

**AN IMPLEMENTATION FOR A HEURISTIC  
RANGE-BASED CLASSIFICATION ALGORITHM**

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## Declaration

I hereby declare that this dissertation is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the dissertation.

This dissertation has also not been submitted for any degree in any university previously.

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Phuong Anh Tran

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## **Acknowledgments**

To my supervisor, Dr Jinhua Shao, whom inspires me with confidence and beyond.

## Abstract

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## List of Algorithms

# SECTION 1

## Introduction

The ability to extract meaningful information from a set of data has been a crucial problem within data mining and machine learning research. One approach is to recognise certain patterns within a dataset, then transform these patterns into rules. In the future, these rules could be used to predict an classified outcome for any given instance of that dataset. The ability to transform such patterns is thus a deciding factor in producing accurate predictions. Subsequently, its accuracy relies on the choices of methods and algorithms in learning and deriving useful and relevant rules.

The goal of this project is to investigate an algorithm to derive classification rules for range-based data. Ranges pose a more challenging problem to assess since there are more possible patterns to deduce than that of categorical values. Therefore, before patterns can be learnt, the data must be split into ‘right intervals’ [src] so that the rules devised will be more fitting. The process of deducing relevant subset of data thus plays a significant part in deciding the rule accuracy, and an important step before actual classification can take place.

In details, this project analyse and implement a method that aims to solve the above issues i.e. to classification rules for range-based numerical dataset, developed in a previously published paper by Shao, J. and Tziatzios, A. [src]. The original method withholds two distinctive features: firstly, the data trimming process is done by an algorithm similar to Kadane’s [src] solving maximum-array problem, which is highly efficient due to its linear time complexity ( $\log N$ ). Secondly, in order to mimic that max-sum method, chosen ranges are analysed by assigning binary tags upon their covered items depending on the items’ class values. By using class values, the given ranges can be narrowed down to to be more relevant to the rules derived. These

two features make for a fast and efficient way to classify range-based dataset. This method is then analysed further in order to produce an improved[?] version that is implemented as a final software using Java.

What was improved?

Outcome? Your own work?

# SECTION 2

## Background

The project implements an algorithm originated from [SRC]. The algorithm utilises a similar approach to association rule mining: it searches for associated ranges in each attribute, then combine these ranges to form a larger rule. To make this search more efficient, class values are used to guide the search i.e. only ranges that have relevant class tags are considered. The algorithm is explained in the following sections.

### 2.1 Preliminaries

Assuming that we have a dataset that could be presented as a table  $T(A_1, A_2, A_3, ..A_m, C)$ , where  $A_{j,m}$  as  $1 \leq j \leq m$  are range attributes and  $C$  is the categorical class value. A single tuple within  $T$  is denoted as  $t_k = (v_1, v_2, v_3..v_m, C)$  where  $v_m$  is a value under  $A_m$ .

A sample dataset served as an example for this section can be shown in Table 2.1 below:

**Table 2.1:** A sample dataset as table

$T$	$A_1$	$A_2$	$A_3$	$A_4$	$C$
$t1$	0.75	1.45	2.13	4.56	$c_1$
$t2$	0.64	1.62	2.64	4.75	$c_2$
$t3$	0.71	1.21	3.11	3.97	$c_1$
$t4$	0.57	1.23	2.75	4.24	$c_1$
$t5$	0.80	1.53	2.34	4.11	$c_2$

**Definition 1 (range)** Assume within the domain of attribute  $A$  exists two values  $a$  and  $b$  that

represents a continuous range over  $A_j$ , denoted  $r = [a, b]_{A_j}$ . This range covers a set of values in  $A$  that lies between  $a$  and  $b$ .

*Example 1:* From Table 2.1, a range of  $[0.64, 0.75]_{A_1}$  would cover a set of values 0.64, 0.71 and 0.75 in  $A_1$ .

**Definition 2 (cover)** Assume  $r = [a, b]_{A_j}$  to be a range over attribute  $A$ . This range  $r$  covers a set of tuples where their values are between  $a$  and  $b$  where  $a \leq v_j \leq b$ . This set of tuples that is covered by  $r$  is denoted  $\tau(r)$ .

*Example 2:* From Example 1, a range of  $[0.64, 0.75]_{A_1}$  would cover a set of tuples  $t_2, t_3, t_1$  hence its cover is  $t_2, t_3, t_1$ .

**Definition 3 (associated ranges)** Assume  $r_1 = [a_1, b_1]_{A_1}$  to be a range over  $A_1$  and  $r_2 = [a_2, b_2]_{A_2}$  to be a range over  $A_2$ . Those ranges are associated ranges if  $\tau(r_1) \cap \tau(r_2) \neq \emptyset$

*Example 3:* Assume  $r_1 = [0.64, 0.75]_{A_1}$  and  $r_2 = [1.21, 1.45]_{A_2}$ . Table 2.1 shows that  $r_1$  covers  $t_1, t_2, t_3$  and  $r_2$  covers  $t_1, t_4, t_3$ , which means  $r_1 \cap r_2 = \{t_1, t_2, t_3\} \cap \{t_1, t_3, t_4\} = \{t_1, t_3\}$ . Since there are mutual tuples between these ranges,  $r_1$  and  $r_2$  are associated ranges.

