University of Applied Sciences and Arts Northwestern Switzerland
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Rule-Based Systems I: Decision Modeling, Decision Tables, Decision Trees

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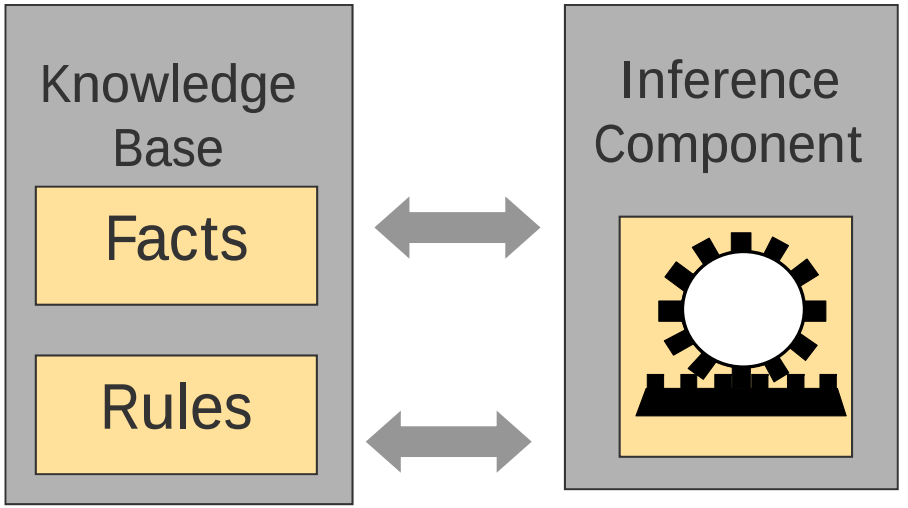
Rule-based Systems

- Rule-based Systems consist of
  - Rule base
  - Fact base
  - Inference engine



- Rules are of the form
  - IF <antecedent> THEN <consequent>

Different Types of Rule-based Systems

- Condition-Action Rules (Production Rules)
  - <consequent> is a set of actions
  - <antecedent> is a set of conditions
  - Example:
    IF car X has been sold THEN delete X from the catalogue
- Logical rules
  - <antecedent> and <consequent> are formulas of first-order logic
  - IF … THEN is equivalent to implication
  - Example:
    IF X is a man THEN X is mortal

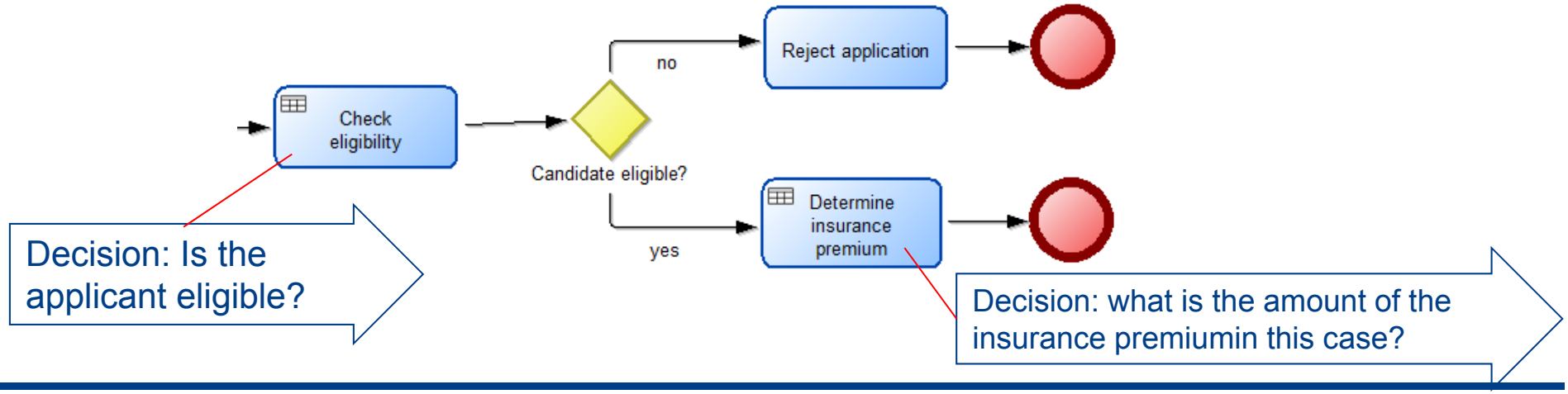
Representation of Rules

There is a large variety of rule representations:

- decision tables
- decision trees
- graphical representation
- textual representation
  - logical formulas
  - Structured English
  - „Code“

Decision Tasks in Business Processes

- A **decision task** is a task in which some decision is made
- The business logic that is used for decision making is called *decision logic*
- Two kinds of decision tasks:
  - Decision tasks deriving values for data
  - Decision tasks providing data for gateways
    - At the gateway only the result of the decision should be tested (for the selection of the path) not the criteria for the decision



Basic Elements of Operational Business Decisions

- A decision is characterized by a *question*, for example:
  - Should the insurcance claim be accepted, rejected or examined for fraud?
  - Which resource should be assigned to this task?
  - Which service should be used to ship this package?
- A *potential outcome* is some result, conclusion, or answer that might be deemed appropriate for a case. Examples:
  - some form of yes/no (e.g. eligible/non-eligible)
  - some quanitities (e.g. dollar amounts)
  - some categories (e.g. silver, gold, or platinum customer)
  - some real-world instances (e.g. software product to be purchased)
  - some course of action (e.g. on-site visit, teleconference, email)
- A *case* is some particular matter or situation arising in a day-to-day business activity and requiring consideration
- The *outcome* is the result, conclusion, or answer for a *given* case
- The business logic that is used for decision making is called *decision logic* (the set of all decision rules selecting a decision outcome) (Ross 2011, p. 152f)

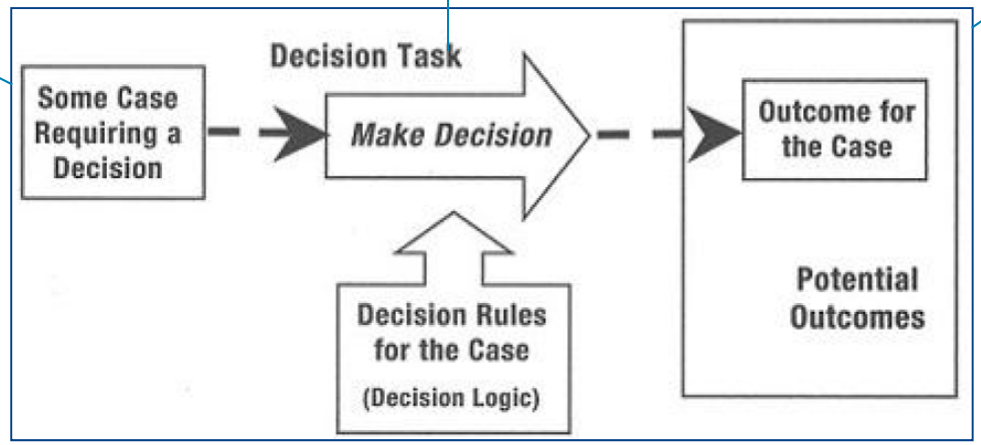
Example for a Business Decision: Data for Gateway

- Process: Handling auto insurance applications
- Decision Task: Check Eligibility of Applicant
- Potential outcomes: "yes" and "no" (i.e. eligible/non-eligible)
- Decision Logic: Terms of insurance

