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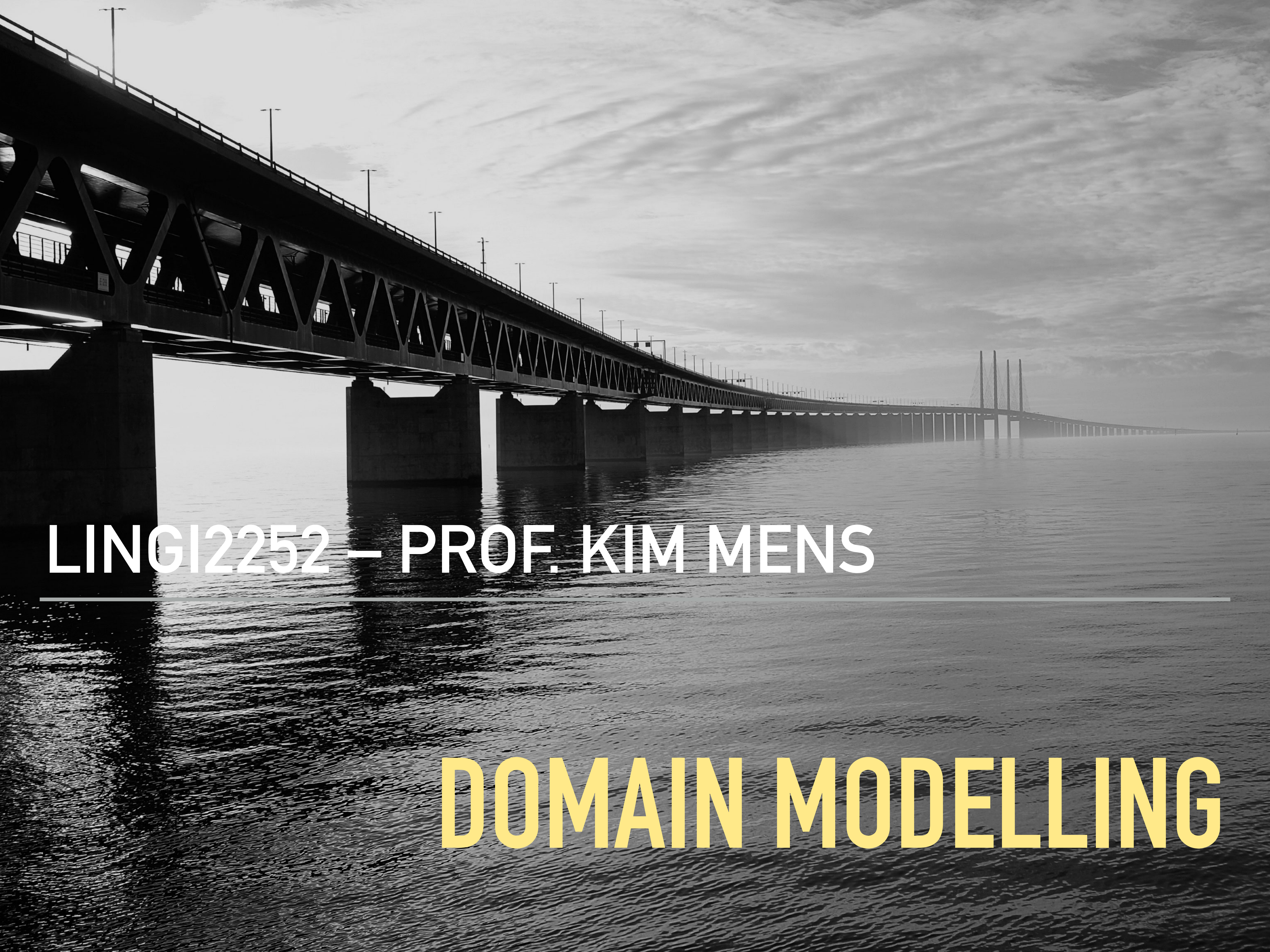
SOFTWARE MAINTENANCE & EVOLUTION



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DOMAIN MODELLING

MAIN CAUSES OF MAINTENANCE PROBLEMS

DOMAIN ANALYSIS TO THE RESCUE

Poor quality of the software documentation

Poor software quality (e.g., unstructured code, too large components, inadequate design)

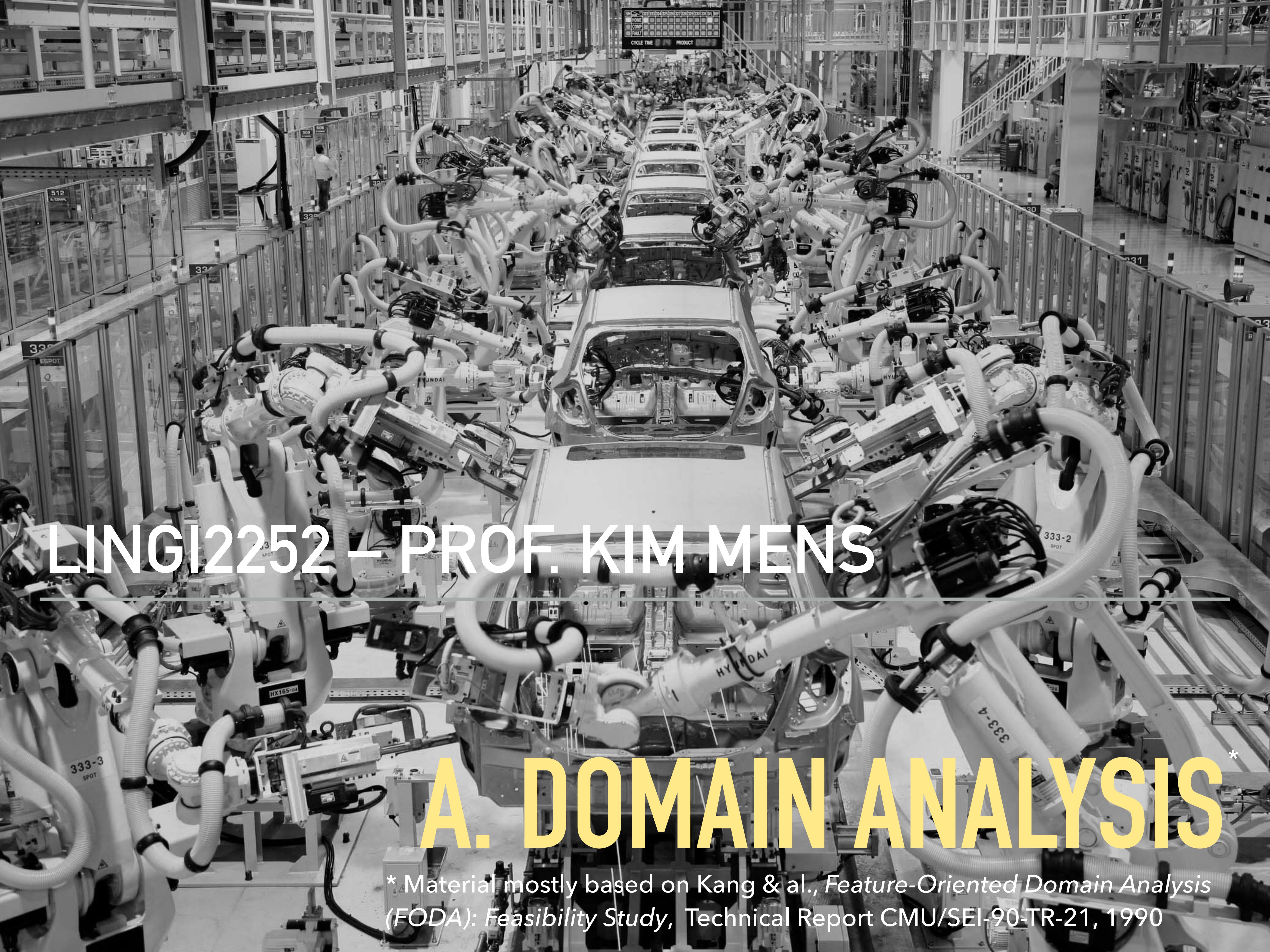
Insufficient knowledge about the system and its domain

- (maybe unavailable due to personnel turnover)

REMEMBER?

Ineffectiveness of maintenance team

- low productivity, low motivation, low skill levels, competing demands for programmer time



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A. DOMAIN ANALYSIS*

* Material mostly based on Kang & al., *Feature-Oriented Domain Analysis (FODA): Feasibility Study*, Technical Report CMU/SEI-90-TR-21, 1990

ASSEMBLY LINES*

Factory assembly lines

are able to build a series of similar products in large quantities

Economies of scale: *savings from using technology to produce a greater volume of a single output with the same or less inputs*

* Slide based on slides by A. van Deursen, Domain Engineering, 2001

SOFTWARE PRODUCT LINES *

Inspired by factory assembly lines

Software product lines (SPL)

- are about building a family of software systems
- sharing a set of common (and differing) features
- that satisfy the needs of a particular domain

Economies of scope: savings from using technology to build a greater diversity of outputs with the same or less inputs

* Slide based on slides by A. van Deursen, Domain Engineering, 2001

EXAMPLES OF DOMAINS

Window management systems* (MSWindows, X windows, …)

Text or graphical editors

Television broadcast planning systems

Air traffic control systems

Telephone switches

Insurance portals

On-line banking applications

* Example used in [Kang & al. 1990]

SOFTWARE PRODUCT LINES *

Today many systems are engineered using a Software Product Line approach

Product Line architectures exploit the commonalities and variabilities of systems to maximise reuse across all products and market segments

The product portfolio of a company is (sometimes) described in terms of "features" rather than a set of requirements

Industrial Software Product Lines face the challenge to manage hundreds of features and the diversity of the product portfolio

* Slide based on slides by R. Capilla, Variability in the Context, 2018

SNEAK PREVIEW

OBJECT-ORIENTED APPLICATION FRAMEWORKS*

- One particular implementation technique for building software families
- Object-oriented application frameworks
  - Support reuse beyond the class level
  - by defining a set of cooperating classes embodying an abstract design
  - that can be used to solve a family of related problems
- Building a custom application from a framework is typically done through class specialisation
- Principle of inversion of control: framework calls the application code

MORE ON THIS LATER...

* Slide based on slides by A. van Deursen, Domain Engineering, 2001

DOMAIN ANALYSIS*

Captures **domain knowledge** of experts for **related class of systems**

Supports **software reuse** by capturing **domain expertise** and **understanding**

Method for discovering and representing **commonalities** among related software systems

