VICCI

Visual and Interactive Cyber-Physical Systems Control and Integration

Capturing Variability in Space and Time with Hyper Feature Models

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> Agenda

- Background
  - Software Ecosystems (SECOs) and Variability
  - Formalization of Feature Models
- Problem: No Variability in Time in Feature Models
- Contributions
  - Hyper Feature Models (HFMs)
  - Version-Aware Constraint Language
  - Automatic Version Selection
- Conclusion: Capturing Variability in Space and Time with HFMs

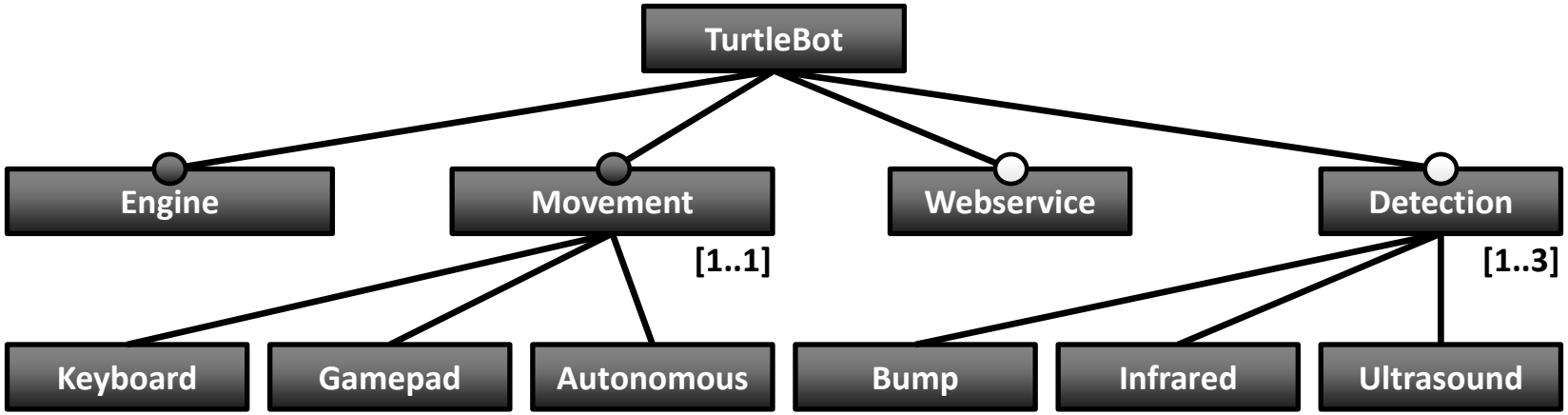
Background

- Software Ecosystems (SECOs)
  - Family of closely related software systems
  - E.g., Eclipse, Android, ROS etc.
  - Similar to SPLs, but…
    - **Multiple** contributors
    - **Frequent (unsynchronized) evolution** of variable assets



- Variability in Space
  - Configuration
  - ➢ <u>Variant</u> of system
- Variability in Time
  - Evolution
  - ➢ <u>Version</u> of system

