L01.02
Coding Cost model
Document Distance

50.004 Introduction to Algorithm

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(slides adapted from Dr. Simon LUI)
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About the coding requirement of the course

coding requirement of this course

- we will be reading and understanding code / pseudo code
- You need to do some coding in exercise/ homework/problem set

- You need to read/write code in exam
  - E.g. read a code, tell me if it is O(n) or O(nlogn)

coding requirement of this course

What is pseudo code

```
if a is divisible by 3
    print “OH YEAH”
```

What is code

```
if (a%3 == 0)
    print “OH YEAH”;
```

How to read code and find its T(n)

How to read code

```
Print(“GREAT”);
```

$T(n) = 1$

i.e. the number of steps required to complete this program is 1

This code is $\Theta(1)$

How to read code

```
Print(“GREAT”);
Print(“GREAT”);
Print(“GREAT”);
Print(“GREAT”);
```

$T(n) = 4$

i.e. the number of steps required to complete this program is 4

This code is $\Theta(1)$

How to read code

```
For (i=0;i<5;i++)
    Print("GREAT");
```

$T(n) = 5$

i.e. the number of steps required to complete this program is 5

This code is $\Theta(1)$

How to read code

```
For (i=0;i<n;i++)
    Print("GREAT");
```

$T(n) = n$

i.e. the number of steps required to complete this program is n

This code is $\Theta(n)$

How to read code

```
For (int i=0;i<n;i++)
    For (int j=0;j<n;j++)
        Print(“GREAT”);
```

$T(n) = n^2$

i.e. the number of steps required to complete this program is n^2

This code is $\Theta(n^2)$

How to read code

```
For (i=0;i<n;i++)
    For (j=0;j<n;j++)
        Print(“GREAT”);
For (k=0;k<n;k++)
    print(“GREAT”);
```

$T(n) = n^2+n$

i.e. the number of steps required to complete this program is n^2+n

This code is $\Theta(n^2)$

How to read code

```
For (i=0;i<n;i++)
    For (j=0;j<n;j++)
        Print(“GREAT”);
For (k=0;k<n;k++)
    print(“GREAT”);
print(“GREAT”);
print(“GREAT”);
print(“GREAT”);
```

$T(n) =$
n^2+n+3

i.e. the number of steps required to complete this program is n^2+n

This code is $\Theta(n^2)$

The cost model of code

Python cost model

$L = [a_1, a_2, \ldots, a_n]$ L is a list

Commands	complexity (time)	
L[i]=x	Θ(1)	
L.append(x)	Θ(1)	Add x to L
L_1.extend(L_2)	Θ(|L_2|)	Add L_2 to L_1
A = L_1+L_2	Θ(|L_1|+|L_2|)	Add L_2 and L_1 to A
x in L	Θ(|L|)	Search for x

$D = \{x_1 : y_1,\ x_2 : y_2,\ \ldots,\ x_n : y_n\}$ D is a dictionary

Commands	complexity (time)	
D[x_i]=y_i	Θ(1)	X is index, y is value
x in D	Θ(1)	Search for x

Document distance

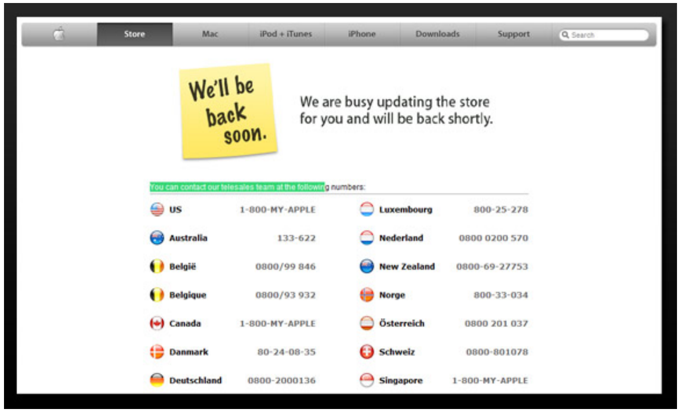
- *Document* means sequence of words
- The Problem: Given 2 documents, find out how similar are they
- The Algorithm: we will talk about it

Document distance - usage

1. *detect plagiarism*
2. *Web update check*

- *Simon loves iPhone. He wants to be the world first person to buy it*
- *So he write a DOCUMENT DISTANCE code to check if the apple webpage has updated*
  - *If updated, probably there are new product.*
  - *So, send a email to notify Simon*

Document distance - usage



We'll be back soon.

We are busy updating the store for you and will be back shortly.

You can contact our telesales team at the following numbers:

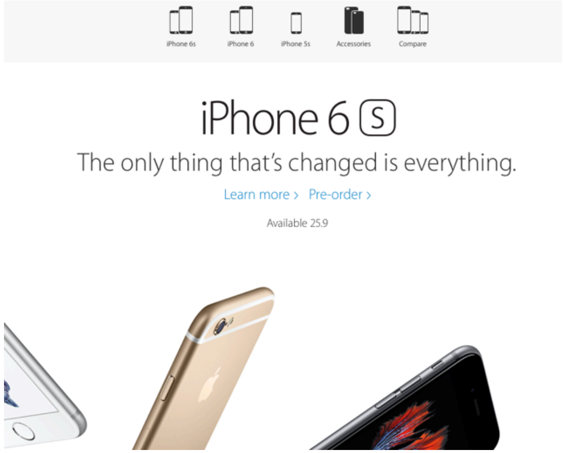
US	1-800-MY-APPLE	Luxembourg	800-25-278
Australia	133-622	Nederland	0800 0200 570
België	0800/99 846	New Zealand	0800-69-27753
Belgique	0800/93 932	Norge	800-33-034
Canada	1-800-MY-APPLE	Österreich	0800 201 037
Danmark	80-24-08-35	Schweiz	0800-801078
Deutschland	0800-2000136	Singapore	1-800-MY-APPLE

```
<!DOCTYPE html>
<html class="singapore sg nojs en en-sg apac" lang="en-SG">
        <head>
          <meta name="viewport" content="width=1024" />
    <title>Pre-order iPhone 6s and iPhone 6s Plus - Apple (SG)</
title>
    <meta charset="utf-8" />
    <meta http-equiv="X-UA-Compatible"
content="IE=edge,chrome=1" />
    <meta name="format-detection" content="telephone=no" />
    <meta http-equiv="Set-Cookie"
content="as_sfa=MnxzZ3xzZ3x8ZW5fU0d8Y29uc3VtZXJ8aW50ZXJ
uZXR8MHwwfDE=; path=/; domain=.apple.com; expires=Mon,
15-Sep-2025 04:18:11 GMT;" />

                              <meta property="og:type"
content="product" />
```

Apple.com/iphone.html
…at 11:58am

COMPARE



iPhone 6 Ⓢ

The only thing that's changed is everything.

Learn more › Pre-order ›

Available 25.9

```
<!DOCTYPE html>
<-equiv="X-UA-Compatible" content="IE=edge,chrome=1" />
    <meta name="format-detection" content="telephone=no" />
    <meta http-equiv="Set-Cookie"
content="as_sfa=MnxzZ3xzZ3x8ZW5fU0d8Y29uc3VtZXJ8aW50ZXJ
uZXR8MHwwfDE=; path=/; domain=.apple.com; expires=Mon,
15-Sep-2025 04:18:11 GMT;" />

                              <meta property="og:type"
content="product" />
                              <meta property="og:title" content="iPhone
6s" />
                                              <meta property="og:url"
content="http://www.apple.com/sg/shop/buy-iphone/
iphone6s" />
                                              <meta prope
```

Apple.com/iphone.html
…at 11:59am

Problem definition

- Document D: sequence of words
- Word w: sequence of characters
- Word frequency D(w): number of occurrences of w in D

- For example
  - D: “good morning good good”
  - w: {“good”, “morning”, “good”, “good”}
    - w[0] = “good”
    - w[1] = “morning”
    - w[2]= “good”
    - w[3] = “good”
  - D(“good”) = 3

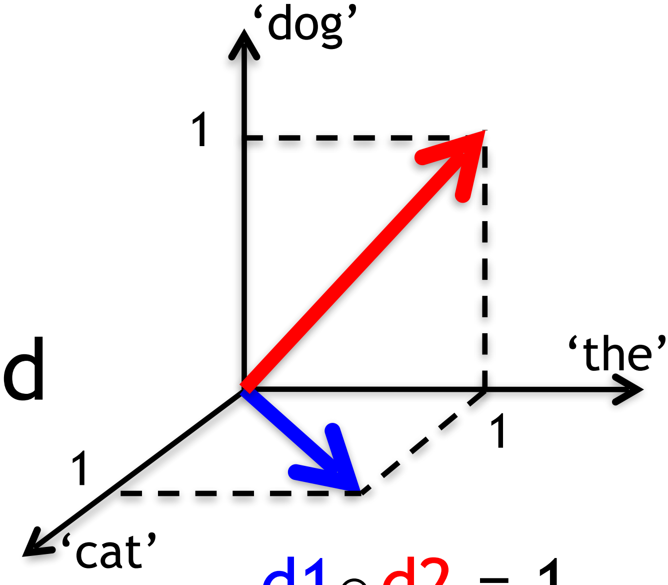
What we will do today

- I will show you some VERY COMPLICATED CODE
- No need to understand them (out of syllabus)
- I just want see
  - the running time of O(1), O(n) and O(n^2) function can be very different
  - How to improve the speed of a code

Algorithm for document distance - Vector space model

- Treat each document as a vector of its words
  - one coordinate per word of the English dictionary

e.g. doc1 = “the cat”
doc2 = “the dog”



d1∘d2 = 1

The dot product between D1 and D2 represent their similarity

$$D_1 \circ D_2 \equiv \sum_w D_1(w) \cdot D_2(w)$$

Algorithm for document distance - Vector space model

e.g.

“the cat”。”the dog”

= [the x the + cat x dog]

= 1 + 0

= 1

Algorithm for document distance - Vector space model

e.g.

“the the cat cat”。”the the dog dog”

= the x the + the x the + cat x dog + cat x dog

= 1 + 1 + 0 + 0

= 2

Algorithm for document distance - Vector space model

… wait,

A: “the cat” vs “the dog”

B: “the the cat cat” vs ”the the dog dog”

Both problem A and B are 50% similar.
Why B score more (2) than A (1)?

So, we need to normalize the result

Algorithm for document distance - Vector space model

e.g.

[“the cat”。 ”the dog”] / sqrt(2 x 2)

= [the x the + cat x dog] / 2

= [1 + 0] / 2

= 50%

Algorithm for document distance - Vector space model

e.g.

[“the the cat cat”。 ”the the dog dog”] / sqrt(4 x 4)

= [the x the + the x the + cat x dog + cat x dog] / 4

= [1 + 1 + 0 + 0]/4

= 50%

Vector space model

- Normalization
  - divide by the length of the vectors

$$\frac{D_1 \circ D_2}{||D_1|| \cdot ||D_2||}$$

$$D_1 = aD_2$$

  - measure distance by angle between vectors:

$$\theta(D_1, D_2) = \mathrm{acos}\left(\frac{D_1 \circ D_2}{||D_1|| \cdot ||D_2||}\right)$$

e.g. $\theta=0$ documents “identical”
(if of the same size, permutations of each other)
$\theta=\pi/2$ not even share a word

Algorithm

aa*b*cv*bnl*bg*b*aa*nl*aau*b*aa*nl*cv*b*xf*eof*

- Read file

Algorithm

aa*b*cv*bnl*bg*b*aa*nl*aau*b*aa*nl*cv*b*xf*eof*

- Read file
- Make word list (divide file into words)

[aa,cv] + [bg,aa] + [aau,aa] + [cv,xf]

[aa, cv, bg, aa, aau, aa, cv,xf]

Algorithm

aa*b*cv*bnl*bg*b*aa*nl*aau*b*aa*nl*cv*b*xf*eof*

- Read file
- Make word list (divide file into words)
- Count frequencies of words

[aa, cv, bg, aa, aau, aa, cv,xf]

↓

[(aa,3), (cv,2), (bg,1), (aau,1),(xf,1)]

Algorithm

aa*b*cv*bnl*bg*b*aa*nl*aau*b*aa*nl*cv*b*xf*eof*

- Read file
- Make word list (divide file into words)
- Count frequencies of words
- Compute dot product

D_1:[(aa,3), (aau,1), (bg,1), (cv,2)]

D_2:[(aa,2), (ba,2), (bg,2), (ca,1), (fv,2)]

Algorithm

aa*b*cv*bnl*bg*b*aa*nl*aau*b*aa*nl*cv*b*xf*eof*

- Read file
- Make word list (divide file into words)
- Count frequencies of words
- Compute dot product
  - for every word in the first document, check if it appears in the other document; if yes, multiply their frequencies and add to the dot product
    - worst case time: order of

      #words(D_1) x #words(D_2)

Algorithm

aa*b*cv*bnl*bg*b*aa*nl*aau*b*aa*nl*cv*b*xf*eof*

- Read file
- Make word list (divide file into words)
- Count frequencies of words
- Compute dot product
  - for every word in the first document, check if it appears in the other document; if yes, multiply their frequencies and add to the dot product
    - worst case time: order of

      $\#\text{words}(D_1) \times \#\text{words}(D_2)$
  - micro-optimization:
    - sort documents into word order (alphabetically)
    - compute inner product in time