- e.g., common capabilities and data

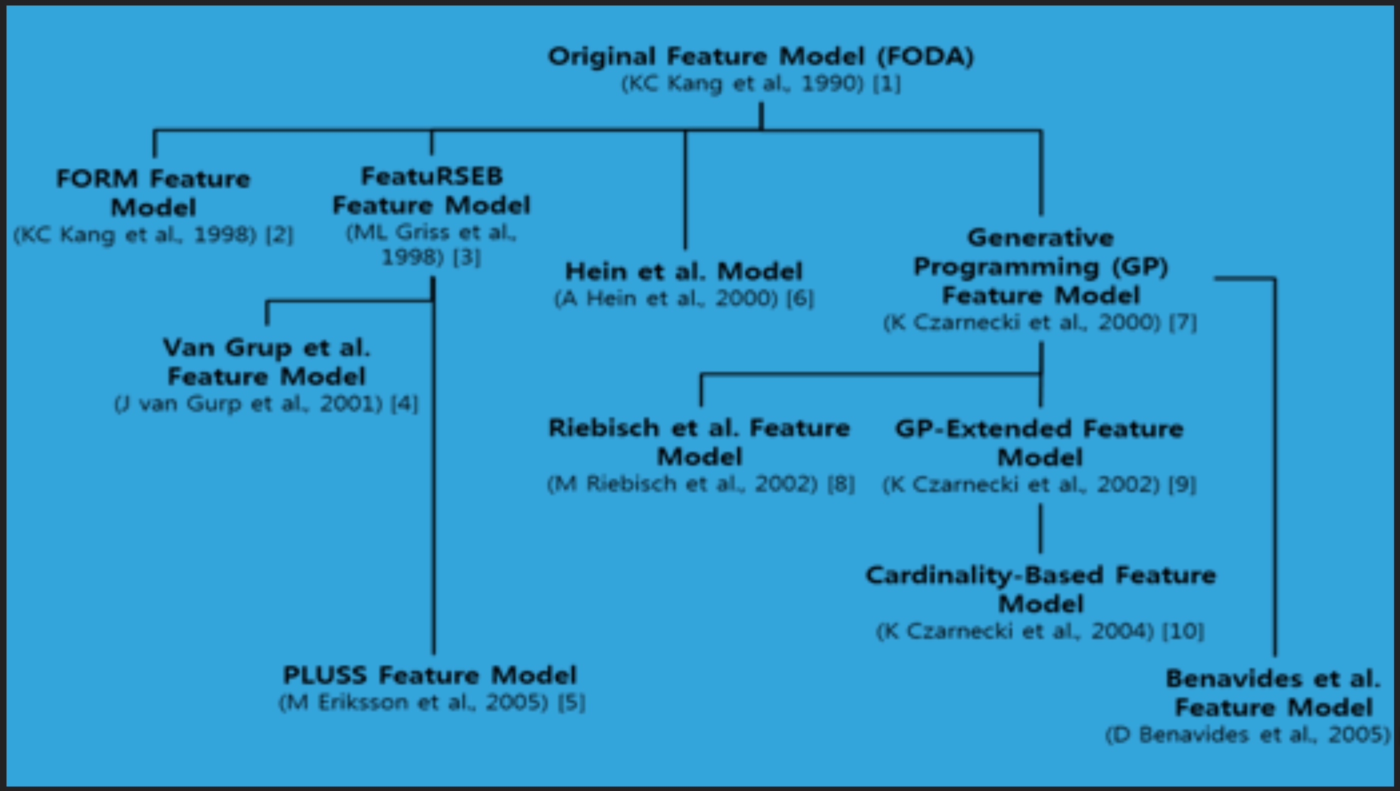
Feature-Oriented Domain Analysis as particular domain analysis technique

* [Prieto-Diaz1990] Ruben Prieto-Diaz, Domain Analysis: An Introduction. *ACM SIGSOFT Software Engineering Notes* 15(2):47-54, April, 1990.

FEATURE-ORIENTED DOMAIN ANALYSIS (FODA) *

FODA is a technique used since ~30 years for modelling the common and variable aspects of systems

Different FODA models and their extensions have been proposed over these years



* Slide based on slides by R. Capilla, Variability in the Context, 2018

FEATURE-ORIENTED DOMAIN ANALYSIS (FODA) *

Primary focus is the identification of **prominent or distinctive features** of software **systems in a domain**

- **Commonalities** = what features all systems in the domain have in common
- **Variabilities** = distinguishing features between different systems in the domain

Leads to the creation of a set of products that define the domain

- Analysis of a **product family**, as opposed to a single product

* [Kang & al. 1990] Kang & al., *Feature-Oriented Domain Analysis (FODA): Feasibility Study*, Technical Report CMU/SEI-90-TR-21, 1990

FEATURES

Features are "*user-visible aspects or characteristics*" of a particular application domain

Define both **common** aspects of (the systems in) a domain

As well as **differences** between related systems in the domain

Describe **mandatory**, **optional**, or **alternative** characteristics of these related systems

LINK WITH SOFTWARE REUSE

Domain analysis provides a generic and **reusable** description of the **requirements of a class of systems.**

Defines what is **common** across all systems in that domain.

These common features may be implemented as **reusable components** that may be reused across different systems.

SOME TERMINOLOGY *

Application : a system which provides a set of general services for solving some type of user problem.

Context : the circumstances, situation, or environment in which a particular system exists.

(Application) domain : a set of current and future applications which share a set of common capabilities and data.

Domain analysis : The process of identifying, collecting, organising, and representing the relevant information in a domain based on the study of existing systems and their development histories, knowledge captured from domain experts, underlying theory, and emerging technology within the domain.

* From [Kang & al. 1990]

SOME TERMINOLOGY *

Domain engineering: An encompassing process which includes domain analysis and the subsequent construction of components, methods, and tools that address the problems of system development through the application of the domain analysis products.

Domain model: A definition of the functions, objects, data, and relationships in a domain.

Feature: A prominent or distinctive user-visible aspect, quality, or characteristic of a software system or systems.

User: Either a person or an application that operates a system in order to perform a task.

Reusable component: A software component (including requirements, designs, code, test data, etc.) designed and implemented for the specific purpose of being reused.

* From [Kang & al. 1990]

DOMAIN ANALYSIS PROCESS

Three basic phases :

1. **Context analysis** defines the extent (or bounds) of the domain under analysis
2. **Domain modelling** describes the problems to be addressed by the software in the domain
3. **Architecture modelling** creates the overall software architecture to implement a solution to the problems in that domain

1. CONTEXT ANALYSIS

A domain analyst interacts with users and domain experts to establish the bounds of the domain

The analyst gathers sources of information for performing the analysis

The results of this phase define the scope of the analysis.

- This requires identifying the primary inputs and outputs of software in the domain as well as software interfaces

2. DOMAIN MODELLING

A domain analyst uses information sources and other products of the context analysis to support the creation of a domain model

- Acquiring domain information: experts, legacy systems, literature, prototyping, …

Domain model is reviewed by the user, domain expert, and requirements analyst

Domain model can consist of several artefacts:

- A feature model to describe the software features (commonality & variability)
- A dictionary to define a standard lexicon of domain terminology
- An entity-relationship diagram to document main software entities and their relationships
- Other diagrams to specify generic software requirements, like control flow or data flow diagrams

3. ARCHITECTURE MODELLING

Using the domain model, the domain analyst then produces an architecture model.

This model should be reviewed by the domain expert, the requirements analyst, and the software engineer.

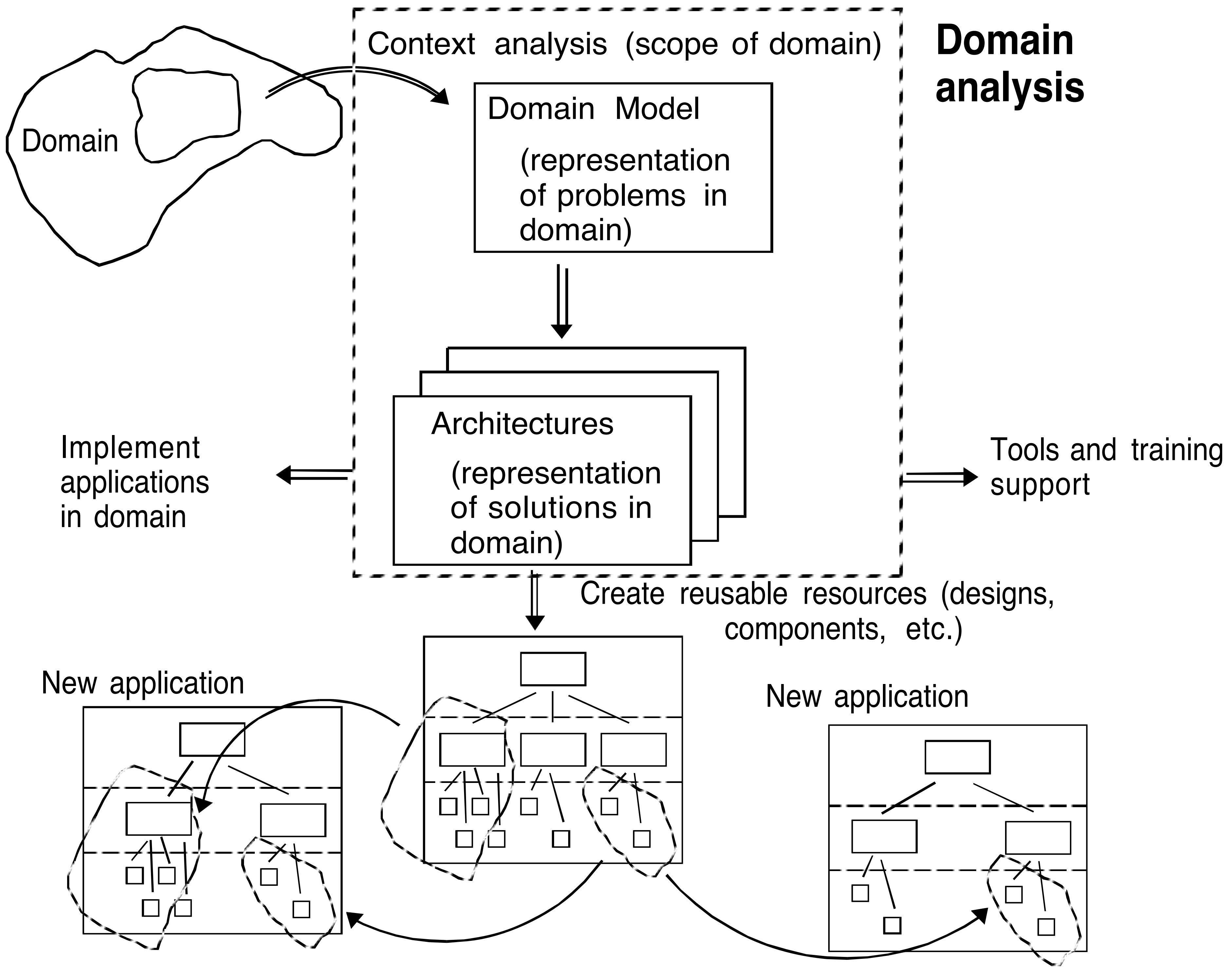
The user does not need to participate in this review.

Architecture model captures the overall structure of the implementation of different software systems in the domain

- different technologies possible: reusable components, domain-specific languages, generators, application frameworks, …

SUMMARY *

* Source: Figure 1-4, page 8 of Kang & al., *Feature-Oriented Domain Analysis (FODA): Feasibility Study*, Technical Report CMU/SEI-90-TR-21, 1990



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B. FEATURE MODELLING

FEATURE (DEFINITIONS)

"A prominent or distinctive user-visible aspect, quality, or characteristic of a software system or systems."

[Kang & al. 1990]

"An increment of a program functionality"

[Bat05]

"A structure that extends and modifies the structure of a given program in order to satisfy a stakeholder's requirement, to implement and encapsulate a design decision, and to offer a configuration option"

