How to Build Smarter Decision Models Capable To Make Optimal Decisions

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Decision Management Tools

Software Tools for Decision Management . . . . www.decision-tools.org

Tool Catalogues   Decision Model Collection

This website maintains **Live Catalogues of Decision Management Software** currently available on the market:

- Business Decisions and Rules Management Systems
- Predictive Analytics Tools
- Complex Event Processing and Real-Time Intelligence Tools
- Decision Modeling Tools
- Decision Optimization
  - Constraint Programming Solvers
  - Linear Programming Tools
- Business Process Management Software

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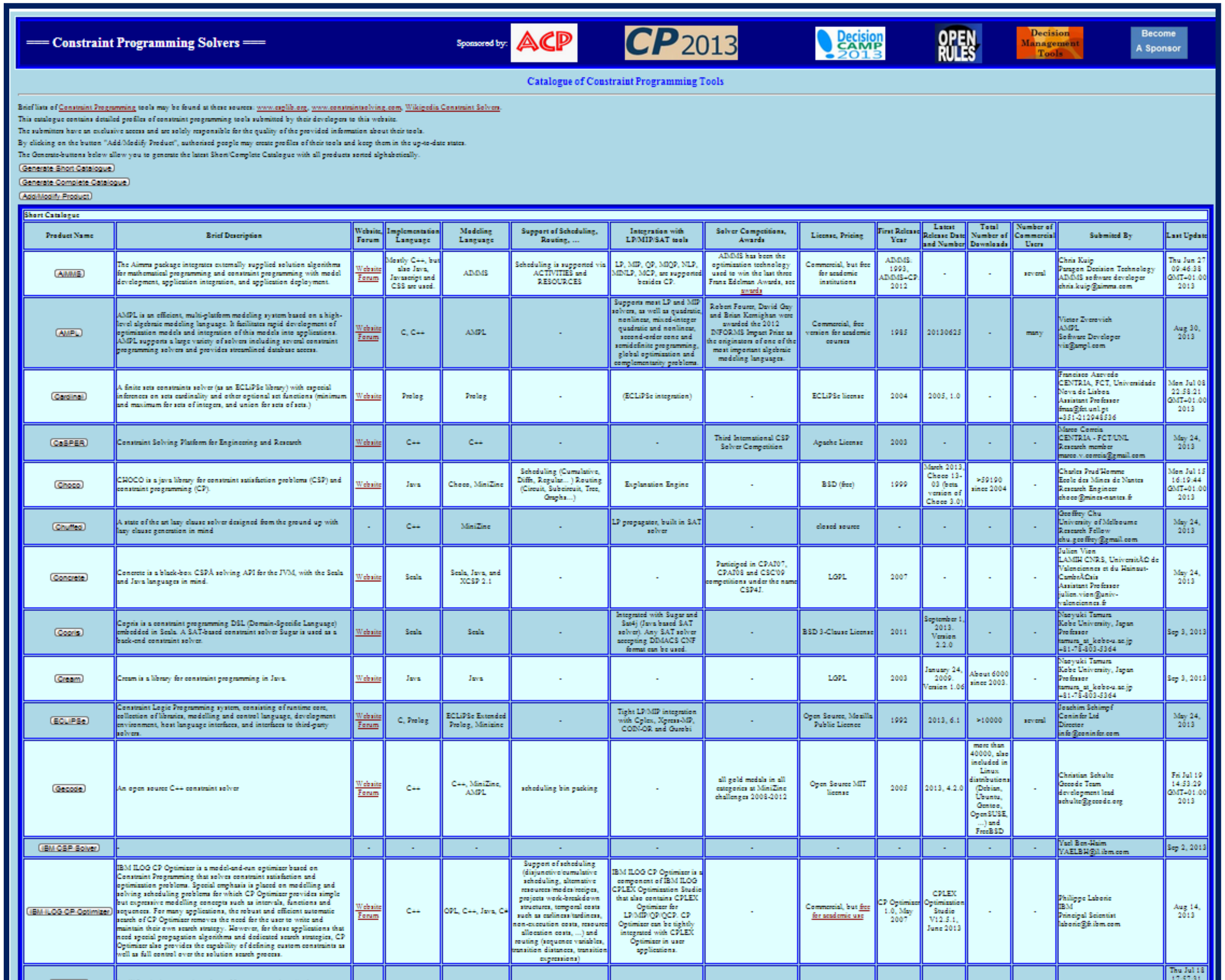
Live Catalogues of Optimization Tools

