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Application of Belief Rule-Based Methodology to Map Consumer Preferences and Set Product Targets

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THE QUEEN'S AWARDS FOR ENTERPRISE: INTERNATIONAL TRADE 2005

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Background

- Funded jointly by DEFRA, Natural Science Foundation of China and industry
- Led by Professor Jian-Bo Yang (MBS)
- Feasibility study carried out from January 2006 to December 2006

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Overview of Presentation

- Quality Model
- Existing methods
- Introduction to Belief Rule-based (BRB) methodology
- Case study
- Conclusion

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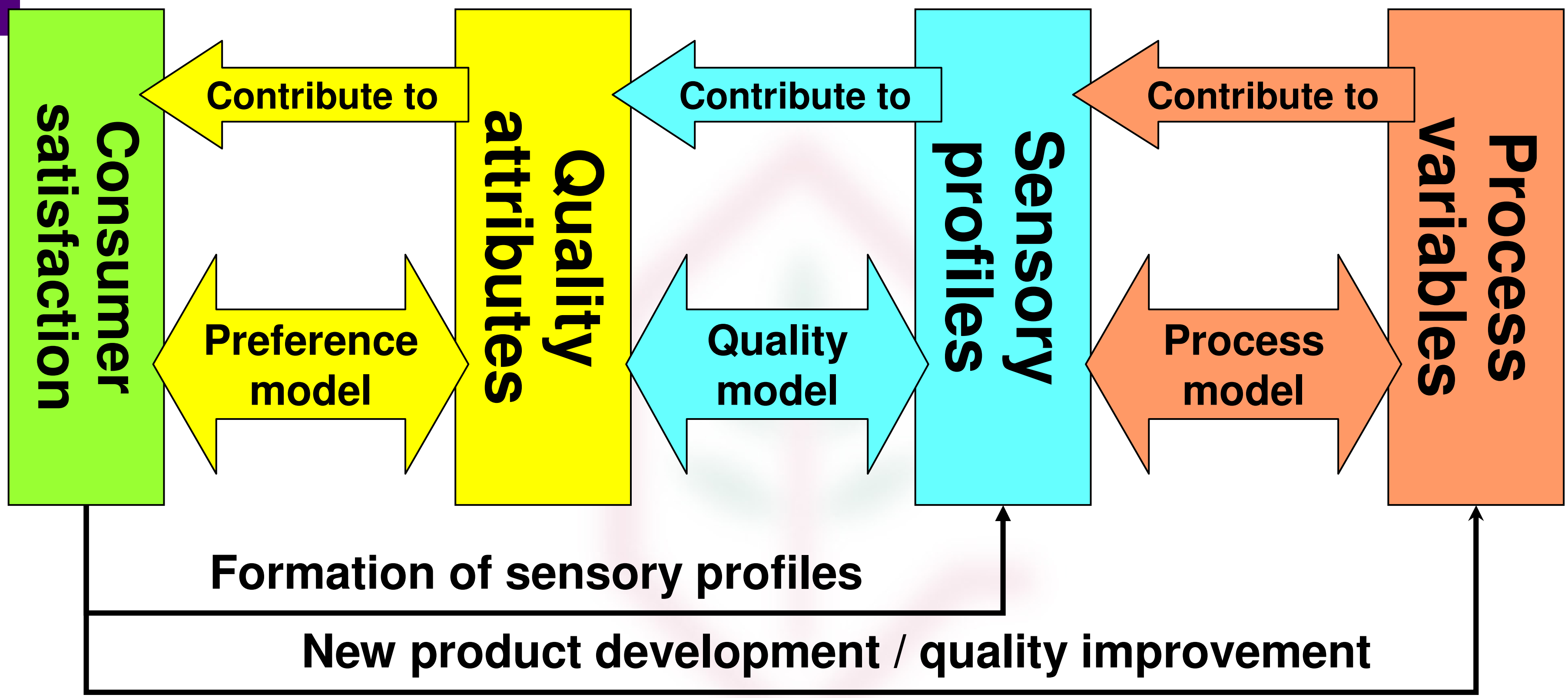
Quality Model for Food and Drink



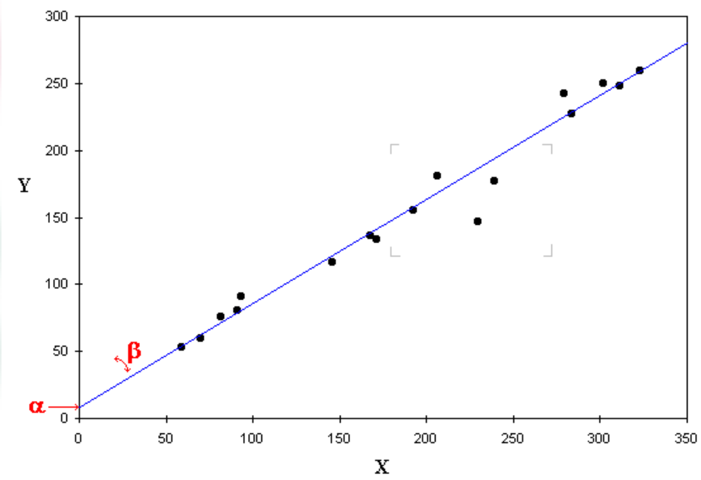
Existing Methods

- Multiple Linear Regression (MLR)
- External Preference Mapping
- Artificial Neural Networks
- Support Vector Machines

