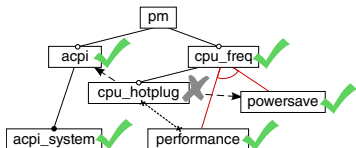
- 1 Introduction
- 2 Procedures**
- 3 Evaluation
- 4 Conclusions

Configuration semantics.

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



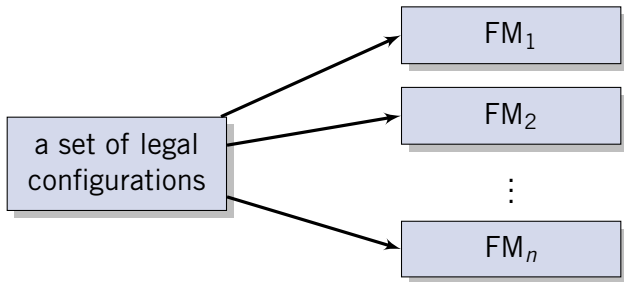
Legal configuration.



Illegal configuration.

Reverse-engineering.

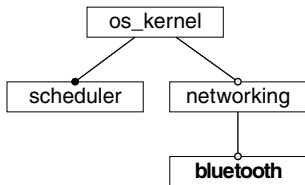
A set of legal configurations can be represented by many possible feature models.



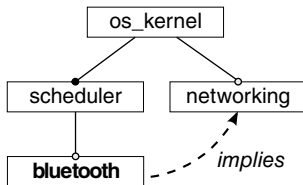
- The configuration semantics alone are not enough to identify a unique FM.

Domain semantics.

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

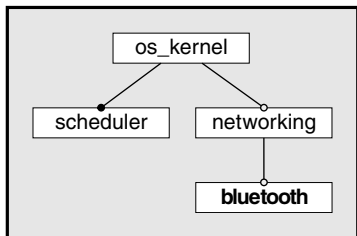


V.S.

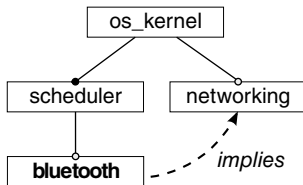


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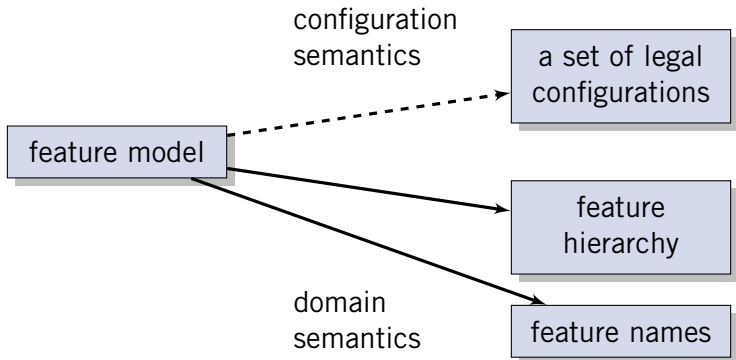


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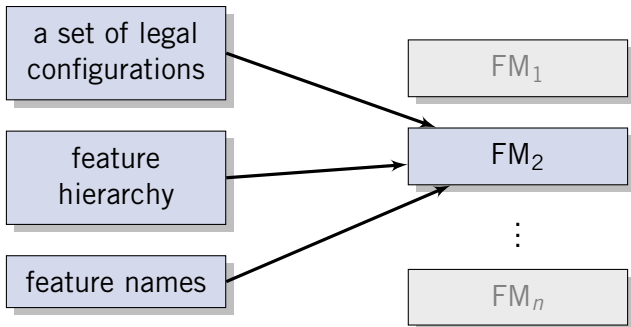
bluetooth is a network driver.

Domain semantics (cont.)

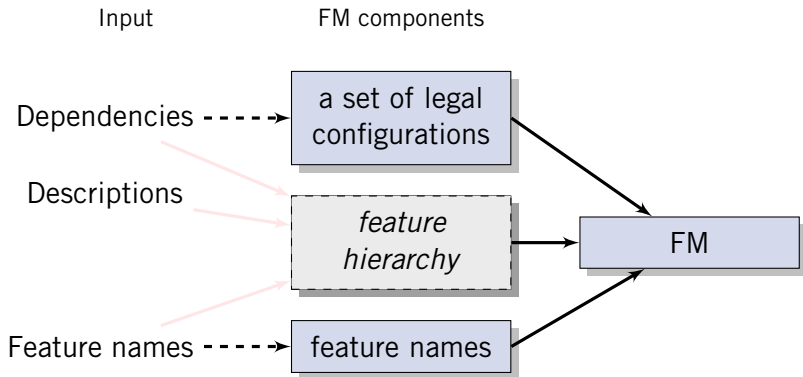


Reverse-engineering II.