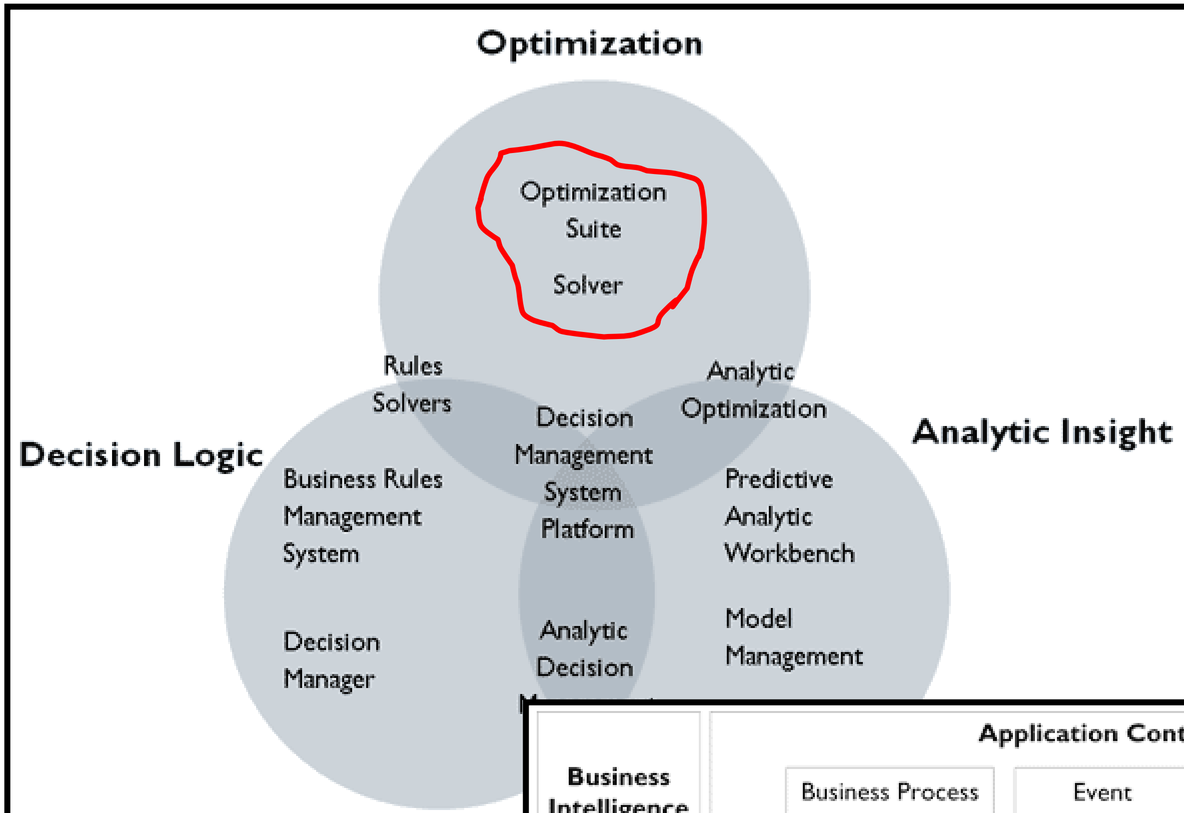
Contains detailed profiles of open source and commercial tools:

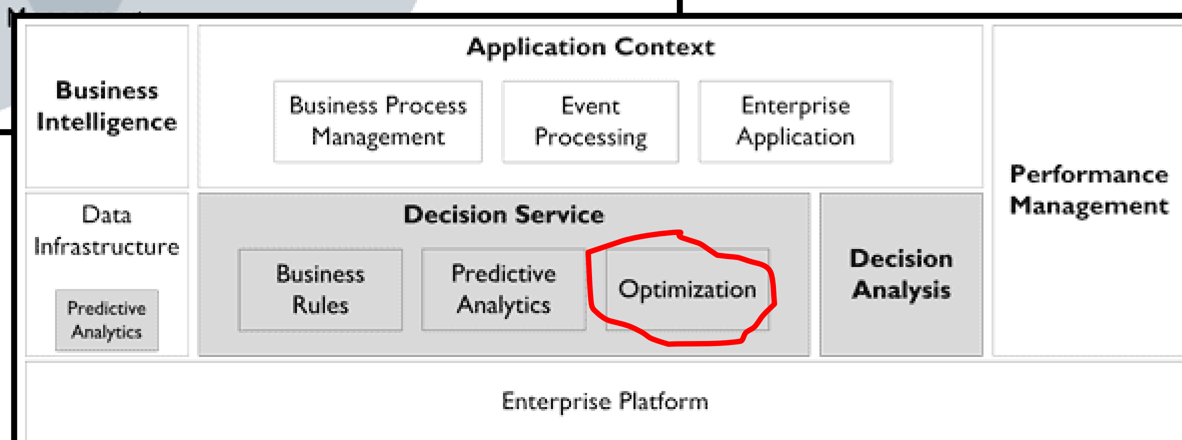
- **30 Constraint Solvers**
- **11 Linear Solvers**



