Data Analysis and Integration

String matching

Introduction

- Comparing the two databases
  - departments

dept_no	dept_name
d009	Customer Service
d005	Development
d002	Finance
d003	Human Resources
d001	Marketing
d004	Production
d006	Quality Management
d008	Research
d007	Sales

departmentid	departmentname
101	IT
102	HR
103	Finance
104	Sales
105	marketing

Introduction

- Comparing the two databases
  - job titles

```
+--------------------+
| title              |
+--------------------+
| Senior Engineer    |
| Staff              |
| Engineer           |
| Senior Staff       |
| Assistant Engineer |
| Technique Leader   |
| Manager            |
+--------------------+
```

similar jobs/roles?

```
+-------------------+
| jobtitle          |
+-------------------+
| CEO               |
| Director          |
| President         |
| Vice President    |
| Sr. Manager       |
| Accoutant         |
| Sales Manager     |
| Reporting Manager |
| Team Leader       |
| Sales Rep         |
| Software Engineer |
| Admin             |
| Network Engineer  |
+-------------------+
```

Introduction

- Applications of string matching in data integration
  - data matching

dept_no	dept_name
d009	Customer Service
d005	Development
d002	Finance
d003	Human Resources
d001	Marketing
d004	Production
d006	Quality Management
d008	Research
d007	Sales

departmentid	departmentname
101	IT
102	HR
103	Finance
104	Sales
105	marketing

title
Senior Engineer
Staff
Engineer
Senior Staff
Assistant Engineer
Technique Leader
Manager

similar jobs/roles?

jobtitle
CEO
Director
President
Vice President
Sr. Manager
Accoutant
Sales Manager
Reporting Manager
Team Leader
Sales Rep
Software Engineer
Admin
Network Engineer

Introduction

- Applications of string matching in data integration
  - schema matching

dept_no	dept_name
d009	Customer Service
d005	Development
d002	Finance
d003	Human Resources
d001	Marketing
d004	Production
d006	Quality Management
d008	Research
d007	Sales

departmentid	departmentname
101	IT
102	HR
103	Finance
104	Sales
105	marketing

title
Senior Engineer
Staff
Engineer
Senior Staff
Assistant Engineer
Technique Leader
Manager

jobtitle
CEO
Director
President
Vice President
Sr. Manager
Accoutant
Sales Manager
Reporting Manager
Team Leader
Sales Rep
Software Engineer
Admin
Network Engineer

Introduction

- Applications of string matching in data integration
  - schema matching via data matching

dept_no	dept_name
d009	Customer Service
d005	Development
d002	Finance
d003	Human Resources
d001	Marketing
d004	Production
d006	Quality Management
d008	Research
d007	Sales

departmentid	departmentname
101	IT
102	HR
103	Finance
104	Sales
105	marketing

title
Senior Engineer
Staff
Engineer
Senior Staff
Assistant Engineer
Technique Leader
Manager

jobtitle
CEO
Director
President
Vice President
Sr. Manager
Accoutant
Sales Manager
Reporting Manager
Team Leader
Sales Rep
Software Engineer
Admin
Network Engineer

String matching

- String matching is based on measures
  - measures of **distance** between strings
    - lower is better, higher is worse
  - measures of **similarity** between strings
    - higher is better, lower is worse

Outline

- String matching measures
  - sequence-based
  - set-based
  - phonetic

Sequence-based measures

- View the strings as sequences of characters
  - edit distance (Levenshtein)
  - Damerau-Levenshtein distance
  - Needleman-Wunsch measure
  - Jaro measure
  - Jaro-Winkler measure

Edit distance (Levenshtein)

- Number of changes to transform one string into another
  - if the character matches: no change
  - if the character does not match: mismatch or use gap

Austria	Austria	Austria
Autriche	Autriche	Au␣triche
?	**mismatch**	**use gap**

Edit distance (Levenshtein)

- Number of changes to transform one string into another
  - if the character matches: no change
  - if the character does not match: mismatch or use gap

```
Austria         Austria         Austria

Au␣triche       Au␣triche       Au␣triche
```

use gap

?

