Knowledge-based (re)configuration: an ASP approach

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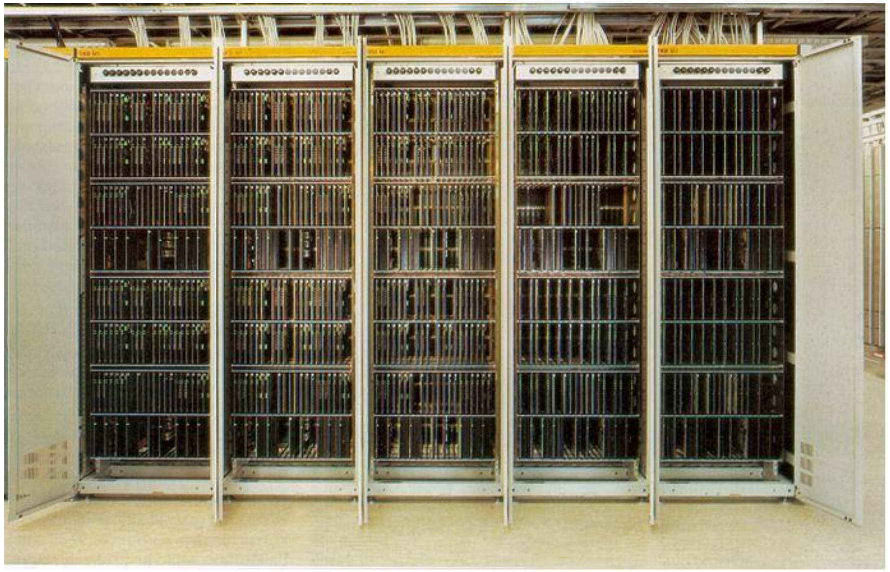
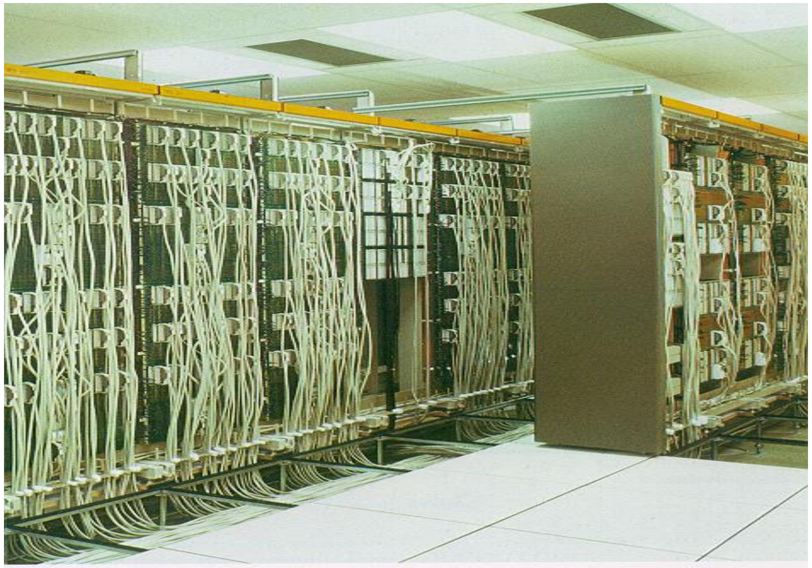
Outline

- Motivation
- Configuration problem
  - Problem definition
  - Example: House problem
- Configuration KRRs
  - A bit of history
  - Overview of modern KRRs
- Reconfiguration problem

Telecom switches (1997)

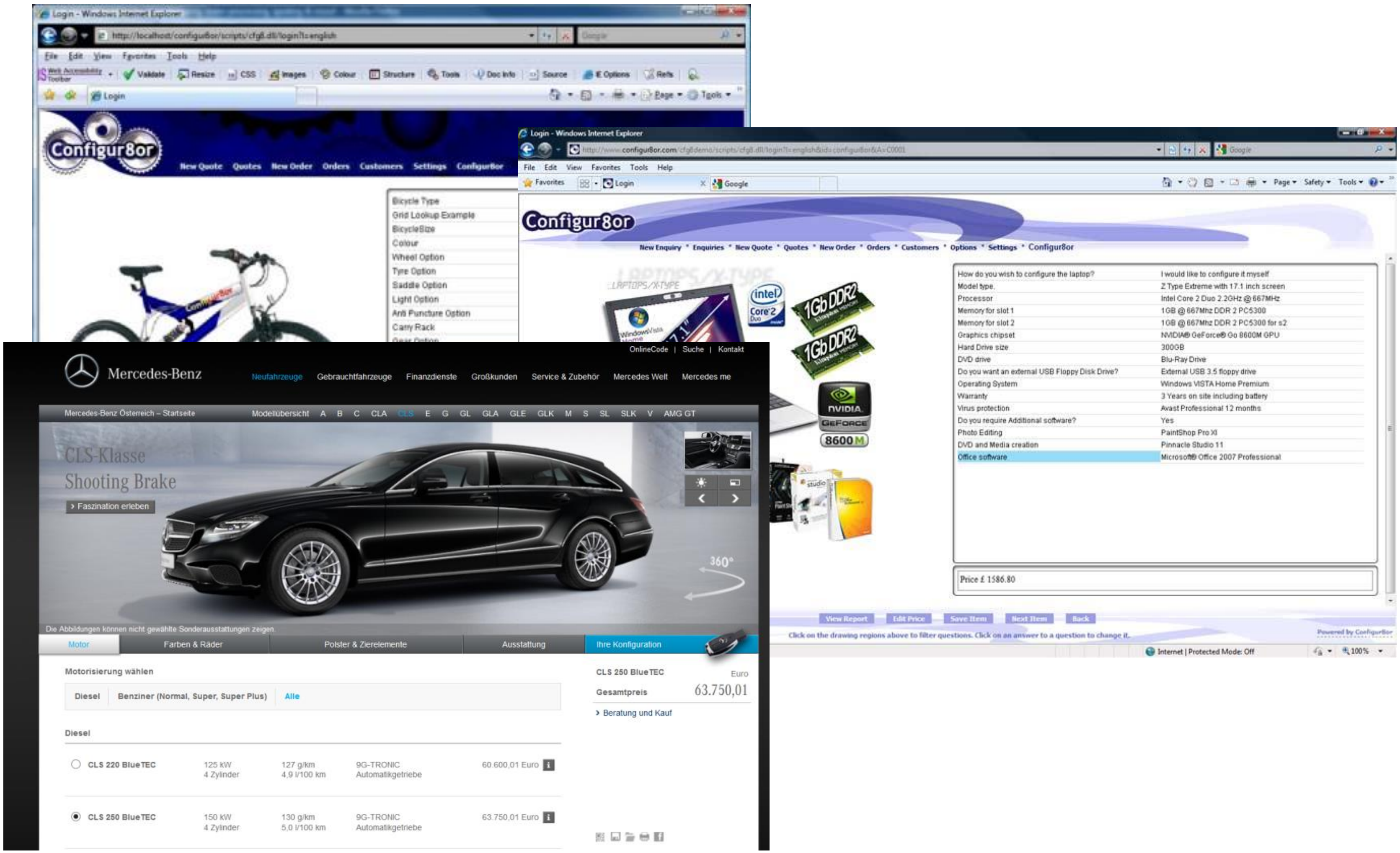
- 200 racks, 1000 frames, 30000 modules
  10000 cables
- Successful configuration system





