Chapter

A Global Method for a Two-Dimensional Cutting Stock Problem in the Manufacturing Industry

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Abstract

A two-dimensional cutting stock problem (2DCSP) needs to cut a set of given rectangular items from standard-sized rectangular materials with the objective of minimizing the number of materials used. This problem frequently arises in different manufacturing industries such as glass, wood, paper, plastic, etc. However, the current literatures lack a deterministic method for solving the 2DCSP. However, this study proposes a global method to solve the 2DCSP. It aims to reduce the number of binary variables for the proposed model to speed up the solving time and obtain the optimal solution. Our experiments demonstrate that the proposed method is superior to current reference methods for solving the 2DCSP.

Keywords: two-dimensional cutting stock problem (2DCSP), rectangular items, optimal solution, deterministic model

1. Introduction

Two-dimensional cutting stock problem (2DCSP) is a well-known problem in the fields of management science and operations research. The problem frequently arises in the manufacturing processes of different products such as wood, glass, paper, steel, etc. In the 2DCSP, a set of given rectangular items is cut from a set of rectangular materials with the aim of determining the minimum number of materials [1, 2]. These applications include sawing plates from wood stocks [3], reel and sheet cutting at a paper mill [4], cutting plates of thin-film-transistor liquid-crystal display (TFT-LCD) from glass substrate [5, 6], placing devices into a system-on-a-chip circuit [7], and container loading or calculation of containers [8, 9]. Minimizing the number of materials is normally the target in this type of the problem because it does not only reduce the overhead consumption but also enhances environmental protection. The problem in the literatures have been classified as one-dimensional, 1.5-dimensional, and 2DCSPs (Hinxman [10] and Lodi et al. [11]) and suggested two categories of approaches in solving the problems, namely, the heuristic and deterministic approaches (Belov [12], Burke et al. [13], Chen et al. [14], Hopper and Turton [15], Lin [16] and Martello et al. [17]).

Various heuristic approaches have been proposed and discussed in the literatures. The primary advantage of this approach is easier in solving the 2DCSP within an acceptable and economical timeframe [18, 19]. The feasible solution is obtained within a reasonable time, while the optimal solution cannot be guaranteed. Chazelle [20] first proposed a popular heuristic algorithm, called the bottom-left heuristic algorithm. Berkey and Wang [21] proposed a finite best strip heuristic algorithm to improve the original bottom-left method which packs the items directly into the bins with a best-fit policy. On the other hand, Lodi et al. [22] proposed an integrated heuristic approach that initiates the solution by paralleling the edges of the items and bins (i.e., materials) and utilizes a Tabu search [23, 24] to explore the neighborhood and refine the possible solution. In order to enhance the effectiveness of the algorithm used, Boschetti and Mingozzi [25, 26] consider empty bins in turn and fill the bins with items in a sequence defined by the prices attributed to the items and update them iteratively. Likewise, Monaci and Toth [27] initially used Lagrangian-based heuristic to generate a set of covering programming model to obtain a lower bound solution, in which the items cannot be rotated. They applied geometric analytical techniques and Dantzig-Wolfe decomposition to produce various lower bounds of the 2DCSP so that a better solution can be compared and obtained [28–31].

Despite the development of heuristic approaches can obtain possible solution in a reasonable time, however there is a scarcity of literature attempting to ensure the achievement of an optimal solution. Moreover, the distance between one random feasible solution and the actual global optimal solution can be enlarged with an increasing problem size. Only a few studies attempted to develop deterministic approaches for an optimal solution. For example, Chen et al. [32] formed a mathematical model for packing a set of given rectangular items into a rectangular space in which the dimension of the rectangular space is minimized. The packing problem is equal to the cutting problem, and the problem can also be called as an assortment problem. Moreover, Williams [33] formulated a mathematical model considering the increased generalization of 2DCSP, to solve the problem with various sizes of bins. However, Williams' model contains an excessive number of binary variables as indicated by Pisinger and Sigurd [31] who showed that Williams' model has difficulty in solving a standard 2DCSP by their computational experiments. The subsequent studies by Li and Chang [34], Li et al. [35, 36], Hu et al. [37], and Tsai et al. [38] (these approaches are called Li's approach in this study) enhanced Chen's model with reformulation techniques based on reducing binary variables and piecewise linearization technique. The deterministic approaches can guarantee the achievement of global optimization with an acceptable tolerance; however, these approaches are only suitable for the assortment problem (i.e., cutting rectangular items from one material only), while many manufacturing situations require considering minimal number of materials.

Aiming to close the knowledge gap, this study modifies the two programs of the assortment problem proposed by Chen et al. [32] and Li and Chang [34] to be two corresponding deterministic models for the 2DCSP. As an innovative approach, a global approach of the 2DCSP with a logarithmic number of binary variables and extra constraints is proposed and demonstrated.

The remainder of this study is organized as follows: Section 2 discusses the 2DCSP formulations. Section 3 proposes the 2DCSP models with logarithmic number of binary variables and extra constraints. Numerical examples are given in Section 4 to demonstrate the theoretical advances and advantages of the proposed global approach. Section 5 gives the concluding remarks.

2. Problem formulations

Given n small rectangular items, the 2DCSP is to cut all items within large rectangular materials with the objective of minimizing the number of materials used. Denote x and y as the width and the length of the enveloping rectangle. By referring to the method of Chen et al. [32], a mathematical program can be formed with the objective of minimizing the volume (i.e., Min xy) as discussed in Section 2.1. In the 2DCSP, the minimal number of materials can reduce the manufacturing costs. Thus Section 2.2 explains how to reformulate two new 2DCSP programs based on the original model in Section 2.1. Firstly, the terminologies, including decision variables and parameters, are introduced in **Tables 1** and **2**.

2.1 Cutting problem in one material

The cutting problem considering one material is also called the assortment problem, which considers cutting a set of given rectangular items within a rectangular material of minimum area. Avoiding the overlapping of items is the core requirements. Chen et al. [32] and Li and Chang [34] use four binary variables $(a_{i,j}, b_{i,j}, c_{i,j}, d_{i,j})$ and two binary variables $(u_{i,j}, v_{i,j})$, respectively, to handle the non-overlapping conditions, as shown in **Table 3**.

The following assortment program is proposed by Chen et al. [32]:

Original (a)

Min xy

$$s.t.\ x_j + p_j s_j + q_j(1 - s_j) \leq x_i + \overline{x}(1 - a_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \tag{1}$$

Parameter	Meaning
n	The number of given rectangular items needed to be cut
m	The number of rectangular materials with the same size
(p_i, q_i)	The width and length of given rectangular item i for $i = 1, ..., n$
$(\overline{x}, \overline{y})$	$\overline{x}$ and $\overline{y}$ are the upper bounds of x and y, respectively. These items also denote the width and length of a given rectangular material

Table 1.
Parameters in the 2DCSP.

Variable	Meaning
(x_i, y_i)	The bottom-left coordinate of rectangular item i
(x, y)	The top-right coordinate of the rectangular material
$(a_{i,j}, b_{i,j}, c_{i,j}, d_{i,j})$	A set of binary variables expressing the non-overlapping conditions for a pair of rectangular items i and rectangular items j for $i < j$, which are defined by Chen et al. [32]
$(u_{i,j}, v_{i,j})$	A pair of binary variables expressing the non-overlapping conditions for a pair of rectangular items i and rectangular items j for $i < j$, which are defined by Li and Chan [34]
s_i	An orientation indicator for a given rectangular item i. $s_i = 1$ if p_i is parallel to the x-axis; otherwise, $s_i = 0$ if p_i is parallel to the y-axis (s_i is a binary variable)
Y	The accumulated length of all materials used.

Table 2.
Decision variables in the 2DCSP.

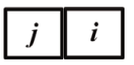
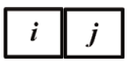
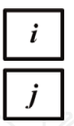
Method		Chen et al. [32]			Li and Chang [34]		Condition
Case	$a_{i,j}$	$b_{i,j}$	$c_{i,j}$	$d_{i,j}$	$u_{i,j}$	$u_{i,j}$	
1	1	0	0	0	0	0	
2	0	1	0	0	1	0	
3	0	0	1	0	0	1	
4	0	0	0	1	1	1	

Table 3.
Four cases of non-overlapping conditions.

$$x_i + p_i s_i + q_i(1 - s_i) \le x_j + \overline{x}(1 - b_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (2)$$

$$y_j + q_j s_j + p_j(1 - s_j) \le y_i + \overline{y}(1 - c_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (3)$$

$$y_i + q_i s_i + p_i(1 - s_i) \le y_j + \overline{y}(1 - d_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (4)$$

$$a_{i,j} + b_{i,j} + c_{i,j} + d_{i,j} = 1 \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (5)$$

$$x_i + p_i s_i + q_i(1 - s_i) \le x \le \overline{x} \text{ for } i = 1, ..., n, \quad (6)$$

$$y_i + q_i s_i + p_i(1 - s_i) \le y \le \overline{y} \text{ for } i = 1, ..., n, \quad (7)$$

where $a_{i,j}, b_{i,j}, c_{i,j}, d_{i,j}$, and s_i are binary variables; x_i and y_i are nonnegative continuous variables; Constraints (1)–(5) ensure that the rectangular items are non-overlapping, and Constraints (6) and (7) are to cut all of the rectangular items within an enveloping rectangular material $(\overline{x}, \overline{y})$.

Remark 1. Original (a) uses $2n^2 - n$ binary variables $(a_{i,j}, b_{i,j}, c_{i,j}, d_{i,j})$ and $2.5n(n-1) + 2n$ constraints to formulate an assortment problem with n rectangular items.

By referring to Li and Chang [34], an alternative mathematical model can be expressed as follows:

Original (b)

Min xy

s.t. (6) and (7),

$$x_j + p_j s_j + q_j(1 - s_j) \le x_i + \overline{x}(u_{i,j} + v_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (8)$$

$$x_i + p_i s_i + q_i(1 - s_i) \le x_j + \overline{x}(1 - u_{i,j} + v_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (9)$$

$$y_j + q_j s_j + p_j(1 - s_j) \le y_i + \overline{y}(1 + u_{i,j} - v_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (10)$$

$$y_i + q_i s_i + p_i(1 - s_i) \le y_j + \overline{y}(2 - u_{i,j} - v_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (11)$$

where $u_{i,j}, v_{i,j}$, and s_i are binary variables; x_i and y_i are nonnegative continuous variables; and Constraints (8)–(11) ensure that the rectangular items are non-overlapping.

Remark 2. Original (b) uses n^2 binary variables $(u_{i,j}, v_{i,j})$ and $2n^2$ constraints to formulate an assortment problem with n rectangular items.

However, these two models are inappropriate for directly solving the general 2DCSP because the objective of the 2DCSP must minimize the number of materials used for cutting all items. By referring to the two models above, two corresponding 2DCSP models are proposed in Section 2.2.

2.2 General deterministic models of 2DCSP

As mentioned above, we need to find out the minimal number of materials used for cutting all items. Original (a) is then reformulated as a general deterministic model of 2DCSP, where cutting n rectangular items from m materials, as shown in P1 (a):

P1 (a)

Min Y

s.t. (1), (2) and (5) in Original (a),

$$y_j + q_j s_j + p_j(1 - s_j) \le y_i + m\bar{y}(1 - c_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \tag{12}$$

$$y_i + q_i s_i + p_i(1 - s_i) \le y_j + m\bar{y}(1 - d_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \tag{13}$$

$$x_i + p_i s_i + q_i(1 - s_i) \le \bar{x} \text{ for } i = 1, ..., n, \tag{14}$$

$$y_i + q_i s_i + p_i(1 - s_i) \le \sum_{k=1}^{m} k\bar{y} Q_{i,k} \text{ for } i = 1, ..., n, \tag{15}$$

$$y_i \ge \sum_{k=1}^{m} (k - 1)\bar{y} Q_{i,k} \text{ for } i = 1, ..., n, \tag{16}$$

$$\sum_{k=1}^{m} Q_{i,k} = 1 \text{ for } i = 1, ..., n, \tag{17}$$

$$y_i + q_i s_i + p_i(1 - s_i) \le Y \text{ for } i = 1, ..., n, \tag{18}$$

where $s_i, a_{i,j}, b_{i,j}, c_{i,j}, d_{i,j}$, and $Q_{i,k}$ are binary variables; x_i, y_i and Y are nonnegative continuous variables; Constraints (1), (2), (5), (12) and (13) ensure that the rectangular items are non-overlapping; Constraints (15)–(17) mean that each rectangular item is fitly cut from one of the m materials; Constraint (18) obtains the accumulated length of materials used; and the objective function minimizes the accumulated length of materials used.

There are nm new binary variables (i.e., $Q_{i,k}$ for $i = 1, 2, ..., n$ and $k = 1, 2, ..., m$) in Constraints (15)–(17) of P1 (a) model. It aims to cut the ith rectangular item from the kth material if $Q_{i,k} = 1$, and Constraint (17) forces any rectangular item to be cut from one of such materials. Supposing that rectangular item i' is cut from the k'th material, then $Q_{i',k'} = 1$ and $Q_{i',k} = 0$ for $k \ne k'$ and $k = 1, 2, ..., m$. Constraints (15)–(17) will force the y-axis position of rectangular item i' cut from the k'th material as shown below:

$$y_{i'} + q_{i'} s_{i'} + p_{i'}(1 - s_{i'}) \le k'\bar{y}, \tag{19}$$

$$(k' - 1)\bar{y} \le y_{i'}. \tag{20}$$

Remark 3. P1 (a) requires $2n^2 - n(1 - m)$ binary variables and $(5n^2 + 3n)/2$ constraints to form a 2DCSP program.

Referring to the Original (b), another corresponding 2DCSP program can be formulated as follows:

P1 (b)

Min Y

s.t. (8), (9), (14)–(18),

$$y_j + q_j s_j + p_j(1 - s_j) \le y_i + m\bar{y}(1 + u_{i,j} - v_{i,j}) \text{ for } i, j = 1, ..., n \text{ and } i < j, \tag{21}$$

$$y_i + q_i s_i + p_i(1 - s_i) \le y_j + m\bar{y}\left(2 - u_{i,j} - v_{i,j}\right) \text{ for } i, j = 1, ..., n \text{ and } i < j, \quad (22)$$

where $s_i, u_{i,j}, v_{i,j}$, and $Q_{i,k}$ are binary variables and x_i, y_i, and Y are nonnegative continuous variables.

Remark 4. P1 (b) requires $n^2 + nm$ binary variables and $2n(n+1)$ constraints to formulate a 2DCSP program.

Although both P1 (a) and P1 (b) can obtain a minimal number of materials used, there is mainly an issue needed to be addressed. That is, an excessive number of binary variables $Q_{i,k}$ is used to assign rectangular item i into one of the materials; such that the computational load becomes a serious burden as the size of the problem grows.

As indicated by Li et al. [39], reducing the number of binary variables can accelerate the solving speed. Hence, we can roughly estimate the number of materials by the following remark.

Remark 5. The number of materials can be reduced from m to f where $f \le m$ by the following initial calculating:

$$f \cong \lceil \sum_{i=1}^{n} x_i y_i / \bar{x} \times \bar{y} \rceil, \quad (23)$$

where if f value is not big enough, i.e., in solving P1(a) and P1(b) are infeasible, then we can accumulate f, i.e., $f = f + 1$, until feasible solutions exist.

By referring to Remark 5, the number of binary variables in Constraints (15)–(18) can be reduced from nm to nf where $f \le m$. Moreover, this study proposes a reformulation technique using logarithmic number of binary variables for the P1 (a) and P1 (b) models. The detail of technique is then discussed in Section 3.

3. Logarithmic reformulation technique of 2DCSP

After considering Remark 5, for a 2DCSP with n rectangular items and f materials, the P1 (a) and P1 (b) models will require nf binary variables ($Q_{i,k}$) to cut each rectangular item from one of the materials. The computational efficiency of the P1 (a) and P1 (b) models become a serious burden when an increasing size of the 2DCSP. For any rectangular item i, Constraint (17) ($\sum_{k=1}^{f} Q_{i,k} = 1$) is an SOS1 constraint [40], which is an ordered set of variables where only one variable may be one. An SOS1 constraint model with size f will generally require f binary variables. However, Vielma and Nemhauser [41] use SOS1 constraint with a logarithmic number of binary variables and constraints. This section utilizes the concept of Vielma and Nemhauser [41] and introduces the binary variables $Q_{i,r}$ ($i = 1, ..., n$ and $r = 1, ..., \lceil \log_2 f \rceil$) to replace the original binary variables ($Q_{i,k}$) of the P1 (a) and P1 (b) models. Thus, the number of required binary variables can be reduced from nf to $n\lceil \log_2 f \rceil$. The following remarks and propositions discuss the logarithmic reformulation technique of the 2DCSP.