Case: *John Smith applies for an auto insurance*

Decision Task: *Check Eligibility*

Outcome: *John Smith is eligible for auto insurance*



(Ross 2011, p. 152f)

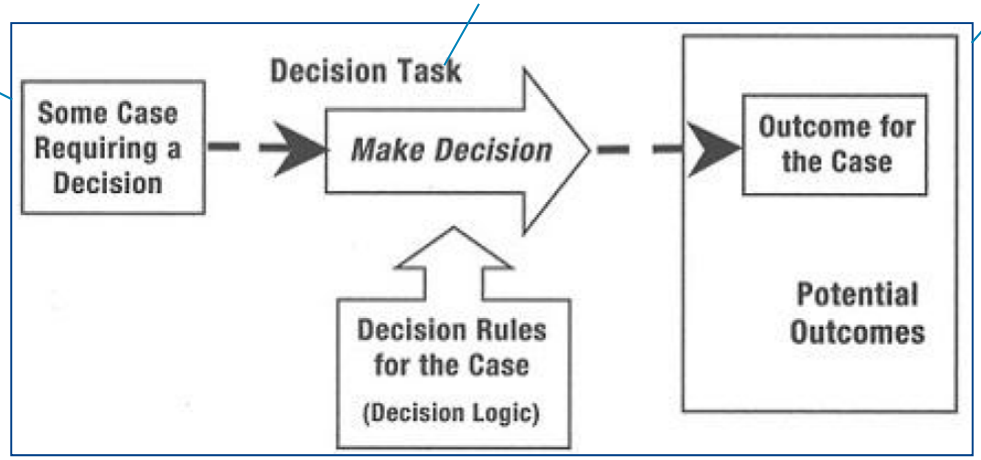
Example for a Business Decision:

- Process: Handling auto insurance applications
- Decision Task: Determine insurance premium
- Potential outcomes: amount of premium (i.e. amount)
- Decision Logic: Calculations for premiums

Case: *John Smith applies for an auto insurance*

Decision Task: *Determine insurance premium*

Outcome: *John Smith has to pay CHF 700 per year*



(Ross 2011, p. 152f)

Representation of Decision Rules

- There are a variety of ways to represent decision rules, e.g.
  - Semi-formal description
    - *The reimbursement is 90% if the patient visited a doctor's office and the physican was present*
  - Decision Table

Conditions	1	2	3	4	5	6
1. Type of visit	D	D	H	H	L	L
2. Participating Physician?	Y	N	Y	N	Y	N
Effects						
1. Reimburse 50%		X				
2. Reimburse 70%				X		X
3. Reimburse 90%	X					
4. Impossible or no reimbursement			X		X	

Reimbursement depends on whether the patient visited the doctor‘s office (D), a hospital (H) or a lab (L) and whether the Doctor is a Participating Physician

Each column represents a rule.

http://web.sxu.edu/rogers/sys/decision_tables.html

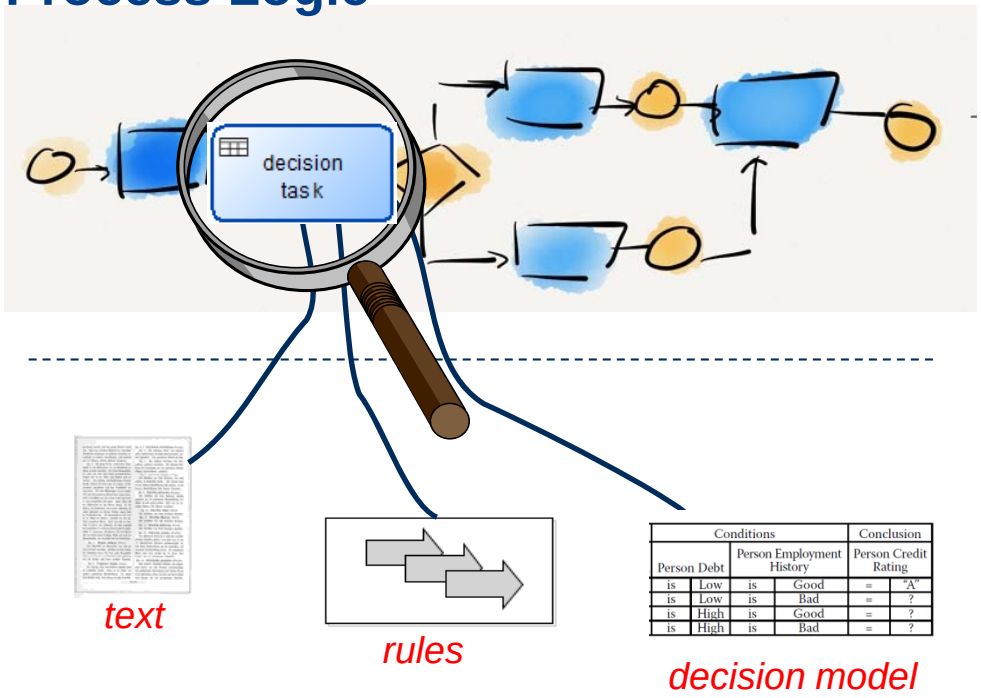
Perspectives on Process Modeling

- A new perspective on process modeling is reflected in the combination of three ideas
  - **Process:** an organized, coordinated flow of activities, conducted by participants, acting on and deciding with data and knowledge, to achieve a business goal.
  - **Decision:** decisions are made by applying business knowledge in the form of business rules or other decision logic to process data. A decision model likewise reflects how a decision is made.
  - **Event:** A process can also be considered a connected sequence of events that respond to states, causes, and conditions. In an event-based view, the process is a linkage of the transitions from one processing state to another.

(Debevoise & Taylor 2014)

Decision-Aware Process Models:
Managing Process Logic and Decision Logic Separately