Tool profiles are maintained by their authors

Decision Optimization within Decision Management Platforms



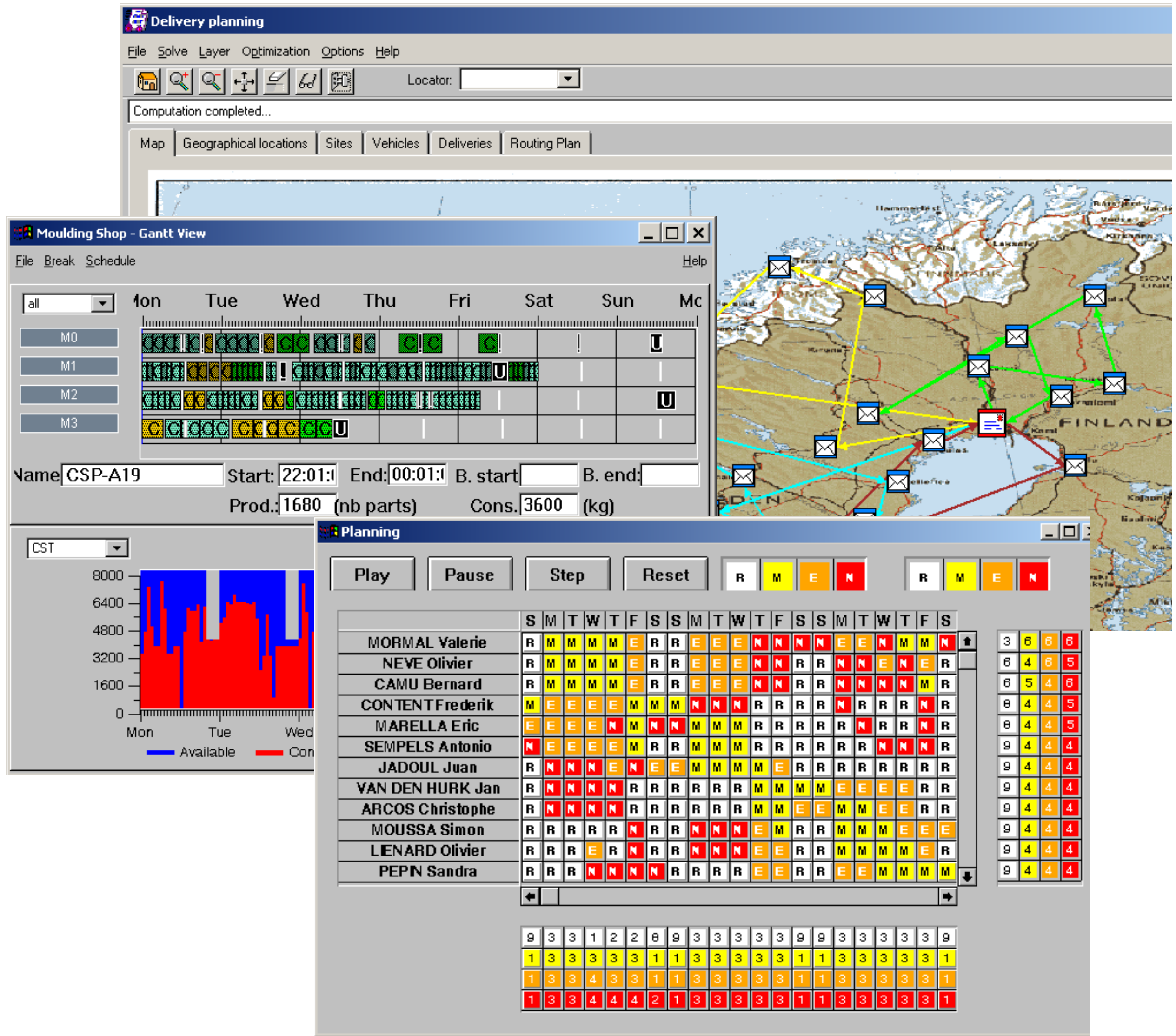


Decision Optimization

- Decision Optimization helps *business* people to:
  - make *better decisions* subject to different *business* and *time* constraints
  - consider alternative decisions
  - find *optimal* (or close to optimal) decisions
- Finds the *best* possible resource utilization to achieve a desired optimization objective such as:
  - minimizing expenses or travel time
  - maximizing ROI or service level
- Relies on proven mathematical techniques such as:
  - Constraint Programming (CP) and Linear Programming (LP)
  - Integrated in modern decision modeling frameworks

Typical Optimization Applications

- Scheduling and Resource Allocation
- Complex Configuration Problems
- Supply Chain Management
- Staff Rostering
- Vehicle Routing



Constraint Satisfaction Problem - CSP

- CSP represents a decision optimization problems defining *decision variables* subject to *constraints*
- Typical CSP structure:
  1. **Problem Definition (what to do)**
     a. Define Decision Variables with all possible values
     b. Define Constraints on the decision variables
  2. **Problem Resolution (how to do it)**
     a. Find Solution(s) that defines a value for each variable such that all constraints are satisfied or
     b. Find an optimal solution that minimizes/maximizes a certain objective (a function of decision variables)

JSR-331 “Java CP API” Standard

- JSR-331 “Java Constraint Programming API” – an official Java Community Process (JCP) standard www.jsr331.org
- JSR-331 covers key concepts and design decisions related to the standard representation and resolution of constraint satisfaction and optimization problems
- Utilizes de-facto standardized decisions from multiple CP solvers
- JSR-331 current implementations:
    - **4 CP-based solvers**
    - **6 LP-based solvers**