      $\#\text{words}(D_1) + \#\text{words}(D_2)$

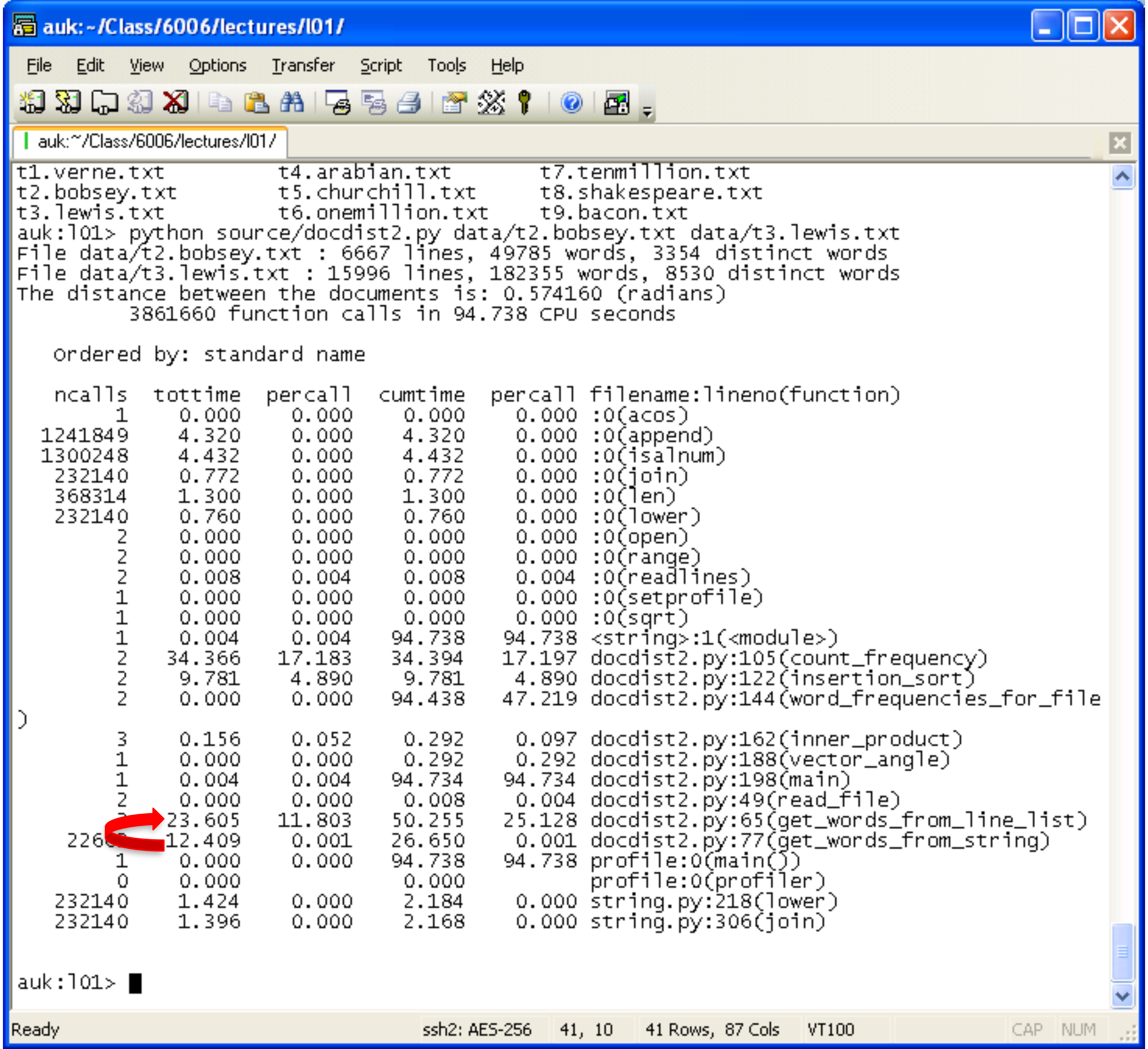
Python Implementation

- Docdist1.py (see handout)

- Read file: read_file(filename)
  - Output: list of lines (strings)
- Make word list: get_words_from_line_list(L)
  - Output: list of words (array)
- Count frequencies: count_frequency(word list)
  - Output: list of word-frequency pairs
- Dot product: inner_product(D1, D2)
  - Output: number

cProfiling.run()

- return T(n)
  - import profile
  - profile.run(“main()”)



```
t1.verne.txt          t4.arabian.txt        t7.tenmillion.txt
t2.bobsey.txt         t5.churchill.txt      t8.shakespeare.txt
t3.lewis.txt          t6.onemillion.txt     t9.bacon.txt
auk:l01> python source/docdist2.py data/t2.bobsey.txt data/t3.lewis.txt
File data/t2.bobsey.txt : 6667 lines, 49785 words, 3354 distinct words
File data/t3.lewis.txt : 15996 lines, 182355 words, 8530 distinct words
The distance between the documents is: 0.574160 (radians)
         3861660 function calls in 94.738 CPU seconds

   Ordered by: standard name

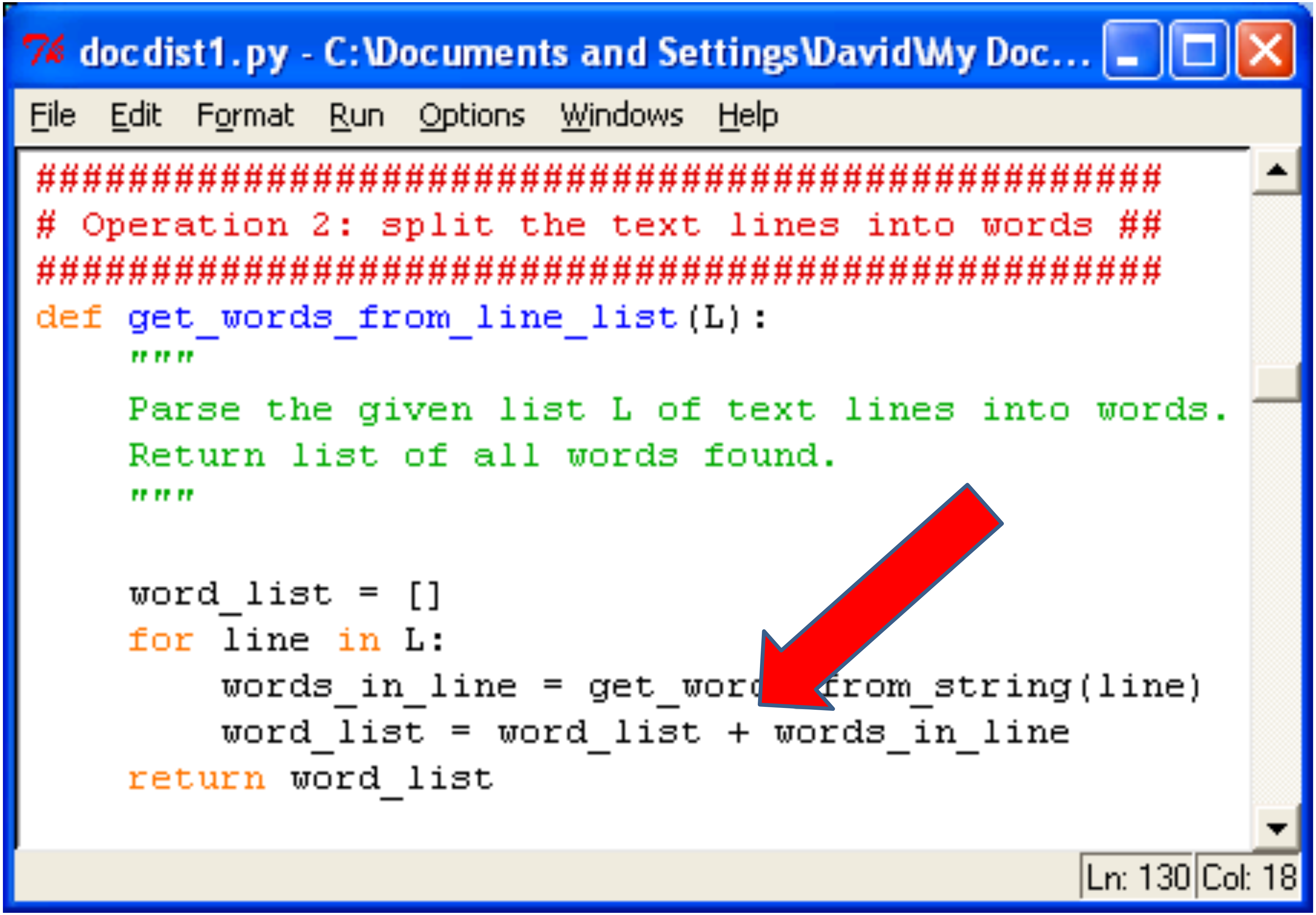
   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
        1    0.000    0.000    0.000    0.000 :0(acos)
  1241849    4.320    0.000    4.320    0.000 :0(append)
  1300248    4.432    0.000    4.432    0.000 :0(isalnum)
   232140    0.772    0.000    0.772    0.000 :0(join)
   368314    1.300    0.000    1.300    0.000 :0(len)
   232140    0.760    0.000    0.760    0.000 :0(lower)
        2    0.000    0.000    0.000    0.000 :0(open)
        2    0.000    0.000    0.000    0.000 :0(range)
        2    0.008    0.004    0.008    0.004 :0(readlines)
        1    0.000    0.000    0.000    0.000 :0(setprofile)
        1    0.000    0.000    0.000    0.000 :0(sqrt)
        1    0.004    0.004   94.738   94.738 <string>:1(<module>)
        2   34.366   17.183   34.394   17.197 docdist2.py:105(count_frequency)
        2    9.781    4.890    9.781    4.890 docdist2.py:122(insertion_sort)
        2    0.000    0.000   94.438   47.219 docdist2.py:144(word_frequencies_for_file
)
        3    0.156    0.052    0.292    0.097 docdist2.py:162(inner_product)
        1    0.000    0.000    0.292    0.292 docdist2.py:188(vector_angle)
        1    0.004    0.004   94.734   94.734 docdist2.py:198(main)
        2    0.000    0.000    0.008    0.004 docdist2.py:49(read_file)
        2   23.605   11.803   50.255   25.128 docdist2.py:65(get_words_from_line_list)
   226[illegible]   12.409    0.001   26.650    0.001 docdist2.py:77(get_words_from_string)
        1    0.000    0.000   94.738   94.738 profile:0(main())
        0    0.000             0.000          profile:0(profiler)
   232140    1.424    0.000    2.184    0.000 string.py:218(lower)
   232140    1.396    0.000    2.168    0.000 string.py:306(join)


auk:l01> █
```

docdist1

- Docdist1.py is slow
- Docdist2.py is faster
- Docdist3.py is even faster
- ….
- Docdist8.py is the best

- Now let’s look at docdist1.py



```
##################################################
# Operation 2: split the text lines into words ##
##################################################
def get_words_from_line_list(L):
    """
    Parse the given list L of text lines into words.
    Return list of all words found.
    """

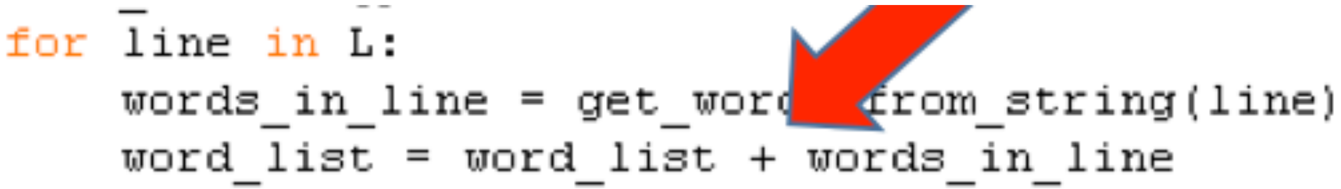
    word_list = []
    for line in L:
        words_in_line = get_words_from_string(line)
        word_list = word_list + words_in_line
    return word_list
```

+ is slow, need to improve it

- Look at word_list = word_list + words_in_line
- + : concatenation of arrays

- running time = $T(k)$
  - k = length (word_list) + length(words_in_line)

- Total $T(n)$ is $1+2+\ldots+n = n(n+1)/2 = \Theta(n^2)$



```
for line in L:
    words_in_line = get_words_from_string(line)
    word_list = word_list + words_in_line
```

Solution

- word_list = word_list + words_in_line: $\Theta(n^2)$
  - docdist1.py (3.7s)
- word_list.extend(words_in_line) : $\Theta(n)$
  - docdist2.py (2.722s)

- How to run:
  - Python docdist1.py file5.txt file4.txt

Further Improvements

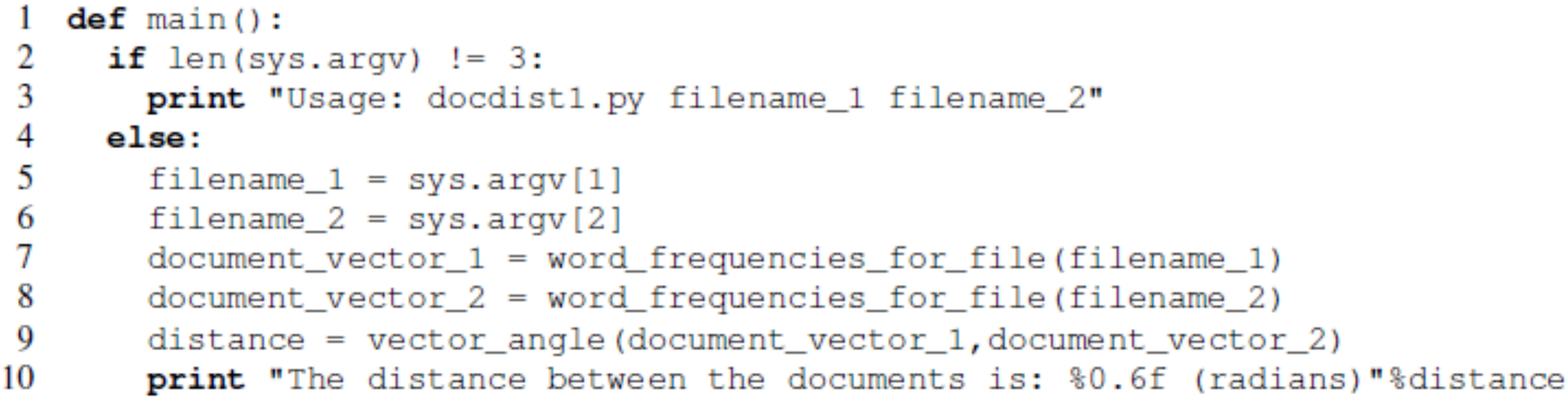
- Docdist3.py: sort the data first (2.657s)
- Docdist4.py: Instead of inserting words in list, insert in dictionary: (0.735s)
- Docdist5.py: Process words instead of chars (0.138s)
- Docdist6.py: better sorting algorithm (0.069s)
  - merge sort instead of insertion sort
- Docdist7.py: dictionary instead of sort. (0.052s)