Process Logic



Business Logic / Decision Logic

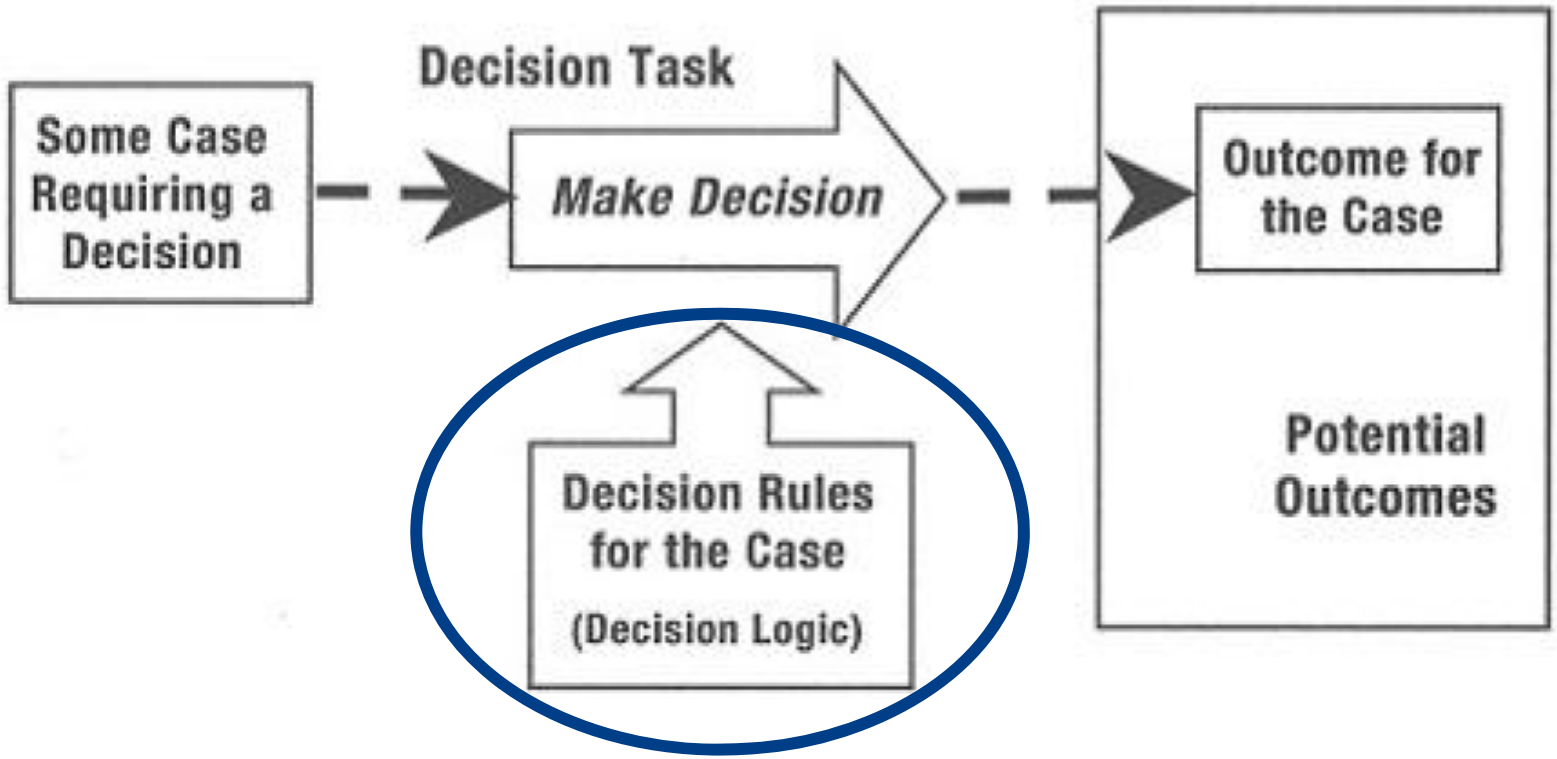
- The process model contains the process logic → **procedural**
- Decision logic is externalized from decision tasks and represented in a different kind of model → **declarative**
- Separating business decisions from business process tasks
  - simplifies the business process model
  - allows to manage business logic in a declarative form

Distinguishing a Procedural Task from a Declarative Decision

- A procedural solution specifies how, in a step-by-step manner, something is to be done.
  - A business process model is a procedural solution because it prescribes a set of tasks that are carried out in a particular sequence.
- A declarative solution only specifies what needs to be done, with no details as to how, in a step-by-step manner, it is to be carried out, because sequence is irrelevant to arriving at the correct result.
  - A Decision Table is a declarative solution because it is a set of unordered business logic, not a set of ordered tasks.

(von Halle & Goldberg 2010, p. 67)

Decision Logic and Decision Task



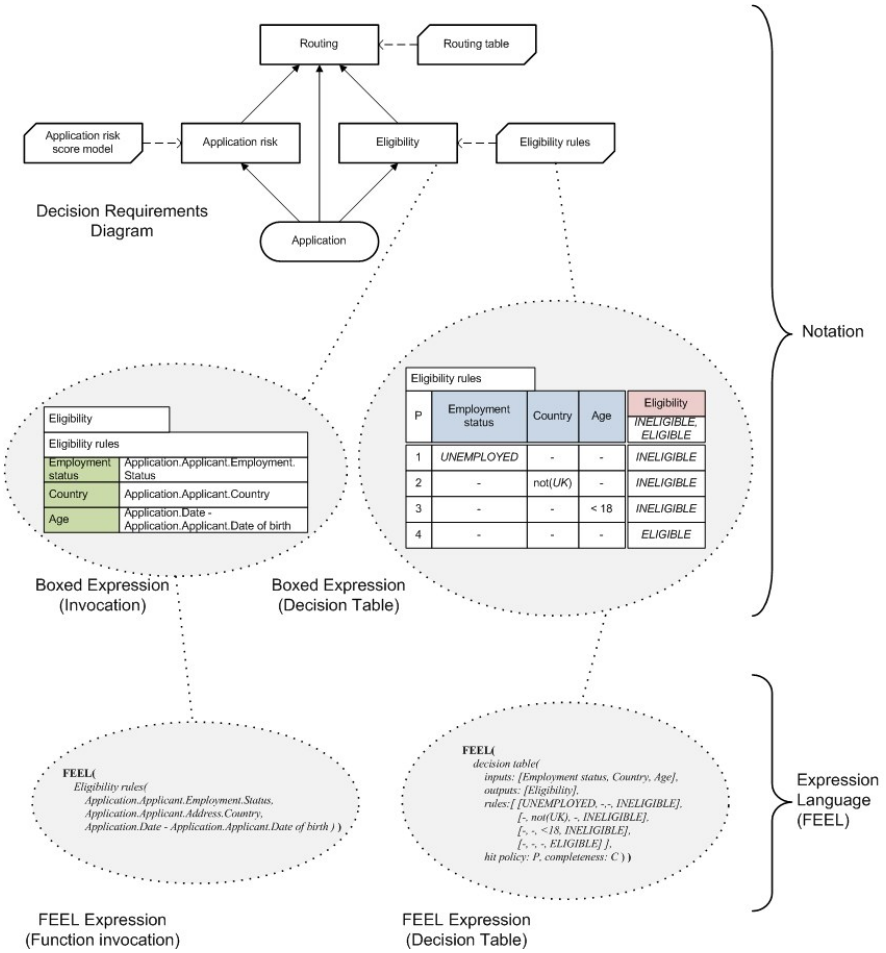
(Ross 2011, p. 152f)

Decision Model and Notation

Beta1

Decision Model and Notation (DMN)

Decision Model and Notation (DMN)



- The Decision Model and Notation is a new standard from the OMG
- It is currently published in its version 1.0
- Purpose of DMN: provide the constructs that are needed to model decision, so that organizational decision-making can be
  - readily depicted in diagrams
  - accurately defined by business analysts
  - (optionaly) automated