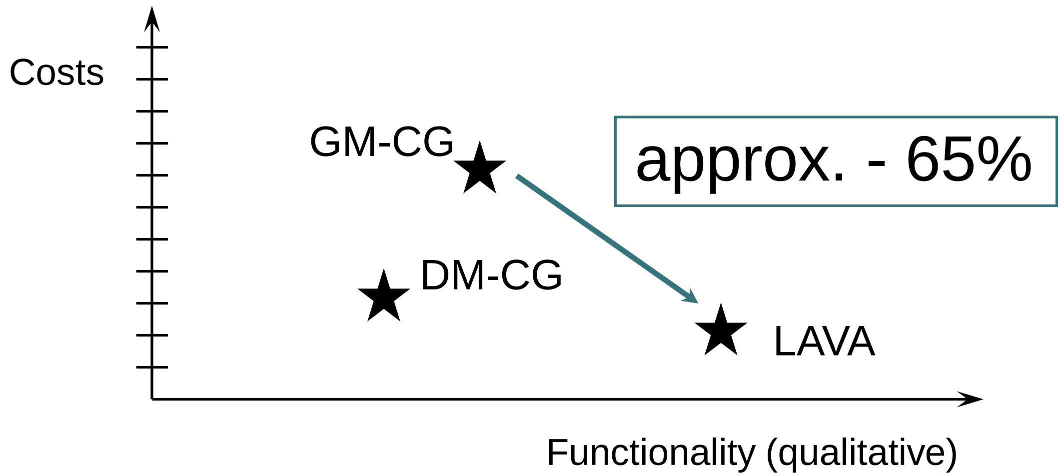
Server farms (@CERN)

Product customization



Knowledge-based configuration

Development costs for configurators:



Since 1997

Additional functionality:

- Interactive configuration
- Improved user interface
- Explanations
- Extension of existing configurations

...

DM- & GM-CG: standard procedural approach
LAVA: **"constraint based programming"** (generative, incomplete)

Requirements to a configurator

- Declarative language for problem description
  - Ideally: every programmer must be able to use it after some (moderate) training
- Computation of solutions in admissible time
- Optimization of found solutions (optionally)

Is there a KRR approach for satisfying the requirements?

Configuration problem

Configuration problem

Given

- Requirements (restricted FOL sentences)
  - Configuration or *general requirements* R_G
  - Customer or *instance requirements* R_I
- A set of predicated $R_S = \{p_1, \dots, p_n\}$ corresponding to a *solution schema*

Find a finite, subset minimal set of ground atoms, called *configuration*, $CONF = \pi_{R_S} M$

- M is a Herbrand model of $R_G \cup R_I$
- $\pi_{R_S} M$ is a projection of ground atoms M onto ground atoms over predicates R_S

Optimization problem

Given

- requirements R_G, R_I and solution schema R_S
- *cost function* $f: \boldsymbol{CONF} \mapsto \mathbb{N}$, where $\boldsymbol{CONF}$ denotes a set of all configurations
- *bound* $B \in \mathbb{N}$

Find a configuration $CONF$ such that

$$f(CONF) \leq B$$

Requirements overview I

Configuration requirements R_G

- Components catalog defines
  - Types (motherboard, cpu, fan, hdd, etc.)
  - Attributes (cpu frequency, motherboard format)
    - Ports (socket type of a motherboard component)
- Valid relations between the components
  - Cpu2Motherboard: for each cpu there exists a motherboard with a compatible socket

Encoded as linear Tuple Generation Dependencies (TGD) (see e.g. $Datalog^{\pm}$ [Calì et al., 2010])

