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3.5 SYMBOL TABLE APPLICATIONS

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



Algorithms

ROBERT SEDGEWICK | KEVIN WAYNE

<http://algs4.cs.princeton.edu>

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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
```

← list of exceptional words

```
% 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
```

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

Exception filter: Java implementation

- Read in a list of words from one file.
- Print out all words from standard input that are 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 in list

Exception filter: Java implementation

- Read in a list of words from one file.
- Print out all words from standard input that are **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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- ▶ *sets*
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- ▶ *sparse vectors*

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
```

domain name is key IP is value

domain name 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
...
```

Dictionary lookup

Command-line arguments.

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

Ex 2. Amino acids.

codon is key name is value

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

```
% 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
...
```

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 section
 is value

```
% more classlist.csv
13,Berl,Ethan Michael,P01,eberl
12,Cao,Phillips Minghua,P01,pcao
11,Cehoud,Christel,P01,ccehoud
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
12,Korac,Damjan,P01,dkorac
11,MacDonald,Graham David,P01,gmacdona
10,Michael,Brian Thomas,P01,bmichael
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
:
```

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]);
```

← process input file

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

← build symbol table

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

← process lookups
with standard I/O

```
    }  
}
```



Algorithms

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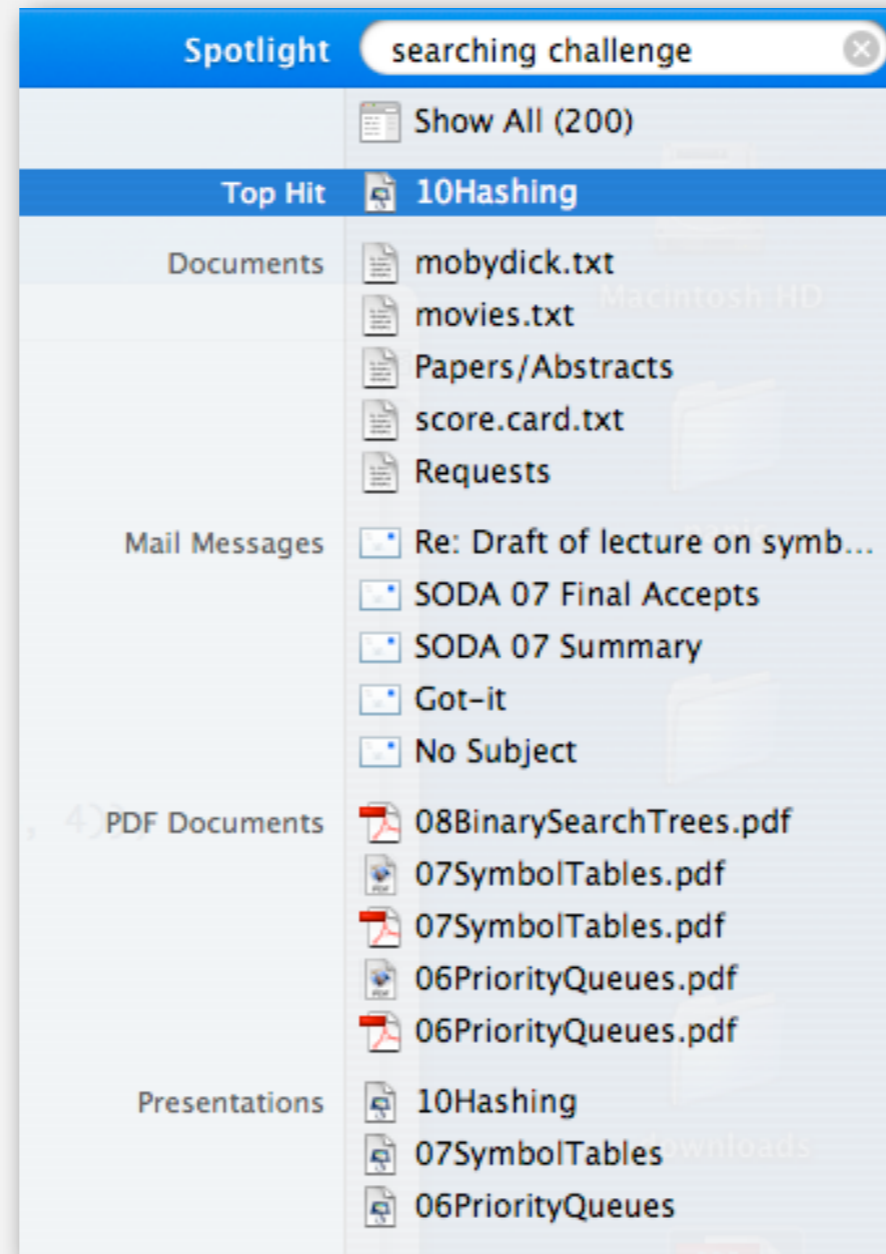
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- ▶ *indexing clients*
- ▶ *sparse vectors*