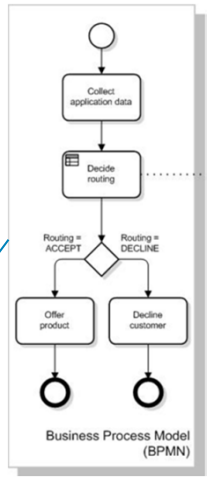
Main Concepts of DMN

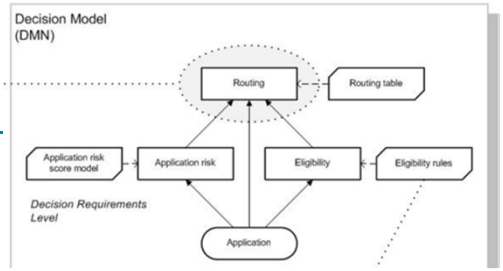
More details

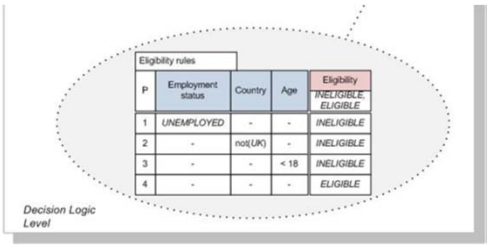
Business Process

Decision Requirements

Decision Logic





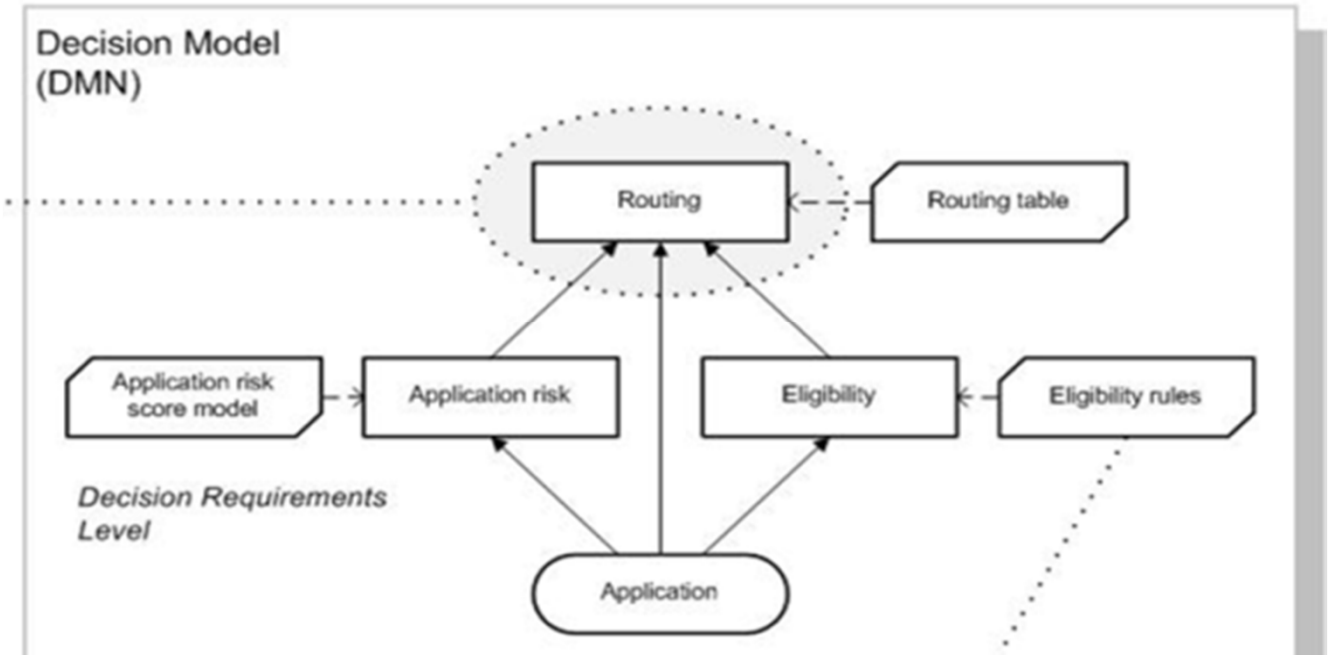


(Coenen 2013)

Main concepts – Decision Requirements Level

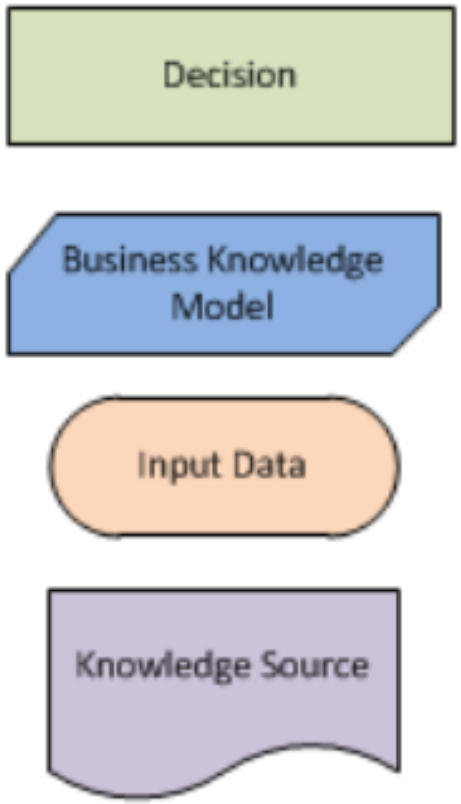
- Business concepts only
- Business decisions
- Areas of business knowledge
- Sources of business knowledge

Decision Requirements



(Coenen 2013)

DRD Elements



The determination of an output from a number of inputs, using decision logic, which may reference one or more Business Knowledge Models

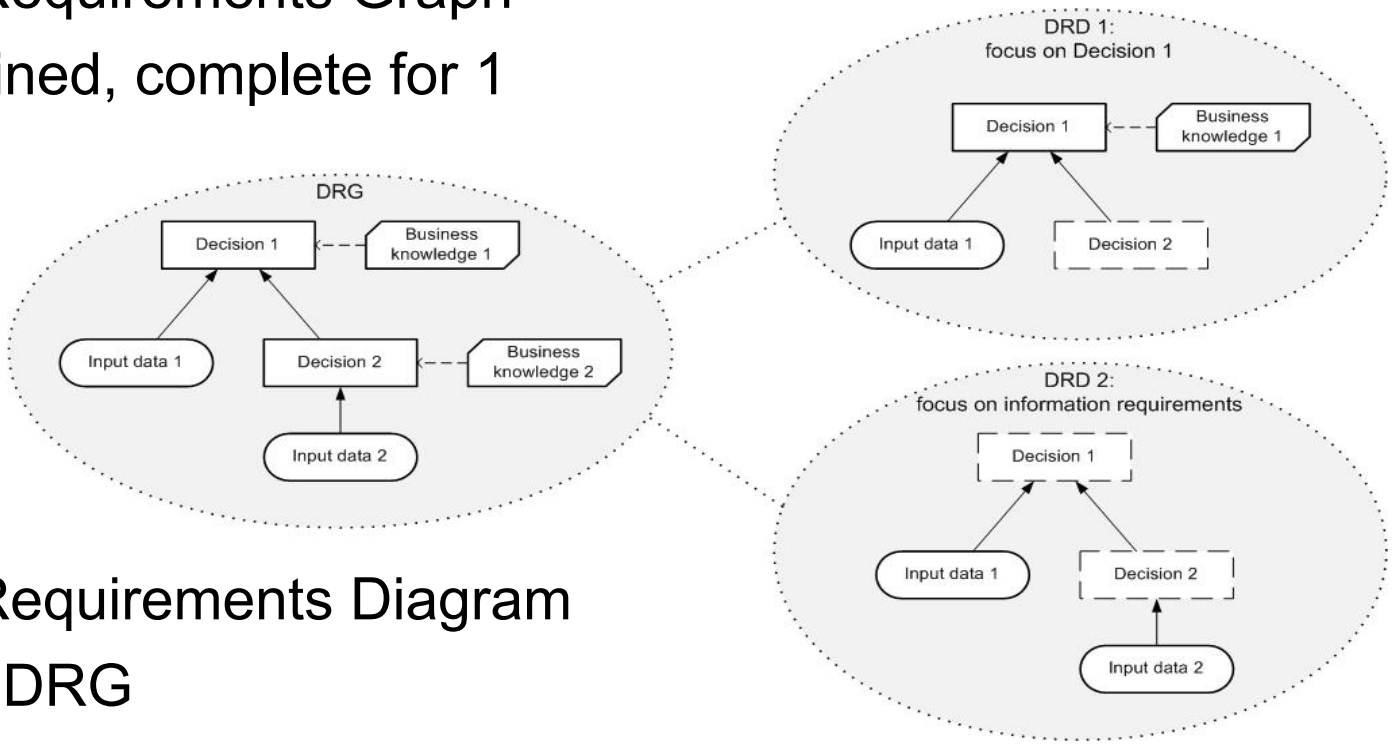
A function encapsulating knowledge, such as a decision table