Remark 6. Let $K = \{1, 2, ..., f = 2^\theta\}$, $\theta = \lceil \log_2 f \rceil$, and $k \in K$ be the injective function for $B : \{1, 2, ..., 2^\theta\} \to \{0, 1\}^\theta$, which can be expressed as follows:

$$B(k) = [w_1, w_2, ..., w_\theta]^T \text{ and } w_r = 1 - \left(\lceil \frac{k}{2^{r-1}} \rceil \%2 \right) \text{ for } r = 1, ..., \theta. \quad (24)$$

Proposition 1. Let $K = \{1, ..., f\}$, $\theta = \lceil \log_2 f \rceil$ and $k \in K$; the original SOS1 Constraint in (25) which requires f binary variables (Q_k) can be replaced by the Constraint set (26) and (27):

$$\sum_{k=1}^{f} Q_k = 1 \text{ and } Q_k \in \{0,1\}. \tag{25}$$

The Constraint set (25) and (26) only requires θ binary variables (Q_r), 2θ additional constraints, and f additional continuous variables (λ_k):

$$\sum_{k=1}^{f} \lambda_k = 1, \tag{26}$$

$$\sum_{k \in S^+(r)} \lambda_k = Q_r \text{ for } r = 1, ..., \theta, \tag{27}$$

where

i. $Q_r \in \{0,1\}$.

ii. $B(k)$ is an injective function based on Remark 6 (i.e., $B(k) = [w_1, w_2, ..., w_\theta]^T$ with $w_r \in \{0,1\}$ for $r = 1, ..., \theta$).

iii. $S^+(r) = \{k \in K | \forall B(k) \textit{ where } w_r = 1\}$ and $S^-(r) = \{k \in K | \forall B(k) \textit{ where } w_r = 0\}$.

Proof: Following Li et al. [39], Constraints (26) and (27) are used to construct the SOS1 property.

Following Proposition 1, we then have Proposition 2 that uses $\lceil \log_2 f \rceil$ binary variables to determine whether rectangular item i could be exactly cut from one of the given materials.

Proposition 2. Let f be the number of materials, $\bar{y}$ the length of material, and y_i the y-axis position of rectangular item i. The original Constraint set (15)–(17) of the P1 (a) and P1 (b) models will be re-expressed by the following linear system, which holds the rectangular item i to be cut from one of the given materials:

$$y_i + q_i s_i + p_i(1 - s_i) \le \sum_{k=1}^{f} k\bar{y}\lambda_{i,k} \text{ for } i = 1, ..., n, \tag{28}$$

$$y_i \ge \sum_{k=1}^{f} (k-1)\bar{y}\lambda_{i,k} \text{ for } i = 1, ..., n, \tag{29}$$

$$\sum_{k=1}^{f} \lambda_{i,k} = 1 \text{ for } i = 1, ..., n, \tag{30}$$

$$\sum_{k \in S^+(r)} \lambda_{i,k} = Q_{i,r} \text{ for } i = 1, ..., n \text{ and } r = 1, ..., \theta = \lceil \log_2 f \rceil, \tag{31}$$

where $S^+(r)$ and $S^-(r)$ are the same as the notations in Proposition 1 and $s_i, Q_{i,r} \in \{0,1\}$.

Proof: According to Proposition 1, the continuous variables $\lambda_{i,k}$ with the Constraint set (30) and (31) have the characteristics of binary variables. Therefore, the Constraint set (28)–(30) is equivalent to the Constraint set (15)–(17).

Two types of 2DCSP models are formulated by utilizing Proposition 2 as the following P2 (a) and P2 (b), respectively:

Items	P1(a)	P1(b)	P2(a)	P2(b)
Concept of non-overlapping	Chen et al. [32]	Li and Chang [34]	Chen et al. [32]	Li and Chang [34]
Constraints for assigning rectangular items into materials	$\sum_{k=1}^{f} Q_{i,k} = 1$	$\sum_{k=1}^{f} Q_{i,k} = 1$	Proposition 2	Proposition 2
No. of binary variables	$2n^2 - n(1-f)$	$n^2 + nf$	$n(2n+\theta-1)$	$n(n+\theta)$
No. of continuous variables	$2n+1$	$2n+1$	$2n+nf+1$	$2n+nf+1$
No. of constraints	$(5n^2+5n)/2$	$2n^2+3n$	$n(5n+10)+4\theta$	$n(2n+2\theta+3)$
where $\theta = \lceil \log_2 f \rceil$				

Table 4.
Comparison of the four ways of expressing the 2DCSP.

P2 (a)
Min Y
s.t. (1), (2), (5), (12)–(14), (18) and (28)–(31),
where $Y, x_i, y_i, \lambda_{i,k} \geq 0$ and $a_{i,j}, b_{i,j}, c_{i,j}, d_{i,j}, s_i, Q_{i,r} \in \{0,1\}$ for $i, j = 1, ..., n$, $i < j$, $k = 1, ..., f$, and $r = 1, 2, ... \lceil \log_2 f \rceil$.

Remark 7. P2 (a) requires $n\left(2n + \lceil \log_2 f \rceil - 1\right)$ binary variables and $5n^2 + 10n + \lceil \log_2 f \rceil$ constraints to express a 2DCSP model.

P2 (b)
Min Y
s.t.(8), (9), (14), (18), (28)–(31),
where $Y, x_i, y_i, \lambda_{i,k} \geq 0$ and $s_i, u_{i,j}, v_{i,j}, Q_{i,r} \in \{0,1\}$ for $i, j = 1, ..., n$, $i < j$, $k = 1, ..., f$ and $r = 1, ..., \lceil \log_2 f \rceil$.

Remark 8. P2 (b) requires $n\left(n + \lceil \log_2 f \rceil\right)$ binary variables and $n\left(2n + 2\lceil \log_2 f \rceil + 3\right)$ constraints to express another 2DCSP model.

Table 4 shows a comparison of the four ways of expressing the 2DCSP, and it clearly lists the number of binary variables, auxiliary continuous variables, and constraints.

4. Numerical examples

There are two examples modified from Tsai et al. [38]. The detail sizes of rectangular items and materials are listed in **Table 5**. We implement a Java program, which embedded an optimization package GUROBI (2011) as an MIP solver

Problem	Size of material	Qty. of items	f	Size of items (p_i, q_i)
1	(40, 69)	8	2	(25, 20), (16, 20), (15, 20), (14, 20), (20, 18), (15, 17), (30, 16), (30, 14)
2	(25, 150)	12	2	(32, 24), (26, 20), (25, 20), (24, 20), (40, 18), (35, 17), (20, 16), (18, 16), (38, 15), (50, 15), (18, 4), (25, 5)

Table 5.
Sizes of rectangular items and materials.

Items		P1 (a)	P1 (b)	P2 (a)	P2 (b)
Problem 2 Y = 83	No. of 0–1 variables	136	80	128	72
	No. of cont. variables	17	17	33	33
	No. of constraints	180	152	404	168
	Iterations	621,821	686,982	263,296	293,432
	Nodes	176,776	211,564	70,154	111,173
	Solving time	18.8	18.0	7.5	9.1
Problem 2 Objective = 293	No. of 0–1 variables	300	168	288	156
	No. of cont. variables	25	25	49	49
	No. of constraints	390	324	844	348
	Iterations	31,166,357	1,017,922	1,114,911	805,136
	Nodes	9,766,654	244,444	266,672	229,701
	Solving time	856.5	24.5	34.9	19.4

Table 6.
Experiment results of two problems.

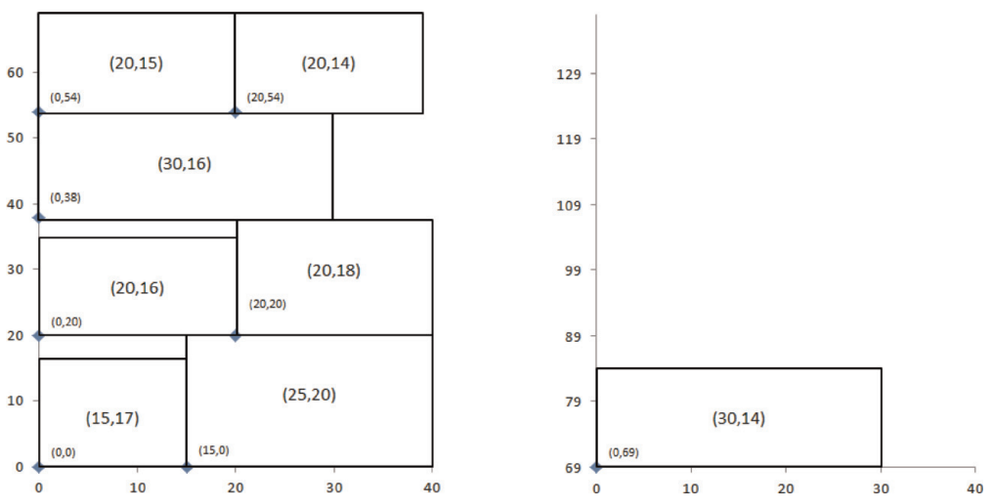


Figure 1.
Visualization result of Example 1.

for solving the two examples with the four proposed models (P1 (a), P1 (b), P2 (a), P2 (b)). The experimental tests were run on a PC equipped with an Intel® Core™ 2 Duo CPU, 4GB RAM, and 32 bit Windows 7 operating system.

The two problems with the number of materials firstly estimated to be 2 (i.e., $f = 2$) are solved by using the four models including P1(a), P1(b), P2(a), and P2 (b). **Table 6** shows the experiment results of two problems. Both of **Figures 1** and **2** depict the visualization solutions. In solving four models, we obtain the same objective values of (83) and (293) in Problem 1 and Problem 2, respectively. The results clearly indicate that solving P2(a) and P2(b) is much more computationally efficient than that of P1(a) and P1(b). By observing the four models, we know that both P2(a) and P2(b) use proposed approach to reduce the numbers of binary variables. The results demonstrate that the adoption of a smaller number of binary variables can enhance the solving efficiency in solving 2DCSP.

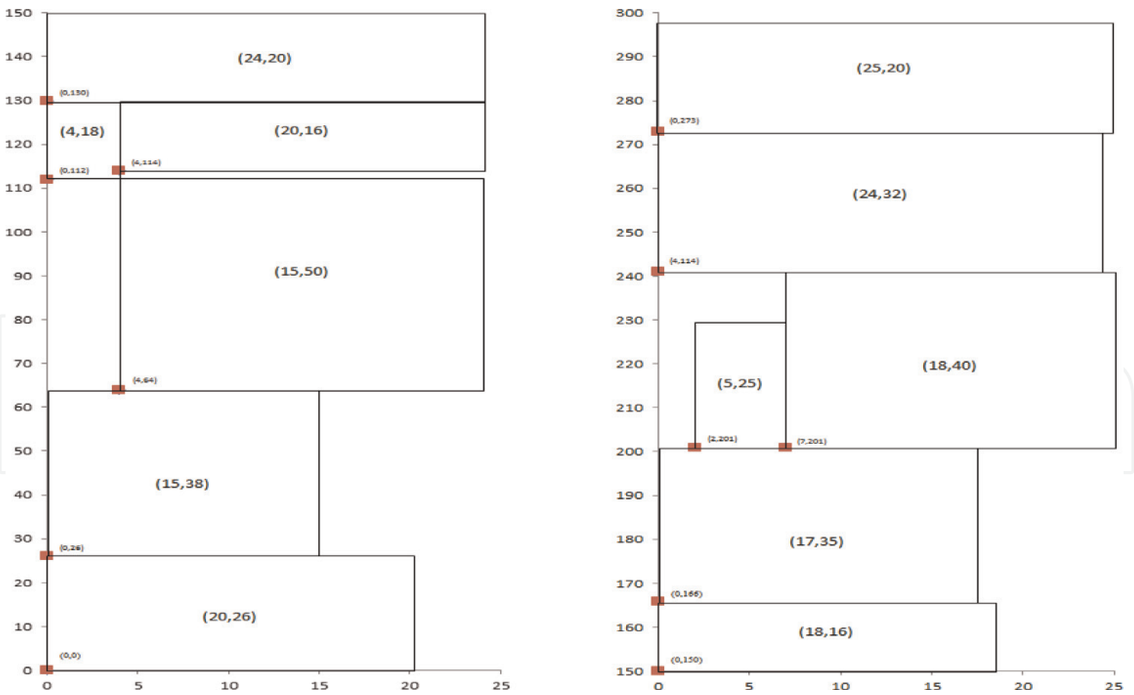


Figure 2.
Visualization result of Example 2.

5. Conclusions

This study develops a logarithmic reformulation technique for reducing the required binary variables of the mixed integer program for two-dimensional cutting stock problem in the manufacturing industry. A reformulated logarithmic technique in the deterministic method reduces the number of binary variables to speed up the solving time. The deterministic methods are guaranteed to find a global optimal solution, but the computational complexity grows rapidly by increasing the number of variables and constraints. Future studies are suggested to enhance the computational efficiency for globally solving large-scale 2DCSP, such as column generation, cloud computing and meta-heuristic algorithms.

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Chapter

Selection of Food Items for Diet Problem Using a Multi-objective Approach under Uncertainty

Saman Hassanzadeh Amin, Samantha Mulligan-Gow and Guoqing Zhang

Abstract

It is a problem that concerns us all: what should we eat on a day-to-day basis to meet our health goals? Scientists have been utilizing mathematical programming to answer this question. Through the use of operations research techniques, it is possible to find a list of foods that, in a certain quantity, can provide all nutrient recommendations in a day. In this research, a multi-objective programming model is provided to determine the selected food items for a diet problem. Two solution approaches are developed to solve this problem including weighted-sums and ε-constraint methods. Two sources of uncertainty have been considered in the model. To handle these sources, a scenario-based approach is utilized. The application of this model is shown using a case study in Canada. Using the proposed model and the solution approaches, the best food items can be selected and purchased to minimize the total cost and maximize health.

Keywords: food optimization, diet, nutrition, multi-objective programming, uncertainty

1. Introduction

It is common knowledge that diet affects general health in extraordinary ways. What is less clear is what specific diet results in the best health. Some diets restrict the quantity of carbohydrates or fats, others require particular percentages of the three macronutrients (carbohydrates, fats, and protein), some depend solely on liquids, and the list continues [1–5]. There are unlimited amounts of unique diets being used today by people all over the world, especially since countless health trends have become the new normal. One thing that can be agreed upon is the recommended dietary allowances (RDA), given by the federal government of Canada, which presents the quantity of vitamins and nutrients needed to meet requirements. So it is important to determine the combination of the seemingly infinite food items that reaches nutrient goals in the most efficient manner.

The diet problem was first introduced by Stigler [6] as a way to determine the minimum cost of feeding an adult for a year. Many models have since explored diet optimization with the objectives of reaching recommended nutrient levels while keeping the diets similar to actual intakes, decreasing environmental impact, or satisfying taste. There are numerous models that can be used to create unique diets

based on the main target criteria. These models include linear and nonlinear, multi-objective, goal-oriented, integer, and mixed-integer programming. Each yields specific results due to the mathematical basis.

2. Literature review

In this section, some related papers are discussed, classified on the subject of the model's goal. Most research of the diet problem is centered on at least one of the following targets: cost of diet, similarity of diet, environmental sustainability of diet, prevention of health implications by diet, and taste/satisfaction of diet.

2.1 Cost of diet

The first diet problem [6] focused on minimizing the cost of food. The author showed that to feed one man for a year can cost as little as $39.93 (1939 prices). Certainly, lowering the grocery bill is a desire for all and this type of objective is quite common to this day. One paper discusses whether it is too expensive to follow a healthy diet, comparing 2012 and 1980 costs [7]. Stigler's problem was reinvented with updated costs and nutritional information in 1999 [8] and taste of diet was included in the cost minimization by Smith [9].

In recent years, further papers focused on more specific problem statements and how they are affected by expense. In Mozambique, the affordability of a nutritious meal plan was studied and fortified foods were assessed with the hopes of creating more economic value [10]. Specific diets have also been studied to determine whether they can be accomplished in a cost-effective manner [11]. To attempt a solution of high-cost food, James David Ward studied urban agriculture and how it could reduce grocery expenses [12].

2.2 Sustainability of diet

Considering that livestock production is a major contributor to greenhouse gas emissions, worldwide [13], the question of nutritional sustainability has been asked and answered. Multi-objective linear programming was used to formulate three unique diets that minimized cost, environmental indicators (H_2O use, amount of land to regenerate the resources, and CO_2 emissions), and the integration of the two [13]. Another study was completed in which the optimal diet was to be as similar to the general, observed diet [14]. This chapter noted that a sustainable diet reduces greenhouse gas emissions by 27% [14]. Mathematical programming was also used to study which food sources contributed least to environmental footprints such as land use, carbon and nitrogen footprints [15]. Barre et al. [16] found diets by using – on the reduction percentage of environmental impacts being at least 30%. It was concluded that all diets required a decrease in meat consumption to meet the sustainability factors [16]. The cost of feeding cattle was found to increase (by as much as 48.5%) in a hypothetical scenario where there was either a tax on greenhouse gas emissions or a constraint on methane emissions applied [17].