Multiple Linear Regression

$$y = a + b_1 x_1 + b_2 x_2 + \ldots + b_k x_k$$

- Probably simplest…
- … but not adequate
- Relationships complex and non-linear
- Attribute set > product set



External Preference Mapping

- Vector:

$$y = a + b_1 x_1 + b_2 x_2 + \varepsilon$$

- Circular:

$$y = a + b_1 x_1 + b_2 x_2 + c(x_1^2 + x_2^2) + \varepsilon$$

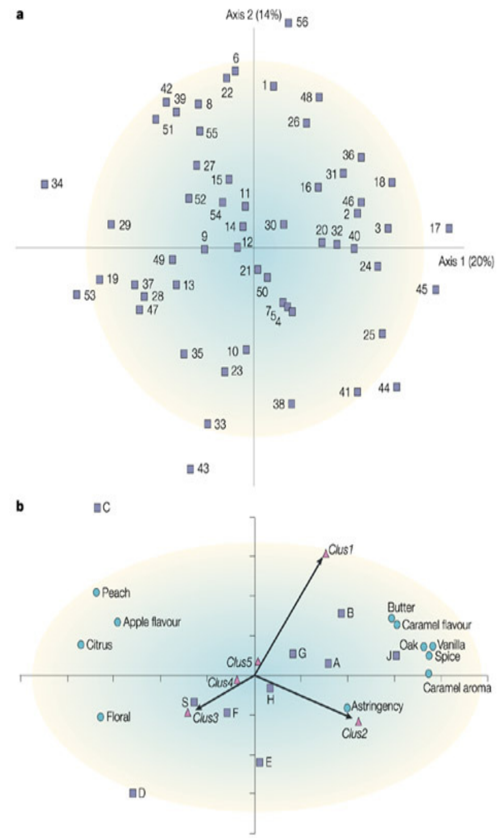
- Elliptical:

$$y = a + b_1 x_1 + b_2 x_2 + c_1 x_1^2 + c_2 x_2^2 + \varepsilon$$

- Quadratic:

$$y = a + b_1 x_1 + b_2 x_2 + c_1 x_1^2 + c_2 x_2^2 + d x_1 x_2 + \varepsilon$$

Most extensively used…?
Models preferences as function of PCs



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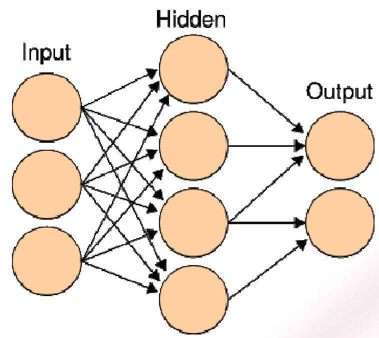
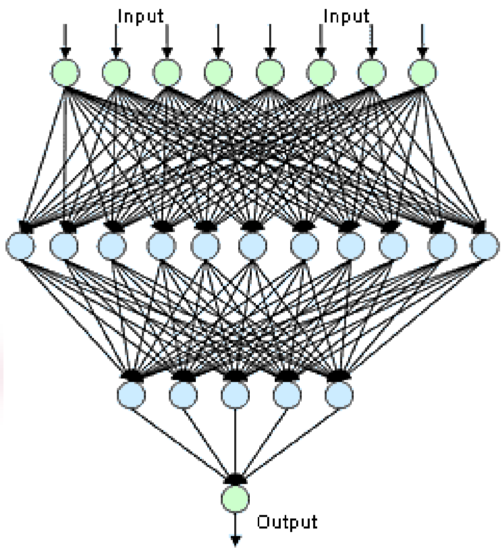
Artifical Neural Networks



- Models preferences as functions of attributes
- Multilayer network
- Attributes as inputs; preferences as output
- 3-layer networks most commonly used
- Black box simulator!!!