Information used as an input to one or more decisions. Provides the parameters for a Business Knowledge Model

Has authority for a Business Knowledge Model or Decision

Notation

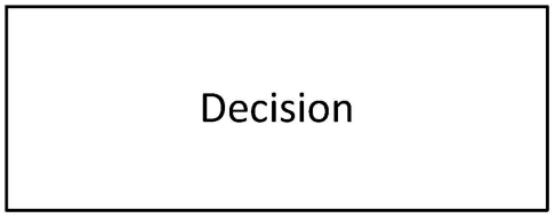
- DRG
  - Decision Requirements Graph
  - Self-contained, complete for 1 Decision



- DRD
  - Decision Requirements Diagram
  - = View on DRG
  - Incomplete, showing specific aspects or perspectives

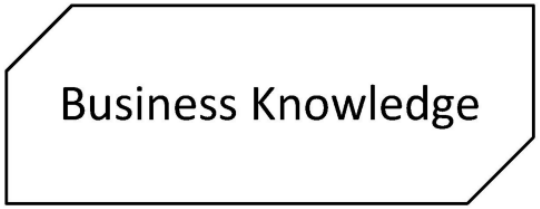
(Coenen 2013)

Decision



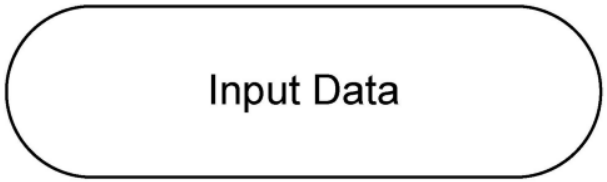
- A decision determines an output from a number of inputs by applying some decision logic. Decisions can be thought of as selecting an answer from a range of possible answers.
- Decisions can be decomposed into sub-decisions. Lower level decisions often will simply provide input to other decisions.
- Two properties should be captured for every decision:
  - Question: A natural language statement that represents the decision in the form of a question. This should be specific and detailed.
  - Allowed Answers: A natural language description of the possible answers to this question.
- For action-oriented decisions, the allowed answers represent the responses that the process must handle when the decision model is invoked by a business rule task.

Business Knowledge Models



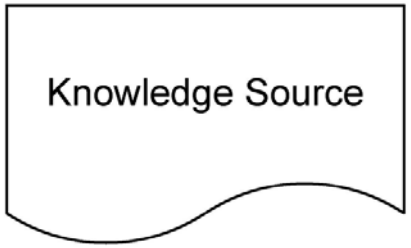
- Business knowledge models represent functions that encapsulate reusable decision making logic. The logic they encapsulate might be a set of business rules, a decision tree, a decision table, or an analytic model.
- The specifics of knowledge representation involved need not be displayed on the diagram but could be.
- The decision logic that can be specified in a business knowledge model can also be linked directly to a decision, but encapsulating it in a business knowledge model allows it to be reused, parameterized and displayed on a Decision Requirements Diagram

Input Data



- Decisions require inputs, and many of these are input data, which is data that is input to the decision making from outside the decision context.
- Input data elements typically represent business entities that are being used in the decision making, such as Policy or Customer. However, sometimes they can represent any information element at any level of detail.
- Each input data element can be described in terms of a hierarchical information model that specifies exactly what information elements comprise the input data.

Knowledge Source



- Knowledge sources represent the source of know-how for making a decision. This could be regulations or policies about how a decision must be made, best practices or expertise on how it should be made, or even analytic knowledge on how it might be made more accurate.
- Knowledge sources are the authorities for a decision and typically refer to some external document or source that contains detailed guidance

DRG/DRD Relationships

= *used as input*

Information Requirement: Shows that Input Data or Decision output is required as an input by another Decision

= *invokes*

Knowledge Requirement: Shows that a Business Knowledge Model is invoked by a Decision or another Business Knowledge Model

= *depends on*

Authority Requirements: Shows the dependency of a DRD Element on a Knowledge Source

Elements and Allowed Relationships of the Requirements Graph

Decision 1 is **used as input** for decision 2

Decision **depends on** Knowledge Source

Business Knowledge **invokes** a Decision

Business Knowledge 1 **invokes** Business Knowledge 2

Input data is **used as input** for decision

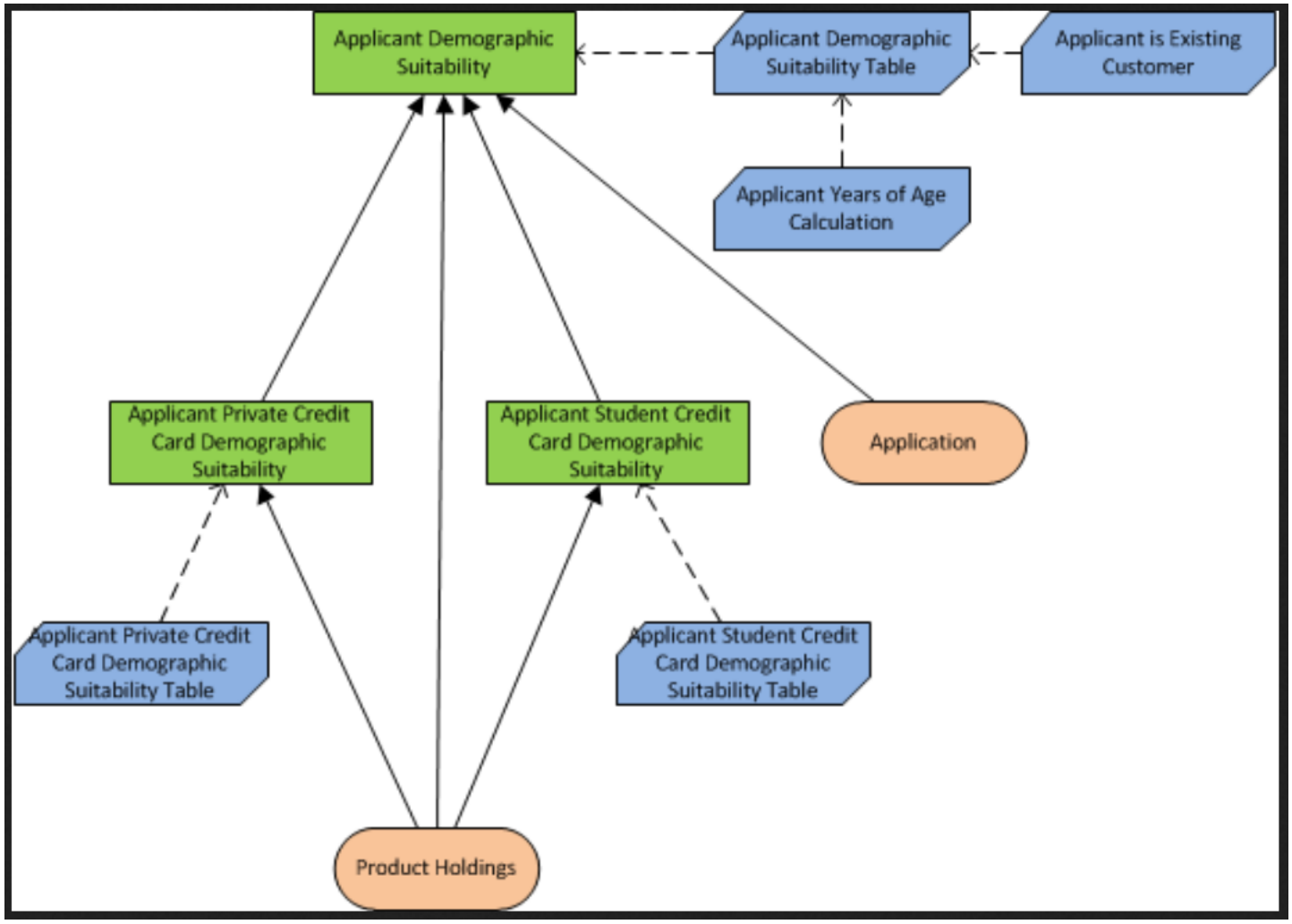
Input data **depends on** Knowledge Source

