# Knowledge Engineering for Configuration Systems

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- Configurator Development Lifecycle
- Debugging Configuration Knowledge Bases

# Motivation

- Increasingly large and complex configuration knowledge bases
- Requirements:
  - Integration into standard software development processes
  - Automated testing and debugging

# Configurator Development Process

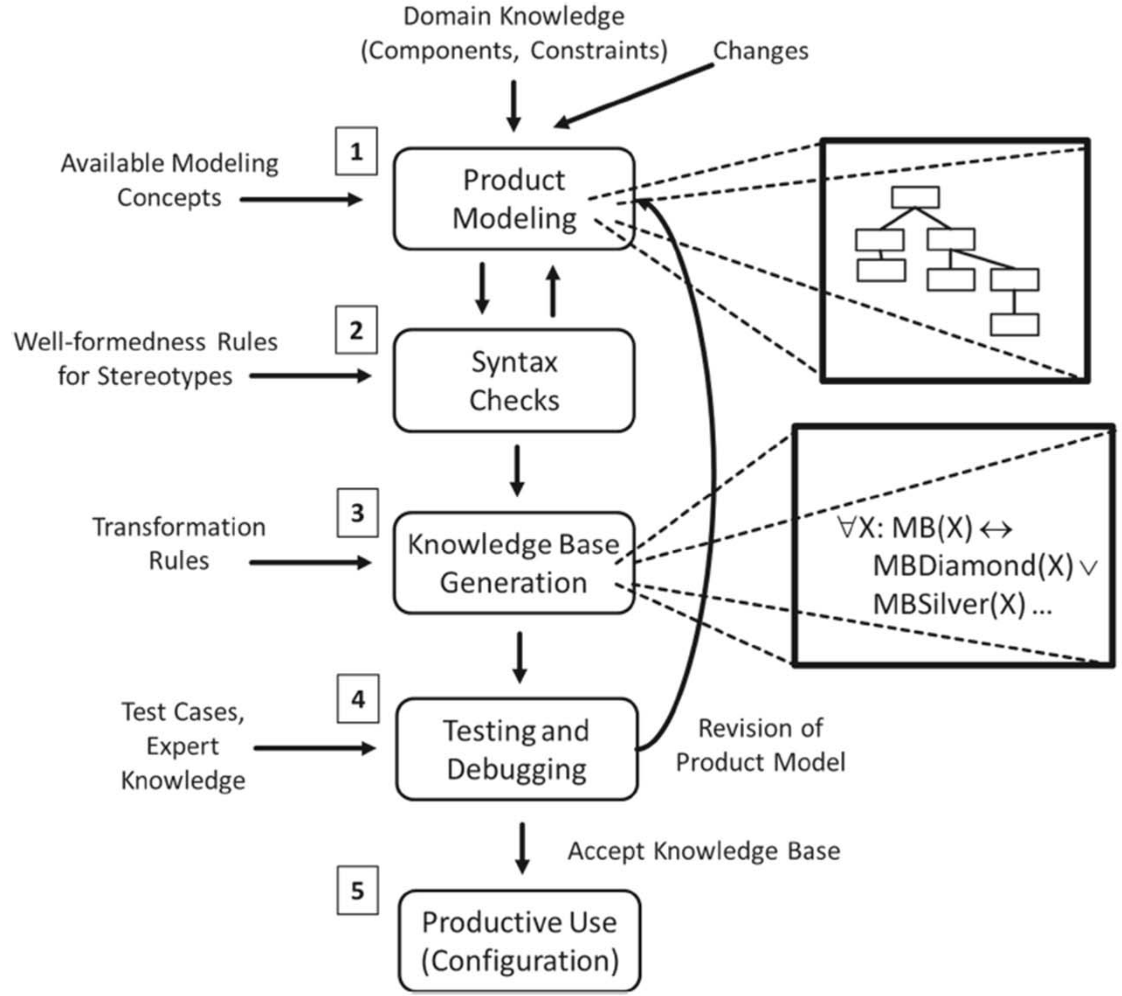



**FIGURE 11.1**

Configurator development process adapted from Felfernig et al. (2000a).

