WEB SERVICE FOR 19TH CENTURY IRISH PERSONAL NAME MATCHING

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Dedicated to my dear parents and family.
For mom and dad who always know the best things for me.

ABSTRACT

Before the first Irish civil registration on 1864, census materials were mostly lost or incomplete. So genealogical research uses parish records and also some 'census substitute' documents, such as land ownership and tenancy records. However, some of these documents may not contain enough information in identify individuals. Some of them contains a name and address, whereas others might contain only a name.

Record linkage is one method to gather scattered information among many documents. It uses a person's name as a reference to link that person's information between many documents. With patience, a more complete information about that person can be obtained.

Therefore linking or matching a person's name is important in the process. Unfortunately, in the 19^{th} century, in Ireland, there was no standard spelling of names, handwriting could be difficult to read and contractions or abbreviations were often used. The names with the same pronunciation and for the same individual could be written in many different ways. Moreover, names in the Irish language which are equivalent to English names were used, for example, Irish version of 'Smith' could be 'Gowan'. A further complication is that historical and genealogical research often requires large quantities of names to be matched.

To handle these name variations, various solutions have been created to find matching different names that refer to the same person. However, for our extent knowledge, there is yet no public system which encodes those solutions together and provides a service of bulk name matching. Thus, we developed a web service system using Ruby on Rails framework to achieve our goal. The system is initially encoded with 4 matching algorithms, Levenshtein distance, soundex, Irish soundex, and lookup table. We also present a web interface for a client to use the system from the web browser. It is designed to be simple and extensible from using inheritance.

The system performs matchings on large quantities of names in a reasonable time. We test our system with 12,944 name matchings and the result were completed in no more than half a minute (28,786 milliseconds, to be precise). However, the system consumes a large amount of memory (around 373 megabytes). We believe that, with proper optimisation, we would reduce the memory usage along with a shortened processing time. Further matching algorithms could also be implemented for names in other languages, so that it can handle a broader domain of names.

DECLARATION

I declare that the dissertation report and code for "Web service for 19^{th} century Irish personal name matching" submitted for assessment is my own work except where credit is explicitly given to others by citation or acknowledgement. This work was accomplished during the current academic year except where otherwise stated.

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Phattara Wangrungarun,
June 8, 2015

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1 https://github.com/ipython

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Part I

THE BACKGROUND

1 INTRODUCTION

This project contains some backgrounds which are not part of computer science. Here we introduce adequate information in order to introduce the area.

1.1 MOTIVATION

The first civil registration in Ireland was performed on 1864 [1]. Before that time census meterials were mostly lost or incomplete. So genealogical research needs to rely on parish records and also some 'census substitute' documents, such as land ownership and tenancy records[1].

However, for these documents, each of them usually does not contain enough information to identify individuals. Some of them contains a name and address, whereas others might contain only a name. In order to find missing information about one individual scattered among many documents, *Record linkage* is one method used.

"Record linkage is used in historical research, social studies, marketing, administration and government as well as in genealogy" – Winstanley [2] section 2.2

Record linkage uses a person's name as a referece to link that person's information between many documents. Together with other coherant attributes to ensure the link is correct, a more complete information about that person can be obtained.

In addition, this is not only just for one person in isolation. We can find the relationship of the person to others that might be close to, and apply the information to those people as well. For example, if we know that there is a record that is believed to consist of people from the same area in each page [3] (but no area or address is mentioned, or some is missing in the page), and we can find one or more person's addresses in that page by using record linkage. We might be able to apply those addresses to all people in that page as well.

Therefore linking or matching a person's name is important in the process. Unfortunately, in the 19^{th} century, in Ireland, there was no standard spelling of most names, handwriting could be difficult to read and contractions or abbreviations were often used. Many people were not literate, so they asked literate people to write their names. So even names with the same pronounciation and for the same individual could be written in many different ways, depending on who wrote them.

1 [2] section 1.1

In addition to the various ways of spelling one's name, people from this time also often use names in the Irish language which are equivalent to English names, for example, Irish version of 'Smith' could be 'Gowan'. There are also some Irish prefixes like 'O'', 'M'', 'Mac', etc. When combined together this would result in 'O'Gowan' or 'M'Gowen', and so on.

An example list of possible equivalent Irish names of 'Smith' could be as follow.

> Smith, Smyth, Smythe, Smeeth, Going, Gowing, Maizurn, McGhoon, MaGough, M'Ghoon, MacGivney, MacGivena, M'Givena, MacGhoon, M'Evinie, McGivney, MacEvinie, McGivena, M'Givney, McEvinie, MacAvinue, M'Avinue, McAvinue, McCona, MaGowen, MaGowan, MaGovern, MaGeown, McGowan, McGoween, McGown, M'Cona, MeCowan, MeGowan, MacGown, MacGoween, MacGowan, MacCona, M'Gowan, M'Gowen, M'Gown, Ogowan, O'Gowan, Gowen, Gowan, Gow, Goan

To explain why names may not be standardised, consider the following situation.

> Patrick McFeelon was a tenent farmer in 1840 in County Laois. His landlord kept a record of the rent paid and in the rent roll recorded the name as P. Feelin. Patrick got married in 1842 but was illiterate and signed his name with an x. The minister entered the name in the register as Patricius McFeelin. Patrick has several children. At their baptisms, there surnames were recorded as variously McFelin, McFeelon, Feelin and Feelon. His eldest son, also called Patrick, could read and write. On a political petition in 1860 he signed his name in Irish as Padraig Mac Feilian. On his marriage however, he signed the register as Patrick McFeelon. His eldest son was also called Patrick. He was born after birth certificates were introduced in 1864. On his birth certificate his father spelt the surname as Feelon. Having a paper record of that spelling, he tended to use the same spelling in subsequent documents.

Therefore, a historian or genealogist trying to trace the McFeelon family would have to take into account all these name variations.

Also historic sources contain large quantities of names and matching the names from these sources to link records is very time consuming.

Various solutions have been created to find matching different names that refer to the same person. However, for our extent knowledge, there is yet no public system which encodes those solutions together

and provides a service of name matching. This project is to create one system to achieve this.

1.2 RESEARCH QUESTIONS

From the motivation, we address our research questions as follow.

1. Can we provide a web service to match names, where matching can be a complicated process because of the way people record their names.
2. Can the web service act as a platform system for general names or words matching system so that it can be extended to other languages as well.

The first question derives directly from the motivation. The second question is an enhancement for the system. It can be designed as a more general purpose matching system rather than just specified only for Irish names. Therefore it should be extensible for any further matching algorithms to be developed in the future.

In addition to the web service, web interface is to be introduced as well for the purpose of user friendly usage, individual usage, and demonstration.

1.3 OBJECTIVE AND AIMS

The objective of this project is to provide a web service that encodes several of matching algorithms and produces matching results between two lists of names.

The project aims to be a part of a bigger system, such as genealogy research. These client systems, at some point, they might need a service of a name matching on demand, so then they can use this web service, providing their lists of name, algorithms be be used, and threshold as inputs, and get matching results for their further usage.

We would start by focusing on Irish *surname* first. For any further kind of names we would leave it for future works.

1.4 REPORT STRUCTURE

This report is separated into four parts, The Background, The Solution, and Appendix.

THE BACKGROUND: Current part, states about background of this project. Introduces the initial problem, also some historical sit-

uations and terms which are not resident to computer science. Also related works that are involved in the project.

THE SOLUTION: The implementation to solve the problem. Details about algorithm, tools, language, frameworks, etc. which being used in the project.

THE OUTCOME: Evaluation of its performance, conclusion of the outcome of the project. encountered problems, and future works for extending and improvements.

APPENDIX: The 'user manual' of the project. Presents technical aspects, for example, how to use the web service in real world situation, or how to create an environment to host this project.

2 RELATED WORK

From research questions on section 1.2, there are three aforementioned terms that will be core research fields of this project. These fields are *name matching*, *web service*, and *extensible platform*.

2.1 NAME MATCHING

There are many methods for matching names. This project encodes various of them at the starting state.

2.1.1 *Edit distance*

> Edit distance is a way of quantifying how dissimilar two strings (e.g., words) are to one another by counting the minimum number of operations required to transform one string into the other. – Edit distance, Wikipedia [4]

An direct string operation way of comparing two string could work with name matching too. One of the edit distance variant, *Levenshtein distance* [5] is chosen to be implemented in this project.

2.1.2 *Soundex*

Soundex [6] encodes a name (or any string) into a 4 character code which represents an essence of its sound as pronounced in English. The idea is to encode letters with similar sound into the same group, and ignore vowels (unless it is the first letter). For example, 'Smith' is translated to `S530`, and 'Simon' is translated to `S550`.

Irish Soundex[1] is a modified version of Soundex, aims to improve capability of a traditional one upon Irish surnames. By applying rules accroding to the langauage characteristics and make some adjustment to distinguish names properly.

Both Soundex variants are also implemented in the project.

1 [2] Appendix 3.

2.1.3 *Lookup Table*

In 1901, Robert Edwin Matheson, the assistant registrar-general in Dublin, developed a name classification system [7] for an aid of register indexing and searching. He used a report on surnames in Ireland extracted from civil registers [8] in 1894 as a base of his system[2].

He gathered information from registry offices, focusing on people or members of close families. When these people made official register records with the office, they might use different variant of their surnames. For example, Mr. Green can be registered as dead by his son using the name Huneen.

With these information, Matheson classified the surnames in Ireland into 2091 groups. For example, group 753 consists of these names.

> Green, Greenan, Greenaway, Greene, Grene, Guerin, Houneen, Huneen, MacAlasher, MacAlesher, MacGlashan, MacGlashin, MacIllesher, M'Alasher, M'Alesher, McAlasher, McAlesher, McGlashan, McGlashin, McIllesher, M'Glashan, M'Glashin, M'Illesher, Oonin.

This classification also includes multiple mapping between names. One name can belong to one or more group. For example, 'Green' belongs to groups 753, 754, 768, and 1350.

By using this classification information, we can construct a lookup table for Irish names by having names in the same group hold the same reference number.

2.2 WEB SERVICE

One convenient way to bring this service to public is to create a *web service*. A web service is a tool or function that can be accessed by other programs over the web (via http) [9]. A result from web service is designed to be used by computer programs rather than humans.