2.3 Disease prevention of diet

It is commonly known that what you eat affects your health. Studies have been conducted to explain how diets can reduce your risk of certain health risks and concerns. Observed diets and those recommended by the World Cancer Fund and the American Institute of Cancer Research were compared by Masset et al. [18].

Furthermore, obesity and its relation to dietary intake has been a frequent topic of interest. Silva et al. [19] presented the possibility of a diet that constricts amount of calories by increasing the quantity of proteins eaten in a day, which will then create the opportunity for weight loss.

2.4 Similarity of diet

In many papers, one of the objectives (usually secondary) is to minimize the difference between the proposed diet and the current, observed diet of a group of people being studied [16, 20–23]. This is done for many reasons: to ensure palatability, ease of acceptance, and culturally appropriate solutions. This focus is often the backbone of the programming calculation as it guarantees a certain level of logic and reality.

In **Table 1**, related papers are organized by which mathematical programming approach was utilized. Linear programming (LP) is used for optimizing (maximizing or minimizing) a linear function of many variables [24], while nonlinear programming (NLP) does the same when there is(are) one or more nonlinear functions in the problem [25, 26]. For computing problems with multiple objectives, goal programming (GP) is often used [27]. This technique is popular in recent diet studies due to its potential ability to achieve a more realistic food balance [28]. Linear programming has been seen in **Table 1** as the most commonly used technique for diet problems, including a paper done to disavow goal programming [29].

Publication	LP	NLP	GP	MOP	Un	Final Diet	Nutrients	Model Only
[9]	✓					✓		
[32]	✓					✓		
[33]	✓					✓		
[34]				✓		✓		
[8]	✓					✓	✓	
[20]								
[21]	✓							
[10]	✓		✓			✓	✓	
[11]	✓					✓	✓	
[18]	✓							✓
[35]	✓					✓	✓	
[22]				✓	✓			✓
[10]	✓					✓		
[17]	✓							
[15]	✓		✓				✓	
[7]	✓		✓					✓
[13]			✓					
[23]	✓					✓		
[12]	✓							
[13]	✓			✓				
[14]	✓					✓		✓
[19]				✓		✓	✓	
[16]	✓	✓						
Our paper	✓			✓	✓	✓		

Goal Programming (GP); Linear Programming (LP); Multi-Objective Programming (MOP); Non-Linear Programming (NLP); Uncertainty (Un).

Table 1.
Review of some related papers and their operations research techniques [32–34].

Multi-objective programming (MOP) is used when there are multiple, competing objectives that result in more than one optimal solution [30]. With uncertain environments, fuzzy set theory (FST) and some specific techniques can be applied so that qualitative statements can be described numerically without losing precision [31].

Included in **Table 1** is the format of the results in each respective paper. Some papers explicitly create day-to-day diets, including exact foods and their quantities. We call them "Final Diet." Other papers note the nutrients that their proposed model offers if created into a diet. These are called "Nutrients" in **Table 1**. Other papers only present the model that is used to create a diet without stating which foods should be chosen. In these papers, no specific food intake is specified, rather only the math is presented.

2.5 Research gaps

There are some gaps in the literature of diet problems. There are a few papers in the literature that have considered multiple objectives in diet problems. Among them, most publications have focused on two objectives. Therefore, the research gap can be filled by considering more than two objectives. The other point is related to the availability of data. In recent years, companies have been forces to provide nutritional information for the packages and products. Therefore, a lot of useful information is available that is new and valuable in this field. Case studies can be conducted based on the available information. The other gap in the literature is about the uncertainty of the parameters in diet problems. Most of the papers in this area have ignored uncertain parameters and their effects on the results.

2.6 Research contributions

The main research contributions of this paper are defined in this section.

- A novel optimization model is provided to determine personal food selection.
- Multiple objectives are considered in the mathematical model. To our knowledge, these objectives have not been considered simultaneously in the other papers in the literature.
- The mathematical formulation is solved by two solution approaches including weighted-sums and ε-constraint approaches. As a result, the efficient solutions are obtained.
- Uncertainty in the parameters is considered using an effective scenario-based solution approach. Different combinations of the scenarios are analyzed in this paper.
- The application of the model is shown using real data and a case study in Canada.

3. Problem statement

As discussed previously, the optimization of diets is a continuously important problem since we all eat every day. What is more, the food costs money and affects our health and well-being. Some diseases related to obesity (e.g., cardiovascular and

diabetes) have significant impacts in Canada. Some factors of diets such as sugars, sodium, and fat play important roles on health of people. A study done by Hajizadeh et al. [35] found that body mass index, an indicator of obesity, is negatively related to household income (and fruit and vegetable consumption). Families across Canada suffer from food poverty: the inability to purchase healthy, nutritious food for their loved ones [36]. There are people who have to make the difficult decision to either pay rent, or buy groceries. These people should be able to know that what money they put toward food is being used in the most efficient way possible. On the other hand, if food can be used to combat major health concerns within our population, this information should be taken advantage of. Obesity is an extensive issue in all regions of Canada and the major contributor is nutrition [35].

The government of Canada provides health and nutrition information online. The federal government has also created legislation that ensures all food items show a nutrition facts table on the packaging. This information covers facts on recommended macronutrients and micronutrients. Carbohydrates give the body energy and are separated into three categories: starch, fiber, and sugars [36]. Fat is a macronutrient that also provides energy to the body as well as helps digest essential vitamins. Fats are categorized into trans, saturated, and unsaturated but only trans and saturated are needed on nutrition facts tables as they are the fats that increase blood cholesterol level [36].

Cholesterol is a type of fat that is produced by the body but can also be consumed through food. High levels of cholesterol can increase risk of developing heart disease. Only animal-based foods contain cholesterol. Protein is the third macronutrient which helps tissues and muscles build recover from strain and as well as provide energy [36]. Sodium is a nutrient that is prevalent in our society due to our use of salt to preserve food, which raises blood pressure, increasing the risk of stroke, heart and kidney diseases. Calcium is a mineral found in our bones but can also be eaten in order to strengthen our bones and help our muscles work [36]. Another mineral, iron, helps produce red blood cells and helps carry oxygen through the body. Some important vitamins the government emphasizes are vitamins A and C [36]. Vitamin A maintains healthy skin and normal bone growth. Vitamin C facilitates the absorption of iron, is an antioxidant, and helps heal wounds [36].

Another resource from the Government of Canada is the recommended number of food guide servings per day [37]. They have created a table that presents the number of servings needed of each food group for all ages and genders of the Canadian population. The four food groups are: vegetables and fruit (VG), grain products (GP), milk and alternatives (MA), and meat and alternatives (ME). The ages of population categories are split into 2–3, 4–8, 9–12, 14–18, 19–50, and 51 and over [37].

In this problem, selected food items should be determined (to be purchased) according to some constraints and goals. There are four goals in this diet problem based on the available information for foods in Canada. They allow the cost of the food to be minimized while decreasing the trans/saturated fats and sugar, and maximizing the amount of fiber. This combination of objectives aims to limit nutrients that are harmful to the human body, as noted above. The diet will be based on the consumption of the chosen foods for 1-month period. Since nutrition guidelines vary based on age, the chosen population group for this study is 51 and older. This group was chosen due to the aging population of Canada.

Figure 1 shows an example of nutrition facts table. In addition, examples of four food groups (vegetables and fruit (VF), grain products (GP), milk and alternatives (MA), meat and alternatives (EA)) are illustrated in **Figure 2**.

Nutrition Facts

Per 9 crackers (23 g)

Amount	% Daily Value
Calories 90	
Fat 4.5 g	**7** %
Saturated 2.5 g + Trans 0 g	**13** %
Cholesterol 0 mg	
Sodium 280 mg	**12** %
Carbohydrate 12 g	**4** %
Fibre 1 g	**4** %
Sugars 0 g	
Protein 3 g	

Vitamin A	0 %	Vitamin C	0 %
Calcium	2 %	Iron	8 %

Figure 1.
An example of nutrition facts table [38].

Figure 2.
Examples of four food groups (vegetables and fruit (VF), grain products (GP), milk and alternatives (MA), meat and alternatives (EA)).

4. Optimization model

In this section, a multi-objective programming formulation is proposed to determine the numbers of the foods that should be consumed. The definitions of sets, parameters, and decision variables are provided in this section.

Sets

i = Type of food (1, 2, ..., I).
h = Food group (1, 2, ..., H).

t = Period (1, 2, ..., T).
j = Vitamin (1, 2, ..., J).

Parameters

a_{ih} = Size of food i in food group h.
A_{iht} = Cost of food i in food group h and period t.
B_t = Minimum total calories in period t.
C_{ih} = Calories of food i (in each unit) in food group h.
D_t = Maximum total calories in period t.
E_{jt} = Minimum total vitamin j in period t.
F_{jih} = Vitamin j in food i (in each unit) and food group h.
G_{jt} = Maximum total vitamin j in period t.
K_{ih} = Saturated and trans fats of food i (in each unit) in food group h.
L_{ih} = Sugar of food i (in each unit) in food group h.
M_{ih} = Fiber of food i (in each unit) in food group h.
O_t = Minimum total cholesterol in period t.
P_{ih} = Cholesterol of food i (in each unit) in food group h.
Q_t = Maximum total cholesterol in period t.
R_t = Minimum total sodium in period t.
S_{ih} = Sodium of food i (in each unit) in food group h.
V_t = Maximum total sodium in period t.
X_t = Minimum total protein in period t.
Y_{ih} = Protein of food i (in each unit) in food group h.
Z_t = Maximum total protein in period t.
β_t = Minimum total calcium in period t.
λ_{ih} = Calcium of food i (in each unit) in food group h.
α_t = Maximum total calcium in period t.
ρ_t = Minimum total iron in period t.
γ_{ih} = Iron of food i (in each unit) in food group h.
σ_t = Maximum total iron in period t.
ψ_{ht} = Amount of food guide servings per month in food group h in period t.

Decision Variables

N_{iht} = Number of food i in food group h and period t.

$$\text{Min } z_1 = \sum_t \sum_h \sum_i A_{iht} N_{iht} \tag{1}$$

$$\text{Min } z_2 = \sum_t \sum_h \sum_i a_{ih} K_{ih} N_{iht} \tag{2}$$

$$\text{Min } z_3 = \sum_t \sum_h \sum_i a_{ih} L_{ih} N_{iht} \tag{3}$$

$$\text{Max } z_4 = \sum_t \sum_h \sum_i a_{ih} M_{ih} N_{iht} \tag{4}$$

s.t.

$$B_t \le \sum_h \sum_i a_{ih} C_{ih} N_{iht} \le D_t \qquad \forall t \tag{5}$$

$$E_{jt} \le \sum_h \sum_i a_{ih} F_{jih} N_{iht} \le G_{jt} \qquad \forall j, t \tag{6}$$

$$O_t \le \sum_h \sum_i a_{ih} P_{ih} N_{iht} \le Q_t \qquad \forall t \qquad (7)$$

$$R_t \le \sum_h \sum_i a_{ih} S_{ih} N_{iht} \le V_t \qquad \forall t \qquad (8)$$

$$X_t \le \sum_h \sum_i a_{ih} Y_{ih} N_{iht} \le Z_t \qquad \forall t \qquad (9)$$

$$\beta_t \le \sum_h \sum_i a_{ih} \lambda_{ih} N_{iht} \le \alpha_t \qquad \forall t \qquad (10)$$

$$\rho_t \le \sum_h \sum_i a_{ih} \gamma_{ih} N_{iht} \le \sigma_t \qquad \forall t \qquad (11)$$

$$\sum_i a_{ih} N_{iht} = \psi_{ht} \qquad \forall h, t \qquad (12)$$

$$N_{iht} \ge 0 \qquad \forall i, h, t \qquad (13)$$

The total cost of the foods is minimized in the first objective function. The second objective minimizes saturated and trans fats in the foods. In addition, the third objective minimizes the sugar of the foods. Besides, the fourth objective function maximizes the fiber of the foods.

Constraint (5) is related to the minimum and the maximum required calories in the foods. Constraint (6) is about the vitamins in the foods. In addition, constraints (7)–(11) are about the minimum and the maximum values of cholesterol, sodium, protein, calcium, and iron in the diet, respectively. Constraint (12) considers the recommended amount of food guide servings. Finally, the last constraint ensures that the variables are nonnegative.

5. Solution approach

In this section, a solution approach counting weighted-sums method and ε-constraint method is described. The main goal is to convert the multi-objective model to a single objective one.

5.1 Weighted-sums method

In this technique, a weight is assigned to each objective function. Then, the objective functions are combined to build a single objective function [39–45]. Suppose that the weight of objective function w is W_w. Thus, W_1, W_2, W_3, and W_4 should be determined in this problem. The summation of the weights is one. The weights represent the importance of the objectives for the decision-makers. The proposed optimization model is converted to the following optimization formulation using the weighted-sums method.

$$Miz \; z_5 = W_1 z_1 + W_2 z_2 + W_3 z_3 - W_4 z_4 \qquad (14)$$

$$s.t. \qquad \sum_w W_w = 1 \qquad (15)$$

Constraints (1)–(15).

5.2 ε-constraint method

In ε-constraint technique, the most prominent objective among others is chosen as the primary objective function. Other objective functions are considered as constraints of the optimization model [46–50]. The first objective function is the most important one in this model. Therefore, it is selected as the main objective function. Three constraints are added to the mathematical model [constraints (17)–(19)]. It is noticeable that the signs of the inequalities are related to the types of the objective functions (minimization or maximization).

$$Miz \ z_6 = z_1 \tag{16}$$

$$s.t. \tag{17}$$

$$z_2 \leq \varepsilon_2$$

$$z_3 \leq \varepsilon_3 \tag{18}$$

$$z_4 \geq \varepsilon_4 \tag{19}$$

Constrains (5)–(13)

6. Results of the case study

Four types of foods are considered in four food groups including vegetables and fruit, grain products, milk and alternatives, and meat and alternatives. The recommended number and amount of food guided servings in a month are provided in **Table 2**. This table is based on the information in Food-guide-basics, 2018. We focus on 51+ year-old females in this case. The last column of the table shows 50% of the required amount of food. It is supposed that the other 50% nutrition is supplied by other sources. Two periods (months) are considered in this case study. Two types of vitamins including vitamin A and vitamin C are taken into account because information about them is provided in nutrition facts tables of the products in Canada. Mentioning the values of other vitamins in the tables is optional for Canadian food producers. The other data of the case are provided in Appendix A.

In this research, the General Algebraic Modeling System (GAMS) software is employed to write the codes and find the solutions. First, different weights are devoted to the objective functions and the problem is solved. Each solution of the multi-objective model is called efficient solution. Efficient solutions cannot be improved without scarifying other objective functions [46, 51–56]. The results have been collected in **Table 3**. As it can be seen, the weights are assigned between 0 and 1. The efficient solutions are presented to the decision-makers. The second part of

Food group	Examples of one food guide serving	Number of food servings	Amount of food servings	50% of the amount
Vegetables and fruit (VF)	125 mL (½ cup) fresh, frozen or canned vegetable or fruit or 100% juice	210	26,250 ml	13,125 ml
Grain products (GP)	1 slice (35 g) bread or ½ bagel (45 g)	180	6,300 g	3,150 g
Milk and alternatives (MA)	250 mL (1 cup) milk or fortified soy beverage	90	22,500 mg	11,250 mg
Meat and alternatives (EA)	75 g (2 ½ oz.)/125 mL (½ cup) cooked fish, shellfish, poultry or lean meat	60	4,500 g	2,250 g

Table 2.
Recommended number and amount of food guided servings in a month for 51+ year-old females.

a) Weighted-sums method				
(w_1, w_2, w_3, w_4)	z_1	z_2	z_3	z_4
(0.7, 0.1, 0.1, 0.1)	147.197	372.000	3,957.000	588.000
(0.25, 0.25, 0.25, 0.25)	288.572	228.000	3,642.000	588.000
(0.1, 0.2, 0.5, 0.2)	297.812	181.059	3,464.118	148.235
(0.9, 0.025, 0.025, 0.05)	106.997	372.000	4,587.000	588.000
b) ε-constraint method				
$(\varepsilon_2, \varepsilon_3, \varepsilon_4)$	z_1	z_2	z_3	z_4
(1,820, 34,900, 586)	98.436	835.500	4,587.000	588.000

Table 3.
The efficient solutions.

Table 3 includes the results of ε-constraint method. The main objective function is about the cost objective. Based on the information in **Table 3**, more efficient solutions have been obtained in weighted-sums method. Consequently, this method is selected to solve the mathematical model.