Appendix –
how to optimize the code

docdist<1-8>.py – Iterative improvements

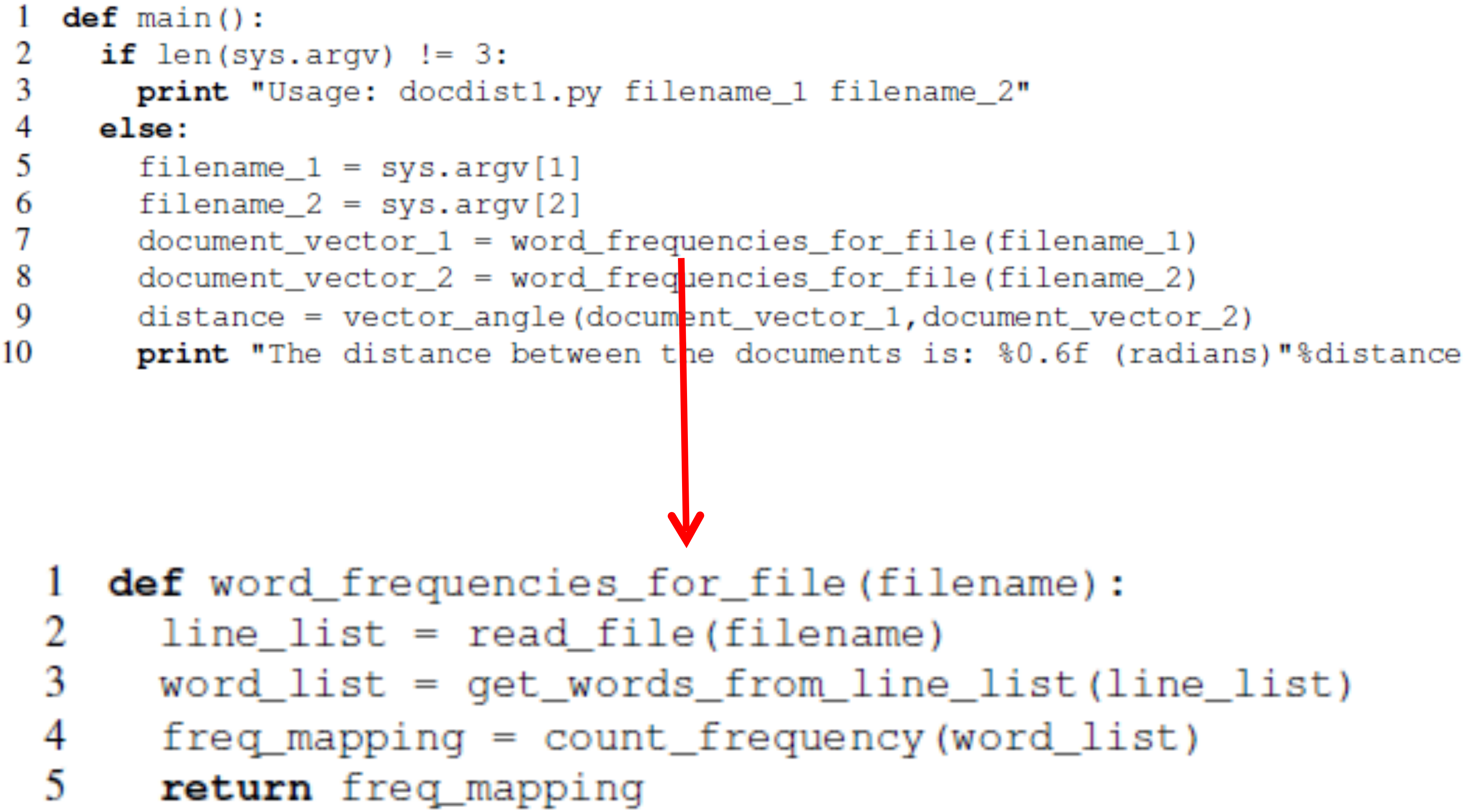
- Objective
  - To arrive at the most efficient implementation in terms of running time
- Approach
  - At each iteration, analyze the running times of various parts of the code
  - Based on the biggest consumer of running time, refactor the code by
    - Introducing faster algorithms
    - Using features of the Python language
    - Simplifying and optimizing code

docdist1 – Code structure



```
def main():
  if len(sys.argv) != 3:
    print "Usage: docdist1.py filename_1 filename_2"
  else:
    filename_1 = sys.argv[1]
    filename_2 = sys.argv[2]
    document_vector_1 = word_frequencies_for_file(filename_1)
    document_vector_2 = word_frequencies_for_file(filename_2)
    distance = vector_angle(document_vector_1,document_vector_2)
    print "The distance between the documents is: %0.6f (radians)"%distance
```

docdist1 – Code structure



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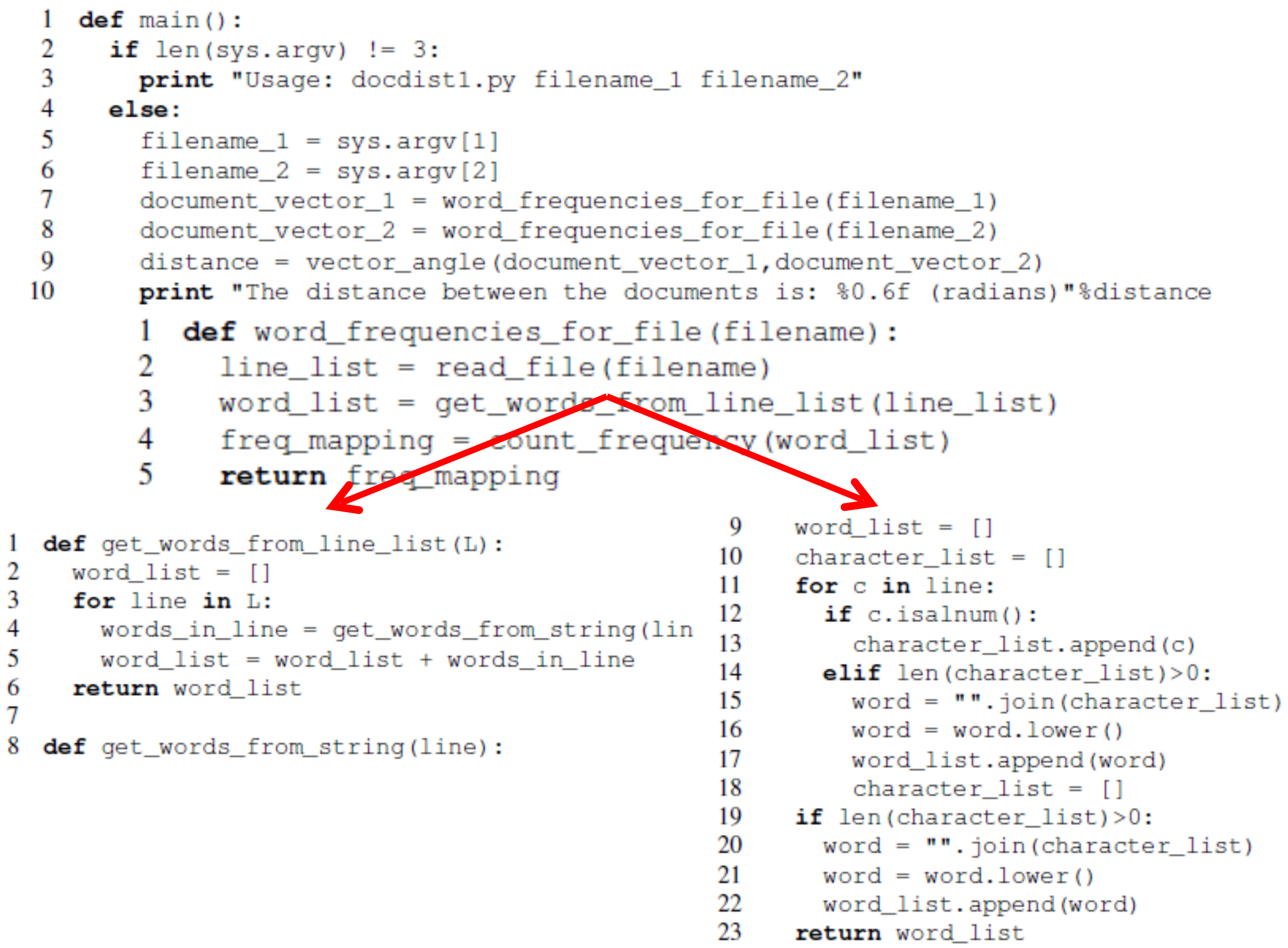
    document_vector_2 = word_frequencies_for_file(filename_2)
    distance = vector_angle(document_vector_1,document_vector_2)
    print "The distance between the documents is: %0.6f (radians)"%distance
```

```
def word_frequencies_for_file(filename):
  line_list = read_file(filename)
  word_list = get_words_from_line_list(line_list)
  freq_mapping = count_frequency(word_list)
  return freq_mapping
```

docdist1 – Code structure



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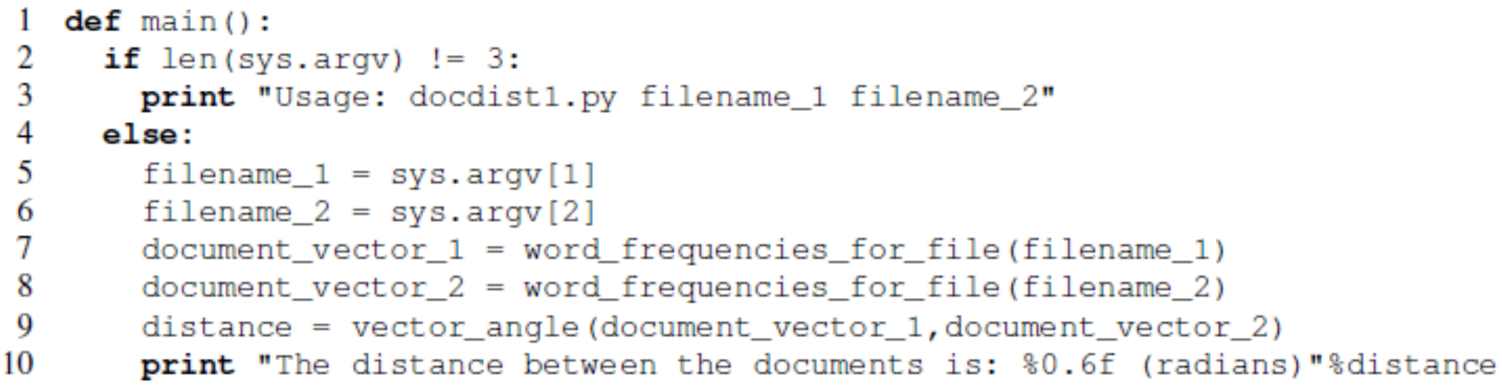
```

```
def get_words_from_line_list(L):
  word_list = []
  for line in L:
    words_in_line = get_words_from_string(lin
    word_list = word_list + words_in_line
  return word_list

def get_words_from_string(line):
  word_list = []
  character_list = []
  for c in line:
    if c.isalnum():
      character_list.append(c)
    elif len(character_list)>0:
      word = "".join(character_list)
      word = word.lower()
      word_list.append(word)
      character_list = []
  if len(character_list)>0:
    word = "".join(character_list)
    word = word.lower()
    word_list.append(word)
  return word_list
```

docdist1 – Code structure



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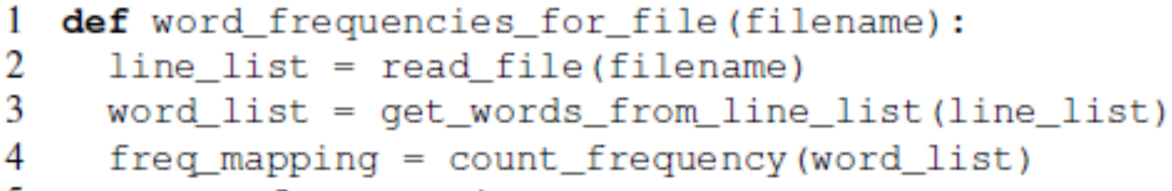

