

On the Compiled Approach of Solving Configuration Constraint Problems

2012 Oxford Configuration Workshop

Henrik Reif Andersen et al



About Configit

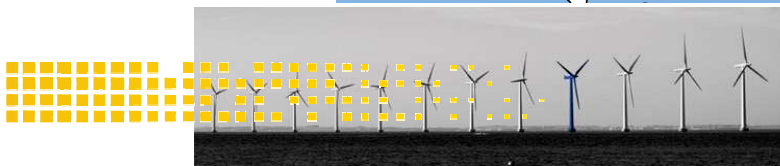
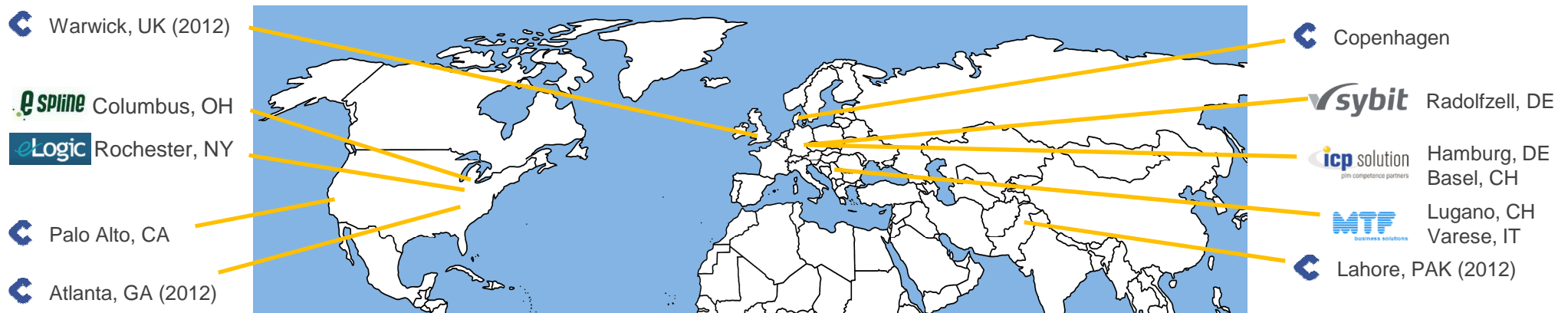
- Founded in 2000 as spin off from academia
- Part of Moesgaard Group (~200 employees)
- >1.3 mio. users of Configit's software
- Customers in 14 countries
- More than 25% of employees in Configit have PhDs in Computer Science



Configit headquarters Copenhagen



New R&D center in Warwick, UK



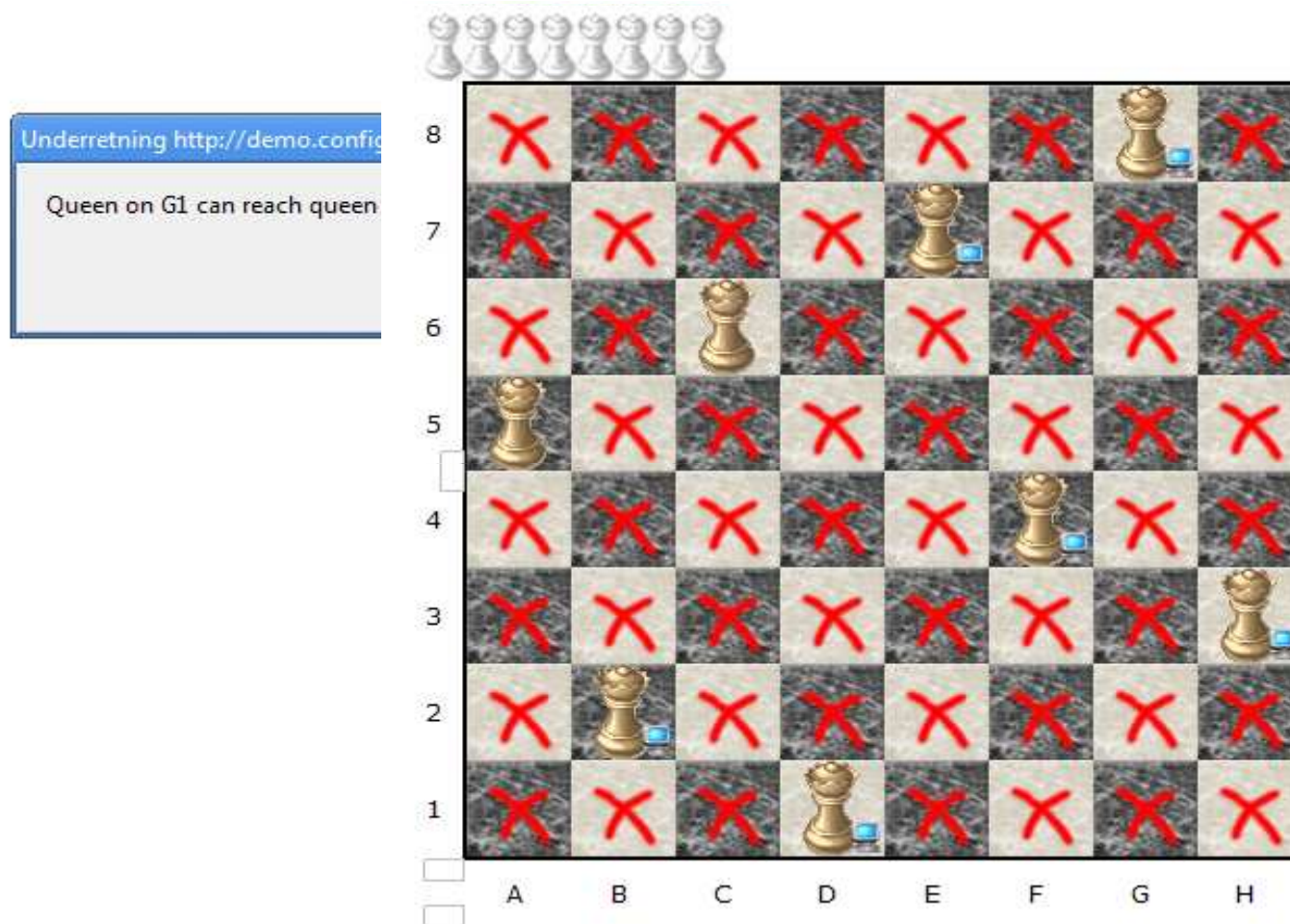
Interactive Configuration Problems

Constraint satisfaction problem (CSP):