One of the efficient solutions in **Table 3** has been obtained by considering equal weights (w_1 = 0.25, w_2 = 0.25, w_3 = 0.25, and w_4 = 0.25). The values of the decision variables related to this solution are as follows: $N_{1.3.1}$ = 11.250, $N_{1.3.2}$ = 11.250, $N_{2.2.1}$ = 4.667, $N_{2.2.2}$ = 4.667, $N_{3.4.1}$ = 3.775, $N_{3.4.2}$ = 3.775, $N_{4.1.1}$ = 7.500, and $N_{4.1.2}$ = 7.500. In other words, Food 1 in Group 3 in Periods 1 and 2, Food 2 in Group 2 in Periods 1 and 2, Food 3 in Group 4 in Periods 1 and 2, and Food 4 in Group 1 in Periods 1 and 2 should be purchased to have optimal solution.

7. The optimization model under uncertainty

In reality, several parameters are uncertain. In this section, the effects of uncertainty in two parameters including cost of foods and amount of food guide servings per month are examined in the mathematical model. These two parameters are very important factors of food items. Suppose that u represents a scenario among U scenarios. The decision variables (nonnegative variables in this case) are written based on each scenario [39]. A_{ihtu} is defined as cost of food i in food group h and period t in scenario u. It is noticeable that the costs of foods in different stores are usually different. Furthermore, Ψ_{htu} represents the amount of food guide servings per month in food group h in period t in Scenario u. m_u is introduced as the probability related to Scenario u. The new optimization model under uncertainty is written as follows:

$$\text{Min } z_1 = \sum_u \sum_t \sum_h \sum_i m_u A_{ihtu} N_{ihtu} \tag{20}$$

$$\text{Min } z_2 = \sum_u \sum_t \sum_h \sum_i m_u a_{ih} K_{ih} N_{ihtu} \tag{21}$$

$$\text{Min } z_3 = \sum_u \sum_t \sum_h \sum_i m_u a_{ih} L_{ih} N_{ihtu} \tag{22}$$

$$\text{Max } z_4 = \sum_u \sum_t \sum_h \sum_i m_u a_{ih} M_{ih} N_{ihtu} \tag{23}$$

$$s.t.$$

$$B_t \le \sum_h \sum_i a_{ih} C_{ih} N_{ihtu} \le D_t \qquad \forall t, u \qquad (24)$$

$$E_{jt} \le \sum_h \sum_i a_{ih} F_{jih} N_{ihtu} \le G_{jt} \qquad \forall j, t, u \qquad (25)$$

$$O_t \le \sum_h \sum_i a_{ih} P_{ih} N_{ihtu} \le Q_t \qquad \forall t, u \qquad (26)$$

$$R_t \le \sum_h \sum_i a_{ih} S_{ih} N_{ihtu} \le V_t \qquad \forall t, u \qquad (27)$$

$$X_t \le \sum_h \sum_i a_{ih} Y_{ih} N_{ihtu} \le Z_t \qquad \forall t, u \qquad (28)$$

$$\beta_t \le \sum_h \sum_i a_{ih} \lambda_{ih} N_{ihtu} \le \alpha_t \qquad \forall t, u \qquad (29)$$

$$\rho_t \le \sum_h \sum_i a_{ih} \gamma_{ih} N_{ihtu} \le \sigma_t \qquad \forall t, u \qquad (30)$$

$$\sum_i a_{ih} N_{ihtu} = \psi_{htu} \qquad \forall h, t, u \qquad (31)$$

$$N_{ihtu} \ge 0 \qquad \forall i, h, t, u \qquad (32)$$

It is supposed that the values of the two sources of uncertainty can increase, decrease, or remain same. Therefore, three situations exist for each source of uncertainty. The combination of the two sources of uncertainty produces nine

Scenario	Cost of food	Amount of food servings	Probability
1	$1.05A_{iht}$	$1.05\ \Psi_{ht}$	0.04
2	$1.05A_{iht}$	Ψ_{ht}	0.16
3	$1.05A_{iht}$	$0.95\ \Psi_{ht}$	0.04
4	A_{iht}	$1.05\ \Psi_{ht}$	0.16
5	A_{iht}	Ψ_{ht}	0.2
6	A_{iht}	$0.95\ \Psi_{ht}$	0.16
7	$0.95A_{iht}$	$1.05\ \Psi_{ht}$	0.04
8	$0.95A_{iht}$	Ψ_{ht}	0.16
9	$0.95A_{iht}$	$0.95\ \Psi_{ht}$	0.04

Table 4.
Nine scenarios in the diet problem.

	u	1	2	3	4	5	6	7	8	9
i	$h.t$									
1	3.1	11.812	11.250	10.687	11.812	11.250	10.687	11.812	11.250	10.687
1	3.2	11.812	11.250	10.687	11.812	11.250	10.687	11.812	11.250	10.687
2	2.1	4.899	4.667	4.433	4.899	4.667	4.433	4.899	4.667	4.433
2	2.2	4.899	4.667	4.433	4.899	4.667	4.433	4.899	4.667	4.433
3	4.1	3.963	3.775	3.763	3.963	3.775	3.763	3.775	3.775	3.763
3	4.2	3.963	3.775	3.763	3.963	3.775	3.763	3.775	3.775	3.763
4	1.1	7.875	7.500	7.125	7.875	7.500	7.125	7.875	7.500	7.125
4	1.2	7.875	7.500	7.125	7.875	7.500	7.125	7.875	7.500	7.125

Table 5.
The values of the decision variables (N_{ihtu}) under uncertainty.

scenarios. Based on the historical data, 5% change in the values of each source of uncertainty is examined. The basic scenario is Scenario 5. A summary of different scenarios in this problem is provided in **Table 4**.

The new model under uncertainty is solved by GAMS, and the values of the decision variables are calculated. There are 365 equations and 4,149 nonzero elements. **Table 5** includes the results. For instance, $N_{1.3.1.1}$ = 11.812. The results of Scenario 5 are the numbers that were calculated in the deterministic multi-objective model in the previous section. The maximum deviations are observed in scenarios 1, 3, 7, and 9.

8. Conclusions

Diet problem has been formulated in the form of optimization models in the literature. The main goal of the models is to minimize the total cost of the foods. In this chapter, a unique optimization model has been developed based on a case study in Canada. Four proposed objectives consist of minimizing the total cost, saturated and trans fats, and sugar; and maximizing the fiber of the foods. The data of this problem have been gathered based on the information in the official website of the government of Canada. The recommended number of food guide servings and the nutrition information are available in that website. In addition, nutrition facts tables are good sources of the core nutrients in the foods. They are mandatory for most of the foods in Canada. The proposed multi-objective model has been solved by two approaches containing weighted-sums and ε-constraint solution approaches. Then, the efficient solutions have been provided in two tables.

The effects of uncertainty in two parameters of the mathematical model have been investigated by a scenario-based solution approach. To this aim, nine scenarios for two sources of uncertainty (cost of foods and amount of food guide servings per month) have been investigated. Furthermore, the results have been analyzed. The proposed multi-objective model under uncertainty can be applied in real cases, and determine the food items accurately.

There are several opportunities to extend this research. We focused on a case in Canada. The proposed mathematical model can be extended based on the other cases in other countries such as European countries. Another future opportunity for research is related to the uncertainty in the problem. We concentrated on two sources of uncertainty. It is interesting to investigate the impacts of more sources of uncertainty at the same time. For the case of four uncertain sources, 3*3*3*3 = 81 scenarios should be considered. Therefore, computational time is an important factor for several sources of uncertainty.

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Appendix A

Based on the information in [57], the maximum total calories in 1 month (D_t) is estimated as 2100 * 30 = 63,000 (for females over 51). The minimum is 0.

Based on some studies, no more than 300 * 30 = 9000 milligrams (mg) of cholesterol for each month is recommended [58].

Based on the information in [36], the maximum total sodium in 1 month (V_t) is estimated as 2300 * 30 = 69,000 mg (for people over 51). The minimum is considered 0.

The maximum amount of vitamin A for 1 month is considered 1000 * 30 = 30,000 RE (retinol equivalents). In addition, the maximum value of vitamin

a_{ih}	1 (ml)	2 (g)	3 (ml)	4 (g)
1	1,750	675	1,000	1,224
2	1,750	675	1,000	750
3	1,750	675	1,000	596
4	1,750	400	1,000	537

Table A1.
Sizes of the foods.

A_{iht}	1	2
1.1	4.27	4.27
1.2	2.99	2.99
1.3	2.97	2.97
1.4	2.97	2.97
2.1	1.59	1.59
2.2	2	2
2.3	2.89	2.89
2.4	2.47	2.47
3.1	2.58	2.58
3.2	2.47	2.47
3.3	2	2
3.4	2.58	2.58
4.1	12.24	12.24
4.2	9	9
4.3	12.47	12.47
4.4	7.17	7.17

Table A2.
Costs of the foods ($).

C_{ih}	1	2	3	4
1	110/250	230/85	110/250	270/100
2	130/250	180/75	160/250	220/100
3	130/250	220/79	130/250	100/100
4	120/250	110/43	130/250	160/100

Table A3.
Calories of the foods (in each unit).

F_{jih}	1	2	3	4
1.1	0/250	0/85	100/250	0/100
1.2	0/250	0/75	100/250	0/100
1.3	0/250	0/79	100/250	0/100
1.4	0/250	0/43	100/250	20/100
2.1	1000/250	0/85	0/250	0/100
2.2	1000/250	0/75	0/250	0/100
2.3	1000/250	0/79	0/250	0/100
2.4	1100/250	0/43	0/250	0/100

Table A4.
Vitamins of the foods (in each unit), j = 1 (Vitamin A), j = 2 (Vitamin C).

K_{ih}	1	2	3	4
1	0/250	0.5/85	1.5/250	10.5/100
2	0/250	1/75	1.5/250	7/100
3	0/250	1/79	3.1/250	0.2/100
4	0/250	0.4/43	3.1/250	3/100

Table A5.
Fats of the foods (in each unit).

L_{ih}	1	2	3	4
1	25/250	1/85	12/250	0/100
2	31/250	3/75	26/250	0/100
3	28/250	2/79	12/250	0/100
4	22/250	2/43	12/250	0/100

Table A6.
Sugar of the foods (in each unit).

M_{ih}	1	2	3	4
1	0/250	2/85	0/250	0/100
2	0/250	7/75	0/250	0/100
3	0/250	2/79	0/250	0/100
4	0/250	1/43	0/250	0/100

Table A7.
Fiber of the foods (in each unit).

P_{ih}	1	2	3	4
1	0/250	0/85	10/250	70/100
2	0/250	0/75	10/250	65/100
3	0/250	0/79	20/250	60/100
4	0/250	0/43	20/250	75/100

Table A8.
Cholesterol of the foods (in each unit).

S_{ih}	1	2	3	4
1	15/250	480/85	120/250	55/100
2	20/250	300/75	170/250	60/100
3	10/250	420/79	120/250	50/100
4	0/250	230/43	120/250	80/100

Table A9.
Sodium of the foods (in each unit).

Y_{ih}	1	2	3	4
1	0.4/250	9/85	9/250	18/100
2	1/250	8/75	9/250	19/100
3	1/250	8/79	9/250	25/100
4	2/250	4/43	9/250	18/100

Table A10.
Protein of the foods (in each unit).

λ_{ih}	1	2	3	4
1	22/250	66/85	33/250	0/100
2	0/250	88/75	33/250	0/100
3	22/250	66/79	33/250	0/100
4	0/250	22/43	33/250	22/100

Table A11.
Calcium of the foods (in each unit).

γ_{ih}	1	2	3	4
1	0/250	2.8/85	0/250	2.1/100
2	0/250	1.4/75	0.28/250	2.1/100
3	0.28/250	2.8/79	0/250	1.12/100
4	0/250	1.4/43	0/250	1.12/100

Table A12.
Iron of the foods (in each unit).

C for 1 month is considered a big number. Furthermore, the maximum total calcium is assumed 1100 * 30 = 33,000 mg for each month. The maximum amount of iron is supposed 14 * 30 = 420 mg for 1 month. These values have been calculated according to the information in Percent-daily-value, 2018. The maximum total protein is considered as a big number because no daily-value has been mentioned for this element in [58, 59]. **Tables A1** to **A12** include other data of the problem.

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Chapter

Contribution of Professional Pedagogy to Decision-Making

Franco Blezza

Abstract

The aim is to offer a contribution to the problem of decision-making in the world of the higher intellectual professions, considering the pedagogy as a paradigmatic profession in the social, caring, and helping field. Pedagogy is an ancient science and profession, like medicine and jurisprudence, as it is known. The professional practice, in the social field as in the health and in other fields, consists in reconnecting the complex phenomenology of each singular particular case to a more limited number of general cases, theories, or disciplinary casuistries. It is a question of making a diagnosis, in a broad sense of the term. For this procedure, both the positive inductivist approach, from many facts to the generalization, and the idealistic and deductive approach, from general a priori ideas to the particular, are obsolete. We then examine the pragmatistic concept of abduction and, more generally, the contributions of the most up-to-date methodology, just as it is applied in the practice of professionals.

Keywords: professional pedagogy, methodology, abduction, clinical method, Sozialpädagogik, social professions

> *Il mio maestro era veramente molto acuto.*
> *"Ma quali conclusioni traete da questa scoperta?" chiesi allora.*
> *"Nessuna," mi rispose "solo delle premesse."*
>
> *My teacher was really very intelligent.*
> *"But what conclusions do you draw from this discovery?" I asked then.*
> *"None," he replied me, "just some premises."*
>
> *(Umberto Eco, 1980)*

1. Aim

Pedagogy is a fully fledged science in the wide field of the *human- sozial- geistes- Wwrtschafts- Wissenschaften* or human- social- intellectual economics (sciences). A fundamental methodology is common to all these sciences: a beginning by problem posing and attempting solutions, subject to the rules of logical coherence and factual control; otherwise they cannot accurately call themselves sciences/Wissenschaften.

As such, it brings its contribution to other social sciences, particularly the problems of application of decision science in business and management. This is, from a general point of view, the fundamental aim of the present chapter.

Methodological considerations will broadly demonstrate their necessity and essence, as indeed was to be expected and is perfectly logical.

2. A profession and a science current with an ancient history: perhaps they can help us

Although the term seems to have appeared at the end of the fifteenth century, pedagogy as a science and a profession has over 2500 years of history, and this claim has a meaningful sense as many of the conceptual and operational tools and many technical terms date back to those remote origins, as well as subsequent developments.

Among the Greek-classical conceptualities of the ante litteram pedagogy, it will be enough to mention some of the most famous ones: ὁ διάλογος (the dialogue) in its two phases ἡ ειρωνεία; (irony) and ἡ μαιευτική τέχνη (the art of the midwife); γνῶθι σεαυτόν nosce te ipsum (let know yourself) and condemnation of ‘ὕβρις, the superb and arrogant violation of this character, tools and warning of the latter’s evident momentum; πολιτέια (politics in the city-state), classic Logic and ‘ρητορεία (rhetorics) and all that pertains to political life, the art of public speaking, of obtaining consent, of constructing well-made sentences, ἡ ἐπιστήμη and οἱ λόγοι, two different ways of speaking about sciences and fields of study. Other examples of specific interest in our theme will bring us back to that historical period in their utmost importance, as we shall see.

But they are just some particularly emerging examples. Much of the Greek-class philosophy, including the described examples, can be summarized on the basis of the colossal *scientific culture* of that people: a knowing that it aroused our admiration, but that it was never intended for the application, even though it included electricity, magnetism, heat transformation in mechanical energy, and much more knowledge that would revolutionize human life in different periods, with particular regard to the last two to three centuries.

To understand today’s professional pedagogy [1, 2], it is necessary to carefully consider the historical and cultural turning point of fundamental importance that came with the end of the proper modern era (sixteenth, twelfth, and eighteenth centuries, anticipating the beginning of some decades) with the Enlightenment, the bourgeois revolutions, the end of the modern or absolute state, the seizure of power by the bourgeoisie, and the Industrial Revolution and the related enormous changes and accelerated processes.

It was a turning point of fundamental and easily understandable importance for education, rapidly consolidating an educational system that has held up until 50 years ago but also for relationalities, society, the human psyche, and man in general.

In fact, in the nineteenth century, the Sozialpädagogik [3–5][1,2] was born; skittles like sociology, psychology, psychoanalysis, and many other disciplines that would have founded the corresponding social professions in the following century, responding to an increasingly strong, obvious, specific social demand, were born.

3. Method issues

From the teaching of Wilhelm Windelband (1848–1915) until today, the distinction between the sciences and between knowledges, between the various ways of using human creativity, must be traced not to the subject of study but to the method of study and professional application, also of professional application. Medicine, surgery, psychology, anthropology, and pedagogy study the same man, but with essentially different methods and professional applications.

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[1] See also the abundant and significant production of social pedagogy of Émile Durkheim, widely accessible in public domain as for the work we’ll mention.

[2] The complexive synthesis on Sozialpädagogik is in Ref. [5].

Generally speaking, the method of pedagogy, which identifies it and distinguishes it from other sciences and professions, is a composite method. Pedagogy is a field for collecting and incorporating different inputs, for integration, and for addressing educational purposes that are not the aims of the original sciences.