Requirements overview II

Example of a linear TGD (LoCo [Aschinger et al, 2014])

$$\forall(id_1,\vec{x})\ C_1(id_1,\vec{x})$$
$$\rightarrow \exists_l^u(id_2)\ [C_2(id_2,\vec{y}) \wedge C_1 2C_2(id_1,id_2) \wedge \phi(id_1,id_2,\vec{x},\vec{y})]$$

- $C_i(id_j,\vec{x})$ denotes a component type with an identifier id_j and a vector of attributes $\vec{x}$
- $C_i 2C_j\left(id_i,id_j\right)$ denotes a relation between 2 components
- $\phi(id_1,id_2,\vec{x},\vec{y})$ is a formula expressing additional constraints
- $l \geq 0$ and $u > 0$ are lower and upper bounds

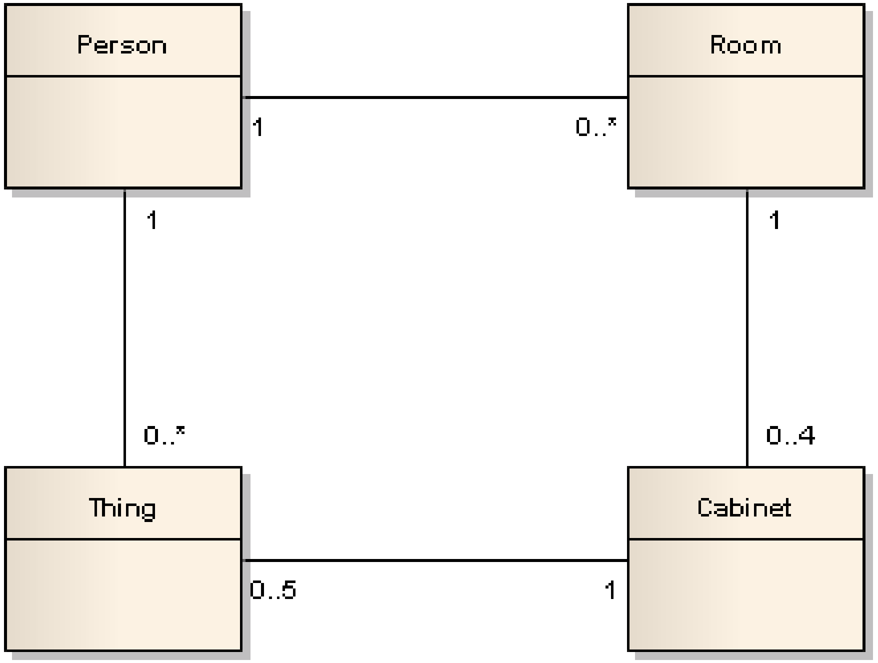
Requirements overview III

Customer requirements R_I

- Define available components
  - Facts of the form $C_j(id_i, \vec{x})$
- Specify input relations
  - Facts of the form $C_j2C_i\left(id_j, id_i\right)$
- Declare a solution schema
  - Set of predicates
- Provide preference criteria (optimization)

Configuration example (House)

things**s** (lamps) are related to **a** person (signal),
things**s** are stored in **a** cabinet (module),
cabinet**s** are placed in **a** room (frame)



1-n relations
+
additional constraints

(Siemens©)

House problem

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Customer requirements:

Declaration of available persons, things and ownership relations between them

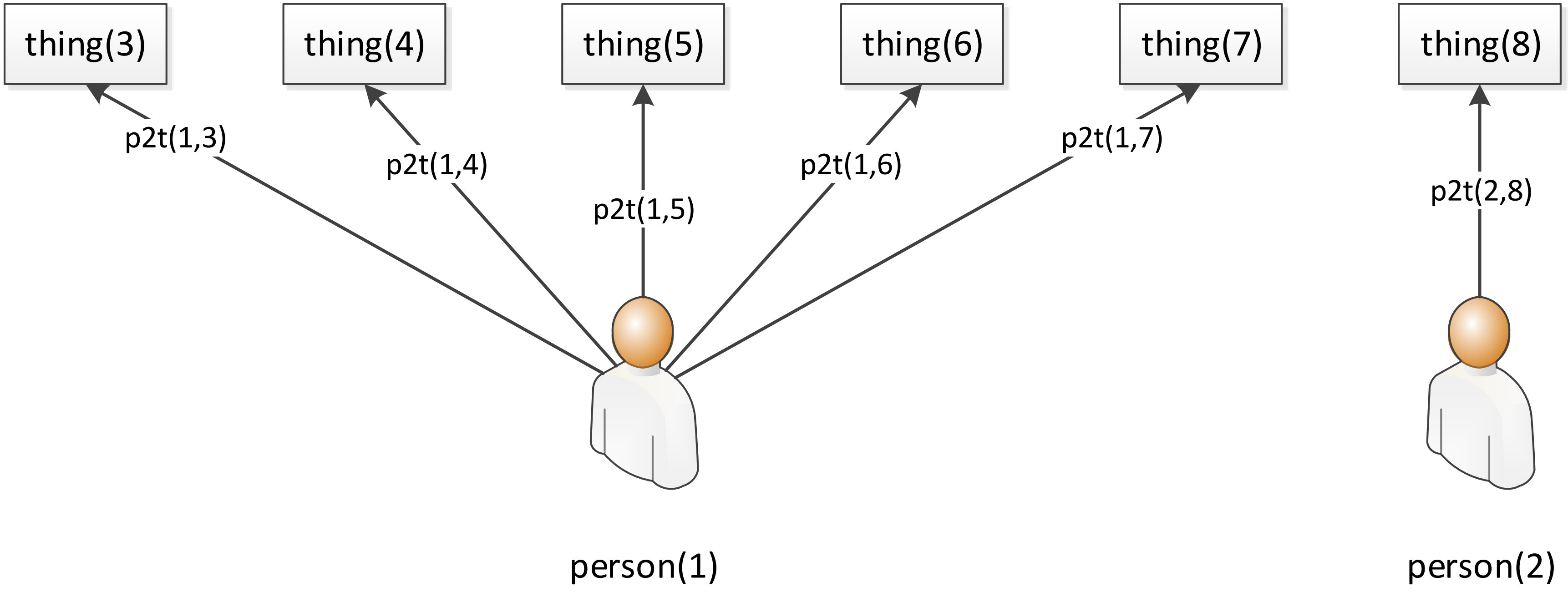
Configuration requirements:

1. each thing must be stored in exactly one cabinet
2. a cabinet can contain at most 5 things
3. every cabinet must be placed in exactly one room
4. a room can contain at most 4 cabinets
5. each room belongs to a person
6. and a room may only contain cabinets storing things of the owner of the room

Goal: store all things in a house such that the set of requirements is fulfilled

Sample customer requirements

- Person 1 owns things 3,4,5,6,7
- Person 2 owns thing 8



Predicates: `person/1, thing/1` and `p2t/2`

House encoding

- Customer requirements (facts)
- Configuration requirements
  - each thing must be stored in exactly one cabinet and a cabinet can contain at most 5 things

$$\forall id_T \; thing(id_T) \rightarrow \exists_1^1 id_C \; [cabinet(id_C) \land t2c(id_T, id_C)]$$
$$\forall id_C \; cabinet(id_C) \rightarrow \exists_0^5 id_T \; [thing(id_T) \land t2c(id_T, id_C)]$$

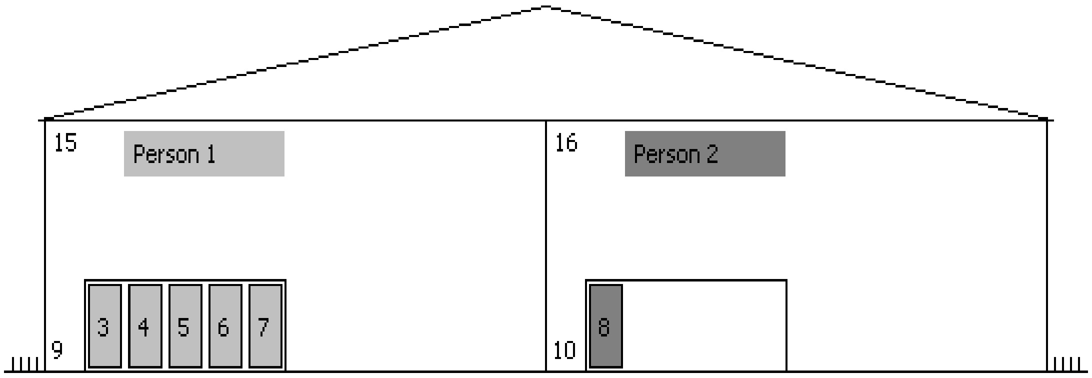
  - each room belongs to a person

$$\forall id_P, id_T, id_C, id_R \quad p2t(id_P, id_T) \land t2c(id_T, id_C) \land c2r(id_C, id_R) \rightarrow p2r(id_P, id_R)$$

Sample solution

- Solution schema: `cabinet/1, room/1, t2c/2, c2r/2` and `p2r/2`
- Solution:

```
cabinet(9). cabinet(10). room(15). room(16). ...
p2r(1,15). p2r(2,16). ...
c2r(9,15). c2r(10,16). ...
t2c(3,9).  t2c(8,10). ...
```



Configuration KRRs

KRRs overview

- Production rules (R1/XCON [McDermott, 1992], ILOG JRules, OpenRules)
- Case-based [Rahmer et al., 1996; Tseng et al., 2005]
- Model-based (Oracle, SAP, Siemens)
  - Constraint-based [Mittal et al 1989], Dynamic CSP [Mittal et al., 1990], Generative CSP [Stumptner 1997]
  - Specific languages: UML [Felfernig et al., 2000], Feature models [Dhungana et al., 2011], LoCo [Aschinger et al., 2014]
  - Description logics [McGuinness 2003]
  - SAT [Aschinger et al 2011] and ASP [Friedrich et al., 2011]
  - Hybrid approaches [Hotz et al., 2006]

CSPs

- De facto standard KRR for configuration Variables $V = \{v_1, \ldots, v_n\}$ and their domains $D = \{dom(v_1), \ldots, dom(v_n)\}$ represent components, attributes and relations
- Constraints define allowed compositions of components
  - TGDs are approximated by global cardinality constraints
- Supports optimization and heuristics
- Possible modeling language MiniZinc [Nethercote et al., 2007]

