# Formal Semantics

## 1 Defining Concrete Examples

Figure 1: Example Robot 1

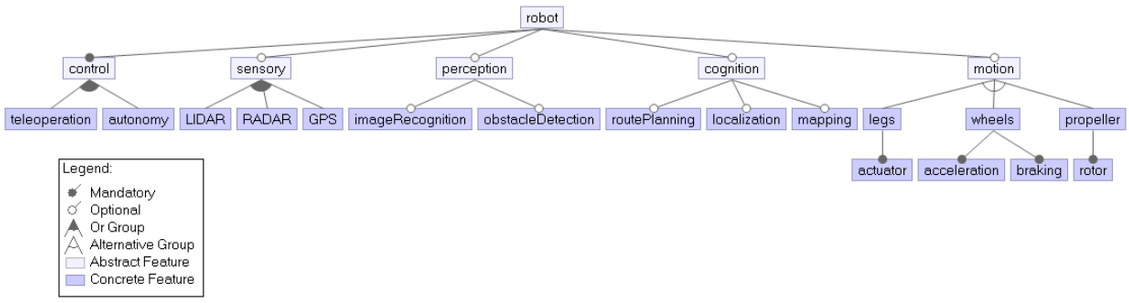


Table 1: Allowed Binding Times and Modes For Figure 1

| Feature | Property | Static Early (SE) | Static Late (SL) | Dynamic Early (DE) | Dynamic Late (DL) |
|---|---|---|---|---|---|
| robot(root) | Mandatory | ✓ | ✗ | ✗ | ✗ |
| control | Mandatory | ✓ | ✓ | ✗ | ✗ |
| sensory | Optional | ✓ | ✗ | ✗ | ✗ |
| perception | Optional | ✓ | ✗ | ✗ | ✗ |
| cognition | Optional | ✓ | ✗ | ✗ | ✗ |
| motion | Optional | ✓ | ✗ | ✗ | ✗ |
| teleoperation | OR | ✓ | ✓ | ✓ | ✓ |
| autonomy | OR | ✓ | ✓ | ✓ | ✓ |
| LIDAR | OR | ✓ | ✓ | ✓ | ✓ |
| RADAR | OR | ✓ | ✓ | ✓ | ✓ |
| GPS | OR | ✓ | ✓ | ✓ | ✓ |
| imageRecognition | Optional | ✗ | ✗ | ✓ | ✓ |
| obstacleDetection | Optional | ✗ | ✗ | ✓ | ✓ |
| routePlanning | Optional | ✗ | ✗ | ✓ | ✓ |
| localization | Optional | ✗ | ✗ | ✓ | ✓ |
| mapping | Optional | ✗ | ✗ | ✓ | ✓ |
| legs | XOR | ✗ | ✗ | ✓ | ✓ |
| actuator | Mandatory | ✓ | ✓ | ✗ | ✗ |
| wheels | XOR | ✗ | ✗ | ✓ | ✓ |
| acceleration | Mandatory | ✓ | ✓ | ✗ | ✗ |
| braking | Mandatory | ✓ | ✓ | ✗ | ✗ |
| propeller | XOR | ✗ | ✗ | ✓ | ✓ |
| rotor | Mandatory | ✓ | ✓ | ✗ | ✗ |