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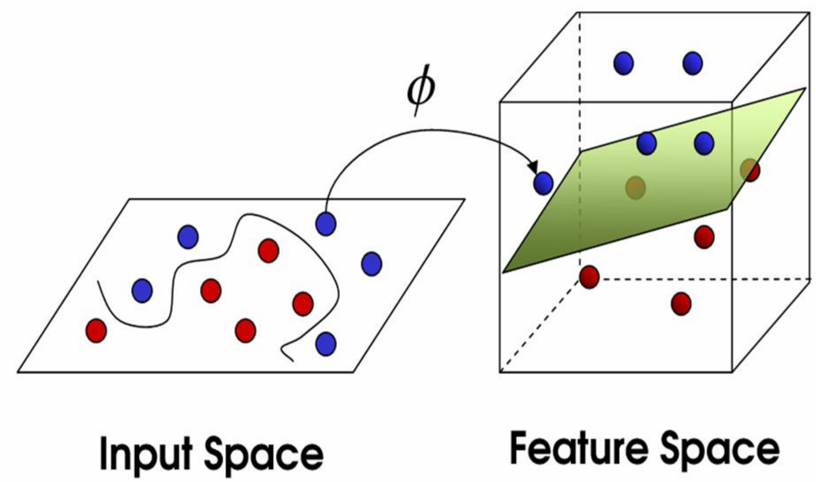
Support Vector Machines

- Machine learning algorithm
- Classification and regression
- Requires specifying relationships in advance

Principle of Support Vector Machines (SVM)



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Belief Rule-Based System

Belief Rule-Based System (BRB)

- Causality characterised by BRB…
- … generalisation of IF-THEN rules
- Example Belief Rule:

IF (Taste is HIGH) and
(Aroma is HIGH)
THEN Quality is
(Good, 50%)
(Average, 40%) and
(Poor, 10%)

Attributes

Outcomes

Belief Degrees

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General Belief Rule

$$R_k: \text{ If } \mathrm{A}_1^{\mathrm{k}} \text{ and } \mathrm{A}_2^{\mathrm{k}} \text{ and} \ldots \text{and } \mathrm{A}_{\mathrm{T}}^{\mathrm{k}}$$

$$\text{THEN } (\mathrm{D}_1, \beta_{1k}), (D_2, \beta_{2k}), \ldots, (D_N, \beta_{Nk})$$

$k \in \{1, \ldots, L\}$

$$\sum_{i=1}^{N} \beta_{i,k} \leq 1.$$

With a rule weight θ_k and attribute weights δ_{1k}, δ_{2k},…, δ_{Nk},

Matrix Expression of Belief Rules

Belief Output	Input					
	$A^1\ (w_1)$	$A^2\ (w_2)$	…	$A^k\ (w_k)$	…	$A^L\ (w_L)$
D_1	$\beta_{1,1}$	$\beta_{1,2}$	…	$\beta_{1,k}$	…	$\beta_{1,L}$
D_2	$\beta_{2,1}$	$\beta_{2,2}$		$\beta_{2,k}$		$\beta_{2,L}$
			…		…	
D_i	$\beta_{i,1}$	$\beta_{i,2}$	…	$\beta_{i,k}$	…	$\beta_{i,L}$
			…		…	
D_N	$\beta_{N,1}$	$\beta_{N,2}$	…	$\beta_{N,k}$	…	$\beta_{N,L}$

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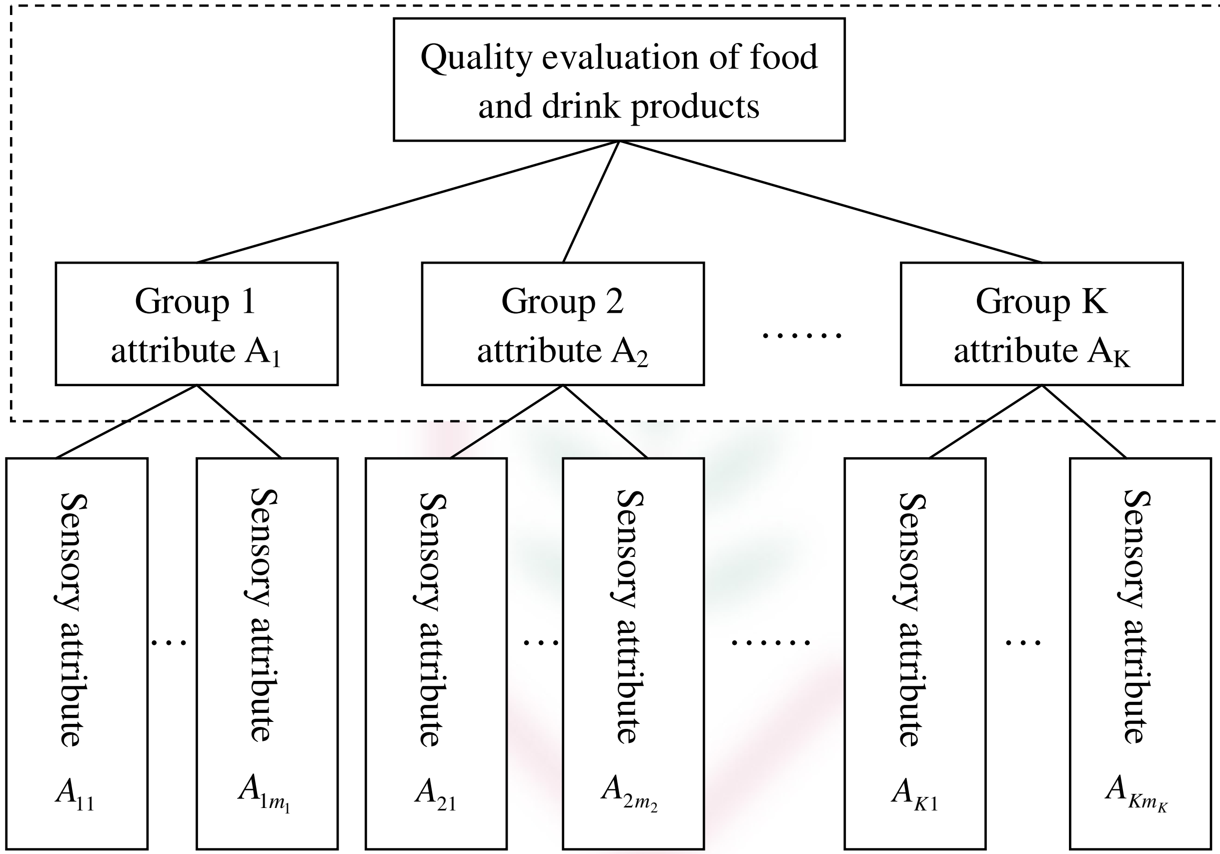
Preference Mapping by BRB