**Definition 4 (range-based classification rule)** Assume  $c$  to be a class value from  $C$  and  $r_1, r_2, r_3..r_h$  be a set of associated ranges.  $r_1, r_2, r_3..r_h \rightarrow c$  is a range-based classification rule.

By definition, any tuple  $t_k$  can form a rule. However, this will not be accurate nor useful. To determine whether a rule is qualified, there are criteria to be used, which are to be discussed in the sub-section below.

## 2.2 Criteria

There are three criteria used in this algorithm: support, confidence and density. This sub-section presents the formal definitions for those measures, while examples are to be provided in the next sub-section where the actual algorithm is reviewed.

**Definition 5 (support)** Assume  $T$  to be a table and  $r_1, r_2, r_3..r_h \rightarrow c$  to be a range-based classification rule derived from  $T$ . The support for  $r$ , provided  $|\cdot|$  being the size of a set,

is:

$$\sigma(r) = \frac{|\tau(r_1) \cap \tau(r_2) \cap \dots \cap \tau(r_h)|}{|T|}$$

**Definition 6 (confidence)** Assume similar settings from Definition 5, the confidence for  $r$  in  $T$  is:

$$\delta(r) = \frac{|\tau(r_1) \cap \tau(r_2) \cap \dots \cap \tau(r_h) \cap \tau(c)|}{|\tau(r_1) \cap \tau(r_2) \cap \dots \cap \tau(r_h)|}$$

**Definition 7 (density)** Assume similar settings from Definition 5, the density for  $r$  in  $T$  is:

$$\gamma(r) = \frac{|\tau(r_1) \cap \tau(r_2) \cap \dots \cap \tau(r_h) \cap \tau(c)|}{|\tau(r_1) \cup \tau(r_2) \cup \dots \cup \tau(r_h)|}$$

## 2.3 Original algorithm

As mentioned, the algorithm provides a more efficient way to discover associated ranges than the traditional brute-force solution. Instead of traversing through all possible combinations of ranges among all attributes, this algorithm first divides the data into sub-data pools in accordance to its class value. Then, under each attribute, it searches for sub-ranges that could pass certain user-defined thresholds (confidence, support and density). These sub-ranges are then collected and ready to be tested for possible combinations between each other that passes certain thresholds similar to the previous step, which are then collected and ready to be tested for larger combinations. Additionally, after larger combinations are found, an extra adjustment step is done on class values of relevant tuples within the new associated ranges. Afterwards, new associated ranges are ready to be analysed again to find more possible sub-ranges and new combination of sub-ranges. This iteration continues until no possible combinations can be found, so that the last standing associated ranges are translated into the concluding classification rule for that class value.

To get a clearer structure of the algorithm, its proceedings can be divided into two phases:

**Phase I (Analyse)** This phase has its primary concern as to analyse ranges. Based on the algorithm description, it includes:

1. Partition data into sub-data pool using class values.

2. For each attribute in sub-data pool, find a maximum and minimum range within that attribute and use it as a starting range for next step.
3. From min-max starting ranges, search for sub-ranges that passes certain user-specified thresholds such as confidence, support and density. Sub-ranges are collected and passed onto Phase II to generate larger associated ranges.

**Phase II (Generate)** This phase has its primary concern as to generate larger associated ranges for the next iteration. Based on the algorithm, it includes:

1. For each sub-range obtained from last phase, check for possible combination of that range with the remaining ones.
2. Adjust class values of relevant tuples  $r_1, r_2, r_3..r_h \rightarrow c$  under the new combined sub-range.

Details for each phase are as follows:

### 2.3.1 Original Phase I Analyse

Given a table  $T(A_1, A_2, A_3, ..A_m, C)$ , the algorithm attempts to seek for classification  $r_1, r_2, r_3..r_h \rightarrow c_j$  by finding, among instances that are under class  $c_j \subset C$ , a number of associated ranges  $r_1, r_2, r_3..r_h$  that have at least a minimum support ( $\sigma_{min}$ ), density ( $\delta_{min}$ ) and confidence ( $\gamma_{min}$ ) that had previously been specified by the user. This process can be explained in Phase I (Analyse) in which the algorithm seeks for associated ranges and checks if thresholds are satisfied. From [SRC], this phase is outlined as below:

A step-by-step explanation of this algorithm is as follows:

**Step 1-2** As the beginning steps of the algorithm, they selects a set of tuples  $t_1, t_2, t_3..t_N$  from  $T$  that has class value  $c_j \subset C$  and store them in  $T_{c_j}$ . *Example:* Using Table 2.1 from last section, for class  $c_j$  where  $j = 1$  (class 1), tuple set  $T_{c_1}$  under this class are:

**Step 3** In this single step, from  $T_{c_j}$ , for each attribute  $A_i$  the algorithm derives a set of ranges  $[v_{min}, v_{max}]_{A_i}$  for that attribute. These ranges are formed by seeking for the minimum and the maximum values of  $A_i$  in  $T_{c_j}$ . This is denoted as candidate ranges  $cr$ , since they are

**Algorithm 1** *R-CARM*


---

**input:**  $T(A_1, A_2, \dots, A_m, C)$ , where each  $A_i$  is numerical  
and  $C$  is categorical

**output:**  $R$ , a set of range-based classification rules

1. **for each**  $c_j \in C$  **do**
2.    $T_{c_j} \leftarrow \text{select}(T, c_j)$
3.    $CR_1 \leftarrow \{[v_{min}, v_{max}]_{A_1}, [v_{min}, v_{max}]_{A_2}, \dots, [v_{min}, v_{max}]_{A_m}\}$  from  $T_{c_j}$
4.   **for** ( $k = 1, CR_k \neq \emptyset, k++$ ) **do**
5.      $LR_k \leftarrow \emptyset$
6.     **for each**  $cr \in CR_k$  **do**
7.        $S \leftarrow \text{analyse\_range}(cr, c_j)$
8.       **for each**  $s \in S$  **do**
9.          **if**  $\sigma(s) \geq \sigma_{min}$  **and**  $\gamma(s) \geq \gamma_{min}$  **then**
10.            $LR_k \leftarrow LR_k \cup s$
11.           **if**  $\delta(s \Rightarrow c_j) \geq \delta_{min}$  **then**
12.              $R \leftarrow R \cup \{s \Rightarrow c_j\}$
13.     $CR_{k+1} \leftarrow \text{generate}(LR_k)$
14. **return**  $R$

---

**Figure 2.1:** Original Phase I Analyse algorithm**Table 2.2:** A subset of tuples under class 1

$T_{c_j}$	$A_1$	$A_2$	$A_3$	$A_4$	$C_j$
$t1$	0.75	1.45	2.13	4.56	1
$t3$	0.71	1.21	3.11	3.97	1
$t4$	0.57	1.23	2.75	4.24	1



still subjected to a check to see whether they have the required minimum thresholds needed to form the rules. *Example:* From Table 2.2, for each attribute a candidate range can be generated as follows:  $A_1 = [0.57, 0.75]$   $A_2 = [1.21, 1.45]$   $A_3 = [2.13, 3.11]$   $A_4 = [3.97, 4.24]$

**Step 4-13** In these remaining steps lie the core analysis of Phase I, which could be separated into three main components: sub-range derivation, threshold check and larger range generation. Firstly, for each range in  $cr$ , an analysis is performed to derive possible sub ranges from this range. The reason for this analysis is because for continuous ranges,  $[v_{min}, v_{max}]_{A_i}$  could cover more than necessary tuples that consequently reduces the rule accuracy if not trimmed down. *Example:* Consider the example  $A_1 = [0.57, 0.75]$  from the previous step. Using this range on the original set of tuples  $T$  in Table 2.1, the tuples that the range covers are:

**Table 2.3:** A subset of tuples under class 1 and range  $r$  of attribute 1

$T$	$A_1$	$C$
$t1$	0.75	1
$t2$	0.64	2
$t3$	0.71	1
$t4$	0.57	1

Under this range  $A_1 = [0.57, 0.75]$  which is a candidate rule, its cover of  $t_1, t_2, t_3, t_4$  gives a  $\frac{3}{4}$  correct classification. However, by adjusting the range to  $A_1 = [0.68, 0.75]$  which covers  $t_1, t_3, t_4$ , it now gives  $\frac{4}{4}$  correct classification. Although the support for this range is reduced, higher classification accuracy is achieved. Therefore it shows a need to prune(?) these candidate ranges before proceeding to the next step. The pruning process lies within step 7.

**Step 7** The pruning process is represented by the *analyse\_range* function, where a method is implemented to find sub-ranges. This method is based on the solution to the max sum problem [SRC], which is for finding a maximal gained sub-array within a given array of discrete numbers (its details will be discussed further in the next section). To apply the similar approach to finding maximum sub-ranges, for class  $c_j$ , each tuple in  $T_{c_j}$  that is

covered by range  $[v_{min}, v_{max}]_{A_i}$  is scored with 1 if its class is  $c_j$  and  $-1$  otherwise. This is to convert continuous values into discrete (in this case, binary) scores of numbers, that are then used to calculate the max sum scores. Those max sum scores represents the candidate sub-ranges, which could be the desired sub-ranges once they satisfy the support confidence and density constraints. There can be multiple sub-ranges and thus all sub-ranges are collected and store the result in set  $S$ . Sub-ranges in set  $S$  is checked in the following step 8-12 for threshold requirements.