- Finite domains D_1, \dots, D_n
 - Variables x_1, \dots, x_n
 - Constraints C_1, \dots, C_m each over a subset of the variables
 - Correctness formula $\varphi(x_1, \dots, x_n) \stackrel{\text{def}}{=} C_1 \text{ and } \dots \text{ and } C_m$
 - CSP: *Is φ satisfiable?*
-
- A user repeatedly selects any variable x_i and a value v for it, giving at any point in time a sequence of assignments ρ
 - A *valid domains computation* is performed by finding, for a given ρ , for each j the set of *valid values* $V_j \subset D_j$ defined as:
$$v \in V_j \text{ iff } \varphi[\rho][v/x_j] \text{ is satisfiable.}$$
 - The valid domain computation enables an *interactive guided search*




Example of Interactive Configuration: 8-Queens



Live at
www.configit.com
(under demos)



(A bit) More Realistic Example

 bike demo

Information

Customer number

Region

Currency

Special requirements

Preferences

Frame type

☐ City bike

☒ Mountainbike

☐ Racer Bike

Frame type

☐ Female

☐ Male

My height

Average driving distance

Parts

Frame color

Frame

Frame Size

Gear

Number of speeds

3

4

5

7

16

18

21

24

27

Rims

Rim width

Tires

Tire profile

Pedals

Extras

☒ Carrier

☒ Basket

☐ Propstand

☐ Lock

☐ Bottle

☐ Pump

☐ Cateye

☐ Front reflex

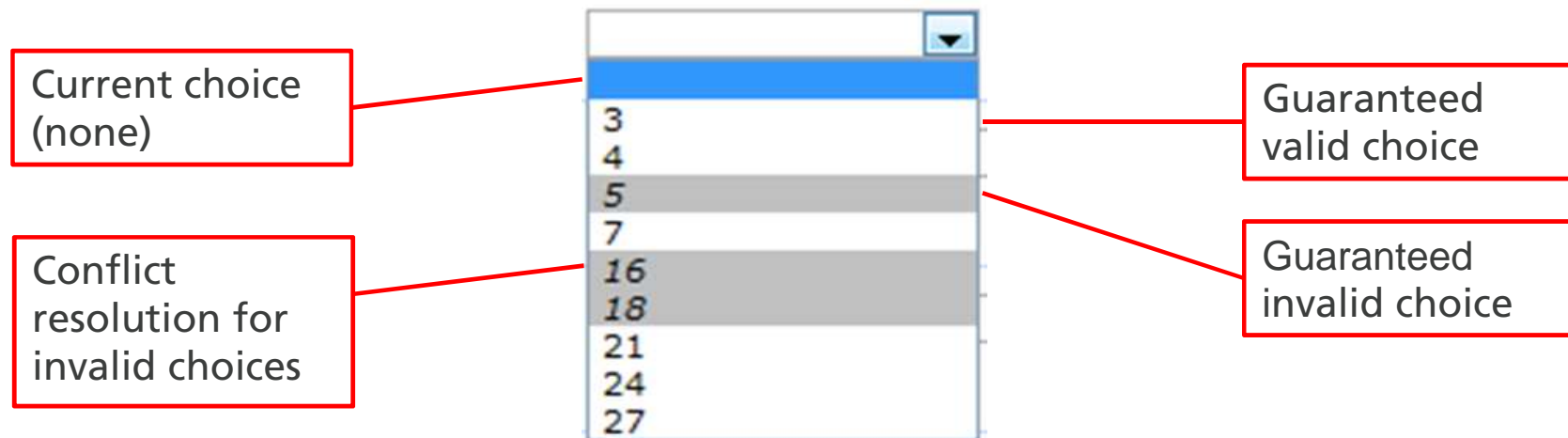
☐ Side reflex

☐ Shoes

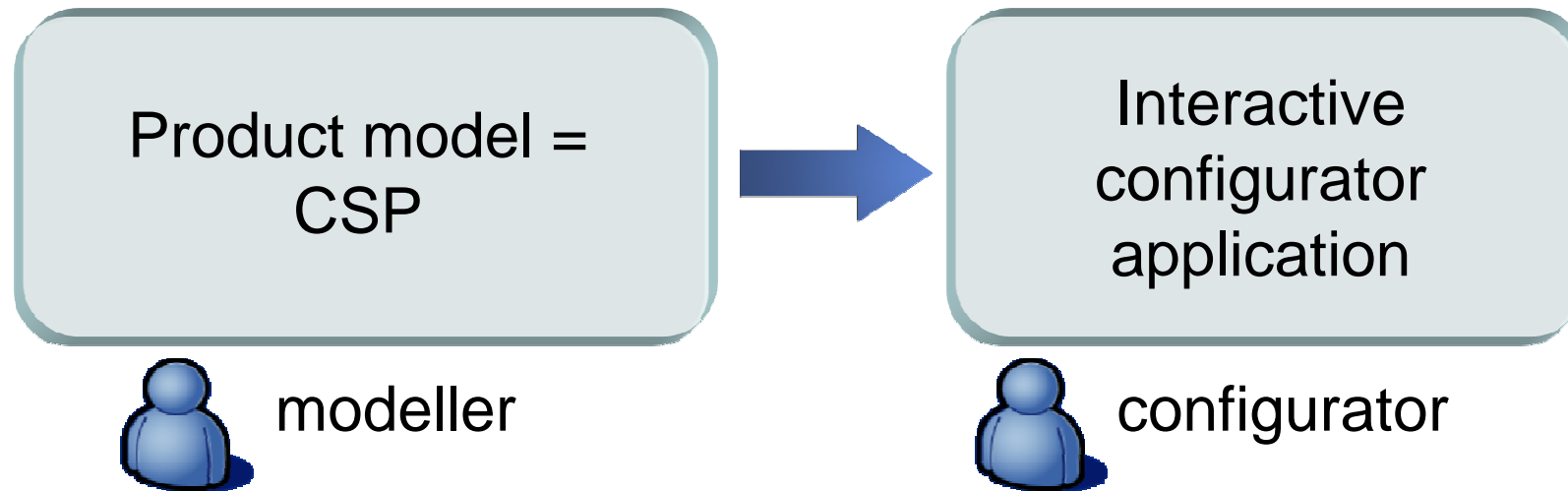


Why full user guidance?