The methodology of pedagogy is articulated with continuity between two opposite and mutually exclusive polarities:

- The operational statistical methodology.
- The situational case study (casuistry) methodology.

The first methodological polarity, a search for measurable data in large populations to be treated with statistical methods, is widely present in the quantitative studies and researches of the social sciences, including an important part of pedagogy; in Italy we speak about *pedagogia sperimentale*. The components of the sample population can be correctly called "individuals." We will not take away from this methodology in this chapter.

In the particular field of the scholastic pedagogy, the most relevant institutional pedagogy and in certain aspects non-secondary of Sozialpädagogik, a situational casuistic methodology has long been followed and for decades on this basis progressively increasing, and more essential elements of operational statistical method have been inserted and integrated.

In this chapter we will deal with the second polarity, which besides all is the canonical methodological choice for pedagogical counseling, interlocution, dialog (Socratic διάλογος but without ἀλήθεια), and more generally for the personal provision of the aid's relationship specifically pedagogical.

It is the most suitable for the treatment of personal problems, of couples, family, parenting, and of single persons in social situations, including school and work.

This second choice of method currently takes the name of "clinical" method. In the use of this adjective, and of the corresponding noun, we can also recognize a meaning of etymological type. In classical Greek, κλινικός was an adjective referring to the intervention on the couch (κλίνε) where the patient was; that is to say, an intervention properly in situation, an intervention in which the professional enters, correctly and strictly, in the context, in the environmental contingency, of the recipient; and this is consistent with the way in which the professional practice of the medical doctor is intended to refer to the patient's illness or disease, as is immediately evident. There is no substantivation: today's "clinic" may correspond to ἡ κλινιχή τέχνε.

We should also remember the increasing use of the Anglo-American term clinic, to indicate a sports or musical session, for example, with an athlete, an artist, and an example of particular value, in which the great personage of human activity enters in the context of a team or a complex or a band or other human societies, to bring his own example in the very particular case in which the clinic takes place. And this is an exceptionally effective way of proceeding as education and Bildung, which generally requires limited time and efforts.

In this methodological approach, for the interlocutor, the Latin term persona is used, the actor's mask which allows to recognize some characters and which was also used figuratively. The proponent of this term (in Greek πρόσοπον) which was to become the technical term for the social sciences was Johannes Damascenus (from Damascus, 675–749).

In a reciprocal way with respect to the statistical procedure, in the clinical method, every single subject is unrepeatable and must be considered with all its peculiarities. Doctors often say that they treat sick people and not diseases. A pedagogist could say that he cares for men who have complaints and not human problems.

The question, at this point, concerns general cases: it is understood that there is neither science nor higher intellectual profession without general laws and theories and general cases: so for a medical doctor (the diseases), as for a pedagogist (the casuistries of general cases), as for an architect (the construction science), and so on. How does one go back from particular cases to general cases?

The solution to the question lies in the human mediation of the qualified professional and with his experience, and in a little-known conceptuality, abduction (abduction), called also retro-ductio (retro-duction). Here is also the substantial contribution that pedagogy can bring to the decision-making process, as previously intended in this chapter.

The professional pedagogy, as in this particular regard as in all professional practice, involves the use of old ‘απαγωγή known by Aristotle (384–322 BC), used as a figure of speech in particular in the field of philosophy, logic and legal or juridical, approachable to reductio ad absurdum of Zeno from Elea (489–430 BC). This is used to justify the falsity of a statement underlining the absurdity of the consequences of its application.

The whole theoretical framework of reference for the profession pedagogy refers to the classic Pragmatism [6, 14, 15][3] or to a Neopragmatism current perspective.[4] The[5] concept of abduction was formulated by Charles S. Peirce (1839–1914) [14–17], as inference and not as an argument or a demonstration; it represents an alternative to induction and deduction, which provides an opportunity and a chance that we would call “corroboration” in accordance with the concept of the critical rationalism by Popper [19], with some similarity to the concept of “educated guess,” about which we’ll have to discuss later too.

4. The decision process in the pedagogical interlocution context: the abduction

In substance, and taking the topic of this contribution into account, we can describe synthetically the abduction as follows:

Rule	the general case A presents (or can present) the B_1, B_1, B_2, … B_n, … phenomenology
Data	the evidences B_1, B_2, … B_n, … of a particular case repeat aspects that can be considered professionally experienced to include reference into the A general case. and no other reasonable hypothesis explains these evidences as well
———	———
Clinical diagnosis: …	the case we are studying, with the B_1, B_2, … B_n, … evidences, constitutes a particular case of the general case A

Pay attention: the abduction is not a valid syllogism; it concerns a possible example of a general case or of a rule, whose actual pertinence to this general case or this rule is mediated by the professional or expert assumptions.

[3] Among the rich production of John Dewey we exemplify [8–10]. All these works are public dominium in the Web.

[4] We have been dealing with pedagogical Neopragmatismum since the 1990s, see [11, 12]. It is a research that continues through the developments of Pedagogy as a social profession.

[5] A good comprehensive treatise in Italian language is [13].

Someone speaks of gambling and of guessing, and instead it is the maximum exaltation of professionalism and, ultimately, of human mediation, of the anthropological principle.

It is suitable to increase our knowledge, to advance new hypotheses, and make predictions, which can find their substance in the past experiences, particularly thanks to some professional skills. But it is also the operative way of reasoning to be more subject to the risk of error. It, like the induction, doesn't contain its logical validity in itself; therefore it must be assessed through empirical tests, the previous mentioned *future experience*, following a fundamental thought (or principle) of the classical Pragmatism.

Abduction with diagnosis and choice of the general case is an important type of decision; if it is expressed, the translation of the previous table in terms of decision-making is immediate and clearly evident. It is essential in any case the mediation of the professional with his experience and his competence, which, more generally, is a reference to the value of the anthropological principle; reality is knowable, diagnosable, and decidable because there is man.

Given that factories of certainty and finality do not exist and cannot exist in human affairs, we observe that this is certainly a risk, but an inevitable risk, calculated and not arbitrary. The essential is the professional meditation, which is the human factor.

Knowledge	the general decision A is indicated for the phenomenology $B_1, B_2, \ldots B_n, \ldots$
Data	the evidences $B_1, B_2, \ldots B_n, \ldots$! of a particular case repeat aspects that can be considered professionally experienced to include reference into the A general case, and no other reasonable hypothesis explains these evidences as well
Clinical decision	in the case we are studying, the $B_1, B_2, \ldots B_n, \ldots$ evidences, constitutes a particular case of A

5. Decision-making, *Logik der Forschung*, professional pedagogy, open society, coexistence, and civil and democratic society

We can understand from the pedagogical professional approach that we are following the problem of decision-making, having given the essential importance to methodology, that there is a huge common domain for the natural sciences and for the humanities, both being absolutely analogous in method.

These are speeches that still face heavy resistance in contexts like the Italian one, where for a long time philosophy has imposed a tyrannical power, claiming to judge, devaluate, upset, and hierarchize other knowledges.

In the background, we come to identify the closed dualism between positivism and idealism. It is a nineteenth-century philosophical railway that cannot be resolved, but with respect to which it is necessary to place oneself decidedly and unconditionally outside.

It is particularly suitable for our purposes what has been done since the nineteenth century by the American Pragmatism, while the Positivism-Idealism dualism was European; and, in the twentieth century, from Epistemology and in particular

from Karl R. Popper (1902–1994) who built his "Logik del Forschung" precisely starting from the critique of Logical Neopositivismum and any form of cognitive inductivism.

Logic induction is not just an obsolete theory, but also it does not exist. This, since it is not possible from a number how much high of positive data, how much it can be desired, to infer actually the universal quantifier "always", "for every A of a certain domain". We must recall that the logical form of scientific laws is indeed a universal implication in a domain, i.e. "for every A in a certain domain, if A then B", Well, we cannot generalize even if we have observed or detected many Bn referring to A and without exception.

But there is not even an inductive decision making process: the experiences and facts, always provided they are numerous and consistent, are rather a requirement that the decision maker, the diagnostician, the pedagogist, the designer, the teacher must possess as a professional experience, but this abduction, the professional decision, remains only "corroborated", possible and valid until proven otherwise. The decision is a hypothesis built by man to try to solve human problems; the answers to the questions "what do you do when you have raised a problem" and "what do you do when you have to make a decision" are not "you solve it" and "you take it" but "you make an attempt of decision or solution"; a well-founded example of possible decision and solution is devised on the basis of one's own professionalism and experience, without ever being able to be certain.

At this point, there is often an answer that exemplifies dual reasoning, the simplest and most trivial one, that of younger children, that of people not at the forefront of civilization, and also that of all digital tools, which are notoriously stupid and yet have the advantage of speed and huge data processing.

Among those who emphasize the nonexistence of the inductive method, it is indeed easy to find someone whose reasoning skills are limited to dualism, which replies by proposing the use of the deductive method, as if it were the only alternative available. If we cannot proceed inductively, can we proceed deductively? Finally, if abduction is not a tautology, the modus ponens is an immediately intuitable tautology, and it is quite obvious: "if A, and A implies B, then B."

The fundamental argument is that in human affairs, that is, in everything we are dealing with in this chapter, we have no way of establishing the truth of an A which is its own, and the deductive method, however appealing it may be, has no applicability.

We can explain it more clearly: the truth of the deductions has as a necessary condition the a priori condition of the premises. We can proceed "as if" the premises were true, and as long as the deductions work, we can also benefit. But A may be false as it is believed to be true, and we should be fully aware of it if we make decisions by deduction.

In Italy exists a τόπος *la matematica non è un'opinione*, translated as more or less "mathematics is not an opinion." It is absolute dogmatism, or trust, in the deductive and axiomatic method even among those who ignore what is the axiomatic of numbers or of sets theory and perhaps have a vague idea of a single axiomatic geometry, that is, that Euclidean one. The scientific ignorance, a serious responsibility of the philosophical neo-idealist tyranny in Italy mentioned above, also leads to this.

And yet, any nonintuitive but axiomatic mathematical theory is true as long as this or that system of axioms is assumed to be true: Euclidean geometry in particular had a critical point in the last of its five axioms, and indeed replacing it with alternative axioms created various families of "non-Euclidean" geometries. We could also exemplify with logic or set theory; the negative conclusion remains: it is not true that mathematics is not an opinion.

Two and a half millennia after Socrates and after so much classical, Latin, and medieval philosophies, we can affirm that we do not only need any αλιεια, in

human things such as natural and social sciences, or technique, but also philosophy, literature, and figurative arts.

Which takes the place of so many unthinkable absolutisms is the idea of a continuous research, without end or τέλος, with a continuous position of problems—questions—alternatives—decision-making moments and so on, the practice of human creativity to face them with products that are always fallible both in terms of internal consistency or logic and in terms of empirical testing, what Pragmatists called "the future experience."

The result is the image of an open society, which values experience to the extent that it is part of a very specific professional competence practiced and applied in the interests of all. Nothing is true, everything is questionable. Human history, neither the macrostoria nor the mycristorias of each of us, doesn't have and cannot have a direction; there is no progress if not local and partial; rather history, in all senses, has a verse, that of increasing entropy that of the arrow of time, that of cultural evolution, and that for which one cannot retrace in the opposite direction what one has already traveled. And it is not even possible to stop.

Let us take a look at a historical background already made, after the transformations at the end of the eighteenth century that constituted a transition from an historical epoch (the modern era) to the following that still does not have its own historiographically consolidated name. Well, in 1814/1815 Der Wiener Kongress represented an illusion and a pathetic operation that would have tended to make the hands of history go back or at least stop the evolution of new ideas. It is well seen: the illusion would have lasted a few decades.

Be careful, we talk about "evolution" and not about "progress"; the Latin etymology is illuminating. The term "progress" derives from the Latin *progredior*, that is, to go forward: it is a matter of believing that humanity gives rise to a history that is like a linear proceeding with a prevalence of improvements. We rather use the term "evolution," from *e*—from and *volveo*—I turn away, just in the sense that there is no direction and in the sense that there is no turning back.

6. Karl R. Popper: *Logik der Forschung* and open society

Popper's (1902–1994) first proposal concerned epistemology [20]. This proposal of philosophy of science, which he himself preferred to call Logik of Forschung just as from the title of his fundamental work. The "scientific" booklet was added only with the English edition of its fundamental work [20]. In the middle there where the Second World War and the first postwar period with the Cold War.

His vision of science is known as critical rationalism, or fallibilism, although the first to speak of fallibility was Charles S. Peirce (1839–1914) [18], the scholar of logic among the founders of Pragmatism.

His proposal in the political field [21, 22], the open society theory, was known later, even if in Italy it was known previously.

In order for a society can be defined strictly "open," the fundamental and unavoidable condition is not who should govern, but that government practice is controlled by the sovereign people: controlled in itinere, with the social tools of today's information, which suggest the pedagogical importance of the public speaking in the ancient Greece and, in imperial Rome, Marcus Fabius Quintilianus (35–96) and *Institutio oratoria* (70–90 about); and above all by the time the decision returns to the same sovereign people, who can confirm the ruler or revoke it and replace it with another, without this handing over involves any problem or any violent and bloody implication.

In summary, we derive the teaching that decision-making must go hand in hand with general and intersubjective controllability, without privileged controllers being possible or even conceivable.

7. The scientific contribution of Umberto eco: a semiologist novelist

Umberto Eco (1932–2016) is internationally known to the general public first of all as a writer, as a novelist. But he is even better known among the experts as a semiologist, as a scientist of signs, from the fundamental *Opera aperta* [23]. The title's locution indicates a work that includes several readings, which allows multiple interpretations, and in the most important part of his university career, he completed in the faculties of architecture (of Florence and Milan).

Umberto Eco wrote in his most famous narrative work (a novel) *Il nome della rosa* (Bompiani, Milan (1980)), discussing of solving a mystery which for us is a very general way of understanding the diagnosis, the formulation of a scientific law, the decision-making, and the hypothesis of a solution in a single phrase of a problem.

The narrator is the elderly monk Adso von Melk, who tells an extremely involving story of when he was a young novice, a student of the expert and critic William of Baskerville, Franciscan monk on the occasion among the Benedictines.

The whole book focuses on a complex of mysteries and deaths, so it allows us to extend our methodological analogy to detection, which also involves a complex of decisions, in particular on the causes and the colas of events.

William tries to explain to Adso in simple terms the methodology to be followed: "*risolvere un mistero non è la stessa cosa che dedurre da principi primi*.
E non equivale neppure a raccogliere tanti dati particolari per poi inferirne una legge generale. Significa piuttosto trovarsi di fronte a uno, o due, o tre dati particolari che apparentemente non hanno nulla in comune, e cercare di immaginare se possano essere tanti casi di una legge generale che non conosci ancora, e che forse non è mai stata enunciata."[6]

The discourse has a complex articulation opposed to the deduction from the first philosophical principles. They are assumed, precisely, as if they were unquestionably true for theological reasons and for this reason susceptible of deduction that produces certainties.

William is cautious, hypothetical, inspired by a genuine benefit of the doubt: "Onestamente, io non so se le ragioni che ha trovato siano quelle buone, né ho mai controllato [...] la ricerca delle leggi esplicative, nei fatti naturali, procede in modo tortuoso. Di fronte ad alcuni fatti inspiegabili tu devi provare a immaginare molte leggi generali, di cui non vedi ancora la connessione coi fatti di cui ti occupi: e di colpo, nella connessione improvvisa di un risultato, un caso e una legge, ti si profila un ragionamento che ti pare più convincente degli altri. Provi ad applicarlo a tutti i casi simili, a usarlo per trarne previsioni, e scopri che avevi indovinato. Ma sino alla fine non saprai mai quali predicati introdurre nel tuo ragionamento e quali lasciar cadere. E così faccio ora io. Allineo tanti elementi sconnessi e fingo delle ipotesi. Ma ne devo fingere molte, e numerose sono quelle così assurde che mi vergognerei di dirtele. [...] Vinsi, ma avrei anche potuto perdere. Gli altri mi hanno creduto saggio perché ho vinto, ma non conoscevano i molti casi in cui sono stato stolto perché ho perso [...] Ora, sui casi dell'abbazia, ho molte belle ipotesi, ma non c'è nessun fatto evidente che mi permetta di dire quale sia la migliore. E allora, per non apparire

[6] "*solving a mystery is not the same as deducting from first principles. Nor does it amount simply to collecting a number of particular data from which to infer a general law. It means, rather, facing one or two or three particulars data apparently with nothing in common, and traying to imagine whether they could represent so many instances of a general law you don't yet know, and which perhaps has never been proposed.*" [24].

sciocco dopo, rinuncio ad apparire astuto ora. Lasciami ancora pensare, sino a domani, almeno."[7]

In fact, it is a novel for its developments. The anticipation of the *Hypotheses non fingo* formula by Isaac Newton (1642–1727) in a novel set at the beginning of the fourteenth century would be excellent, but in the English translation in our opinion is not put in proper evidence.