There are many ways to implement web services. Two famous ones are *Simple Object Access Protocol (SOAP)* and *Representational State Transfer (REST)*. Both has their own advantages [10]. We decided to implement our service using REST due to its simplicity and scalability [11][12].

At this initial state, data resulting from our web service is in `JSON` [13] format. Since it is widely used in web development and becoming more and more popular [14]. However, our service can be extended into any other format easily as well, such as traditional `XML`.

2 [2] section 2.3.

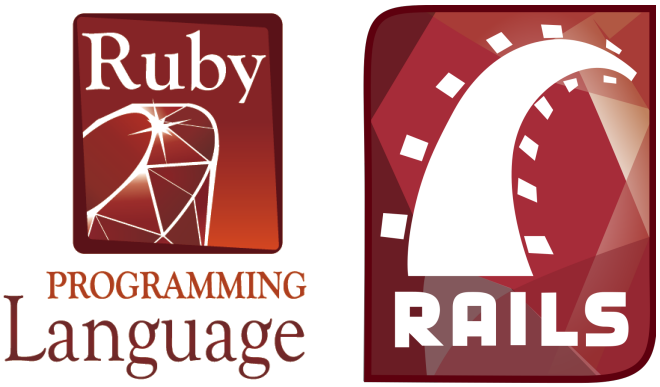

Figure 1: Ruby programming language (left) and Ruby on Rails framework (right).

2.3 EXTENSIBLE FRAMEWORK

"Ruby is designed to make programmers happy."
– Venners [15]

Our system is implemented in *Ruby* [16] programming language. Ruby is a well-balanced language, it can be used as an traditional object-oriented language [17] and also capable of performing functional programming [18], thus making it very flexible and versatile.

The system sits on top of *Ruby on Rails* (or *Rails*, in short) [19] framework. Rails is a mature and stable framework that has been in web development for decades [20]. So it has a great support and a large community bebind. A great choice for building a sustainable system.

Rails is capable of both web service and web interface. By sharing the same algorithm we could provide a service for both programs (targeted by web service) and humans (targeted by web interface).

Part II

THE SOLUTION

3

NAME MATCHING ALGORITHMS

This chapter describes the details how matching algorithms in the project are implemented. Note that algorithms and codes listed here are written in Ruby programming language, which is the main language of the project.

We will start off by detailing bundled matching algorithms here. Each matching algorithm calculates the *similarity score* between two strings.

The score is ranging between 0.0 to 1.0, where 0.0 means two strings are completely different and 1.0 means both are extactly matched.

Also note that string inputs here is in all in the uppercase format, in order to prevent letter-case difference.

3.1 LEVENSHTEIN DISTANCE

This algorithm measures the difference between two strings. It tells the minimum number of opearations needed to change string to another. These opeations are insertions, deletions, or substitutions. Consider these following examples.

- SM**I**TH → SM**Y**TH
  the minimum operation to change is 1, which is to substitute 'I' to 'Y', therefore Levenshtein distance for these two strings is 1.
- GOWAN → **MC**GOWAN
  2 insertions of 'M' and 'C' is required.
- SM**I**TH**E** → SM**Y**TH
  1 deletion of 'E' and 1 substitution of 'I' to 'Y' are required.

The implementation used in the project is done by Battley [21][1]. Once the distance is calculated, it will be compared to the length of the longer string between the two (or if they are the same length, use that length).

For example, Levenshtein distance between 'SMYTH' and 'SMITHE' is 2, compare 2 to length of the longer string, 'SMITHE', which is 6. So the *similarity score* of these two strings are $6 - (2/6) = 0.667$.

The code of this algorithm is as in listing 1, note that `@name` and `@base_name.name` are two strings to be matched.

1 levenshtein.rb

```
def cal_score
  @value = Text::Levenshtein.distance(@name, @base_name.name)
  size = [@name.size, @base_name.name.size].max
  @score = ((size - @value).to_f / size)
end
```

Listing 1: Levenshtein distance implementation.

3.2 SOUNDEX

Soundex encodes a string into a 4 character code representing an essence of its sound as pronounced in English. It operates in the following steps.

1. Take the first letter of a string.
2. Encode each remaining letters into a group following table 1. Discards A, E, I, O, U, H, W, and Y
3. Remove two adjacent same characters.
4. If a group of a first letter is the same as the second letter, remove the second letter.
5. Trim or pad with zeros as necessary, making the result 4 characters long.

GROUP	LETTERS
1	B, F, P, V
2	C, G, J, K, Q, S, X, Z
3	D, T
4	L
5	M, N
6	R
-	A, E, I, O, U, H, W, Y

Table 1: Soundex letter group.

Let us follow these steps by step, consider we are going to encode the string 'PFISTTER'.

1. Take first letter of 'PFISTTER'.
   PFISTTER $\rightarrow$ P

2. Encode remaining letter 'FISTTER'.
   PFISTTER → P1-233-6 → P12336
3. Remove two adjacent same characters.
   PFISTTER → P12336 → P1236
4. P is also in group 1, so remove the second 1 letter.
   PFISTTER → P1236 → P236
5. P236 is 4 characters long, so no need to be trimmed or padded.
   PFISTTER → P1236 → P236

Therefore, soundex of 'PFISTTER' is `P236`.

The implementation of soundex (listing 2) in this project is adapted from Winstanley's *Irish soundex* implementated in Visual Basic[2]. The code is commented following the same aforementioned steps.

```
def self.soundex(name)
  # Take the first letter of a string.
  result = name.first

  # Encode remaining letters.
  name[1..name.length].split('').each do |n|
    result = result + category(n).to_s
  end

  # Remove two adjacent same characters.
  result.gsub!(/([0-9])\1+/, '\1')

  # If category of 1st letter equals 2nd character, remove 2nd
      character.
  if result.size >= 2 && category(result[0]).to_s == result[1]
    result.slice!(1)
  end

  # Trim or pad with zeros as necessary.
  result = if result.size == 4
           result
         elsif result.size > 4
           result[0..3]
         else
           result.ljust(4, '0')
         end
end
```

Listing 2: Soundex implementation.

The `category` function implements soundex grouping table (table 1) as in listing 3.

2 [2] Appendix 3.

```
def self.category(c)
  if c.match(/[AEIOUHWY]/).present?
    ""
  elsif c.match(/[BPFV]/).present?
    1
  elsif c.match(/[CSKGJQXZ]/).present?
    2
  elsif c.match(/[DT]/).present?
    3
  elsif c.match(/[L]/).present?
    4
  elsif c.match(/[MN]/).present?
    5
  elsif c.match(/[R]/).present?
    6
  else
    ""
  end
end
```

Listing 3: Soundex grouping table implementation.

Now that we encode two strings to be matched in soundexes. We then calculate the *similarity score* of these two soundexes using these steps.

- Compare first characters of each soundex, if they are different, *similarity score* is 0, otherwise move to next step.
- Compare the rest 3 digits by using Levenshtein distance (section 3.1) to calculate the distance between them.

For example, *similarity score* between 'SMITH' and 'SPEED', which soundexes are `S530` and `S130` respectively, is 0.75 (1 substitution from '5' to '1', so 1 difference of length 4).

The code of this soundex *similarity score* is as in listing 4.

```
def soundex_distance_score(s1, s2)
  if s1.first != s2.first
    0 # Different category, so they suppose to be completely
        different.
  else
    (s1.size - Text::Levenshtein.distance(s1, s2).to_f ) / s1.size
  end
end
```

Listing 4: Soundex similarity score implementation.

3.3 IRISH SOUNDEX

Irish soundex is another variant of traditional soundex. It determines characteristics of Irish names and normalised them to modern names. This algorithm also follows Winstanley's *Irish soundex*[3].

Irish names might contain some prefix, e.g. 'Mc' or 'O', which are obstructive to soundex result. These prefixes are to be discarded. Moreover, there is no initial soft 'C' in Irish names, instead 'K' is used. So the first letter 'C' is changed to 'K'. It is implemented as in listing 5.

3 [2] Appendix 3.

```
def self.soundex(name)
  # Change initial ST. to SAINT.
  name = name.match(/^ST\./).present? ? "SAINT
      #{name[3..name.length]}" : name

  # Discard Irish prefixes.
  name = if name.match(/^O /).present?
         name[1..name.length].gsub(' ', '')
       elsif name.match(/^O'/).present?
         name[2..name.length].gsub(' ', '')
       elsif name.match(/^MC/).present?
         name[2..name.length].gsub(' ', '')
       elsif name.match(/^M'/).present?
         name[2..name.length].gsub(' ', '')
       elsif name.match(/^MAC/).present? && name != 'MAC'
         name[3..name.length].gsub(' ', '')
       else
         name
       end

  # Change initial C to K.
  name = name.strip.gsub(/^C/, 'K')

  # Call to traditional soundex.
  return {
    :label => name,
    :soundex => Soundex.soundex(name)
  }
end
```

Listing 5: Irish soundex implementation.

Irish soundex algorithm in this project calls traditional soundex described in section 3.2 to minimise repeated code. It also calculates *similarity score* the same way soundex does, as in listing 4.

3.4 LOOKUP TABLE

Lookup table is constructed from Robert Edwin Matheson's classification of Irish names. All classification information is stored in a Database, using PostgreSQL, which is a powerful, open source object-relational database system [22].

Matheson classified the surnames in Ireland into 2091 groups. Each group has one or more names, and on the other hand, each name belongs to one or more group.

In this section, we will consider the names as strings input. So the term *string* will be used in consistent with previous sections.

For example, considering the string 'ACHESON', this string belongs to two groups, 4 and 42. So 'ACHESON' will have 2 records in the database. One with reference to group 4 and another with reference to group 42.

Next, let us consider group 4 and 42.

> 4 → ACHESON, ACHISON, AITCHISON, ATCHESON, ATCHIESON, ATCHISON, ATKINSON
> 42 → ACHESON, ARKESON, ATKINS, ATKINSON

By combining two groups together, these are all possible strings that match 'ACHESON' according to Matheson's classification.

Now is the process to match two strings using Lookup table, suppose two strings are 'ACHESON' and 'ATKINS'.