File indexing

Goal. Index a PC (or the web).



File indexing

Goal. Given a list of files, 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

% java FileIndex *.java

import
FileIndex.java SET.java ST.java

Comparator
null
```

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

File indexing

```
import java.io.File;
public class FileIndex
{
    public static void main(String[] args)
    {
        ST<String, SET<File>> st = new ST<String, SET<File>>();

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

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

ST<String, SET<File>> st = new ST<String, SET<File>>();

← symbol table

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

← list of file names
from command line

← for each word in file,
add file to
corresponding set

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

← process queries

Book index

Goal. Index for an e-book.

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Concordance

Goal. Preprocess a text corpus to support concordance queries: given a word, find all occurrences with their immediate contexts.

```
% java Concordance tale.txt
cities
tongues of the two *cities* that were blended in

majesty
their turnkeys and the *majesty* of the law fired
me treason against the *majesty* of the people in
  of his most gracious *majesty* king george the third

princeton
no matches
```

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

Concordance

```
public class Concordance
{
    public static void main(String[] args)
    {
        In in = new In(args[0]);
        String[] words = in.readAllStrings();
        ST<String, SET<Integer>> st = new ST<String, SET<Integer>>();
        for (int i = 0; i < words.length; i++)
        {
            String s = words[i];
            if (!st.contains(s))
                st.put(s, new SET<Integer>());
            SET<Integer> set = st.get(s);
            set.add(i);
        }

        while (!StdIn.isEmpty())
        {
            String query = StdIn.readString();
            SET<Integer> set = st.get(query);
            for (int k : set)
                // print words[k-4] to words[k+4]
        }
    }
}
```

← read text and
build index

← process queries
and print
concordances



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- ▶ *sparse vectors*

Matrix-vector multiplication (standard implementation)

$$\begin{matrix} & \mathbf{a}[\][\] & \mathbf{x}[\] & = & \mathbf{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}$$

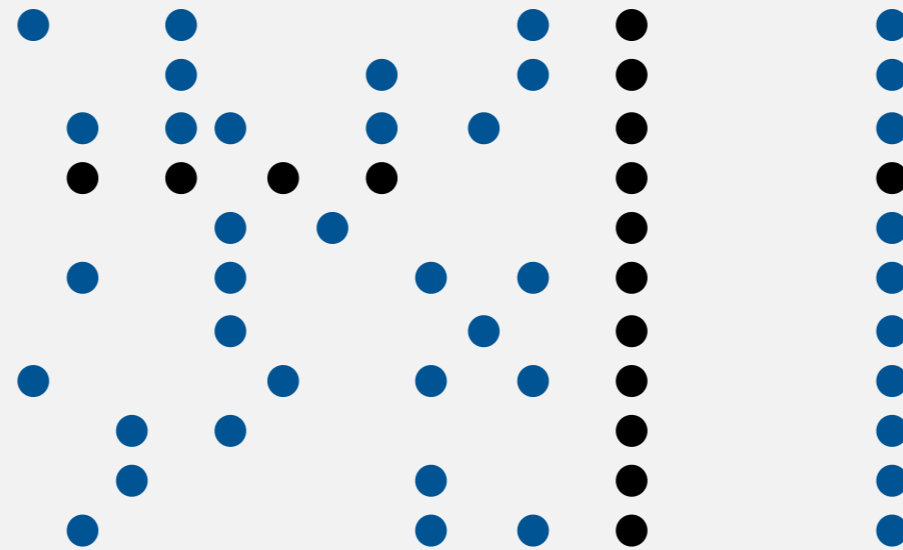
```
...
double[][] a = new double[N][N];
double[] x = new double[N];
double[] b = new double[N];
...
// initialize a[][] and x[]
...
for (int i = 0; i < N; i++)
{
    sum = 0.0;
    for (int j = 0; j < N; j++)
        sum += a[i][j]*x[j];
    b[i] = sum;
}
```