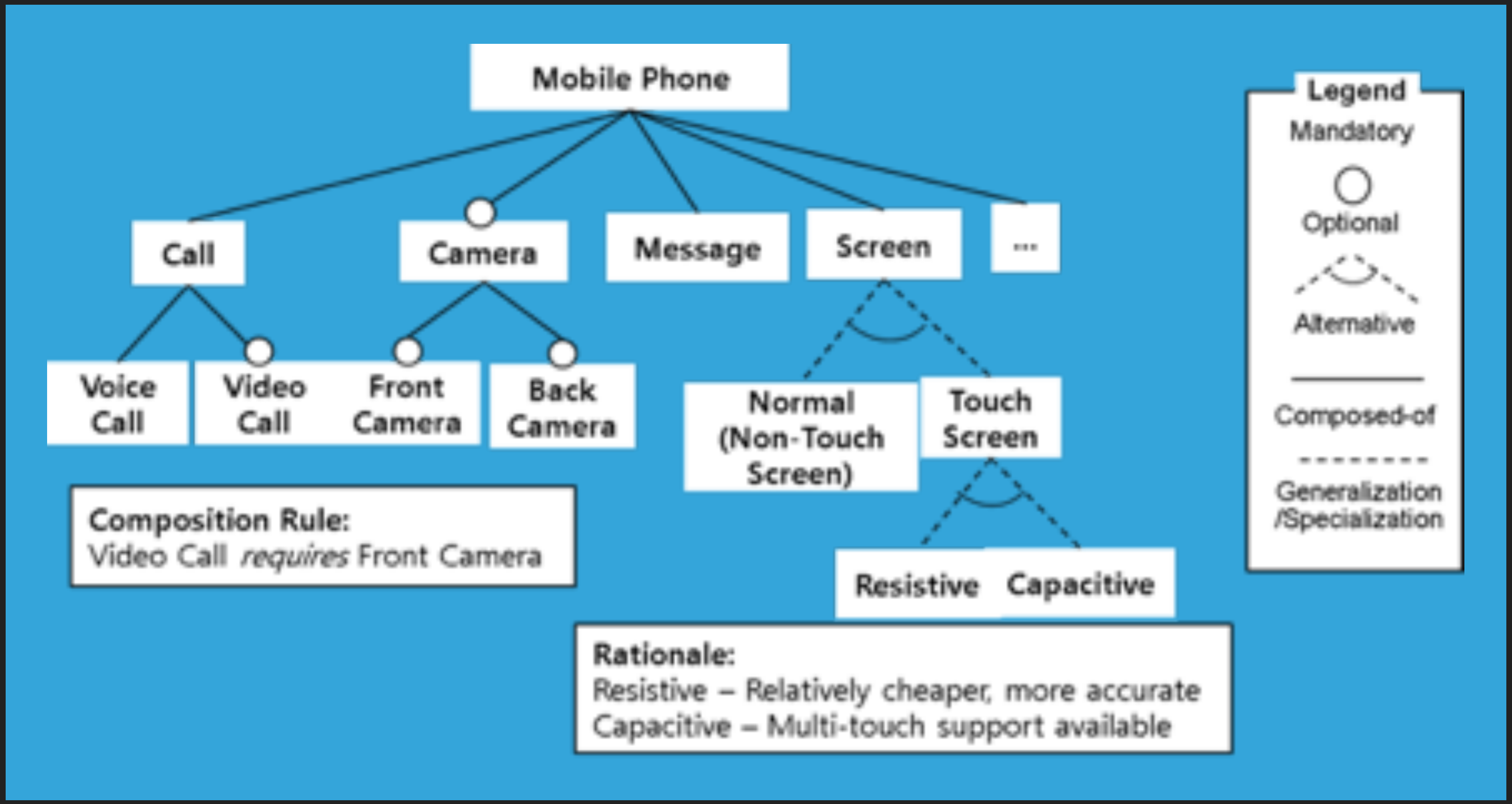
[Apel & al. 2008]

FEATURE MODELLING

Used in domain analysis and software product lines (SPL)

to express commonalities and variabilities of a family of systems

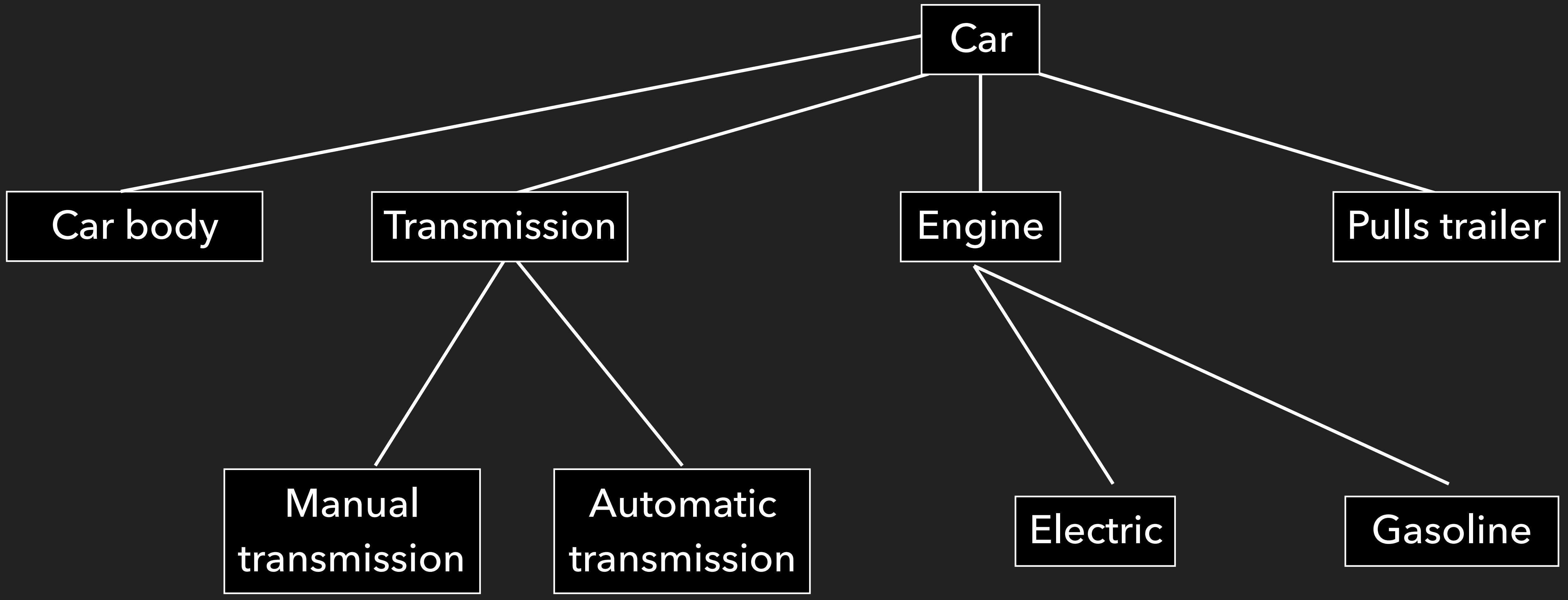
in terms of the features they may offer



FEATURE MODEL – HIERARCHY

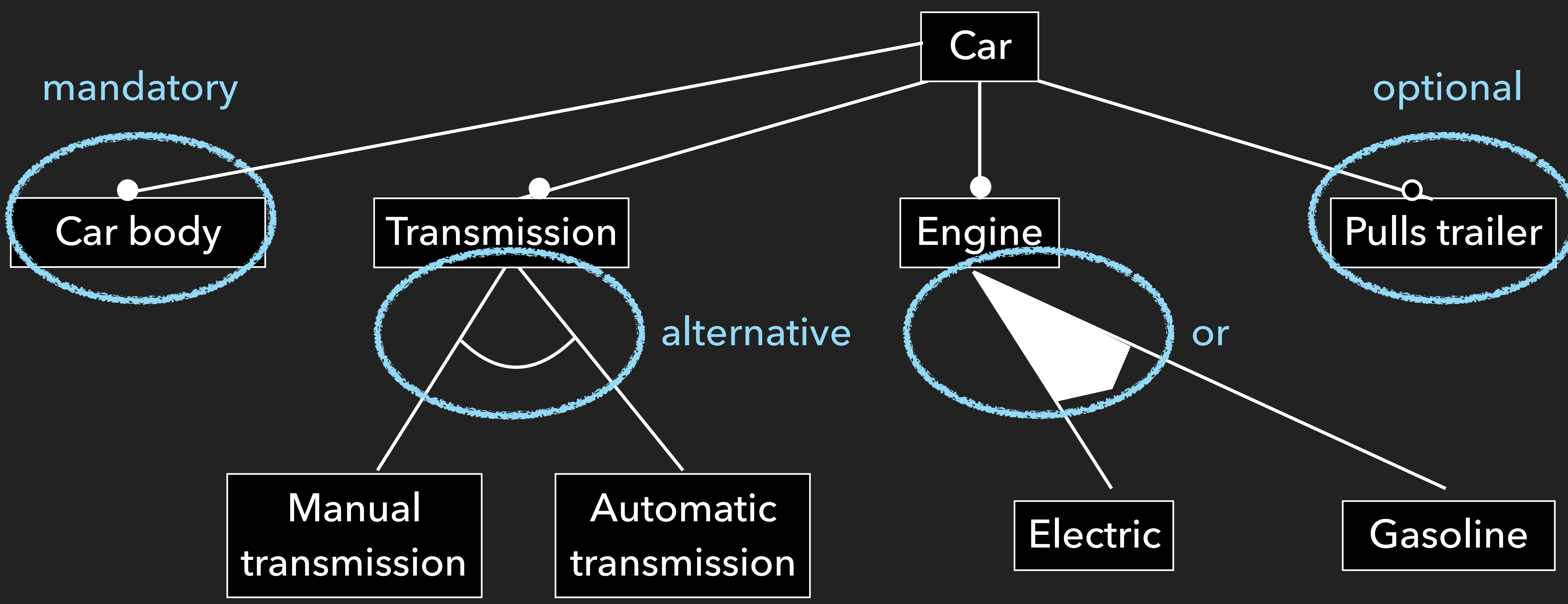
A **hierarchically** arranged set of **features**.

Typically represented using a **tree-like** graphical notation:

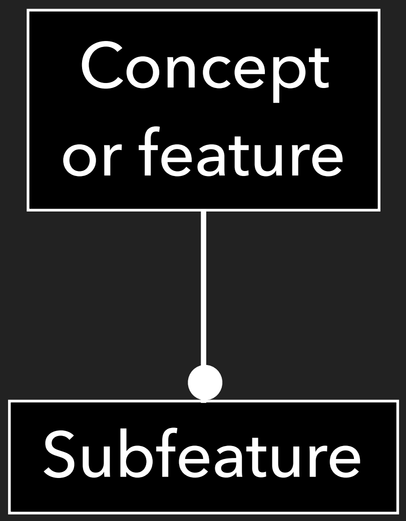


FEATURE MODEL – RELATIONSHIPS

Relationships between parent and child features are expressed using the following notations :

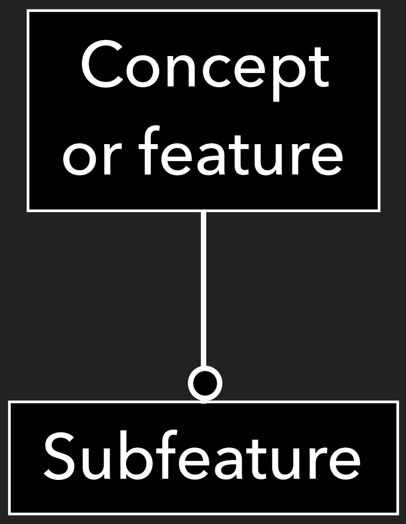


FEATURE MODEL – SEMANTICS OF RELATIONSHIPS



Mandatory features *must* be selected, whenever their parent feature is

- Used to express **commonalities** in the domain
- All *cars* must have *body*, *transmission* and *engine*



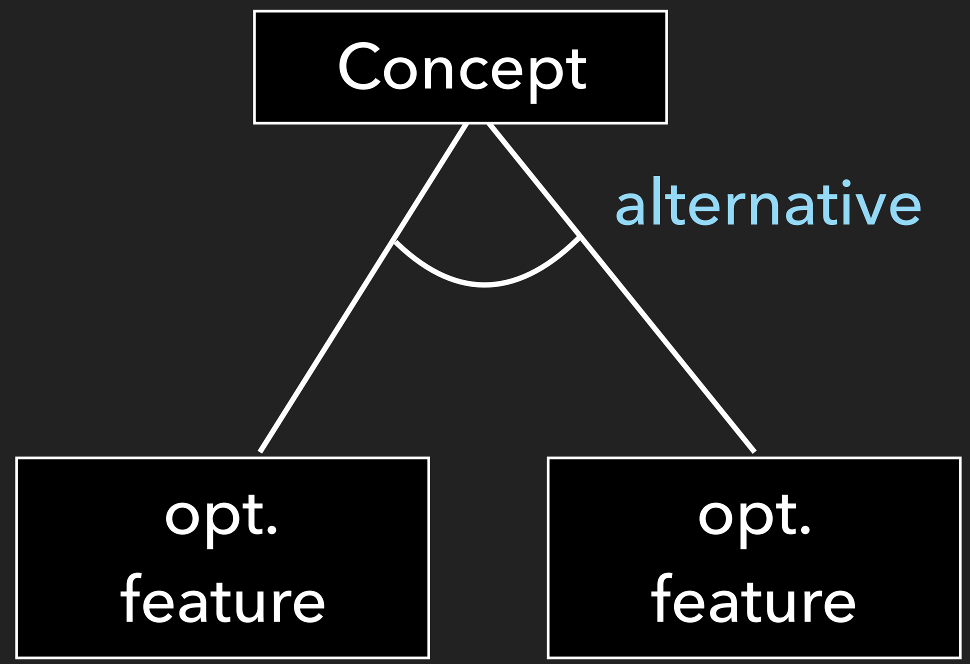
Optional features *can* be selected, but do not *have to*