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BRBs for Preferences & Group Attributes

Rule	Rule weight	Antecedent attributes (weight)				Consequence			
		$A_1(\delta_1)$	$A_2(\delta_2)$	...	$A_K(\delta_K)$	C_1	C_2	...	C_N
1	θ_1	A_1^1	A_2^1	...	A_K^1	β_{11}	β_{12}	...	β_{1N}
2	θ_2	A_1^2	A_2^2	...	A_K^2	β_{21}	β_{22}	...	β_{2N}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	...	$\vdots$	$\vdots$	$\vdots$	...	$\vdots$
M	θ_M	A_1^M	A_2^M	...	A_K^M	β_{M1}	β_{M2}	...	β_{MN}

Rule	Rule weight	Antecedent attributes (weight)				Consequence (A_h)			
		$A_{h1}(\delta_{h1})$	$A_{h2}(\delta_{h2})$	...	$A_{hm_h}(\delta_{hm_h})$	C_{h1}	C_{h2}	...	C_{hT_h}
1	θ_{h1}	A_{h1}^1	A_{h2}^1	...	$A_{hm_h}^1$	$\beta_{11}^{(h)}$	$\beta_{12}^{(h)}$	...	$\beta_{1T_h}^{(h)}$
2	θ_{h2}	A_{h1}^2	A_{h2}^2	...	$A_{hm_h}^2$	$\beta_{21}^{(h)}$	$\beta_{22}^{(h)}$	...	$\beta_{2T_h}^{(h)}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	...	$\vdots$	$\vdots$	$\vdots$	...	$\vdots$
M_h	θ_{hM_h}	$A_{h1}^{M_h}$	$A_{h2}^{M_j}$	...	$A_{hm_h}^{M_h}$	$\beta_{M_h1}^{(h)}$	$\beta_{M_h2}^{(h)}$	...	$\beta_{M_hT_h}^{(h)}$

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Training

Product	Consumer preference					Output of BRB model				
	C_1	C_2	…	C_N	Average score	C_1	C_2	…	C_N	Expected value
1	b_{11}	b_{12}	…	b_{1N}	y_1	α_1^1	α_2^1	…	α_N^1	O_1
2	b_{21}	b_{22}	…	b_{2N}	y_2	α_1^2	α_2^2	…	α_N^2	O_2
$\vdots$	$\vdots$	$\vdots$	…	$\vdots$	$\vdots$	$\vdots$	$\vdots$	…	$\vdots$	$\vdots$
n	b_{n1}	b_{n2}	…	b_{nN}	y_n	α_1^n	α_2^n	…	α_N^n	O_n

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In summary

- Each rule has a set of attributes (input) and a set of outcomes (output)
- Each attribute has an importance (weight)
- Each outcome has a probability (belief)
- Belief-rules are formed from training data (inputs and outputs)
- Rules aggregated into groups

Case Study - Lemonade

- 28 products profiled and rated
- 12 attributes assessed
- 1 hedonic rating (9-point)