- The purpose of interactive configurators is to enable valid configuration of complex products for non-experts
- We therefore strongly believe in the need for *full guidance*
- What is full guidance?
 - The user can never unknowingly be led down a blind path
 - The user is guided towards a valid configuration



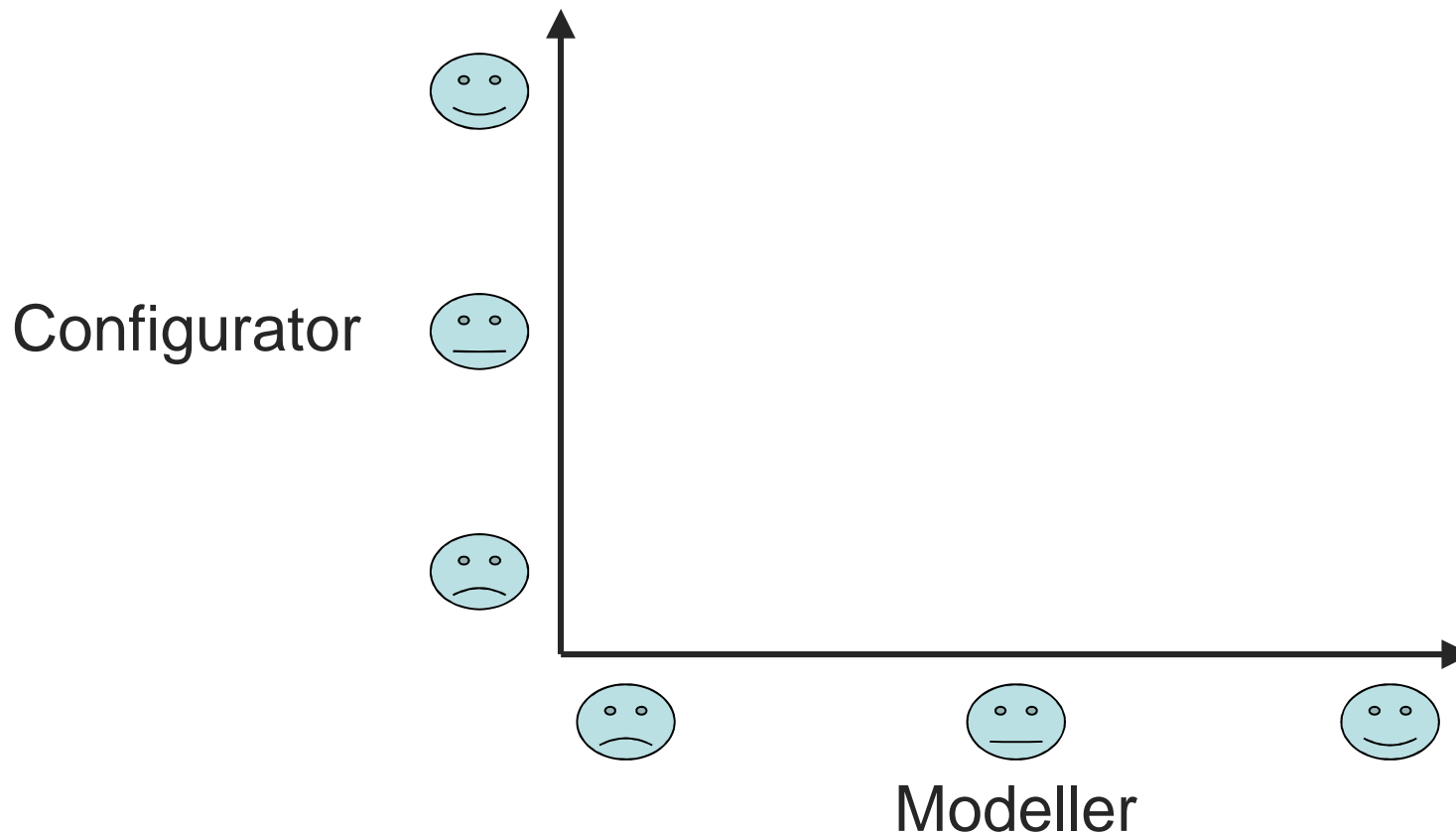
Two types of users in interactive configuration