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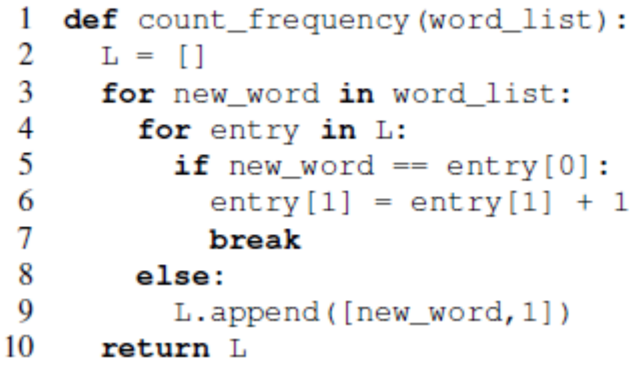
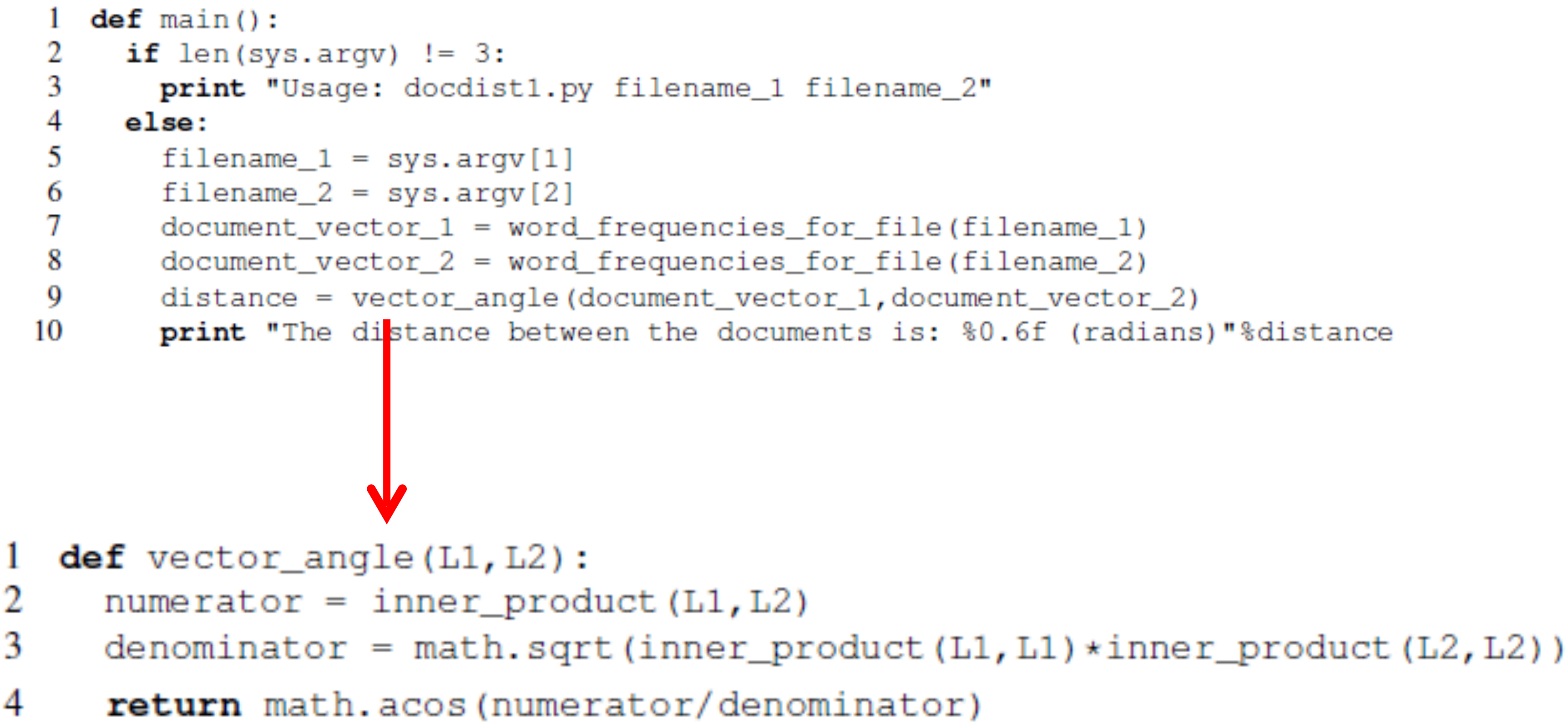


```
def count_frequency(word_list):
  L = []
  for new_word in word_list:
    for entry in L:
      if new_word == entry[0]:
        entry[1] = entry[1] + 1
        break
    else:
      L.append([new_word,1])
  return L
```

docdist1 – Code structure



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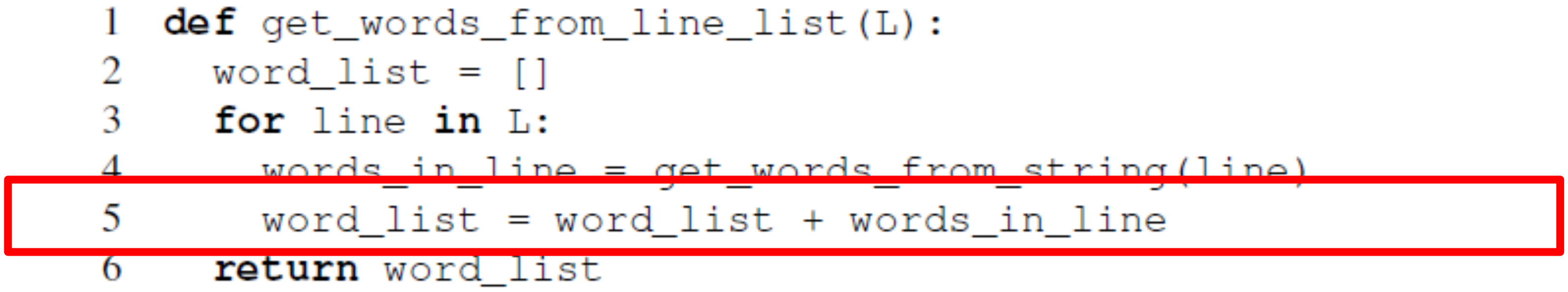
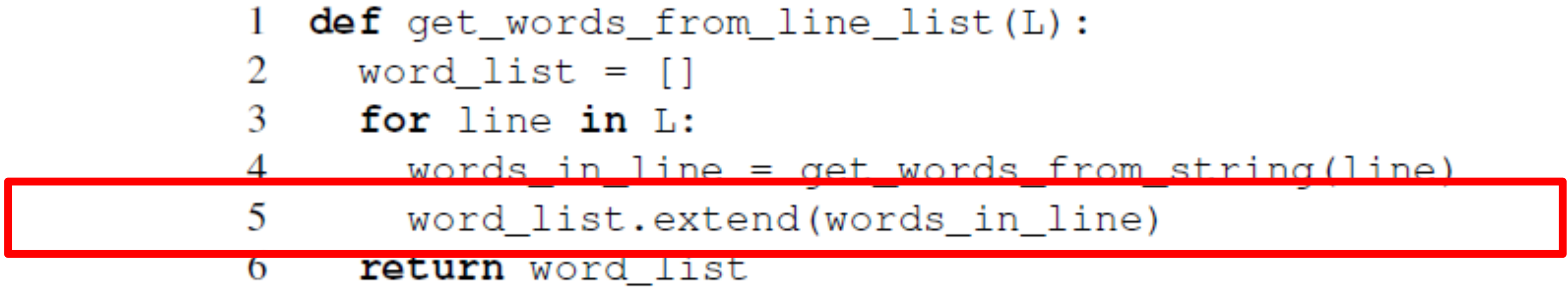
    document_vector_2 = word_frequencies_for_file(filename_2)
    distance = vector_angle(document_vector_1,document_vector_2)
    print "The distance between the documents is: %0.6f (radians)"%distance
```

```
def vector_angle(L1,L2):
  numerator = inner_product(L1,L2)
  denominator = math.sqrt(inner_product(L1,L1)*inner_product(L2,L2))
  return math.acos(numerator/denominator)
```

docdist1 vs. docdist2

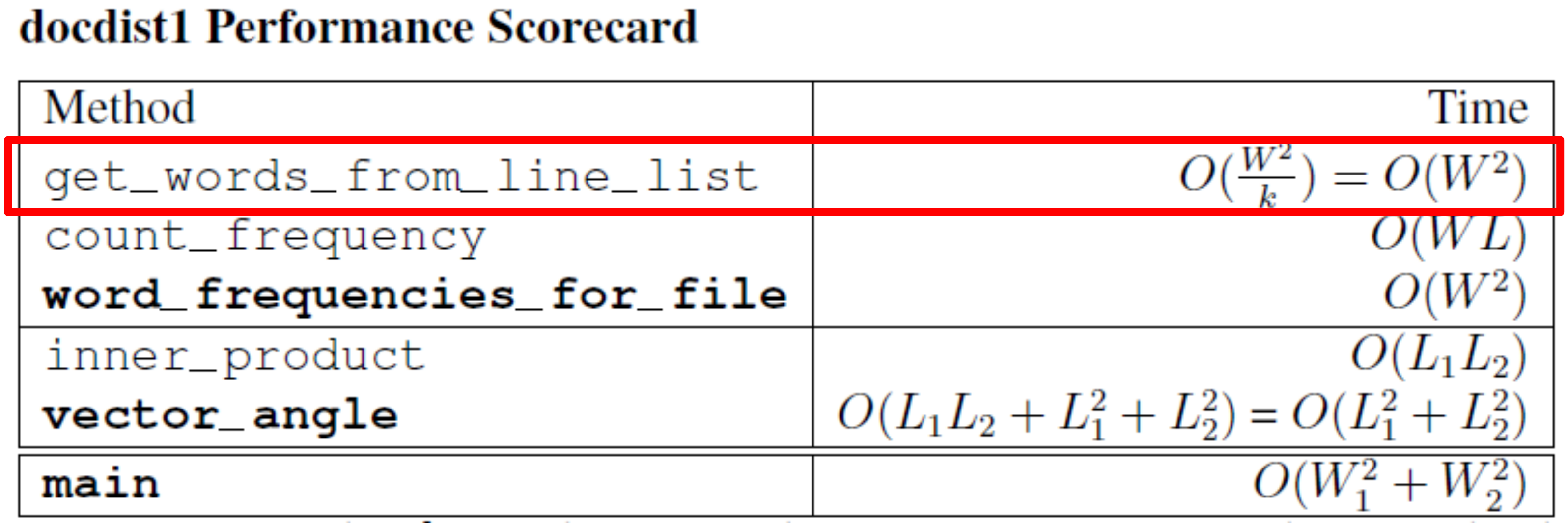


```
def get_words_from_line_list(L):
  word_list = []
  for line in L:
    words_in_line = get_words_from_string(line)
    word_list = word_list + words_in_line
  return word_list
```



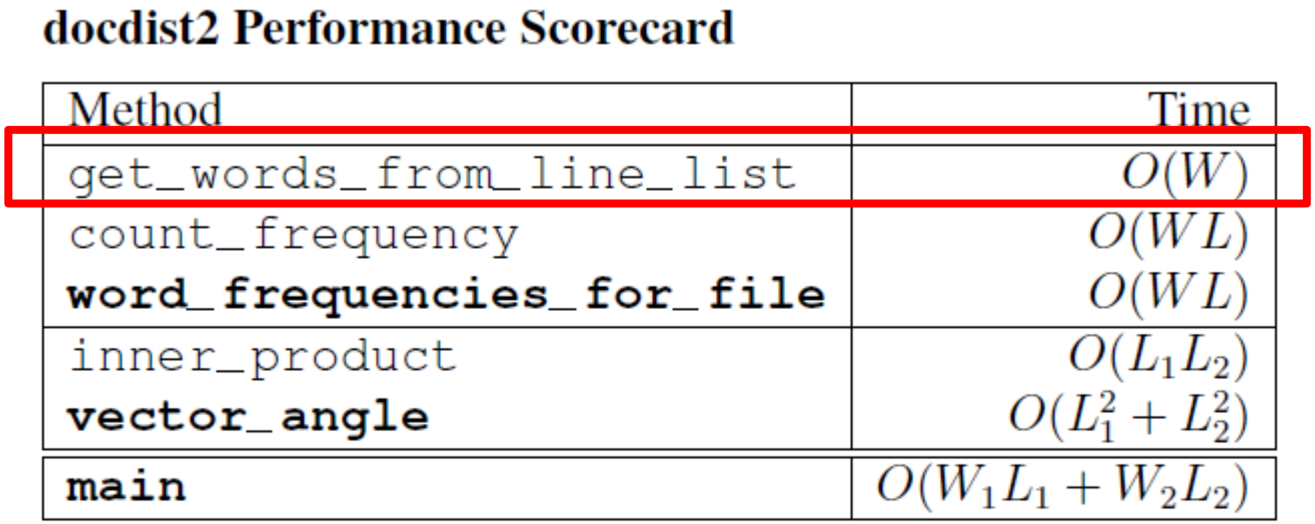
```
def get_words_from_line_list(L):
  word_list = []
  for line in L:
    words_in_line = get_words_from_string(line)
    word_list.extend(words_in_line)
  return word_list
```

docdist1 vs. docdist2



docdist1 Performance Scorecard

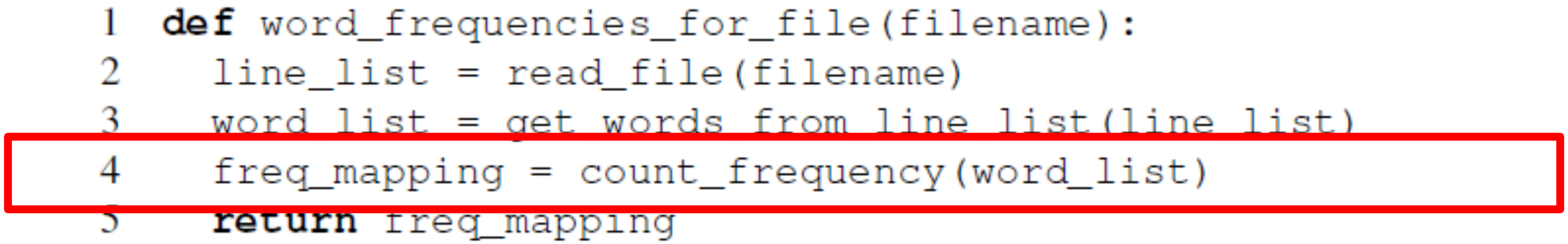
Method	Time
get_words_from_line_list	$O(\frac{W^2}{k}) = O(W^2)$
count_frequency	$O(WL)$
word_frequencies_for_file	$O(W^2)$
inner_product	$O(L_1 L_2)$
vector_angle	$O(L_1 L_2 + L_1^2 + L_2^2) = O(L_1^2 + L_2^2)$
main	$O(W_1^2 + W_2^2)$



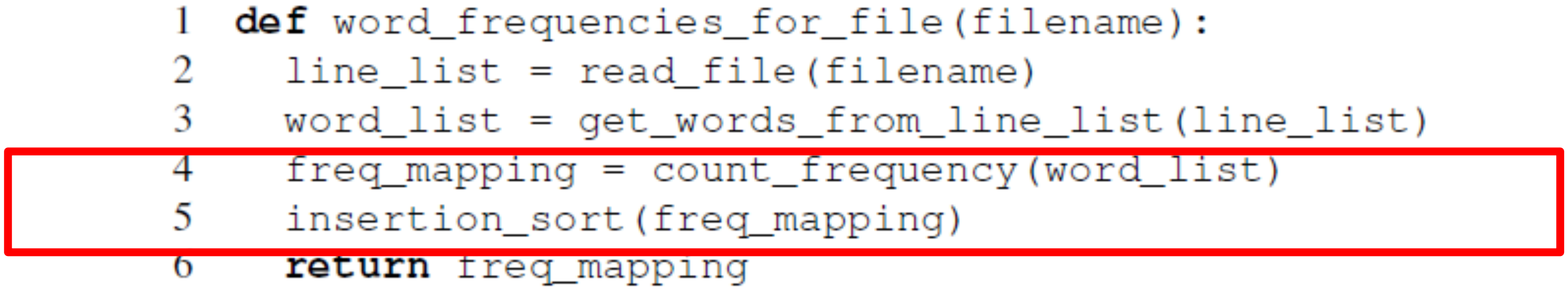
docdist2 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(WL)$
word_frequencies_for_file	$O(WL)$
inner_product	$O(L_1 L_2)$
vector_angle	$O(L_1^2 + L_2^2)$
main	$O(W_1 L_1 + W_2 L_2)$

docdist2 vs. docdist3

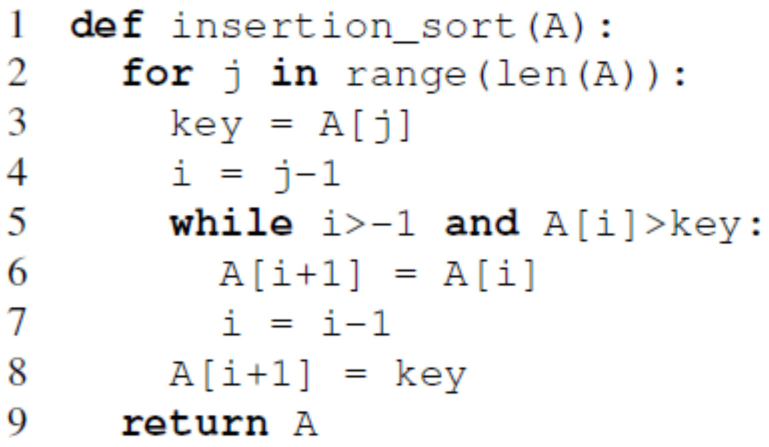