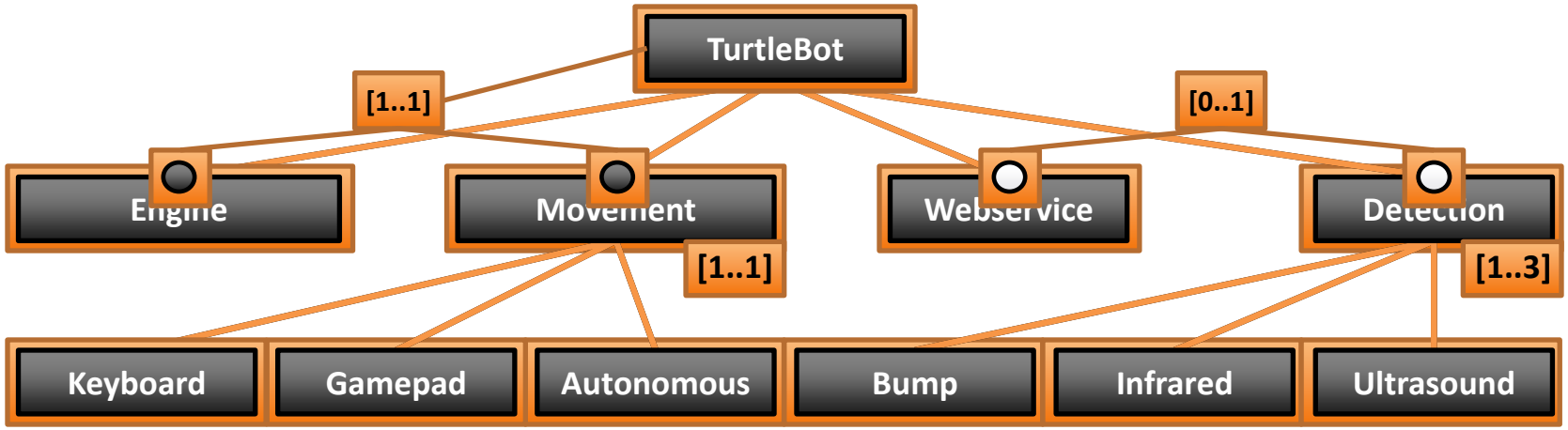
Running Example: TurtleBot Driver



Cross-Tree Constraints

1. Autonomous $\rightarrow$ Detection
2. Keyboard $\vee$ Gamepad $\rightarrow$ Webservice

Definition 1: Feature Model



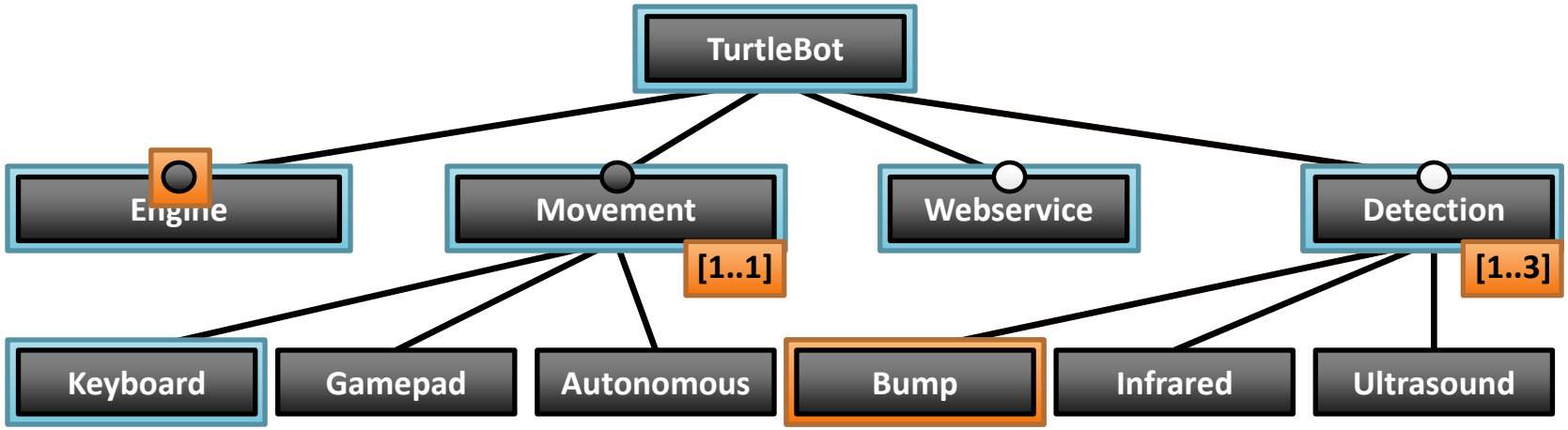
Cross-Tree Constraints

1. Autonomous → Detection
2. Keyboard ∨ Gamepad → Webservice

Definition 1 (Feature Model). *A feature model is a 4-tuple* $FM = (\mathcal{F}, \prec, \lambda, \Phi)$ *with*

1. $\mathcal{F}$: *a finite set of features*
2. $\prec \subseteq \mathcal{F} \times \mathcal{F}$: *a decomposition relation on* $\mathcal{F}$ *forming a rooted tree of features*
3. $\lambda : \mathcal{P}(\mathcal{F}) \rightharpoonup \mathbb{N}_0 \times \mathbb{N}_0$: *a function assigning minimum and maximum cardinality to features and feature groups*
4. Φ: *a set of propositional formulas over* $\mathcal{F}$ *representing cross-tree constraints*