- Used to express **variabilities** in the domain
- Some *cars* have a hook to *pull a trailer*

FEATURE MODEL – SEMANTICS OF RELATIONSHIPS

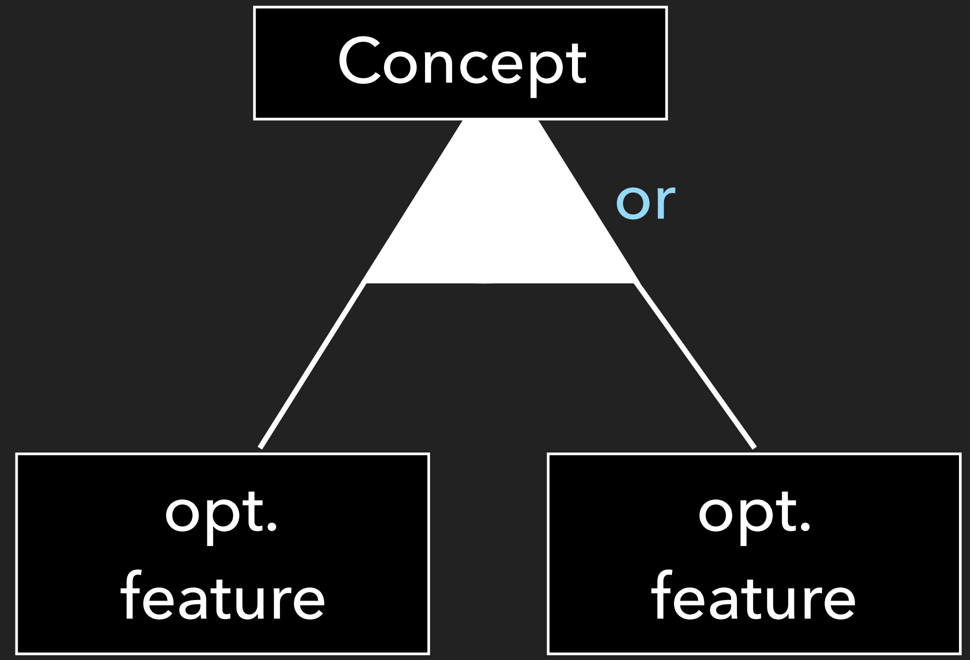
Alternative features = *only one* of these subfeatures can be selected

- Represents an **XOR** between features
- Every car must have *either* a manual *or* an automatic transition, but *cannot have both*



OR features = *one or more* subfeatures can be selected

- At least one, but several are possible too
- A car can have an electric engine or run on gasoline; it can even have both if it's a hybrid



CROSS-TREE CONSTRAINTS

Relationships between features not directly related in the hierarchy of the feature tree

Can be expressed using predefined **feature dependencies** between those features (implication, exclusion)

Or using more generic cross-tree constraints expressed in textual notation with **propositional logic**

CROSS-TREE CONSTRAINTS – FEATURE DEPENDENCIES

"requires" or "implies"

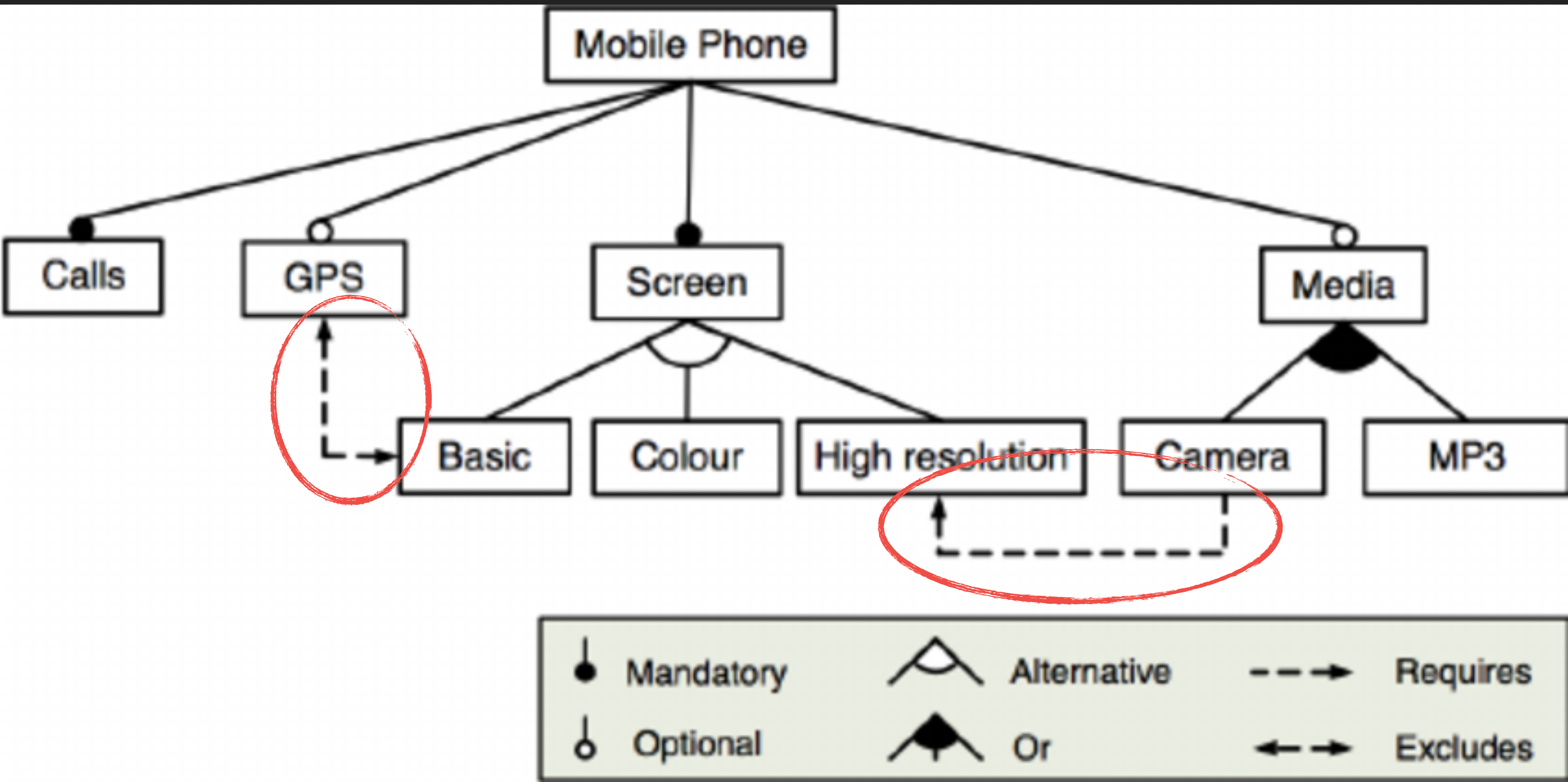
- when the inclusion of one feature depends on the inclusion of another
- (a mandatory feature is a special case of this, but implication relations can also exist between more distant features in the feature hierarchy)

"exclusion"

- when two features cannot co-exist
- (an XOR is a special case of this, but mutual exclusions can also exist between more distant features in the feature hierarchy)

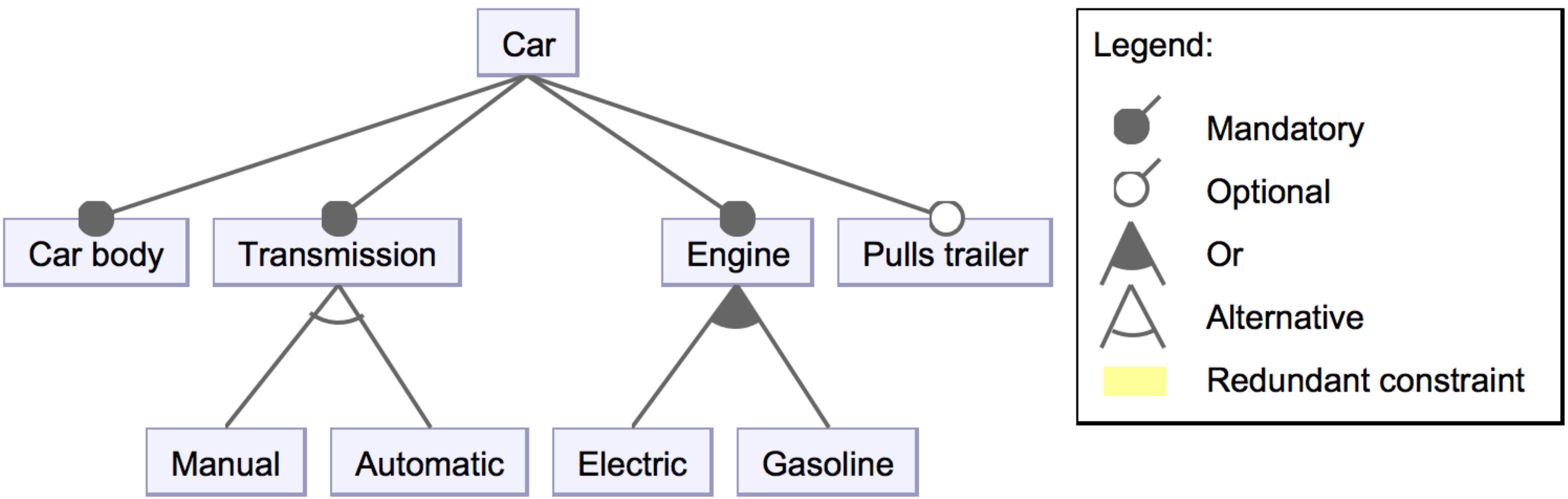
CROSS-TREE CONSTRAINTS – FEATURE DEPENDENCIES

Example : Feature model of a mobile phone



CROSS-TREE CONSTRAINTS – PROPOSITIONAL LOGIC

(Illustrated here as redundant constraints expressing information already present in the original feature model.)



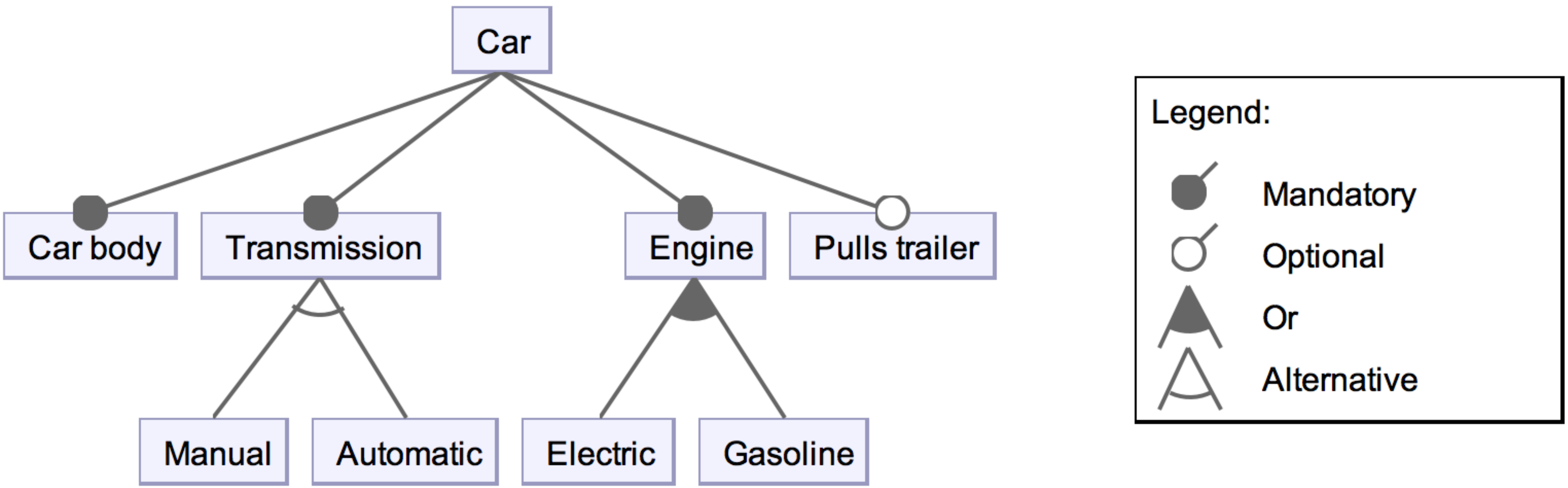
Electric ∨ Gasoline

(Manual ∧ ¬ Automatic) ∨ (Automatic ∧ ¬ Manual)