```
def word_frequencies_for_file(filename):
  line_list = read_file(filename)
  word_list = get_words_from_line_list(line_list)
  freq_mapping = count_frequency(word_list)
  return freq_mapping
```



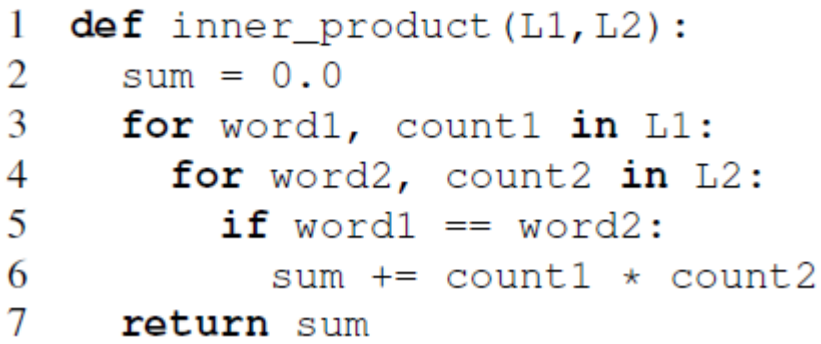
```
def word_frequencies_for_file(filename):
  line_list = read_file(filename)
  word_list = get_words_from_line_list(line_list)
  freq_mapping = count_frequency(word_list)
  insertion_sort(freq_mapping)
  return freq_mapping
```

docdist3 – Implementing insertion_sort()

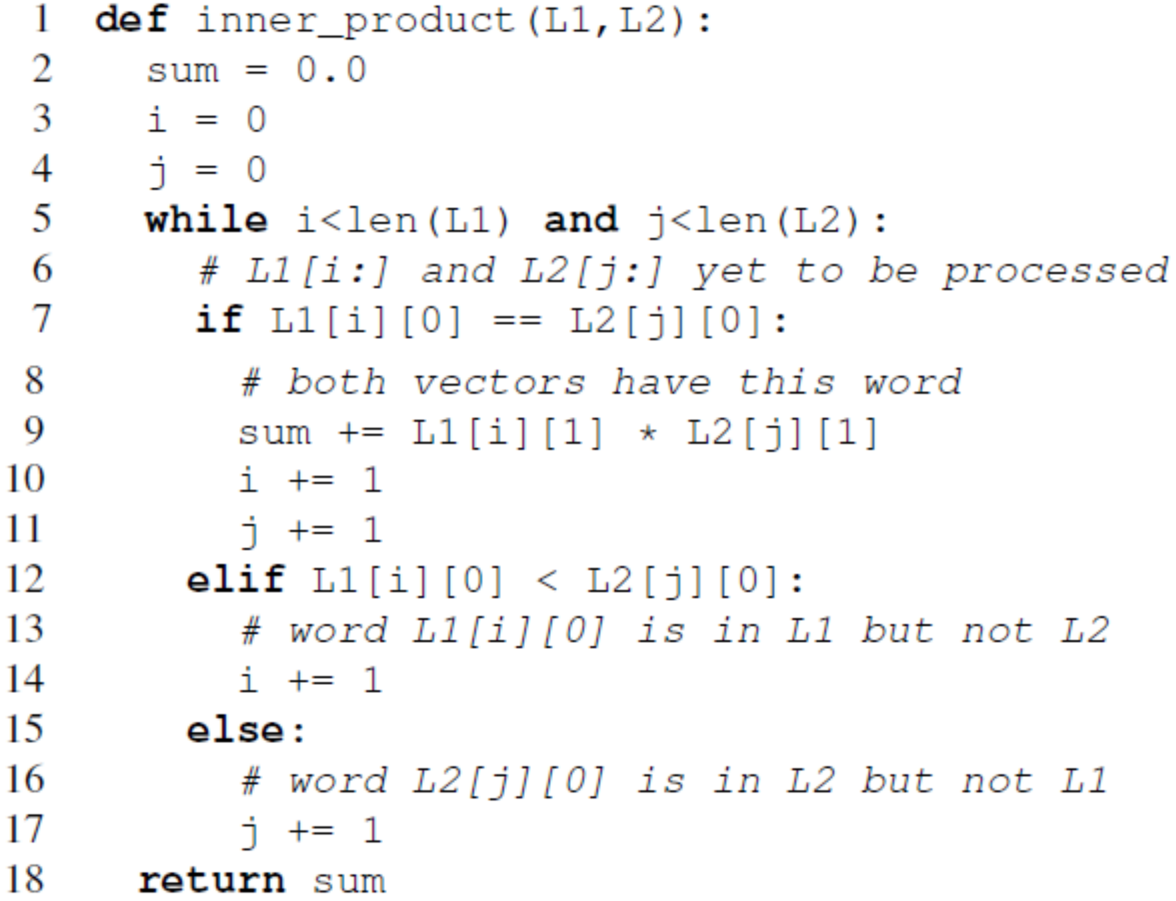


```
def insertion_sort(A):
  for j in range(len(A)):
    key = A[j]
    i = j-1
    while i>-1 and A[i]>key:
      A[i+1] = A[i]
      i = i-1
    A[i+1] = key
  return A
```

docdist3 - Reimplementing inner_product()

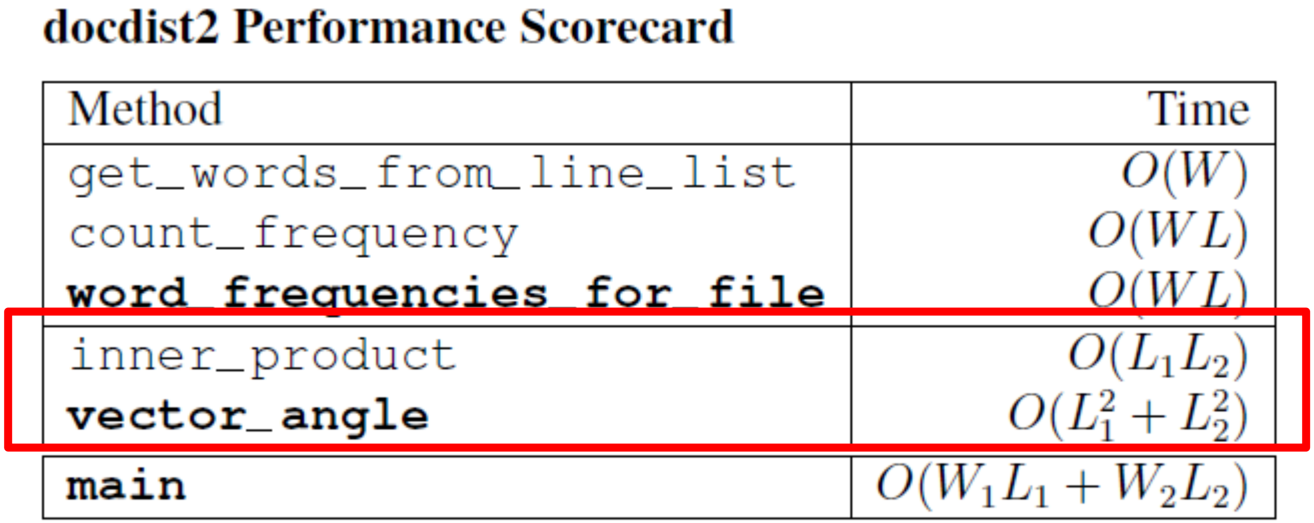