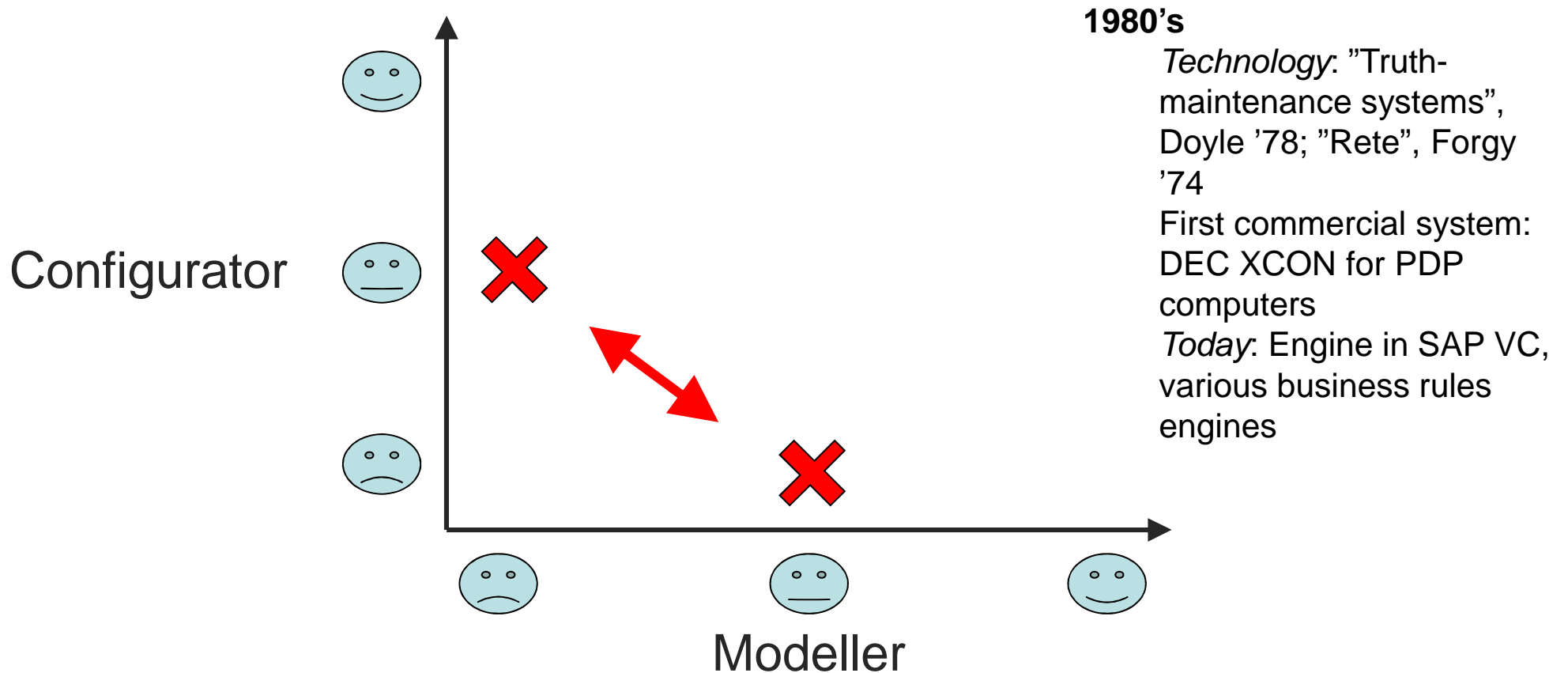
- The *modeller* models the products: the options and rules (in essence, authors the CSP)
- The *configurator* uses the configurator application to perform an interactive configuration of a product



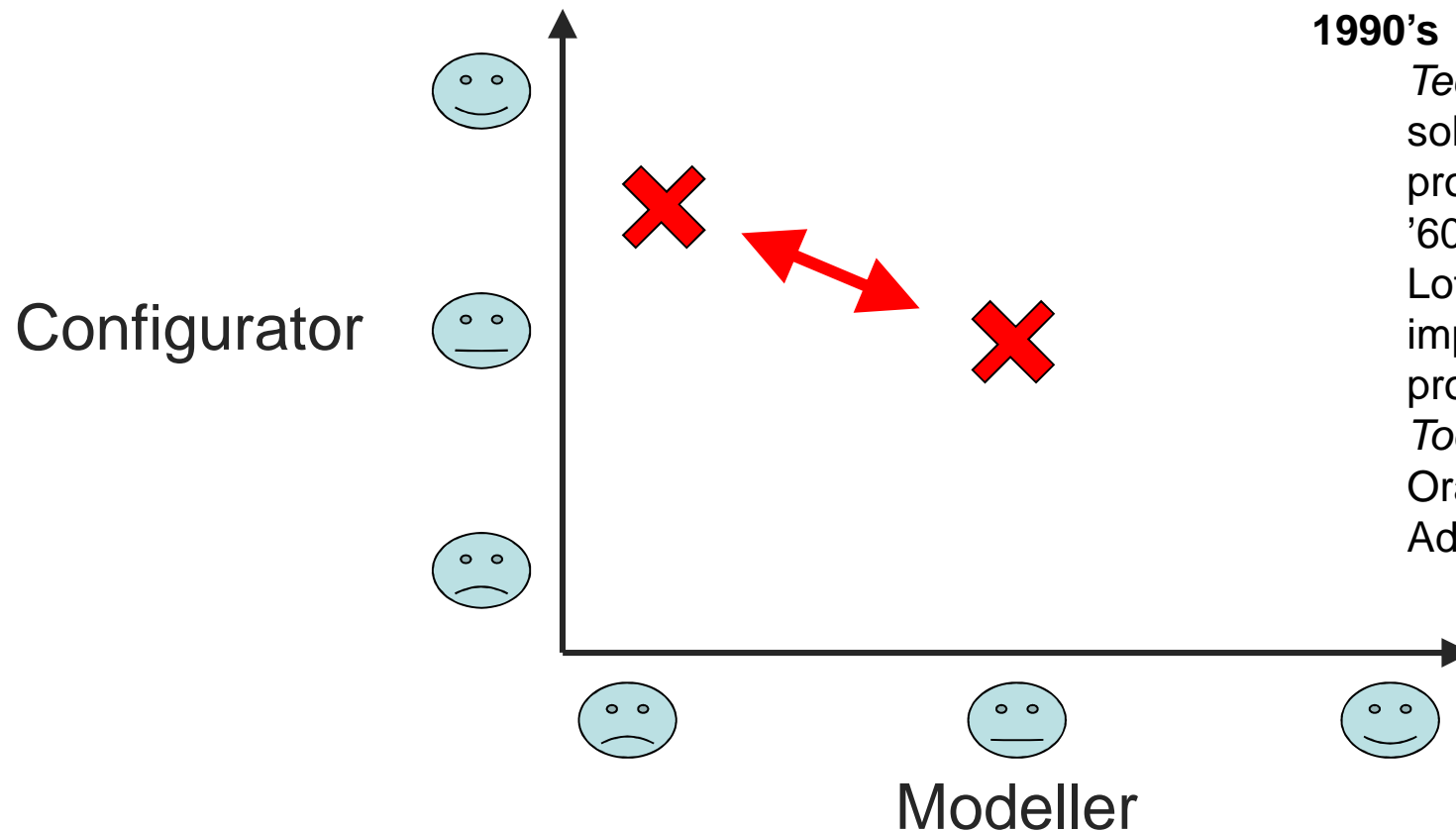
A trade-off between the user experiences for the *configurator* and the *modeller*