Edit distance (Levenshtein)

- Number of changes to transform one string into another
  - if the character matches: no change
  - if the character does not match: mismatch or use gap

```
Austria␣␣     Austri␣a␣     Austri␣␣a

Au␣triche     Au␣triche     Au␣triche
```

4 changes **4 changes** **4 changes**

Edit distance (Levenshtein)

- **Minimum** number of changes to transform one string into another
  - corresponds to an **optimal alignment**

```
Austria␣␣      Austria␣␣      Austria␣␣
Au␣triche      Aut␣riche      Autr␣iche
```

4 changes **5 changes** **6 changes**

Computing the edit distance

- Create a score matrix to find the best string alignment
  - edit distance is 4

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	3
e	8	7	6	6	6	5	4	4

Computing the edit distance

- Create a score matrix to find the best string alignment

		A	u	s	t	r	i	a
	0							
A								
u								
t								
r								
i								
c								
h								
e								

Computing the edit distance

- Create a score matrix to find the best string alignment

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A								
u								
t								
r								
i								
c								
h								
e								

Austria…

␣␣␣␣␣␣␣…

Computing the edit distance

- Create a score matrix to find the best string alignment

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1							
u	2							
t	3							
r	4							
i	5							
c	6							
h	7							
e	8							

Austria…
␣␣␣␣␣␣␣…

␣␣␣␣␣␣␣␣…
Autriche…

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0						
u	2							
t	3							
r	4							
i	5							
c	6							
h	7							
e	8							

A
A — (diagonally) **0 changes**

A␣
␣A — (vertically) **2 changes**

␣A
A␣ — (horizontally) **2 changes**

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1					
u	2							
t	3							
r	4							
i	5							
c	6							
h	7							
e	8							

Au
␣A
(diagonally)
2 changes

Au␣
␣␣A
(vertically)
3 changes

Au
A␣
(horizontally)
1 change

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2							
t	3							
r	4							
i	5							
c	6							
h	7							
e	8							

```
Austria…
A␣␣␣␣␣␣…
```

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1						
t	3	2						
r	4	3						
i	5	4						
c	6	5						
h	7	6						
e	8	7						

```
Austria…
A␣␣␣␣␣␣…
```

```
A␣␣␣␣␣␣␣…
Autriche…
```

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0					
t	3	2						
r	4	3						
i	5	4						
c	6	5						
h	7	6						
e	8	7						

Au
Au
(diagonally)
0 changes

Au␣
A␣u
(vertically)
2 changes

A␣u
Au␣
(horizontally)
2 changes

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2						
r	4	3						
i	5	4						
c	6	5						
h	7	6						
e	8	7						

Austria…
Au␣␣␣␣␣…

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1					
r	4	3	2					
i	5	4	3					
c	6	5	4					
h	7	6	5					
e	8	7	6					

Austria…
Au␣␣␣␣␣…

Au␣␣␣␣␣␣…
Autriche…

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1				
r	4	3	2					
i	5	4	3					
c	6	5	4					
h	7	6	5					
e	8	7	6					

Aus
Aut
(diagonally)
1 change

Aus␣
Au␣t
(vertically)
2 changes

Au␣s
Aut␣
(horizontally)
2 changes

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1			
r	4	3	2					
i	5	4	3					
c	6	5	4					
h	7	6	5					
e	8	7	6					

```
Aust
Au␣t
```
(diagonally)
1 change

```
Aust␣
Au␣␣t
```
(vertically)
3 changes

```
Aust
Aut␣
```
(horizontally)
2 changes

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2					
i	5	4	3					
c	6	5	4					
h	7	6	5					
e	8	7	6					

Austria…
Au␣t␣␣␣…

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2				
i	5	4	3					
c	6	5	4					
h	7	6	5					
e	8	7	6					

```
Au␣s
Autr
```

(diagonally)
2 changes

```
Aus␣
Autr
```

(vertically)
2 changes

```
Au␣␣s
Autr␣
```

(horizontally)
3 changes

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2				
i	5	4	3	3				
c	6	5	4	4				
h	7	6	5	5				
e	8	7	6	6				

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2			
i	5	4	3	3	3			
c	6	5	4	4	4			
h	7	6	5	5	5			
e	8	7	6	6	6			

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1		
i	5	4	3	3	3			
c	6	5	4	4	4			
h	7	6	5	5	5			
e	8	7	6	6	6			

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3			
c	6	5	4	4	4			
h	7	6	5	5	5			
e	8	7	6	6	6			

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2		
c	6	5	4	4	4	3		
h	7	6	5	5	5	4		
e	8	7	6	6	6	5		

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	
c	6	5	4	4	4	3		
h	7	6	5	5	5	4		
e	8	7	6	6	6	5		

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3		
h	7	6	5	5	5	4		
e	8	7	6	6	6	5		

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	
h	7	6	5	5	5	4	3	
e	8	7	6	6	6	5	4	