The pupil and novice Adso, narrator of the novel in old age, reports his reflections: "*Capii in quel momento quale fosse il modo di ragionare del mio maestro, e mi parve assai difforme da quello del filosofo che ragiona sui principi primi, così che il suo intelletto assume quasi i modi dell'intelletto divino. Capii che, quando non aveva una risposta, Guglielmo se ne proponeva molte e diversissime tra loro. Rimasi perplesso*.

> *"E voi," dissi con infantile impertinenza, "non commettete mai errori?"*
>
> *"Spesso" rispose, "Ma invece di concepirne uno solo ne immagino molti, così non divento schiavo di nessuno."*
>
> *Ebbi l'impressione che Guglielmo non fosse affatto interessato alla verità, che altro non è che l'adeguazione tra la cosa e l'intelletto. Egli invece si divertiva a immaginare quanti più possibili fosse possibile.*
>
> *In quel momento, lo confesso, disperai del mio maestro e mi sorpresi a pensare: "Meno male che è arrivata l'inquisizione." Parteggiai per la sete di verità."*[8]

The young Adso, perhaps even as an old man, seeks the truth by describing it with the philosophical phrase *Adaequatio rei et intellectus* which was expressed a few years before the story told by Thomas Aquinas (1225–1274) based on previous sentences of Avicenna (980–1037) and before that by Isaac Israeli ben Solomon,

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[7] "*Honestly, I do not know whether his conclusions are the right ones […]. I was trying to tell you that the search for explicative laws in natural facts proceeds in a tortuous fashion. In the face of some inexplicable facts you must try to imagine many general laws, whose connection with your facts escapes you. Then suddenly, in the unexpected connection of a result, a specific situation, and one of those laws, you perceive a line of reasoning that seems more convincing than the others. You try applying it to all similar cases, to use it for making predictions, and you discover that your intuition was right. But until you reach the end you will never know which predicates to introduce into your reasoning and which to omit. And this is what I am doing now. I line up so many disjointed elements and I venture some hypotheses. I have to venture many, and many of them are so absurd that I would be ashamed to tell them to you. […] Now, for the events of the abbey I have many fine hypotheses, but there is no evident fact that allows me to say which is best. So, rather than appear foolish afterward, I renounce seeming clever now. Let me think no more, until tomorrow at least.*" [24].

[8] *I understood at that moment my master's method of reasoning, and it seemed to me quite alien to that of the philosopher, who reasons by first principles, so that his intellect almost assumes the ways of the divine intellect. I understood that, when he didn't have an answer, William proposed many to himself, very different one from another. I remained puzzled.*

> *"But then …" I venture to remark, "you are still far from the solution. …"*
> *"I am very close to one," William said, "but I don't know which."*
> *"Therefore you don't have a single answer to your questions?" […]*
> *I had the impression that William was not at all interested in the truth, which is nothing but the adjustment between the thing and the intellect. On the contrary, he amused himself by imagining how many possibilities were possible.*
> *At that moment, I confess, I despaired of my master and caught myself thinking, "Good thing the inquisitor has come. Was on the side of that thirst for truth", [25].*

(855–955) which referred to the correspondence between reality and its linguistic and conceptual representation.

The indicated methodology is the way through which to carry out this passage: this is the meaning of the Greek-classical locution μέθοδος (μετά through, in search of, in the direction of; and *ὁδός*, road, itinerary).

Abduction, or retro-duction, is neither positivistic and empiricist inductivism nor idealism with the postulations of some a priori truth.

It is significant that the inspiring master and philosopher of the protagonist, Brother William of Baskerville, acute inquiring and investigator, is Roger Bacon, Doctor Mirabilis (1214– about 1294), also a Franciscan friar, an empiricist thinker, and precursor of the science of the modern age.

8. No progress, no direction in history, and no increase in verisimilitude in scientific research, in society, and in decision-making

The renunciation of speaking of truth in human affairs, such as those in this chapter, has left the conditions for a very particular conception of progress, at least in the Popper of fundamental works, and for about 50 years.

In a science devoid of truth and always falsifiable, it was believed to identify a criterion of progress in verisimilitude, in the sense that a theory was to be considered progressive with respect to the previous one in that it was able to explain the same phenomenology and explained it further. In extreme synthesis, one would never have truth, but a little more truth, or an approach to the truth, or a greater similarity to some image of truth.

But it was Popper [26–29] who admitted his mistake to the very brief expiry of the knowledge of the now well-known theorem of Pavel Tichý[9,10] [32].

All this is equally true for decision-making. The overall pragmatist methodological framework from the nineteenth century and then epistemological and neopragmatist in the twentieth century has kept its function perfectly and to this day has no alternative.

In fact, one should easily guess that it makes no sense to talk about approaching the truth or bringing about verisimilitude, where truth has also been renounced as a conceptual tool, and in any case the renunciation remains, at most the truth can become an ideal trend, which could therefore not even exist.

A little more complex is understanding the substance of Pavel Tichý's message: more or less in a theory that cannot be said to be true, one cannot add truth without thereby adding falsehood, and vice versa one cannot remove falsehood without thereby even take away the truth. It is less difficult to guess than to formalize. Are we willing to take this into account in decision-making?

Among the epistemologists/philosophers of science/logics of research and also among the historians of Popperian matrix, an orientation was expressed for a vision of science on a journey through a particular type of utilitarianism; the evolution of science is progressive as it allows ever greater applications and benefits for man and mankind. This shifts the problem to utility criteria: there are achievements of science that improve some aspects of life and make it worse than others or that improve life for some and not for others, and so on.

For a philosopher, even a philosopher of science, it is certainly a heavy withdrawal to resort to instrumentalism where science was affirmed as a form of

[9] On Popper's definition of verisimilitude [30].

[10] Verisimilitude redefined [31].

essential knowledge; it is not so for pedagogy, so much so that Dewey's pedagogical theory, which is the most substantial part of pedagogical Pragmatism, was called instrumentalism. For us pedagogists the only essence is the man: all the rest, starting with education and pedagogy, are tools for man and humanity.

From a narrow epistemological point of view, it should be added that rather than talking about truth in any way in the research process, we should talk about reality or the phenomenology of reality. Perhaps to some extent, the scientific research in its historical evolutionary course is approaching: the phenomenology of the real, its prediction, its understanding, and an interaction that can be more functional to humanity. But it is not even said that this is so. This is just another hypothesis; if we prefer it is a meta-hypothesis.

9. The person and the clinical eye

In decision-making, as in pedagogy, the concept of the person avoids this complex of difficulties, confusion, and lack of solutions and answers. It is all the more clear that pedagogical help lends itself to the person, even for his being part of a couple, a family, a partnership, a service, and any social aggregation, and if we speak of "helping the family" or "helping a sports team," we use a synecdoche, a rhetorical figure consisting in talking about a part talking about the whole. We still deal with a social subject, part of the society in its instances, precisely the person always.

The discourse on decision-making can be different, sometimes concerning the person and sometimes not: think of the example of a sports team, which is much more than the sum of the people (players), or of a professional team. However, the sports team or the professional team builds up to common aims and objectives, that is to say to common personal expressions; the decision will be taken by the most expert, the manager, the coach, and so on, for abduction, starting right from the people making up the group and taking into account exactly how much of the group the team allows to realize: over-personal, but essentially personal in nature. The person, unlike the individual of a statistical sample, has his own values, his own sense of life, his own interpersonal communication network, and his own political essence. The decision is constructed precisely considering, in addition to the individuals, these expressions as they become common in the constitution and in the functioning of the group.

On the other hand, having said that empirical induction does not exist and that decision-making abduction is based on the data and evidence that the expert gathers in the group members, it is understood that this survey cannot be general but selective, highly selective and guided by the observer's competence. It is a matter of generalizing and also of the decision-making discourse that the concept of "clinical eye" should not be considered reduced to the only category of surgeons or similar professions. At the base of a good decision of the trainer, the coach, the manager, and the team leader (etc.) is his clinical eye on the evidence of the components to be detected and reworked, an essential part of his professionalism.

Also in other sectors, not only in medicine surgery and in professional pedagogy, the clinical eye is a reasoning eye, and that is the essential premise for the maturation of experience, part of professionalism and leadership.

Who decides can also give the impression of seeking the decision within himself, and in some respects it is so. But an essential premise is a lot of experience on the evidence in the decision field and on the situation in which the decision is required, which must presuppose the clinical eye in the decision-maker.

There is a further reflection to be made between the consequences of Tichý's theorem and the decision by anyone with responsibility for a group, a social reality, a team, an *équipe*, a department, an association, and so on. Stripped of the pretense of having some truth or of being able to conquer it or even approach it, and carefully considering the conceptuality of the person and of the clinical eye, we see that acting on the person is not and should not be considered a limitation as it does not treat his subjects as individuals or elements. This is what gives meaning to his professionalism in the clinical eye, and that fully (or more possible) enhances the group of people being something more and different than the sum of the characters of the individuals of a sample.

Deciding on people is more consequential and different than deciding on individuals.

10. Decisions that cannot admit explicit systematic doubt and must deny fallibility

In summary, from the professional pedagogy comes an indication that crosses the natural sciences, the human and social sciences if and as they are sciences such as the latter and the first, civil and democratic coexistence, and other sectors of the humanities. The decision, sometimes a solution to a problem, sometimes a law or scientific theory or an idiographic description, is always and in any case a hypothesis created by man in an attempt to solve human problems, subject to the laws of logical coherence and above all of fallibility. The systematic doubt should never be lacking; the knowledge involved cannot be considered "strong knowledge," but on the contrary it is weak knowledge, indeed very weak, which owes precisely to their weakness, their ability to evolve and their transferability from one person to another one.

We have seen various implications of this vision, not without mentioning possible misunderstandings deriving from the legacy of the philosophical nineteenth century, of European philosophy polarized between positivism and idealism. This is all the more evident when we consider the professional aspects of these human and cultural sciences, as well as of course of the natural sciences.

All this does not detract from the human need, which is anything but infrequent, to come up with well-defined decisions that leave no room for doubt, which bring with them certainty and decision-making. Among the *théories pratiques*, Durkheim exemplified medicine, politics, strategy [33], and even, scattered in his works, other sciences, techniques, and human professions.

Well, can a surgeon decide for an operation that presents certain risks or not to carry out an operation that presents other certain risks, simultaneously with all those reserves of hypotheticality, doubt, fallibility, and the others that we have illustrated up to here? Can a military commander give the order to attack or retreat with similar clarifications? Could a politician do it in the performance of his duties? In this case we might also think that it should be done more frequently and with more conviction than it actually is, but the problem is that a decision that must be made without any methodological superstructure imposes itself, in politics, almost always. What about the designer of a civil artifact that must rule on its security and on the manufacturer of a drug that must guarantee that the benefits of the administration, given certain conditions and observed certain warnings, are preferable to non-intake? Even the judge, who is a man who professionally sentences about other men on human problems, and who can impose penalties that in some countries reach the death penalty even in our own time, pronounces "beyond every reasonable doubt," when the only reasonable reality of doubt and its irrepressibility anyway?

Without going into the specifics of each of these and the other innumerable examples that we could bring, it is clear that we are dealing always with decisions consisting of hypotheses created by man, fallible and questionable, about which we always and in any case doubt. The suppression, or suspension, of these and all the other warnings, which for those who have a minimum scientific culture are purely formal and will never be substantial in any case, can indicate the need to corroborate the decision-hypothesis in the most humanly way as possible, performing cross-checks, involving different points of view and skills, and bringing together different human, scientific, social, and political positions as such. We can try to reduce the risk of error to the minimum, as much as humanly and socially possible: but infallibility will never be possible in any human thing.

Anymore, the reflections and considerations that we could make on this subject are many, and so far we have remained to the exemplification. But the problem of the need for certainties, around decisions which, being hypotheses and human creations, cannot but be fallible, is in substance unsolved.

11. Toward some conclusions

Ending the chapter, we understand how and why it is not possible to operate some form of "conclusion," since our whole discussion is centered on an institutionally open and unlimited discourse, without end or έλος, in continuous evolution (and not in progress!). It is always a questionable discourse on a social level and on a level political in a broad sense, the heritage of everyone as it is transmissible intersubjectively like any theory, law and scientific evidence and as it is not personal opinions, ideologies, faiths, philosophical theories, and so on, listing what is not it has been the subject of our discussion if not "to complementary."

Curiously, in the Italian language the adjective *discutibile* (questionable) has a fundamentally negative use, tending to devalue what it is applied to. Instead, we will understand that questionability is an invaluable value of a pedagogical discourse, and human in general, as it brings openness, evolution, culture, sociality, and much of what man needs, even or before all in terms of decisions.

Then there is everything that is not considered questionable, but it can only be the object of a personal adhesion. Indeed, as the contemporary Pedagogy warns us, we must stigmatize any attempt to enslave other human persons to, or under, beliefs considered infallible, certain, definitive, dogmatic, ideological. They are all behaviors humanly incongruous. Often such attempts are cloaked in disguise, making one believe that the imposition of an ideology is made "for the good" of the recipient, or of a social class, or of the whole society. This is not the case, and no one must fall into the trap of discussing the goal: man is never a tool to extrinsic ends; he will always be only a purpose in itself.

As such, each human person has every right to make his own decisions or to assume from those who believe the decisions he needs, facing fallibility, doubt, uncertainty, and the limits of human creativity, but also the openness, evolution, the possibility to correct oneself, and so on.

This, in essence, is the lesson of professional pedagogy for just under two centuries. We do not educate despite our limitations but precisely because we have limits and tend to go further, as a sort of personal ethics. Our limits, recognized for such and made the basis of the educational act and pedagogical professional practice, are the highest expression of our love for man and for humanity and of our dedication to those entrusted to our education and our professional pedagogical intervention.

12. Possible overall conclusions

Empirical induction does not exist, as Karl Popper imply demonstrated by placing this critique as the foundation of his *Logik der Forschung*.

The logical deduction is a correct and tautological procedure, but it poses the problem of validating the system of premises, with the current risk of an infinite regression, and also poses the problems of what logic applies, of how inferences are operated.

For the decision in every field, for the medical-surgical diagnosis or for the pedagogical diagnosis, for the proposal and development of laws and theories in nomothetic sciences (both natural sciences and human, social, and culture sciences), and for any human act of choice and determination, even in the economic world and in the world of the work or of business, an alternative exists in Western culture, an alternative which has its roots in classical Greece and which had its strict formalization in the nineteenth century at the Pragmatism of Charles S. Peirce.

These are acts of practice of human creativity in an attempt to resolve certain human problems, in which the passage is from the particular to the general, from evidences or data to the general case, and is operated by the necessary mediation of the qualified, trained professional and expert; logically it is not a tautology, i.e., a true formula, fallibility characterizes the decision as in any case the scientific and technical research, and any human act. The name of this procedure is abductio or retroductio.

The discourse, among other things, centered on the necessary human mediation and on the irrepressibility of the expert man's intervention in confronting impersonal procedures such as both empirical induction and logical deduction, constitutes a way of putting the right emphasis on the anthropological principle.

Nach diesem Sinn, and in the context we have outlined, we can well conclude with the Sophist Protagoras from Abdera (ca. 490-420 BC): "Πάντων χρημάτων μέτρον εστίν άνθρωπος, των μεν όντων ως έστιν, των δε μη όντων ως ουκ έστινπάντων χρημάτων μέτρον ἐστὶν ἄνθρωπος, τόν μὲν ὄντων ὡς ἔστιν, τόν δὲ οὐκ ὄντων ὡς οὐκ ἔστιν".[11]

[11] Man is the measure of all things, of those that are as they are and of those that are not because they are not.

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Chapter

A Query Matching Approach for Object Relational Databases Over Semantic Cache

Hafiz Muhammad Faisal, Muhammad Ali Tariq, Atta-ur-Rahman, Anas Alghamdi and Nawaf Alowain

Abstract

The acceptance of object relational database has grown in recent years; however, their response time is a big concern. Especially, when large data are retrieved frequently on such databases from diverse servers, response time becomes alarming. Different techniques have been investigated to reduce the response time, and cache is among such techniques. Cache has three variants, namely tuple cache, page cache, and semantic cache. Semantic cache is more efficient compared to others due to capability to store already processed data with its semantics.
A semantic cache stores data computed on demand rather than retrieved from the server. Several approaches proposed on relational databases over semantic caching but response time on relational database is unsatisfactory. Hence, we proposed object relational databases over semantic cache. It is a novelty because semantic cache is mature for evaluation of relational databases but not for object relational databases. In this research, the implementation of query matching on object relational database with semantic caching along with object query is investigated to reduce the response time. Then, a case study is conducted on an object relational database model, and an object (relational database) query with semantic segment is applied. Results depict significant improvement in query response time.