Simple CSP in Java (JSR-331)

```
public static void main(String[] args) {
    // ==== PROBLEM DEFINITION ==============================
    Problem p = ProblemFactory.newProblem("Test");
    // ======= Define variables
    Var x = p.variable("X", 1, 10);
    Var y = p.variable("Y", 1, 10);
    Var z = p.variable("Z", 1, 10);
    Var cost = x.multiply(3).multiply(y).minus(z.multiply(4));
    // ======= Define and post constraints
    p.post(x, "<", y); // X < Y
    p.post(x.plus(y), "=", z); // X + Y = Z

    // === PROBLEM RESOLUTION ===============================
    p.log("=== Find Solution:");
    Solver solver = p.getSolver();
    Solution solution = solver.findSolution();
    if (solution != null)
        solution.log();
    else
        p.log("No Solution");
    p.log("Cost " + cost);
}
```

Solution solution = solver.**findOptimalSolution(cost);**

Moving From Java to Business Decision Modeling

- Building business-oriented decision modeling facilities on top of the JSR-331
- Allowing business analysts *to define* a decision optimization problem
  - Using business concepts and decision variables (glossary)
  - Using predefined or custom constraints oriented to business people
- Relying on the standard solvers *to solve* the problem
- OpenRules® Rule Solver provides a decision optimization environment using intuitive decision tables managed in Excel or Google Docs

Example: Where is Zebra?

1. There are five houses
2. The Englishman lives in the red house
3. The Spaniard owns the dog
4. Coffee is drunk in the green house
5. The Ukrainian drinks tea
6. The green house is immediately to the right of the ivory house
7. The Old Gold smoker owns snails
8. Kools are smoked in the yellow house
9. Milk is drunk in the middle house
10. The Norwegian lives in the first house
11. The man who smokes Chesterfields lives in the house next to the man with the fox
12. Kools are smoked in the house next to the house where the horse is kept
13. The Lucky Strike smoker drinks orange juice
14. The Japanese smokes Parliaments
15. The Norwegian lives next to the blue house

Glossary

	Glossary glossary				
	Decision Variables	Business Concept	Attribute	Domain	Unknown
Colors	green	Zebra Problem	green	0-4	TRUE
	ivory		ivory	0-4	TRUE
	blue		blue	0-4	TRUE
	red		red	0-4	TRUE
	yellow		yellow	0-4	TRUE
People	Norwegian		norwegian	0-4	TRUE
	Ukrainian		ukrainian	0-4	TRUE
	Japanese		japanese	0-4	TRUE
	Englishman		englishman	0-4	TRUE
	Spaniard		spaniard	0-4	TRUE
Drinks	juice		juice	0-4	TRUE
	tea		tea	0-4	TRUE
	milk		milk	0-4	TRUE
	water		water	0-4	TRUE
	coffee		coffee	0-4	TRUE
Pets	snail		snail	0-4	TRUE
	dog		dog	0-4	TRUE
	fox		fox	0-4	TRUE
	horse		horse	0-4	TRUE
	ZEBRA		zebra	0-4	TRUE
Cigarettes	Chesterfield		chesterfield	0-4	TRUE
	Parliament		parliament	0-4	TRUE
	Lucky		lucky	0-4	TRUE
	OldGolds		oldGolds	0-4	TRUE
	Kools		kools	0-4	TRUE

Decision "FindZebra"

Decision FindZebra	
Decisions	**Execute Rules**
All Diff Constraints	:= AllDiffConstraints()
Zebra Constraints 1	:= ZebraConstraints1()
Zebra Constraints 2	:= ZebraConstraints2()

All Different Constraints

DecisionTable AllDiffConstraints
ActionAllDiff
Variables
green,ivory,blue,red,yellow
Norwegian,Ukrainian,Japanese,Englishman,Spaniard
juice,tea,milk,water,coffee
snail,dog,fox,horse,ZEBRA
Chesterfield,Parliament,Lucky,OldGolds,Kools

Zebra Constraints 1

DecisionTable ZebraConstraints1			
ActionXoperY			
X <oper> Y			
Englishman	=	red	The Englishman lives in the red house
Spaniard	=	dog	The Spaniard owns the dog
coffee	=	green	Coffee is drunk in the green house
Ukrainian	=	tea	The Ukrainian drinks tea
OldGolds	=	snail	The Old Golds smoker owns snails
Kools	=	yellow	Kools are smoked in the yellow house
milk	=	2	Milk is drunk in the middle house
Norwegian	=	0	The Norwegian lives in the first house
Lucky	=	juice	The Lucky Strike smoker drinks orange juice
Japanese	=	Parliament	The Japanese smokes Parliament