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	
e	8	7	6	6	6	5	4	

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	3
e	8	7	6	6	6	5	4	

Computing the edit distance

- Create a score matrix to find the best string alignment
  - in each cell, choose minimum of 3 possibilities

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	3
e	8	7	6	6	6	5	4	4

Computing the edit distance

- Create a score matrix to find the best string alignment
  - edit distance is 4

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	3
e	8	7	6	6	6	5	4	4

Computing the edit distance

- Create a score matrix to find the best string alignment
  - going backwards: there are 3 possible alignments

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	3
e	8	7	6	6	6	5	4	4

```
Austria␣␣
Au␣triche
```

Computing the edit distance

- Create a score matrix to find the best string alignment
  - going backwards: there are 3 possible alignments

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	3
e	8	7	6	6	6	5	4	4

```
Austria␣␣
Au␣triche

Austri␣a␣
Au␣triche
```

Computing the edit distance

- Create a score matrix to find the best string alignment
  - going backwards: there are 3 possible alignments

		A	u	s	t	r	i	a
	0	1	2	3	4	5	6	7
A	1	0	1	2	3	4	5	6
u	2	1	0	1	2	3	4	5
t	3	2	1	1	1	2	3	4
r	4	3	2	2	2	1	2	3
i	5	4	3	3	3	2	1	2
c	6	5	4	4	4	3	2	2
h	7	6	5	5	5	4	3	3
e	8	7	6	6	6	5	4	4

```
Austria␣␣
Au␣triche

Austri␣a␣
Au␣triche

Austri␣␣a
Au␣triche
```

Computing the edit distance

- Recurrence equation
  - for two strings $\boldsymbol{x} = x_1 x_2 \cdots x_n$ and $\boldsymbol{y} = y_1 y_2 \cdots y_m$

$$d(i,j) = min \begin{cases} \begin{cases} d(i-1, j-1) & if \quad x_i = y_j \\ d(i-1, j-1) + 1 & if \quad x_i \neq y_j \end{cases} & \text{(diagonally)} \\ d(i-1, j) + 1 & \text{(vertically)} \\ d(i, j-1) + 1 & \text{(horizontally)} \end{cases}$$

Computing the edit distance

- Recurrence equation
  - for two strings $\boldsymbol{x} = x_1 x_2 \cdots x_n$ and $\boldsymbol{y} = y_1 y_2 \cdots y_m$

mismatch costs 1

$$d(i,j) = min \begin{cases} \begin{cases} d(i-1,j-1) & if \quad x_i = y_j \\ d(i-1,j-1) + 1 & if \quad x_i \neq y_j \end{cases} \\ d(i-1,j) + 1 \\ d(i,j-1) + 1 \end{cases}$$

using a gap costs 1

Damerau-Levenshtein distance

- Similar to edit distance, but considers another type of change
  - mismatch
  - use gap
  - transposition between two adjacent characters
    - in the Levenshtein distance this would be 2 changes instead of 1

Damerau-Levenshtein distance

- Examples

	Austria Autriche	Ireland Ierland	Dinamarca Danimarca	Chipre Cypern
Levenshtein	4	2	2	4
Damerau-Levenshtein	4	1	2	4

Needleman-Wunsch measure

- Similar to edit distance but:
  - mismatch and gap have negative scores
  - match has zero or positive score
- Needleman-Wunsch is a similarity measure
  - the higher the score, the better
- Needleman-Wunsch is flexible
  - scores for match, mismatch and gap can be adjusted

Needleman-Wunsch measure

- Example

mismatch = -1   gap = -1   match = 0

		A	u	s	t	r	i	a
	0	-1	-2	-3	-4	-5	-6	-7
A	-1	0	-1	-2	-3	-4	-5	-6
u	-2	-1	0	-1	-2	-3	-4	-5
t	-3	-2	-1	-1	-1	-2	-3	-4
r	-4	-3	-2	-2	-2	-1	-2	-3
i	-5	-4	-3	-3	-3	-2	-1	-2
c	-6	-5	-4	-4	-4	-3	-2	-2
h	-7	-6	-5	-5	-5	-4	-3	-3
e	-8	-7	-6	-6	-6	-5	-4	-4

mismatch = -1   gap = -1   match = 2

		A	u	s	t	r	i	a
	0	-1	-2	-3	-4	-5	-6	-7
A	-1	2	1	0	-1	-2	-3	-4
u	-2	1	4	3	2	1	0	-1
t	-3	0	3	3	5	4	3	2
r	-4	-1	2	2	4	7	6	5
i	-5	-2	1	1	3	6	9	8
c	-6	-3	0	0	2	5	8	8
h	-7	-4	-1	-1	1	4	7	7
e	-8	-5	-2	-2	0	3	6	6