# UML Configuration Model

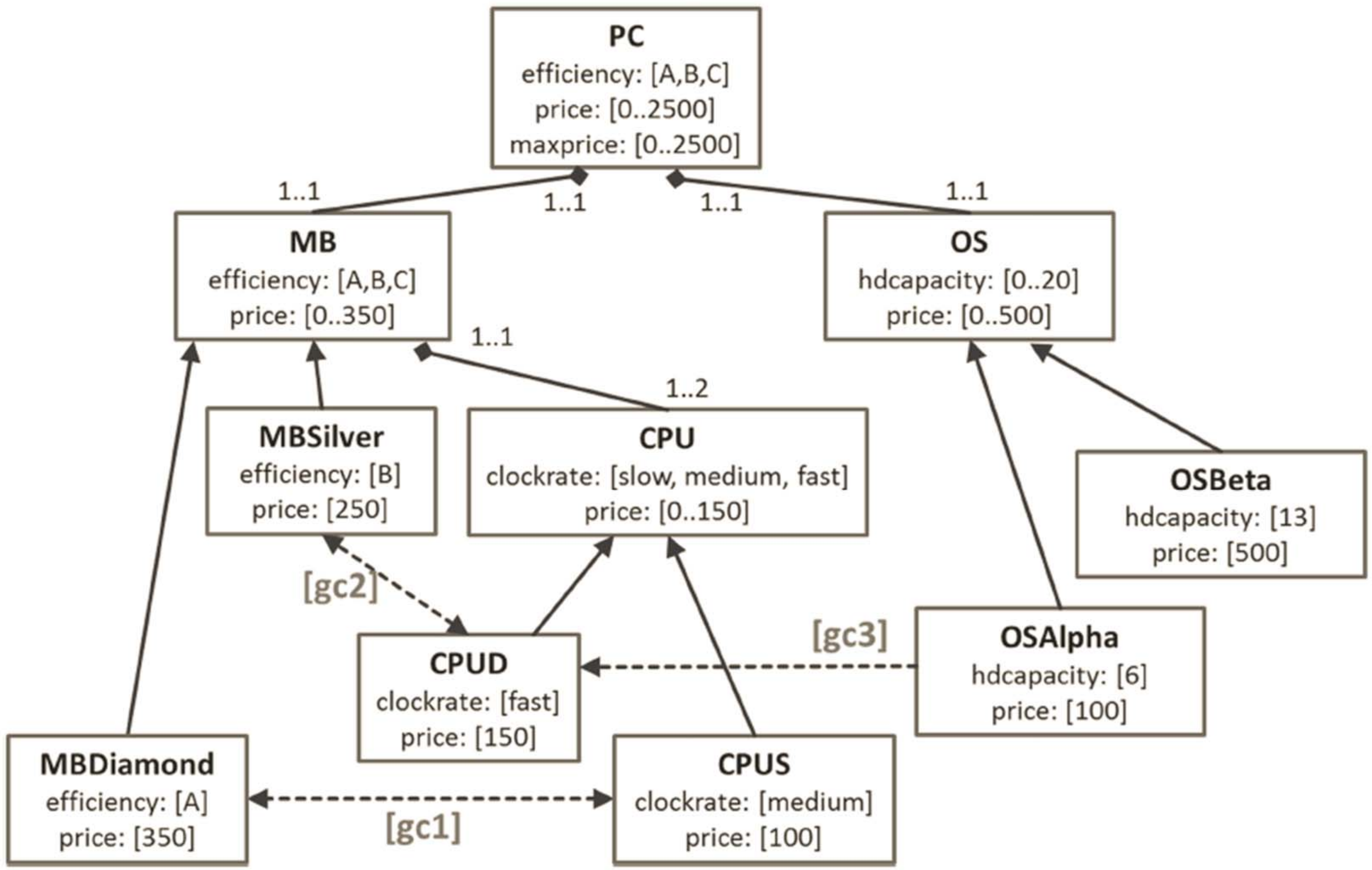



**FIGURE 6.9**

Fragment of the PC model (adapted part of Figure 6.7).