Definition 2: Feature Model Semantics



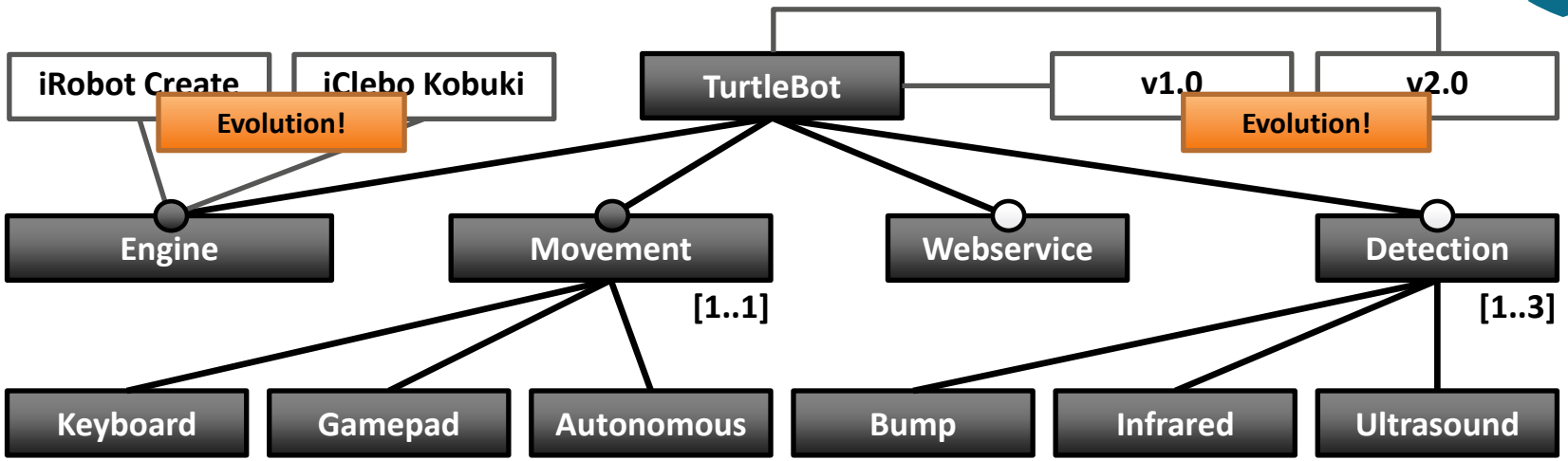
Cross-Tree Constraints

1. Autonomous → Detection
2. Keyboard ∨ Gamepad → Webservice

Definition 2 (Feature Model Semantics). *A configuration $\mathcal{C} \subseteq \mathcal{F}$ of a feature model has to satisfy the following conditions to be valid:*

1. *Cardinality constraints of features and feature groups are respected by the configuration.*
   $f \in \mathcal{C} \wedge f \prec F \wedge \lambda(F) = (k, l) \Rightarrow k \leq |F \cap \mathcal{F}| \leq l$
2. *For each selected feature, the parent feature has to be in the configuration.*
   $f_1 \in \mathcal{C} \wedge f_2 \in \mathcal{F} \wedge f_2 \prec f_1 \Rightarrow f_2 \in \mathcal{C}$
3. *All propositional formulas of the cross-tree constraints have to be satisfied by the configuration.*
   $\mathcal{C} \models \bigwedge_{\phi_i \in \Phi} \phi_i$

> Problem: No Variability in Time in Feature Models



- Constraints caused by evolution (excerpt)
  - iClebo Kobuki is incompatible with TurtleBot v1.0
  - iClebo Kobuki requires at least TurtleBot v2.0
- Problem
  - Feature model captures only variability in space
  - Only exactly one version of variable asset in feature model (no variability in time)

Requirements on Solution

- **Requirement 1**
  Support for feature versions as units of configuration.

- **Requirement 2**
  Specification of the relation of versions in logical development lines (i.e., predecessor and successor versions including branching).