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 .



$$A * x = b$$

Vector representations

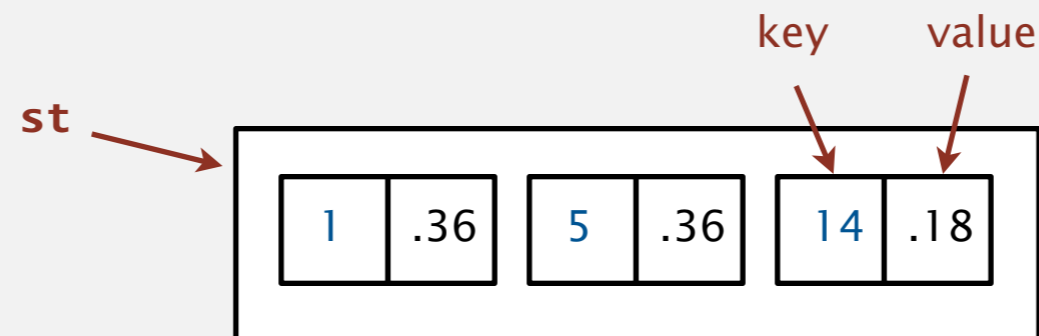
1d array (standard) representation.

- 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;
```

← HashST because order not important

```
    public SparseVector()  
    {
```

```
        v = new HashST<Integer, Double>();  
    }
```

← empty ST represents all 0s vector

```
    public void put(int i, double x)  
    {
```

```
        v.put(i, x);  
    }
```

← $a[i] = \text{value}$

```
    public double get(int i)  
    {
```

```
        if (!v.contains(i)) return 0.0;  
        else return v.get(i);  
    }
```

← return $a[i]$

```
    public Iterable<Integer> indices()  
    {
```

```
        return v.keys();  
    }
```

← iterate through indices of
nonzero entries

```
    public double dot(double[] that)  
    {
```

```
        double sum = 0.0;  
        for (int i : indices())  
            sum += that[i]*this.get(i);  
        return sum;  
    }
```

← dot product is constant
time for sparse vectors