Keywords: semantic cache, query matching, probe query, remainder query, object relational query

1. Introduction

Data size increased day by day, due to large data response time is going slow. In this regard, according to [1], relational databases can be used due to their better response time. Its idea is based on distributed database, which is helpful to reduce the data load and make access easy. In several scenarios, it occurs that structure must be continuously modified in multiple respects due to change in data types [2]. A relation in database is made up of several relations corresponding to relational database schema. The objective of a relational database design is to create a set of relation schema that allows user to store information and to retrieve information easily [2]. Relational database is structured in table, fields, and records. Relational database also delivers relational operator to manipulate the information kept in the

database tables [3]. Most RDBMS use SQL as database query language. The relational data base model is an extensively used data model, and a huge majority of existing database systems are based on the relational model [2]. Dr. E.F. Codd, a mathematician and research scientist at IBM, designed the relational model. Although most of the current RDBMS are not aligned to the Codd's model, yet it is considered as RDBMS [4]. Mitigating data redundancy and enhancing data integrity are two design principles of Codd's model [5]. The relational model also defines several logical operations that could be performed over the data. The relational data model has established itself as the main data model for commercial data processing applications [4]. Its achievement in this area has led to its applications outside data processing in systems for computer aided design and other environments [6]. Various issues in efficiency arise in RDBMS such as lack of handling the advanced data type, a restricted set of built-in types that use only numbers and strings. Also, certain types of relationships between database objects are hard to represent in the relational database model [7]. The RDBMS is pretty good in handling most information problems. But for new type of data type's problems, RDBMS technology could be superior upon. So, to attain the deficiency of RDBMS, we move on to ORDBMS [3]. To conform to the SQL standards, relational database model is reconsidered by ORDBMS; however, the object relational data model is a new definition altogether [7]. Object oriented languages like Java and C# can be integrated to ORDBMS, pertaining to their class, method, and objects features that are useful for the programmers for better integration. Moreover, ORDBMS schemas have additional features compared to its earlier counterpart [8]. ORDBMS model supports the object oriented features like abstraction, polymorphism, inheritance, etc. [9]. Like RDBMS, ORDBMSs rely on SQL queries and declarative approach for accessing and manipulating data rather than a procedural approach [10]. Occasionally, a mismatch in the programming language structure (procedural, declarative, or functional) and ORDBMS engine may occur at the time of database connectivity and access, which may results in performance issues. In a architectural point of view, ORDBMS is different than OODBMS that use a distributed approach while the former uses a centralized approach [8]. Nevertheless, this issue can be resolved by replicating ORDBMS over several machines. The further significant outcome of the technology is that it makes it possible to build information systems to address data management problems that are usually considered to be too challenging. In terms of interoperability, ORDBMS has two benefits. First is compatibility with the existing RDBMS components and second an object oriented access for the users and programmers. Similarly, storage and access mechanism, query processing, and optimization are the significant challenges in employing ORDBMS [7]. One of the efficient ways to mature a very large database is to distribute it between various server nodes [11]. Now ORDBMS is going to convert into the semantic caching and query result is more efficient in the semantic cache. Semantic cache is used to response the query in part such as Probe and Remainder [1]. Some part of query is answered from the cache and some is from the server [4]. ORDMBS is used in this technique in an intelligent way to answer the query result [8]. Different methodologies are easily making on semantic cache, and different definition of semantic cache content is used. Semantic cache content is {Rs, As, Ps, Cs}. Result is accessed according to the cache content, and a complete set of cache part is known as cache [1]. Suppose a user gives a query SELECT student id, name FROM student WHERE age < 28. In this query, Student ID and Name are answered from Probe part (saved in cache) but for Name, where clause it will be accessed by the remainder part (server result). So, it will consume more time if query is complex and more result is accessed from server [1]. For that ORDBMS is mainly focused on sematic caching but query optimizing technique is used, and this technique is going to be improved

by Query Matching part of query optimizing. For more understanding, we take the help from the problem statement.

- Query matching technique on ORDBMS is hard to implement.
- Query retrieving is time consuming.
- Query matching approach is unsatisfied on complex data.

The objective of this research is to overcome the said issues. In this regard, semantic cache query matching technique is proposed to extract useful contents from the cache to improve query response time. Then, query matching is investigated for object relational query on complex data by exploiting the semantic cache, and results of object query and relational database query are compared. In this section we take discussion for our proposed approach for query matching on object relational database query over semantic cache. Query matching approach is satisfying the query result with the object relational semantic content. Our projected approach being employed is on semantic cache architecture with object query and with the below concept. Firstly, the query is accessed on the complex structure and data set, so object relational query is used with row reference to access the query [7]. Secondly, the relation in database is retrieved with the object query but in the form of object [10]. The query is into the part by using query semantic content of QS, QF, and QS and result is retrieved according to adaptive region of semantics segments [1]. The study is mainly focused to indicate various advantages of semantic caching and then the simple workloads where the indication also includes the low overheads, decreased amount of network traffic, physical layout of database that is insensitive, and additionally a source to minimize and answer the queries without the participation of server [4]. In addition, handling the complexity of the workloads and depth coding for queries is left for quick processing query at server. By manifesting the semantic caching works on object database with usage of complex workloads, we would investigate the wide variety of applications particularly in an environment that is network constrained [12]. Semantic cache plays an important role in fetching results. Semantic cache is divided into two main parts. One part that is answered with the help of cache is the Probe query and the second part that is answered from server is the Remainder query. Query when passed to on a Query algorithm is decomposed into various parts depending upon the data required. Before passing query to algorithm, first check whether the current data is available in cache or not; if it is, then fetching data from the server. If some of data are available in local cache, then decompose query in such a way that data not available in cache should only be fetched from semantic cache [1]. To increase the power of semantic cache, we use the object relational model that made the query on complex structure as efficient [7]. ORDBMSs deliver the lowest access time for development and for greatest performance combination when using objects because they stored objects on disk and have the translucent program integration with object programming languages [5]. Performance is boosted by storing objects directly on disk which excludes impedance mismatch. Development period are reduced because there is no need to program the caching for the application programs and there is only one model to develop [10].

In this approach, we mainly focus on the object relational query matching on complex data and structures which have many tuples to increase the complexity of query matching and they are time consuming. In this research, we proposed the approach ORDBMSs in semantic cache that reduce the cost and use less time for result; we easily increase the trust of database user by using his model. Data latency

and workload can easily be distributed and handled. Rest of the chapter is organized as follows: Section 2 contains review of literature and related work in the field. Section 3 contains proposed work and results are obtained in Section 4, while Section 5 concludes the chapter.

2. Review of literature

In this section, a comprehensive survey of cache is presented. In Sections 2.1–2.3, the concept and work of semantic cache on query is discussed. Sections 2.4 and 2.5 are dedicated to databases, while the related work is given in Section 2.6.

2.1 Cache

It comprises of small-sized type of volatile memory like the memory of computer that is useful in terms of providing high speed data while having an easy access to the processor and storage to install programs, applications, and data that are frequently used by the computer. It is considered to have memory that is fastest and is placed on the motherboard directly connected to the processor or Random Access Memory. Cache that has pronunciation as "cash" neither "catch" nor "cashay," saves information that is recently used for it to have accessibility later. A PC memory with short access time utilized for capacity of every now and again or as of late utilized directions or information called likewise reserve memory [11]. PCs consolidate a few unique kinds of storing with a specific end goal to run more productively, in this manner enhancing execution. There are few of the caches that comprise of browser cache, disk cache, memory cache, and processor cache [13].

2.1.1 Browser cache

The webpage data by default are found in the browser cache. For instance, when the webpage is being visited, the browser might cache the HTML, images, and any CSS or JavaScript files that are being referred by the page. When the website is accessed by different pages and of utilization similar pictures, CSS, or JavaScript, your program will not need to redownload the records. Rather, the program can basically stack and store them on a local hard drive from the cache [4].

2.1.2 Memory cache

During the time of a running application, there is a chance that is cache of data in system memory or Random Access Memory. The example is if there is a video project you are working on, the video clips and audio tracks from the hard drive into Random Access Memory may get loaded on the video editor, since this can reduce the delay while importing the files and editing them and RAM has easier accessibility than hard drive [4].

2.1.3 Disk cache

The HDDs and SSDs present have a small amount of Random Access Memory that fulfills the need of disk cache. The typical disk cache of 1 TB has 32 megabytes, while a 2 TB hard drive may have a 64 MB cache. Therefore, the little measure of Random Access Memory can have a major effect in the execution of drive. The example is of when an envelope is opened with a substantial number of records, the

referring of documents might be naturally spared. The list of files is loaded instantly despite taking some time to appear when the folder is opened [11].

2.1.4 Processor cache

They are smaller in size as compared to disk cache. The reason is of the processor cache that has some tiny blocks of data that are basically instructions that are used frequently and can be accessed by the CPU quickly. Present day processors frequently contain a L1 reserve that is appropriate by the processor and a L2 store that is marginally further away. The L1 reserve is the littlest (around 64 KB), while the L2 store might associate with 2 MB in measure. Some top of the line processors even incorporate a L3 store that is bigger than the cache L2. The data might get moved to the level that is low to access it faster when the processor tries to access data from a level that is higher in caches [4]. The caching done in background will not get noticed. However, browser cache is the only cache that can be controlled. There is choice to view the settings of cache and change the size of browser and even empty it if there is a need [11].

2.2 Cache levels

Following are different cache levels and their details.

2.2.1 L1 cache

L1 (Level 1 cache) is a memory bank built into the CPU chip. Also known as the "primary cache," the cache that has the fastest memory is L1 in computer and is closer to processor.

2.2.2 L2 cache

L2 (Level 2 cache) has a memory bank that is made inside the CPU with a package present inside the component or is built on motherboard. The L2 cache feeds the L1 cache, which feeds the processor. The L1 memory is better than L2; basically L2 is slower than L1.

Figure 1 illustrates the working of cache on database—to access the data with the help of cache and improve the answer time of query.

2.3 Semantic cache

This works for the caches query result. And the elements that are present in the semantic cache are known as the regions or segments [14]. This term semantic caching is derived from the semantics of SQL queries that work for systematically handling the information of cache and building conclusions of the availability or unavailability of query results in the cache [12].

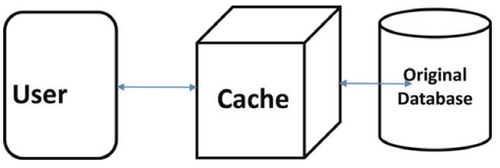

Figure 1.
Cache working.

The performance of the client-server systems is improved by the caching at local clients. The novel caching scheme being introduced is hence called the semantic caching. The transformation of the semantic storing can enhance the efficacy of XML inquiry that is prepared in the Web condition [9]. Semantic storing increases reserved information with a semantic depiction of the information.

These semantic depictions can be utilized to enhance execution time for comparable inquiries by recovering little information from reserve and issuing a leftover portion question for the rest. Benefits of semantic reserving include low network overhead, independence of physical format of the database, decreased system activity, and the capacity to answer a few inquiries without reaching the server. For workloads that are less complex, there is a need to maintain efficacy of the query processing by cautious coding of queries that are remainder at the server. For workloads that are very complex, using very complex workloads, there is a display of semantic caching that works better in a variety of applications specifically in the environments that were constrained [9].

2.3.1 Semantic cache scenarios

Semantic cache answers the query in different scenario's which are described below [15] in **Figures 2–5**, respectively. The scenarios are, namely

- full answer;
- partial answer; and
- no answer.

Example:

The semantic data are being extracted from the query while there is addition to this semantic data that will be used for more matching and the cache [16]. This high-power semantic fragment reserve is versatile, which means that, as and when the client is entering the inquiry for which the appropriate response is to be discovered, the applicable characteristics of the database will be populated in the store. The part of the cache that is semantic basically the highlights and the content which is refined just add quality in boosting the performance in a manner that is convincing and exuberant [14].

In case of the semantic cache, the semantics stored on the cache are compared to the input user query and subject to availability of data, the decision is taken. It is carried out by two processes known as splitting that involves division of query based on its clauses and rejecting if a certain clause is missing, e.g., WHERE

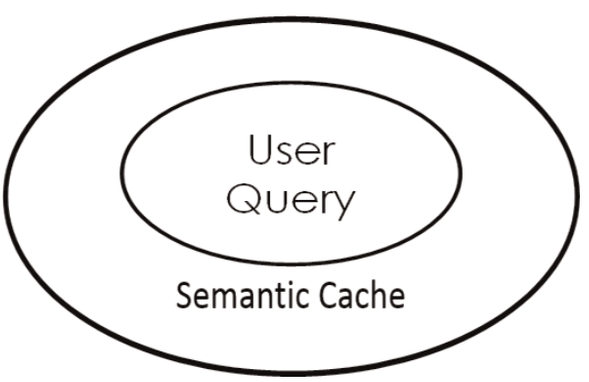

Figure 2.
Semantic cache full answer.

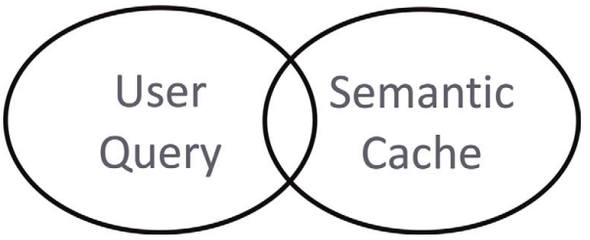

Figure 3.
Semantic cache partial answer.

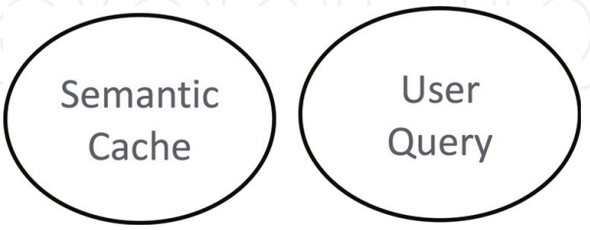

Figure 4.
Semantic cache no answer.

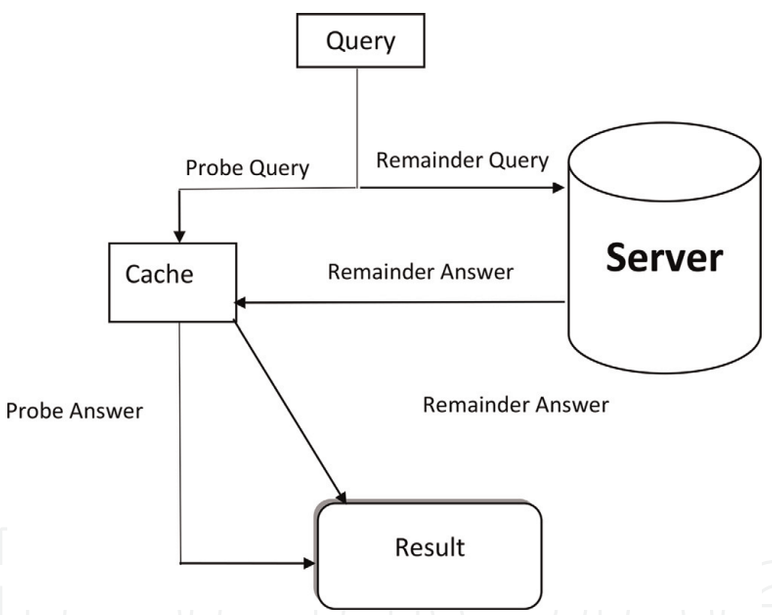

Figure 5.
Semantic cache working.

and so on [1]. The queries that are matched (overlapped) either fully or partially are answered locally by the semantic cache. Query processing and cache management are the main critical aspects of semantic cache, yet it performs way better than simple data (page, tuple) cache. Semantic caching provides the significance workload reduction in distributed systems, especially in mobile computing as well as improves the performance. However, the performance is purely based on the efficiency of its subprocesses like query trimming, indexing, etc. [1].

2.4 Relational database

A relational database is a category of database. It uses an arrangement that lets us to recognize and access data in relation to additional part of data in the database. Often, data in a relational database are organized into tables [5]. A relational

database management system (RDBMS) is a program that allows you to create, update, and administer a relational database [17]. Most relational database management systems use the SQL language to access the database. In RDBMS, the data are stored in the form of relations (tables) in a row-column architecture. It is comprised of records (rows) that are uniquely identified by a key attribute. There are several ways to access the stored data without manipulating the database relations as such [5].

Example:

In this example, a case study is used to understand the relational database and query is conducted on data model to understand working (**Tables 1** and **2**).

A query is conducted "Query: - Select Account=6 From Main account, Employee table" and for answer of query, every record is checked which is time consuming.

2.5 Object relational database

Object relational query processing is needed to speed up queries over object relational databases. We are here to define a couple of features mentioned in to characterize an ORDBMS. These structures are desired to model real-world problems in a method that is instinctive and easy for the developer and proposals noble performance for the application (**Figure 6**).

In this example, the query is answered directly by object which saves the time, and query efficiency is increased.