First generation of commercial configurators: *Rule-based systems*



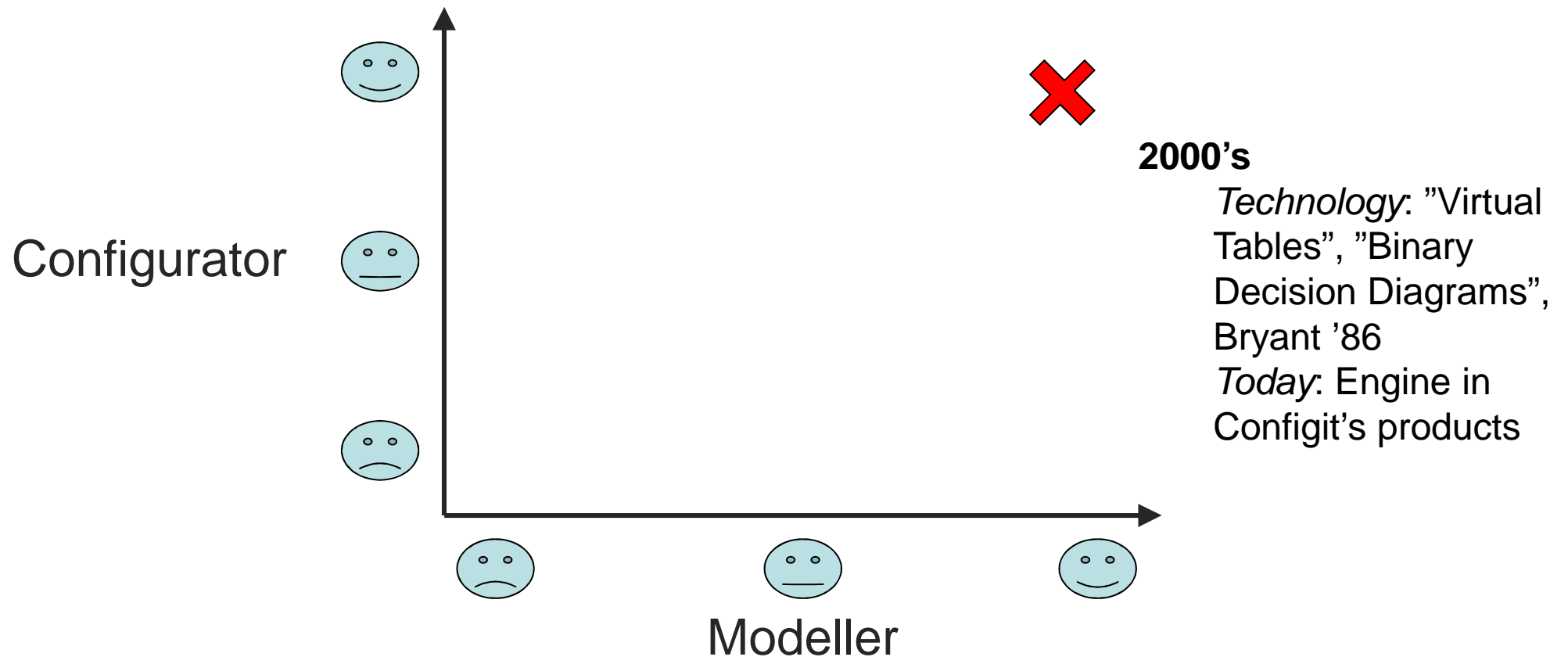
Second generation of commercial configurators: *Constraint-based systems*



Technology: "Constraint solvers", constraint propagation + branching, DPLL '60, '62
Lots of commercial implementations of sales and product configurators
Today: Engine in Tacton, Oracle, Selectica, Trilogy, SAP Adv. Mode, ...



Third generation of commercial configurators: *Compilation-based systems*



Reduced Ordered Binary Decision Diagrams [Bryant'86]

Given a *variable ordering* $x_1 < x_2 < \dots < x_n$

DEFINITION

An *ROBDD* (BDD) is a rooted and directed acyclic graph with:

- Terminal nodes **0** and **1** with no out-going edges.
- Non-terminal nodes u labelled with $var(u) = x_i$ and two out-going edges $low(u)$ and $high(u)$.

(Ordered) On any path from the root to a terminal node, the labels on the non-terminal nodes respect the ordering.

(Reduced) There are no occurrences of *redundant* nodes

- $low(u) = high(u)$
- If $low(u) = low(v)$ and $high(u) = high(v)$ then $u = v$

DEFINITION

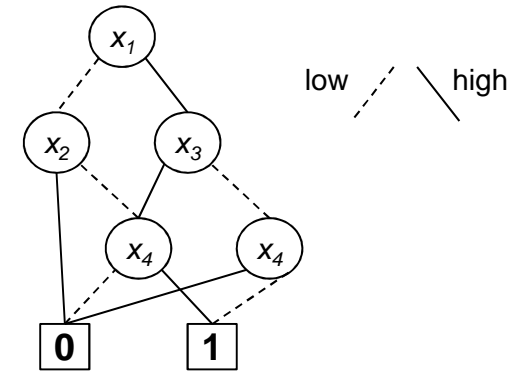
An node u defines a Boolean function $f_u : \{0,1\}^n \rightarrow \{0,1\}$:

$$f_u = 0, f_u = 1, f_u = \text{if } var(u) \text{ then } f_{high(u)} \text{ else } f_{low(u)}$$

OBSERVATION

A node u represents a set: $S_u = \{ (x_1, \dots, x_n) \mid f_u = 1 \}$

(f_u is the indicator/characteristic function for the set S_u)



THEOREM (ROBDDs are canonical)

For any $f : \{0,1\}^n \rightarrow \{0,1\}$ there is exactly one ROBDD u with $f_u = f$

ALGORITHMS

(Apply) Given ROBDDs u and v there is an algorithm $apply(op, u, v)$ that computes any Boolean operation $u \ op \ v$ in space and time $O(|u||v|)$

(Exists) Given ROBDD u and a subset of the variables X there is an efficient algorithm to compute $\exists X. u$ (a projection)