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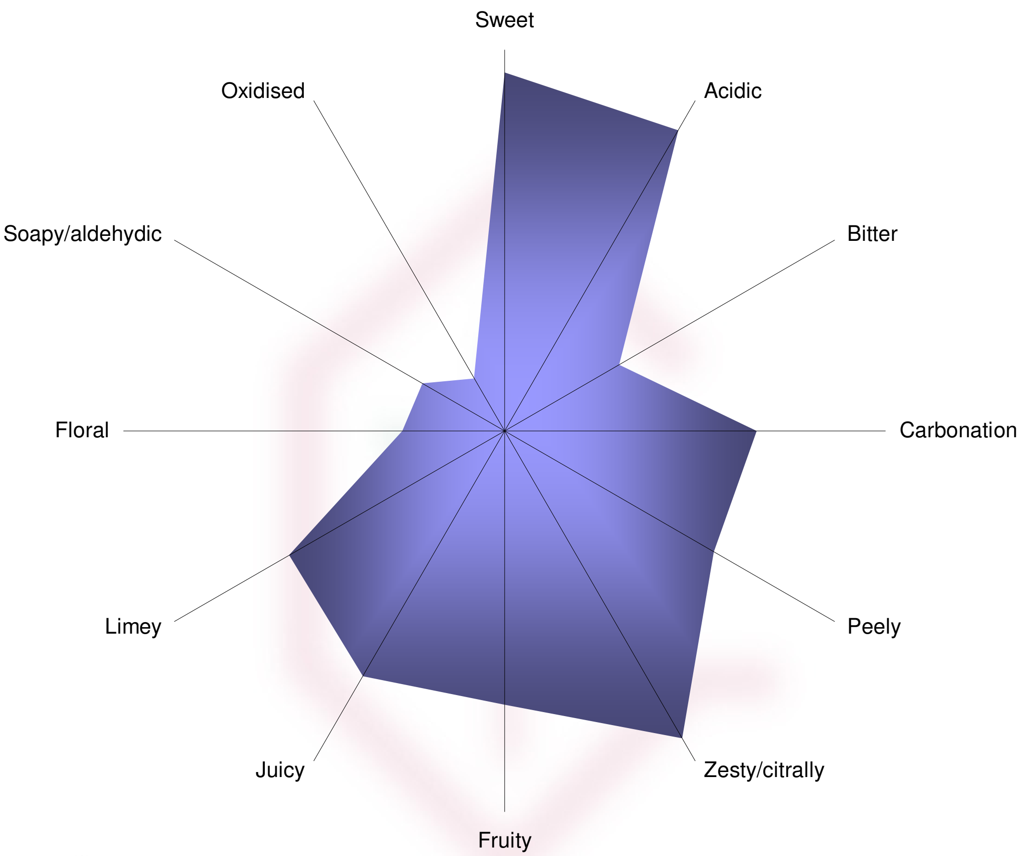
Profiles



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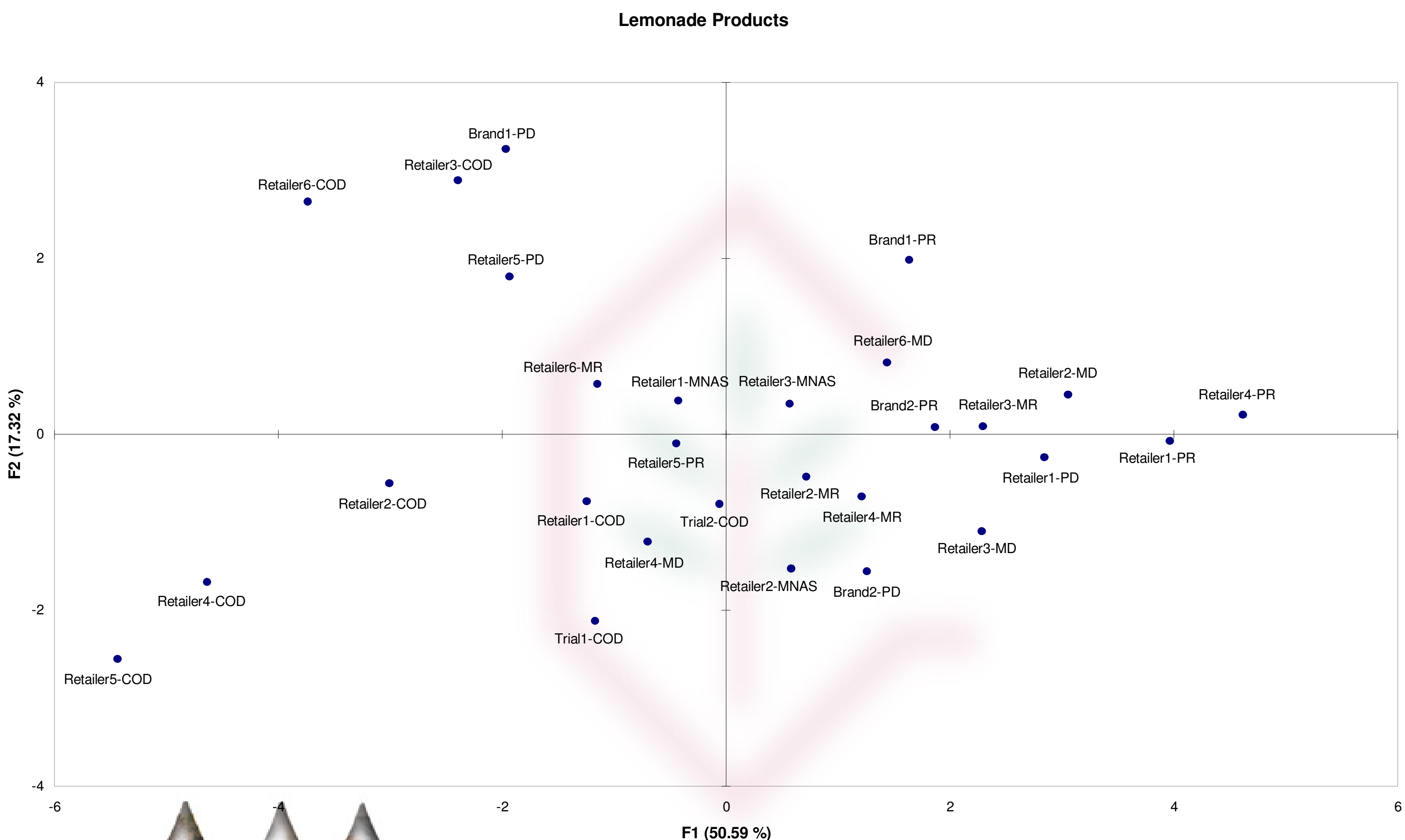
PCA