TOOL SUPPORT

Tool support : FeatureIDE

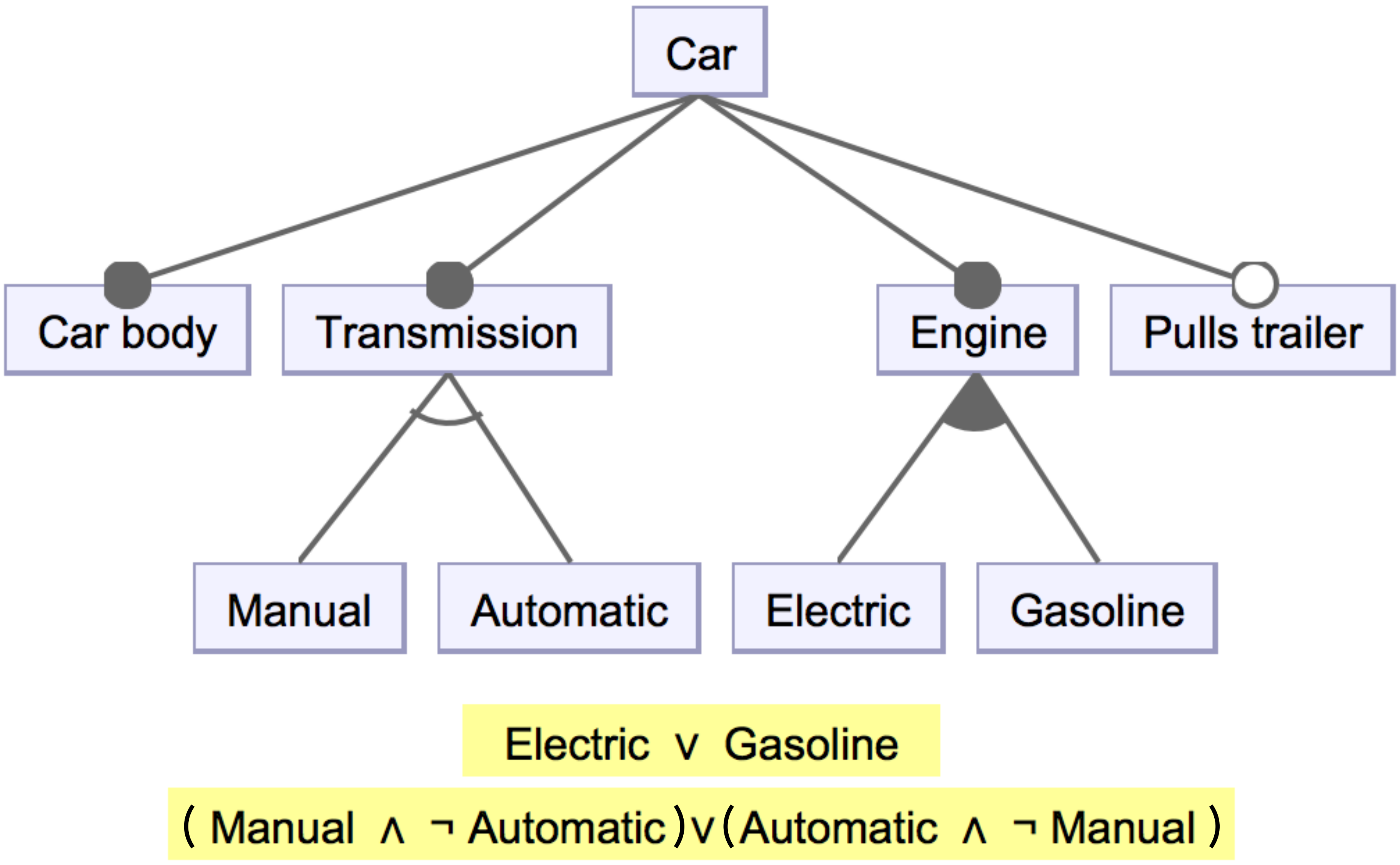
an Eclipse plug-in for FOSD

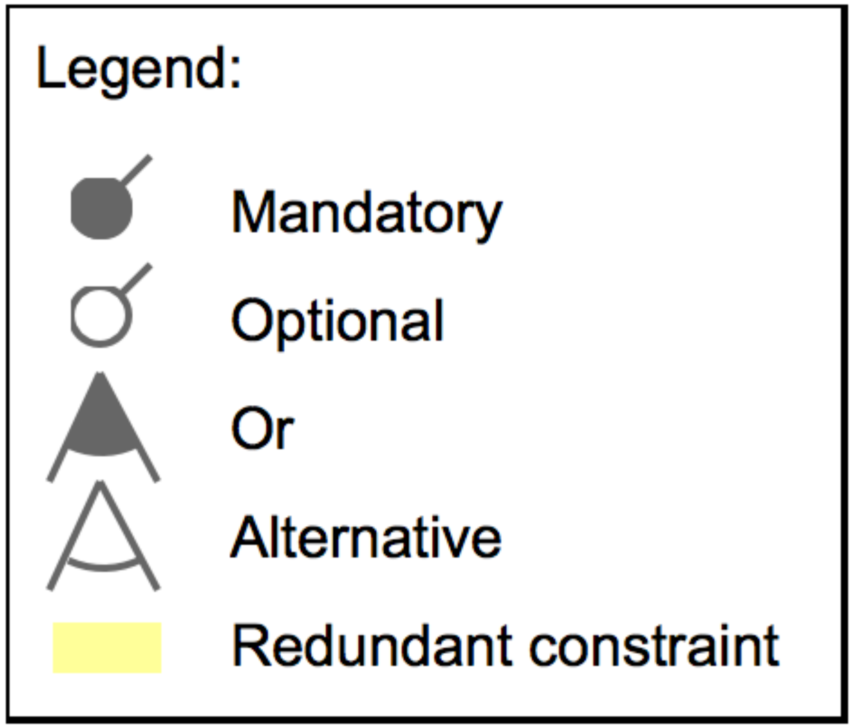


TOOL SUPPORT

FeatureIDE supports constraints: not, and, or, implies, iff, ()

FeatureIDE tool even checks for redundant constraints

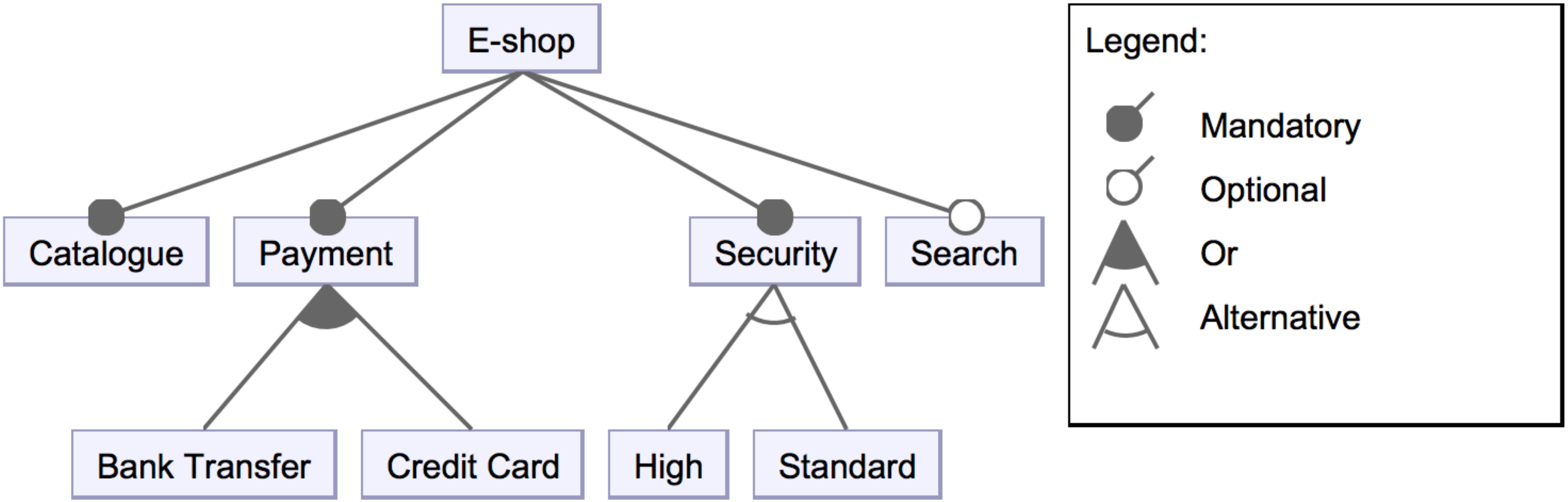




For some reason the version of FeatureIDE which I used in 2016 seemed to flag the additional constraints as a "redundant" constraint. In the new version of 2017 that issue seems to be resolved (on the assistant's computer)

TOOL SUPPORT : ANOTHER EXAMPLE

Feature model of an e-shop software product line



Credit Card => High

FEATURE MODEL

* Source: Fig. 7-6, page 64 of Kang & al., *Feature-Oriented Domain Analysis (FODA): Feasibility Study*, Technical Report CMU/SEI-90-TR-21, 1990

A slightly more elaborate example

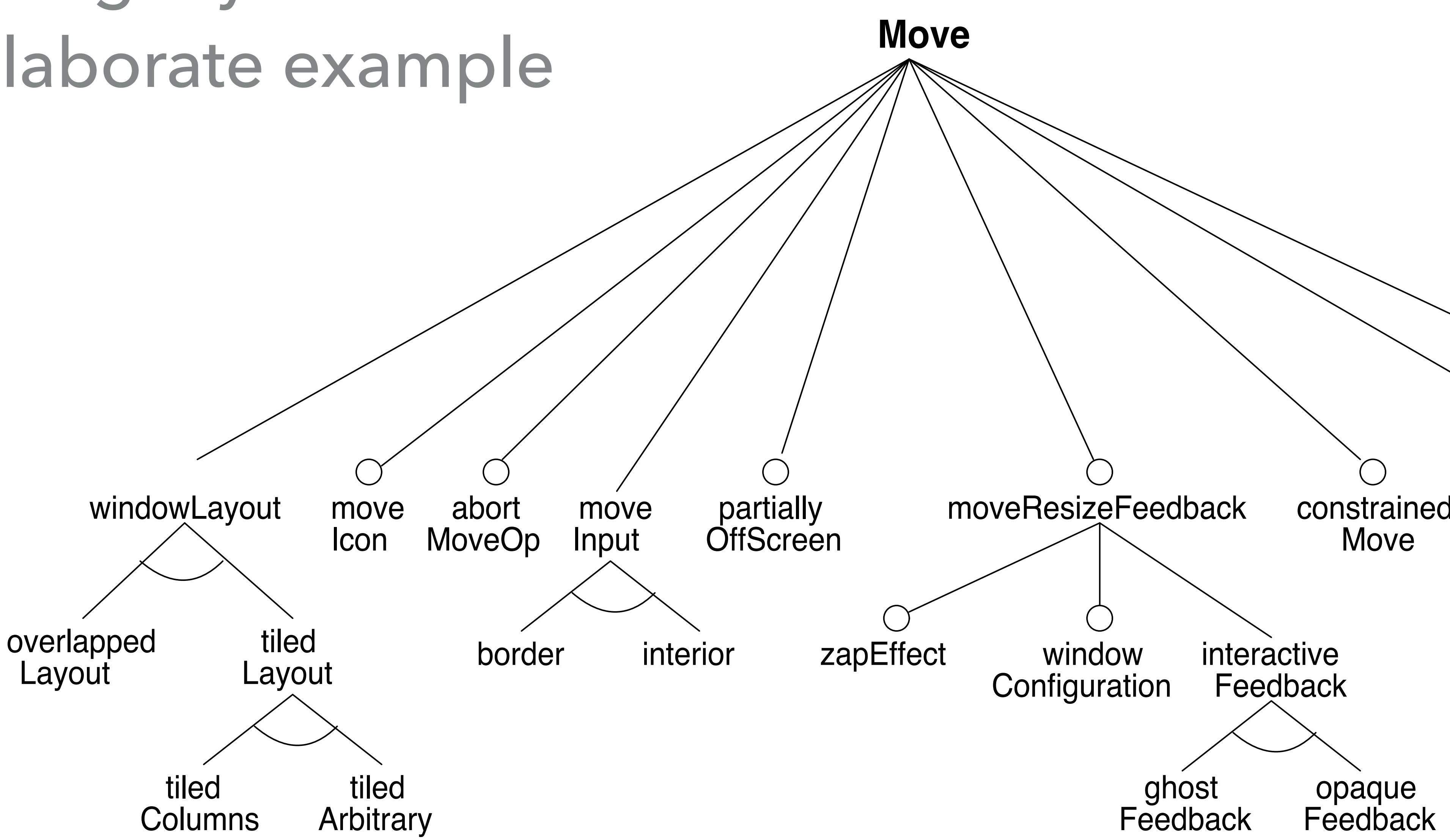


Figure 7-6: Features for the Window Manager Move Operation *

FEATURE MODEL

* Source: Fig. 7-7, page 65 of Kang & al., *Feature-Oriented Domain Analysis (FODA): Feasibility Study*, Technical Report CMU/SEI-90-TR-21, 1990