Compilation, BDDs

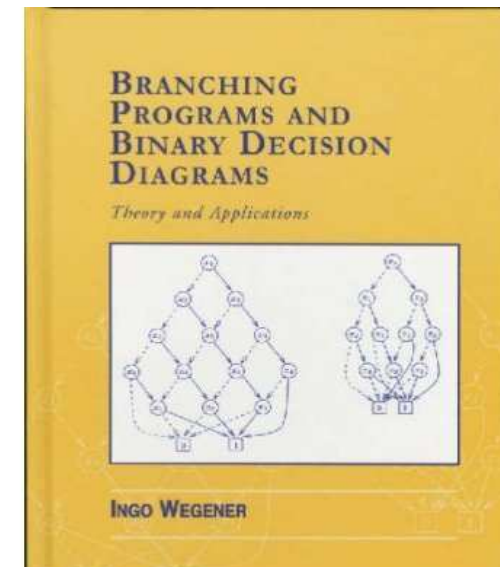
Constraint satisfaction problem (CSP):

- Finite domains D_1, \dots, D_n
- Variables x_1, \dots, x_n
- Constraints C_1, \dots, C_m

Compilation (if D_i 's are Boolean)

- Select ordering $x_1 < \dots < x_n$
- **Compile each constraint**
 $C_j \rightarrow u_j$
- Decide conjunctive schedule
 $C_1 < \dots < C_m$
- Compute according to schedule
 $u \leftarrow (\dots ((u_1 \text{ and } u_2) \text{ and } u_3) \dots \text{ and } u_m$

Compile each constraint $C_j \rightarrow u_j$
Construct BDD for C_j using BDD
apply-operation (and others)



Runtime, BDDs

- The CSP is represented by $u: \varphi = f_u$
- A *valid domains computation* is performed by finding, for a given ρ , for each j the set of valid values V_j D_j defined as: \subset
$$v \in V_j \text{ iff } \varphi[\rho][v/x_j] \text{ is satisfiable}$$
- $\rho \leftarrow \text{empty}$
Loop until done
 - **Compute V_j 's**
 - Display V_j 's to user
 - User selects $x_i := v$
 - $\rho \leftarrow \rho[v/x_i]$End loop

Compute V_j 's

For each x_i not in ρ :

$V_i \leftarrow$ solutions represented by projecting u onto dimension i

Can be done in time linear in the sum of the sizes of the domains

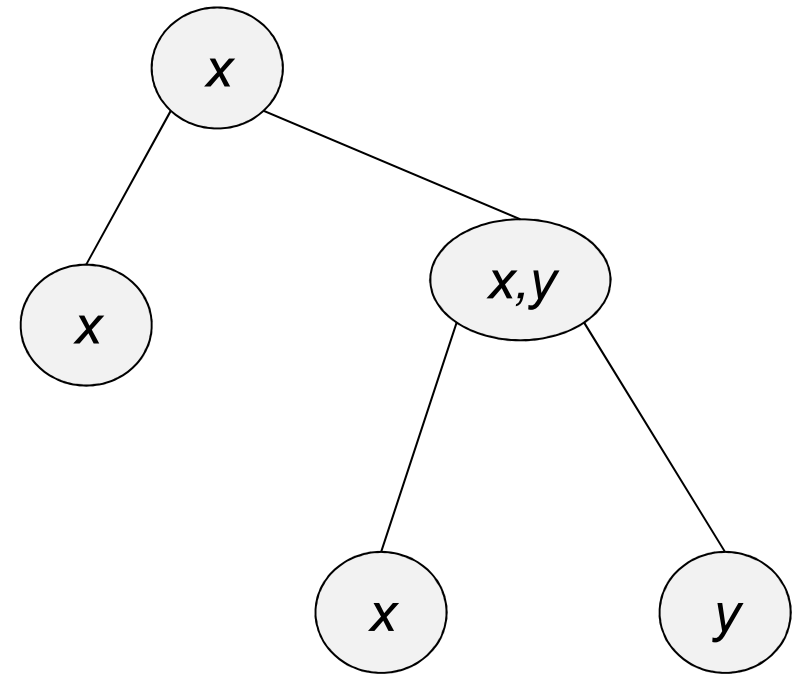
$$\sum_{j=1, \dots, n} |D_j|$$

"Goodies": explanations



Modular compilation; join graphs

- A *join graph* for a CSP
 - Vertices, V , are the constraints
 - Edges, E , are between constraints sharing variables; must fulfill connectedness condition: if x in v and x in w then there is a path from v to w containing x in each node
- Observation: *If a CSP has an acyclic join graph, valid domains can be computed in polytime.*



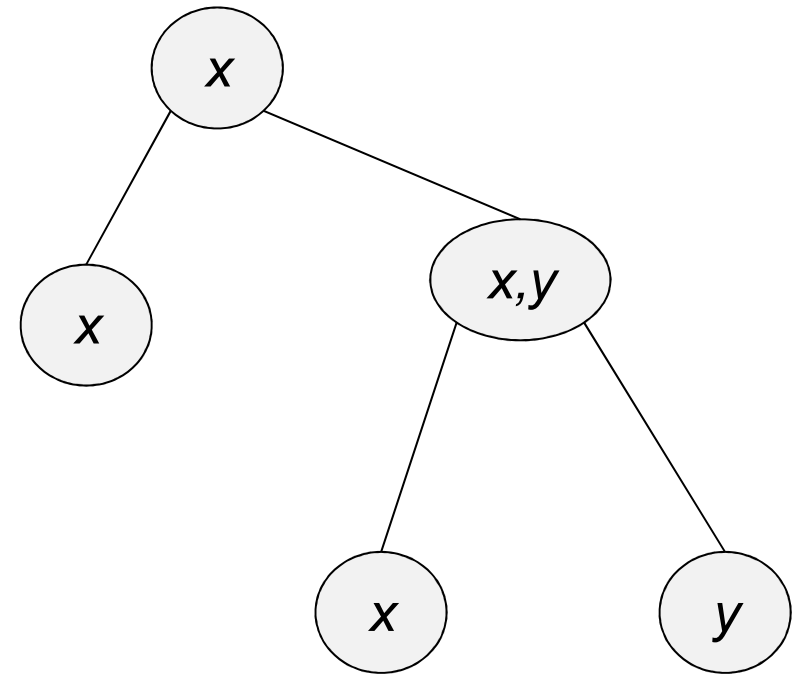
Modular compilation, tree decomposition

Compile time

- Start with first two steps of BDD compilation (up to conjunctive schedule)
- Perform tree decomposition:
 - Transform CSP into an CSP with acyclic join graph "and'ing" constraints into new constraints C'_i as BDDs u'_i