1. Find references of 'ACHESON'. We get references for group 4 and 42. Note the use of `pluck` method to select reference attribute (`ref`) here[4].

```
LookupTableRecord.where(:name => 'ACHESON').pluck(:ref)
=> [4, 42]
```

2. Find reference to matching string 'ATKINS' and also specify the reference groups from step 1. If there is no match `where` method will return empty array. `present?` method is used to check the result if it is not empty[5].

```
LookupTableRecord.where(:ref => [4, 42], :name =>
    'ATKINS').present?
=> true
```

   By specifying both matching string and references group, we can ensure the matching name is also in the one of the same reference group of the base name. In this case, we conclude that there is a match between 'ACHESON' and 'ATKINS' via group 4 or 42 (or more specifically, 42, because 'ATKINS' belongs to group 41 and 42).

4 Use pluck as a shortcut to select one or more attributes without loading a bunch of records just to grab the attributes you want. http://api.rubyonrails.org/classes/ActiveRecord/Calculations.html#method-i-pluck

5 http://api.rubyonrails.org/classes/Object.html#method-i-present-3F

If a reference is found on both steps, *similarity score* for lookup table of the two strings is 1.0. If the system fails to find any reference on any step, consider a no match and the score is 0.0.

By following these steps, the implementation of lookup table is as in lisiting 6.

```
def cal_score
  # Look for a reference for base name.
  base = LookupTableRecord.where(:name => @base_name.name)

  @score = if base.nil? # Could not find reference for base name,
      no matches.
          0
        else
          # Find any reference that has 1) same name 2) same
              reference.
          base = base.map(&:ref)
          refs = LookupTableRecord.where(:ref => base, :name =>
              @name)

          if refs.present?
            @label = (base & refs.map(&:ref)).join(', ')
            @value = "Matched"
            1
          else # Could not find reference for matching name, no
              matches.
            0
          end
        end
end
```

Listing 6: Lookup table implementation.

4 ARCHITECTURE

Now that we already know how to match (by comparing and calculating *similarity score* from section 3), we then proceed to a bigger picture. This section describes how the architecture of overall system is.

4.1 INITIAL IDEA

Let us start by the basic idea of this project.

As mentioned in section 1.3, the objective of this project is to provide a web service that produces matching result between two *lists* of names. As we see the word *list* here, that means our inputs are not only a pair of names, but rather two lists. In real world use, this list can be large, a hundred or thousand, depending on the client who uses the system.

We will introduce two terms, *base name* and *to-match name*. *Base name* acts as a base and will be matched against each *to-match name* in their list, from start until the end, then proceed to the next *base name*, match against the whole *to-match name* list again, and so on.

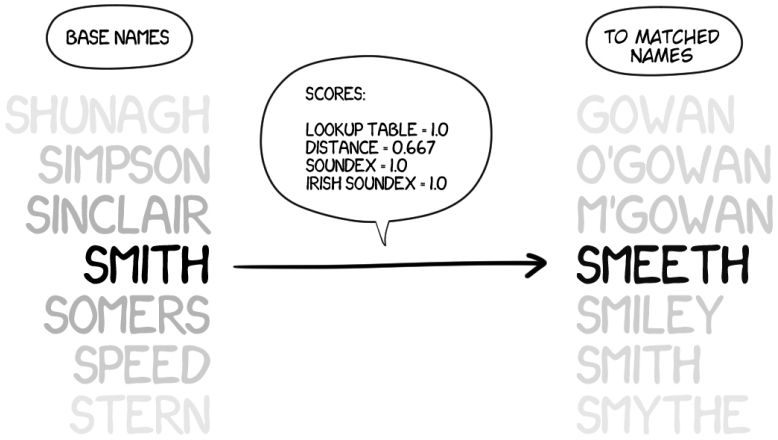

Figure 2: *Base name* 'SMITH' comparing to *to-match name* 'SMEETH'. Scores of each matching algorithms are presented in the bubble above the arrow.

Figure 2 shows a snapshot of an attempt to match between *base name* 'SMITH' against *to-match name* 'SMEETH'. *Similarity score* for

each matching algorithms have been calculated. And by these scores, we can calculate *overall score* for 'SMITH' and 'SMEETH'.

So the next step is to match current *base name*, 'SMITH', against next *to-match name*, 'SMILEY'.

Once *base name* 'SMITH' completes all *to-match name*'s in their list, the system then process to the next *base name*, 'SOMERS', and start over the matching process against the whole *to-match name* list again, from start to the end.

4.2 WEIGHTING MATCHING ALGORITHMS

We realised that, for matching names, each matching algorithms should not be treated as all the same priority. For example, for Irish names, it would be better if we favour *Irish soundex* over the traditional *Soundex*, because it produces more accurate result.

By this idea we also implement *weight* for each matching algorithm. We will suggest initial values, but also allow client to change these values. Table 2 states these suggested initial weights.

MATCHING ALGORITHM	WEIGHT
Levenshtein distance	1
Soundex	3
Irish soundex	6
Lookup table	10

Table 2: Matching algorithm weights.

By summarising products of each matching algorithm *similarity score* and its weight, dividing by sum of all weight, we can obtain *overall weighted score* (OWS). This sentence can be represented by equation 1.

$$OWS = \frac{\sum_{i=1}^{n} (s_i \times w_i)}{\sum_{i=1}^{n} w_i} \tag{1}$$

Where s and w are *similarity score* and weight of matching algorithm i respectively. n is number of available matching algorithms.

This *overall weighted score* will represent each matching and all results will be sorted by this score. Usage and calculation of this weighting will be described in more detail in the next section (4.3).

4.3 ACTUAL SYSTEM

Following our basic idea from previous sections, we then design the architecture of our system.

Suppose we have two inputs, list of *base names* of length b, and list of *to-match names* of length t. We need to process the matching for $b \times t$ times. We call this single matching between *base name* and *to-match name* as *matching cycle*.

In this following figure 3 we once again show a snapshot of an attempt to match between *base name* 'SMITH' against *to-match name* 'SMEETH'. But now in a *matching cycle* style.

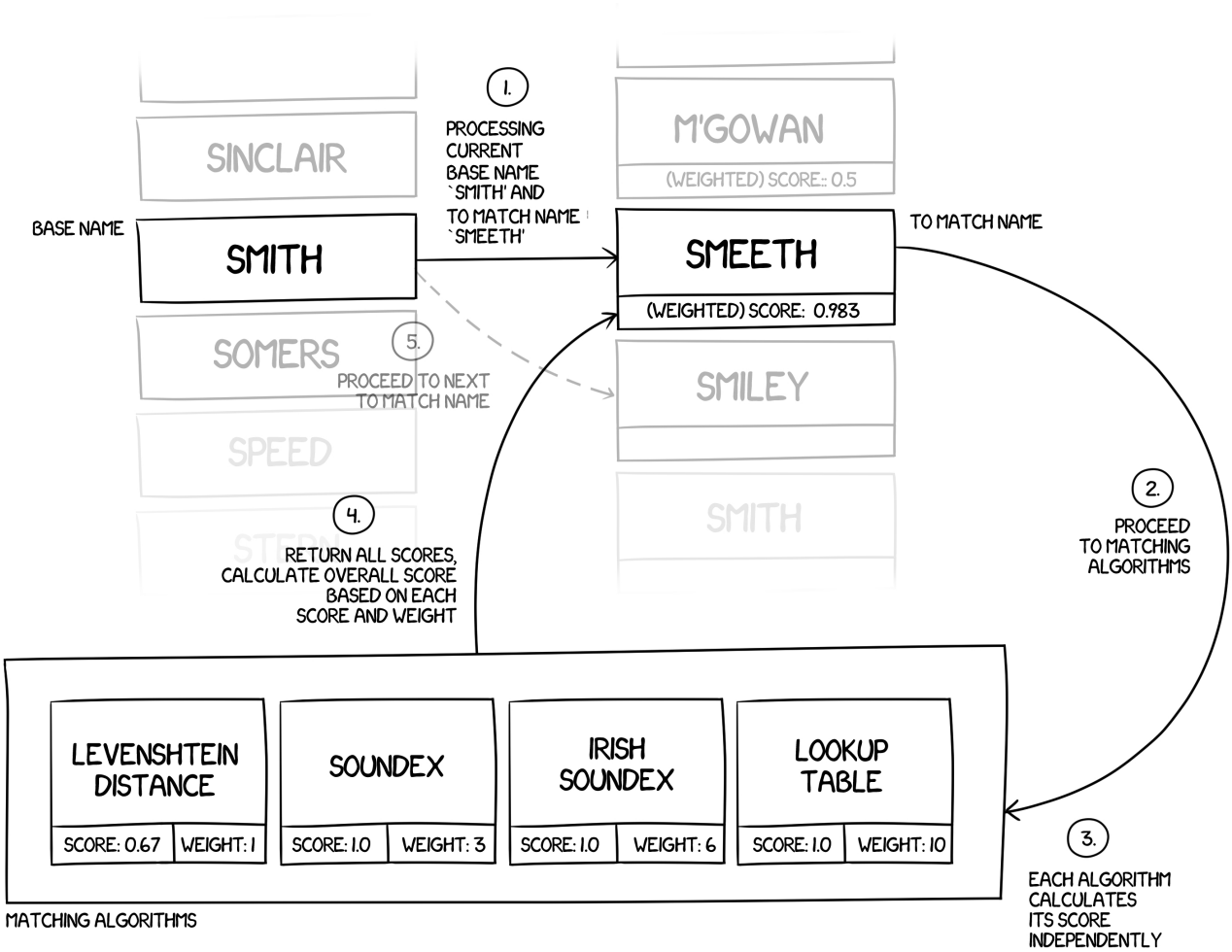

Figure 3: One matching cycle.

One matching cycle consists of 5 steps as shown in figure 3.

1. Processing current *base name* 'SMITH' and *to-match name* 'SMEETH'
2. Proceed to matching algorithms.

3. Each algorithm calculates its score indepedently.
   a) Levenshtein distance between 'SMITH' and 'SMEETH' is 2 (1 substitution of *I* to *E* and 1 insertion of *E*). So *similarity score* is $(6-2) \div 6 = 0.667$ where 6 comes from thelength of the longer string, 'SMEETH'.