Needleman-Wunsch measure

- Scores can also be configured on a per-letter basis
  – e.g. match A-A with higher score than T-T
  – e.g. mismatch A-C with lower score than A-E
- Such scores can be configured in a **score matrix**

Needleman-Wunsch measure

- Example of score matrix
  – match between vowels (+2) and between consonants (+1)
  – mismatch between vowels (-2) and between consonants (-1)

	a	b	c	d	e	f	…
a	+2	-2	-2	-2	-1	-2	…
b	-2	+1	-1	-1	-2	-1	…
c	-2	-1	+1	-1	-2	-1	…
d	-2	-1	-1	+1	-2	-1	…
e	-1	-2	-2	-2	+2	-2	…
f	-2	-1	-1	-1	-2	+1	…
…	…	…	…	…	…	…	…

Needleman-Wunsch measure

- Recurrence equation
  - for two strings $\boldsymbol{x} = x_1 x_2 \cdots x_n$ and $\boldsymbol{y} = y_1 y_2 \cdots y_m$

from score matrix

$$s(i,j) = max \begin{cases} s(i-1,j-1) + c(x_i, y_j) \\ s(i-1,j) + c_g \\ s(i,j-1) + c_g \end{cases}$$

note: max

gap score (negative)

Jaro measure

- Used to compare short strings, such as first/last names
- Main focus on **common characters** and **transpositions**
  - **common character** means $x_i = y_j$ and $|i - j| \leq \frac{min\{|x|,|y|\}}{2}$ (i.e. x_i and y_j must be equal and not too distant)
  - compare sequence of common chars (should be equal unless there are transpositions)
  - each mismatch counts as one **transposition**

Jaro measure

- Examples

$\lvert i-j\rvert \le 3$	$\lvert i-j\rvert \le 3$	$\lvert i-j\rvert \le 4$	$\lvert i-j\rvert \le 3$
`Austria`	`Ireland`	`Dinamarca`	`Chipre`
`Autriche`	`Ierland`	`Danimarca`	`Cypern`
$c = 5$	$c = 7$	$c = 9$	$c = 4$

`Autri`	`Ireland`	`Dinamarca`	`Cpre`
`Autri`	`Ierland`	`Danimarca`	`Cper`
$t = 0$	$t = 2$	$t = 2$	$t = 2$

Jaro measure

- Formula

$$jaro(x,y) = \frac{1}{3}\left(\frac{c}{|x|} + \frac{c}{|y|} + \frac{c - \frac{t}{2}}{c}\right)$$

Austria	Ireland	Dinamarca	Chipre
Autriche	Ierland	Danimarca	Cypern
$c = 5$	$c = 7$	$c = 9$	$c = 4$
$t = 0$	$t = 2$	$t = 2$	$t = 2$
$jaro \approx 0.78$	$jaro \approx 0.95$	$jaro \approx 0.96$	$jaro \approx 0.69$

Jaro-Winkler measure

- A variant of Jaro for strings with a common prefix

```
Österreich
Österrike
```

$\underbrace{\text{Öster}}_{\text{prefix}}$

  - let PL be the prefix length
  - let PW be the prefix weight (typically 0.1)

$$\boxed{jarowinkler(x, y) = (1 - PL * PW) * jaro(x, y) + PL * PW}$$

Jaro-Winkler measure

- Examples

	<u>Au</u>stria <u>Au</u>triche	<u>I</u>reland <u>I</u>erland	<u>D</u>inamarca <u>D</u>animarca	<u>C</u>hipre <u>C</u>ypern	<u>Österr</u>eich <u>Österr</u>ike
Jaro	0.78	0.95	0.96	0.69	0.85
Jaro-Winkler	0.82	0.96	0.97	0.72	0.91

Jaccard measure

- This is a **set-based** measure based on ***n*-grams** (substrings with length n)
  - most common are **2-grams** or **bigrams**

```
Austria    {#A, Au, us, st, tr, ri, ia, a#}

Autriche   {#A, Au, ut, tr, ri, ic, ch, he, e#}
```

    - in the two sets of bigrams above, there are bigrams in common

Jaccard measure

- Let B_x be the set of bigrams of string x
- Let B_y be the set of bigrams of string y

$$jaccard(x, y) = \frac{|B_x \cap B_y|}{|B_x \cup B_y|}$$

number of common bigrams
(no duplicates)

number of all bigrams
(no duplicates)