Lemonade Products
Brand1-PD
Retailer3-COD
Retailer6-COD
Retailer5-PD
Brand1-PR
Retailer6-MD
Retailer6-MR
Retailer1-MNAS
Retailer3-MNAS
Retailer2-MD
Retailer4-PR
Brand2-PR
Retailer3-MR
Retailer5-PR
Retailer1-PR
Retailer1-PD
Retailer2-MR
Retailer2-COD
Retailer1-COD
Trial2-COD
Retailer4-MR
Retailer3-MD
Retailer4-MD
Retailer2-MNAS
Brand2-PD
Retailer4-COD
Trial1-COD
Retailer5-COD
F2 (17.32 %)
F1 (50.59 %)
4
2
0
-2
-4
-6
-4
-2
0
2
4
6

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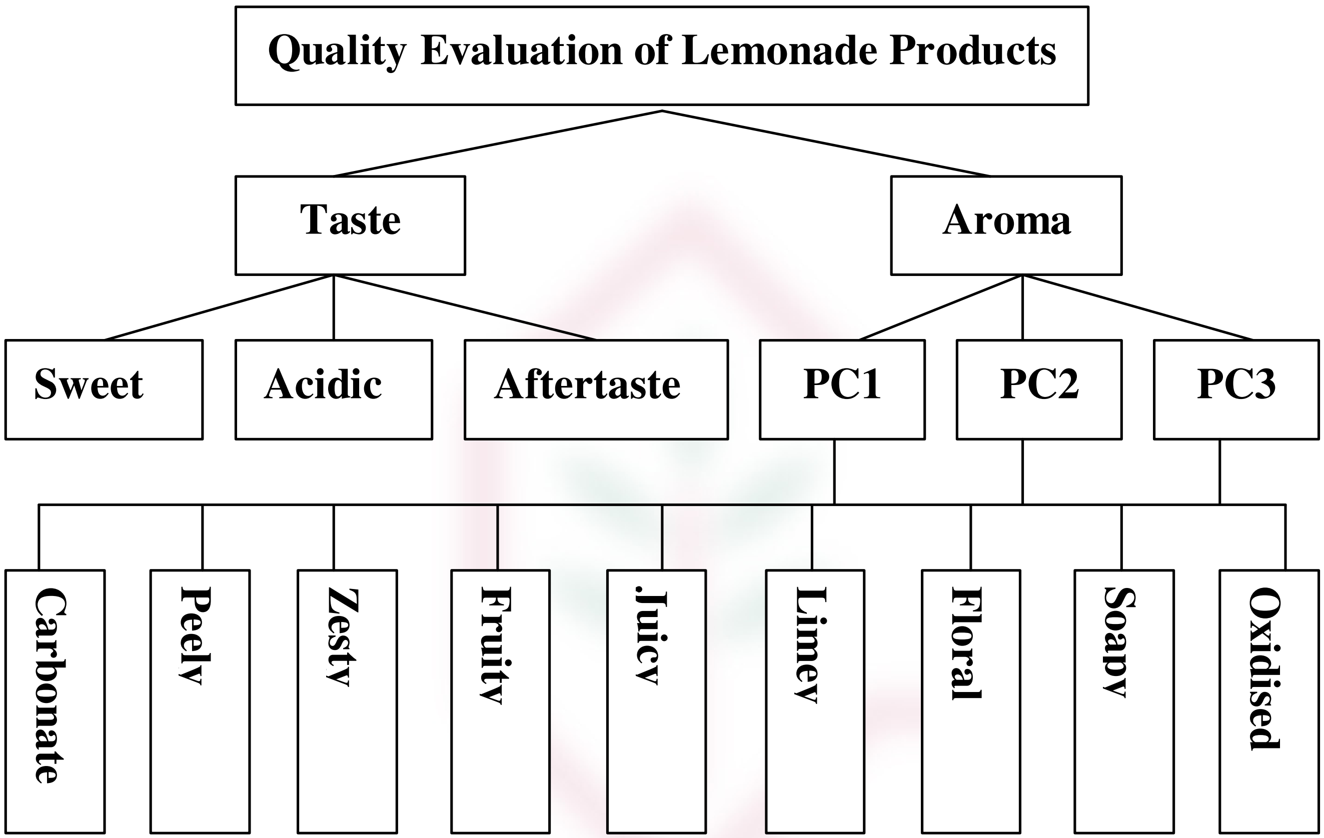
BRB Model