2.6 Related work

In [9], authors proposed an XML-based system "XPERANTO" for data representation and the access is duly retrieved from a native database for

Account no	First name	Last name	Amount
1	John	Doe	277$
2	Clay	Russell	586$
3	Albert	Luke	321$
4	Christina	Jorge	448$
5	Tim	Joe	520$
6	Dany	Clark	459$

Table 1.
Main account.

Account no	Emp-ID	Title	Branch
1	BW-123	Flipper	California
2	CA-448	Cashier	L.A.
3	DG-456	Manager	Washington
4	FA-114	Washer	London
5	DC-587	Doctor	Canada
6	HG-894	Plumber	England

Table 2.
Employee account.

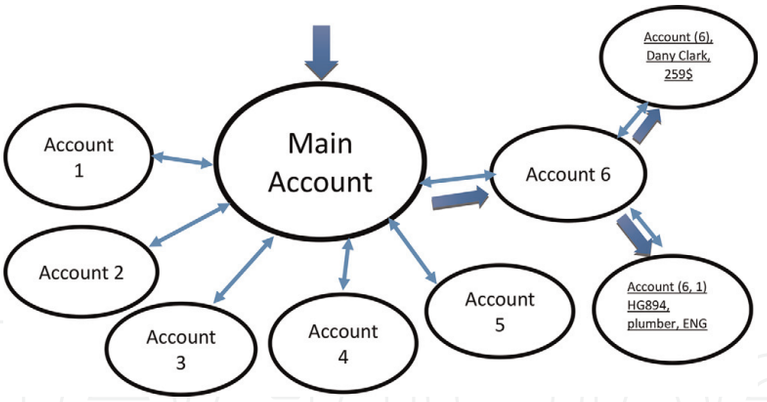

Figure 6.
ORDBMS working.

better accessibility. The system works as a middleware between XML and native database.

In [18], authors proposed a digital library and archiving system for educational institutes. The system takes advantage of ORDMS concept and builds a top layer XML object. These objects are kept in a library that can be accessed by client side QueryX engine duly executed by IBM domino server.

In [19], authors proposed a query optimization technique for RDF data stored in triplet format. The main idea was optimization of the SPARQL query based on the storage type, that is, adjacency list or matrix. It was concluded that the performance depends on the nature of data whether it is dense or sparse.

In [20], authors investigated the TYPE constraint for sake of query optimization in the context of frequent pattern mining. The idea behind this research was the data type that plays an important role in semantic association that increases the likelihood of its access.

Brown [10] presented the ORDBMS technique and investigated its properties related to flexible data access, functional improvement, enhanced efficiency, and organizational integration.

Author in [5] presents the object relational mapping (ORM) approach. The ORM refers to better data and transaction handling on a database using an object oriented approach. The investigation was conducted on a Java-based open source system "Hibernate," which is currently added to Microsoft model for .Net Systems.

In September 2007 [21], the Object Database Technology Working Group of the Object Management Group (OMG) issued a white paper that introduced the concept of an "object calculus" for ODBMSs that is analogous to "relational calculus" in RDBMSs.

In [22], the authors proposed the research of cache moves around in the scalability of new data-intensive environments and applications, and the trade-offs that are highly determined by the characteristics of these applications. Early work on information storing, for instance, concentrated on protest situated database frameworks supporting applications, for example, CAD/CAM; these frameworks had the coupling between the customers and server which took into consideration sharing of individual tuples or entire plate pages. The procedures utilized in examinations have been named physical reserving strategies.

In [23], the authors present the query-based services that do not entirely give out the physical layout of database; furthermore, customers have no power over the internals or interfaces; even application servers have just the data in the inquiries. Regarding the reserving models, the administrations should consequently be dealt with as self-sufficient inheritance frameworks even though they may dwell in best in class business database frameworks. In this condition, physical reserving

strategies are basically no longer pertinent as there is assumption coupling between client and server.

In [24], authors present the Object Relational Query Processing approach for optimizing the queries over ORDBMS. The approach was originally inspired by the object oriented paradigm.

In [25], authors present the idea of a three-level caching for efficient query processing in large Web search engines where a huge number of interactive data queries are posed in small fraction of time. Due to the volume of data access, semantic caching was a plus in efficiently handling data for sake of improving response time and reducing Web traffic. To keep up with this immense workload, large search engines employ clusters of hundreds or thousands of machines, and several techniques such as caching, index compression, and index and query pruning are used to improve scalability. Each level equips the higher level for better accessibility and locality [26].

3. Research methodology

In this section, the proposed model of the work is explained in Section 3.1. Then notation table that is used to understand the model in Section 3.2 and algorithm on query matching in Section 3.3 are discussed, and then a case study is conducted in Section 3.4.

3.1 Proposed model

Figure 7 is used to describe the proposed model, that is, the object relational query as example. Suppose we have a query Select Selection department, Section Marks, Grade From Enrollment Where Student S.Name='Clay' And Section Department='CSCI'.

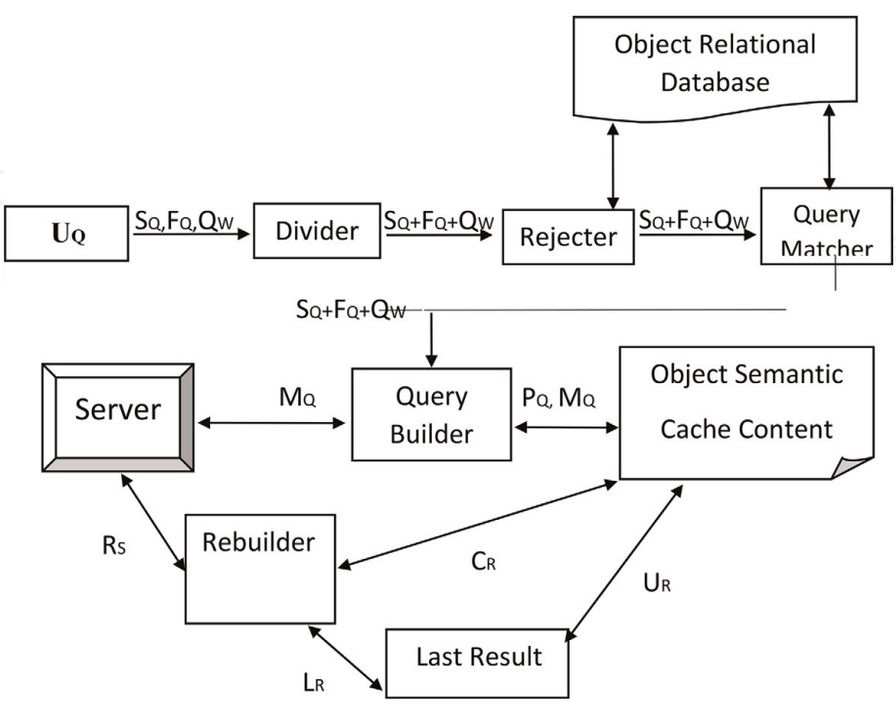

Figure 7.
Proposed model.

Notation	Details
SC	Cache segment
UQ	User query
SQ	***Select*** part of query
FQ	***From*** part of query
WQ	***Where*** part of query
MQ	Modify query
RQ	Remainder query
PQ	Probe query
PA	Predicate attribute
AS	Attribute of segment
PS	Predicate of segment
RS	Relation of segment
CS	Content of segment
AK	Key attribute of segment
SA	Same attributes
RS	Result from server
DA	Difference attribute
LR	Last result
CR	Server result
QR	Query result

Table 3.
Notation table.

All the notations used are enlisted in **Table 3**.

3.2 Proposed algorithms

Algorithm 1:-	The pseudo code of proposed algorithm to match the query
Purpose:-	To enhance the query matching approach on the ORDBMS over semantic cache
Input:-	User query, Semantic cache
Output:-	Result of User Query (Probe Query and Remainder Query)
PROCESSING:-	Get the query from user and go to query splitter
STEP 1:-	DIVIDE _QUERY (**UQ**)
STEP 2:-	Rejecter: - CHECK _REJECTIONS(**SQ**+ **FQ**+ **PA**)
STEP 3:-	IF (Reject= False) I. **SA**, **DA**:= MATCH _ SELECT_CLAUSE (**SQ**) a. IF (**DA** != Empty) b. **RQ**1 = π **DA**σ**PQ** (QR) II. Else rq1= Null

	III. IF (**SA** != Empty) a. IF (! (QPA ⊆ **SP**)) **MQ** = GEN_AMEND_QUERY() b. ELSE **MQ** = Null IV. IF (QP ==>SP) a. PQ:=π**S**AσPS (CS) b. RQ2: Null V. ELSE (QP ^ SP) is Satisfiable PQ : πSAσPS (CS) VI. ELSE IF (QP ^ SP) is Unsatisfiable Pq: Null Rq2 = πCA σSP (QR) a. ELSE b. PQ:= Null c. RQ2:= Null d. LR: = PQ + RQ + RQ2
STEP 4:	ELSE Query Is Incorrect

Algorithm 2	**DIVIDE _UQ()**
Input	**UQ** (Query from user)
Output	**SQ, WQ, FA**
Procedure	**SQ**: - SELECT CLAUSE **WQ**:- WHERE CLAUSE **FA:**- FROM CLAUSE Return:- SQ, WQ, FA

Algorithm 3	CHECK _REJECTIONS(**SQ**, **FQ**, **PA**)
Input	**UQ** (User Query)
Output	**SQ, FQ, PA**
Procedure	I. If all attributes of **SQ** present in schema II. If relation of **FQ** present in schema III. 5 IV. If **PA** is present in schema Return false Else return true V. Else return true VI. Else return true

3.3 Case study

Following schema is taken as a case study to demonstrate the proposed approach. In this regard, following object relational database query is posed. UQ2: "Select (selection) Section, Department, Marks, Grade From Enrollment Where Student S.Name='Clay' And Section Department='CSCI'".

UNIVERSITY							
STUDENT				**ENROLLMENT**			
S.Name	S.ID	Age	Gender	Section	Department	Marks	Grade

Enrollment		**Student**	
S. no	**Cache segment**	**S. no**	**Cache segment**
C1	S.ID	C14	Section
C2	S.name	C15	Department
C3	Gender	C16	Marks
C4	Age	C17	Grade
C5	S.ID, S.name	C18	Section, department
C6	S.ID, gender	C19	Section, marks
C7	S.ID, age	C20	Section, grade
C8	S.ID, S.name, gender	C21	Section, department, marks
C9	S.ID, S.name, age	C22	Section, department, grade
C10	S.ID, gender, age	C23	Department, marks
C11	S.name, gender	C24	Department, grade
C12	S.name, age	C25	Marks, grade
C13	Gender, age	C26	Grade, marks

Table 4.
Cache segments on relation.

For the above given case study of university, there are 26 possible cache segments of the enrollment and student relation. In other words, we can say that 13 are made against the enrollment relation and 13 for the student as in given **Table 4** according to given formula $2^n - 1$ [1].

4. Results and discussion

The discussion on the case study in Section 4.1 and the comparison on the case study in Section 4.2 are conducted.

4.1 Discussion

In the example, there are 30 possible enquiries that make separate segments. But in ORDBMS, the reference is used toward accessing the query result and the reference is added on the row [7]. The given two object oriented user query on possible segments are as follows:

UQ1:- ***Select*** Section department, Section Grade, **F*rom*** Student **W*here*** Student S. Name='Bursch' And Student Age='21'.

UQ2:- ***Select*** Selection department, Section Marks, Grade **F*rom*** Enrollment **W*here*** Student S. Name='Clay' And Section Department='CSCI'

As from above Object queries, UQ1 is rejected as initial state from query rejecter SQ is not coordinated with attributes of Student relation. Now let us assume from UQ2 over projected architecture as with respect to cache segment of Object relational query from **Table 4**. Query split function splits the query into segment with reference as below:

SQ: -{Selection department, Section Marks, Grade}
WQ: -{Enrollment, Student}
FA :-{Student S. Name='Clay' and Section Department='CSCI'}

Rejecter receives these three {SQ, WQ, FQ} and passes it to decider after checking the validity. Then, the decider checks the availability of required attributes by applying the proposed approach.

Here, for simplification, we assume that there exist two segments S12 and S16, for enrollment and student. So, the SA and DA will be composed as follows:

SA = {Department,Marks}

DA = {Grade}

After combining difference and common attribute, query will generate and send the following remainder query to the server.

RQ= Select Grade From Enrollment Where Section Department='CSCI

Common attributes with WQ and FQ will be sent to LQG, whereas probe and remainder queries will be produced by LQG based on similarity with segment on cache [14]. Note that here SQ will be equal to SA. So, probe and remainder queries are given below:

PQ= Select Selection department, Section Marks, From (CS)

RQ= Select Grade from Enrollment Where Section Department='CSCI.

Here, modify query (MQ) is null because PS ⊆ SQ. This process of takeout probe and remainder query will be continued with entirely of segments that are visited or remainder queries become null. Query generator sends all the probe queries to the cache content and final remainder query to the server to retrieve data.

As a final point, rebuilder obtains CR from cache and RS joined to build LR and the semantics in the cache will be updated accordingly.

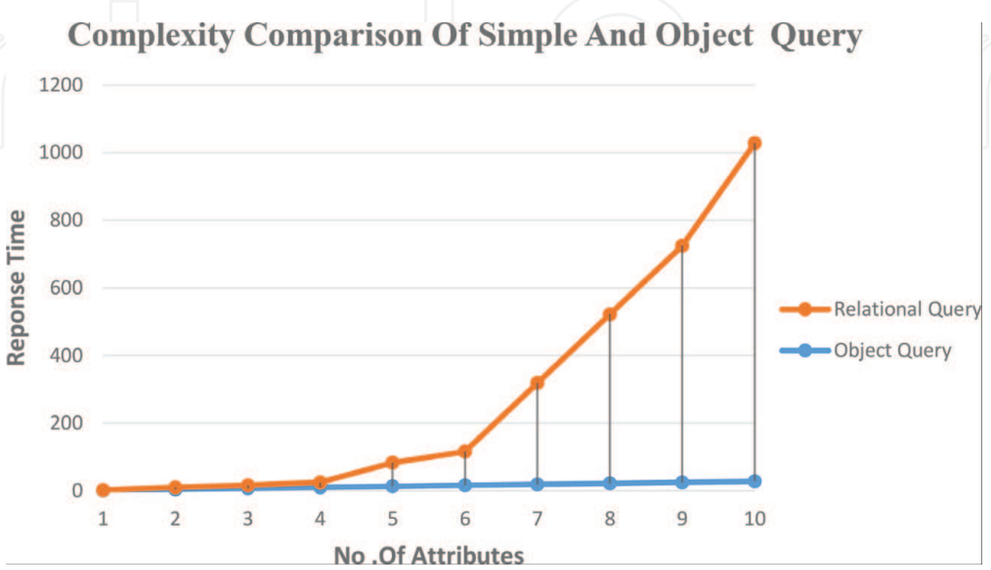

Figure 8.
Complexity comparison.

4.2 Complexity comparison

This section provides comparison between previous work on RDBMS with semantic cache and proposed query matching scheme on ORDBMS with semantic cache [7]. We have used workload parameter, such as response time, no of attribute more detail is given with the help of **Figure 8** present the response time through number of attributes. Comeback time is purely calculated on the bases of complexity expression use as previous (n vs. 2^n-1).

In **Figure 8**, the comparison result is displayed, which is used to show difference between relational query on relational data model with semantic cache and object relational database query with sematic cache, and response time is getting better on object relational query and object relational database can have ability to answer the complex data type. The retrieve time of query on ORDBMS is better and efficient; the query matching approach has improved the working procedure of the object relational query.

5. Conclusion

In this proposal, we talked about the significance of ORDBMS query for associations and organizations. We featured our approaches for outlining model and approach algorithm. Additionally, we talked about contextual analyses of executing RDBMS in online store situations and their methodologies of the implementation.

This exploration, in current stage, centers on outlining and available information which will help for the most part in basic leadership process that is identified with the advertising. We found that the greater part of works in this field have been given diverse ways to deal with the choice of perspectives to appear considering query upkeep cost and time consuming.

The investigations demonstrate that the proposed model can be incorporated with the existing models since it limits the arrangement of perspectives before appearance process.

In this research, we proposed an efficient scheme to reduce the query execution cost by making the query matching process swift. Moreover, in this era, every organization required the records in short time in the presence of big data, data lake, Teradata, etc. On the other hand, the organizations do not want to change their current systems due to the reasons like data losses, delays, and other cost-related issues. To avoid these issues, proposed advanced level query matcher can be a good alternate.

To fix this issue, we present a technique for Query Matcher and semantic cache process over object relational database. We use object query on relational database.

Now we provide solution for decision-makers or user of traditional database that can enhance speed and cost and optimize query matching. We can manage large queries on data set with matching approach and save these results dynamically in semantic cache which updated on run time. Rather accessing the whole large data set from object relational database we pull data from Semantic cache where similar queries answer before that reduce time and system delay. This will increase the confidence of database users.

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