Applications of #SAT Solvers on Feature Models

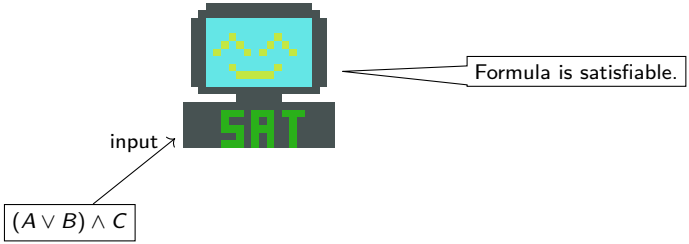
Chico Sundermann, Michael Nieke, Paul Maximilian Bittner, Tobias Heß, Thomas Thüm, Ina Schaefer

VaMoS'21 | February 10, 2020

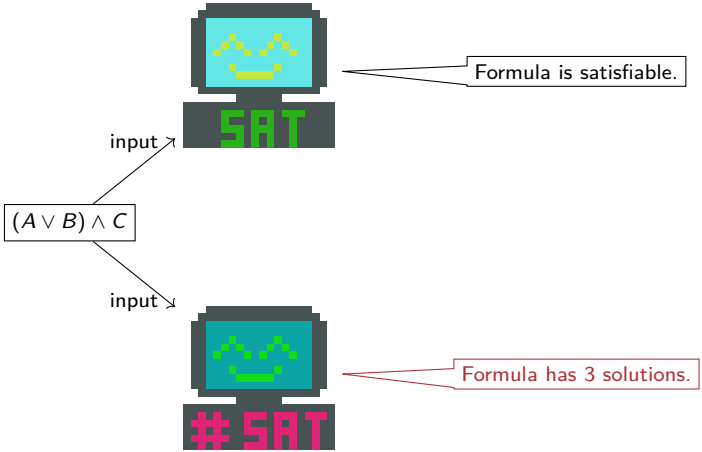
Technische Universität Braunschweig

ulm university universität ulm

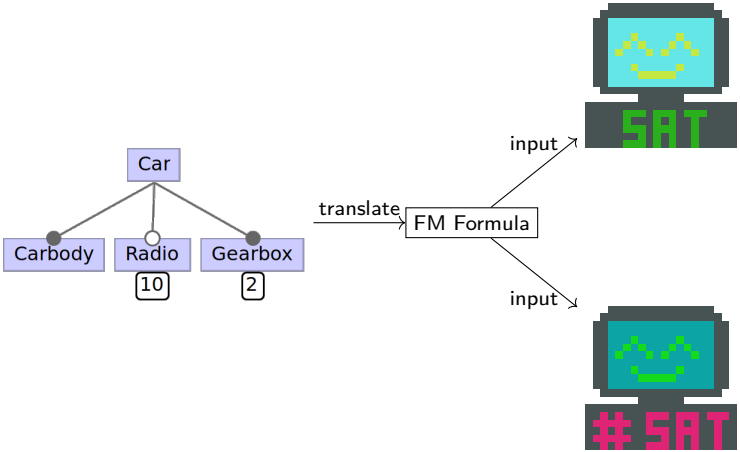
What is SAT?



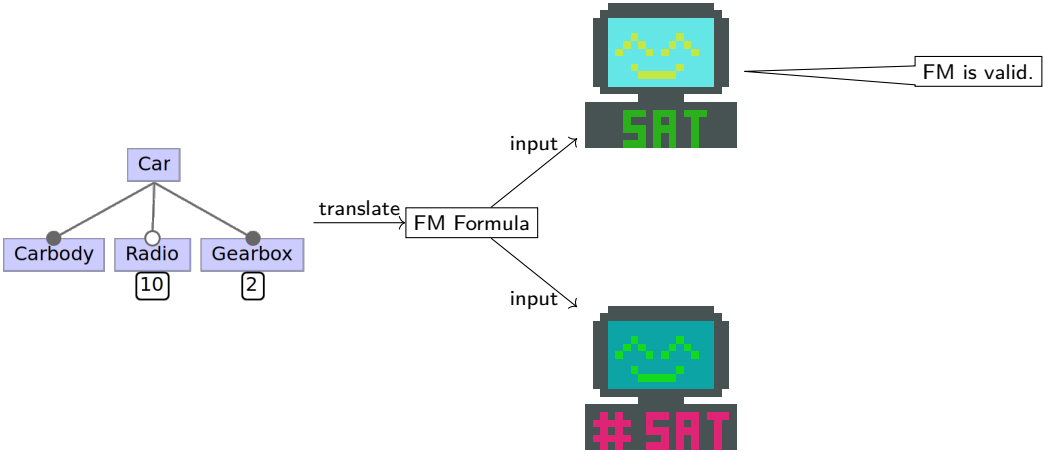
What is #SAT?


Formula is satisfiable.
SAT
input
$(A \vee B) \wedge C$
input
Formula has 3 solutions.
#SAT

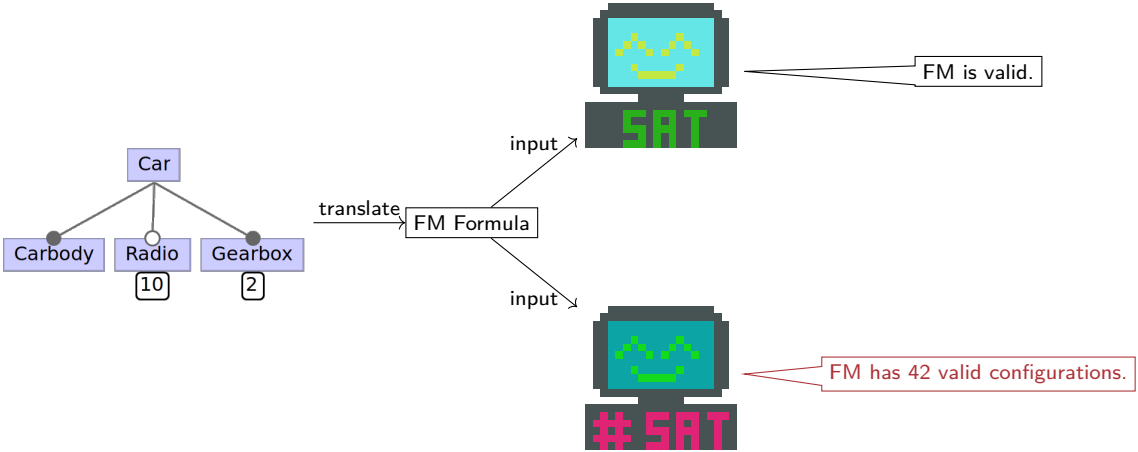
What is #SAT?

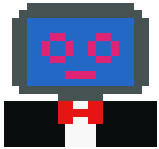

Car
Carbody
Radio
10
Gearbox
2
translate
FM Formula
input
input
SAT
#SAT

What is #SAT?

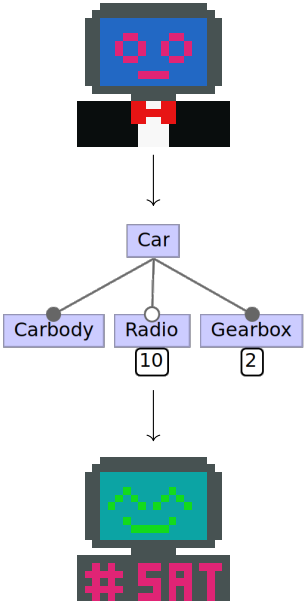

Car
Carbody
Radio
10
Gearbox
2
translate
FM Formula
input
input
SAT
#SAT
FM is valid.

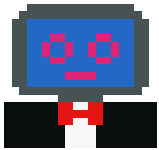
What is #SAT?


Car
Carbody
Radio
10
Gearbox
2
translate
FM Formula
input
input
SAT
#SAT
FM is valid.
FM has 42 valid configurations.