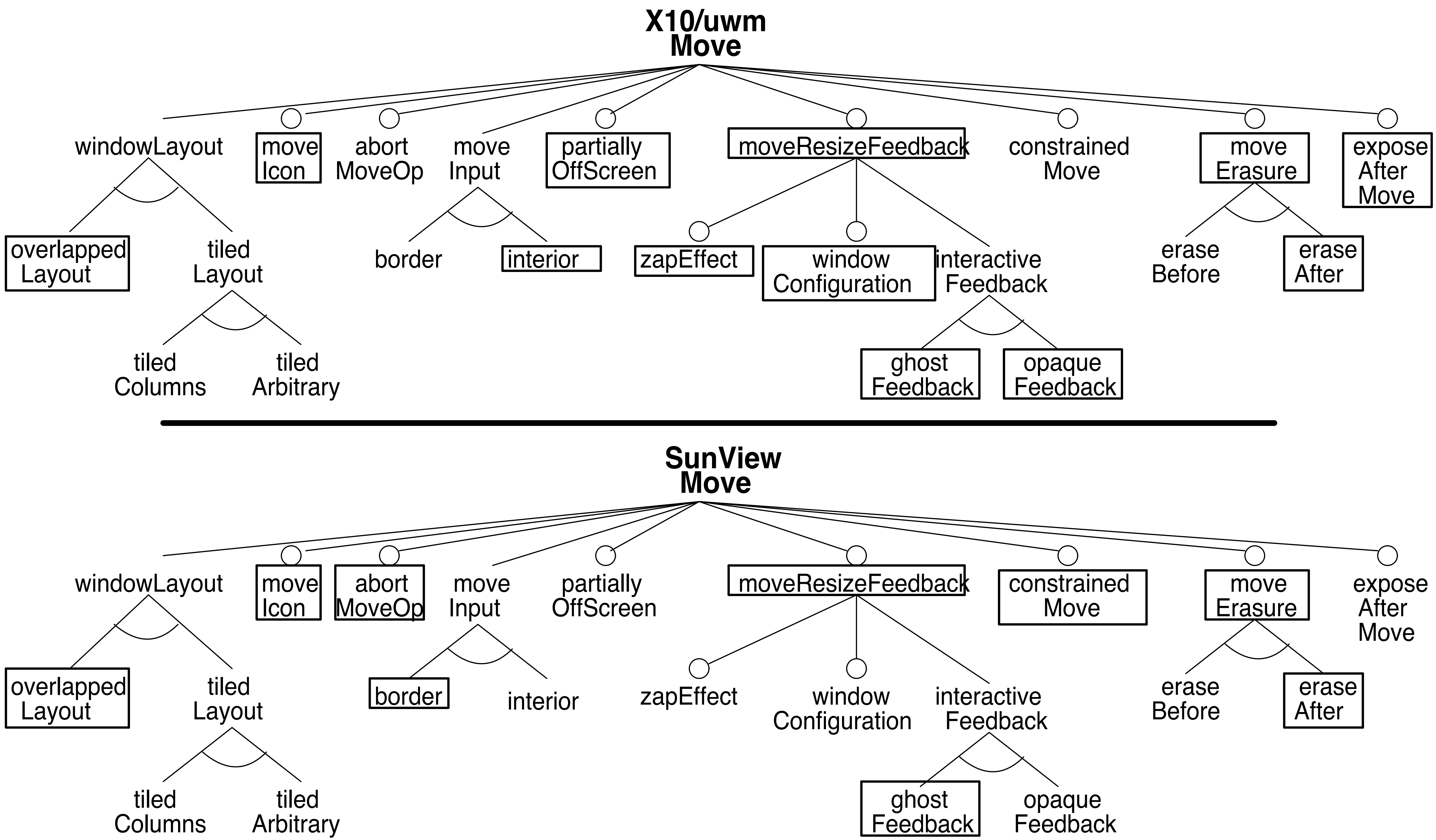


Figure 7-7: Comparison of Move Operation Features in X10/uwm and SunView*

FEATURE MODEL SEMANTICS

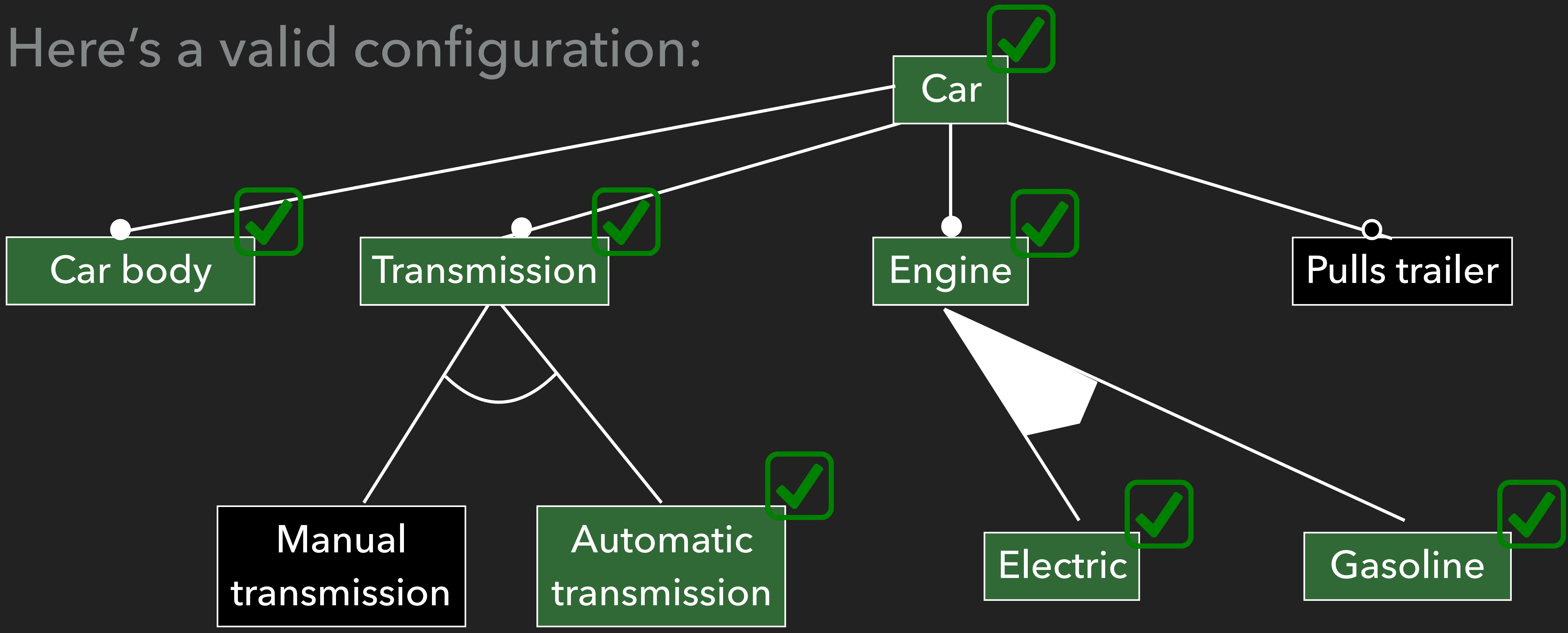
The **semantics of a feature model** is its set of valid configurations

- A **configuration** is an instance of the feature model with a set of features selected
- A configuration is **valid** if it respects the semantics imposed by the relationships and constraints:
  - mandatory features must be selected; optional features may be selected; exactly one must be selected for alternative features; at most one for exclusive features; etc.

FEATURE MODEL CONFIGURATION

In our car feature model, a configuration represents a particular car

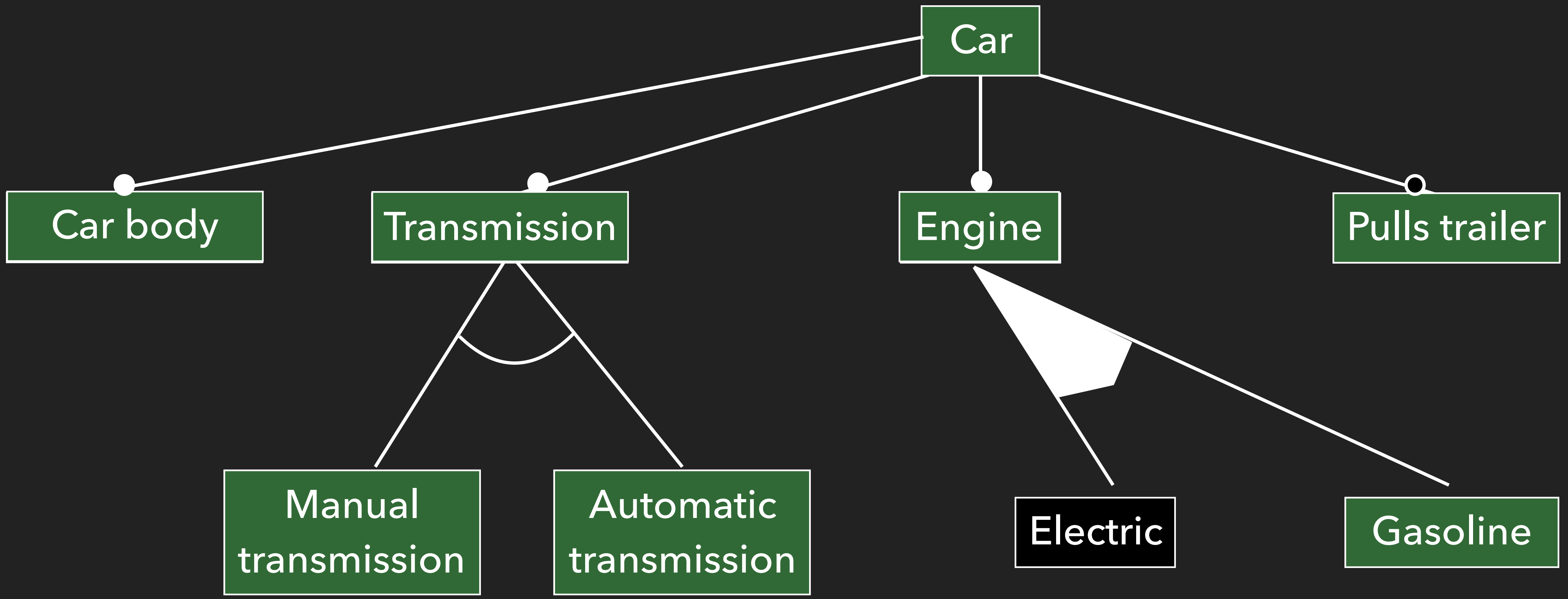
Here's a valid configuration:



FEATURE MODEL CONFIGURATION

Here's an invalid configuration

Why?