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PCs for 9 Attributes

Item	Principal components		
	PC1	PC2	PC3
Eigenvalue	4.725	1.994	0.740
% variance	52.502	22.161	8.226
Cumulative %	52.502	74.663	82.889
Eigenvector			
Carbonation	0.349	-0.017	0.202
Peely	0.338	0.297	0.463
Zesty/citrally	0.411	0.164	0.083
Fruity	0.421	0.044	-0.010
Juicy	0.435	0.059	-0.115
Limey	0.301	0.360	-0.474
Floral	-0.161	0.520	-0.543
Soapy/aldehydic	-0.232	0.519	0.309
Oxidised	-0.241	0.459	0.332

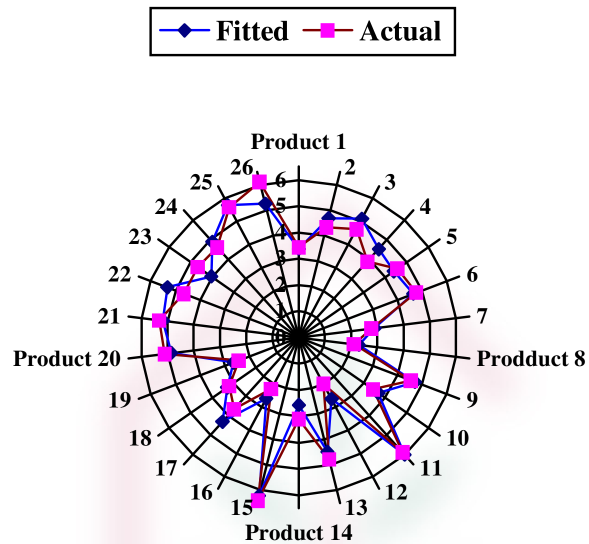
Assessment Grades

Grade	Sweet	Acidic	Aftertaste	PC1	PC2	PC3
High	74.70	65.33	37.95	4.99	5.059	4.752
Medium	46.46	47.46	21.96	0	0	0
Low	18.21	29.59	6.02	-6.25	-4.428	-5.199

BRB for Overall Quality

Rule	Rule weight	Group attributes: Taste (0.5)	Group attributes: Aroma (0.5)	Consumer preferences: 0	1	2	3	4	5	6	7	8	9
1	0.101	Low	Low	0.103	0.005	0.007	0.002	0.107	0.043	0.005	0.254	0.365	0.107
2	0.731	Low	Medium	0.111	0.005	0.005	0.060	0.007	0.782	0.026	0.001	0.003	0.000
3	0.023	Low	High	0.000	0.095	0.132	0.240	0.458	0.013	0.050	0.003	0.004	0.005
4	0.635	Medium	Low	0.171	0.008	0.007	0.033	0.039	0.003	0.614	0.124	0.001	0.002
5	0.318	Medium	Medium	0.009	0.423	0.007	0.529	0.000	0.007	0.009	0.005	0.005	0.005
6	0.546	Medium	High	0.008	0.018	0.000	0.013	0.891	0.000	0.042	0.010	0.007	0.011
7	0.079	High	Low	0.000	0.006	0.027	0.045	0.002	0.913	0.000	0.003	0.001	0.003
8	0.142	High	Medium	0.752	0.153	0.041	0.047	0.002	0.002	0.004	0.000	0.000	0.000
9	1.000	High	High	0.164	0.166	0.600	0.000	0.000	0.000	0.015	0.055	0.000	0.000

Fitted Predictions



Method	Actual mean score	Predicted mean score	Accuracy
BRB methodology	3.11	3.23	96.32%
ANN (12-10-1)	3.11	3.19	97.46%
Multiple linear regression	3.11	2.62	84.09%