# UML Configuration Model: Constraints

**Table 6.3** Constraints related to the configuration model in Figure 6.9.

| Name | Description |
|---|---|
| gc1 | CPUs of type CPUS are incompatible with motherboards of type MBDiamond |
| gc2 | CPUs of type CPUD are incompatible with motherboards of type MBSilver |
| gc3 | Each OS of type OSAlpha requires a CPU of type CPUD |
| prc2′ | The price of one personal computer (PC) is determined by the prices of the motherboard (MB), the CPUs, and the operating system (OS) |
| resc1 | The computer price must be less or equal to the maxprice defined by the customer |

# UML Configuration Model: Formalization of Product Structure

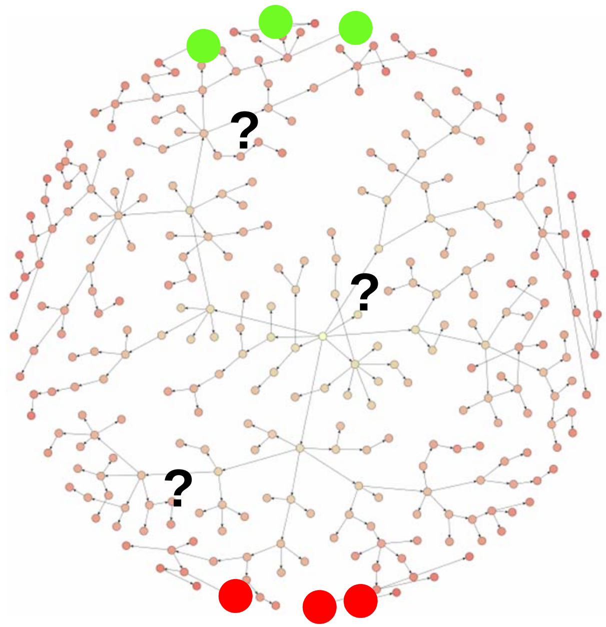
**Table 6.4** Example formalizations of the model ($C_{KB}$) depicted in Figure 6.9. *getcpus* denotes a collection operator (Felfernig et al., 2000a) that collects all *cpus* connected with motherboard $Y$. For reasons of readability we limit the example to attribute range restrictions (e.g., PC(efficiency)).

| Modeling Facility | Example in FOL |
|---|---|
| Component types | {PC/1, MB/1, MBDiamond/1, MBSilver/1, CPU/1, CPUS/1, CPUD/1, OS/1, OSAlpha/1, OSBeta/1} $\subseteq$ *CLANG* |
| Attributes | {efficiency/2, price/2, maxprice/2, clockrate/2, hdcapacity/2} $\subseteq$ *CLANG* |
| Relationships | {pc-of-mb/2, mb-of-pc/2, mb-of-cpu/2, cpu-of-mb/2, pc-of-os/2, os-of-pc/2} $\subseteq$ *CLANG* |
| PC (efficiency) | $\{\forall X : PC(X) \rightarrow \exists_1^1 A_X : efficiency(X, A_X) \wedge A_X = A \vee A_X = B \vee A_X = C.\} \subseteq C_{KB}$ |
| MB (efficiency) | $\{\forall X : MB(X) \rightarrow \exists_1^1 A_X : efficiency(X, A_X) \wedge A_X = A \vee A_X = B \vee A_X = C.\} \subseteq C_{KB}$ |
| MB (price) | $\{\forall X : MB(X) \rightarrow \exists_1^1 A_X : price(X, A_X) \wedge A_X \geq 0 \wedge A_X \leq 350.\} \subseteq C_{KB}$ |
| CPUS (price) | $\{\forall X : CPUS(X) \rightarrow \exists_1^1 A_X : price(X, A_X) \wedge A_X = 100.\} \subseteq C_{KB}$ |
| *part-of* (PC,MB) | $\{\forall X : PC(X) \rightarrow \exists_1^1 Y : MB(Y) \wedge \text{pc-of-mb}(X, Y).\} \subseteq C_{KB}$ <br> $\{\forall X : MB(X) \rightarrow \exists_1^1 Y : PC(Y) \wedge \text{mb-of-pc}(X, Y).\} \subseteq C_{KB}$ |
| *part-of* (PC,OS) | $\{\forall X : PC(X) \rightarrow \exists_1^1 Y : OS(Y) \wedge \text{pc-of-os}(X, Y)\} \subseteq C_{KB}$ <br> $\{\forall X : OS(X) \rightarrow \exists_1^1 Y : PC(Y) \wedge \text{os-of-pc}(X, Y).\} \subseteq C_{KB}$ |