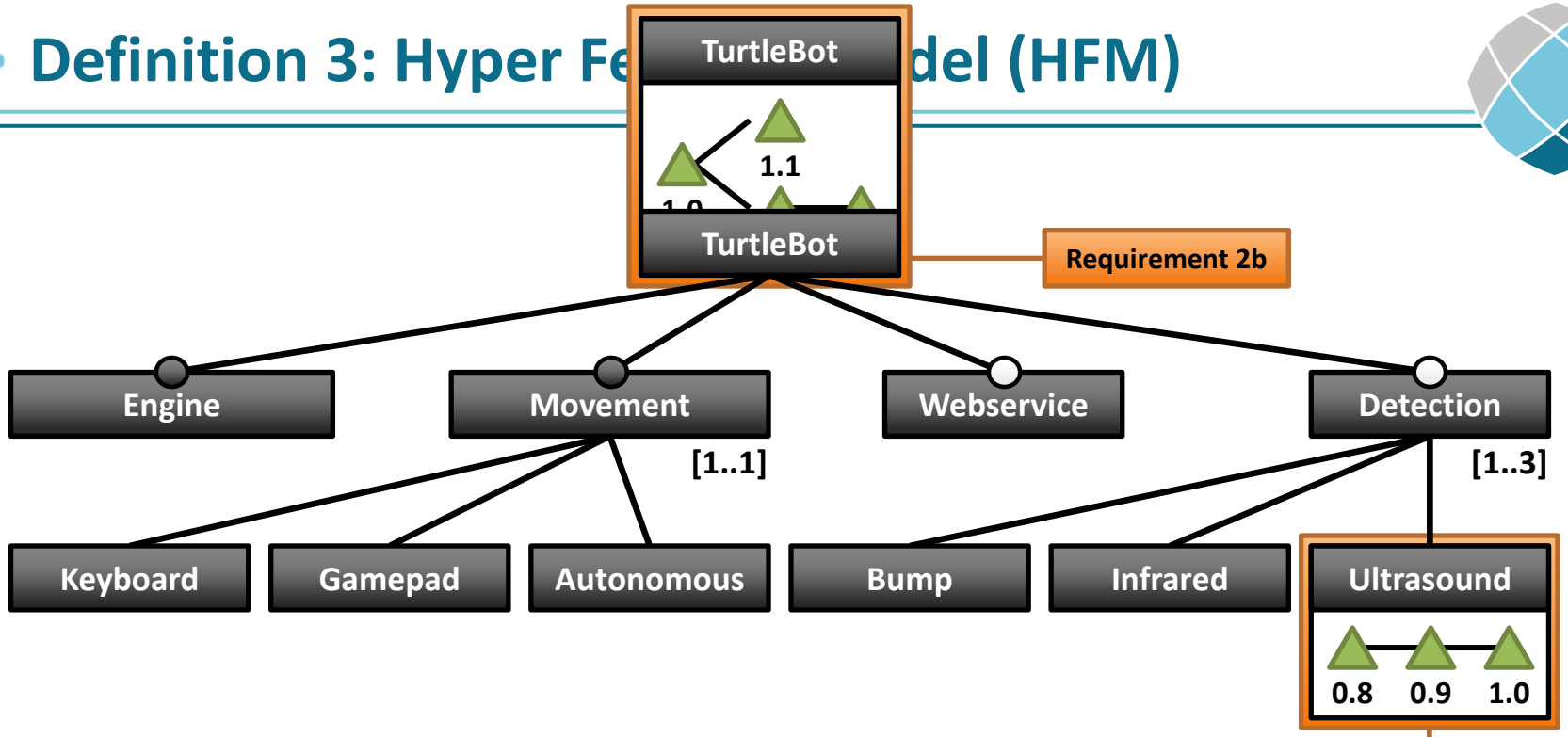
- **Requirement 3**
  Expression of dependencies on and incompatibilities with version ranges.

- **Requirement 4**
  Support for users in selecting suitable combinations of versions from a selection of features.

Contribution 1

Hyper Feature Models (HFMs)