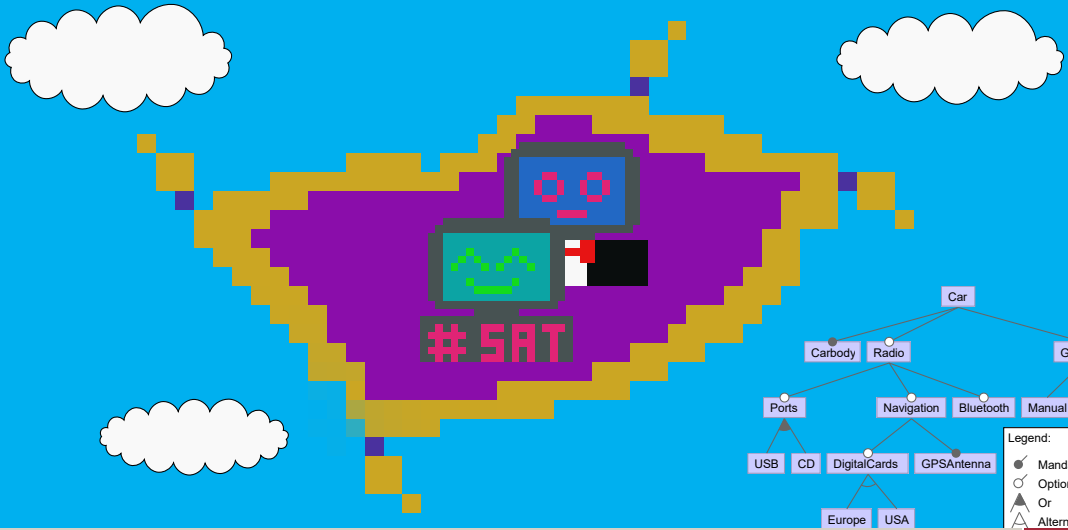
#SAT

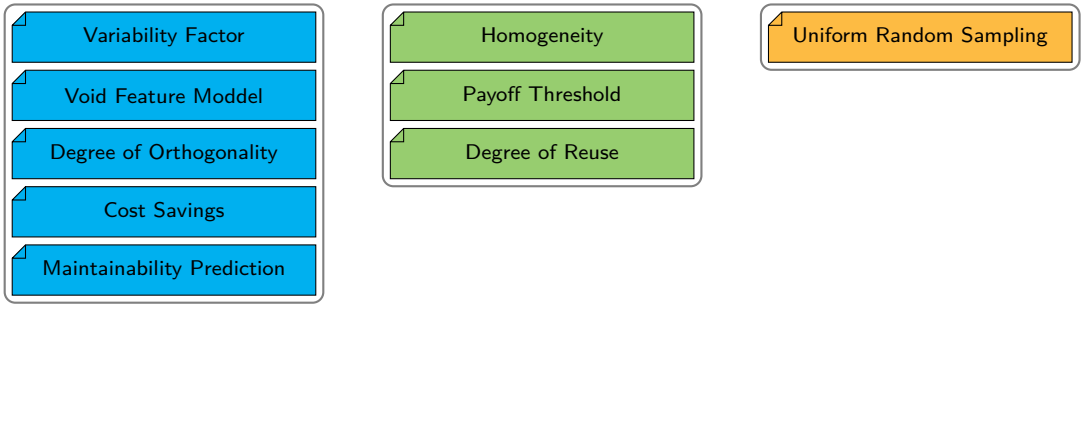

Car
Carbody
Radio
10
Gearbox
2
#SAT

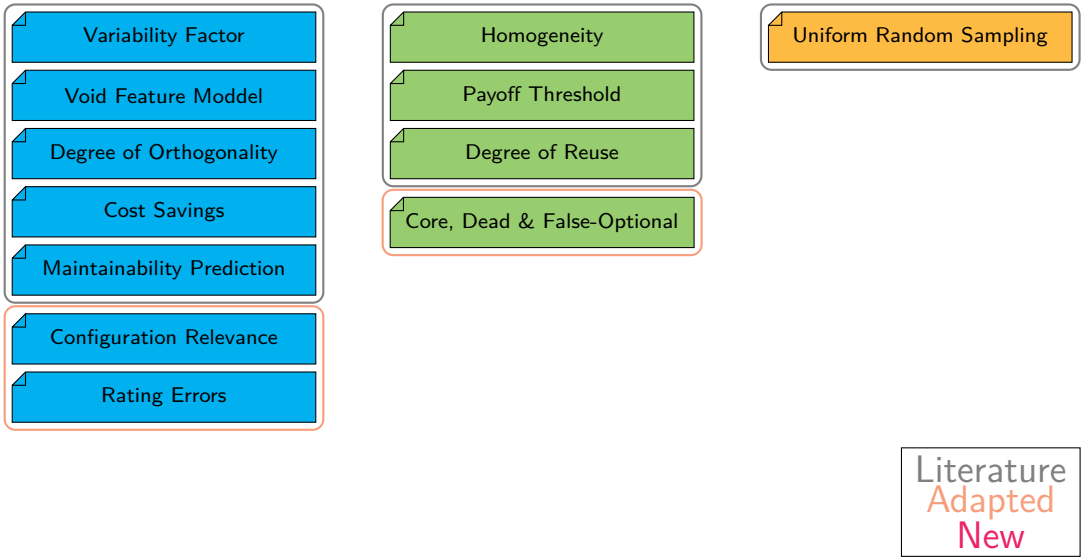


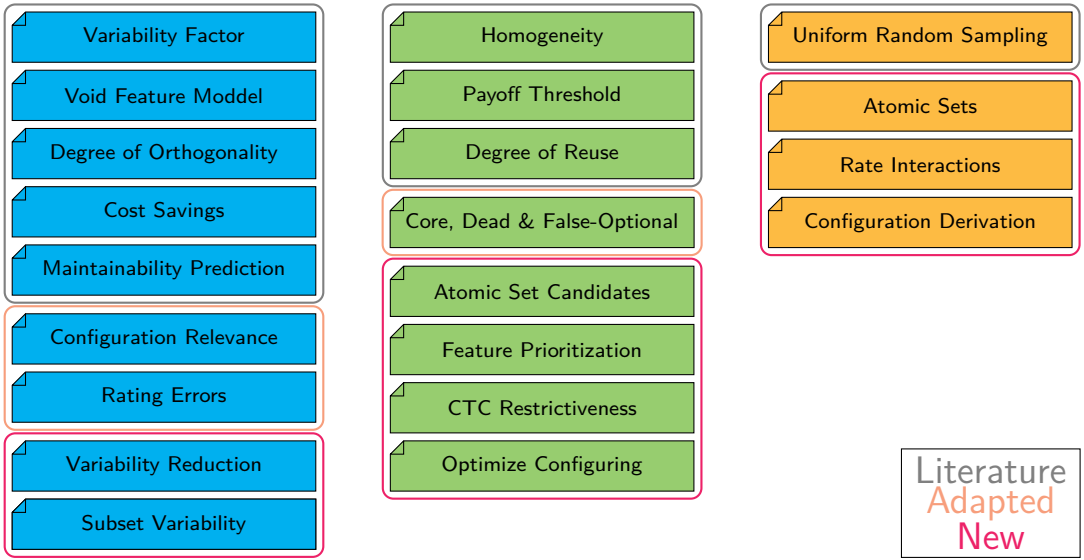
You sell 12467715863077199238873727490314439514330442254979827771939179959
48704895007038086596884750762683178699125554706137139296916402247707623989
44209874897359173593095443687267724538731733090205413699000686174205604563
67918358945723237769032226162401591517046144170618031438553651460038740308
01350065685324847878928481612739525762871421652053586988389048116381601881
76037581684016994400235203403150810331655621013615698057706035390621003047
84859503879593345640078833145636596752961065125514348862370489895791983097
36673417233014005250155052221813897395389431437905641732922313685681317500
13736577090793653032461175202437680317716690037543125535805521623396329598
51136594921793706790008144429927672368215556421058280378775655289115710366
15411765270568810088266268739356230116087196360830692167862459755603055689
84911737263764072946322197760823659018931644830372152412529684198481429399
31845976150777960420140955474136356692610456062245435453098479521665554338
81624352965453269483975729810951995291131521351203210051266848280468625280
93743491549098493785700223513151681610549543583465314724307138800048335461
50908606626583018430487142722274741168056675649788434938634994866281140655
10783811936753647633497463679067687695254056198006082538064697040587889733
81557729554492105622180807407879500664707776577380585585437688717627999998
83391651553343599001454221421034518120990552348929364117299309674386718291
03018536305950720000000000000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000 car variants.

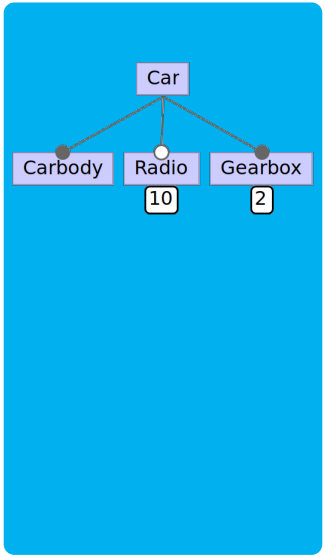
A Whole New World!

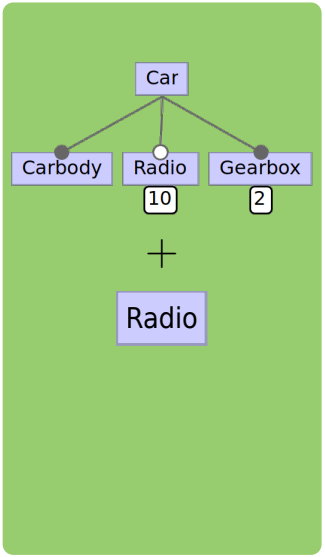


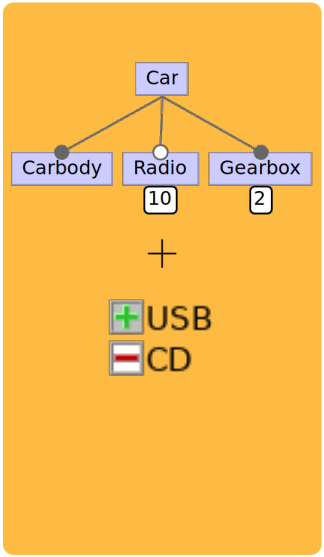

Variability Factor
Void Feature Moddel
Degree of Orthogonality
Cost Savings
Maintainability Prediction
Homogeneity
Payoff Threshold
Degree of Reuse
Uniform Random Sampling
Literature
Adapted
New

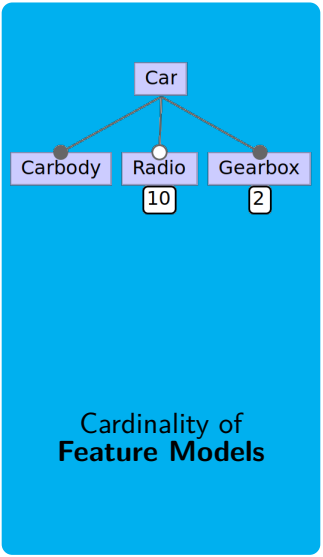

Variability Factor
Void Feature Moddel
Degree of Orthogonality
Cost Savings
Maintainability Prediction
Configuration Relevance
Rating Errors
Homogeneity
Payoff Threshold
Degree of Reuse
Core, Dead & False-Optional
Uniform Random Sampling
Literature
Adapted
New

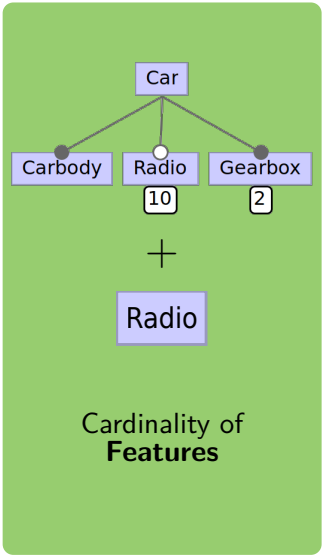

Variability Factor
Void Feature Moddel
Degree of Orthogonality
Cost Savings
Maintainability Prediction
Configuration Relevance
Rating Errors
Variability Reduction
Subset Variability
Homogeneity
Payoff Threshold
Degree of Reuse
Core, Dead & False-Optional
Atomic Set Candidates
Feature Prioritization
CTC Restrictiveness
Optimize Configuring
Uniform Random Sampling
Atomic Sets
Rate Interactions
Configuration Derivation
Literature
Adapted
New

