

3.5 SYMBOL TABLES APPLICATIONS



- ▶ sets
- ▶ dictionary clients
- ▶ indexing clients
- ▶ sparse vectors

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Set API

Mathematical set. A collection of distinct keys.

```
public class SET<Key extends Comparable<Key>>
{
    SET() create an empty set
    void add(Key key) add the key to the set
    boolean contains(Key key) is the key in the set?
    void remove(Key key) remove the key from the set
    int size() return the number of keys in the set
    Iterator<Key> iterator() iterator through keys in the set
}
```

Q. How to implement?

Exception filter

- Read in a list of words from one file.
- Print out all words from standard input that are { in, not in } the list.

```
% more list.txt
was it the of

% java WhiteList list.txt < tinyTale.txt
it was the of it was the of
it was the of it was the of
it was the of it was the of
it was the of it was the of
it was the of it was the of

% java BlackList list.txt < tinyTale.txt
best times worst times
age wisdom age foolishness
epoch belief epoch incredulity
season light season darkness
spring hope winter despair
```

← list of exceptional words

Exception filter applications

- Read in a list of words from one file.
- Print out all words from standard input that are { in, not in } the list.

application	purpose	key	in list
spell checker	identify misspelled words	word	dictionary words
browser	mark visited pages	URL	visited pages
parental controls	block sites	URL	bad sites
chess	detect draw	board	positions
spam filter	eliminate spam	IP address	spam addresses
credit cards	check for stolen cards	number	stolen cards

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Exception filter: Java implementation

- Read in a list of words from one file.
- Print out all words from standard input that are { in, not in } the list.

```
public class WhiteList
{
    public static void main(String[] args)
    {
        SET<String> set = new SET<String>();
        In in = new In(args[0]);
        while (!in.isEmpty())
            set.add(in.readString());
        while (!StdIn.isEmpty())
        {
            String word = StdIn.readString();
            if (!set.contains(word))
                StdOut.println(word);
        }
    }
}
```

← create empty set of strings

← read in whitelist

← print words not in list

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Exception filter: Java implementation

- Read in a list of words from one file.
- Print out all words from standard input that are { in, not in } the list.

```
public class BlackList
{
    public static void main(String[] args)
    {
        SET<String> set = new SET<String>();
        In in = new In(args[0]);
        while (!in.isEmpty())
            set.add(in.readString());
        while (!StdIn.isEmpty())
        {
            String word = StdIn.readString();
            if (!set.contains(word))
                StdOut.println(word);
        }
    }
}
```

← create empty set of strings

← read in whitelist

← print words not in list

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Dictionary lookup

Command-line arguments.

- A comma-separated value (CSV) file.
- Key field.
- Value field.

Ex 1. DNS lookup.

```
% java LookupCSV ip.csv 0 1
adobe.com
192.150.18.60
www.princeton.edu
128.112.128.15
ebay.edu
Not found

% java LookupCSV ip.csv 1 0
128.112.128.15
www.princeton.edu
999.999.999.99
Not found
```

URL is key IP is value

IP is key URL is value

```
% more ip.csv
www.princeton.edu,128.112.128.15
www.cs.princeton.edu,128.112.136.35
www.math.princeton.edu,128.112.18.11
www.cs.harvard.edu,140.247.50.127
www.harvard.edu,128.103.60.24
www.yale.edu,130.132.51.8
www.econ.yale.edu,128.36.236.74
www.cs.yale.edu,128.36.229.30
espn.com,199.181.135.201
yahoo.com,66.94.234.13
msn.com,207.68.172.246
google.com,64.233.167.99
baidu.com,202.108.22.33
yahoo.co.jp,202.93.91.141
sina.com.cn,202.108.33.32
ebay.com,66.135.192.87
adobe.com,192.150.18.60
163.com,220.181.29.154
passport.net,65.54.179.226
tom.com,61.135.158.237
nate.com,203.226.253.11
cnn.com,64.236.16.20
daum.net,211.115.77.211
blogger.com,66.102.15.100
fastclick.com,205.180.86.4
wikipedia.org,66.230.200.100
rakuten.co.jp,202.72.51.22
...
```

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Dictionary lookup

Command-line arguments.

- A comma-separated value (CSV) file.
- Key field.
- Value field.

Ex 2. Amino acids.

```
% java LookupCSV amino.csv 0 3
ACT
Threonine
TAG
Stop
CAT
Histidine
```

codon is key name is value

```
% more amino.csv
TTT,Phe,F,Phenylalanine
TTC,Phe,F,Phenylalanine
TTA,Leu,L,Leucine
TTG,Leu,L,Leucine
TCT,Ser,S,Serine
TCC,Ser,S,Serine
TCA,Ser,S,Serine
TCG,Ser,S,Serine
TAT,Tyr,Y,Tyrosine
TAC,Tyr,Y,Tyrosine
TAA,Stop,Stop,Stop
TAG,Stop,Stop,Stop
TGT,Cys,C,Cysteine
TGC,Cys,C,Cysteine
TGA,Stop,Stop,Stop
TGG,Trp,W,Tryptophan
CTT,Leu,L,Leucine
CTC,Leu,L,Leucine
CTA,Leu,L,Leucine
CTG,Leu,L,Leucine
CCT,Pro,P,Proline
CCC,Pro,P,Proline
CCA,Pro,P,Proline
CCG,Pro,P,Proline
CAT,His,H,Histidine
CAC,His,H,Histidine
CAA,Gln,Q,Glutamine
CAG,Gln,Q,Glutamine
CGT,Arg,R,Arginine
CGC,Arg,R,Arginine
...
```

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Dictionary lookup

Command-line arguments.