Zebra Constraints 2

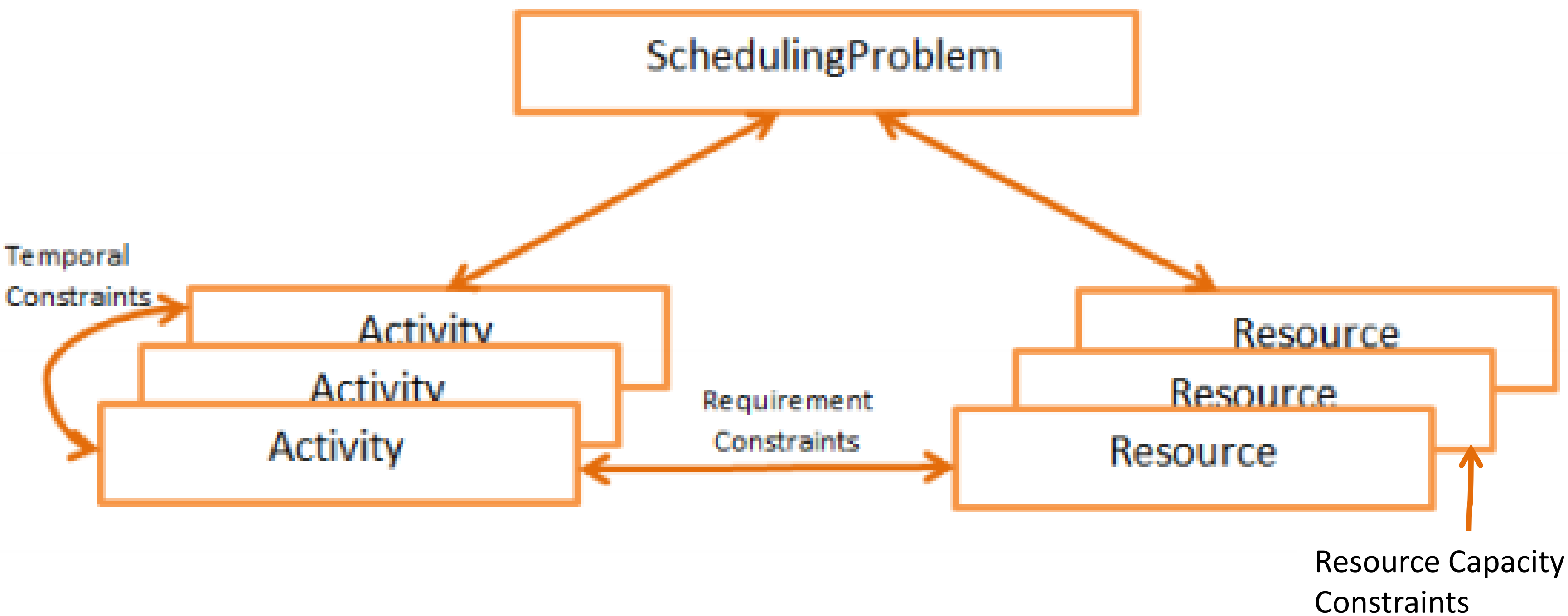
DecisionTable ZebraConstraints2	
ActionConstraint	
Constraint	
`{ Var green = getVar("green"); Var ivory = getVar("ivory"); solver().linear(green,"=",ivory.plus(1)); }`	The green house is immediately to the right of the ivory house
`{ Var Chesterfield = getVar("Chesterfield"); Var fox = getVar("fox"); Constraint right = linear(Chesterfield,"=",fox.plus(1)); Constraint left = linear(Chesterfield,"=",fox.minus(1)); right.or(left); }`	The man who smokes Chesterfields lives in the house next to the man with the fox
`{ Var horse = getVar("horse"); Var Kools = getVar("Kools"); Constraint right = linear(Kools,"=",horse.plus(1)); Constraint left = linear(Kools,"=",horse.minus(1)); right.or(left); }`	Kools are smoked in the house next to the house where the horse is kept.
`{ Var Norwegian = getVar("Norwegian"); Var blue = getVar("blue"); linear(Norwegian,"=",blue.plus(1)).or( linear(Norwegian,"=",blue.minus(1)) ); }`	The Norwegian lives next to the blue house

Zebra Execution Results

House #1: fox yellow Kools water Norwegian
House #2: Chesterfield Ukrainian horse tea blue
House #3: OldGolds milk red Englishman snail
House #4: Lucky juice ivory Spaniard dog
House #5: Parliament Japanese ZEBRA green coffee

OpenRules® Rule Solver

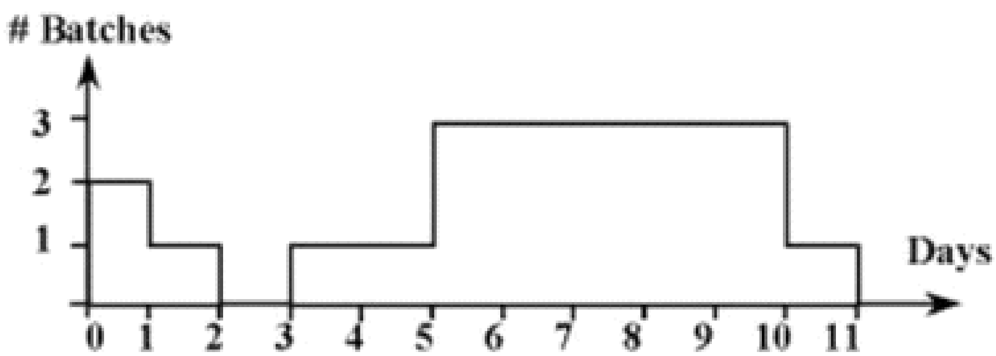
- Includes decision table templates for various binary and global constraints
- Includes decision table templates for scheduling and resource allocation problems:



Real-world Resource Allocation Decisions

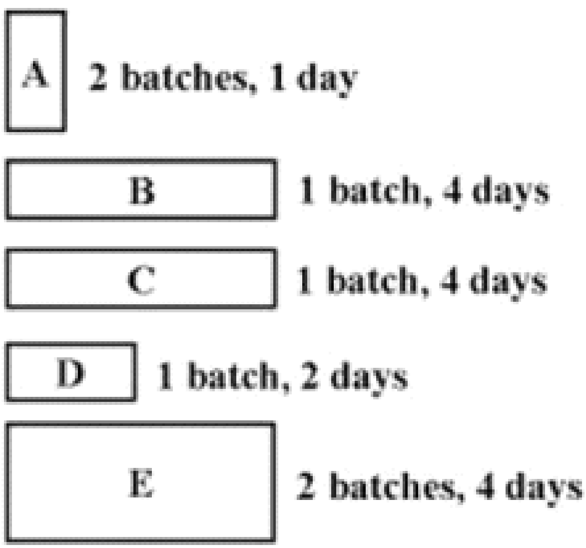
- Many service providers have to make every day decisions by allocation their limited capacity resources to satisfy various customer requests
- Let’s consider a small business that fires batches of bricks in one or several ovens (a resource with a limited capacity)
- This business has to make resource allocation decisions on a constant basis by allocating their limited resources to customer orders while satisfying scheduling and resource constraints

Example of a Resource Allocation Problem

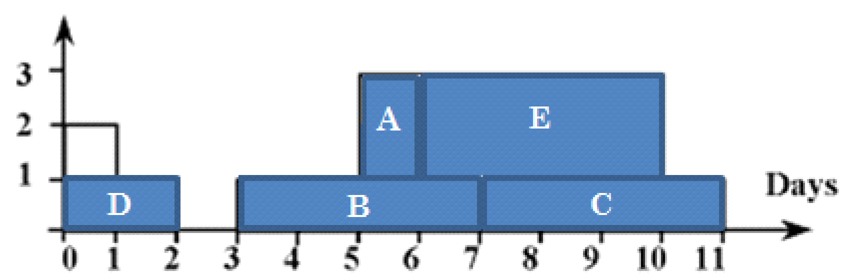


Global capacity of the oven

5 Activities



Possible Solutions:



Decision "DefineOvenSchedule"

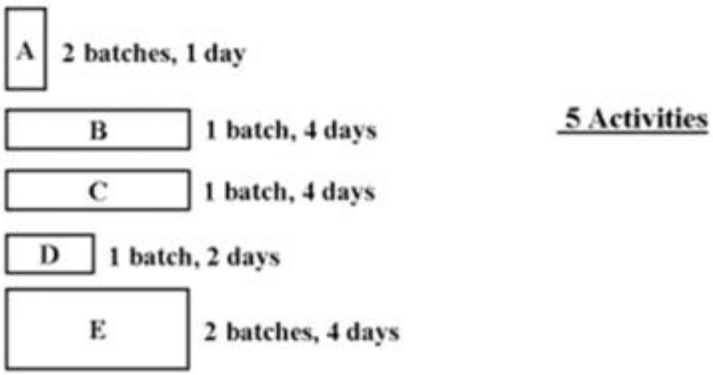
This decision consists of 5 sub-decisions:

Decision DefineOvenSchedule	
Decisions	**Execute Rules**
Define Schedule	:= DefineSchedule()
Define Activities	:= DefineActivities()
Define Oven as Recoverable Resource	:= DefineOvenAsResource()
Define Oven Availability	:= SetOvenCapacities()
Define Resource Requirement Constraints	:= ResourceRequirementConstraints()

Define Schedule and Activities

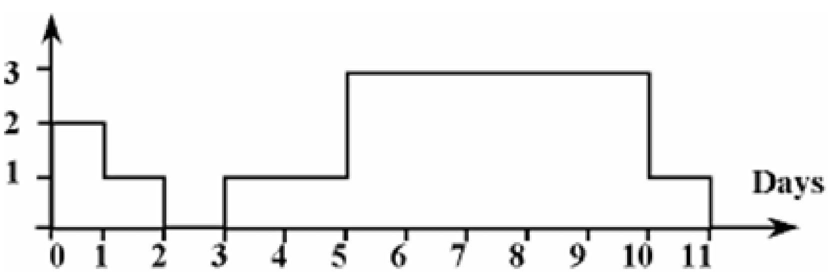
DecisionTable DefineSchedule	
ActionSchedule	
Origin	**Horizon**
0	11

DecisionTable DefineActivities	
ActionAddActivity	
Name	**Duration**
A	1
B	4
C	4
D	2
E	4