      Weight of this algorithm is 1.

      $\therefore$ WEIGHTED SCORE = $0.667 \times 1 = 0.667$

   b) Soundex of both 'SMITH' and 'SMEETH' are `S530` so their *similarity score* is 1.0.

      Weight of this algorithm is 3.

      $\therefore$ WEIGHTED SCORE = $1.0 \times 3 = 3.0$

   c) Irish soundex of both 'SMITH' and 'SMEETH' are `S530` so their *similarity score* is 1.0.

      Weight of this algorithm is 6.

      $\therefore$ WEIGHTED SCORE = $1.0 \times 6 = 6.0$

   d) References between 'SMITH' and 'SMEETH' is found in the Lookup table via group 1897. so their *similarity score* is 1.0

      Weight of this algorithm is 10.

      $\therefore$ WEIGHTED SCORE = $1.0 \times 10 = 10.0$

4. Return all scores and then calculate *overall weighted score* for 'SMITH' and 'SMEETH'. Sum of the scores is $0.667 + 3.0 + 6.0 + 10.0 = 19.667$. Sum of the weights is $1 + 3 + 6 + 10 = 20$. Therefore the *overall weighted score* is $19.667 \div 20 = 0.983$.
5. Matching cycle for 'SMITH' and 'SMEETH' is finished with *overall weighted score* 0.983. Now the system will proceed to the next *to-match name* 'SMILEY'. Matching cycles for *base name* 'SMITH' will continue until the end of *to-match name* list. After that it will start matching cycles for *base name* 'SOMERS' from the start of *to-match names*, and so on.

Once all cycles are fully finished for every *base names* and *to-match names*, we will get all *overall weighted scores* ready. So we can sort and present in web interface (section 4.8), or return as a result in web service (section 4.7).

4.4 THRESHOLDING THE RESULTS

Suppose there are a thousand of *to-match names*, there could be many irreverent results that are not likely to match each *base name*. For example *overall weighted scores* of 'SMITH' and 'CROMBIE' is just 0.007.

Client may opt-out these irreverent results by specifying a floating number *threshold*. Any *to-match name* with *overall weighted scores* lower than *threshold* will be discarded from the result.

4.5 DATA FLOW

In the previous section we describe the essence of this project, how we use matching algorithms to calculate score of similarity between two strings. We know how to process the data. Now in order to make the system becomes useable. We need to consider two more things.

- How to gather inputs from clients.
- How to present or return results to clients.

From research questions (section 1.2) we mentioned two ways to communicate with clients, by *web service* and *web interface*.

Clients who use the system as a web service will send inputs directly without any medium in between, and will receive result back in form of agreed format, e.g. `JSON`.

On the other hand, clients who use the system via web interface will use a form in a web interface (web page) provided by the system to provide inputs, and results will be presented in another page after client submitted the form.

SERVICE TYPE	INPUT SOURCE	RESULT FORMAT
Web service	Web/mobile/desktop application	`JSON`
Web interface	Provided form	Web page result

Table 3: Service types and their inputs and results.

In the next section (4.6) we will describe how we gather inputs and provide results.

4.6 MVC

Our system is based on Ruby on Rails, which is a MVC[1] framework. We will use Rails architecture to encapsulate our system be these following means.

VIEW: where the form for web interface is implemented. It creates a web page with inputs for use to fill in. Client can inputs names

1 Model-View-Controller [23]

manually, or upload a file containing names. He also can choose whether to use any available matching algorithms.

Inputs from *view* are then passed to *controller*.

View is also responsible in displaying result to web interface clients, and generating `JSON` result for web service clients.

CONTROLLER: receives inputs from different sources, inputs from form of web interface style, or direct input from clients using web service style. Inputs will be pre-processed, such as separating lines from file input, removing white spaces, or converting input to upper-case.

Once inputs are ready, *controller* then passes these inputs to *model*, where our matching system lies in.

After inputs are processed, *controller* receives results back from *model*, then *controller* will decide which kind of result it needs to return from input source. It will then pass results to appropriate *view*.

MODEL: this is where we implement our whole matching system in. Model constructs *base names* and *to-match names* from received inputs, then invoke matching algorithms, as described in section 4.3. *Model* will pass results back to *controller* after finished.

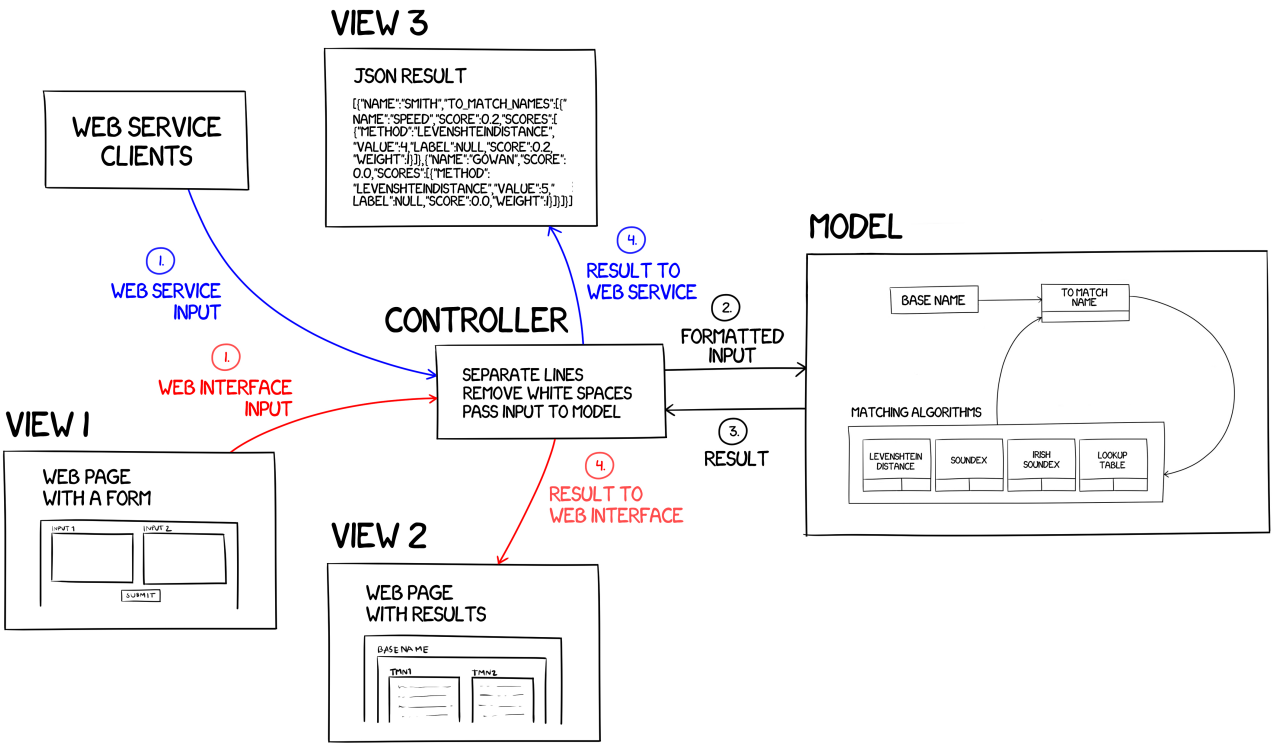

Figure 4: Data flow from web service client and web interface client.

4.7 WEB SERVICE

From figure 4, web service clients use the system by directly pass inputs to the *controller*. Recalling from previous sessions, all possible inputs to the system are as follow.

1. Base names – separated by new lines[2].
2. To-match names – separated by new lines.
3. Matching algorithms – specify needed algorithm names along with its weight (section 4.2).
4. Threshold (section 4.4).
5. Standard list – will be introduced in section 6.1. Specify `true`, `t`, or `1` to use the standard list.

Currently a preferable format is `JSON`. In listing 7 shown a sample `JSON` input for using web service, let us call this `sample.json`.

```
{
  "base_names":"Smith",
  "to_match_names":"Smythe\r\nO'Gowan",
  "matching_algorithms":{
    "1":{"name":"LookupTable", "weight":"10"},
    "2":{"name":"LevenshteinDistance", "weight":"1"},
    "3":{"name":"Soundex", "weight":"3"},
    "4":{"name":"IrishSoundex", "weight":"6"}
  },
  "threshold":"0",
  "standard_list":""
}
```

Listing 7: `sample.json`.

`sample.json` is an attempt to match between *base name* 'SMITH', and *to-match name* 'SMYTHE' and 'O'GOWAN'. Using 4 matching algorithms, and threshold as 0. We will submit this `sample.json` input to the system using cURL [24] in command line.

```
$ curl -H "Accept: application/json" -H "Content-type:
    application/json" -X POST -d @sample.json
    http://localhost:4001/match.json
```

2 Preferably `\n` or `\r`, see http://stackoverflow.com/questions/1761051/difference-between-n-and-r.

We use HTTP POST [25] to submit `sample.json` to the web service, currently running locally, so the `url` using here is `http://localhost:4001/match.json`. The formatted `JSON` result is shown in listing 8, note that the result of matching between 'SMITH' and 'O'GOWAN' is truncated just for readability.


```
[
  {
    "base_name": "SMITH",
    "to_match_names": [
      {
        "to_match_name": "SMYTHE",
        "overall_weighted_score": 0.983,
        "scores": [
          {
            "method": "LookupTable",
            "value": "Matched",
            "label": "1897",
            "score": 1,
            "weight": 10
          },
          {
            "method": "LevenshteinDistance",
            "value": 2,
            "label": null,
            "score": 0.667,
            "weight": 1
          },
          {
            "method": "Soundex",
            "value": "S530 <=> S530",
            "label": null,
            "score": 1,
            "weight": 3
          },
          {
            "method": "IrishSoundex",
            "value": "S530 <=> S530",
            "label": "SMYTHE",
            "score": 1,
            "weight": 6
          }
        ]
      },
      {
        "to_match_name": "O'GOWAN",
        "overall_weighted_score": 0.5,
        ...
```


Listing 8: Result from `sample.json`.