*Example:* From Table 2.3,  $T_{A_1}$  where  $A_1 = [0.57, 0.75]$  and the class value  $c_1$  is 1, the tuples  $t_1, t_2, t_3, t_4$  are covered under this rule and can be presented in ascending order as:

**Table 2.4:** A subset analysed by max-sum method for sub-ranges

	$t_2$	$t_4$	$t_3$	$t_1$
Attribute value	0.64	0.68	0.71	0.75
Class value	$c_2$	$c_1$	$c_1$	$c_1$
Binary values	-1	1	1	1

Assume the max-sum approach requires 100% confidence i.e. correct classification ( $c = 1$ ) for each covered tuple, the resulted optimal binary array will be 111 which represents a sub-range  $s = [0.68, 0.75]$  that covers tuples  $t_4, t_3, t_1$

**Step 8-10** These steps perform a support and density threshold check on sub-ranges in set  $S$ .

For each sub-range  $s$  in  $S$ , a threshold check is performed to see whether it has sufficient support and density specified (Step 9). If sub-range  $s$  does, it is kept in  $LR_k$  where candidate sub-ranges are stored to form larger associated ranges in the next iteration (Step 10). However, if it does not satisfy the specified thresholds, sub-range  $s$  is discarded as it cannot be used to form larger associated ranges due to support and density measures being monotonic [SRC]. All checked ranges  $s$  in  $LR_k$  are then passed on for a final check on confidence threshold in the following step 11-13.

*Example:* From Table 2.4 where sub-range  $s = [0.68, 0.75]_{A_1}$  is found for attribute  $A_1$ ,

the support and density can be computed as follows:

$$\sigma_s = \frac{\{t_3, t_4, t_1\}}{\{t_2, t_4, t_3, t_1\}} = \frac{3}{4} = 0.75$$

$$\gamma_s = 1$$

Assume the condition specified is  $\sigma_s \geq 0.6$  and  $\gamma_s \geq 0.9$ , then sub-range  $s = [0.68, 0.75]_{A_1}$  satisfies the required support and density threshold and therefore accepted. Assume, with the similar rule, another sub-range  $s = [1.21, 1.45]_{A_2}$  is found for attribute  $A_2$  from an initial range  $[1.21, 1.45]_{A_2}$ . The support and density can be computed as follows:

$$\sigma_s = \frac{\{t_3, t_4, t_1\}}{\{t_3, t_4, t_1, t_5, t_2\}} = \frac{3}{4} = 0.75$$

$$\gamma_s = 1$$

With the same support and density measures, sub-range  $s = [1.21, 1.45]_{A_2}$  is also accepted. These two sub-ranges are stored in  $LR_k$  for the next steps, hence  $LR_k = \{[0.68, 0.75]_{A_1}, [1.21, 1.64]_{A_2}\}$ .

**Step 11-12** These steps perform the last check for confidence threshold on ranges in  $LR_k$ .

Using class value  $c_j$ , it checks whether sub-range  $s$  in  $LR_k$  can be used to form range-based classification rules with sufficient confidence (Step 11-12). If  $s$  satisfies the confidence test, sub-range  $s$  is then kept in  $LR_k$  which is then used to form larger association of ranges. The process of forming larger associated ranges is in Phase II (Generate) in Step 13. However, in cases where  $s$  fails to pass the confidence threshold, it is discarded and no longer considered in the next iteration.

*Example:* In Step 8-10 example, sub-range  $s = [0.68, 0.75]_{A_1}$  is shown to have passed threshold for support and density. It is then checked for confidence measure, which is as follows:

$$\delta_s = \frac{\{t_4, t_3, t_1\}}{\{t_4, t_3, t_1\}} = 1$$

Assume the condition specified is  $\delta_s \geq 0.8$ , sub-range  $s = [0.68, 0.75]_{A_1}$  passes the test and

therefore accepted. Similarly for sub-range  $s = [1.21, 1.45]_{A_2}$ :

$$\delta_s = \frac{\{t_3, t_4, t_1\}}{\{t_3, t_4, t_1\}} = 1$$

Hence  $LR_k = \{[0.68, 0.75]_{A_1}, [1.21, 1.64]_{A_2}\}$  is accepted and passed onto Phase II (Generate) in Step 13 to form larger associated ranges.

**Step 13** This step, which represents Phase II (Generate), perform the generation of larger associations of ranges  $CR_{k+1}$  by a generate function. The process is the core in Phase II (Generate) is described in Phase II sub-section below.