Generative CSP

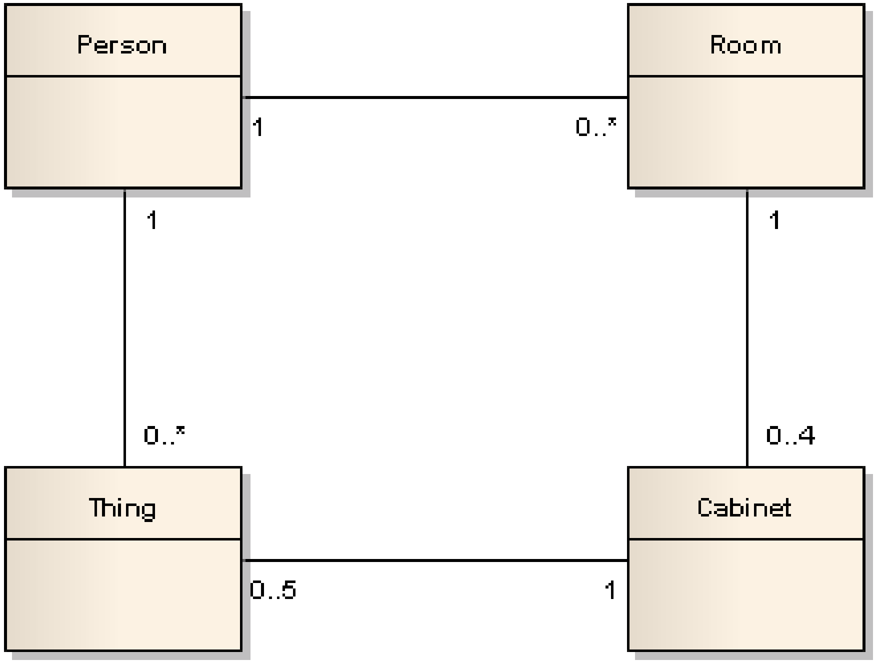
- Differentiate between component variables and other variables
- Component variables – classes
- Language is similar to OO programming

```
class Cpu
   attr socket: integer
class Mb
   attr socket: integer
assoc Cpu.board(1) - Mb.cpu(1)
constraint Mb.compatible :
        cpu.socket = cpu.board.socket
```

Object-oriented approaches

UML:

- Generic language (+)
- Constraints are hard to write (-)



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Description logics

- Components are modeled as concepts (atoms over unary predicates)
- Roles (atoms over binary predicates) are used to model relations and attributes

$$Cpu \sqsubseteq \exists compatible.Mb$$
$$\forall X\; Cpu(X) \rightarrow \exists Y\; [compatible(X,Y) \wedge Mb(Y)]$$

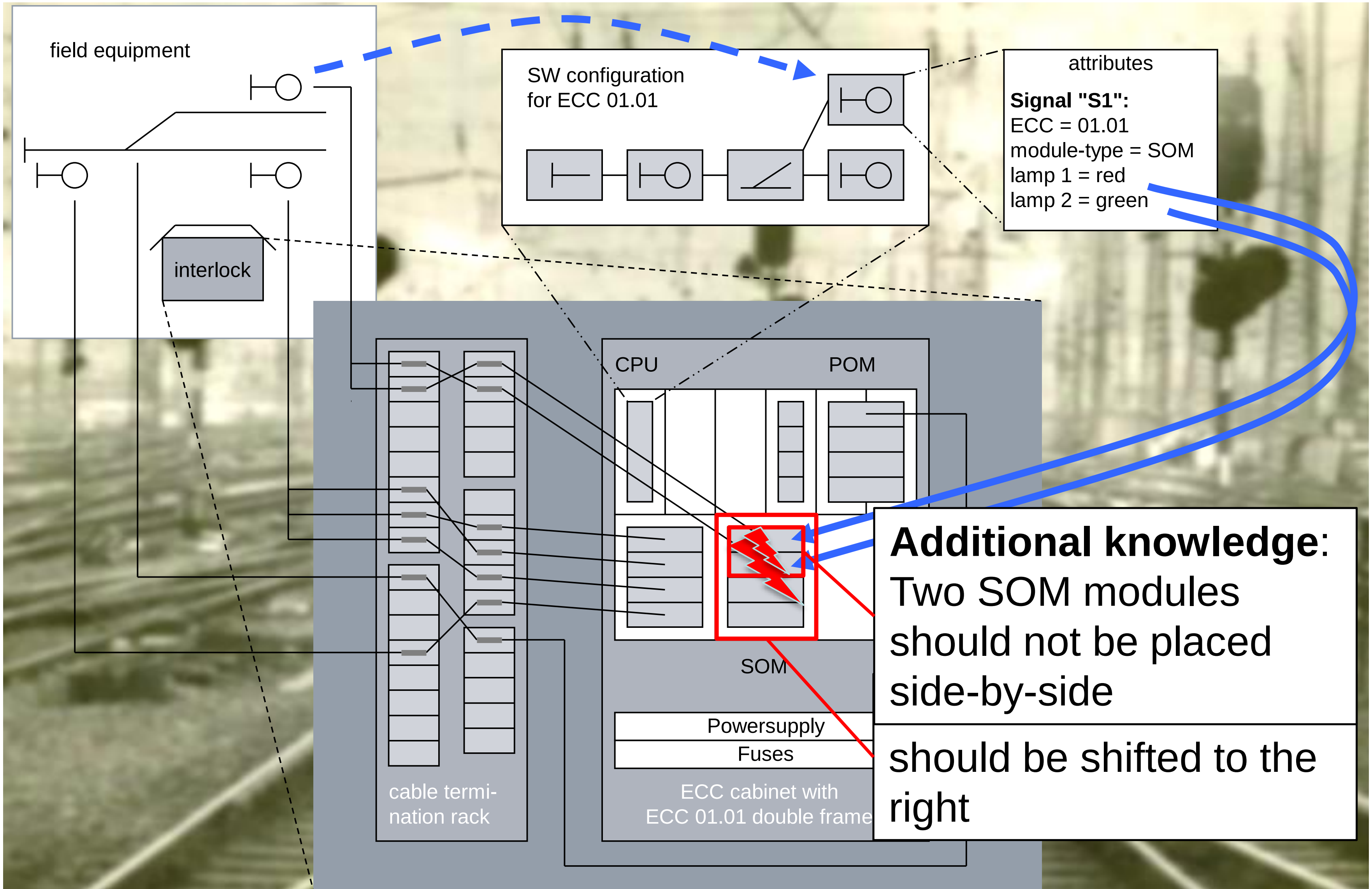
- Reasoning services support query answering
- Generation of a query (configuration) must be done by external tools, e.g. ASP