From the results, *overall weighted score* between 'SMITH' and 'SMYTHE' is 0.983, higher than 'SMITH' and 'O'GOWAN' (0.5), so the former is sorted before the latter.

To generate these results in `JSON`, we use Jbuilder [26], a template for generating JSON structures. The template we use is shown in listing 9.

```
json.array! @matched_names do |matched_name|
 json.base_name matched_name.name

 json.to_match_names do
  json.array! matched_name.to_match_names do |tmn|
   json.to_match_name tmn.name
   json.overall_weighted_score tmn.score

   json.scores do
    json.array! tmn.scores do |s|
     json.method s.class.name
     json.value s.value
     json.label s.label
     json.score s.score
     json.weight s.weight
    end
   end
  end
 end
end
```

Listing 9: Jbuilder template for generating `JSON` results.

4.8 WEB INTERFACE

Our system provides a web interface with inputs form. All possible inputs are equivalent to web service as follow.

1. Base names – clients can fill the names in *input 1*, separated by new lines. alternatively, clients can also upload a file containing names separated by new lines. if the web interface detects that the file input is present, direct text input will be discarded.
2. To-match names – the same way of *base name*, using *Input 2*.
3. Matching algorithms – clients can choose available algorithms from the list along with its weight using checkboxes. Uncheck to opt-out any algorithms.
4. Threshold – clients can specify floating number threshold using input box.

5. Standard list – will be introduced in section 6.1. clients can check the checkbox to use the standard list.

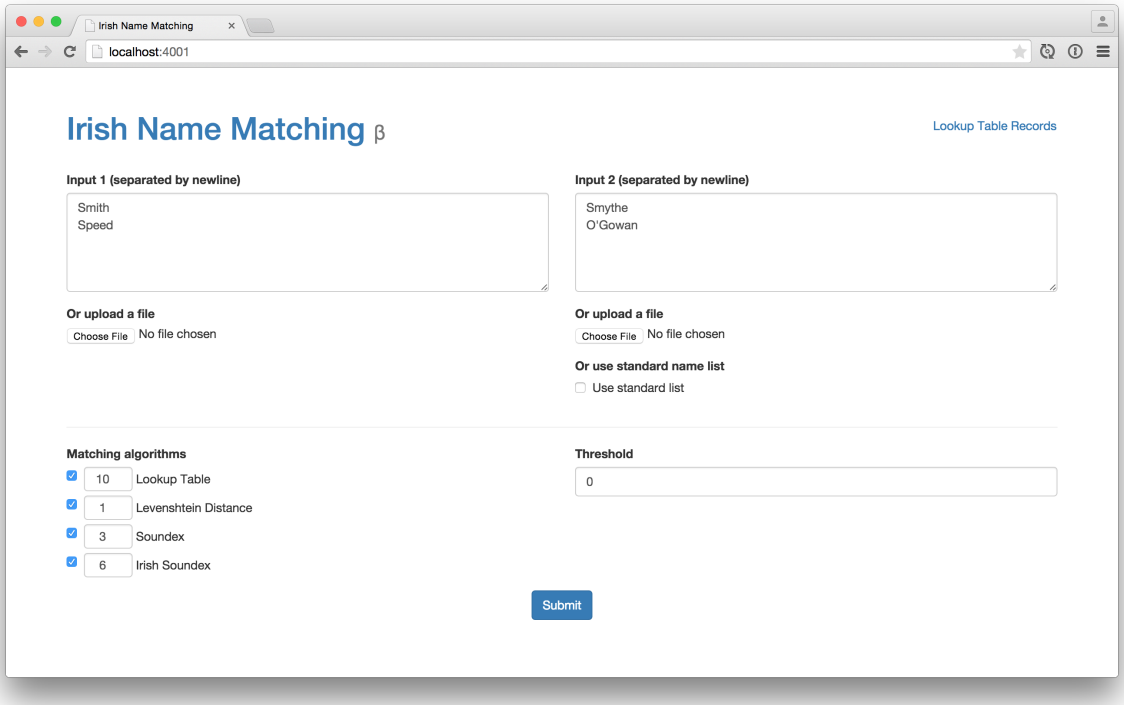

Figure 5: Web interface with input forms.

Figure 5 is an attempt to match between *base name* 'SMITH' and 'SPEED', and *to-match name* 'SMYTHE' and 'O'GOWAN'. Using 4 matching algorithms, and threshold as 0. After finish filling all inputs client may press the blue 'Submit' button to begin matching.

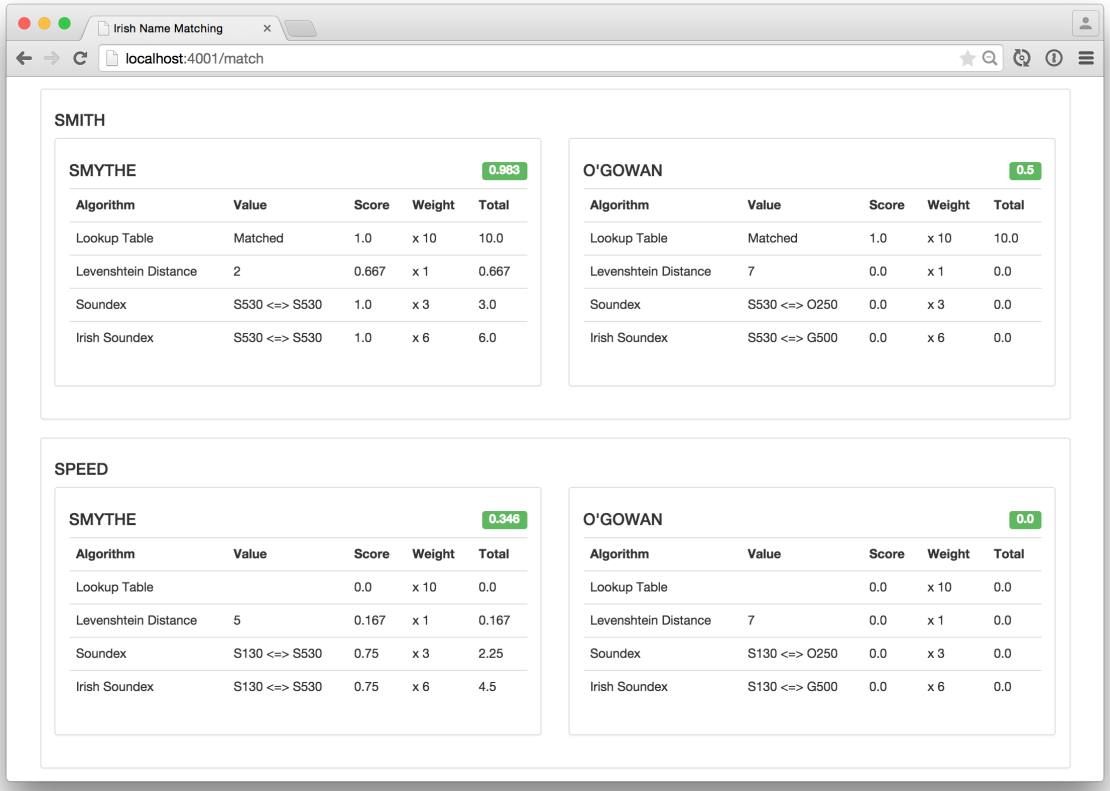

Figure 6: Web interface results page.

Figure 6 shows the web interface result of this matching. There are two *base names* and two *to-match names*, so the results are matchings of total $2 \times 2 = 4$ names. Each outer box is results of matching between each *base names*, with the outer box there is an inner box containing details of each *to-match names*.

From the results, *overall weighted score* (each green labelled box) between 'SMITH' and 'SMYTHE' is 0.983, higher than 'SMITH' and 'O'GOWAN' (0.5), so the former is sorted before the latter.

5 EXTENDING THE SYSTEM

In this section we show how we design our system to be extensible in terms of adding new matching algorithms, also using existing shared methods, or sharing new methods.

5.1 MATCHING ALGORITHMS INHERITANCE

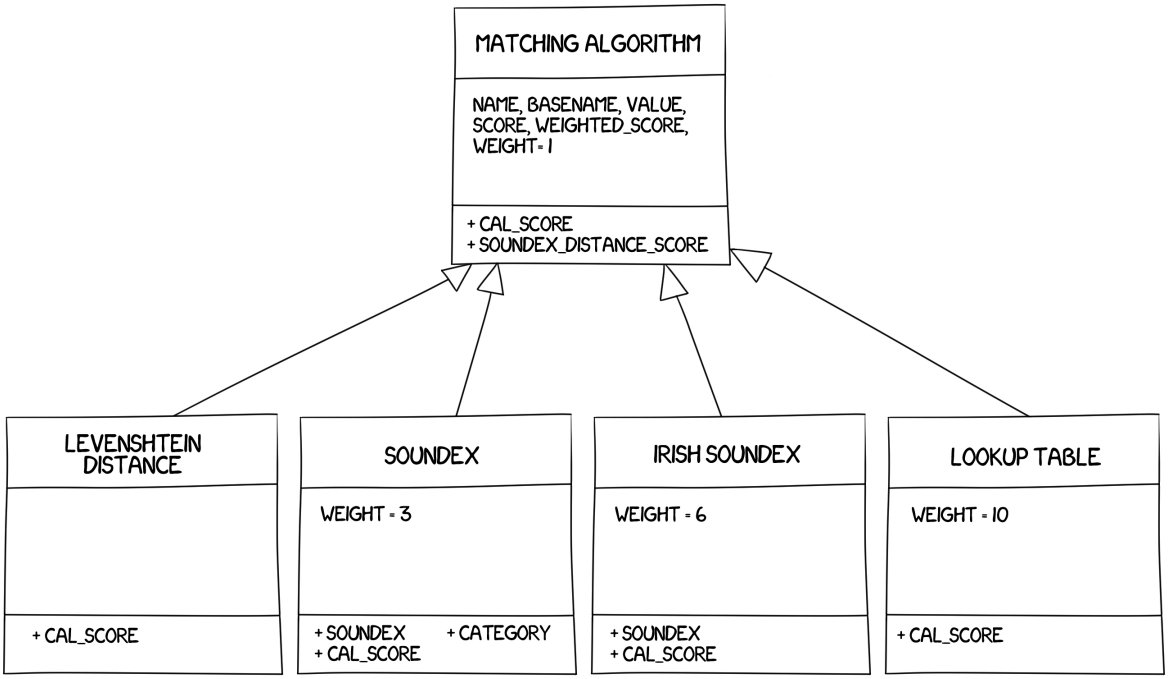

Figure 7: `MatchingAlgorithm` inheritance.