Runtime

- Run polytime valid domains algorithm with BDD operations on join graph



(A bit) More Realistic Example

bike demo



Information

Customer number

Region

Currency

Special requirements

Preferences

Frame type
☐ City bike
☐ Classic
☒ Mountainbike
☐ Racer Bike

Frame type
☐ Female ☐ Male

My height

Average driving distance

Parts

Frame color

Frame

Frame Size

Gear

Number of speeds

Rims

Rim width

Tires

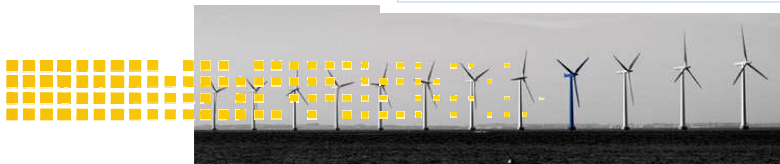
Tire profile

Pedals

Extras

☒ Carrier
☐ Mudguard
☒ Basket
☐ Propstand
☐ Lock
☐ Bottle
☐ Pump
☐ Cateye
☐ Front reflex
☐ Side reflex
☐ Shoes

58 finite domain
variables;
3,379,130,496
solutions;
VT size: 109 kB





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+20,000 finite
domain variables!

Press conference on Vestas' new
organisation



> Live webcast on 12 January 2012 at 2:00 pm CET

Cost of Energy

> How do we reduce the cost of wind energy?

Preliminary financial highlights for the financial year 2011



- Order intake for 2011 amounted to 7,4 GW
 - Revenue: approx mEUR 6,000
 - EBIT margin: approx 0 per cent of revenue
- [>Read the company announcement](#)

Vestas Weather App



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Generator Family





Jaguar Land Rover, UK

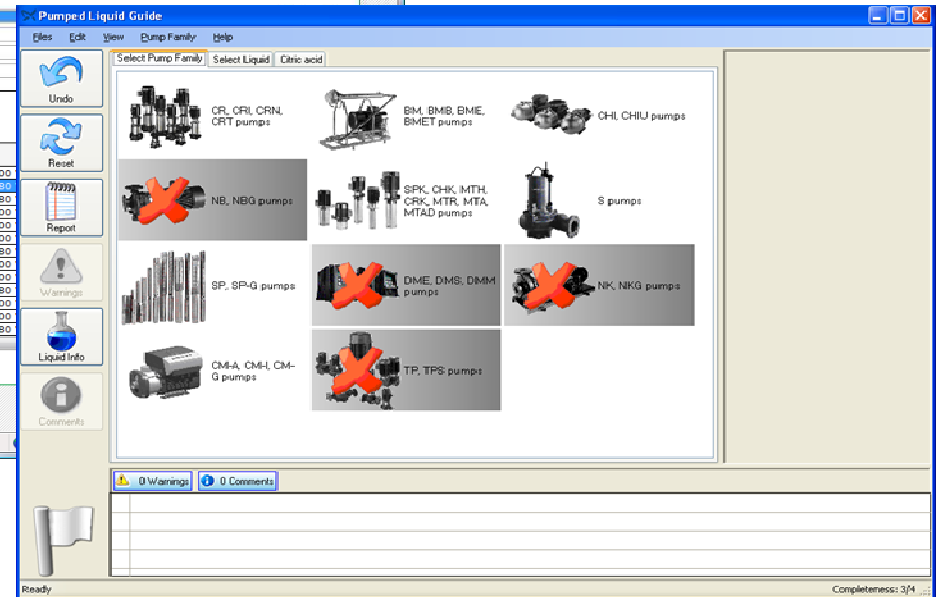
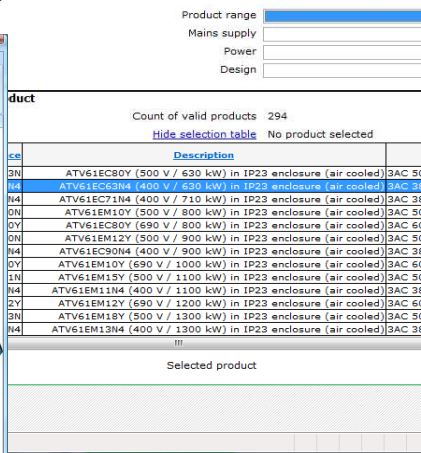
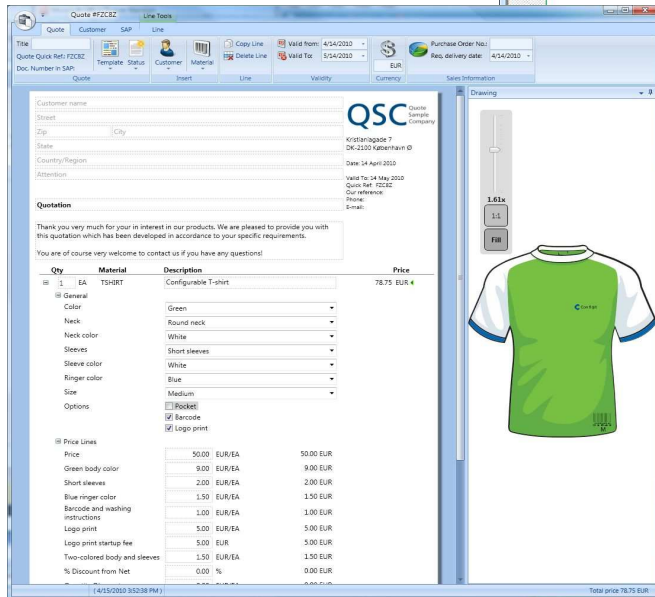
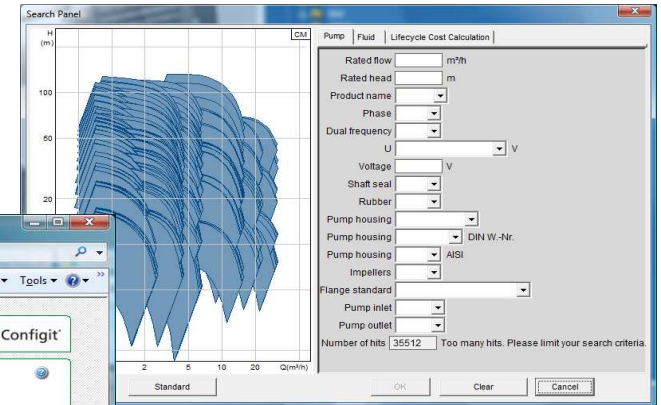
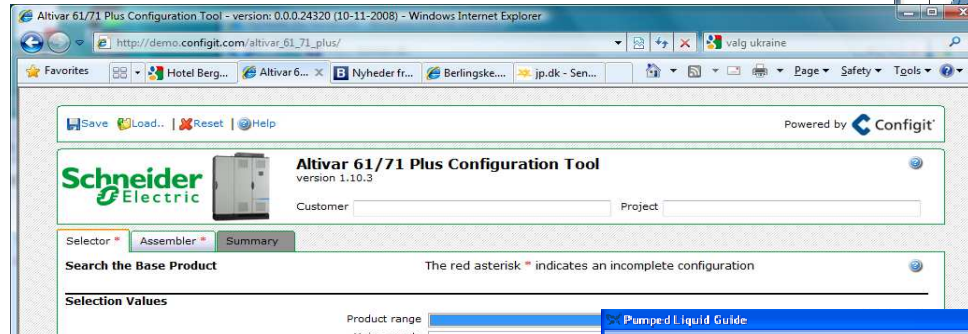