Knowledge Source **depends on** Decision

Knowledge Source **depends on** Business Knowledge

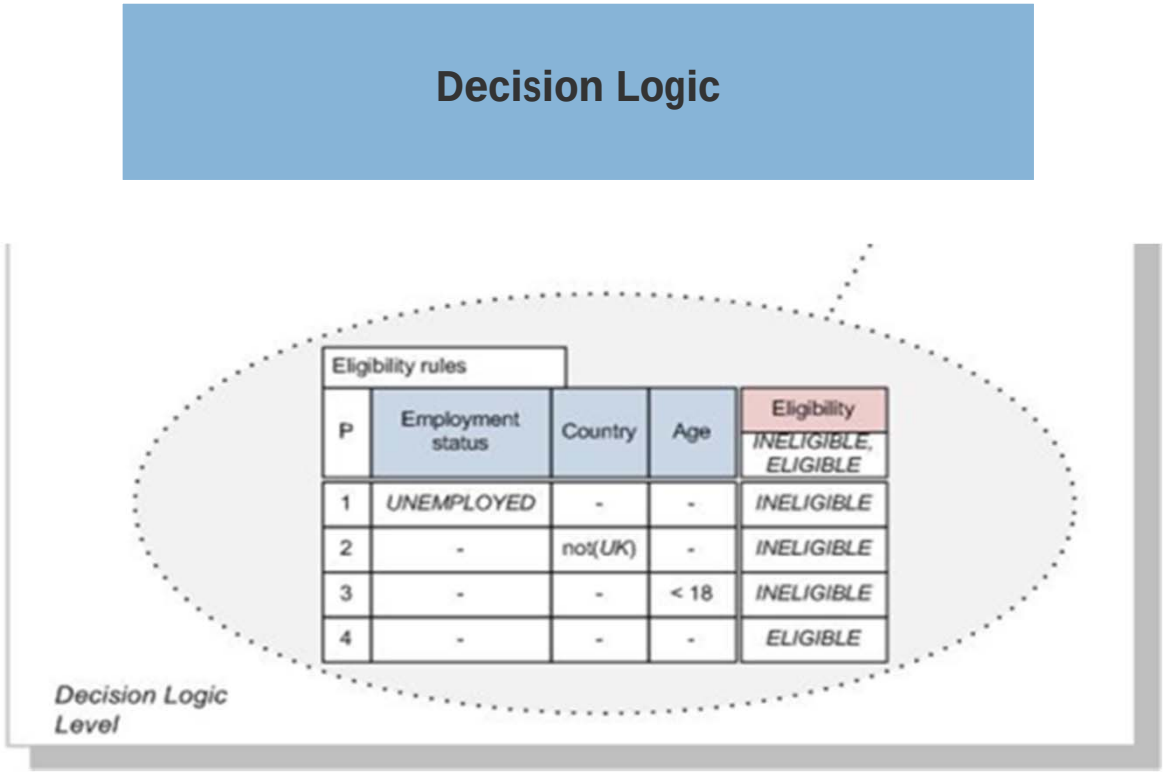
Knowledge Source1 **depends on** Knowledge Source2

(Coenen 2013)


Applicant Demographic Suitability
Applicant Demographic Suitability Table
Applicant is Existing Customer
Applicant Years of Age Calculation
Applicant Private Credit Card Demographic Suitability
Applicant Student Credit Card Demographic Suitability
Application
Applicant Private Credit Card Demographic Suitability Table
Applicant Student Credit Card Demographic Suitability Table
Product Holdings

Main concepts – Decision Logic

- Greater detail
- Business rules
- Calculations
- Automated
- Display



(Coenen 2013)

Decision Table in DMN 1.0 - styles

Rule = row

table name			
HC	input expression 1	input expression 2	Output name
	value 1a, value 1b	*value 2a, value 2b*	*value 1a, value 1b*
1	input entry 1a	input entry 2a	output entry 1a
2		input entry 2b	output entry 1b
3	input entry 1b	-	output entry 1a

Rule = column

table name				
input expression 1	*value 1a, value 1b*	input entry 1a		input entry 1b
input expression 2	*value 2a, value 2b*	input entry 2a	input entry 2b	-
Output name	*value 1a, value 1b*	output entry 1a	output entry 1b	output entry 1a
HC		1	2	3

Rule = crosstab

table name			
Output name		input expression 1	
		input entry 1a	input entry 1b
input expression 2	input entry 2a	output entry 1a	output entry 1a
	input entry 2b	output entry 1b	output entry 1a

(Coenen 2013)

A Decision with an invoked Business Knowledge Model in the form of a Decision Table

The decision itself

The Business Knowledge Model that the decision 'invokes', in this case, a decision table (see below)

The structure represents a 'Boxed Invocation' (a type of 'Boxed Expression')

Applicant Demographic Suitability		
Applicant Demographic Suitability Table		
Applicant Years of Age	Applicant Years of Age Calculation	
	Applicant Date of Birth	Application.Date of Birth
Application Card Type	Application.Card Type	
Applicant is Existing Customer	Applicant is Existing Customer Rules	
	Existing Customer Products Held with Lender	Product Holdings.Number of Products Held
Applicant Private Credit Card Demographic Suitability	Applicant Private Credit Card Demographic Suitability	
Applicant Student Credit Card Demographic Suitability	Applicant Private Credit Card Demographic Suitability	

Invokes another two Business Knowledge Models called 'Applicant Years of Caluclation' and 'Applicant is Existing Customer Rules' that will return the required outcome into this model

For the invoked Business Knowledge Models 'Applicant is Existing Customer Rules', this defined the input data that represents the logical input expression 'Existing Customer Products Held with Lender'.