```
def inner_product(L1,L2):
  sum = 0.0
  for word1, count1 in L1:
    for word2, count2 in L2:
      if word1 == word2:
        sum += count1 * count2
  return sum
```



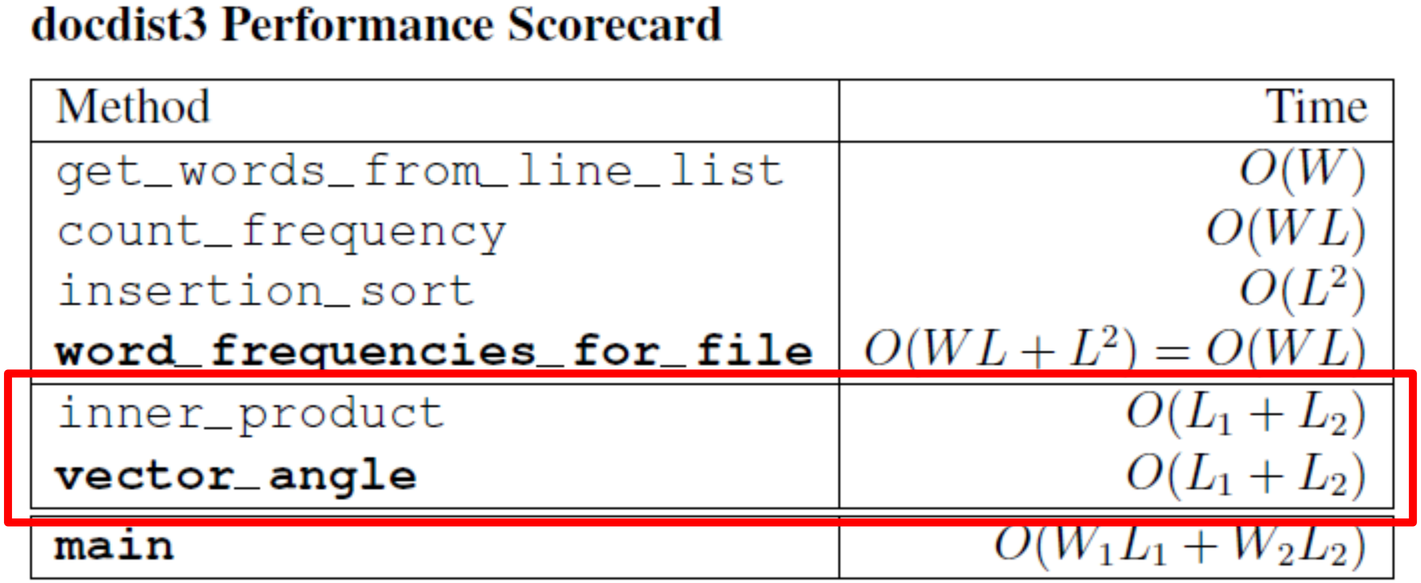
```
def inner_product(L1,L2):
  sum = 0.0
  i = 0
  j = 0
  while i<len(L1) and j<len(L2):
    # L1[i:] and L2[j:] yet to be processed
    if L1[i][0] == L2[j][0]:
      # both vectors have this word
      sum += L1[i][1] * L2[j][1]
      i += 1
      j += 1
    elif L1[i][0] < L2[j][0]:
      # word L1[i][0] is in L1 but not L2
      i += 1
    else:
      # word L2[j][0] is in L2 but not L1
      j += 1
  return sum
```

docdist2 vs. docdist3



docdist2 Performance Scorecard

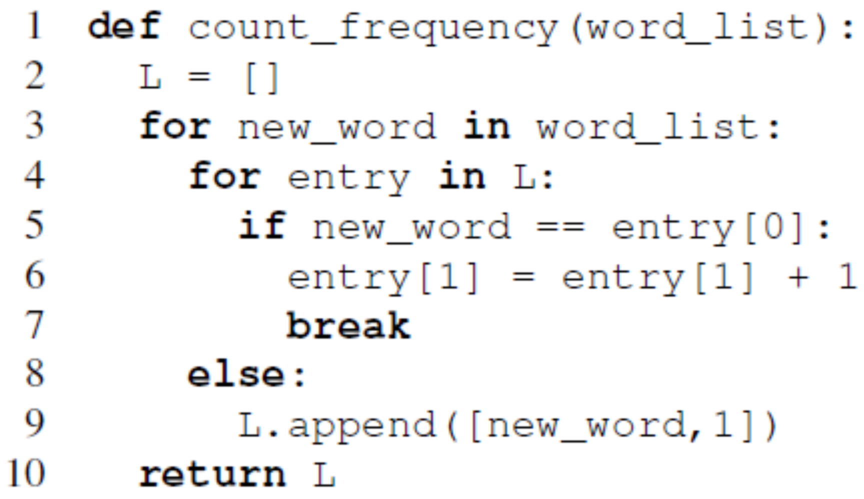
Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(WL)$
word_frequencies_for_file	$O(WL)$
inner_product	$O(L_1 L_2)$
vector_angle	$O(L_1^2 + L_2^2)$
main	$O(W_1 L_1 + W_2 L_2)$



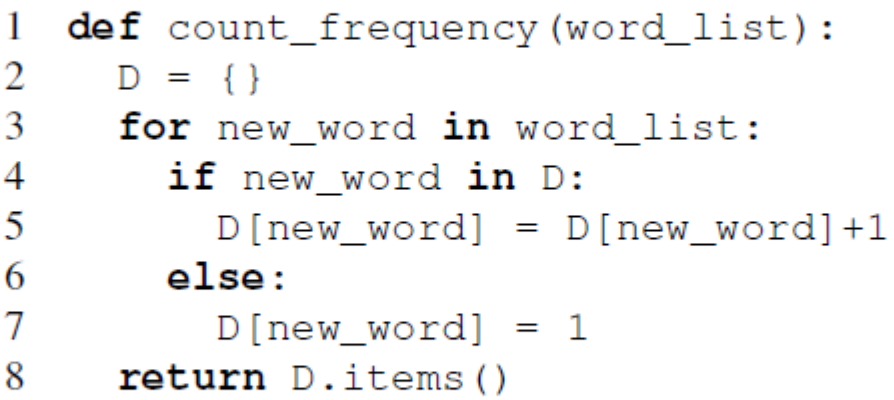
docdist3 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(WL)$
insertion_sort	$O(L^2)$
word_frequencies_for_file	$O(WL + L^2) = O(WL)$
inner_product	$O(L_1 + L_2)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 L_1 + W_2 L_2)$

docdist4 – Refining count_frequency()

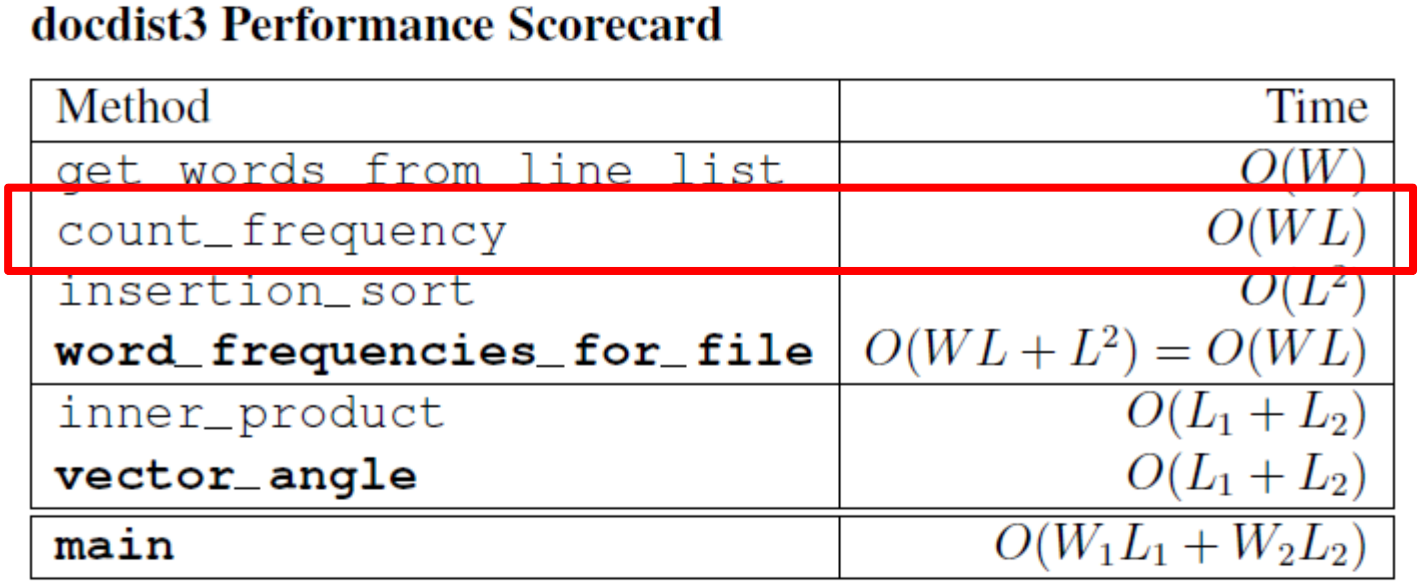


```
def count_frequency(word_list):
  L = []
  for new_word in word_list:
    for entry in L:
      if new_word == entry[0]:
        entry[1] = entry[1] + 1
        break
    else:
      L.append([new_word,1])
  return L
```



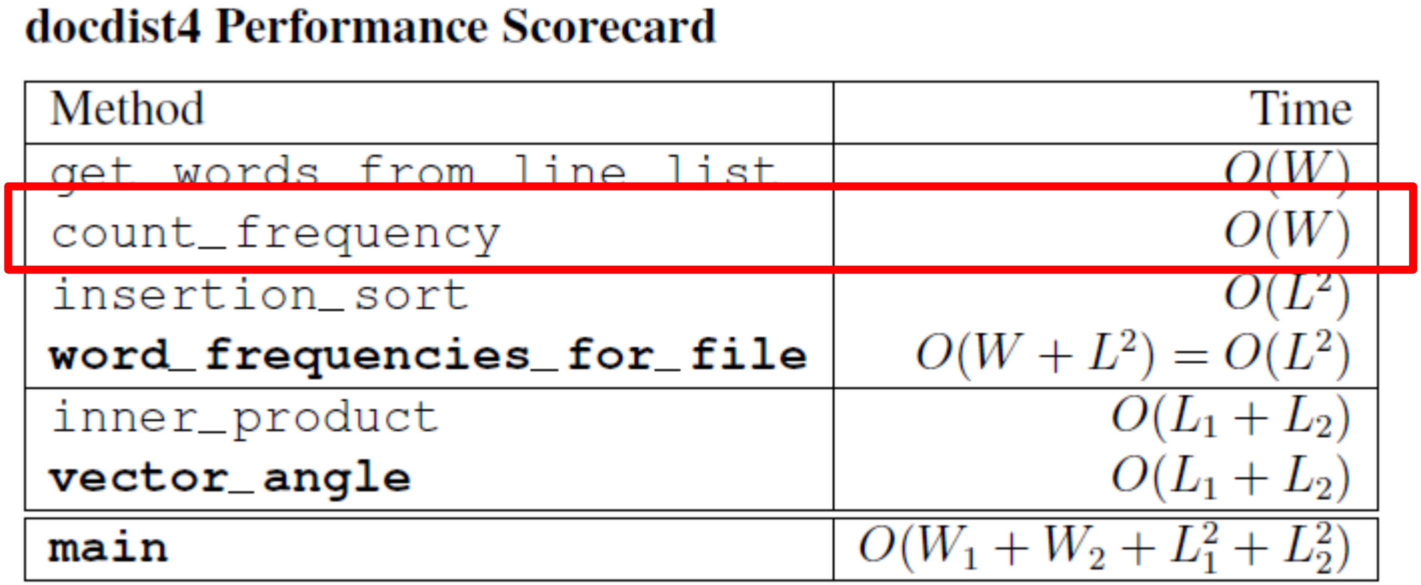
```
def count_frequency(word_list):
  D = {}
  for new_word in word_list:
    if new_word in D:
      D[new_word] = D[new_word]+1
    else:
      D[new_word] = 1
  return D.items()
```

docdist3 vs. docdist4



docdist3 Performance Scorecard

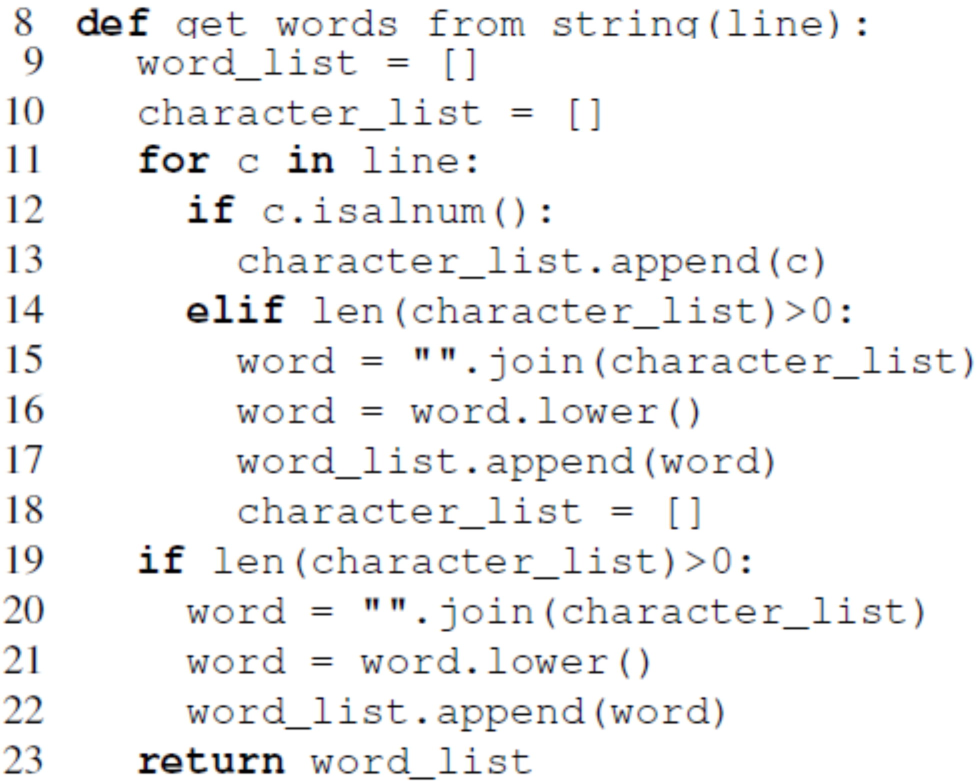
Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(WL)$
insertion_sort	$O(L^2)$
word_frequencies_for_file	$O(WL+L^2)=O(WL)$
inner_product	$O(L_1+L_2)$
vector_angle	$O(L_1+L_2)$
main	$O(W_1L_1+W_2L_2)$



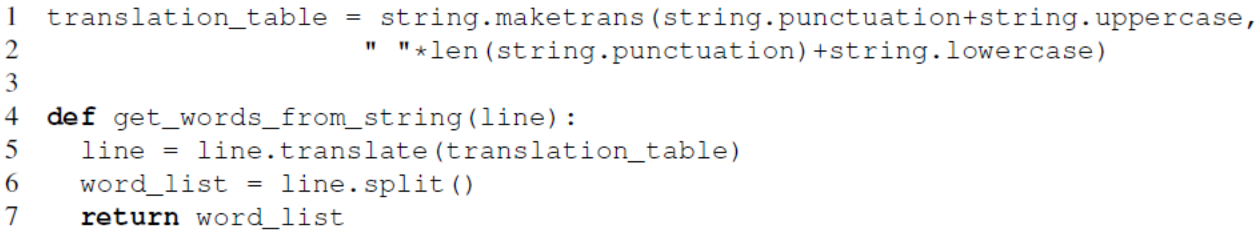
docdist4 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
insertion_sort	$O(L^2)$
word_frequencies_for_file	$O(W+L^2)=O(L^2)$
inner_product	$O(L_1+L_2)$
vector_angle	$O(L_1+L_2)$
main	$O(W_1+W_2+L_1^2+L_2^2)$

docdist5 – Simplifying get_words_from_string()



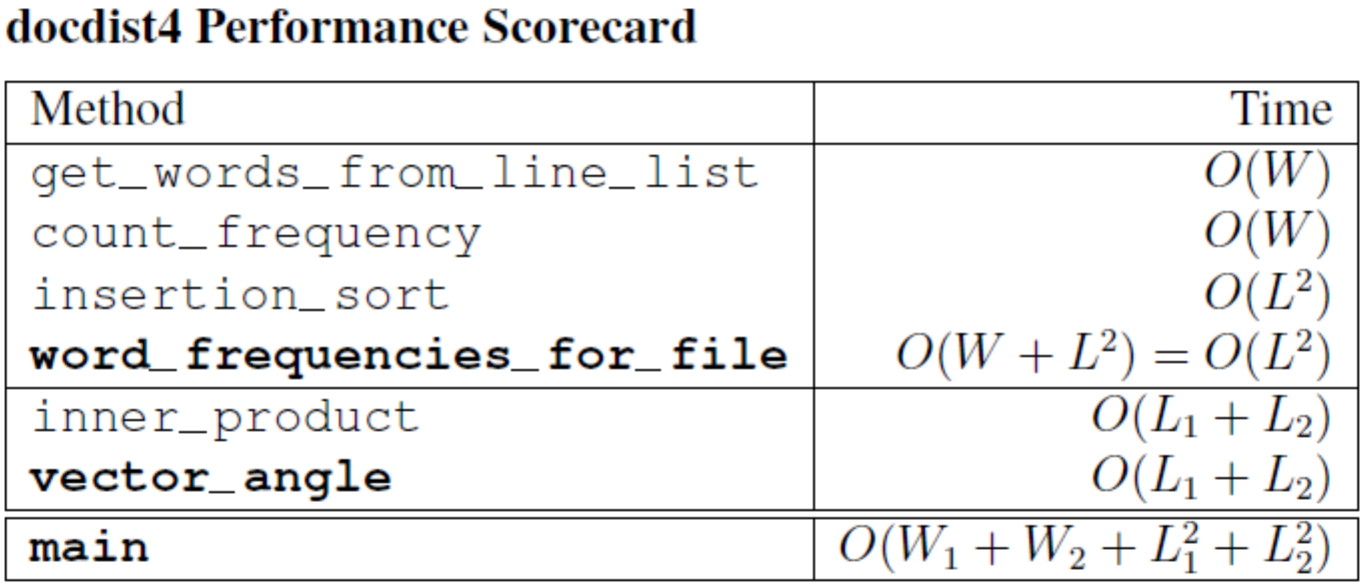
```
def get words from string(line):
  word_list = []
  character_list = []
  for c in line:
    if c.isalnum():
      character_list.append(c)
    elif len(character_list)>0:
      word = "".join(character_list)
      word = word.lower()
      word_list.append(word)
      character_list = []
  if len(character_list)>0:
    word = "".join(character_list)
    word = word.lower()
    word_list.append(word)
  return word_list
```