Target Values

Sensory attribute	Minimum	Maximum	Target values			
			Solution 1	Solution 2	Solution 3	Solution 4
Sweet	18.21	74.7	21.11	21.90	29.85	18.21
Acidic	29.59	65.33	46.44	46.45	46.45	45.40
Aftertaste	6.02	37.95	6.02	6.02	6.02	6.02
Carbonation	24.90	50.87	43.03	50.49	50.22	50.14
Peely	13.52	44.31	41.33	44.22	31.97	27.88
Zesty/citrally	11.30	65.19	47.52	49.44	50.33	55.56
Fruity	10.69	50.74	20.07	14.53	47.86	27.89
Juicy	4.99	51.94	45.97	22.37	14.75	21.94
Limey	7.23	45.63	24.31	45.51	18.23	40.39
Floral	3.27	43.57	24.76	16.33	31.19	11.72
Soapy/aldehydic	9.29	49.8	24.92	15.07	24.15	37.02
Oxidised	10.67	47.29	10.87	15.17	18.44	13.54

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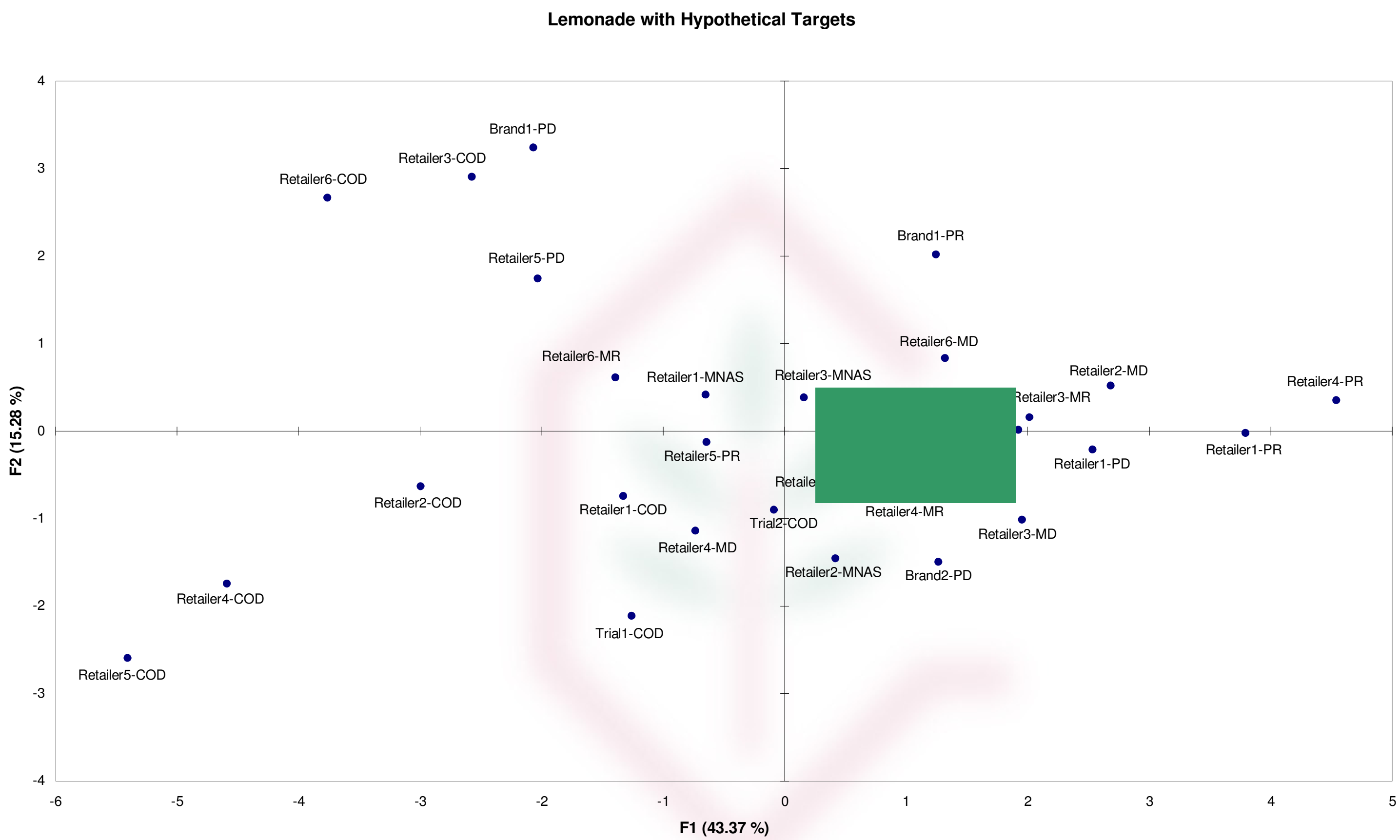
PCA with Target Values



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Conclusions

- Transparent
- Accommodate expert knowledge
- Outputs as distributions
- Retro-fitting
- Handle uncertainty

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Further Work…

- Integration of formulations
- Investigate preference factors
  - Cultural
  - Context
  - Etc

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Credits

- Professor Jian-Bo Yang (Project Leader)
  - jian-bo.yang@mbs.ac.uk
- Department for Environment, Food & Rural Affairs (DEFRA)
  - http://www.defra.gov.uk/

Thank you!

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