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

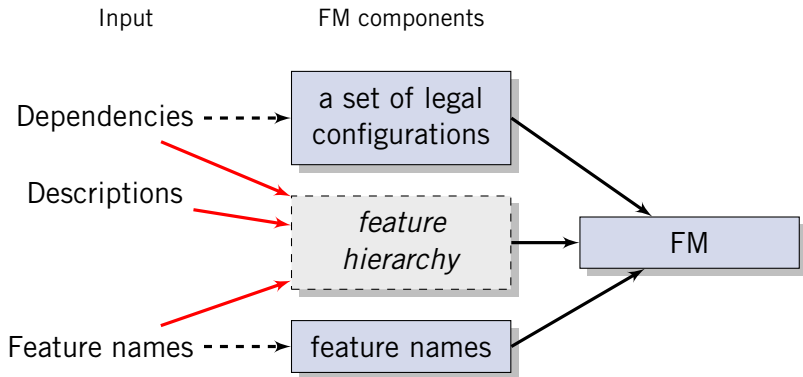


Reverse-engineering II (cont.)



- 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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 - The meaning of the hierarchy in a feature model.
 - Generate an implication graph from dependencies.

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.

Feature names and descriptions

| | |
|-------------------------|--------------------------------|
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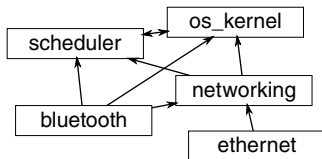
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Selecting a parent for:

`bluetooth`, a network driver.

Implication graph.

A child must imply its parent in the feature hierarchy.



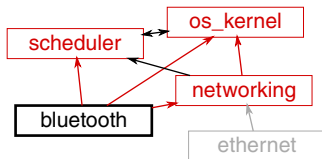
Selecting a parent for:

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.

Implication graph.

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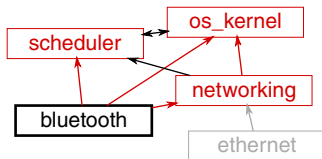
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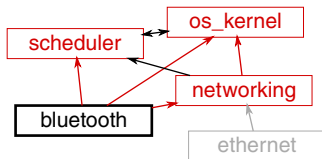
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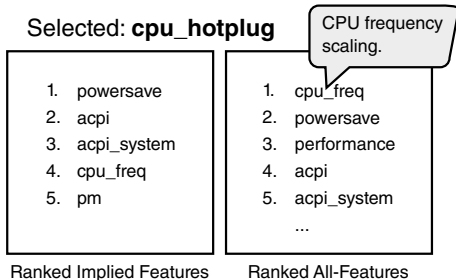


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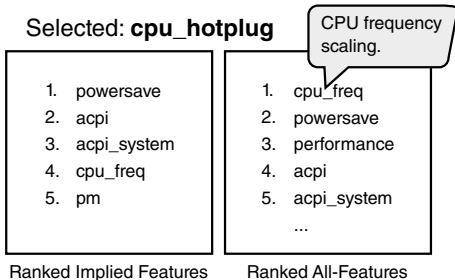
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Two lists: RIFs and RAFs.



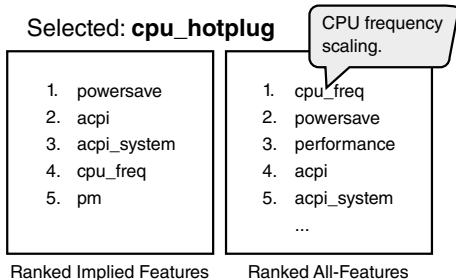
- **Ranked Implied Features (RIFs)**
implied features sorted by similarity to the selected feature.
- **Ranked All-Features (RAFs)**
all features sorted by similarity to the selected feature.

Two lists: RIFs and RAFs.



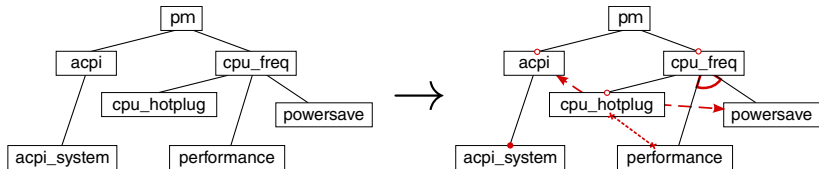
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all features sorted by similarity to the selected feature.

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.

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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.