How to use the compilation technology in practice?

(We call it Virtual Tabulation®)



Standard or customized UIs



Configit Product Modeler

- Graphical modeling environment for authoring, testing, debugging and running product models.

The screenshot displays the Configit Product Modeler interface. The main window shows the 'Structure View' on the left, listing the 'TSHIRT_SMAT' model and its components: 'Sales', 'SynchronizedVariables', and 'BlouseSize'. The 'Variable' editor in the center shows a table with columns for 'BlouseSize', 'ChestGirth', 'Gender', 'Pref', 'Region', and 'ShirtSize'. The 'Edit Feature Tree' on the right shows a hierarchical tree structure for the 'Model', including 'CPU', 'Operating System', and 'Software'.

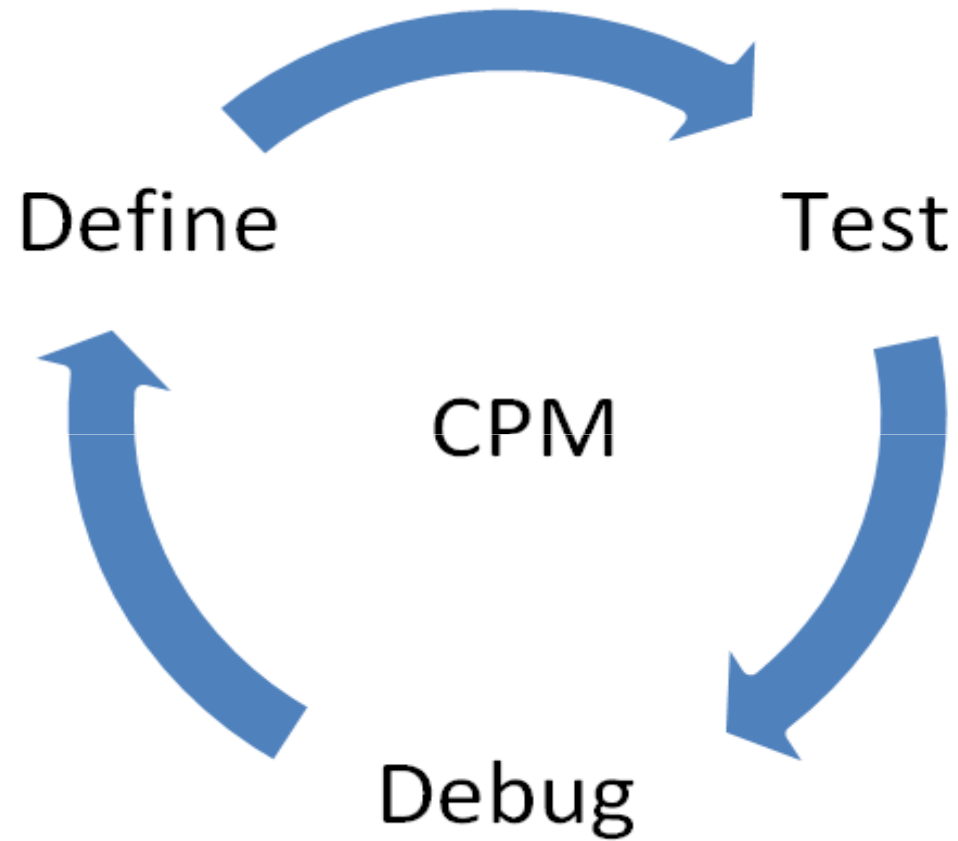
The 'Edit Feature Tree' shows a table with columns for 'Model', 'CPU', and 'Operating System'. The table lists various configurations, including 'Extreme170', 'Intel® Pentium® M Processor 760', and 'Genuine Windows® XP Home Edition'.

The 'Edit relation: Preferences.DualProcessor' dialog box is open, showing a table with columns for 'Cpu', 'DualProcessor True', and 'DualProcessor False'. The table lists various CPU models and their corresponding dual processor configurations.

Cpu	DualProcessor True	DualProcessor False
M360	+	
M370	+	
M733	+	
M735	+	
M740	+	
M750	+	
M755	+	
M760	+	
M770	+	
T1300	+	
T2500		+
T2400		+
T2300		+
M780	+	



Quality assurance cycle



Questions / discussion



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