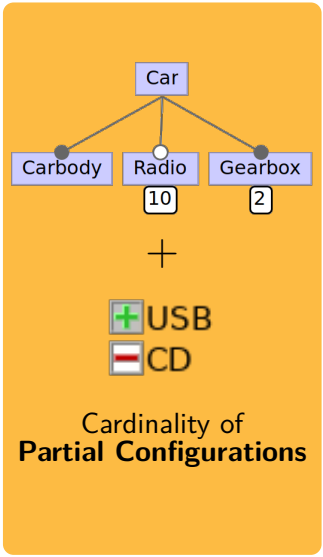

Car
Carbody
Radio
10
Gearbox
2


Car
Carbody
Radio
10
Gearbox
2
+
Radio


Car
Carbody
Radio
10
Gearbox
2
+
USB
CD


Car
Carbody
Radio
Gearbox
10
2
Cardinality of
Feature Models


Car
Carbody
Radio
Gearbox
10
2
+
Radio
Cardinality of
Features


Car
Carbody
Radio
Gearbox
10
2
+
USB
CD
Cardinality of
Partial Configurations

Variability Factor

Void Feature Moddel

Degree of Orthogonality

Cost Savings

Maintainability Prediction

Configuration Relevance

Rating Errors

Variability Reduction

Subset Variability

Homogeneity

Payoff Threshold

Degree of Reuse

Core, Dead & False-Optional

Atomic Set Candidates

Feature Prioritization

CTC Restrictiveness

Optimize Configuring

Uniform Random Sampling

Atomic Sets

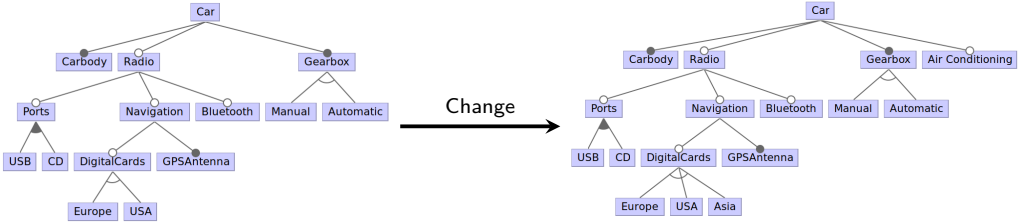
Rate Interactions

Configuration Derivation

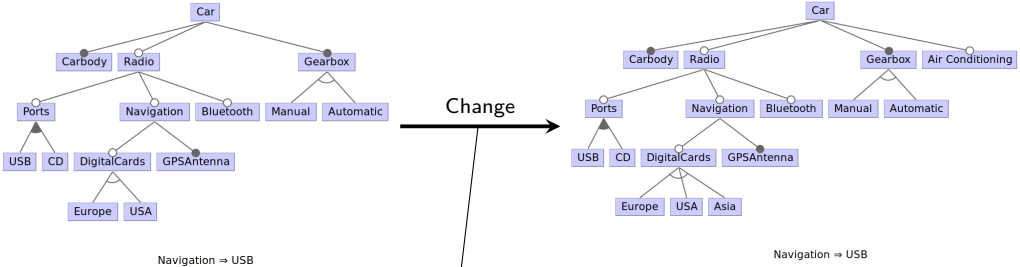
Variability Reduction

Variability Reduction New

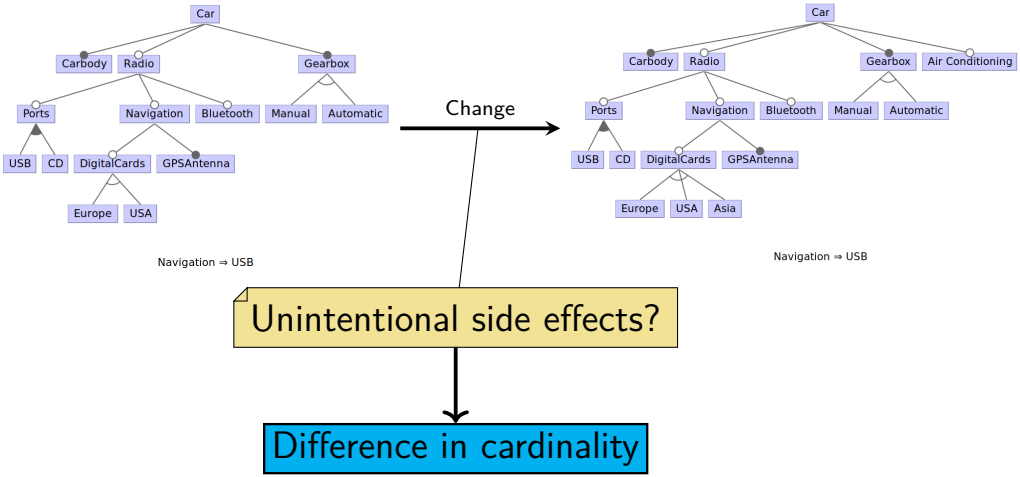
Variability Reduction



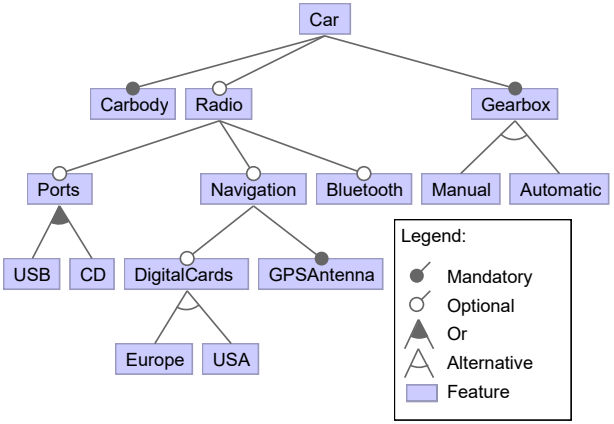
Variability Reduction



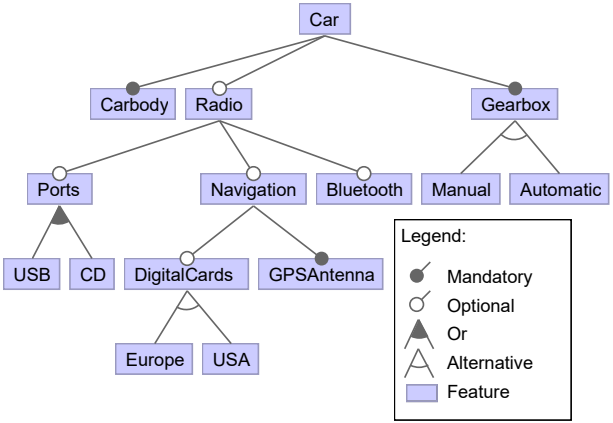
Variability Reduction



Variability Reduction



Navigation ⇒ USB

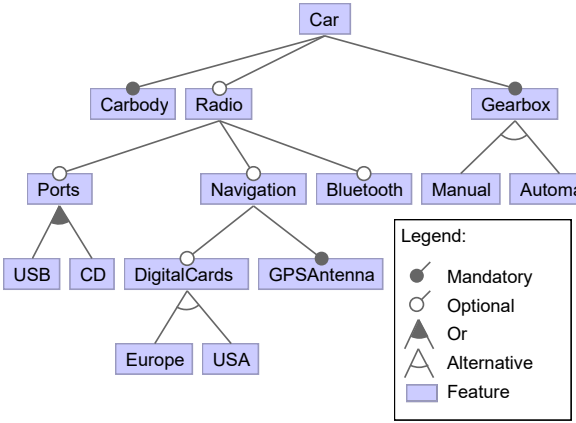


Navigation ⇒ USB

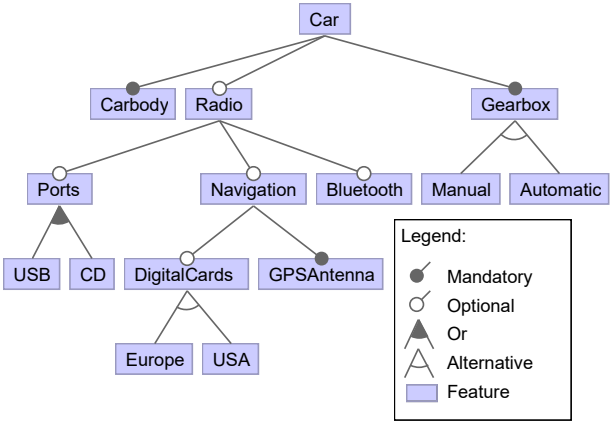
Variability Reduction

42 valid configurations

Variability Reduction



Navigation ⇒ USB

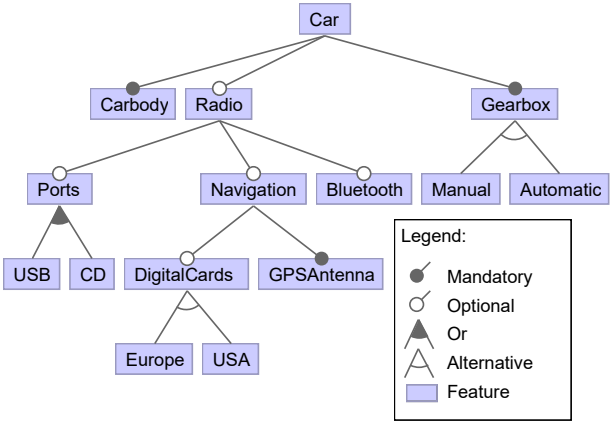


Navigation ⇒ USB

Variability Reduction

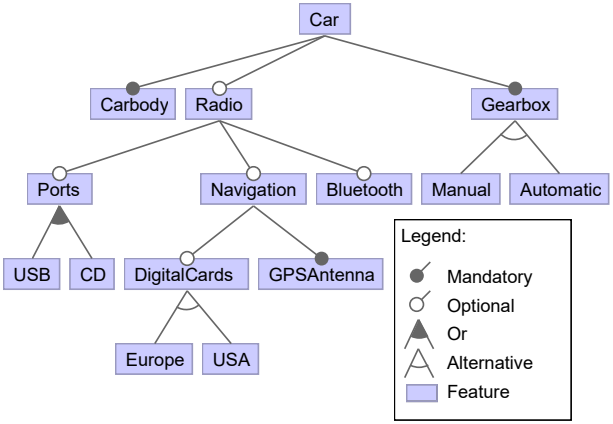
Automatic ⇒ USA

Variability Reduction



Navigation ⇒ USB

Automatic ⇒ USA

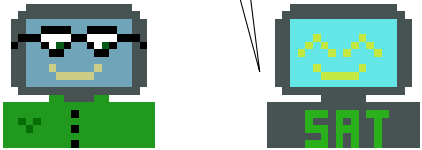


Navigation ⇒ USB

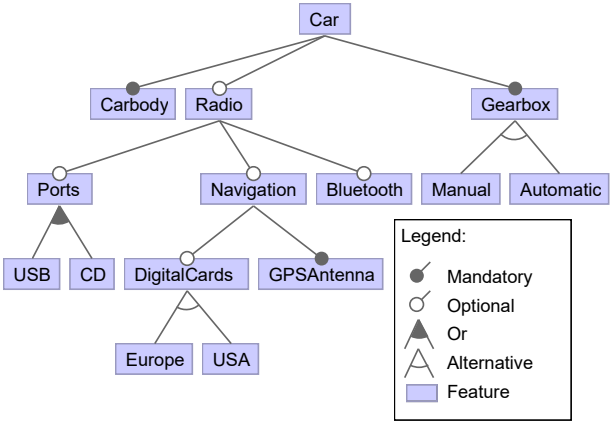
Automatic ⇒ USA

Variability Reduction

No anomalies! ✓

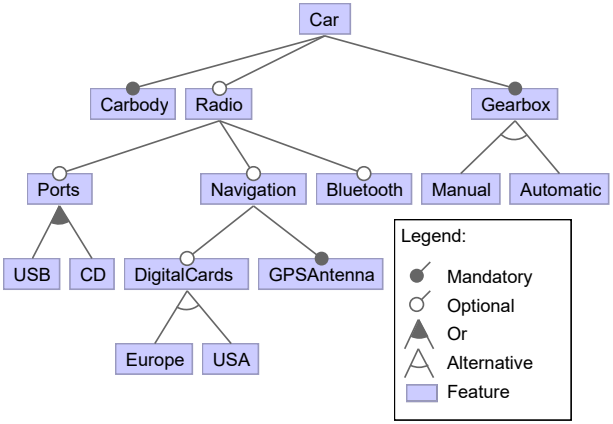


Variability Reduction



Navigation ⇒ USB

Automatic ⇒ USA

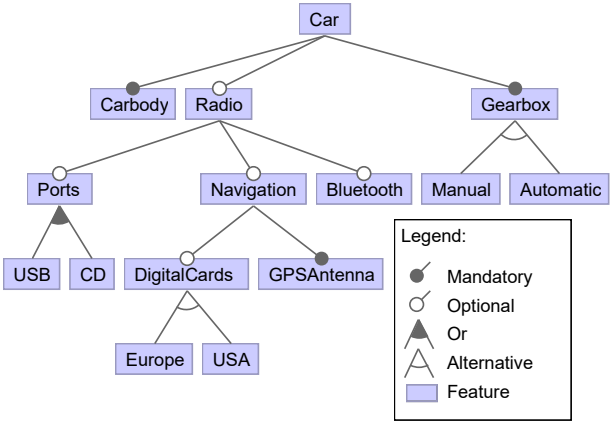


Navigation ⇒ USB

Automatic ⇒ USA

Variability Reduction

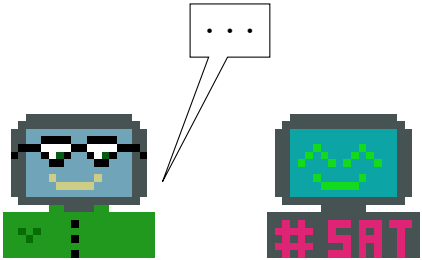
Only 25 valid configurations!