- A comma-separated value (CSV) file.
- Key field.
- Value field.

Ex 3. Class list.

```
% java LookupCSV classlist.csv 4 1
eberl
Ethan
nwebb
Natalie

% java LookupCSV classlist.csv 4 3
dpan
P01
```

login is key first name is value

login is key precept is value

```
% more classlist.csv
13,Berl,Ethan Michael,P01,eberl
11,Bourque,Alexander Joseph,P01,abourque
12,Cao,Phillips Minghua,P01,pcao
11,Chehoud,Christel,P01,cchehoud
10,Douglas,Malia Morioka,P01,malia
12,Haddock,Sara Lynn,P01,shaddock
12,Hantman,Nicole Samantha,P01,nhantman
11,Hesterberg,Adam Classen,P01,ahesterb
13,Hwang,Roland Lee,P01,rhwang
13,Hyde,Gregory Thomas,P01,ghyde
13,Kim,Hyunmoon,P01,hktwo
11,Kleinfeld,Ivan Maximillian,P01,ikleinfe
12,Korac,Damjan,P01,dkorac
11,MacDonald,Graham David,P01,gmacdona
10,Michal,Brian Thomas,P01,bmichal
12,Nam,Seung Hyeon,P01,seungnam
11,Nastasescu,Maria Monica,P01,mnastase
11,Pan,Di,P01,dpan
12,Partridge,Brenton Alan,P01,bpartrid
13,Rilee,Alexander,P01,arilee
13,Roopakalu,Ajay,P01,aroopaka
11,Sheng,Ben C,P01,bsheng
12,Webb,Natalie Sue,P01,nwebb
...
```

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Dictionary lookup: Java implementation

```
public class LookupCSV
{
    public static void main(String[] args)
    {
        In in = new In(args[0]);
        int keyField = Integer.parseInt(args[1]);
        int valField = Integer.parseInt(args[2]);

        ST<String, String> st = new ST<String, String>();
        while (!in.isEmpty())
        {
            String line = in.readLine();
            String[] tokens = database[line].split(",");
            String key = tokens[keyField];
            String val = tokens[valField];
            st.put(key, val);
        }

        while (!StdIn.isEmpty())
        {
            String s = StdIn.readString();
            if (!st.contains(s)) StdOut.println("Not found");
            else
                StdOut.println(st.get(s));
        }
    }
}
```

process input file

build symbol table

process lookups with standard I/O

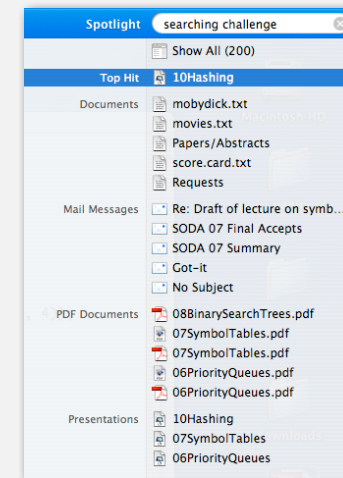
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File indexing

Goal. Index a PC (or the web).



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File indexing

Goal. Given a list of files specified as command-line arguments, create an index so that you can efficiently find all files containing a given query string.

```
% ls *.txt
aesop.txt magna.txt moby.txt
sawyer.txt tale.txt

% java FileIndex *.txt
freedom
magna.txt moby.txt tale.txt

whale
moby.txt

lamb
sawyer.txt aesop.txt
```

```
% ls *.java
BlackList.java Concordance.java
DeDup.java FileIndex.java ST.java
SET.java WhiteList.java

import
FileIndex.java SET.java ST.java

Comparator
null
```

Solution. Key = query string; value = set of files containing that string.

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File indexing

```
public class FileIndex
{
    public static void main(String[] args)
    {
        ST<String, SET<File>> st = new ST<String, SET<File>>();
        ← symbol table

        for (String filename : args) {
            ← list of file names
            File file = new File(filename);
            In in = new In(file);
            while (!(in.isEmpty()))
            {
                ← for each word in file,
                String word = in.readString();
                if (!st.contains(word))
                    add file to
                    st.put(s, new SET<File>());
                    corresponding set
                SET<File> set = st.get(key);
                set.add(file);
            }
        }

        while (!StdIn.isEmpty())
        {
            ← process queries
            String query = StdIn.readString();
            StdOut.println(st.get(query));
        }
    }
}
```