This is a 'Single Hit' decision table with Hit Policy 'First' (the 'F'), meaning that the output returned will be the first rule hit. These can be hard to validate manually because it is so

A decision table is also a type of 'Boxed Expression'

The 'C' following 'F' says that the table is incomplete, that is, all rules have been included in order to reach an outcome

Applicant Demographic Suitability Table

FC	Applicant Years of Age	Application Card Type	Applicant is Existing Customer	Applicant Demographic Suitability
		Student, Private, Balance Transfer	*TRUE, FALSE*	*Suitable, Unsuitable*
1	< 18	-	-	"Unsuitable"
2	-	"Student", "Private"	FALSE	"Unsuitable"
3	-	"Private"	TRUE	Applicant Private Credit Card Demographic Suitability
4	-	"Student"	TRUE	Applicant Student Credit Card Demographic Suitability
5	-	-	-	"Suitable"

An optional section used to show the valid domain values where appropriate

Shows that the output value is actually the result of other decisions.

A dash means that the input value is irrelevant to this particular rule.

(Broom 2014))

The structure represents a 'Boxed Context' (another type of 'Boxed Expression')

Applicant Years of Age Calculation	
Applicant Years of Age	is calculated as (today's date - Applicant Date of Birth)/365.25) rounded down to the nearest integer
Applicant Years of Age	

A natural language expression that defines ow the Years of Age is calculated.

The valute returned by the expression. This will then be used as the input expresion in the 'Applicant Demographic Suitability' Decision Table.

Applicant is Existing Customer Rules	
Applicant is Existing Customer	if Product Holdings.Number of Products Held > 0 then TRUE else FALSE
Applicant is Existing Customer	

(Broom 2014))

These are both 'Single Hit' decision tables, the first with Hit Policy 'Any'. This means that any rule can be hit during the decision, but in the event that multiple rules are hit, they will only return the same conclusion. So if the Customer has both £150 in annual income and £350k in outstanding mortgage borrowings, both rules 1 and 2 will be hit, but will only return "Suitable". The second is 'Unique', meaning no overlap is possible and rules are exclusive.

The outputs of these two tabeles are required as input expressions, in the 'Applicant Demographic Suitability' Decision Table.

Applicant Private Credit Card Demographic Suitability Table				
AC	Existing Customer Sole Annual Income Amount	Existing Customer Outstanding Mortgage Borrowings Amount	Existing Customer Savings and Investments Balance Amount	Applicant Private Credit Card Demographic Suitability
				Suitable, Unsuitable
1	>= 100k	-	-	"Suitable"
2	-	>= 300k	-	"Suitable"
3	-	-	>= 100k	"Suitable"
4	< 100k	< 300k	< 100k	"Unsuitable"

Applicant Student Credit Card Demographic Suitability Table		
UC	Existing Customer Current Account Type	Applicant Student Credit Card Demographic Suitability
	Student, Standard, Silver, Platinum, Black	*Suitable, Unsuitable*
1	"Student"	"Suitable"
2	Not "Student"	"Unsuitable"

(Broom 2014))

Applicant Credit Score	
Applicant Number of Default Payments in Last 12 Months	Applicant Credit File.Year Total Defaults
Applicant has declared Bankruptcy	Applicant Credit File.Bankrupt Indictor
Applicant Amount of Available Credit Used Percentage	Applicant Credit File.Credit Used Percentage
Applicant Years with Current Account Bank	Applicant Credit File.Time with Bank

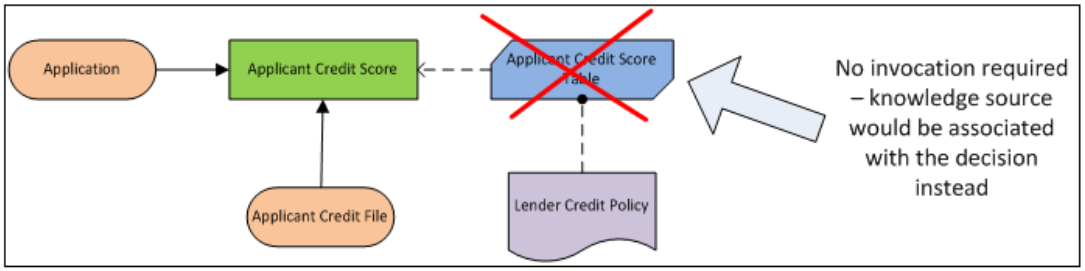
An alternative representation of the Application Credit Score decision.

Rather than having the Decision invoke a Business Knowledge Mode, it is possible for all fo the logic to be carried out within the Decision itself.

The impact on the DRD is shown below the expression.

NC	Applicant Number of Default Payments in Last 12 Months	Applicant has declared Bankruptcy	Applicant Years with Current Account Bank	Applicant Amount of Available Credit Used Percentage	Applicant Credit Score
		TRUE, FALSE			*[0..999]*
1	[1..3]	-	-	-	100
2	[4..6]	-	-	-	50
3	>6	-	-	-	0
4	0	-	-	-	250
5	-	TRUE	-	-	0
6	-	FALSE	-	-	250
7	-	-	<1	-	50
8	-	-	[1..3]	-	150
9	-	-	>3	-	250
10	-	-	-	[0..24]	200
11	-	-	-	[25..49]	249
12	-	-	-	[50..74]	150
13	-	-	-	[75..100]	100
14	-	-	-	>100	0
Aggregation = sum					

How the DRD would be affected



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Languages for Value Expressions

Possible value expression forms:

- **Decision table**

Applicant Risk Rating					
Applicant Age	< 25		[25..60]	> 60	
Medical History	good	bad	-	good	bad
Low	X	-	-	-	-
Medium		X	X	X	
High					X
U	1	2	3	4	5

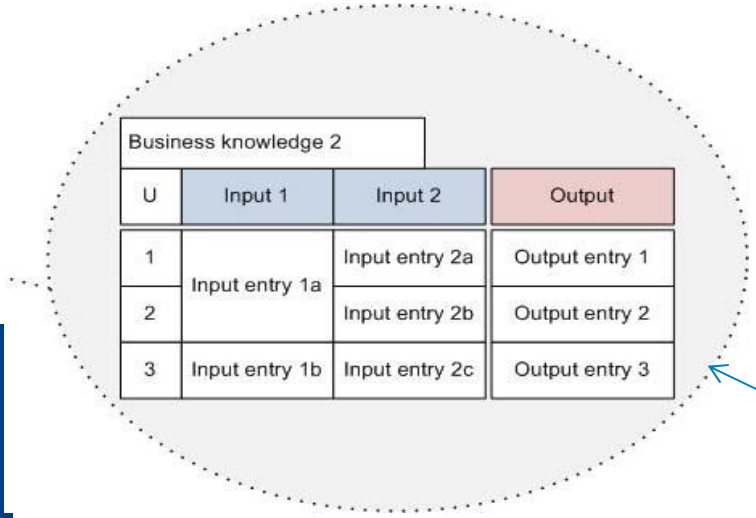
- **Literal expression**

FEEL = Friendly Enough Expression Language

```
{
  Context: {
    tns$Employee: { tns$salary: 13,000 },
    Customer: [
      { loyalty_level: "gold", credit_limit: 10000 },
      { loyalty_level: "gold", credit_limit: 20000 },
      { loyalty_level: "silver", credit_limit: 5000 } ]
  }
}
```

(Coenen 2013)

Other decision logic models can be used, too



It is obligatory that each driver *of* a rental *is qualified*.