```
translation_table = string.maketrans(string.punctuation+string.uppercase,
                   " "*len(string.punctuation)+string.lowercase)

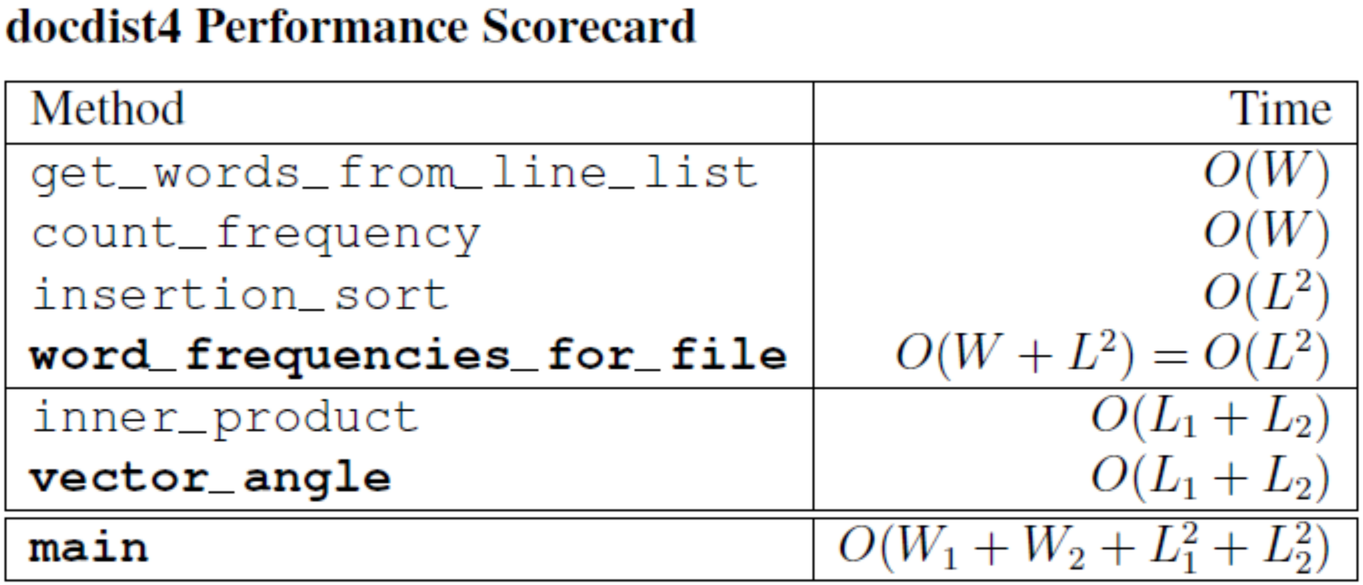
def get_words_from_string(line):
  line = line.translate(translation_table)
  word_list = line.split()
  return word_list
```

docdist4 vs. docdist5 (same as docdist4)



docdist4 Performance Scorecard

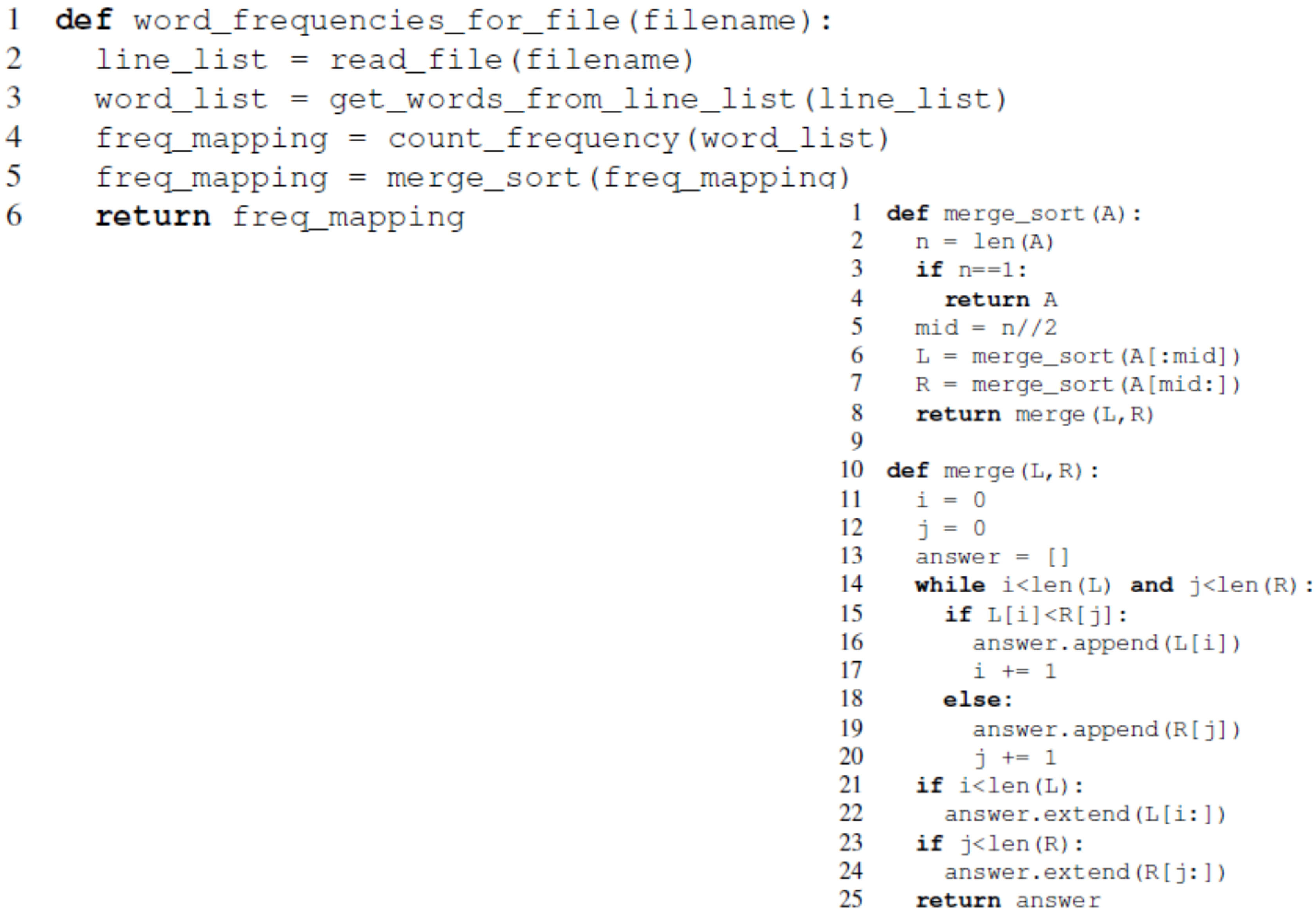
Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
insertion_sort	$O(L^2)$
word_frequencies_for_file	$O(W + L^2) = O(L^2)$
inner_product	$O(L_1 + L_2)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2 + L_1^2 + L_2^2)$



docdist4 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
insertion_sort	$O(L^2)$
word_frequencies_for_file	$O(W + L^2) = O(L^2)$
inner_product	$O(L_1 + L_2)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2 + L_1^2 + L_2^2)$

docdist6 – Replacing insertion sort by merge sort

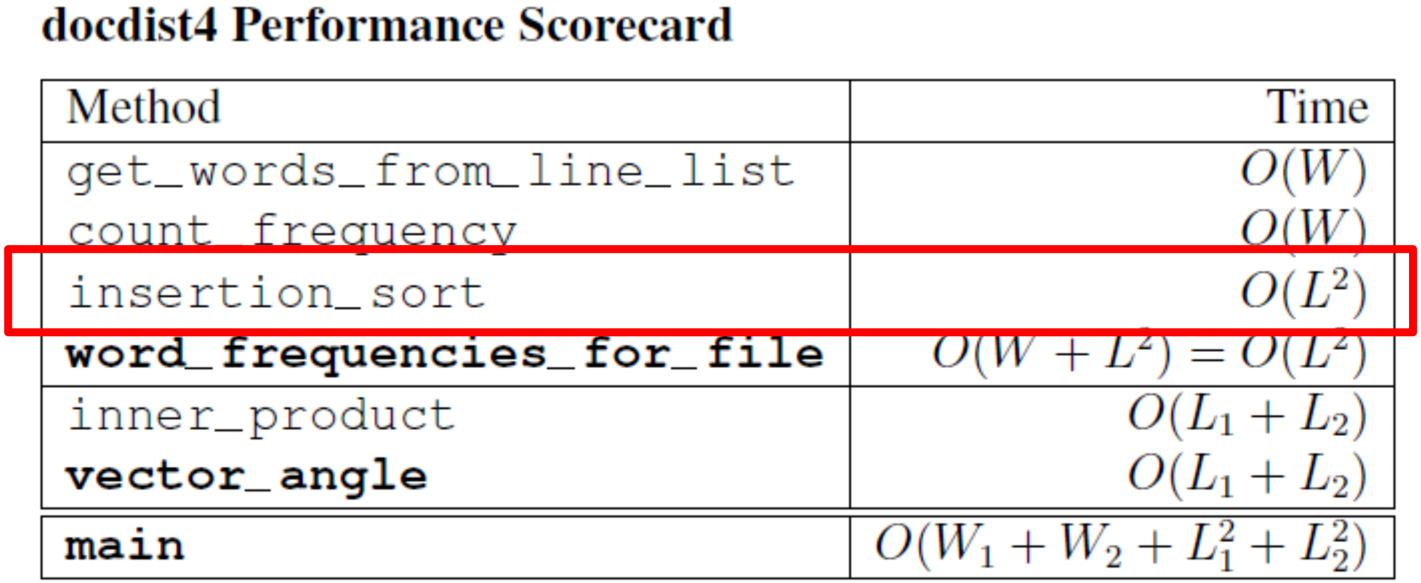


```
def word_frequencies_for_file(filename):
  line_list = read_file(filename)
  word_list = get_words_from_line_list(line_list)
  freq_mapping = count_frequency(word_list)
  freq_mapping = merge_sort(freq_mapping)
  return freq_mapping
```

```
def merge_sort(A):
  n = len(A)
  if n==1:
    return A
  mid = n//2
  L = merge_sort(A[:mid])
  R = merge_sort(A[mid:])
  return merge(L,R)