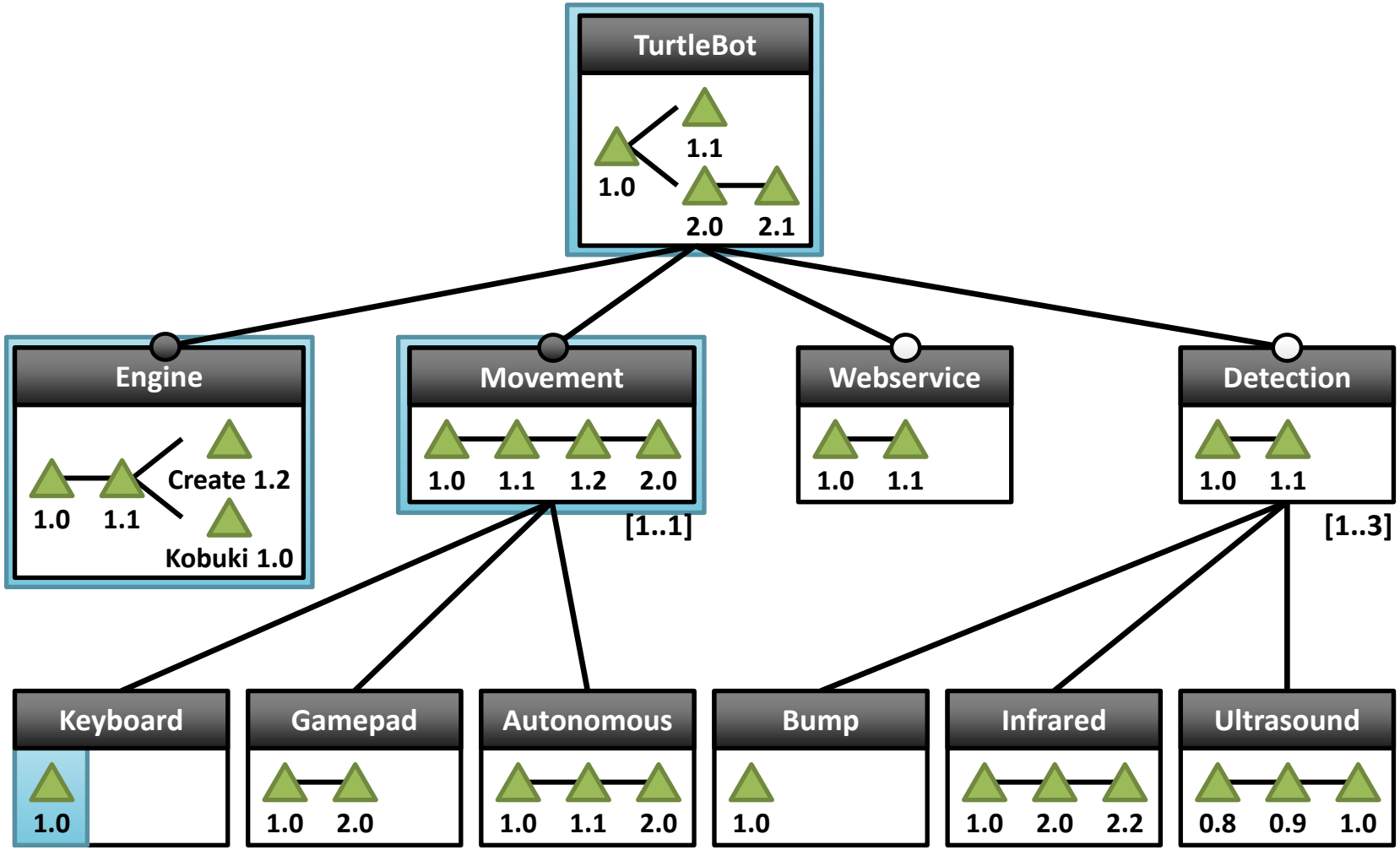
Definition 3: Hyper Feature Model (HFM)



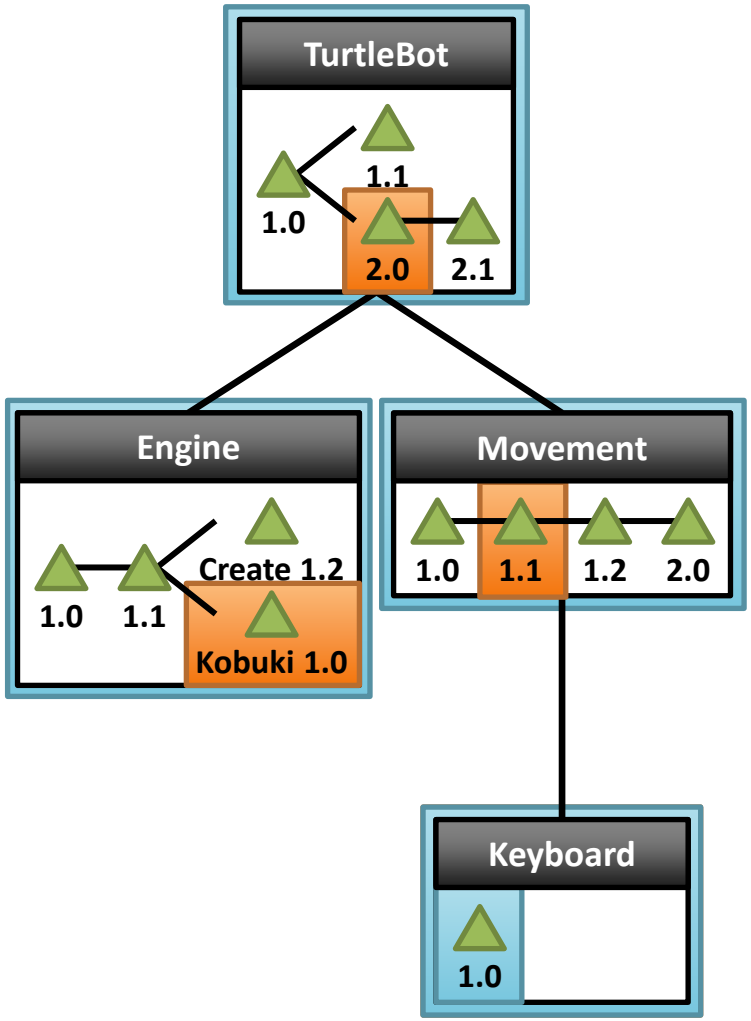
Feature Model (Definition 1)