FEATURE MODEL SEMANTICS

A feature model is **inconsistent** if it has no valid configurations

Two feature models are **equivalent** if they have the same set of valid configurations

A **commonality** is a feature that appears in all of the model's valid configurations

A **variability** is a feature that appears only in some of the configurations

- i.e., optional, alternatives or or-features

FEATURE MODEL ANOMALIES *

We define an **anomaly** in a feature model as either a **redundancy** or **inconsistency** in the model

- Anomalies are typically caused by evolution of the model

A feature model contains **redundancy**, if semantic information is modelled in multiple ways

- In general, this is not preferable and should be avoided

Inconsistencies are contradictions within a feature model

- E.g., a feature that cannot be selected in any configuration

* [Kowal&al2016] M. Kowal, S. Ananieva, T. Thüm. *Explaining Anomalies in Feature Models.* GPCE Conference, 2016.

POSSIBLE FEATURE MODEL ANOMALIES *

Dead Features : if they can never be selected in any variant of the product line.

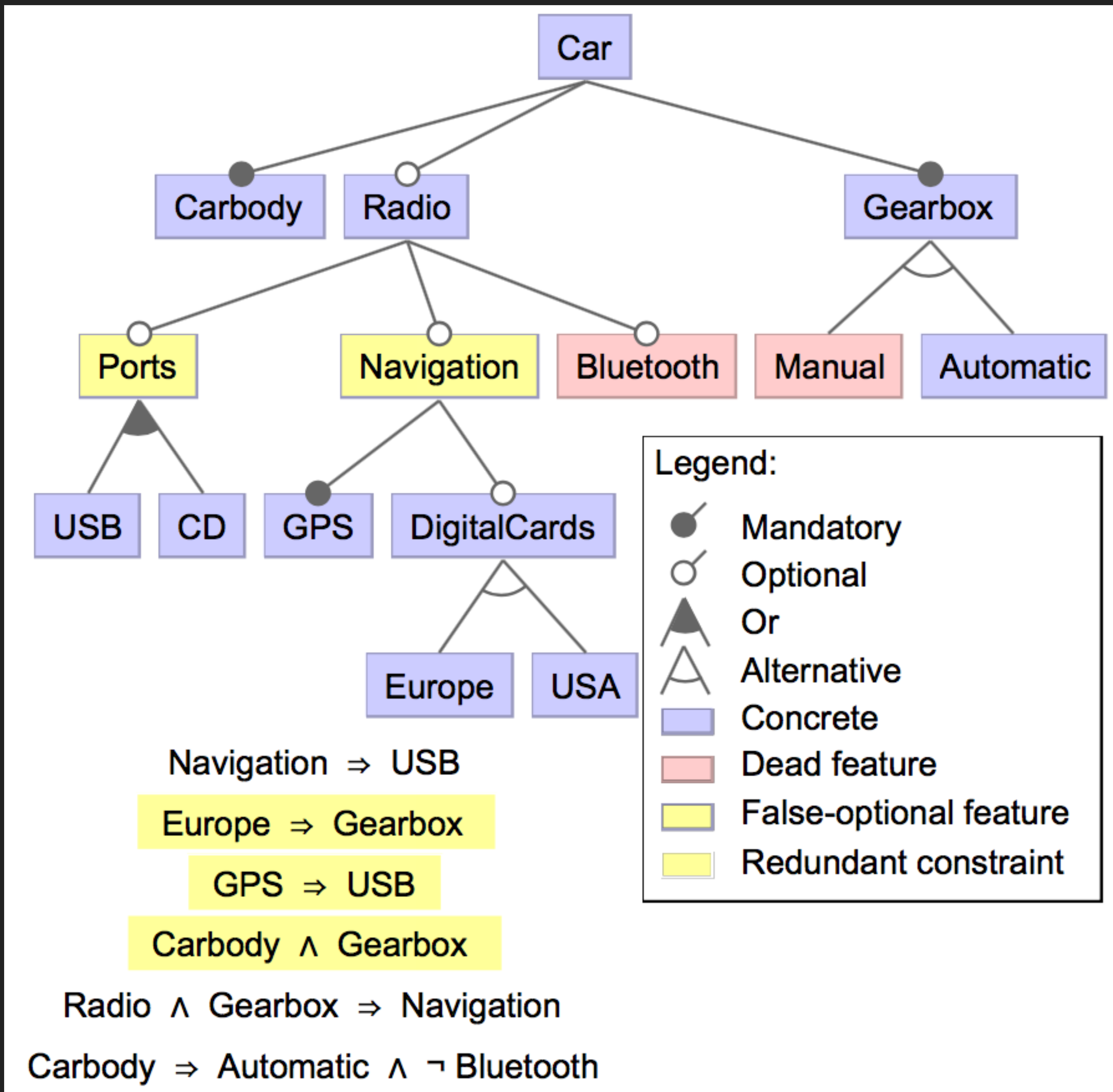
> This anomaly is problematic as software artefacts could be developed but never used.

False-Optional Features : if the selection of its parent makes the feature itself selected as well, even though it is defined as optional and not mandatory.

Redundant Constraints : a cross-tree constraint is redundant if its removal does not change the validity of configurations.

* [Kowal&al2016] M. Kowal, S. Ananieva, T. Thüm. *Explaining Anomalies in Feature Models.* GPCE Conference, 2016.

POSSIBLE FEATURE MODEL ANOMALIES

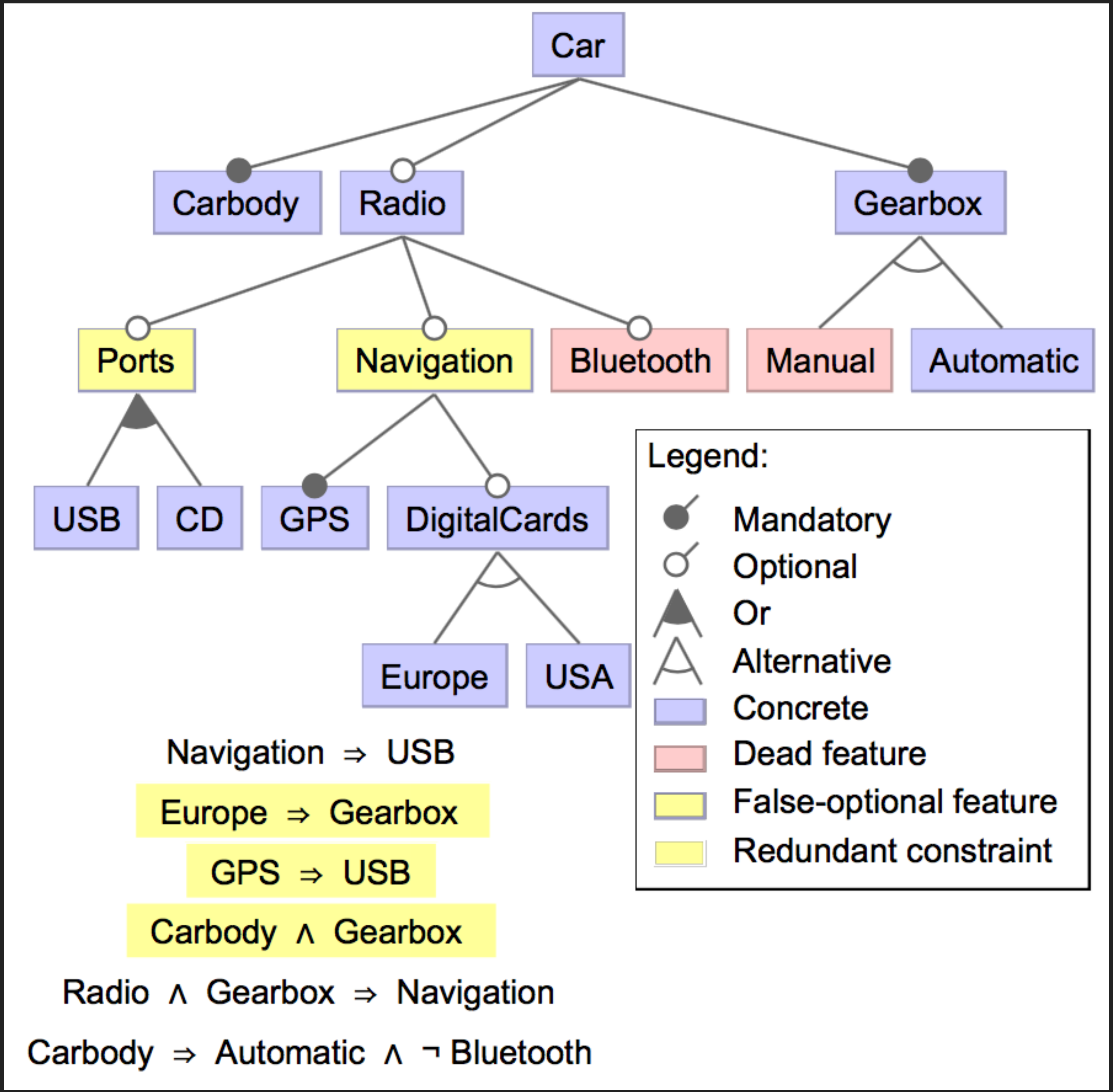


In this example,* Bluetooth and Manual are dead features.

Why?

* [Kowal&al2016]

POSSIBLE FEATURE MODEL ANOMALIES



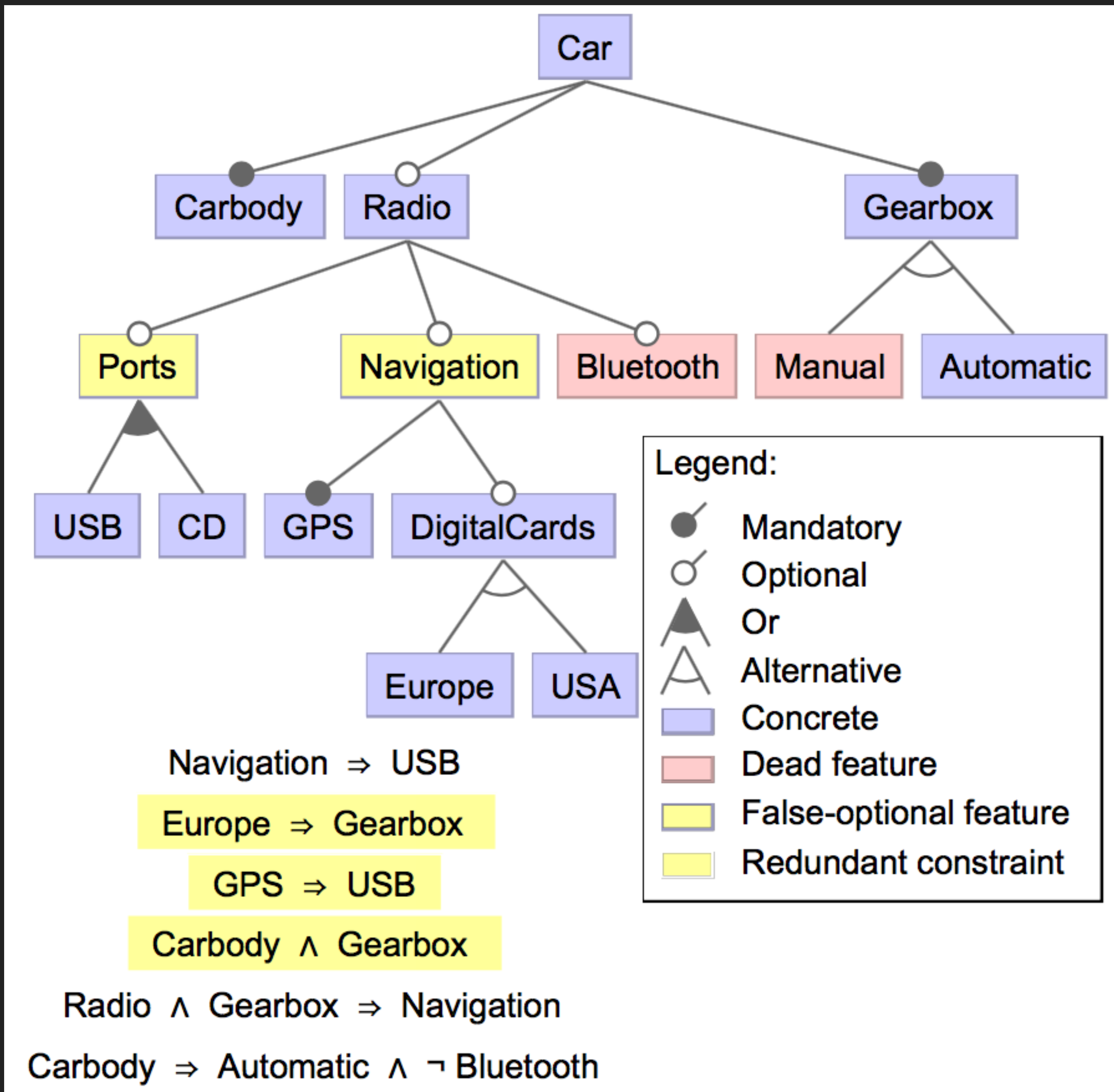
In this example,* Navigation is a false-optional feature.