All matching algorithms (chapter 3) inherit the same superclass, `MatchingAlgorithm` (shown in figure 7 and listing 10). They all use the same class constructor (in Ruby, it is called the *initialize* method). To create an instance of `MatchingAlgorithm`, current *base name*, *to-match name* and *weight* are passed as parameters.

We use *The Strategy Pattern*[1] as a design pattern. In `MatchingAlgorithm` the `cal_score` method is declared and also meant to be overridden, so every matching algorithm needs to override this method using their own matching logic. Each matching algorithm class will call

1 [27], page 24

`cal_score` to calculate its scores. `cal_score` is also private to be only used within the subclasses themselves.

We also define `soundex_distance_score` method to be shared between soundex algorithms. Any further shared methods can be declare here as well.

`MatchingAlgorithm` class is shown in listing 10.

```
class MatchingAlgorithm
  WEIGHT = 1 # Default weight of every matching algorithm.

  attr_accessor :name,
    :base_name,
    :value,
    :label,
    :score,
    :weight,
    :weighted_score

  def initialize(params = {})
    @name    = params.fetch(:name)
    @base_name = params.fetch(:base_name)
    @weight = params.fetch(:weight)

    cal_score
    @score = @score.round(3)
    @weighted_score = (@score * @weight).round(3)
  end

  private

  def cal_score
    raise NotImplementedError
  end

  def soundex_distance_score(s1, s2)
    if s1.first != s2.first
      0 # Different category, so they suppose to be completely
          different
    else
      (s1.size - Text::Levenshtein.distance(s1, s2).to_f ) /
          s1.size
    end
  end
end
```

Listing 10: `MatchingAlgorithm` class.

For example of a concrete matching algorithm, we have already shown some `cal_score` overridings. For *Levenshtein distance* is as in in listing 1. Here we will show whole `LevenshteinDistance` class, which is a subclass of `MatchingAlgorithm`, as in listing 11.

```
class LevenshteinDistance < MatchingAlgorithm
  private

  def cal_score
    @value = Text::Levenshtein.distance(@name, @base_name.name)
    size = [@name.size, @base_name.name.size].max
    @score = ((size - @value).to_f / size)
  end
end
```

Listing 11: `LevenshteinDistance` class.

Also for *Lookup table* is as in listing 6. Here we will show whole `LookupTable` class, which is another subclass of `MatchingAlgorithm`, as in listing 11. Note that `LookupTable` overrides default *weight*, which `LevenshteinDistance` does not.

```
class LookupTable < MatchingAlgorithm
  WEIGHT = 10 # Overriding default weight.

  private

  def cal_score
    ...
  end
end
```

Listing 12: `LookupTable` class.

5.2 EXPORTING A CLASS METHOD

When we mentioned soundex implementation in listing 2, we introduced `self.soundex` method instead of `cal_score`. Defining a method with `self.` is to create a *class method* [28]. *Class method* can be called directly without creating instance of the class, it is the same as *static method* in Java. For example as in listing 13.

```
[7] pry(main)> Soundex.soundex('SMITH')
=> "S530"
```

Listing 13: Calling class method *Soundex.soundex*.

By defining this method to be a *class method*, it can be reused in other class as well. In listing 14 we will show whole `Soundex` class, which is another subclass of `MatchingAlgorithm`.

```
class Soundex < MatchingAlgorithm
  WEIGHT = 3

  def self.soundex(name)
    ...
  end

  private

  def self.category(c)
    ...
  end

  def cal_score
    name_soundex  = self.class.soundex(@name)
    base_name_soundex = self.class.soundex(@base_name.name)

    @value = "#{base_name_soundex} <=> #{name_soundex}"
    @score = soundex_distance_score(name_soundex,
        base_name_soundex)
  end
end
```

Listing 14: `Soundex` class.

Note that we have already covered `self.soundex` and `self.category` implementation in listing 2 and 3 respectively, so both are truncated for readability. Here we focus on the `cal_score` overriding on `Soundex` class. The use of `self.class.soundex` in `cal_score` refers to `Soundex.soundex`. And `soundex_distance_score` is defined in `MatchingAlgorithm`.

As for Irish soundex, it also contains its own `self.soundex` *class method*. But this `self.soundex` also calls `Soundex.soundex` to use original soundex code, as in listing 15 (extracted from `IrishSoundex.soundex` implementation, listing 5).

```
# Call to traditional soundex.
return {
  :label => name,
  :soundex => Soundex.soundex(name)
}
```

Listing 15: `IrishSoundex.soundex` calls to `Soundex.soundex`.

In listing 16 we will show whole `IrishSoundex` class, which is another subclass of `MatchingAlgorithm`.

```
class IrishSoundex < MatchingAlgorithm
  WEIGHT = 6

  def self.soundex(name)
    ..
  end

  private

  def cal_score
    name_soundex  = self.class.soundex(@name)
    base_name_soundex = self.class.soundex(@base_name.name)

    @value = "#{base_name_soundex[:soundex]} <=>
        #{name_soundex[:soundex]}"
    @label = name_soundex[:label]
    @score = soundex_distance_score(name_soundex[:soundex],
        base_name_soundex[:soundex])
  end
end
```

Listing 16: `IrishSoundex` class.

Note that we have already covered `self.soundex` implementation in listing 5, so it is truncated for readability. Here we focus on the `cal_score` overriding on `IrishSoundex` class. The use of `self.class.soundex` in `cal_score` refers to `IrishSoundex.soundex`. And `soundex_distance_score` is defined in `MatchingAlgorithm`.

5.3 IMPLEMENTING NEW MATCHING ALGORITHMS

Currently there are 4 matching algorithms derived from `MatchingAlgorithm`.

1. `LevenshteinDistance`

2. `Soundex`
3. `IrishSoundex`
4. `LookupTable`

The implementations of all of these classes are within the same file as their superclass, `MatchingAlgorithm`, the path is `app/models/matching_algorithm.rb`. The structure of this file is shown in listing 17.

```
class MatchingAlgorithm
  ..
end

class LevenshteinDistance < MatchingAlgorithm
  ..
end

class Soundex < MatchingAlgorithm
  ..
end

class IrishSoundex < MatchingAlgorithm
  ..
end

class LookupTable < MatchingAlgorithm
  ..
end
```

Listing 17: `matching_algorithm.rb`.

To add a new matching algorithm, suppose we were to implement another soundex for Indian [29]. We would call this `IndianSoundex`. Here is the list of steps to do so.

1. Modify the file `app/models/matching_algorithm.rb` where all the matching algorithms are in. Append the class definition to the file.

```
..

class LookupTable < MatchingAlgorithm
  ..
end

class IndianSoundex < MatchingAlgorithm
  private

  def cal_score
    # To be implemented.
  end
end
```

2. Override `cal_score`, fulfil the algorithm for Indian soundex.
3. You may create *class method* `self.soundex` to follow the same pattern as `Soundex` and `IrishSoundex`, making it reusable too.
4. You may also use *class method* of soundex and Irish soundex by calling to `Soundex.soundex` and `IrishSoundex.soundex`.
5. You may also use shared method `soundex_distance_score` to calculate distance score like two other soundexes do.

You may consider adding more shared methods to `MatchingAlgorithm` superclass if considered appropriate, i.e. many subclasses will use it. On the other hand, if you need some method just inside the class, consider create just private methods.

Part III

THE OUTCOME

6 EVALUATION

After finishing implementing our system, we began to evaluate it in terms of performance of response speed and memory usage. To evaluate the system, we need a large amount of sample data, so here we introduce the standard name list.

6.1 INTRODUCING STANDARD NAME LIST

In subsection 2.1.3, we mentioned Robert Edwin Matheson, who developed a classification of Irish names. He classified the surnames in Ireland into 2091 groups. Adam Winstanley's work on this classification [2] looked through these groups and came up with a total 12,944 names in this classification. We use all these names to build up our lookup table (section 3.4).

We also decide to use all these records as a standard name list, for example, a client may want to match the *base name* 'MONAHAN' for all any possible matching *to-match names*. A client has an option to choose to match 'MONAHAN' with all 12,944 names in our standard list.

For web service clients, specify `standard_list` as `true`, `t`, or `1` to use the standard list. For example in listing 18, note that `to_match_names` is left blank and `standard_list` value is 1.

```
{
  "base_names":"Monahan",
  "to_match_names":"",
  "matching_algorithms":{
    "1":{"name":"LookupTable", "weight":"10"},
    "2":{"name":"LevenshteinDistance", "weight":"1"},
    "3":{"name":"Soundex", "weight":"3"},
    "4":{"name":"IrishSoundex", "weight":"6"}
  },
  "threshold":"0",
  "standard_list":"1"
}
```

Listing 18: Sample `JSON` with a standard name list option.

For web interface clients, check the "Use standard list" checkbox to use the standard list, as shown in figure 8.