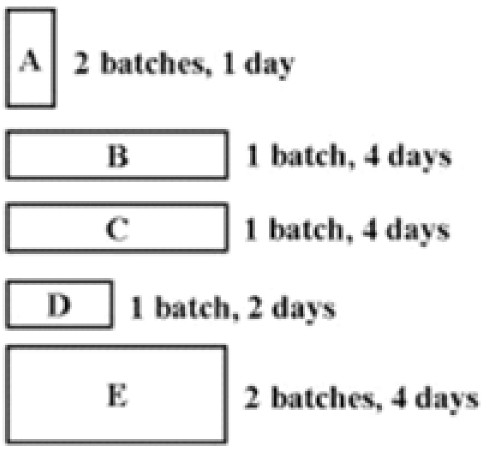
Define Oven and its Availability

DecisionTable DefineOvenAsResource		
ActionAddResource		
Name	**Resource Type (Consumable/Recoverable)**	**Max Capacity**
Oven	Recoverable	3



DecisionTable SetOvenCapacities			
ActionResourceCapMax			
Resource	**From**	**To**	**Capacity**
Oven	0	1	2
Oven	1	2	1
Oven	2	3	0
Oven	3	5	1
Oven	5	10	3
Oven	10	11	1

Define Resource Requirements



DecisionTable ResourceRequirementConstraints		
ActionActReqResource		
Activity	Required Resource	Required Capacity
A	Oven	2
B	Oven	1
C	Oven	1
D	Oven	1
E	Oven	2

Run Decision from Java to Find One Feasible Solution

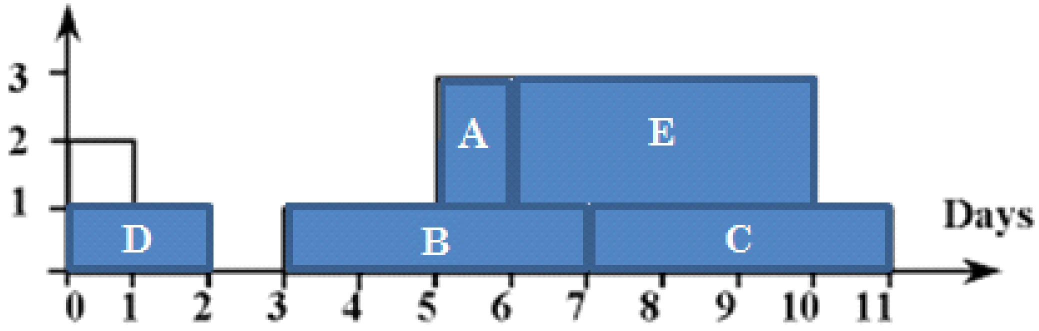
```
public class Main {

    public static void main(String[] args) {

        String fileName = "file:rules/Decision.xls";
        System.setProperty("OPENRULES_MODE", "Solve");
        Decision decision = new Decision("DefineOvenSchedule",fileName);
        decision.execute();
    }
}
```

One Feasible Solution

SOLUTION:
A[5 -- 1 --> 6)   requires oven[2]
B[3 -- 4 --> 7)   requires oven[1]
C[7 -- 4 --> 11) requires oven[1]
D[0 -- 2 --> 2)   requires oven[1]
E[6 -- 4 --> 10) requires oven[2]



Run Decision from Java to Find <u>ALL</u> Feasible Solutions

```
public class Main {

    public static void main(String[] args) {

        String fileName = "file:rules/Decision.xls";
        System.setProperty("OPENRULES_MODE", "Solve");
        Decision decision = new Decision("DefineOvenSchedule",fileName);
        decision.put("MaxSolutions", "10");
        decision.execute();
    }
}
```

All Feasible Solutions

Solution 1:
A[5 -- 1 --> 6) requires Oven[2]
B[3 -- 4 --> 7) requires Oven[1]
C[7 -- 4 --> 11) requires Oven[1]
D[0 -- 2 --> 2) requires Oven[1]
E[6 -- 4 --> 10) requires Oven[2]

Solution 2:
A[5 -- 1 --> 6) requires Oven[2]
B[7 -- 4 --> 11) requires Oven[1]
C[3 -- 4 --> 7) requires Oven[1]
D[0 -- 2 --> 2) requires Oven[1]
E[6 -- 4 --> 10) requires Oven[2]

Solution 3:
A[9 -- 1 --> 10) requires Oven[2]
B[3 -- 4 --> 7) requires Oven[1]
C[7 -- 4 --> 11) requires Oven[1]
D[0 -- 2 --> 2) requires Oven[1]
E[5 -- 4 --> 9) requires Oven[2]

Solution 4:
A[9 -- 1 --> 10) requires Oven[2]
B[7 -- 4 --> 11) requires Oven[1]
C[3 -- 4 --> 7) requires Oven[1]
D[0 -- 2 --> 2) requires Oven[1]
E[5 -- 4 --> 9) requires Oven[2]

Another Real-World Example “Workforce Management”

- Workforce management is central to efficient operations and good customer service.
- Proper scheduling of employees can mean the difference between profitability and business failure.
- As the manager, you are required to hire and set the weekly work schedule for your employees.