### 2.3.2 Original Phase II Generate

In this phase, the algorithm prepares  $CR_{k+1}$  for the next iteration by combining two relevant ranges in  $LR_k$ , thus extending the current ranges. The combining process mirrors the A-priori algorithm in generating frequent itemsets in association rule mining. Although A-priori applies on categorical values, it is adapted to this range-based classification algorithm by using an additional step on range adjustment. The algorithm is denoted in Figure 2.2 below:

**Step 1-5** Given  $LR_k$  from previous phase, these steps traverses through all sets of associated ranges in  $LR_k$  and for each set of associated ranges  $ar$ , it looks for another remaining set  $ar$  as a possible set to combine to make a larger range. The condition to combine is in the following Step 6-7.

**Step 6-7** These steps decide whether  $ar$  and  $ar$  can be combined by searching whether  $ar$  and  $ar$  differs by only one last attribute.  $first_{k-1}$  is a function to retrieve the first attribute in each set, and  $last$  is a function to retrieve the last attribute in the same set. So if the last function of  $ar$  returns an attribute that is larger than the that which is returned by the last function of  $ar$ , this pair is accepted. A new extended set of associated range is formed based on this pair, in which the starting range is the same  $first_{k-1}$  range and the ending range is the larger  $last$  range between the two ranges (Step 7).

*Example:* From Phase I example,  $LR_k = \{[0.68, 0.75]_{A_1}, [1.21, 1.64]_{A_2}\}$  is found. Assume another  $LR_k = \{[0.68, 0.75]_{A_1}, [2.75, 3.11]_{A_3}\}$  is found. A pair between these  $LRs$  can

---

**Algorithm 2** *Generate*


---

**input:**  $LR_k$ , a set of associated ranges that have sufficient support and density

**output:**  $CR_{k+1}$ , a set of candidate associated ranges

```

1.  $CR_{k+1} \leftarrow \emptyset$ 
2. for each  $ar \in LR_k$  do
3.    $A \leftarrow getAttributes(ar)$ 
4.   for each  $ar' \in LR_k$  do
5.      $A' \leftarrow getAttributes(ar')$ 
6.     if  $first_{k-1}(A) = first_{k-1}(A')$  and
        $last(A) < last(A')$  then
7.        $cr \leftarrow [v_{min}, v_{max}]_{first(A), \dots, [v_{min}, v_{max}]_{last(A), [v_{min}, v_{max}]_{last(A)'}}$ 
8.        $cr \leftarrow adjust\_range(cr)$ 
9.        $CR_{k+1} \leftarrow CR_{k+1} \cup cr$ 
10.    break
11. return  $CR_{k+1}$ 

```

---

**Figure 2.2:** Original Phase II Generate algorithm

be formed since  $A_1 = A_1$  and  $A_3 > A_2$ . A new extended set of associated ranges  $cr$  is  $cr = \{[0.68, 0.75]_{A_1}, [1.21, 1.64]_{A_2}, [2.75, 3.11]_{A_3}\}$

However, before this set is passed onto the next iteration, an adjustment is necessary since similar issue is encountered from Phase I : A combination of two continuous ranges may cover more than necessary set of tuples. For instance, it occurs when a tuple might be covered in range 1, but not covered in range 2 and vice versa. As the new extended set is passed onto the next iteration, those tuples that fail to be covered in all specified ranges shall be set aside. In this algorithm, the algorithm preserves a strict policy of selection: it presumes those tuples would produce wrong classification at the end, thus will change their classes to *Null* which signifies a possible elimination on the next iteration (recall maxsum process in Phase I where it might eliminates tuples that are not under the same class value to trim down the candidate range).

*Example:* An extended set of associated ranges  $cr = \{[0.68, 0.75]_{A_1}, [1.21, 1.64]_{A_2}, [2.75, 3.11]_{A_3}\}$  is found from the last step. This set  $cr$  covers tuples under  $A_1, A_2, A_3$  respectively as:

$$cr = \{[0.68, 0.75]_{A_1}, [1.21, 1.64]_{A_2}, [2.75, 3.11]_{A_3}\}$$

$$\{t_4, t_3, t_1\}\{t_3, t_4, t_1\}\{t_4, t_3\}$$

It can be seen that tuple  $t_1$  is not covered under  $A_3$  range. Initially,  $t_1$  has class  $c_1$ , but since it was not covered completely under this set, the algorithm will convert  $c_1$  to *Null* in  $t_1$ . From Table 2.1,  $t_1$  is now presented as:

**Table 2.5:** A tuple turned Null in class value during generate phase

$T_{c_j}$	$A_1$	$A_2$	$A_3$	$A_4$	$C_j$
$t1$	0.75	1.45	2.13	4.56	Null

Its class will be kept for all iterations under class  $c_1$ .

Once Phase II (Generate) is completed, it repeats Phase I (Analyse) but on the new extended set of associated ranges instead. The iteration continues until no possible pair can be formed, which is when the algorithm is concluded. The remaining pair become the classification rule for that class.