```
}
```

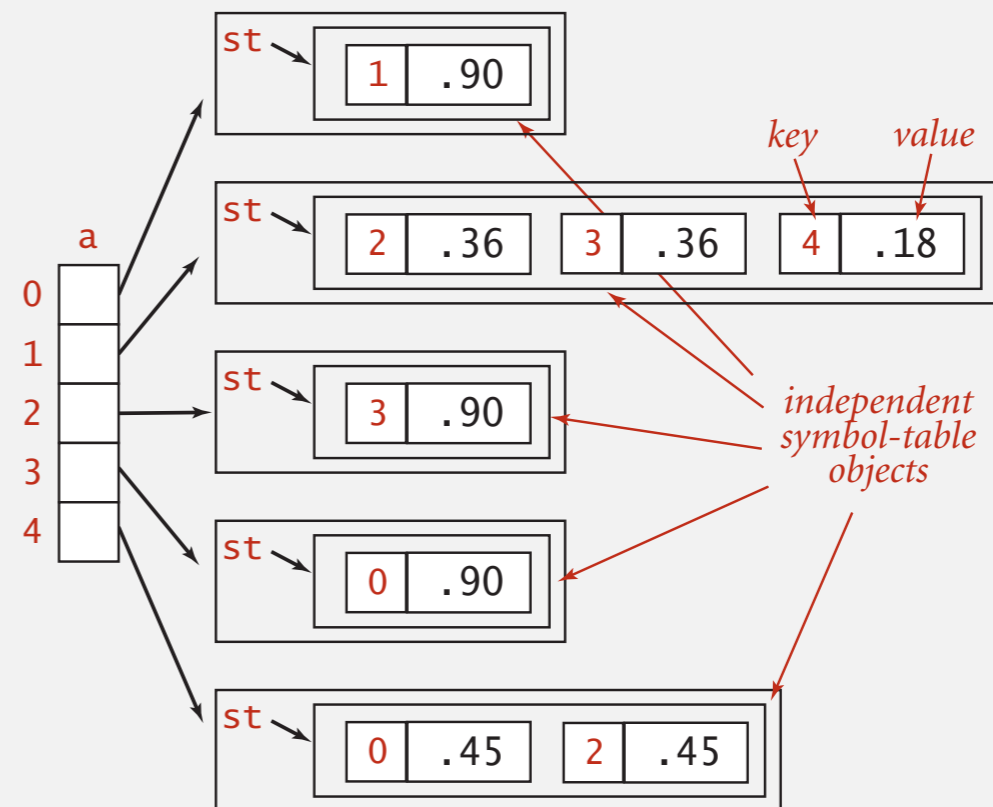
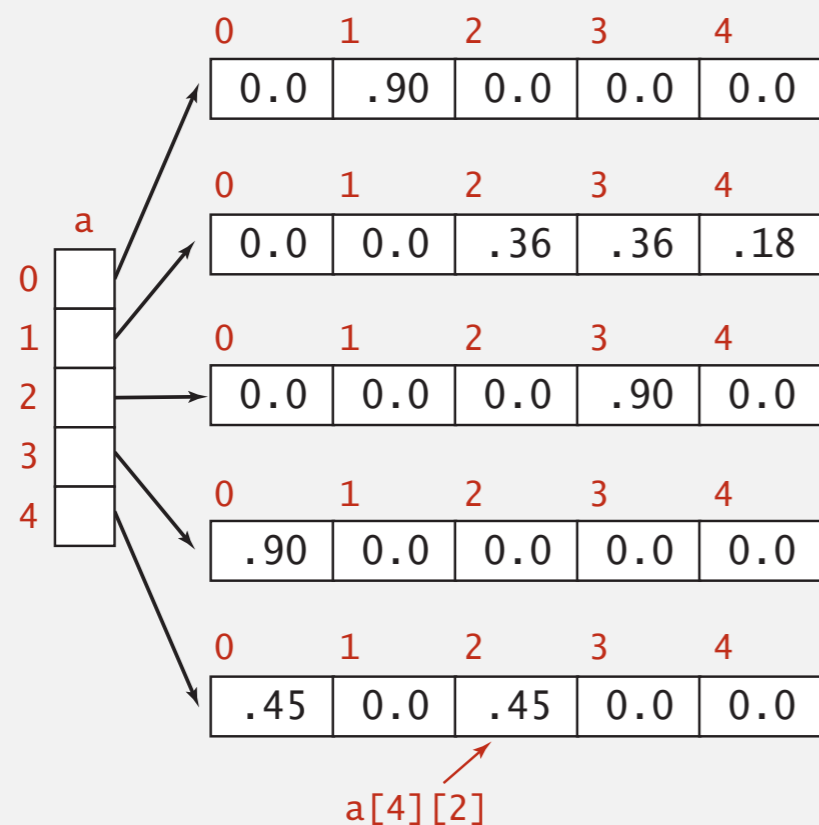

Matrix representations

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).



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