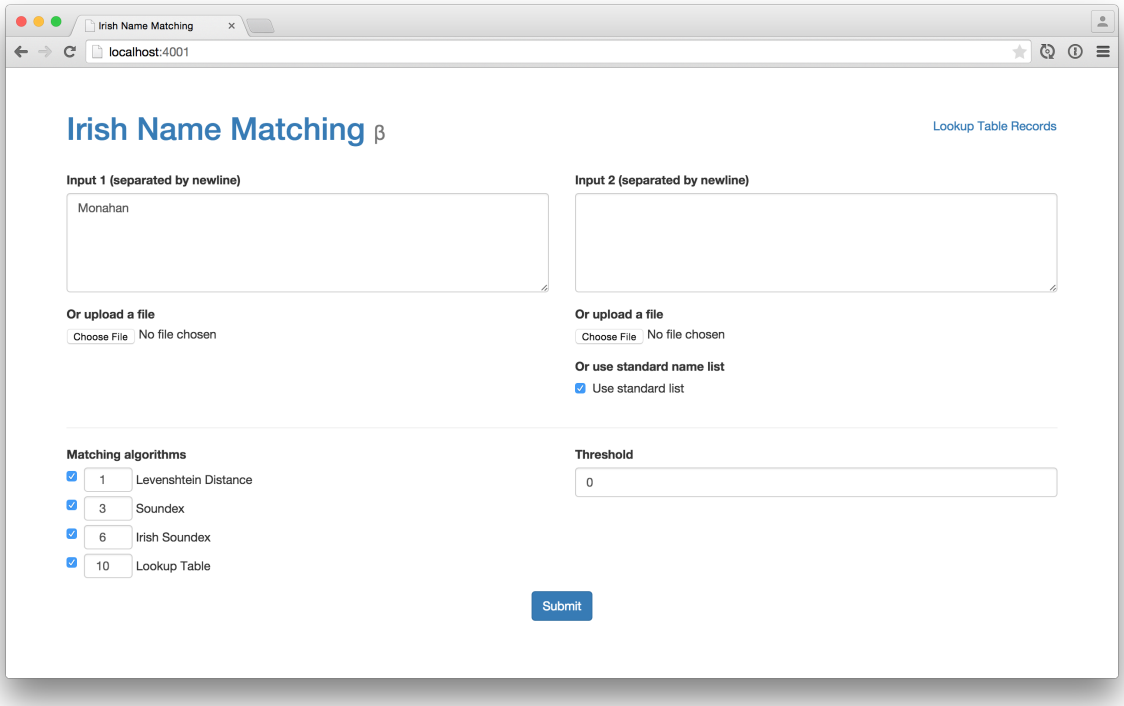

Figure 8: Web interface with a standard name list option.

Using a standard name list option generates many results. Clients are allowed to specify a threshold (section 4.4) to discard irreverent results.

In listing 19 is a result of matching between *base name* 'MONAHAN' and the standard name list, using threshold as 0.9. The results' detailed scores are truncated for readability.

```
[
  {
    "base_name": "MONAHAN",
    "to_match_names": [
      {
        "to_match_name": "MONAHAN",
        "overall_weighted_score": 1,
        ..
      },
      {
        "to_match_name": "MOYNAHAN",
        "overall_weighted_score": 0.994,
        ..
      },
      {
        "to_match_name": "MONOHAN",
        "overall_weighted_score": 0.993,
        ..
      },
      {
        "to_match_name": "MONEHAN",
        "overall_weighted_score": 0.993,
        ..
      },
      {
        "to_match_name": "MOYNIHAN",
        "overall_weighted_score": 0.988,
        ..
      },
      {
        "to_match_name": "MOYNAN",
        "overall_weighted_score": 0.979,
        ..
      }
    ]
  }
]
```


Listing 19: Results of matching *base name* 'MONAHAN' with a standard name list.

6.2 TEST ENVIRONMENT SETUP

We run, test, and profile our system locally, using these following environmental setup.

TEST MACHINE: MacBook Pro (Retina, 13-inch, Mid 2014).

- Processor – 2.6 GHz Intel Core i5
- Memory – 8 GB 1600 MHz DDR3
- Hard disk – APPLE SSD SM0256F

RUBY: 1.9.3p125 (2012-02-16 revision 34643) with GC-Patched MRI[1].

RUBY ON RAILS: version 4.2.0.

DATABASE: PostgreSQL version 9.3.5.

PROFILING TOOLS: rails-perftest [30] 0.0.6.

6.3 RESPONSE SPEED

We test response speed of our system by matching *base name* 'SMITH' with the standard name list of total 12,944 names. Each matching algorithm is tested separately first and then altogether at last.

Listing 20 is our `JSON` setup for response speed testing. Matching algorithms are varies between each scenario and all use default weights.

```
{
  "base_names":"Smith",
  "to_match_names":"",
  "matching_algorithms":{
    ..
  },
  "threshold":"0",
  "standard_list":"1"
}
```

Listing 20: `JSON` setup for performance testing.

To conduct testing, we use *rails-perftest* [30] to run our test cases. Table 4 shows the test result in response speed aspect.

MATCHING ALGORITHMS	RESPONSE SPEED (MS)
Levenshtein distance	1,337
Soundex	2,024
Irish soundex	2,456
Lookup table	24,293
All 4 algorithms	28,786

Table 4: Response speed for each matching algorithms.

1 Installing GC-Patched MRI [30].

From the results, Levenshtein distance is the fastest matching algorithm because it has the simplest logic among the four. Soundex and Irish soundex are second and third because they involve more string converting logic, and Irish soundex has more steps. Lastly, lookup table involves many database queries so that makes it much more slower than the rest.

6.4 MEMORY USAGE

We also test memory usage of our system by matching *base name* 'SMITH' with the standard name list of total 12,944 names. Each matching algorithm is tested separately first and then altogether at last.

Listing 20 is still our `JSON` setup for response speed testing. Matching algorithms are varies between each scenario and all are using default weights. Table 5 shows the test results regarding memory usage.

MATCHING ALGORITHMS	MEMORY USAGE (BYTES)
Levenshtein distance	48,518,621
Soundex	53,066,150
Irish soundex	69,534,598
Lookup table	244,302,744
All 4 algorithms	373,544,727

Table 5: Memory usage for each matching algorithms.

From the results, memory usage for each algorithm follows response speed fashion. Levenshtein distance and two soundexes use much less memory hungry compared to the lookup table.

6.5 DEPENDABILITY

We consider 5 software dependability attributes [31] of our system as follow.

AVAILABILITY: The system is available 24x7 on a virtual private server.

RELIABILITY: We ensure that the result from web service and web interface are always exactly the same. From our evaluation the system generates the results in a reasonable time. Memory consumption is acceptable but also needs to be monitor further.

SAFETY: Current state of the system does not consider on heavy security aspect. We would leave this attribute for the future works.

INTEGRITY: We have a solid backup of the standard name list (section 6.1) which can be regenerated anytime. In future work we also consider a proper database backup solution.

MAINTAINABILITY: The system welcomes maintenance and extension as we describe in detail in chapter 5.

7 CONCLUSION

We successfully developed an extensible web service system to match names. The system is initially encoded with 4 matching algorithms, Levenshtein distance, soundex, Irish soundex, and lookup table. We also present a web interface for a client to use the system from the web browser.

The system is designed to be extended with simple inheritance, thus a developer can understand and develop further algorithm easily. In early state simple design is enough to serve the purpose, so we follow the *Kiss principle* [32].

However, we have encountered some problem, also there are still much room for future works. We will describe these in the following sections.

7.1 ENCOUNTERED PROBLEM

The major problem is that the current system takes too long to process and also uses too much memory. It has not been properly optimised in terms of performance. These following techniques might improve our system furthermore.

7.1.1 *Memoization*

Memoization is the process of storing a computed value to avoid duplicated work by repetitive calls. While each algorithm calculats *similarity score*, there might be many repetitive calculations or database queries.

Ruby has a conditional assignment operator `||=` [33] which is commonly used for memoization. By doing so, it can improve performance of the system and reduce the number of database calls [34], thus shorten response time and lower memory usage.

7.1.2 *find_in_batches*

Matching large amount of name causes high memory consumption and may lead to out of memory situlation, especially in environment which memory are crucial and expensive such as on a remote server.

Rails provides `find_in_batches` which operates an array in batches, thus greatly reducing memory consumption [35]. We can apply the same principle to our *base name* and *to-match name*, also to the *controller* (section 4.6).

7.1.3 *Replace RDBMS with NoSQL*

Current database system (section 6.2) is a *Relational database management system (RDBMS)* [36] and the system relies on traditional database queries. By replacing this with high speed NoSQL database such as Redis [37], which is one of the fastest NoSQL [38], we can obtain better performance while using lookup table algorithm.

7.2 FUTURE WORKS

Our system can be further enhanced in many mays. Here are sample ideas for upcoming features of the system.

7.2.1 *More phonetic algorithms*

A phonetic algorithm [39] indexes words by their pronunciation. Soundex is one of them. We can implement more matching algorithms based on them. For example, Kolner Phonetik [40] is similar to soundex and works well on German words. Daitch-Mokotoff soundex [41] is an improved soundex working well to match surnames of Slavic and Germanic origin.

7.2.2 *Inheritance for similar matching algorithms*

Currently all matching algorithms inherit `MatchingAlgorithm` class. In future, if there are many similar ones or can be categorised in the same group, we can create another level of inheritance so they can share common methods. For example, consider the soundex case, with Kolner Phonetik and Daitch-Mokotoff soundex we can create inheritance with `Soundex` class as in listing 21.

```
class Soundex < MatchingAlgorithm
 WEIGHT = 3

 def self.soundex(name)
 ..
 end

 private

 def self.category(c)
 ..
 end

 def cal_score
 ..
 end

 # Moved from MatchingAlgorithm class to be more specific to
     soundexes.
 def soundex_distance_score(s1, s2)
 ..
 end
end

class IrishSoundex < Soundex
..
end

class KolnerPhonetik < Soundex
..
end

class DaitchMokotoffSoundex < Soundex
..
end
```

Listing 21: `Soundex` inheritance.

7.2.3 *Improve web interface result*

Current web interface result is as in figure 6, just a list of boxes detailed with matching algorithm scores. When it comes to large number of inputs, thousands of boxes will be generated and could overwhelm both browser and client themselves.

We can improve result display by implement a visualised graph base on the results, there are many libraries [42] that are capable if

generating interactive graph. d3js is another well option for starting from scratch.

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Part IV

APPENDIX

A

HOW TO DEPLOY THE SYSTEM ON UBUNTU SERVER

Here is the list of steps we performed to deploy the system on one rental VPS[1] from Digital Ocean[2]. The sample machine was Ubuntu 14.04 x64, but these setup steps should work on any recent Ubutu build as well.

This machine was setup from scratch, from creating a deployment user, up to installing PostgreSQL, Ruby, and Ruby on Rails. We're using the following machine specifications.

- Ubuntu 14.04 x64
- 1 core processor
- 512MB Ram
- 20GB SSD Disk

Most of these steps and wordings are taken directly from Digital Ocean's tutorials [44] [45]. The setup steps are as follow.