However, it must be noted that this null-class converting process is replaced in this project algorithm, as this project adopts a stricter policy that eliminates partly-covered tuples instead of leaving it for consideration in the next iteration. Explanation and reasoning for such approach is discussed in the next section where the project algorithm is reviewed.

# SECTION 3

## Project Algorithm

Based on the original algorithm discussed in the previous section, initially this project only aimed to implement the exact algorithm into hard code. However, during the implementation process, several adjustments were agreed to be made. Some adjustments (e.g additional steps in scanning data input, display final rules to screen) are for the necessary code adaption i.e. pre-processing data for input and output, at beginning and end respectively. Others (e.g max-sum, threshold check, null-class converter) are for possible improvements in algorithmic in the programme.

Respectively, for the technical-related changes, section 4 will discuss them in depth where the actual code implementation is concerned. For the algorithmic changes, they are to be discussed in the remaining sections below.

### 3.1 Similarities

As the project's main goal is to implement the algorithm, the programme structure is entirely similar to the initial algorithm i.e. Phase I (Analyse) and Phase II (Generate) is kept in order. Details are explained in the following sub-sections.

#### 3.1.1 Project Phase I (Analyse)

Phase I contains the range analysis method (max-sum) and the threshold checker (for support, density and confidence). In this project, similar steps are implemented: Firstly, the table of data is divided into sub-data by class value (step 1-2). Secondly, within this sub-data, a  $[v_{min}, v_{max}]$

range is derived for each of the attribute (step 3). Thirdly, for each of these ranges within an attribute, a max-sum analysis is conducted so that sub-ranges can be deduced from the original range (step 4-7). Finally, each of these sub-ranges is then checked to see whether it passes the specified thresholds of support, confidence and density (step 8-12). The accepted sub-ranges are collected and sent to Phase II (Generate) (step 13).

However, in this project, several steps are done differently in terms of algorithm compared to the initial algorithm. Firstly, the max-sum analysis is adapted to fit in this range-based classification problem. While it was not discussed in details in the initial paper, there is a difference in this max-sum compared to the original max-sum solution. That is, this max-sum method will not seek for one maximal array but multiple ones depending on a set of pre-specified conditions. Secondly, in the threshold checking part, the order of threshold tested are no longer support - density - confidence, but support - confidence for first iteration and density - support - confidence for the second iteration onwards. It is to adapt to the different structural as well as technical requirements of different iteration e.g. density is not relevant in the first iteration where no extended ranges have been made yet. Details are to be discussed in the next section.

### 3.1.2 Project Phase II (Generate)

Phase II contains the range combination method (a-priori) and the additional adjustment step (null-class converter). In this project, the first method is implemented but the second part is replaced by an elimination step (eliminator): Firstly, the accepted sub-ranges from Phase I are considered and grouped with each other under the condition that one of them has an extendable range (step 1-7). Secondly, according to the original algorithm, an adjustment method is required by changing the class value of partly-covered ranges to Null (step 8).

However, instead of turning tuple's class value to *Null* only, this project adopts a stricter policy: all partly-covered ranges are eliminated and not considered for the next iteration. It is due to the idea taken from the paper that those tuples are deemed to badly influence the rule accuracy in the long run. While they might as well get eliminated in the next max-sum iteration, the algorithm in this project does not at all consider those tuples to save on processing time and enhance the rule accuracy in exchange for less support. Hence the null-class converting



process (step 8) is replaced with an elimination process. [SUPPORTINGPAPER?] Details will be discussed in the next section.

## 3.2 Differences

As mentioned in the previous section, there are two main algorithmic changes in this project compared to the initial algorithm. They are: [FIG?]

### 3.2.1 Project Phase I (Analyse)

MORE REASONING

- Max-sum method  $\rightarrow$  maxsum() in detail

*Original version:* Max-sum on multiple ranges - not elaborated on paper

*Project version:* Max-sum on multiple ranges in details - elaborated

- Threshold checking method  $\rightarrow$  separated check()

*Original version:* Threshold check consists of three orderly checks: support-density and confidence

*Project version:* Threshold check consists of two orderly checks for first iteration and three orderly checks for second iteration onwards. The order of each threshold check is also altered (for first iteration: support-confidence; for second iteration: density-support-confidence)

### 3.2.2 Project Phase II (Generate)

MORE REASONING

- Null-class converting method  $\rightarrow$  adjust()

*Original version:* a conversion where partly covered tuples have their classes change to Null

*Project version:* a total elimination where partly covered tuples are completely removed and not considered during the next iteration

### 3.3 Final Construction

Algorithm here but of course I am cursed to have files deleted before saving.

LaTeX is not for people with faint hearts.

# SECTION 4

## Implementation

### 4.1 Structure

Based on the project algorithm design, its Java implementation unit complies with the specified structure and thus maintain the two core phases (*Analyse* and *Generate*). However, hard code requires extra handling of data input and output. Hence additional two phases are added: *Scan* and *Monitor*, which read and display input respectively. Moreover, the differences in data type of different iterations require extra treatment would be too clunky to append to the *Analyse* phase. Thus, another phase is in line: *Sub – Analyse*, which inherits *Analyse* range-analysing functions while having additional threshold check (for density) and handle elimination round for partly-covered tuples.