# UML Configuration Model: Formalization of Constraints

| | |
|---|---|
| gc1 | $\{\forall X, Y : \text{mb-of-cpu}(X, Y) \wedge MBDiamond(X) \wedge CPUS(Y) \rightarrow false.\} \subseteq C_{KB}$ |
| gc2 | $\{\forall X, Y : \text{mb-of-cpu}(X, Y) \wedge MBSilver(X) \wedge CPUD(Y) \rightarrow false.\} \subseteq C_{KB}$ |
| gc3 | $\{\forall X, Y : PC(X) \wedge OSAlpha(Y) \wedge \text{pc-of-os}(X, Y) \rightarrow \exists_1^1 U, V : MB(U) \wedge CPUD(V) \wedge \text{pc-of-mb}(X, U) \wedge \text{mb-of-cpu}(U, V).\} \subseteq C_{KB}$ |
| prc2' | $\{\forall X : PC(X) \wedge price(X, PCP) \wedge \text{pc-of-mb}(X, Y) \wedge \text{pc-of-os}(X, Z) \wedge getcpus(Y, CPUs) \rightarrow PCP = \sum_{c \in \{Y,Z\} \cup CPUs \wedge price(c,P)} P.\} \subseteq C_{KB}$ |
| resc1 | $\{\forall X : PC(X) \wedge price(X, PCP) \wedge maxprice(X, PCMP) \rightarrow PCP \leq PCMP.\} \subseteq C_{KB}$ |