Employee Scheduling Requirements

- The required levels for the week are as follows:
  - Total employees required

Mon	Tue	Wed	Thu	Fri	Sat	Sun
5	8	9	10	16	18	12

  - Available employees:

Employee Type	Total	Cost per Day
F/T	14	$100
P/T	4	$150

Possible Solution:

	M	T	W	T	F	S	S
FT	5	8	9	10	14	14	12
PT	0	0	0	0	2	4	0

- Assuming the same staffing requirements continue week after week, **what is the minimal staffing cost**?

Decision "DefineEmployeeSchedule"

- Start with a decision
- Presented in Excel using OpenRules Rule Solver

Mon	Tue	Wed	Thu	Fri	Sat	Sun
5	8	9	10	16	18	12

Decision DefineEmployeeSchedule	
Decisions	**Execute Rules**
Define Employee Daily Demand	:= EmployeeDailyDemand()
Define Total Cost	:= DefineTotalCost()

Employee Type	Total	Cost per Day
F/T	14	$100
P/T	4	$150

Decision's Glossary

- Decision Variables
- For each day one for FT and one for PT

Glossary glossary				
Decision Variable	**Business Concept**	**Attribute**	**Domain**	**Unknown**
Mon FT	Roster	monFT	0-14	TRUE
Mon PT		monPT	0-4	TRUE
Tue FT		tueFT	0-14	TRUE
Tue PT		tuePT	0-4	TRUE
Wed FT		wedFT	0-14	TRUE
Wed PT		wedPT	0-4	TRUE
Thu FT		thuFT	0-14	TRUE
Thu PT		thuPT	0-4	TRUE
Fri FT		friFT	0-14	TRUE
Fri PT		friPT	0-4	TRUE
Sat FT		satFT	0-14	TRUE
Sat PT		satPT	0-4	TRUE
Sun FT		sunFT	0-14	TRUE
Sun PT		sunPT	0-4	TRUE
Total Cost		totalCost	0-20000	TRUE

Decision Table "EmployeeDailyDemand"

DecisionTable EmployeeDailyDemand				
ActionXoperYcompareZ				
Variable	Arith Oper	Variable	Compare Oper	Value
Mon FT	+	Mon PT	=	5
Tue FT	+	Tue PT	=	8
Wed FT	+	Wed PT	=	9
Thu FT	+	Thu PT	=	10
Fri FT	+	Fri PT	=	16
Sat FT	+	Sat PT	=	18
Sun FT	+	Sun PT	=	12

Mon	Tue	Wed	Thu	Fri	Sat	Sun
5	8	9	10	16	18	12

Decision Table “DefineTotalCost”

DecisionTable DefineTotalCost		
ActionScalProd		
Name of the Scalar Product	**Numbers**	**Variables**
Total Cost	100,150,100,150,100,150, 100,150,100,150,100,150, 100,150	Mon FT, Mon PT, Tue FT, Tue PT, Wed FT, Wed PT, Thu FT, Thu PT, Fri FT, Fri PT, Sat FT, Sat PT, Sun FT, Sun PT

Employee Type	Total	Cost per Day
F/T	14	$100
P/T	4	$150

Run Decision from Java to Find One Feasible Solution

```
public class Main {

    public static void main(String[] args) {

        String fileName = "file:rules/Decision.xls";
        System.setProperty("OPENRULES_MODE", "Solve");
        Decision decision = new Decision("DefineEmployeeSchedule",fileName);
        decision.put("MaxSolutions", "30");
        decision.put("Minimize","Total Cost");
        decision.execute();
        decision.execute("PrintSolution");
    }
}
```

OPEN RULES

Decision Results

…
Found a solution with Total Cost[8700]
Found a solution with Total Cost[8650]
Found a solution with Total Cost[8600]
Found a solution with Total Cost[8550]
Found a solution with Total Cost[8500]
Found a solution with Total Cost[8450]
Found a solution with Total Cost[8400]
Found a solution with Total Cost[8350]
Found a solution with Total Cost[8300]
Found a solution with Total Cost[8250]
Found a solution with Total Cost[8200]
Found a solution with Total Cost[8150]
Found a solution with Total Cost[8100]
Found a solution with Total Cost[8100]
*** Execution Profile ***
Number of Choice Points: 94360
Number of Failures: 94333
Occupied memory: 93172496
Execution time: 14885 msec

====== Optimal Solution =======

	M	T	W	T	F	S	S
FT	5	8	9	10	14	14	12
PT	0	0	0	0	2	4	0

COST: 8100
==============================

Smarter Search Strategies

- Adding time limits for:
  - Search of one solution
  - The overall search
- CP solvers provide many search strategies for selecting variables and values to try first, e.g.
  - Notorious "N-Queens" problem: using a selector MIN_DOMAIN_MIN_VALUE improves performance 1,000 times
- CP/LP tools provide different optimization options that may be tried without changing a decision model

Conclusion

- Combination of BR and CP/LP tools creates a powerful while intuitive decision modeling and optimization framework
- Many practical Decision Optimization problems may be successfully modeled and solved by subject matter experts using off-the-shelf CP/LP tools such as OpenRules Rule Solver
- The JSR-331 standard gives all BR vendors an opportunity to add a true optimization component to their product offerings

Q&A

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