Figure 2: Example Robot 2

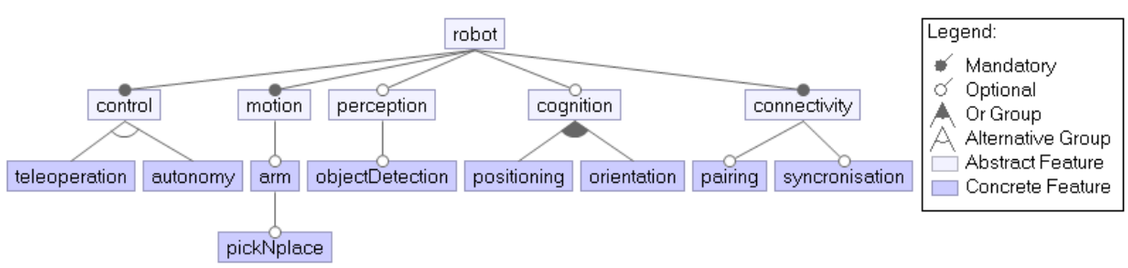

Table 2: Allowed Binding Times and Modes For Figure 2

| Feature | Property | Static Early (SE) | Static Late (SL) | Dynamic Early (DE) | Dynamic Late (DL) |
|---|---|---|---|---|---|
| robot(root) | Mandatory | ✓ | ✗ | ✗ | ✗ |
| control | Mandatory | ✓ | ✓ | ✗ | ✗ |
| motion | Mandatory | ✓ | ✓ | ✗ | ✗ |
| perception | Optional | ✓ | ✗ | ✗ | ✗ |
| cognition | Optional | ✓ | ✗ | ✗ | ✗ |
| connectivity | Mandatory | ✓ | ✓ | ✗ | ✗ |
| pairing | Optional | ✗ | ✗ | ✓ | ✓ |
| synchronisation | Optional | ✗ | ✗ | ✓ | ✓ |
| positioning | OR | ✓ | ✓ | ✓ | ✓ |
| orientation | OR | ✓ | ✓ | ✓ | ✓ |
| objectDetection | Optional | ✗ | ✗ | ✓ | ✓ |
| arm | Optional | ✗ | ✗ | ✓ | ✓ |
| pickNplace | Optional | ✗ | ✗ | ✓ | ✓ |
| teleoperation | XOR | ✗ | ✗ | ✓ | ✓ |
| autonomy | XOR | ✗ | ✗ | ✓ | ✓ |

## 2 Deducing General Language Semantics

For any given feature pairs represented arbitrarily by A and B, where A and B are objects of our meta-model i.e they can be assigned a binding time and binding mode value, the table below represents valid and invalid pairs of A and B that can exist under mandatory, optional, inclusion, exclusion, OR and XOR constraints, for any given feature model. 1s denote that the pairing is valid while 0s denote that a corresponding pairing is invalid.

Table 3: Feature Model Binding Semantics: **S = Static, E = Early, L = Late, D = Dynamic**

| A | B | $\neg$ B | A $\Rightarrow \neg$ B | A $\Rightarrow$ B | A $\Leftrightarrow$ B | A $\vee$ B | A $\oplus$ B |
|---|---|---|---|---|---|---|---|
| SE | SE | DL | 0 | 1 | 1 | 1 | 0 |
| SE | SL | DE | 0 | 0 | 0 | 1 | 0 |
| SE | DE | SL | 0 | 0 | 0 | 1 | 0 |
| SE | DL | SE | 1 | 0 | 0 | 1 | 0 |
| SL | SE | DL | 0 | 1 | 0 | 1 | 0 |
| SL | SL | DE | 0 | 1 | 1 | 1 | 0 |
| SL | DE | SL | 1 | 0 | 0 | 1 | 0 |
| SL | DL | SE | 1 | 0 | 0 | 1 | 0 |
| DE | SE | DL | 0 | 1 | 0 | 1 | 0 |
| DE | SL | DE | 0 | 0 | 0 | 1 | 0 |
| DE | DE | SL | 0 | 0 | 0 | 1 | 1 |
| DE | DL | SE | 1 | 0 | 0 | 1 | 1 |
| DL | SE | DL | 0 | 1 | 0 | 1 | 0 |
| DL | SL | DE | 0 | 1 | 0 | 1 | 0 |
| DL | DE | SL | 1 | 0 | 0 | 1 | 1 |
| DL | DL | SE | 0 | 0 | 0 | 1 | 1 |

Using DNF, the following propositional logic formulas were generated from the table above.

- ***Mandatory:***
  $(A \Leftrightarrow B) \equiv (SE \wedge SE) \vee (SL \wedge SL)$
- ***Optional:***
  $(A \Rightarrow B) \equiv (SE \wedge SE) \vee (SL \wedge SE) \vee (SL \wedge SL) \vee (DE \wedge SE) \vee (DL \wedge SE) \vee (DL \wedge SL)$
- ***Inclusion:***
  $(A \Rightarrow B) \equiv (SE \wedge SE) \vee (SL \wedge SE) \vee (SL \wedge SL) \vee (DE \wedge SE) \vee (DL \wedge SE) \vee (DL \wedge SL)$
- ***Exclusion:***
  $(A \Rightarrow \neg B) \equiv (SE \wedge SE) \vee (SL \wedge SL) \vee (SL \wedge SE) \vee (DE \wedge SE) \vee (DL \wedge SL)$
- ***OR:***
  $(A \vee B) \equiv (SE \wedge SE) \vee (SE \wedge SL) \vee (SE \wedge DE) \vee (SE \wedge DL) \vee (SL \wedge SE) \vee (SL \wedge SL) \vee (SL \wedge DE) \vee (SL \wedge DL) \vee (DE \wedge SE) \vee (DE \wedge SL) \vee (DE \wedge DE) \vee (DE \wedge DL) \vee (DL \wedge SE) \vee (DL \wedge SL) \vee (DL \wedge DE) \vee (DL \wedge DL)$
- ***XOR:***
  $(A \oplus B) \equiv (DE \wedge DE) \vee (DE \wedge DL) \vee (DL \wedge DE) \vee (DL \wedge DL)$