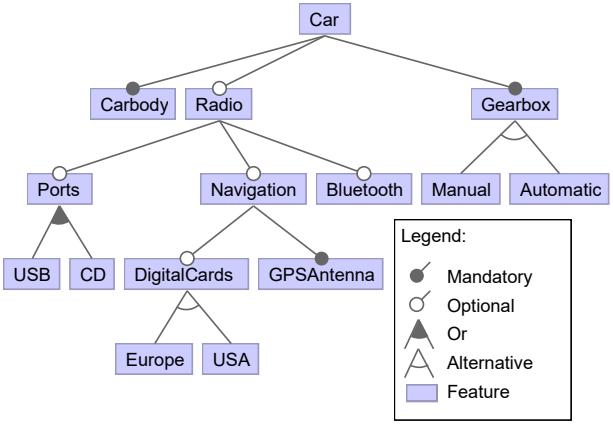


Navigation ⇒ USB

Automatic ⇒ USA

Variability Reduction

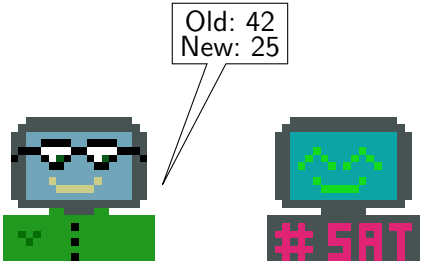


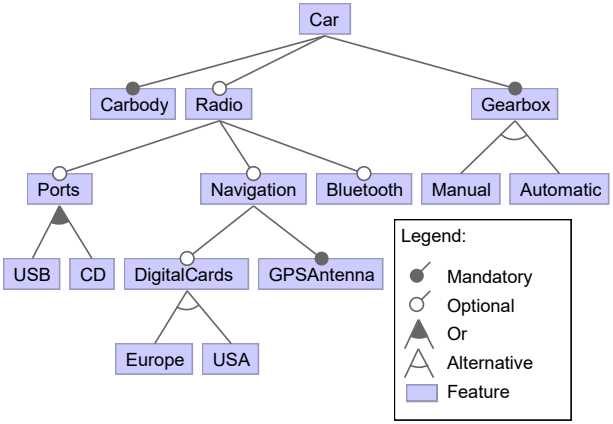


Navigation ⇒ USB

Automatic ⇒ USA

Variability Reduction



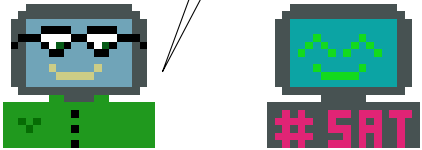


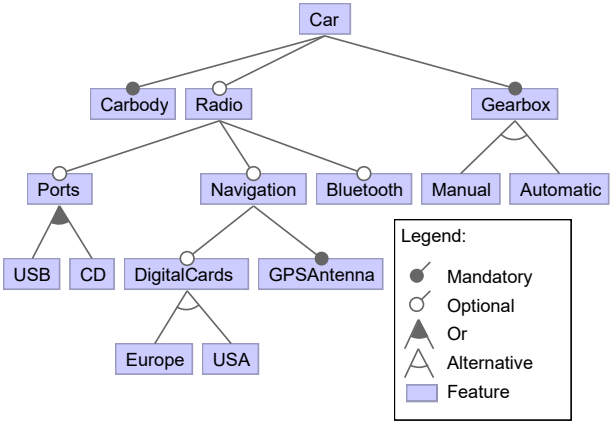
Navigation ⇒ USB

Automatic ⇒ USA

Variability Reduction

Old: 21 manual, 21 automatic
New: 21 manual, 4 automatic



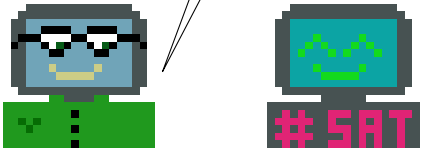


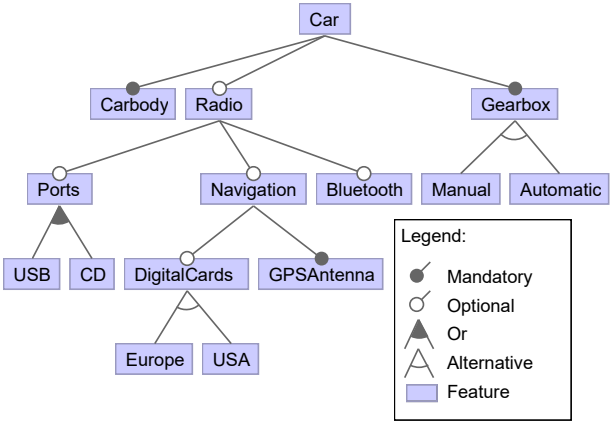
Navigation ⇒ USB

Automatic ⇒ USA

Variability Reduction

Automatic ∧ DigitalCards ⇒ USA

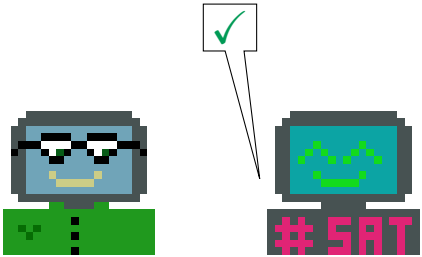




Navigation ⇒ USB

Automatic ∧ DigitalCards ⇒ USA

Variability Reduction



How to use #SAT on Feature Models

Variability Reduction

How to use #SAT on Feature Models

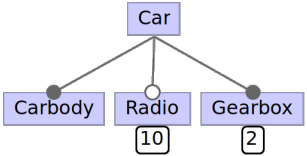
- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability

How to use #SAT on Feature Models

- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability

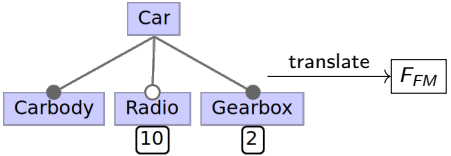
How to use #SAT on Feature Models

- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability



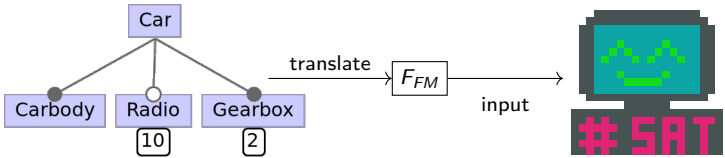
How to use #SAT on Feature Models

- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability



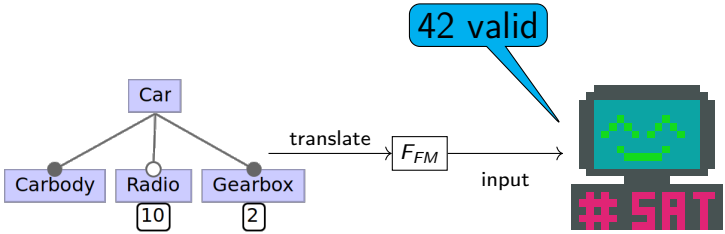
How to use #SAT on Feature Models

- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability



How to use #SAT on Feature Models

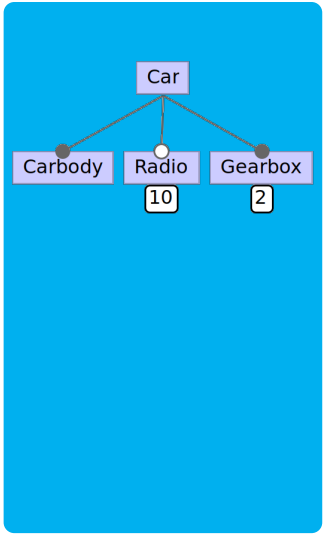
- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability



- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability

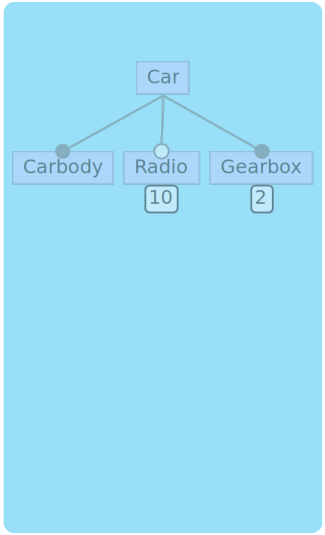
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation



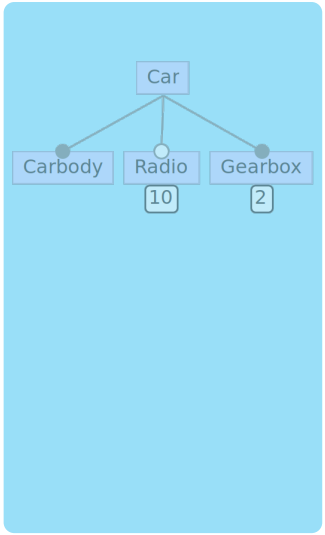
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

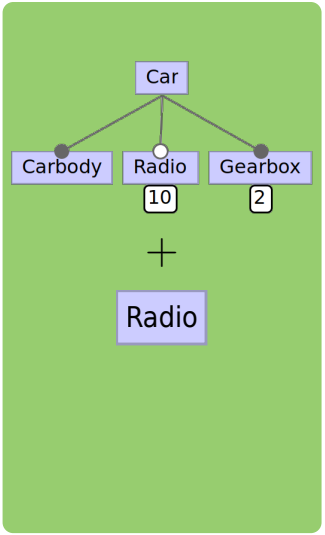
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation



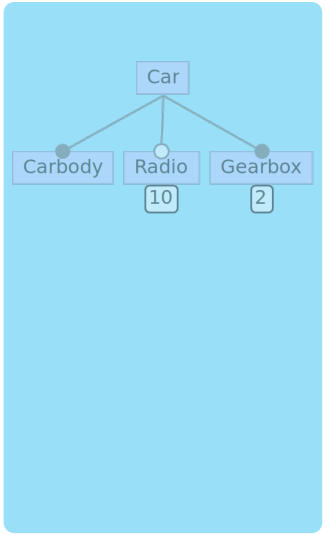
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation





- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation



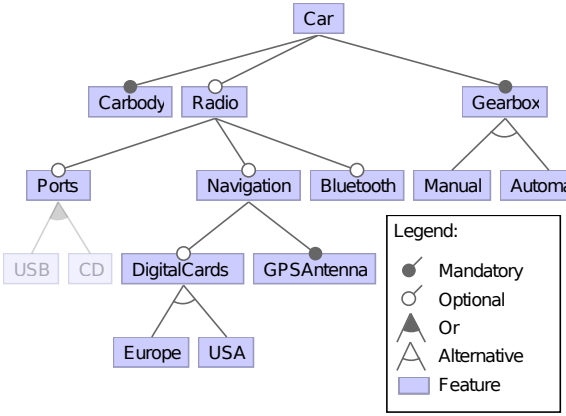
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation

Feature Prioritization

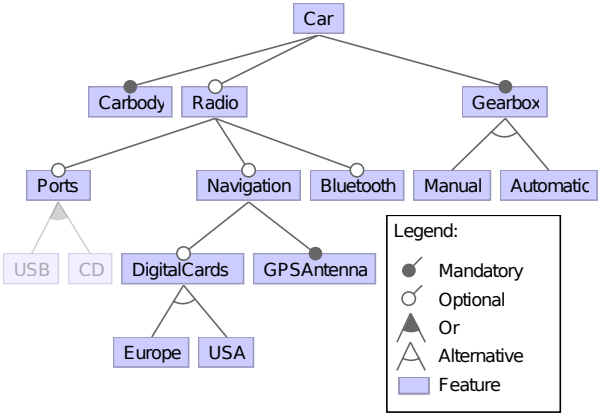
Feature Prioritization
New

Feature Prioritization



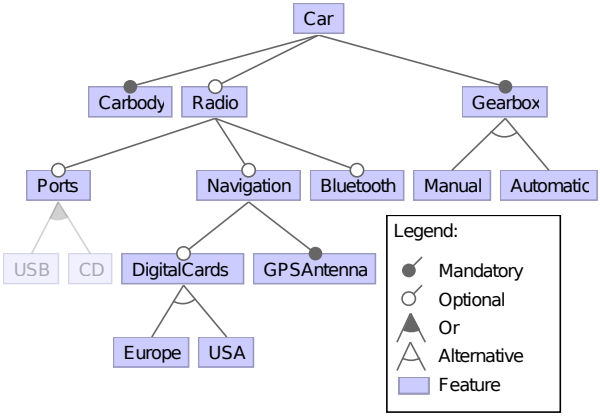
Navigation ⇒ USB

Feature Prioritization



Navigation ⇒ USB

Which feature to develop first?



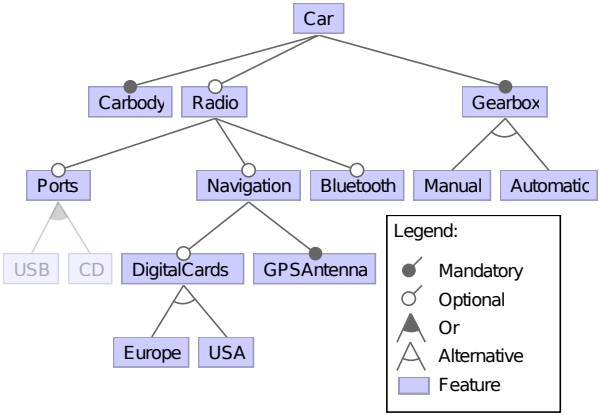
Navigation ⇒ USB

Feature Prioritization

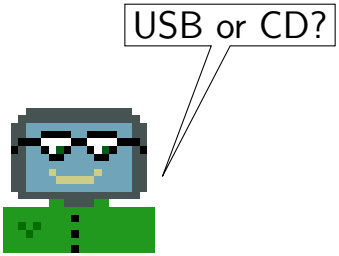
Which feature to develop first?

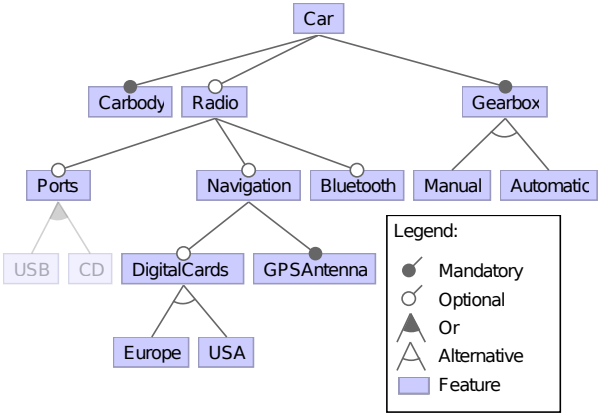
Prioritize based on cardinality

Feature Prioritization



Navigation ⇒ USB



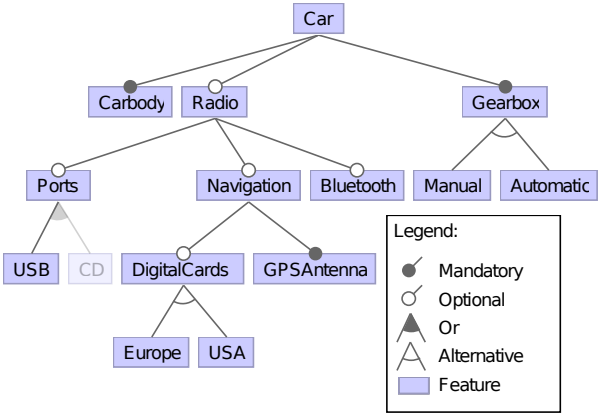


Navigation ⇒ USB

Feature Prioritization

Prioritize USB

#USB > #CD

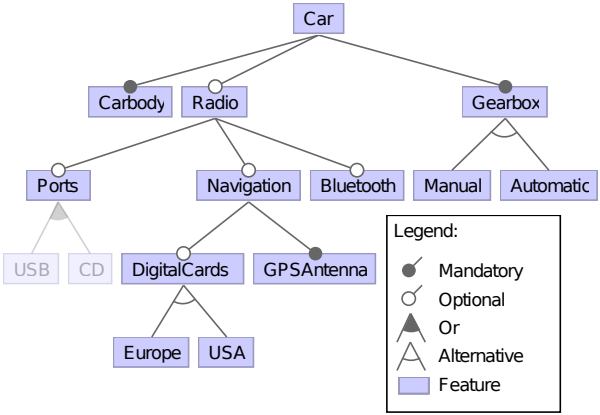


Navigation ⇒ USB

Feature Prioritization

Prioritize USB

#USB > #CD

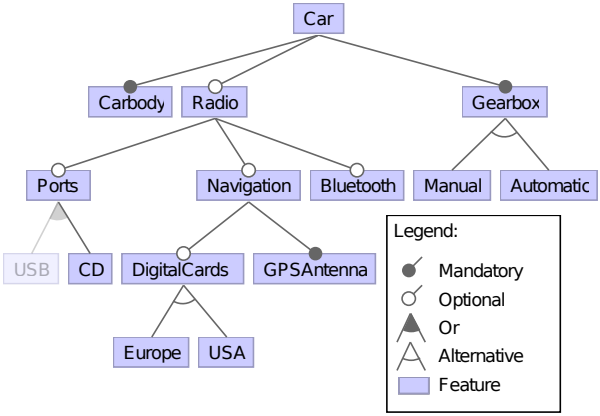


Navigation ⇒ USB

Feature Prioritization

Prioritize CD

$$\frac{\#USB}{\text{Cost}(USB)} < \frac{\#CD}{\text{Cost}(CD)}$$



Navigation ⇒ USB

Feature Prioritization

Prioritize CD

$$\frac{\#USB}{\text{Cost}(USB)} < \frac{\#CD}{\text{Cost}(CD)}$$

How to use #SAT on Features

Feature Prioritization

How to use #SAT on Features

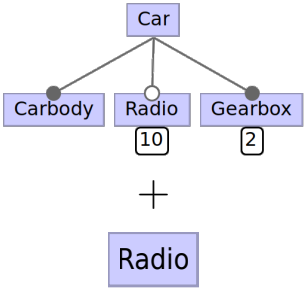
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

How to use #SAT on Features

- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

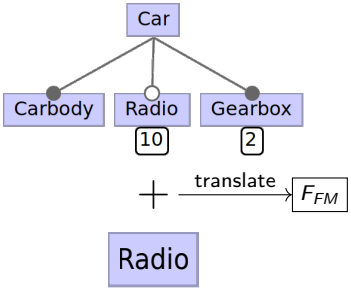
How to use #SAT on Features

- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring



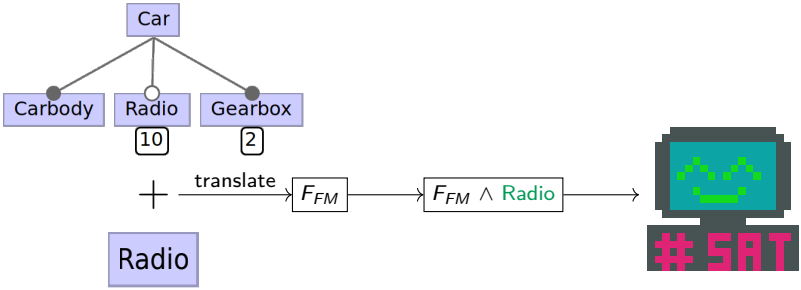
How to use #SAT on Features

- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring



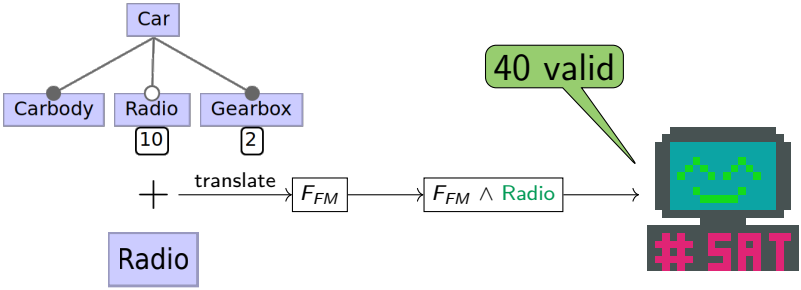
How to use #SAT on Features

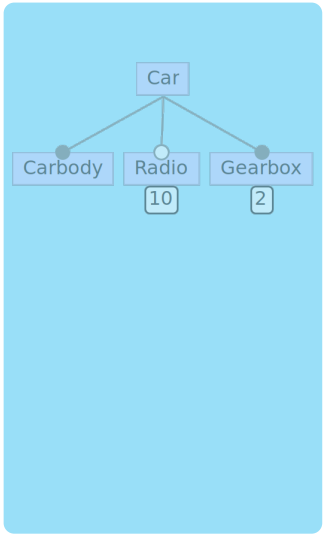
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring



How to use #SAT on Features

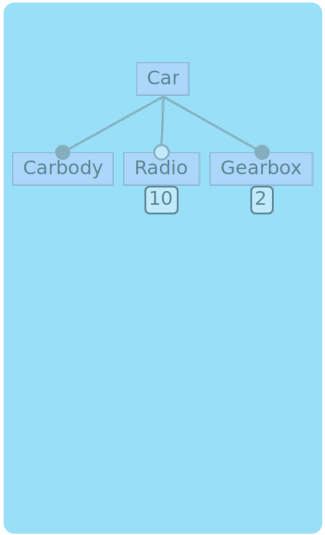
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