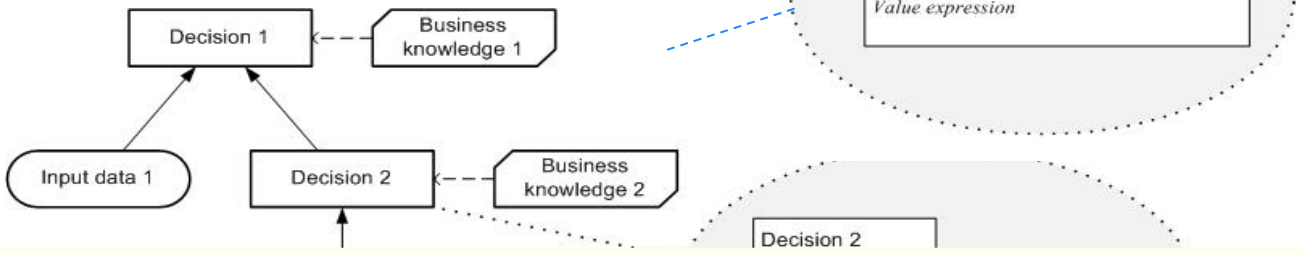
rental *has* driver

driver *is qualified*

The noun concept 'driver' *is* a facet *of* the noun concept 'person.'

SBVR

Supported by DMN

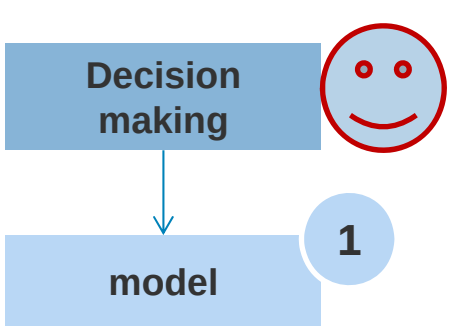


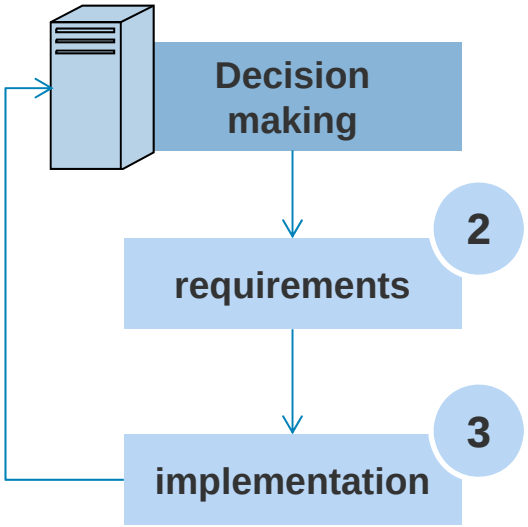
"This will allow the import of many existing decision logic modeling standards (e.g. for business rules and analytic models) into DMN"

(Coenen 2013)

Use of DMN

1. Modeling **human** decision-making
2. Modeling requirements for **automated** decision-making
3. Implementing **automated** decision-making





(Coenen 2013)

Decision Tables – Reducing Combinations

- If effects for several combinations are the same, the combinations can be combined, reducing the number of rules
- Example:
  - If Cause 1 is „Y“ and Cause 2 is „N“, then the effect does not depend on the values of Cause 3
  - In this case, the value of Cause 3 does not need to be taken into account

		Combinations							
Causes	**Values**	1	2	3	4	5	6	7	8
Cause 1	*Y, N*	Y	Y	Y	Y	N	N	N	N
Cause 2	*Y, N*	Y	Y	N	N	Y	Y	N	N
Cause 3	*Y, N*	Y	N	Y	N	Y	N	Y	N
Effects									
Effect 1		X		X	X	X		X	X
Effect 2			X			X	X		X

		Combinations						
Causes	**Values**	1	2	3	4	5	6	7
Cause 1	*Y, N*	Y	Y	Y	N	N	N	N
Cause 2	*Y, N*	Y	Y	N	Y	Y	N	N
Cause 3	*Y, N*	Y	N	-	Y	N	Y	N
Effects								
Effect 1		X		X	X		X	X
Effect 2			X		X	X		X

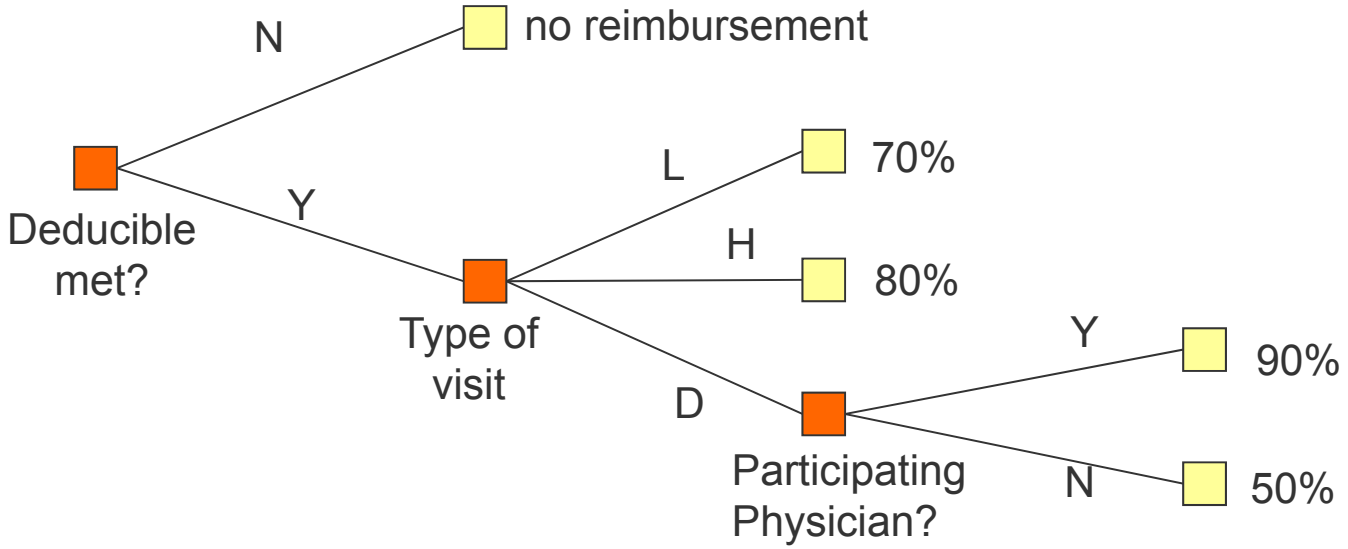
Exercise: Reduce decision table

- The following decision table represents rules for reimbursing expenses by health insurance
- Reimbursement depends on three conditions:
  - whether decuctible is already met,
  - whether the patient visited the doctor‘s office (D), a hospital (H) or a lab (L) and
  - whether – in case of a visit at the doctor’s office – the doctor is a Participating Physician
- The decision table is complete showing all combinations of decisions. Reduce the table to only the really needed number of rules

Conditions	1	2	3	4	5	6	7	8	9	10	11	12
1. Deductible met?	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N
2. Type of visit	D	D	H	H	L	L	D	D	H	H	L	L
3. Participating Physician?	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Effects												
1. Reimburse 50%		X										
2. Reimburse 70%						X						
3. Reimburse 80%				X								
4. Reimburse 90%	X											
5. No reimbursement							X	X		X		X
6. Impossible or N/A			X		X				X		X	

Decision Trees

- Decision trees are a graphical representation of rules
  - Each inner node corresponds to a decision
  - Each edge represents an alternative value for the decision
  - The leaf nodes represent actions or effects



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