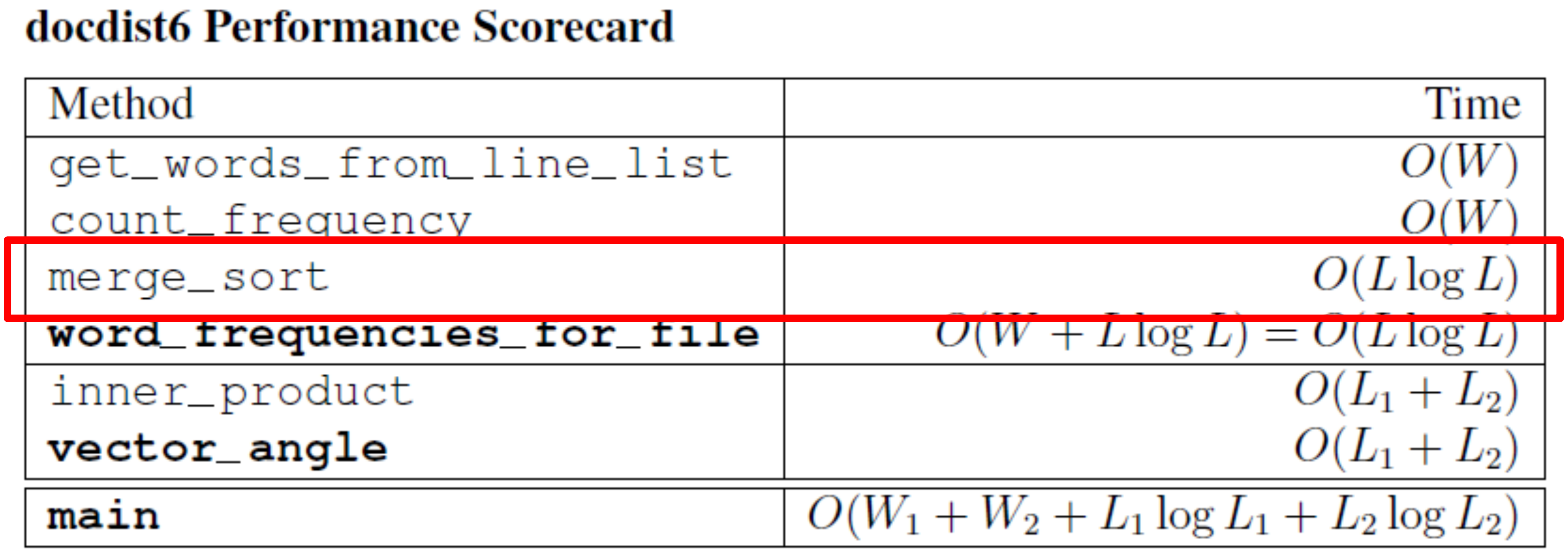
def merge(L,R):
  i = 0
  j = 0
  answer = []
  while i<len(L) and j<len(R):
    if L[i]<R[j]:
      answer.append(L[i])
      i += 1
    else:
      answer.append(R[j])
      j += 1
  if i<len(L):
    answer.extend(L[i:])
  if j<len(R):
    answer.extend(R[j:])
  return answer
```

docdist5 vs. docdist6



docdist4 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
insertion_sort	$O(L^2)$
word_frequencies_for_file	$O(W + L^2) = O(L^2)$
inner_product	$O(L_1 + L_2)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2 + L_1^2 + L_2^2)$



docdist6 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
merge_sort	$O(L \log L)$
word_frequencies_for_file	$O(W + L \log L) = O(L \log L)$
inner_product	$O(L_1 + L_2)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2 + L_1 \log L_1 + L_2 \log L_2)$

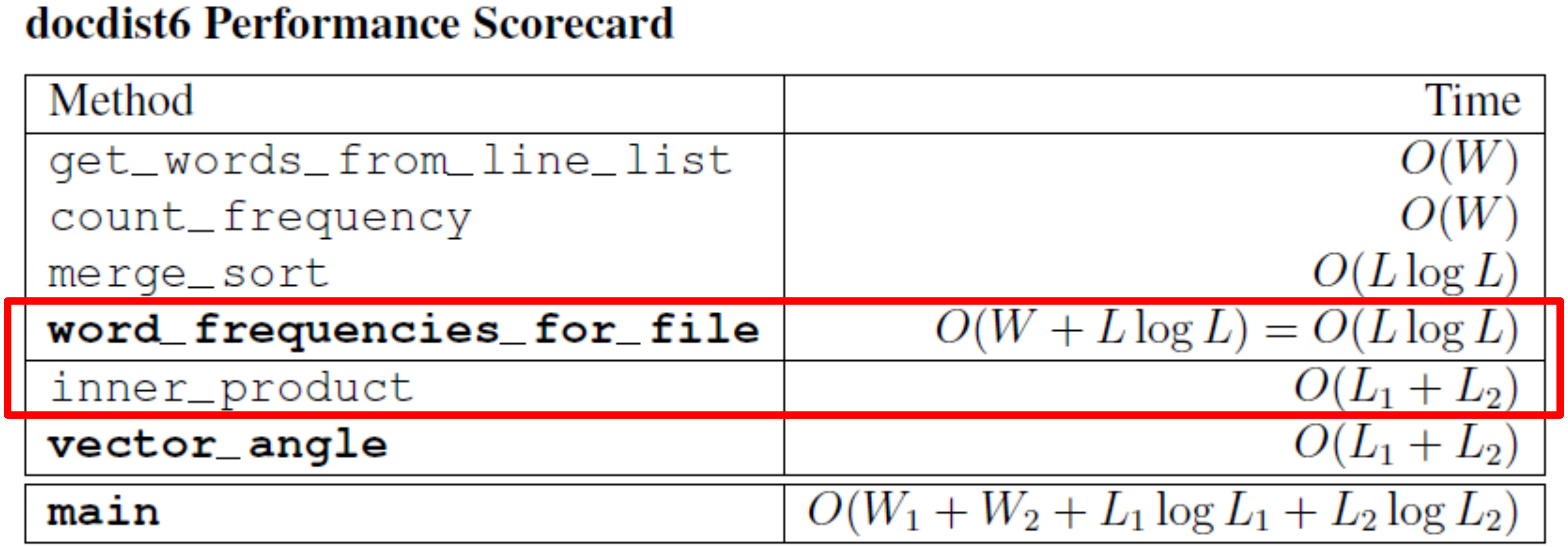
docdist7 – From sorted list to document vectors

```
def count_frequency(word_list):
  D = {}
  for new_word in word_list:
    if new_word in D:
      D[new_word] = D[new_word]+1
    else:
      D[new_word] = 1
  return D
```

```
def word_frequencies_for_file(filename):
  line_list = read_file(filename)
  word_list = get_words_from_line_list(line_list)
  freq_mapping = count_frequency(word_list)
  return freq_mapping
```

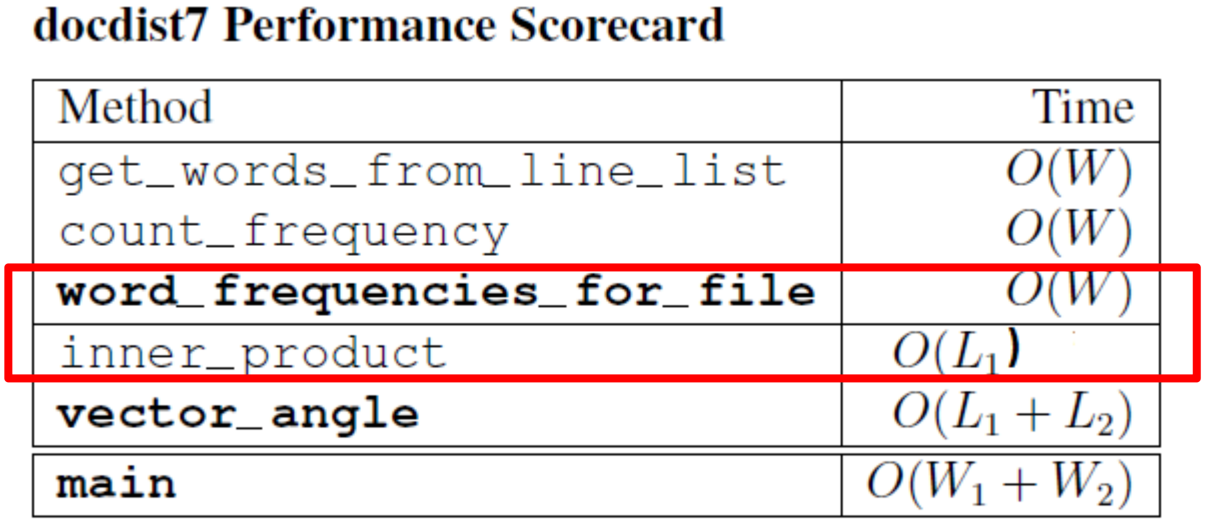
```
def inner_product(D1,D2):
  sum = 0.0
  for key in D1:
    if key in D2:
      sum += D1[key] * D2[key]
  return sum
```

docdist6 vs. docdist7



docdist6 Performance Scorecard

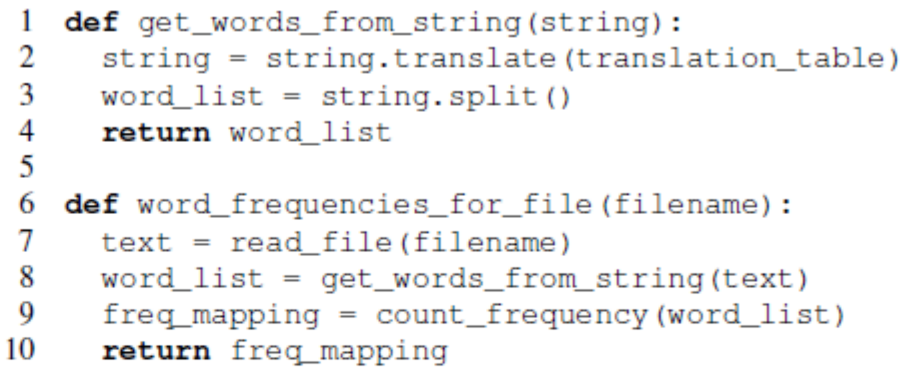
Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
merge_sort	$O(L \log L)$
word_frequencies_for_file	$O(W + L \log L) = O(L \log L)$
inner_product	$O(L_1 + L_2)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2 + L_1 \log L_1 + L_2 \log L_2)$



docdist7 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
word_frequencies_for_file	$O(W)$
inner_product	$O(L_1)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2)$

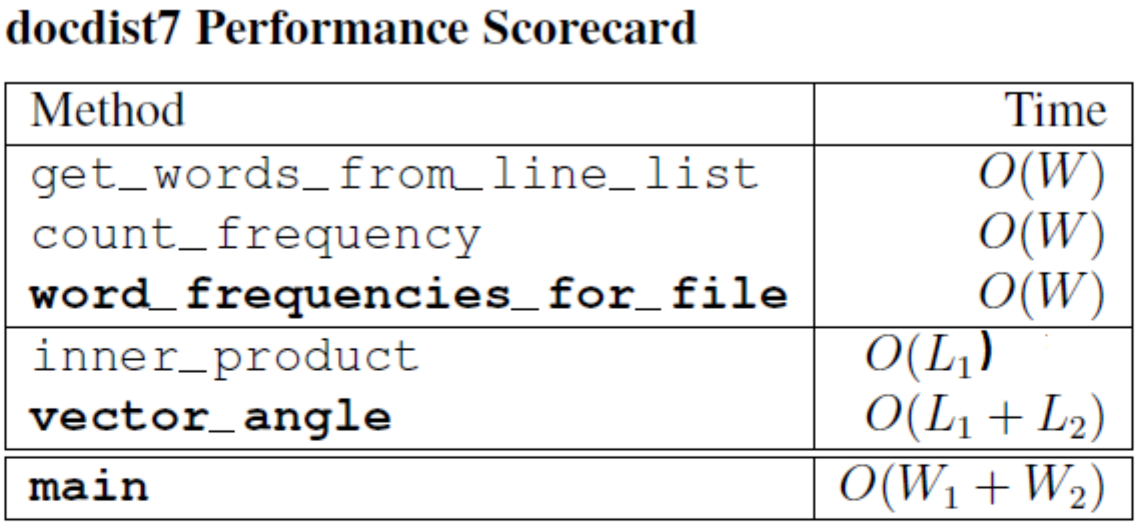
docdist8 – Simplifying the code



```
def get_words_from_string(string):
  string = string.translate(translation_table)
  word_list = string.split()
  return word_list

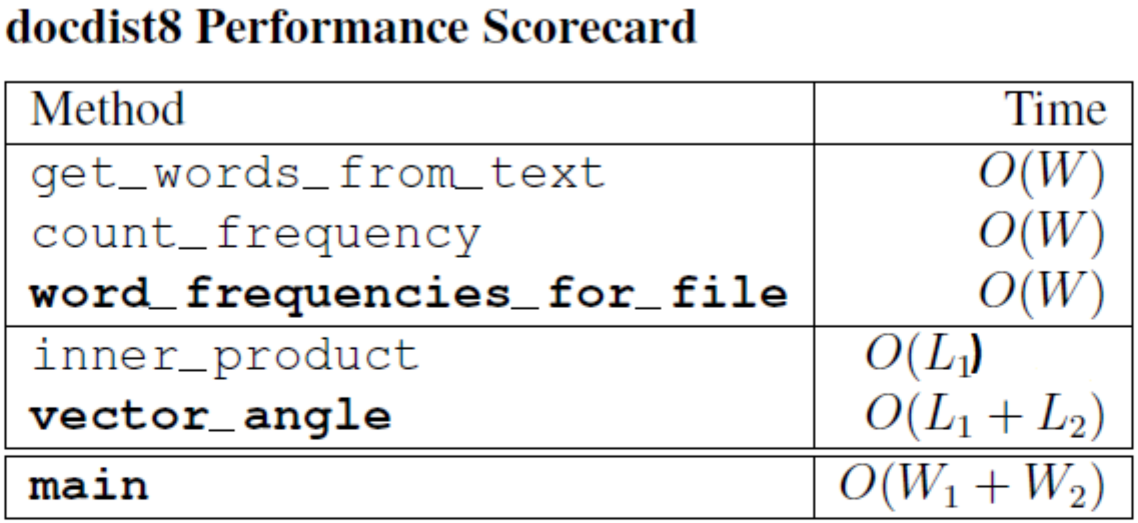
def word_frequencies_for_file(filename):
  text = read_file(filename)
  word_list = get_words_from_string(text)
  freq_mapping = count_frequency(word_list)
  return freq_mapping
```

docdist7 vs. docdist8



docdist7 Performance Scorecard

Method	Time
get_words_from_line_list	$O(W)$
count_frequency	$O(W)$
word_frequencies_for_file	$O(W)$
inner_product	$O(L_1)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2)$



docdist8 Performance Scorecard

Method	Time
get_words_from_text	$O(W)$
count_frequency	$O(W)$
word_frequencies_for_file	$O(W)$
inner_product	$O(L_1)$
vector_angle	$O(L_1 + L_2)$
main	$O(W_1 + W_2)$