1. $\mathcal{F}$: *a finite set of features*
2. $\mathcal{V}$: *a finite set of feature versions*
3. $\prec \subseteq \mathcal{F} \times \mathcal{F}$: *a decomposition relation on* $\mathcal{F}$ *forming a rooted tree of features*
4. $\lambda : \mathcal{P}(\mathcal{F}) \rightharpoonup \mathbb{N}_0 \times \mathbb{N}_0$: *a function assigning minimum and maximum cardinality to features and feature groups*

Definition 5: HFM Semantics



Definition 5: HFM Semantics



Definition 5 (Hyper Feature Model Semantics). *A configuration $\mathcal{C} \subseteq \mathcal{F} \cup \mathcal{V}$ of a Hyper Feature Model has to satisfy the following conditions to be valid:*

1. *Cardinality constraints of features and feature groups are respected by the configuration.*
   $f \in \mathcal{C} \wedge f \prec F \wedge \lambda(F) = (k, l) \Rightarrow k \leq |F \cap \mathcal{F}| \leq l$
2. *For each selected feature, the parent feature has to be in the configuration.*
   $f_1 \in \mathcal{C} \cap \mathcal{F} \wedge f_2 \in \mathcal{F} \wedge f_2 \prec f_1 \Rightarrow f_2 \in \mathcal{C}$
3. *For each selected version, the containing feature also has to be part of the configuration.*
   $\forall v \in \mathcal{C} \cap \mathcal{V} : \Upsilon(f) = \mathcal{V}_f \wedge v \in \mathcal{V}_f \rightarrow f \in \mathcal{C}$
4. *For each selected feature, there has to be exactly one version in the configuration.*
   $\forall f \in \mathcal{C} \cap \mathcal{F} : \Upsilon(f) = \mathcal{V}_f \rightarrow \exists v \in \mathcal{V}_f : v \in \mathcal{C} \wedge (v_1, v_2 \in \mathcal{C} \cap \mathcal{V}_f \rightarrow v_1 = v_2)$

Feature Model (Definition 2)

Contribution 2

Version-Aware Constraint Language

Definition 6: Version-Aware Constraint Syntax

Definition 6 (Version-Aware Constraint Syntax). *Let $f \in \mathcal{F}$ be a feature, $v_a, v_b \in \mathcal{V}$ versions and $op \in \{>, \geq, =, \leq, <\}$: $\mathcal{V} \rightharpoonup \mathcal{P}(\mathcal{V})$ a set of operators over versions. The following are basic expressions of the version-aware constraint language:*

Atomic Expressions

1. f	*(feature presence)*
2. $f\ [v_a - v_b]$	*(version range restriction)*
3. $f\ [op\ v_a]$	*(relative version restriction)*
4. $?f\ [v_a - v_b]$	*(conditional version range restriction)*
5. $?f\ [op\ v_a]$	*(conditional relative version restriction)*

Requirement 3

Let ψ_1 and ψ_2 be version-aware constraints. The following are compound expressions of the version-aware constraint language:

Compound Expressions

6. ψ_1	*(basic expression)*
7. (ψ_1)	*(nested expression)*
8. $\neg\psi_1$	*(negation)*
9. $\psi_1 \wedge \psi_2$	*(conjunction)*
10. $\psi_1 \vee \psi_2$	*(disjunction)*
11. $\psi_1 \rightarrow \psi_2$	*(implication)*

Boolean Algebra

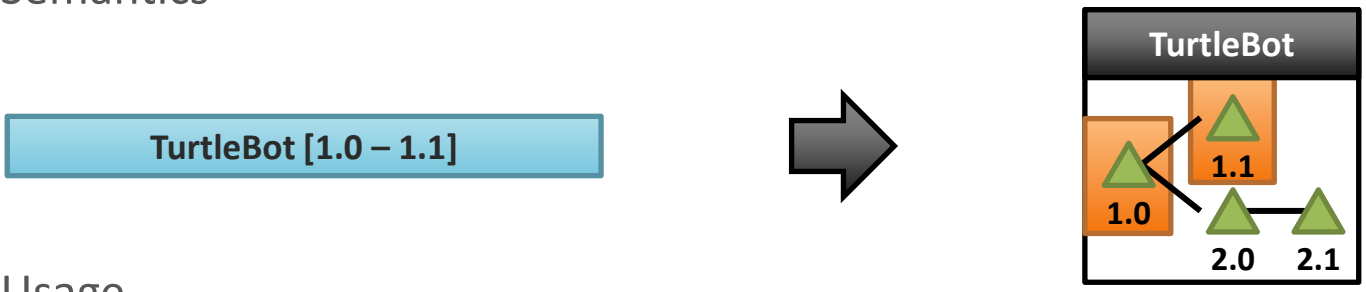
> (Conditional) Version Range Restrictions