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Matrix-vector multiplication (standard implementation)

$$\begin{matrix}
 & a[][] & x[] & b[] \\
 \begin{bmatrix} 0 & .90 & 0 & 0 & 0 \\ 0 & 0 & .36 & .36 & .18 \\ 0 & 0 & 0 & .90 & 0 \\ .90 & 0 & 0 & 0 & 0 \\ .47 & 0 & .47 & 0 & 0 \end{bmatrix} & \begin{bmatrix} .05 \\ .04 \\ .36 \\ .37 \\ .19 \end{bmatrix} & = & \begin{bmatrix} .036 \\ .297 \\ .333 \\ .045 \\ .1927 \end{bmatrix}
 \end{matrix}$$

```

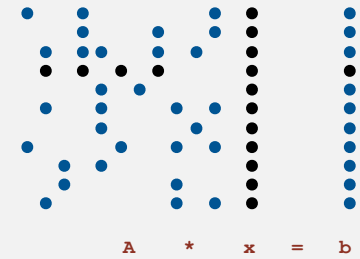
...
double[][] a = new double[N][N];
double[] x = new double[N];
double[] b = new double[N];
...
// initialize a[][] and x[]
...
for (int i = 0; i < N; i++)
{
    sum = 0.0;
    for (int j = 0; j < N; j++)
        sum += a[i][j]*x[j];
    b[i] = sum;
}
    
```

nested loops (N² running time)

Sparse matrix-vector multiplication

Problem. Sparse matrix-vector multiplication.

Assumptions. Matrix dimension is 10,000; average nonzeros per row ~ 10.



Vector representations

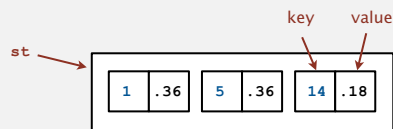
1D array (standard) representation.

- Constant time access to elements.
- Space proportional to N.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	.36	0	0	0	.36	0	0	0	0	0	0	0	0	.18	0	0	0	0	0

Symbol table representation.

- Key = index, value = entry.
- Efficient iterator.
- Space proportional to number of nonzeros.



Sparse vector data type

```

public class SparseVector
{
    private HashST<Integer, Double> v;
    public SparseVector()
    { v = new HashST<Integer, Double>(); }
    public void put(int i, double x)
    { v.put(i, x); }
    public double get(int i)
    {
        if (!v.contains(i)) return 0.0;
        else return v.get(i);
    }
    public Iterable<Integer> indices()
    { return v.keys(); }
    public double dot(double[] that)
    {
        double sum = 0.0;
        for (int i : indices())
            sum += that[i]*this.get(i);
        return sum;
    }
}
    
```

HashST because order not important

empty ST represents all 0s vector

a[i] = value

return a[i]

dot product is constant time for sparse vectors

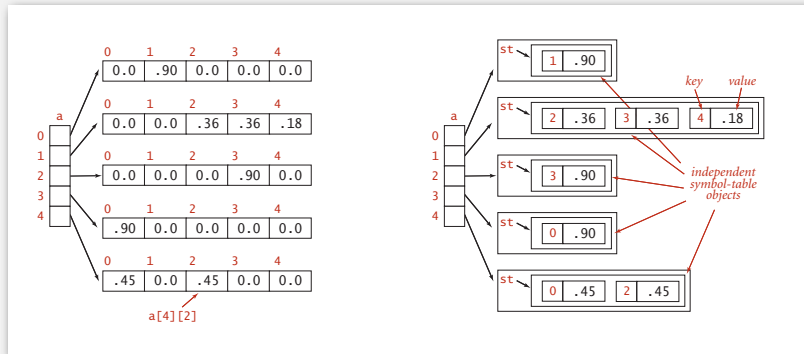
Matrix representations

2D array (standard) matrix representation: Each row of matrix is an **array**.

- Constant time access to elements.
- Space proportional to N^2 .

Sparse matrix representation: Each row of matrix is a **sparse vector**.

- Efficient access to elements.
- Space proportional to number of nonzeros (plus N).



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Sparse matrix-vector multiplication

$$\begin{array}{c}
 \mathbf{a}[][] \\
 \begin{bmatrix} 0 & .90 & 0 & 0 & 0 \\ 0 & 0 & .36 & .36 & .18 \\ 0 & 0 & 0 & .90 & 0 \\ .90 & 0 & 0 & 0 & 0 \\ .47 & 0 & .47 & 0 & 0 \end{bmatrix}
 \end{array}
 \begin{array}{c}
 \mathbf{x}[] \\
 \begin{bmatrix} .05 \\ .04 \\ .36 \\ .37 \\ .19 \end{bmatrix}
 \end{array}
 =
 \begin{array}{c}
 \mathbf{b}[] \\
 \begin{bmatrix} .036 \\ .297 \\ .333 \\ .045 \\ .1927 \end{bmatrix}
 \end{array}$$

```

..
SparseVector[] a = new SparseVector[N];
double[] x = new double[N];
double[] b = new double[N];
...
// Initialize a[] and x[]
...
for (int i = 0; i < N; i++)
    b[i] = a[i].dot(x);
    
```

← linear running time
for sparse matrix

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