# Engineering of CKBs



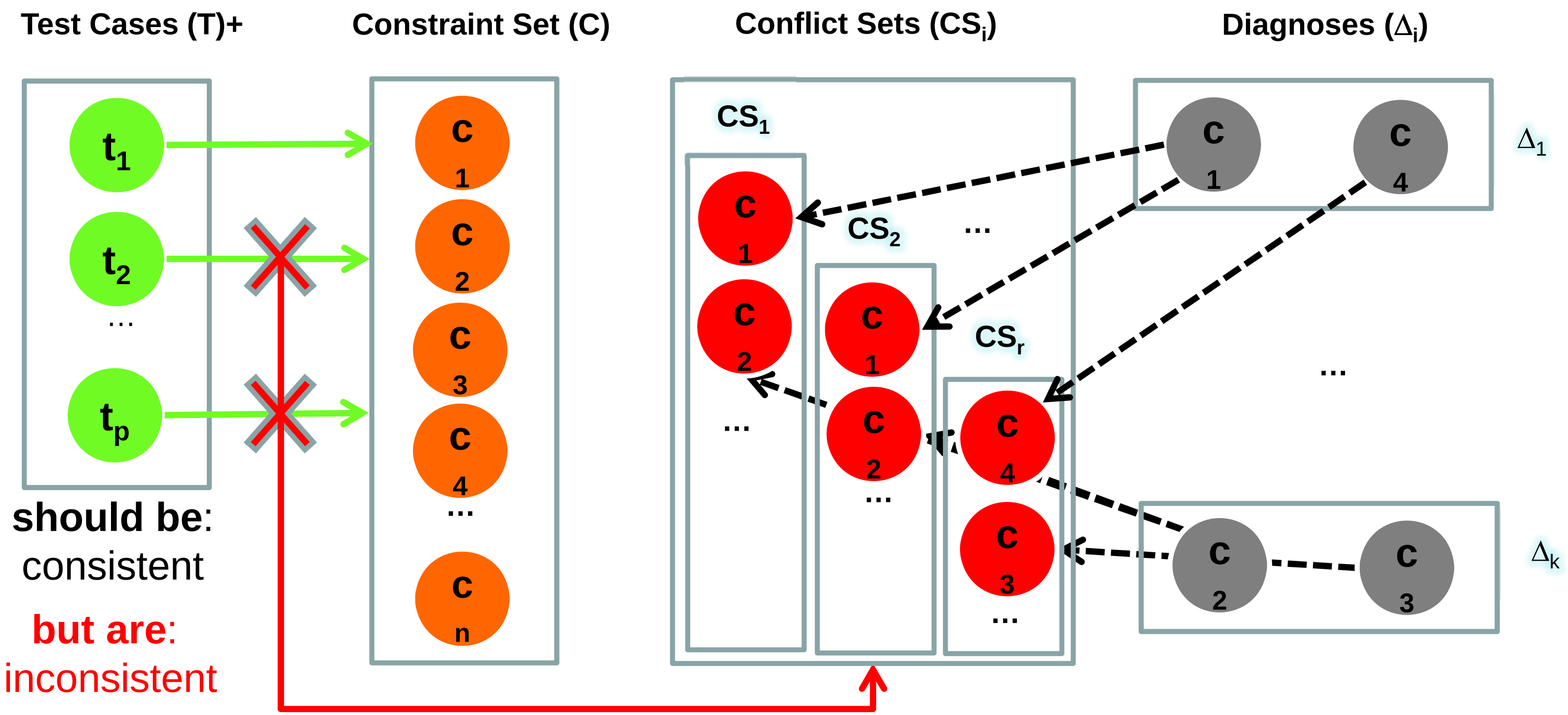

**Goal:** Automated testing & debugging of constraint sets

**Approach**:

- **induce conflicts** in the constraint set
- resolve the conflict sets using **model-based diagnosis**