$$f\ [v_a - v_b]$$

$$?f\ [v_a - v_b] \equiv (f \rightarrow f\ [v_a - v_b])$$

- Examples
  - **TurtleBot [1.0 – 1.1]** → Engine [≤ Create 1.2]
  - **?Movement [1.2 – 2.0]**

- Semantics

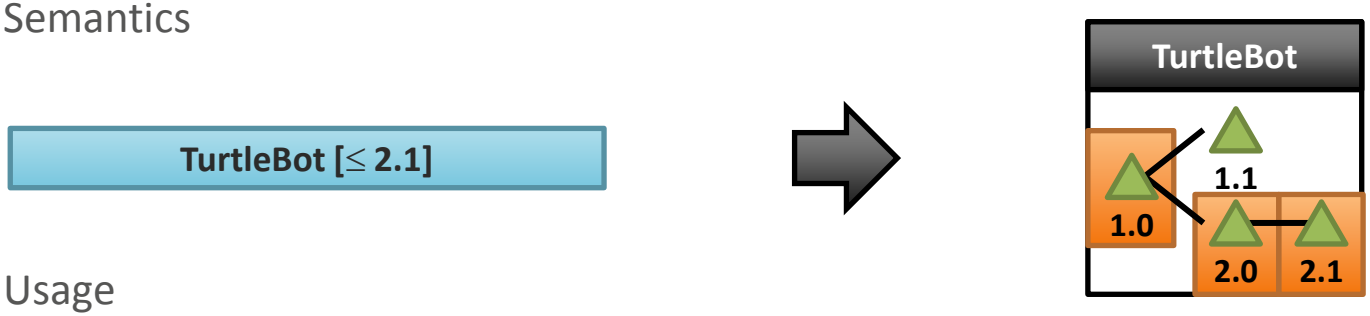


- Usage
  - Closed intervals (fixed even if evolved)
  - E.g., dependencies of Eclipse manifest files

> (Conditional) Relative Version Restrictions

$$\mathbf{f}\ [op\ \mathbf{v_a}]$$
$$?\mathbf{f}\ [op\ \mathbf{v_a}] \equiv (\mathbf{f} \rightarrow \mathbf{f}\ [op\ \mathbf{v_a}])$$

- Operators: op = {>, ≥, =, ≤, <}
- Examples
  - TurtleBot [1.0 – 1.1] → **Engine [≤ Create 1.2]**
  - **?Engine [≥ Kobuki 1.0]**
- Semantics

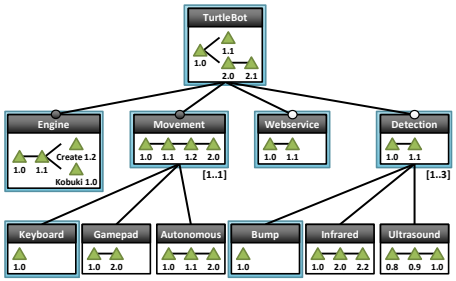


- Usage
  - No need to know all versions in the interval explicitly
  - Open intervals (extended in case of evolution)

Contribution 3

Automatic Version Selection

Automatic Version Selection: General Procedure



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Version-Aware Constraints

1. Autonomous → Detection
2. Keyboard ∨ Gamepad → Webservice
3. Infrared [≥ 2.0] ∨ Ultrasound → Detection [≥ 1.1]
4. TurtleBot [≥ 2.0] → Engine [≥ Kobuki 1.0]
5. TurtleBot [1.0 – 1.1] → Engine [≤ Create 1.2]
6. TurtleBot [≥ 2.0] → ?Webservice [≥ 1.1]

encode

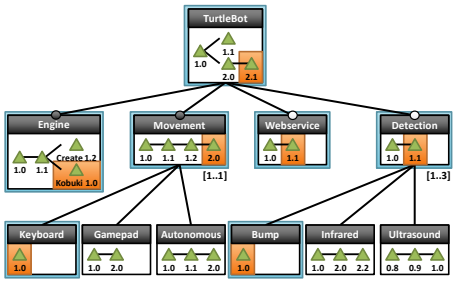
Constraint Satisfaction Problem (CSP) Solver