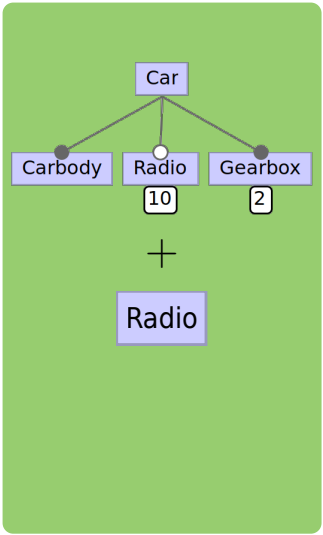




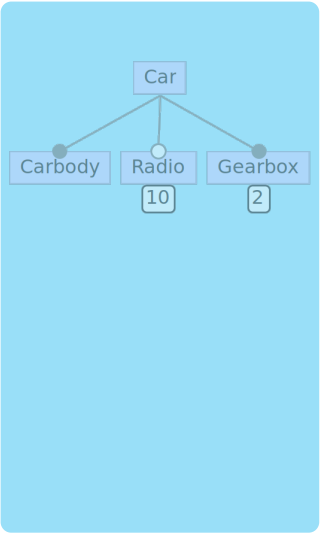
- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

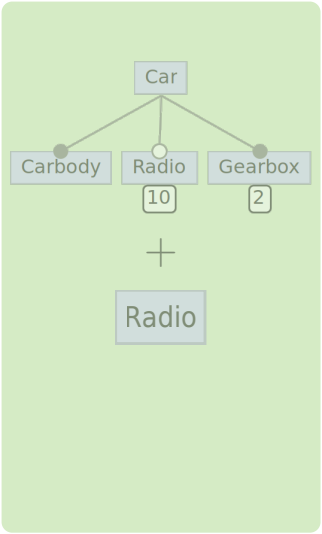
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation



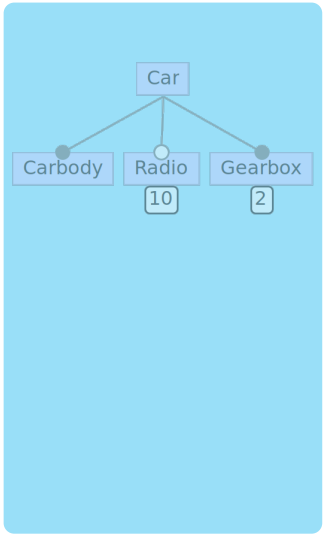


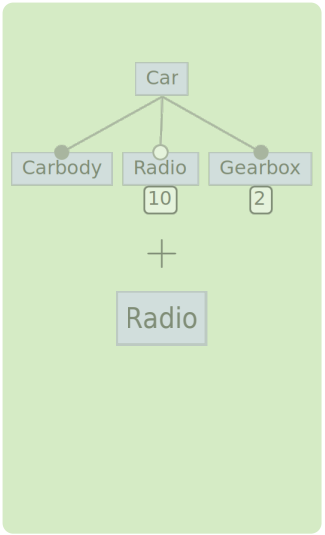
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation

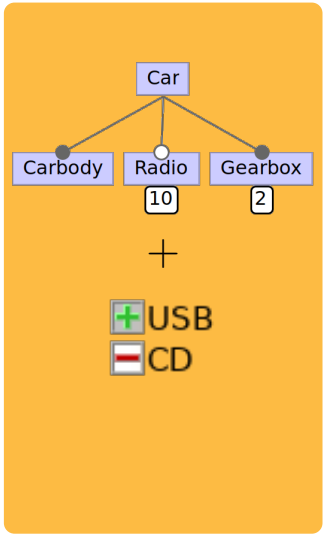


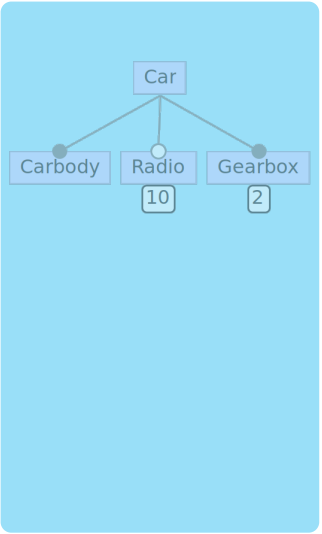


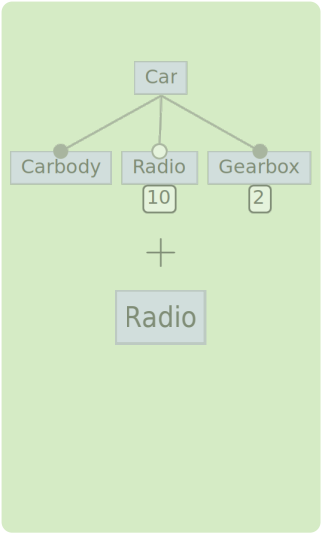
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation


Car
Carbody
Radio
10
Gearbox
2


Car
Carbody
Radio
10
Gearbox
2
Radio


Car
Carbody
Radio
10
Gearbox
2
USB
CD





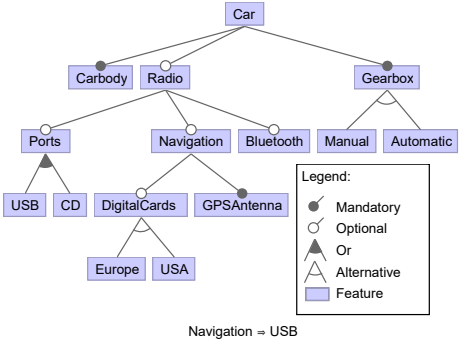
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation

Uniform Random Sampling

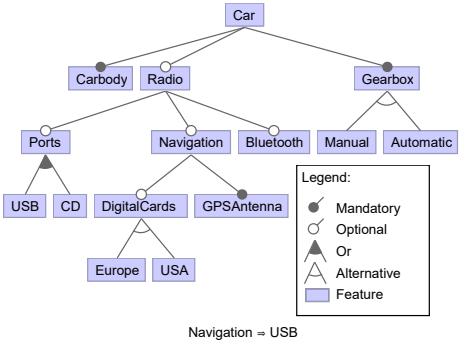
Old

Uniform Random Sampling

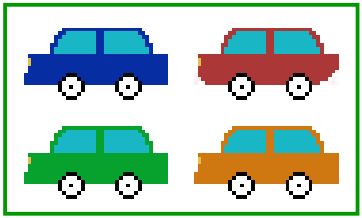
Uniform Random Sampling

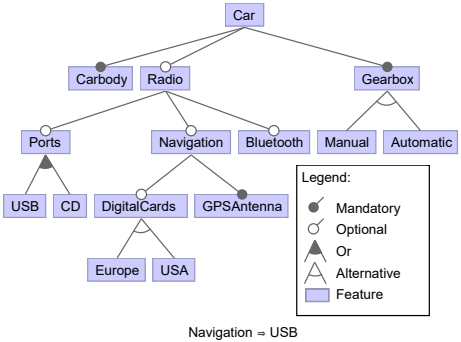


Navigation ⇒ USB

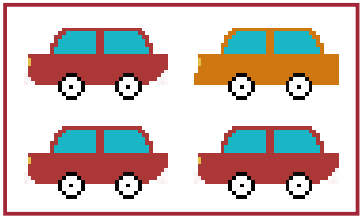


Uniform Random Sampling

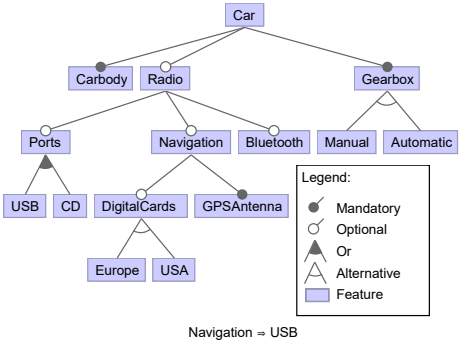




Uniform Random Sampling

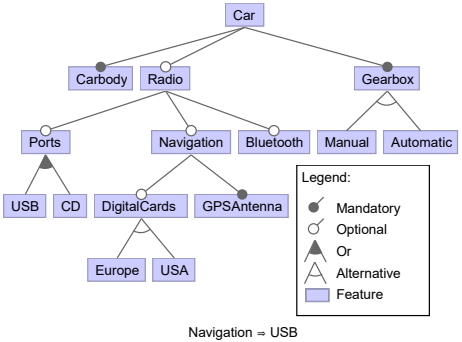


Bias



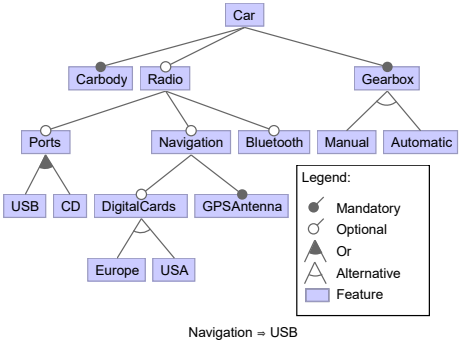
Uniform Random Sampling

- Same chance for each configuration



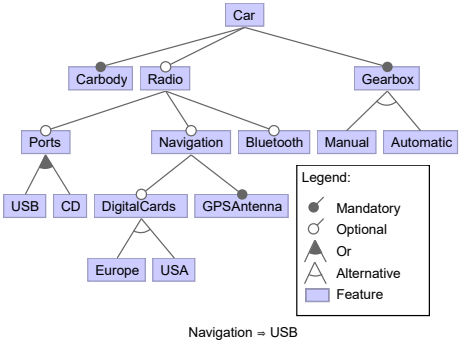
Uniform Random Sampling

- Same chance for each configuration
- Representative sample



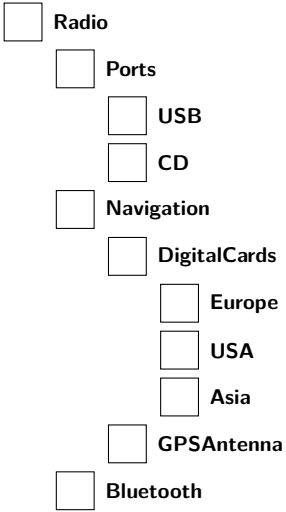
Uniform Random Sampling

- Same chance for each configuration
- Representative sample
- Why is this difficult?

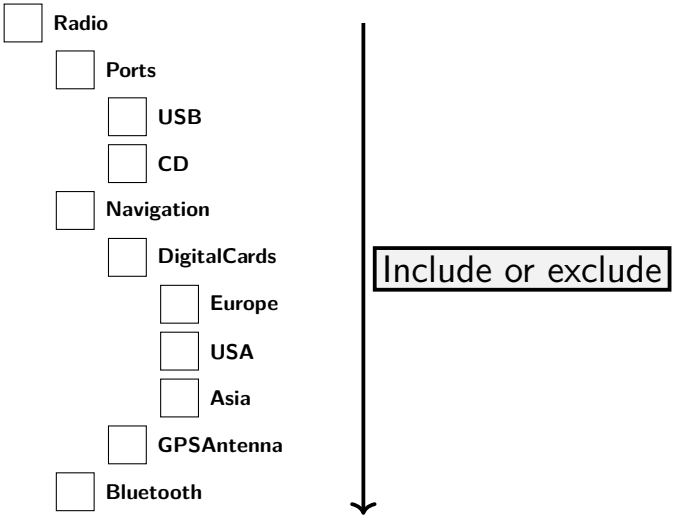


Uniform Random Sampling

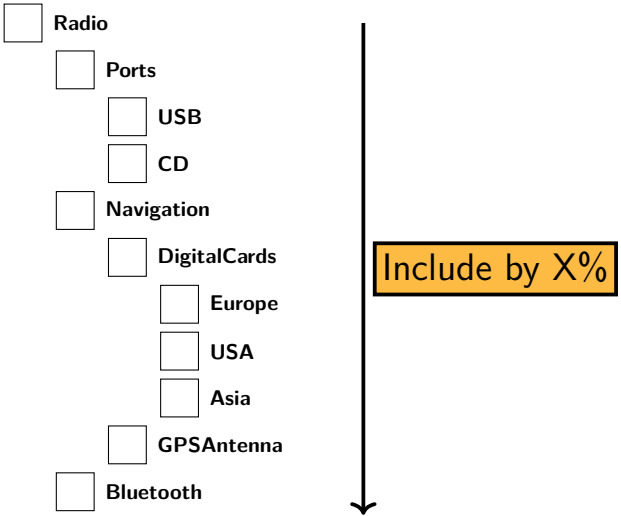
- Same chance for each configuration
- Representative sample
- Why is this difficult?
- Why do we need #SAT?