ASP

- Modeling of components catalog is the same as in FOL
- TGDs are approximated by either
  – disjunctive rules + cardinality constraints or
  – choice rules (cardinality atom in the head)
- Simple and easy to understand modeling language
- Supports optimization

Reconfiguration problem

Motivation



Additional knowledge:
Two SOM modules should not be placed side-by-side

should be shifted to the right

Sample configuration changes I

Additional customer requirements:

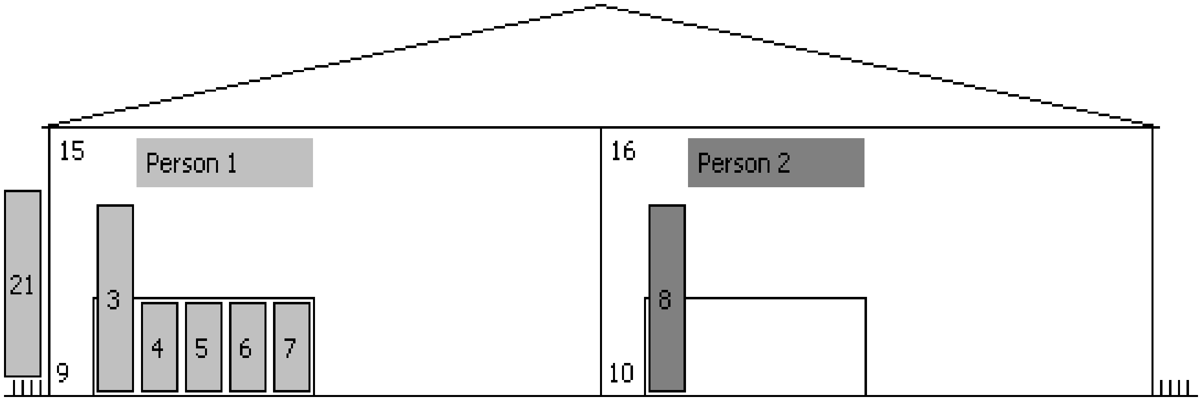
definitions of long and short things

```
thingLong(3). ... thingShort(7). thingLong(8).
thing(21). thingLong(21). p2t(1,21).
```

Sample configuration changes II

Additional configuration requirements:

- a cabinet is either small or high
- a long thing can only be put into a high cabinet
- a small cabinet occupies 1 and a high cabinet 2 of 4 cabinet places available in a room
- all legacy cabinets are small



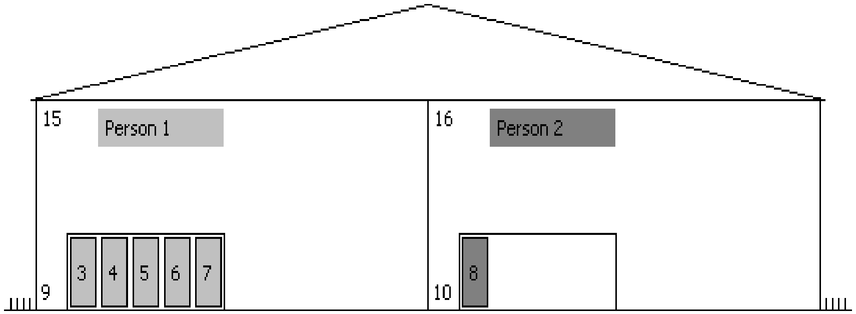
Inconsistent configuration

Transformation changes

Legacy configuration encoding (functional symbols):

```
legacyConfig(c2r(10,16)).
legacyConfig(cabinet(9)).
legacyConfig(cabinet(10)).
```

…



Transformation rules:

- Parts of the legacy configuration can either be reused or deleted
- Individuals of reused relation tuples should also be reused
- Relation tuples of deleted individuals should be excluded

Objective function

- Introduce costs for each action:
  - Creation costs: individuals and relation tuples absent in the legacy configuration
  - Reuse costs: individuals and relation tuples present in both reconfiguration and legacy configuration
  - Deletion costs: individuals and relation tuples of legacy configuration absent in the reconfiguration
- Optimization criterion: minimize sum of all costs

Reconfiguration problem

Given

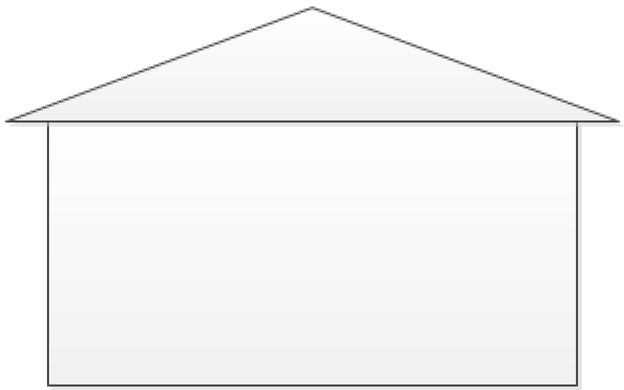
- *legacy configuration* as set of ground literals R_L,
- set of *requirements* $R_G \cup R_I$,
- set of *transformation rules* R_T
- set of predicates describing a *solution schema* R_S
- and an *objective function* f:$\boldsymbol{CONF} \mapsto \mathbb{N}$ and *bound* $B \in \mathbb{N}$