The implementation process can now be divided into five Phases instead of two from the original algorithm. The reasoning is assessed in details below:

**Table 4.1:** 5-Phase Implementation and Reasoning

Reason	Outcome
To read and pre-process data input before analysis	Phase I Scan
To comply with the original structure	Phase II Analyse
To comply with the original structure	Phase II Generate
To adapt to different iteration needs during data analysing process	Phase IV Sub-Analyse
To monitor and record the result	Phase V Monitor

Details will be discussed in sections below for each phase. To demonstrate the structure visually,

a Class Diagram and an Activity Diagram is shown for each phase, that is represented by each class. Reason is because Class Diagram is the most common representation for an overview within and between classes [SRC]. A Sequence Diagram could have been an alternative to Activity Diagram; however, Sequence Diagram fails to demonstrate the actual data flow as the programme needs to call different functions or initialise different objects in different iteration. It means the sequences between classes change depending on which round the programme is on, thus not shown accurately in one data flow chart as in Sequence Diagram [SRC]. Therefore, to demonstrate the purpose of classes, Activity Diagram is in use.

#### 4.1.1 Phase I Scan

**Aim:** There are three aims within this phase or class:

- To read data from .csv file
- To sort data into sub-data pools using class values found when reading data in
- To pass these data into the next phase or class (*Analyser*)

**Input:** Assumed pre-processed csv file i.e. no null values within attributes and the order of element in an instance is attribute 1, attribute 2,..., attribute N, class C

*Reason:* Initial plan included an extra processing unit for filtering csv file when value is Null. However, time constraint did not allow the construction of this unit. Hence the programme only consider pre-processed csv data at the time the report is written.

**Output:** A list of all instances of the data - a list of tuples that are presented as lists (*AllTuples*). Moreover, a partitioned map that contains class values as keys that are connected to their relevant sub-data (list of instances) as values (*AllClassMap*)

*Reason:* *AllTuples* is required to provide access to all original data. *AllClassMap* is required to get the class-based data partition since the key efficiency of this algorithm is to 'divide and conquer' on data partitions guided by class tag [SRC]

**Data type:** *LinkedList* (for tuples), *LinkedHashMap* (for class-based data partitioned map)

*Reason:* A *List* (without specified inner data type) is used for tuples since it needs

multiple types of data (e.g. float number, string class value, integer order). In this case, `LinkedList` is used instead of `ArrayList` due to its ability to add and remove first and last elements more quickly than the alternative [SRC]. It is necessary to retrieve class value at faster rate as class value is the last element in the tuple.

Similarly, a `LinkedHashMap` is used for faster retrieval rate in later parts. A `HashMap` is used for storing partitioned sub-data from class values since each partition of data needs to be recorded with its unique class value. It has `String` class as key and `LinkedList<LinkedList>` List of all tuples as values.

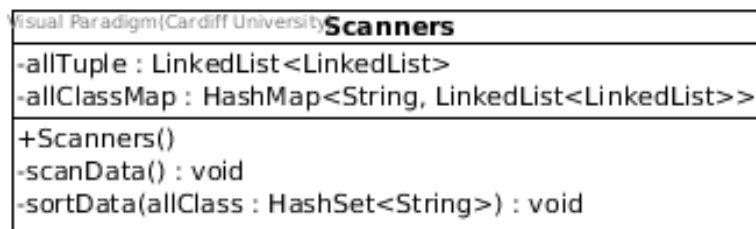
**Class diagram:** Its class diagram is in Figure 4.1, showing two features:

- `scanData()`

This method initialises two scanners, one to scan line-by-line data from csv file (i.e. tuples) and one to scan in-line elements (i.e. attributes). It processes data into 1) `allTuple` (where all instances are recorded from the first scanner) and 2) Class values, Tuple order numbering and Tuple attributes (which is sorted by the second scanners). The Class values become the parameter for the next method, where it helps create the Map that connects Class value to relevant set of Tuples.

- `sortData()`

This method groups sets of tuples according to their Class value by checking their last `String` element. It sorts and partitions `allTuple` into sub-data pools, which are then passed on as parameter to the new class (*Analyser*).