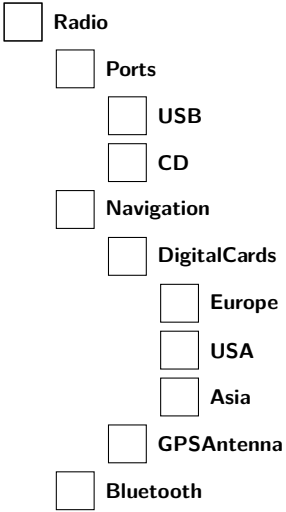
Uniform Random Sampling



Uniform Random Sampling

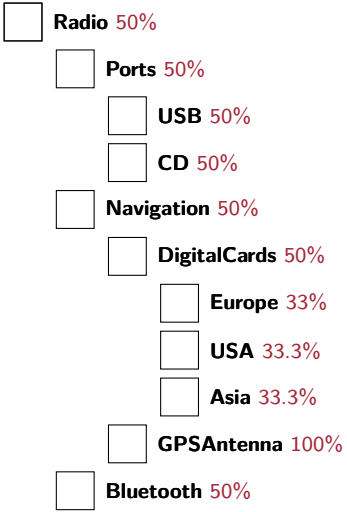


Uniform Random Sampling



Uniform Random Sampling

Naive (SAT)
SharpSAT



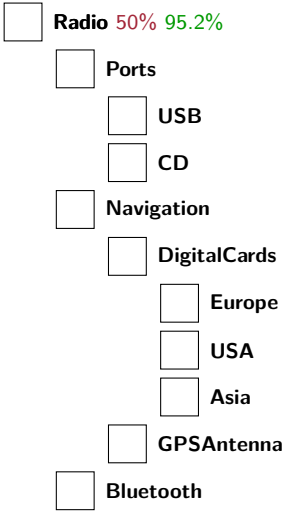
Uniform Random Sampling

Naive (SAT)
SharpSAT

- **Radio** 50% 95.2%
  - **Ports** 50% 90%
    - **USB** 50% 88.9%
    - **CD** 50% 55.6%
  - **Navigation** 50% 60%
    - **DigitalCards** 50% 66.67%
      - **Europe** 33.3% 33.3%
      - **USA** 33.3% 33.3%
      - **Asia** 33.3% 33.3%
    - **GPSAntenna** 100% 100%
  - **Bluetooth** 50% 50%

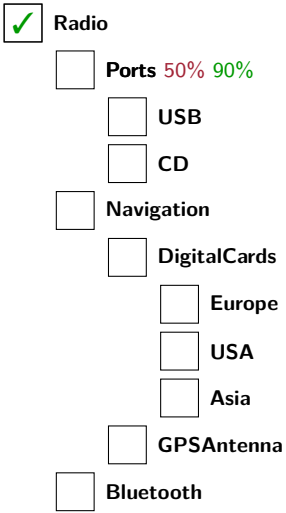
Uniform Random Sampling

Naive (SAT)
SharpSAT



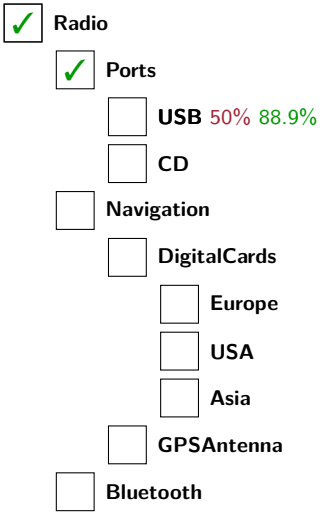
Uniform Random Sampling

Naive (SAT)
SharpSAT



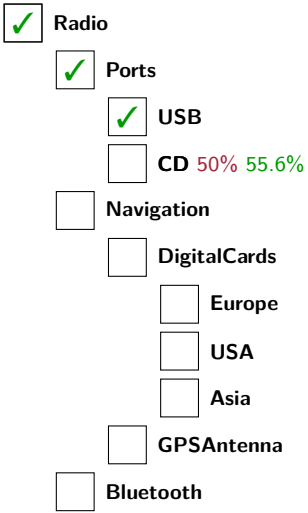
Uniform Random Sampling

Naive (SAT)
SharpSAT



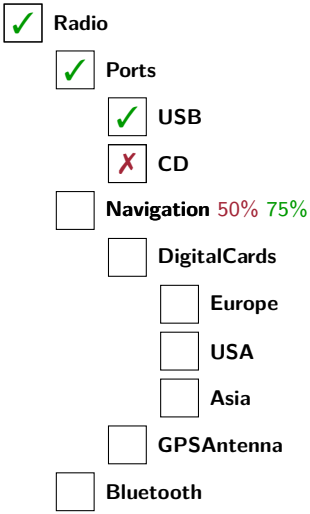
Uniform Random Sampling

Naive (SAT)
SharpSAT



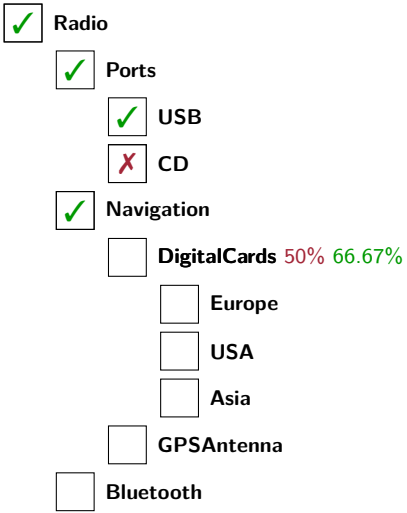
Uniform Random Sampling

Naive (SAT)
SharpSAT



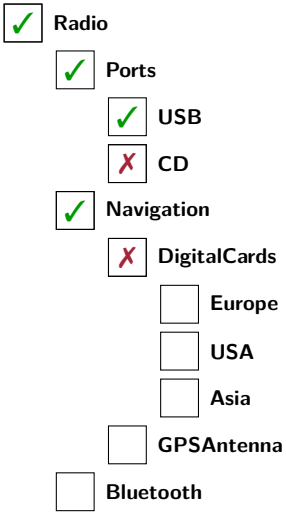
Uniform Random Sampling

Naive (SAT)
SharpSAT



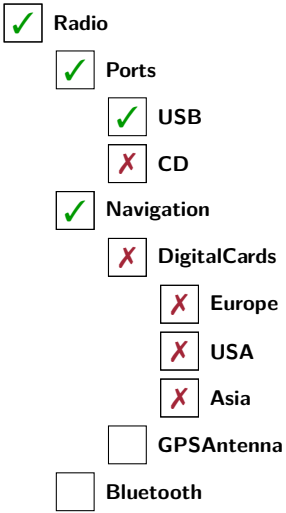
Uniform Random Sampling

Naive (SAT)
SharpSAT



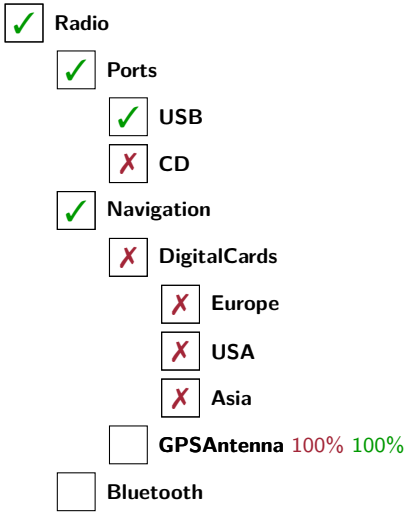
Uniform Random Sampling

Naive (SAT)
SharpSAT



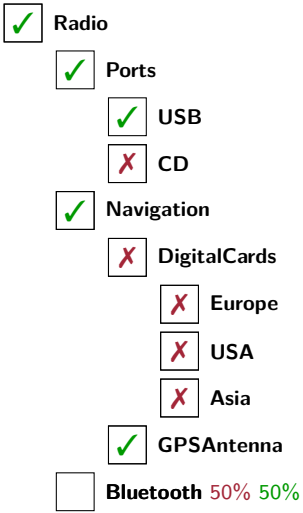
Uniform Random Sampling

Naive (SAT)
SharpSAT



Uniform Random Sampling

Naive (SAT)
SharpSAT

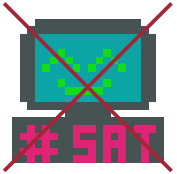


Uniform Random Sampling

Naive (SAT)
SharpSAT

- ✓ Radio
  - ✓ Ports
    - ✓ USB
    - ✗ CD
  - ✓ Navigation
    - ✗ DigitalCards
      - ✗ Europe
      - ✗ USA
      - ✗ Asia
    - ✓ GPSAntenna
  - ✓ Bluetooth

Uniform Random Sampling

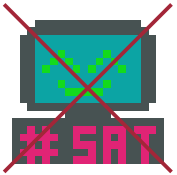


: Bias 6/11

Naive (SAT)
SharpSAT

- ✓ Radio
  - ✓ Ports
    - ✓ USB
    - ✗ CD
  - ✓ Navigation
    - ✗ DigitalCards
      - ✗ Europe
      - ✗ USA
      - ✗ Asia
    - ✓ GPSAntenna
  - ✓ Bluetooth

Uniform Random Sampling



: Bias 6/11

: No bias

Naive (SAT)
SharpSAT

How to use #SAT on Partial Configurations

Uniform Random Sampling

How to use #SAT on Partial Configurations

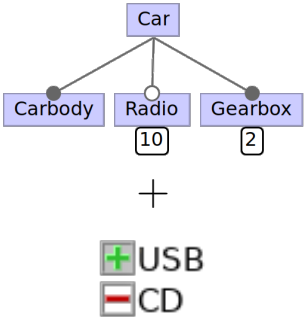
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation

How to use #SAT on Partial Configurations

- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation

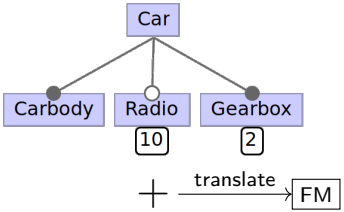
How to use #SAT on Partial Configurations

- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation



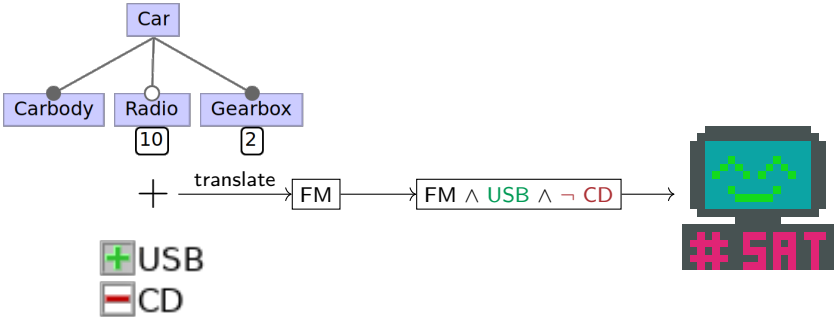
How to use #SAT on Partial Configurations

- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation



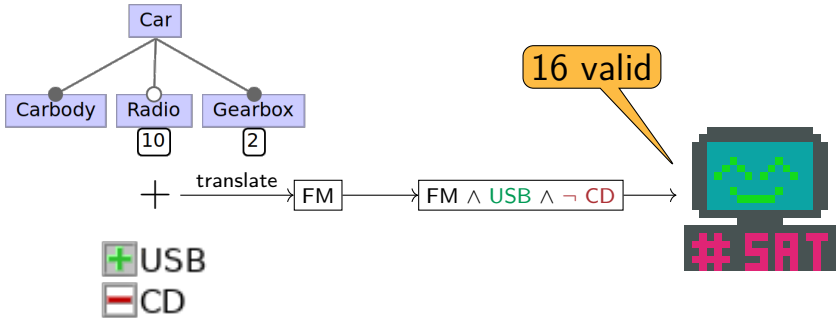
How to use #SAT on Partial Configurations

- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation



How to use #SAT on Partial Configurations

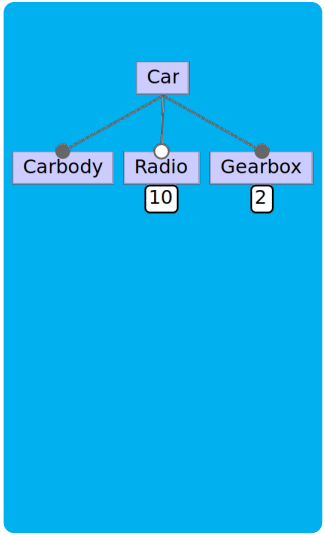
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation

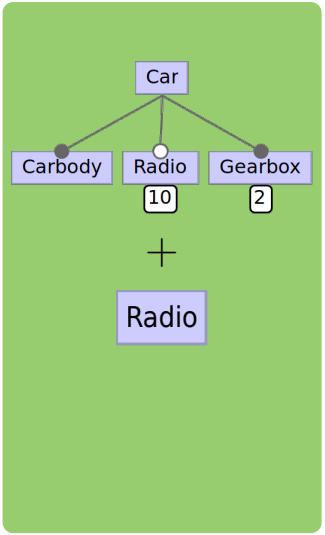


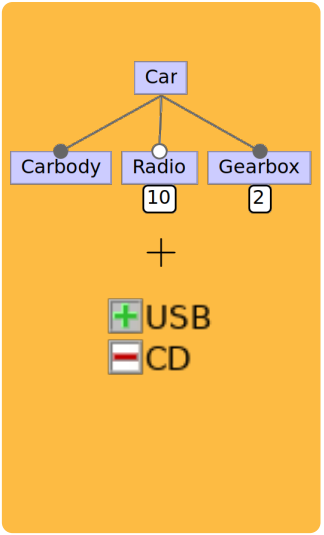
- Variability Factor
- Void Feature Moddel
- Degree of Orthogonality
- Cost Savings
- Maintainability Prediction
- Configuration Relevance
- Rating Errors
- Variability Reduction
- Subset Variability

- Homogeneity
- Payoff Threshold
- Degree of Reuse
- Core, Dead & False-Optional
- Atomic Set Candidates
- Feature Prioritization
- CTC Restrictiveness
- Optimize Configuring

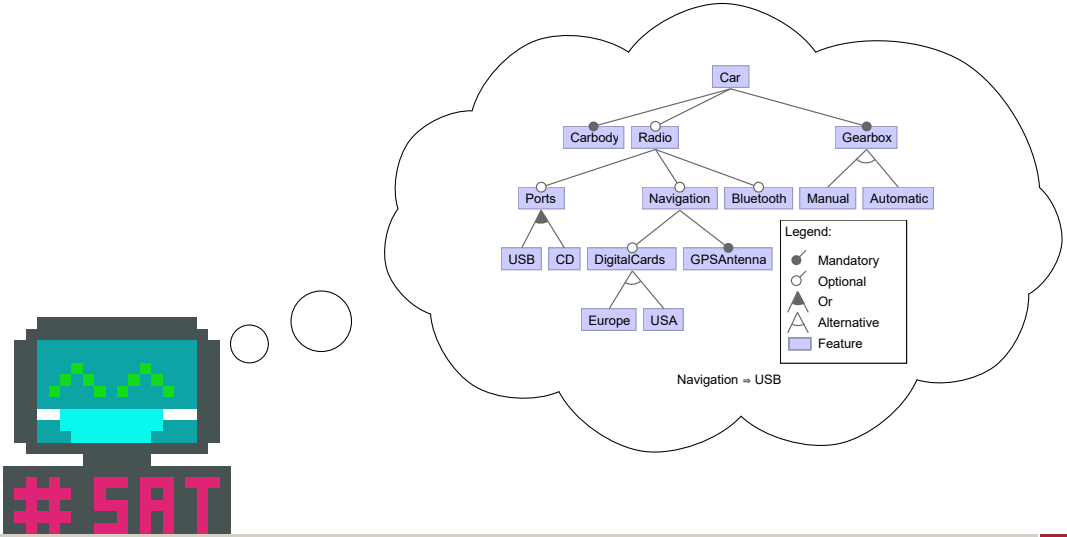
- Uniform Random Sampling
- Atomic Sets
- Rate Interactions
- Configuration Derivation


Car
Carbody
Radio
Gearbox
10
2

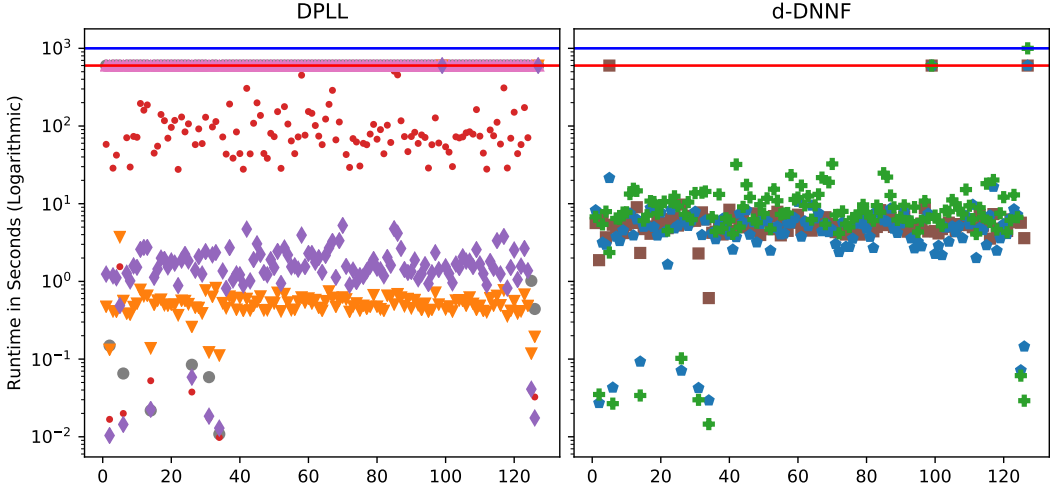

Car
Carbody
Radio
Gearbox
10
2
Radio


Car
Carbody
Radio
Gearbox
10
2
USB
CD

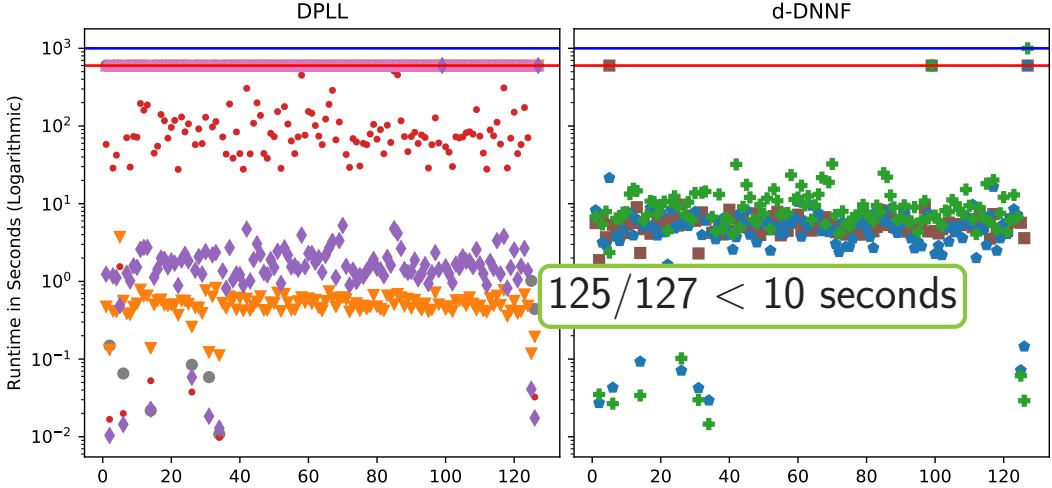
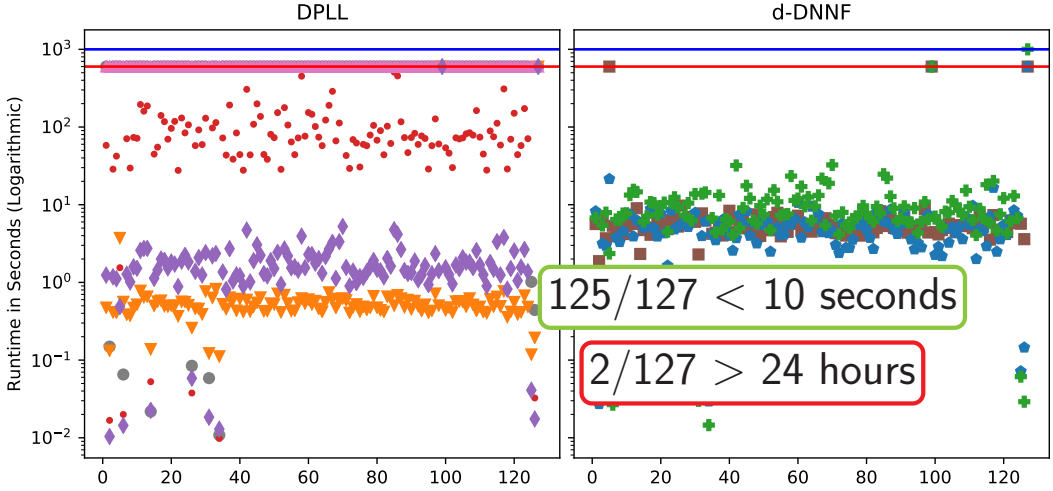
Applications of #SAT Solvers on Feature Models



Scalability of #SAT



Scalability of #SAT



Scalability of #SAT