- set-based metric, and sets have no duplicates

Jaccard measure

- Example

```
Austria      {#A, Au, us, st, tr, ri, ia, a#}
Autriche     {#A, Au, ut, tr, ri, ic, ch, he, e#}
```

$$jaccard(x, y) = \frac{4}{13} \approx 0.31$$

Jaccard measure

- Example

```
Ireland    {#I, Ir, re, el, la, an, nd, d#}

Ierland    {#I, Ie, er, rl, la, an, nd, d#}
```

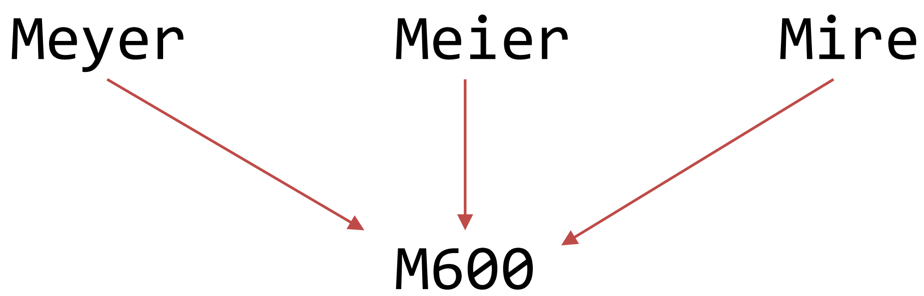
$$jaccard(x, y) = \frac{5}{11} \approx 0.45$$

Phonetic similarity measures

- Match strings based on their sound
  - Soundex
  - Refined Soundex
  - etc.

Soundex measure

- This is a **phonetic** measure, used primarily to match surnames
  – written in a different way, but sounding very similar
  – e.g. Meyer, Meier, Mire; Smith, Smithe, Smythe



Soundex measure

- The Soundex phonetic rules
  1. keep the first letter
  2. remove all occurrences of H and W
  3. replace each letter with a digit (table below)
  4. collapse any sequence of identical digits
  5. drop all non-digit letters (except first one)
  6. keep only four characters (pad with zero if needed)

B F P V	1
C G J K Q S X Z	2
D T	3
L	4
M N	5
R	6

note: not every letter is included in this table

Soundex measure

- Examples

Meyer → Meye6 → M6 → M600

Meier → Meie6 → M6 → M600

Mire → Mi6e → M6 → M600

Soundex measure

- Examples

Smith	Smithe	Smythe
S5i3	S5i3e	S5y3e
S53	S53	S53
S530	S530	S530

Soundex measure

- Examples

Austria	Ireland	Denmark
↓	↓	↓
Au236ia	I6e4a53	De55a62
↓	↓	↓
A236	I6453	De5a62
	↓	↓
	I645	D562

Soundex measure

- Properties
  - is tuned to a particular language (American English)
    - variants have been developed for other languages
  - many false positives
    - Christopher (C623) vs. Christine (C623)
    - Ackermann (A265) vs. Azuron (A265)
  - some false negatives
    - Christian (C623) vs. Kristian (K623)
    - Shultz (S432) vs. Shulz (S420)

Refined Soundex measure

- Uses a different table (more groups)
- Has a group for vowels + H + W + Y
- No truncation to 4 characters
- First letter is kept and encoded as well

A E H I O U W Y	0
B P	1
F V	2
C K S	3
G J	4
Q X Z	5
D T	6
L	7
M N	8
R	9

Refined Soundex measure

- Examples

$$\text{Meyer} \rightarrow \text{M80009} \rightarrow \text{M809}$$

$$\text{Meier} \rightarrow \text{M80009} \rightarrow \text{M809}$$

$$\text{Mire} \rightarrow \text{M8090}$$

Refined Soundex measure

- Examples

Smith	Smithe	Smythe
↓	↓	↓
S38060	S380600	S380600
	↓	↓
	S38060	S38060

Refined Soundex measure

- Examples

Austria	Ireland	Denmark
↓	↓	↓
A036900	I0907086	D6088093
↓		↓
A03690		D608093

Refined Soundex measure

- Properties
  - less false positives
    - Christopher (C3090360109) vs. Christine (C309036080)
    - Ackermann (A0309808) vs. Azuron (A050908)

- Other variants and improvements
  - more complex rules
    - metaphone, double metaphone, etc.