Why?

In this example Ports is a false-optional feature too but that's hard to see, especially because the feature does not even occur in cross-tree constraints. The article explains how SAT solvers can be used to find such problems.

* [Kowal&al2016]

POSSIBLE FEATURE MODEL ANOMALIES



In this example,* there are also three redundant constraints.

Do you see why?

* [Kowal&al2016]

POSSIBLE FEATURE MODEL ANOMALIES *

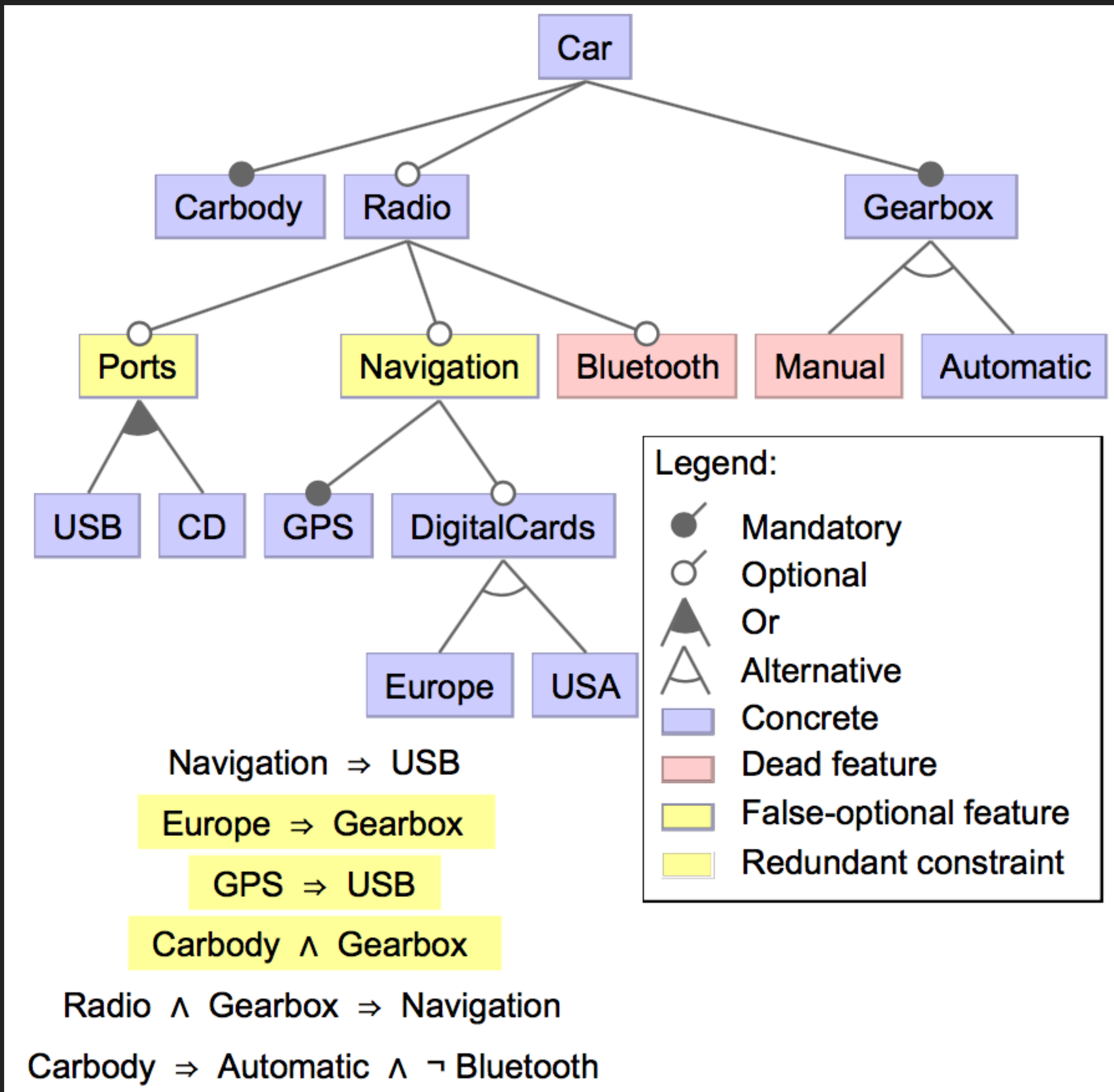
Void Feature Models : a feature model for which it is not possible to derive any valid configuration.

Adding the constraint Carbody $\wedge$ $\neg$Gearbox to the previous example would result in a void feature model.

Why?

* [Kowal&al2016] M. Kowal, S. Ananieva, T. Thüm. *Explaining Anomalies in Feature Models.* GPCE Conference, 2016.

POSSIBLE FEATURE MODEL ANOMALIES

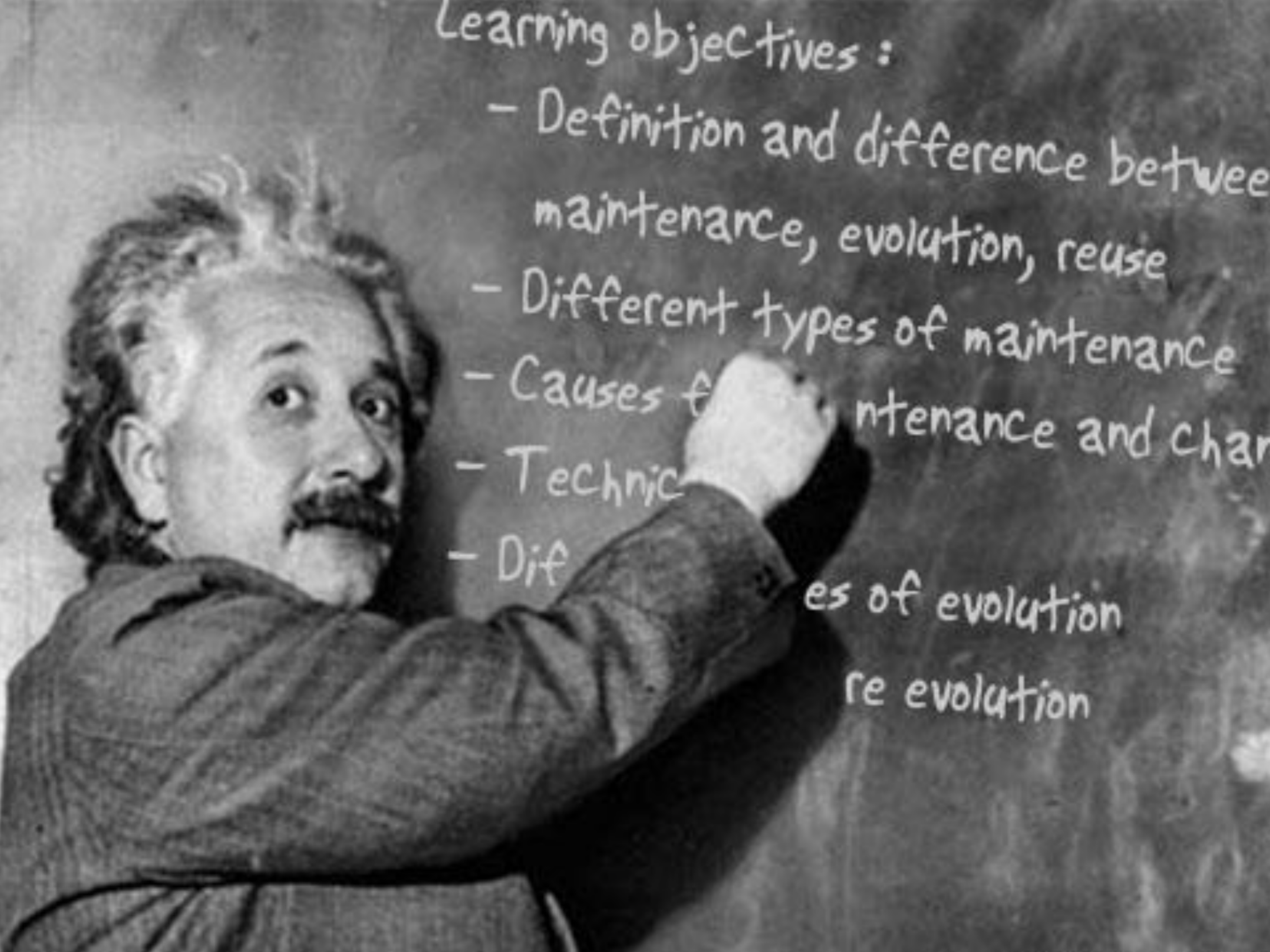


Adding the constraint Carbody ∧ ¬Gearbox to this example results in a void feature model. *

Do you see why?

Because the constraint
Carbody ∧ ¬Gearbox
causes a logical inconsistency
with the constraint
Carbody ∧ Gearbox

* [Kowal&al2016]


Learning objectives :
– Definition and difference betwee
maintenance, evolution, reuse
– Different types of maintenance
– Causes f
ntenance and char
– Technic
– Dif
es of evolution
re evolution

LEARNING OBJECTIVES

- software product lines
- economy of scope
- domain analysis
- feature-oriented domain analysis
- link with software reuse
- domain analysis process
- feature
- commonality
- variability
- feature model(ling)
- feature relationships (mandatory, obligatory, ...)
- feature dependencies
- cross-tree constraints
- FeatureIDE tool
- feature model semantics
- feature model anomalies

FURTHER READING

Prieto-Diaz, Domain Analysis: An Introduction. *ACM SIGSOFT Software Engineering Notes* 15(2): 47-54, April, 1990.

Kang & al., *Feature-Oriented Domain Analysis (FODA): Feasibility Study*, Technical Report CMU/SEI-90-TR-21, 1990

Czarnecki & Eisenecker, *Generative programming: Methods, Tools and Applications*, Addison Wesley, 2000 (Chapter 2: Domain Engineering; Chapter 4: Feature Modeling; and examples in Chapters 12, 13 & 14.)

Batory, *Feature models, grammars, and propositional formulas,* International Conference on Software Product Lines (2005), Springer, pp. 7–20.

Apel, Lengauer, Möller & Kästner. *An algebra for features and feature composition*, International Conference on Algebraic Methodology and Software Technology (2008), Springer, pp. 36–50.

Matthias Kowal, Sofia Ananieva, Thomas Thüm. *Explaining Anomalies in Feature Models.* GPCE Conference, 2016.

POSSIBLE QUESTIONS

8. Define, in your own words, what a software product line is.
9. Explain the difference between economies of scale and economies of scope, in the context of software product lines.
10. Explain the main purpose of domain analysis. Explain and discuss the different phases of the domain analysis process.
11. What is (the goal of) feature-oriented domain analysis (FODA)? What is a feature? How does this relate to software product lines? Explain.

POSSIBLE QUESTIONS

12. Explain and illustrate, on a simple example, the **feature modelling** notation (as well as the different kinds of **feature relationships**, **feature dependencies** and **cross-tree constraints**).

13. What is a **configuration** of a feature model? When is a configuration said to be **valid**? Explain and illustrate on an example. When is a feature model said to be **inconsistent**?

14. Explain, in the context of feature modelling, the notions of **commonality** and **variability**. Illustrate with a concrete example.

15. What is a **feature model anomaly**? What kinds of feature model anomalies exist? Give a concrete example of each on a simple feature model.

CLASS… IS… DISMISSED.