solve

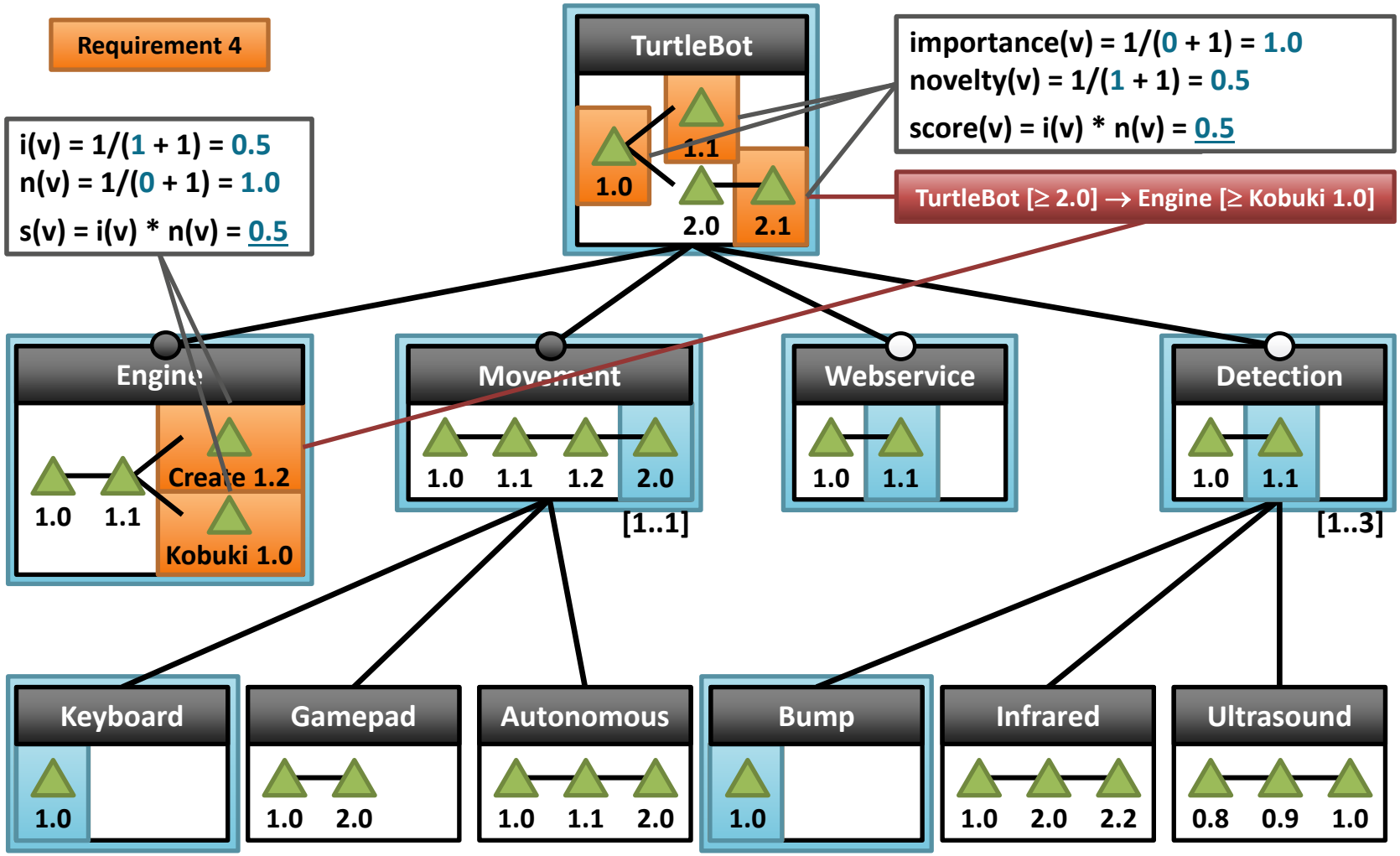
All Possible (Version) Configurations

select

Scoring to find "best" configuration



Scoring to Find "Best" Configuration



> Conclusion

- Problem: No variability in time in Feature Models

- Solution
  - Hyper Feature Models (HFMs)
  - Version-Aware Constraint Language
  - Automatic Version Selection

- Fulfills initially posed requirements
- Evaluated in case study using TurtleBot driver

➢ Capturing variability in space and time in Hyper Feature Models

Thank you for your attention!

Questions, Comments, Feedback?