A.1 ROOT LOGIN

From your local machine, use `ssh` to connect to the remote server. As for sample code from now, we will use `local$` when referring to running a code from local machine, and `remote$` when referring to running a code from remote machine.

```
local$ ssh root@SERVER_IP_ADDRESS
```

Substitute `SERVER_IP_ADDRESS` with your IP address or hostname.

A.2 CREATE A NEW USER

Root access is not recommend since it has very powerful privileges. We will create a new user for deployment and other day-to-day work.

1 Virtual private server [43]
2 https://www.digitalocean.com

```
remote$ adduser demo
```

Substitute `demo` with your prefer new user name. You will be asked a few questions, starting with the account password and fill in any of the additional information if you would like.

A.3 ROOT PRIVILEGES

Now, we have a new user account with regular account privileges. However, we may sometimes need to do administrative tasks.

To add these privileges to our new user, we need to add the new user to the `sudo` group. By default, on Ubuntu 14.04, users who belong to the `sudo` group are allowed to use the sudo command.

As root, run this command to add your new user to the sudo group (substitute `demo` with your new user).

```
remote$ gpasswd -a demo sudo
```

Now you can log out and log in again with your newly created user.

```
local$ ssh demo@SERVER_IP_ADDRESS
```

A.4 INSTALL RBENV

We will install `rbenv`, which we will use to install and manage our Ruby installation. First, update `apt-get`.

```
remote$ sudo apt-get update
```

Then install the `rbenv` and Ruby dependencies with `apt-get`.

```
remote$ sudo apt-get install git-core curl zlib1g-dev
    build-essential libssl-dev libreadline-dev libyaml-dev
    libsqlite3-dev sqlite3 libxml2-dev libxslt1-dev
    libcurl4-openssl-dev python-software-properties libffi-dev
```

Now we are ready to install `rbenv` by running these commands.

```
remote$ cd
remote$ git clone git://github.com/sstephenson/rbenv.git .rbenv
remote$ echo 'export PATH="$HOME/.rbenv/bin:$PATH"' >>
    ~/.bash_profile
remote$ echo 'eval "$(rbenv init -)"' >> ~/.bash_profile
remote$ exec $SHELL

remote$ git clone git://github.com/sstephenson/ruby-build.git
    ~/.rbenv/plugins/ruby-build
remote$ echo 'export
    PATH="$HOME/.rbenv/plugins/ruby-build/bin:$PATH"' >>
    ~/.bash_profile
remote$ exec $SHELL
```

This installs `rbenv` into your home directory, and sets the appropriate environment variables that will allow `rbenv` to work over any machine-installed Ruby.

Next is to use `rbenv` to install Ruby.

A.5 INSTALL RUBY

We will install the latest version of this time, Ruby 2.2.1.

```
remote$ rbenv install -v 2.2.1
remote$ rbenv global 2.2.1
```

The `global` sub-command sets the default version of Ruby that all of your shells will use.

We will also need to install the `bundler` gem to manage Rails dependencies.

```
remote$ gem install bundler
```

Now that Ruby is installed, next is to install Rails.

A.6 INSTALL RAILS

Install Rails 4.2.0 with this command.

```
remote$ gem install rails -v 4.2.0
```

A.7 INSTALL JAVASCRIPT RUNTIME

A few Rails features, such as the Asset Pipeline, depend on a Javascript runtime. We will install Node.js to cover this functionality.

Add the Node.js PPA to `apt-get`, then update `apt-get` and install the Node.js package.

```
remote$ sudo add-apt-repository ppa:chris-lea/node.js
remote$ sudo apt-get update
remote$ sudo apt-get install nodejs
```

A.8 INSTALL POSTGRESQL

Next is the database. We will install PostgreSQL and its development libraries.

```
remote$ sudo apt-get install postgresql postgresql-contrib
    libpq-dev
```

A.9 CREATE DATABASE USER

Create a PostgreSQL superuser user with this command (substitute the `pguser` with your own username).

```
remote$ sudo -u postgres createuser -s pguser
```

Now that we have the language (Ruby), framework (Rails), dependencies manager (bundler), and database (PostgreSQL), we are ready to setup our system.

A.10 GET THE SYSTEM CODE

The system code is stored at `git.cs.nuim.ie/repos/desem/dmsc1407`, we will get the code by using `git`.

```
remote$ cd
remote$ git clone ssh://git.cs.nuim.ie/repos/desem/dmsc1407
remote$ cd dmsc1407
```

A.11 CONFIGURE DATABASE CONNECTION

Open the system database configuration file.

```
remote$ vim config/database.yml
```

Under the default section, find the line that says `pool: 5` and add the following lines under it (replace the `pguser` and `pguser_password` parts with your PostgreSQL user and password).

```
host: localhost
username: pguser
password: pguser_password
```

Listing 22: config/database.yml

Save and exit.

A.12 CREATE APPLICATION DATABASES

Create development and test databases by using this `rake` command.

```
remote$ rake db:create
```

A.13 INSTALL PUMA

Puma is an application server that enables your Rails application to process requests concurrently.

First we need to install the Puma gem, in case the system does not already have it.

```
remote$ vim Gemfile
```

At the end of the file, add the Puma gem with this line.

```
gem 'puma'
```

Listing 23: Gemfile

Save and exit. To install Puma, and any outstanding dependencies, run Bundler.

```
remote$ bundle
```

Puma is now installed, but we need to configure it.

A.14 CONFIGURE PUMA

Before configuring Puma, you should look up the number of CPU cores your server has. You can easily to that with this command.

```
remote$ grep -c processor /proc/cpuinfo
```

Now, let's add our Puma configuration to `config/puma.rb`.

```
remote$ vim config/puma.rb
```

Use this Puma configuration.

```
# Change to match your CPU core count
workers 1

# Min and Max threads per worker
threads 1, 6

app_dir = File.expand_path("../..", __FILE__)
shared_dir = "#{app_dir}/shared"

# Default to production
rails_env = ENV['RAILS_ENV'] || "production"
environment rails_env

# Set up socket location
bind "unix://#{shared_dir}/sockets/puma.sock"

# Logging
stdout_redirect "#{shared_dir}/log/puma.stdout.log",
    "#{shared_dir}/log/puma.stderr.log", true

# Set master PID and state locations
pidfile "#{shared_dir}/pids/puma.pid"
state_path "#{shared_dir}/pids/puma.state"
activate_control_app

on_worker_boot do
  require "active_record"
  ActiveRecord::Base.connection.disconnect! rescue
      ActiveRecord::ConnectionNotEstablished
  ActiveRecord::Base.establish_connection(
    YAML.load_file("#{app_dir}/config/database.yml")[rails_env])
end
```

Listing 24: config/puma.rb

Change the number of workers to the number of CPU cores of your server. Then save and exit.

Now create the directories that were referred to in the configuration file.

```
remote$ mkdir -p shared/pids shared/sockets shared/log
```

A.15 CREATE PUMA UPSTART SCRIPT

Create an Upstart init script so we can easily start and stop Puma using `sudo start` and `sudo stop` commands. and ensure that it will automatically start on boot.

Download the Jungle Upstart tool from the Puma GitHub repository to your home directory.

```
remote$ cd ~
remote$ wget https://raw.githubusercontent.com/puma/puma/master/
 tools/jungle/upstart/puma-manager.conf
remote$ wget https://raw.githubusercontent.com/puma/puma/master/
 tools/jungle/upstart/puma.conf
```

Now open the downloaded `puma.conf` file, so we can configure the Puma deployment user.

```
remote$ vim puma.conf
```

Look for the two lines that specify `setuid` and `setgid`, and replace `apps` with the name of your deployment user and group. For example, if your deployment user is called `demo`, the lines should look like this.

```
setuid demo
setgid demo
```

Listing 25: puma.conf

Save and exit. Now copy the scripts to the Upstart services directory:

```
remote$ sudo cp puma.conf puma-manager.conf /etc/init
```

The `puma-manager.conf` script references `/etc/puma.conf` for the applications that it should manage. Let's create and edit that file now.

```
remote$ sudo vim /etc/puma.conf
```

Each line in this file should be the path to an application that you want `puma-manager` to manage. So we add the path to the system.

```
/home/demo/dmsc1407
```

Listing 26: /etc/puma.conf

Save and exit. Now the system is configured to start at boot time, through Upstart. This means that the system will start even after your server is rebooted.

To start all of your managed Puma apps now, run this command.

```
remote$ sudo start puma-manager
```

Now the system is running under Puma, and it's listening on the `shared/sockets/puma.sock` socket. Before the system will be accessible to an outside user, we must set up the Nginx reverse proxy.

A.16 INSTALL AND CONFIGURE NGINX

As Puma is not designed to be accessed by outside users directly, we will use Nginx as a reverse proxy that will buffer requests and responses between outside users and the system.

Install Nginx using apt-get.

```
remote$ sudo apt-get install nginx
```

Now open the default server block.

```
remote$ sudo vim /etc/nginx/sites-available/default
```

Replace the contents of the file with the following code block. Be sure to replace the the `demo` and `dmsc1407` parts with your username and the system path.

```
upstream app {
  # Path to Puma SOCK file, as defined previously
  server unix:/home/demo/dmsc1407/shared/sockets/puma.sock
      fail_timeout=0;
}

server {
  listen 80;
  server_name localhost;

  root /home/demo/dmsc1407/public;

  try_files $uri/index.html $uri @app;

  location @app {
    proxy_pass http://app;
    proxy_set_header X-Forwarded-For $proxy_add_x_forwarded_for;
    proxy_set_header Host $http_host;
    proxy_redirect off;
  }

  error_page 500 502 503 504 /500.html;
  client_max_body_size 4G;
  keepalive_timeout 10;
}
```

Listing 27: /etc/nginx/sites-available/default

Save and exit. This configures Nginx as a reverse proxy, so HTTP requests get forwarded to the Puma application server via a Unix socket.

Restart Nginx to put the changes into effect.

```
remote$ sudo service nginx restart
```

A.17 FINISH

You have deployed the production environment of the system using Nginx and Puma. Now the system is accessible via your server's public IP address or domain name.