**Result**: **minimal diagnoses** for constraint sets.

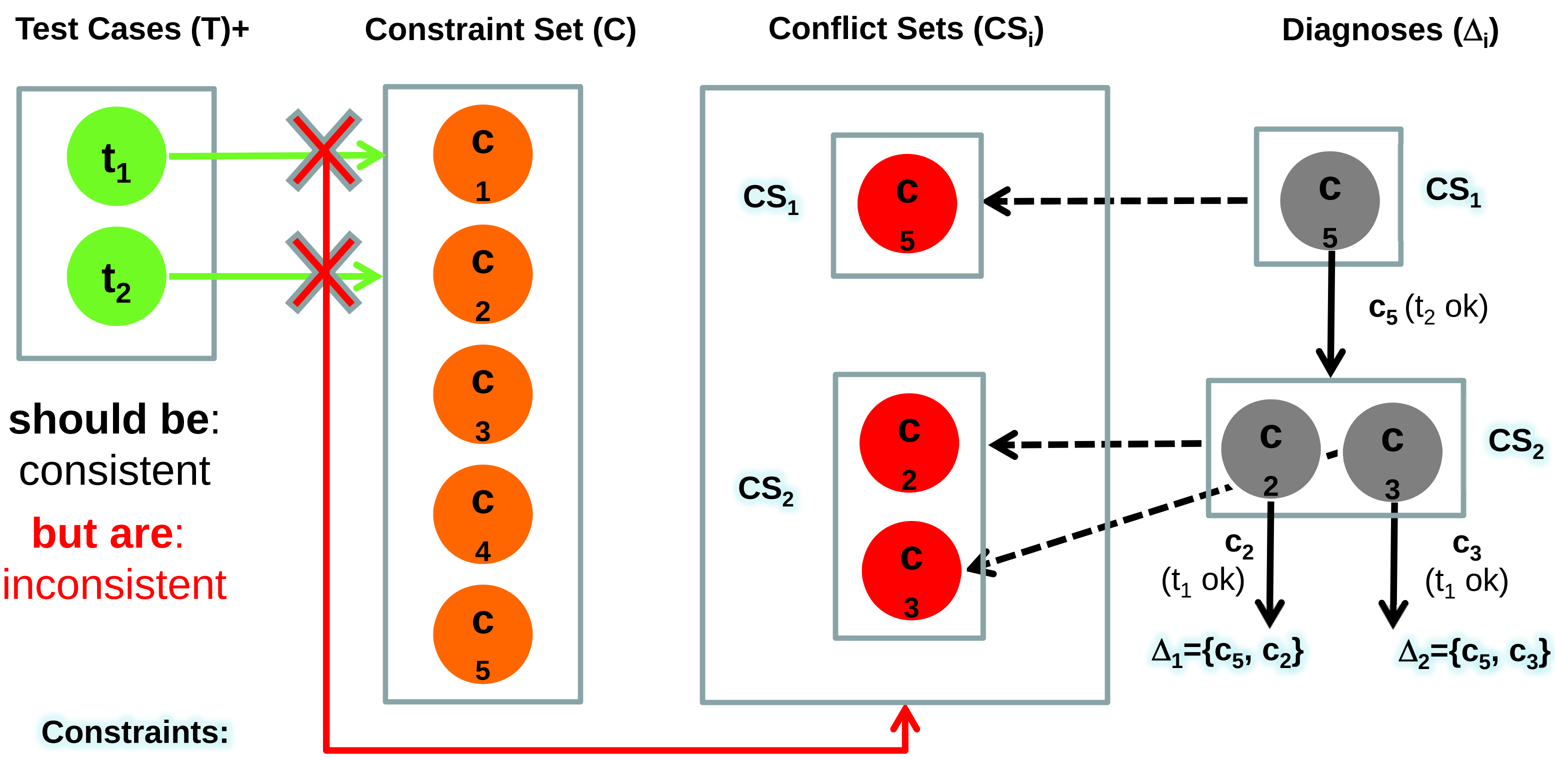
# Diagnosing Constraint Sets: Approach




**Conflict Set CS** = $\{c_1, c_2, \ldots, c_q\} \subseteq C$ s.t. $\exists t_i \in T$: $CS \cup \{t_i\}$ inconsistent.
**Minimal (CS)**: $\nexists$ CS' with $CS' \subset CS$.

**Diagnosis** $\Delta \subseteq C$: $C - \Delta \cup \{t_i\}$ consistent $\forall t_i \in T$.

# Diagnosing Constraint Sets: Example




**Constraints:**

- $c_1$: wr=medium ⇒ ip<>short-t
- $c_2$: wr=high ⇒ ip=long-t
- $c_3$: ip=long-t ⇒ rr=>3-6% ∨ rr=>6-9%
- $c_4$: rr=>9% ⇒ wr=high
- $c_5$: rr=>6-9% ⇒ wr<>low ∧ wr<>medium

**Test cases:**

- $t_1$: wr=high ∧ rr='>9%'
- $t_2$: rr =>6-9% ∧ wr=medium

# Diagnosing Constraint Sets: Example

$V=\{v_1,v_2,v_3,v_4\}$

$d_{v1}=[1..4]$, $d_{v2}=[1..4]$, $d_{v3}=[1..3]$, $d_{v4}=[1..2]$

$c_1$: $v_1 > v_2$

$c_2$: $v_3 > v_1$

$c_3$: $v_3 = v_1$

$c_4$: $v_4 < v_3$

$c_5$: $v_3 > v_2$

$c_6$: $v_4 < v_1$

$c_7$: $v_4 <> v_2$

**Solution?**

**Conflict Set CS** $= \{c_1, c_2, \ldots, c_q\} \subseteq C$ s.t. CS inconsistent.

**Minimal (CS)**: $\nexists$ CS' with CS' $\subset$ CS.

**Diagnosis** $\Delta \subseteq C$: $C - \Delta$ consistent.

# Exercises

1. Is it possible that positive test cases can interfere with each other (explain why)?
2. Is it possible that negative test cases can interfere with each other (explain why)?
3. Is it possible that positive and negative test case can interfere with each other (explain why)?
4. Given the following set of constraints AC={x1=1, x2=2, x3=x4, x3>x2} (dom(xi)=[1,2,3]) and a set of positive test cases T={x1=2, x3=2}. Determine the complete set of minimal conflicts and all corresponding diagoses.

# Thank You!

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