Find a finite, subset minimal set of ground atoms, reconfiguration, $RECONF = \pi_{R_S} M$ such that $f(RECONF) \leq B$

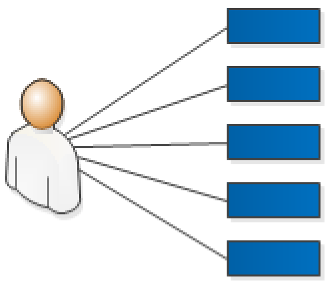
- M is a Herbrand model of $(R_G \cup R_I) \cup (R_L \cup R_T)$ and π is a projection operator

Test cases: Empty

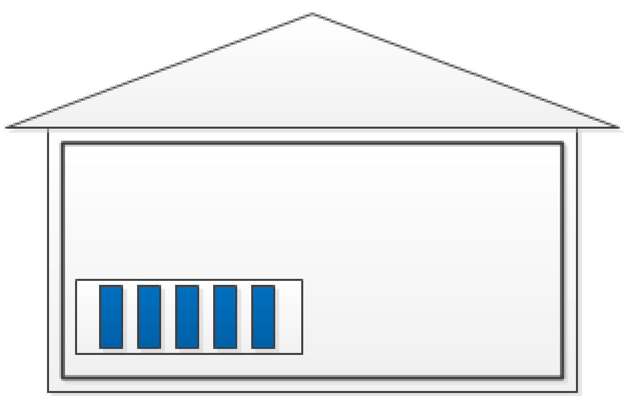
Legacy configuration



Customer requirements

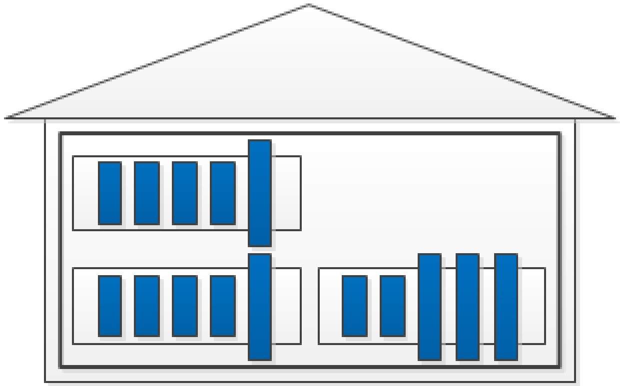


Possible solution

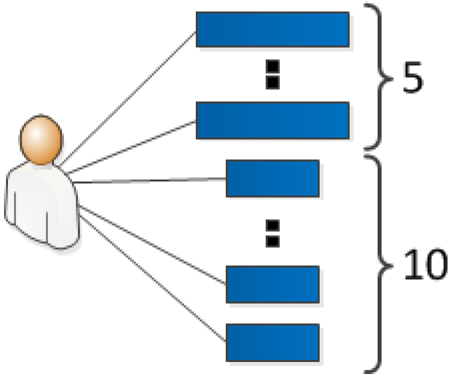


Test cases: Long

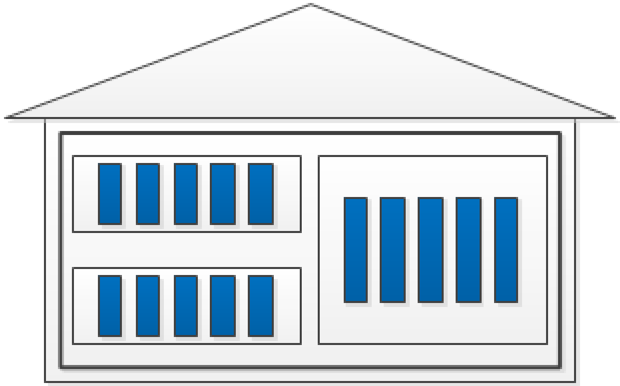