**Figure 4.1:** A Class Diagram for Phase I Scanners

**Activity diagram:** FIG PLS

### 4.1.2 Phase II Analyse

**Aim:** Being the core module of the programme, there are important aims for this phase or class:

- To find (min, max) range for each attribute from class-based map.
- To convert (min, max) range to binary array, which is ready for max-sum analysis.
- To perform max-sum analysis on (min, max), aim to obtain at least one sub-optimal range, which is ready for the threshold test.
- To perform threshold check. As discussed, this check diversifies depending on which iteration. However, support and confidence is always required thus appear in this phase or class.
- To modify the new sub-data pools for the next iteration. Since data set would shrink after pruning process from max-sum and (if applicable) strict-adjust method, current data set is frequently changing. Threshold measures, however, are calculated depending on these sets, thus makes this modification step necessary.
- To pass the modified sub-data pools as well as new sub-ranges to the next phase or class (*Generator*).

**Input:** allClassMap (with class value and sub-data partitions) and allTuple (all instances in data set) from previous phase or class

*Reason:* allClassMap is needed for the class-guided search for the rest of the programme. This map, however, changes as the sub-data pool changes throughout the cycle. Therefore, allTuple is needed to refer back to the original, pre-modification input when necessary.

**Output:** A list of sub-ranges in float values that passed the support-confidence check (**attributeRangeList**). It also returns a modified version of allClassMap, which **AllClassMap** is now divided into two maps: *attributeRange* and *attributeTuple*.

*Reason:* As required for the next *Generate* phase, **attributeRangeList** stores potential associated ranges for new combination. Map, however, diversifies into two:

- One for storing sub-ranges (that are also stored in `attributeRangeList`) for each attributes. That means `attributeRangeMap` has its key quantity equal to the number of attributes, and each key maps to at least one sub-range found from analysing methods.
- One for storing tuples that each sub-range in `attributeRangeMap` covers. That means `attributeRangeMap` has its key quantity equal to the number of sub-ranges available (that are also recorded in `attributeRangeList`), and each key maps to a list of tuples that is covered by that range.

Initially, only `attributeRangeMap` was implemented as it was thought that only attribute and its sub-ranges were necessary to be recorded formally. Tuples covered by sub-ranges were thought to be retrievable by tracing back to the original `AllClassMap`. However, as data was partitioned further the longer the algorithm persisted, there was no fixed map that remained relevant for the entire duration of the programme. With the dynamic nature of tuple sets, it was safer to record them right when their sub-ranges were being processed. Thus there was a need for the additional `attributeTupleMap`.

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**Data type:** `LinkedList` (for tuples), `LinkedHashMap` (for class-based data partitioned map)

*Reason:* A `List` (without specified inner data type) is used for tuples since it needs multiple types of data (e.g. float number, string class value, integer order). In this case, `LinkedList` is used instead of `ArrayList` due to its ability to add and remove first and last elements more quickly than the alternative [SRC]. It is necessary to retrieve class value at faster rate as class value is the last element in the tuple.

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**Class diagram:** Its class diagram is in Figure 4.1, showing two features:

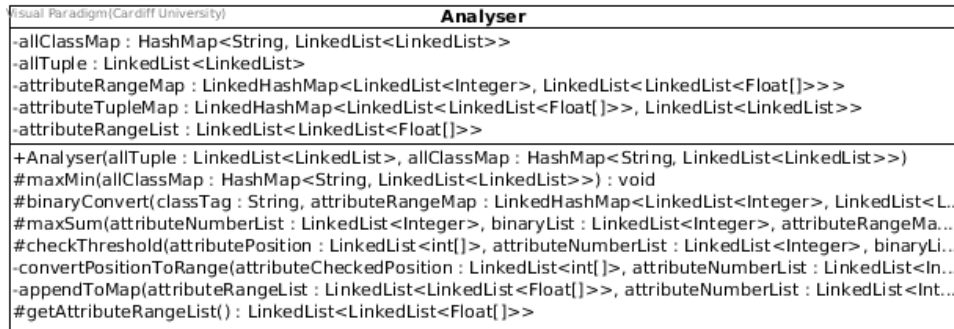


Figure 4.2: A Class Diagram for Phase II Analyser

- `scanData()` This method initialises two scanners, one to scan line-by-line data from csv file (i.e. tuples) and one to scan in-line elements (i.e. attributes). It processes data into 1) `allTuple` (where all instances are recorded from the first scanner) and 2) Class values, Tuple order numbering and Tuple attributes (which is sorted by the second scanners). The Class values become the parameter for the next method, where it helps create the Map that connects Class value to relevant set of Tuples.
- `sortData()` This method groups sets of tuples according to their Class value by checking their last String element. It sorts and partitions `allTuple` into sub-data pools, which are then passed on as parameter to the new class (*Analysers*).

**Activity diagram:**

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4.1.3 Phase III Generate

4.1.4 Phase IV Sub-Analyse

4.1.5 Phase V Monitor

4.2 Development Process

4.2.1 Planning

4.2.2 Technical Platforms

4.2.3 Version Control

# SECTION 5

## Testing

### 5.1 Performance

### 5.2 Accuracy

# SECTION 6

## Conclusion

# SECTION 7

## Future Work

### 7.1 Algorithm

### 7.2 Implementation

# SECTION 8

## Reflection