Legacy configuration



Customer requirements

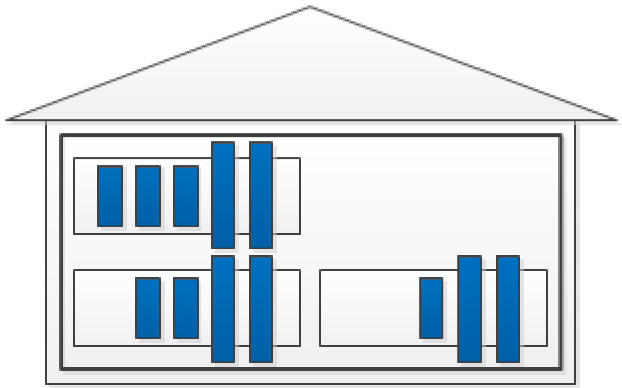


Possible solution

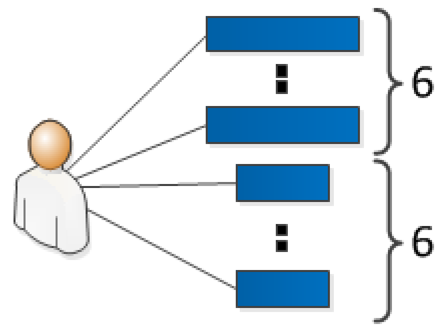


Test cases: New Room

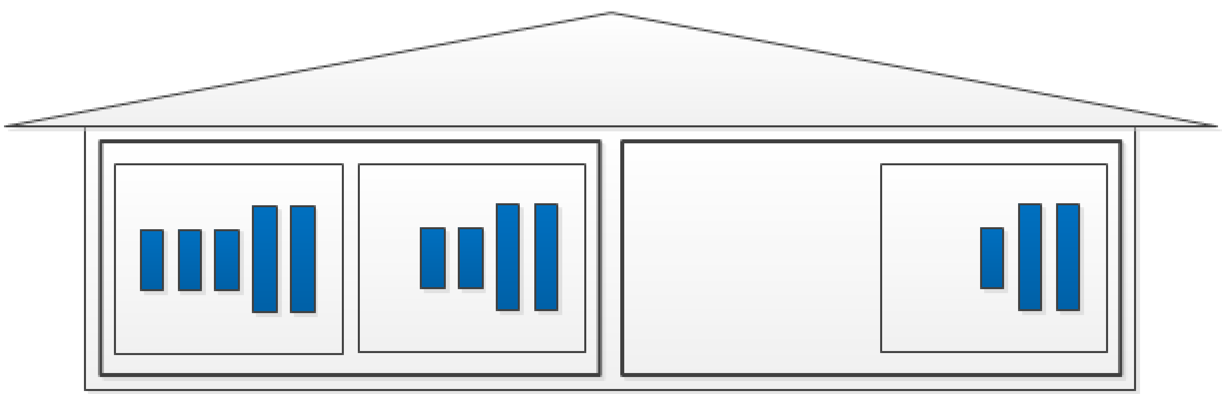
Legacy configuration



Customer requirements

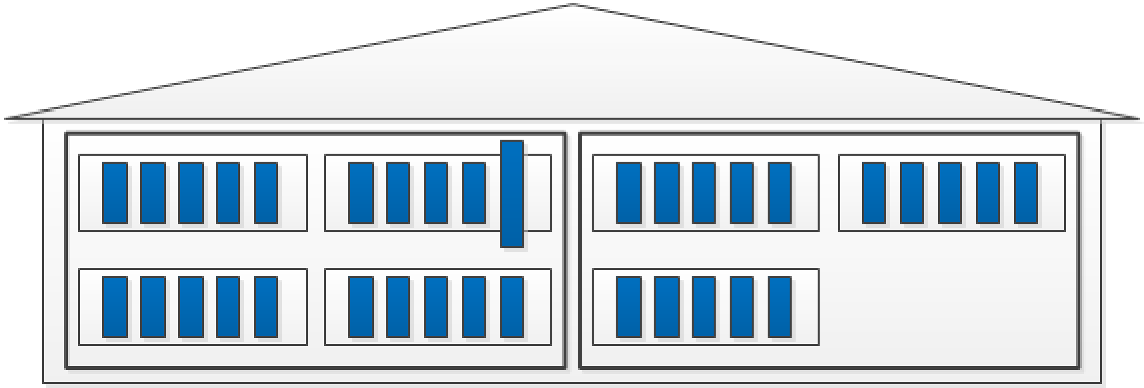


Possible solution

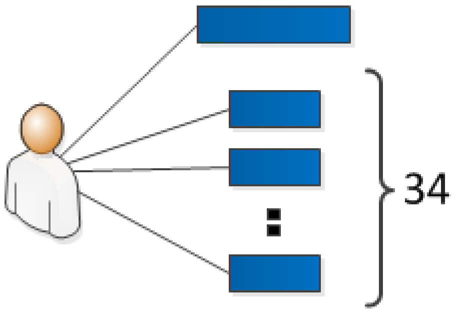


Test cases: Swap

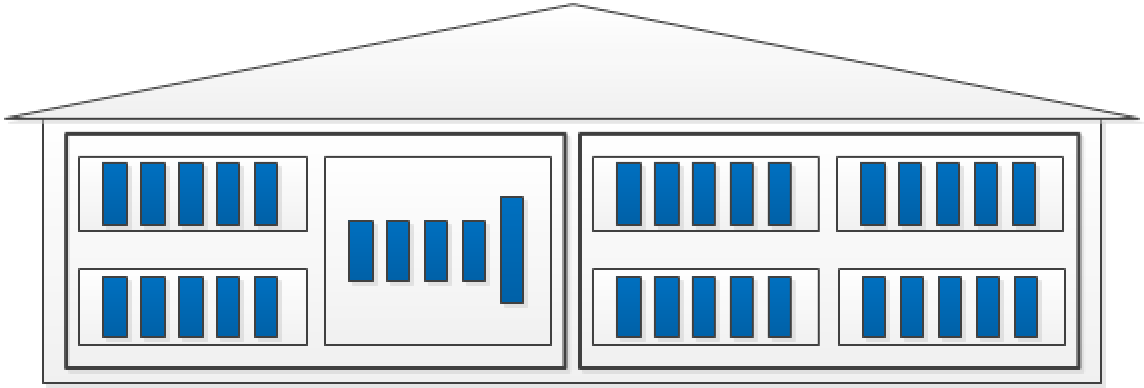
Legacy configuration



Customer requirements



Possible solution



Thank you for your attention!

Questions?