# 4.5 Symbol Table Applications



## Set ADT

Set ADT: unordered collection of distinct keys.

- Insert a key.
- Check if set contains a given key.
- Delete a key.

SET interface.

- `add(key)` insert the key
- `contains(key)` is given key present?
- `remove(key)` remove the key
- `iterator()` return iterator over all keys

Q. How to implement?

Java library: `java.util.HashSet`.



## Set Client: Remove Duplicates

Remove duplicates. [e.g., from commercial mailing list]

- Read in a key.
- If key is not in set, insert and print it out.

```
public class DeDup {
   public static void main(String[] args) {
      SET<String> set = new SET<String>();
      while (!StdIn.isEmpty()) {
         String key = StdIn.readString();
         if (!set.contains(key)) {
            set.add(key);
            System.out.println(key);
         }
      }
   }
}
```



## More Set Applications

| Application | Purpose | Key |
|---|---|---|
| Spell checker | Identify misspelled words | Word |
| Browser | Highlight previously visited pages | URL |
| Chess | Detect repetition draw | Board position |
| Spam blacklist | Prevent spam | IP addresses of spammers |

# Inverted Index

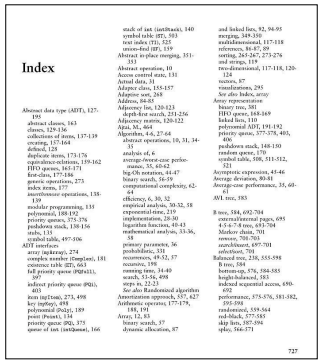
Robert Sedgewick and Kevin Wayne •  • http://www.Princeton.EDU/~cos226



Inverted index. Given a list of documents, preprocess so that you can quickly find all documents containing a given query.

Ex 1. Book index.
Ex 2. Web search engine index.

Key. Query word.
Value. Set of documents.


Index



## Inverted Index Implementation

```
public class InvertedIndex {
   public static void main(String[] args) {
      ST<String, SET<String>> st;
      st = new ST<String, SET<String>>();
                                          use SET to avoid duplicates
      // create inverted index
      for (String filename : args) {
         In in = new In(filename);
         while (!in.isEmpty()) {
            String word = in.readString();
            if (!st.contains(word))
               st.put(word, new SET<String>());
            SET<String> set = st.get(word);
            set.add(filename);
         }
      }
```



## Inverted Index Implementation (cont)

```
      // read queries from standard input
      In stdin = new In();
      while (!stdin.isEmpty()) {
         String query = in.readString();
         if (!st.contains(query))
            System.out.println("NOT FOUND");
         else {
            SET<String> set = st.get(query);
            for (String filename : set)
               System.out.print(filename + " ");
         }
         System.out.println();
      }
   }
}
```

## Inverted Index

Extensions.

- Ignore stopwords: `the`, `on`, `of`, etc.
- Multi-word queries:
  - set intersection (AND)
  - set union (OR).
- Record position and number of occurrences of word in document.



# Sparse Vectors and Matrices



## Vectors and Matrices

Vector. Ordered sequence of N real numbers.
Matrix. N-by-N table of real numbers.

$$a = [\ 0 \quad 3 \quad 15\ ], \quad b = [-1 \quad 2 \quad 2\ ]$$
$$a + b = [-1 \quad 5 \quad 17\ ]$$
$$a \circ b = (0 \cdot -1) + (3 \cdot 2) + (15 \cdot 2) = 36$$

$$A = \begin{bmatrix} 0 & 1 & 1 \\ 2 & 4 & -2 \\ 0 & 3 & 15 \end{bmatrix}, \quad B = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{bmatrix}, \quad A + B = \begin{bmatrix} 1 & 1 & 1 \\ 2 & 6 & -2 \\ 0 & 3 & 18 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 1 & 1 \\ 2 & 4 & -2 \\ 0 & 3 & 15 \end{bmatrix} \times \begin{bmatrix} -1 \\ 2 \\ 2 \end{bmatrix} = \begin{bmatrix} 4 \\ 2 \\ 36 \end{bmatrix}$$



## Sparsity

Def. An N-by-N matrix is sparse if it has O(N) nonzeros entries.

Empirical fact. Large matrices that arise in practice are usually sparse.

Matrix representations.

- 2D array: space proportional to $N^2$.
- Goal: space proportional to number of nonzeros, without sacrificing fast access to individual elements.

Ex. Google performs matrix-vector product with N = 4 billion!

## Sparse Vector Implementation

```
public class SparseVector {
   private final int N;
   private ST<Integer, Double> st = new ST<Integer, Double>();

   public SparseVector(int N) { this.N = N; }

   public void put(int i, double value) {
      if (value == 0.0) st.remove(i);
      else              st.put(i, value);
   }

   public double get(int i) {
      if (st.contains(i)) return st.get(i);
      else                return 0.0;
   }
```

a[i] = value

a[i]



## Sparse Vector Implementation (cont)

```
// return a · b
public double dot(SparseVector b) {
   SparseVector a = this;
   double sum = 0.0;
   for (int i : a.st)
      if (b.st.contains(i)) sum += a.get(i) * b.get(i);
   return sum;
}
```

```
// return c = a + b
public SparseVector plus(SparseVector b) {
   SparseVector a = this;
   SparseVector c = new SparseVector(N);
   for (int i : a.st) c.put(i, a.get(i));
   for (int i : b.st) c.put(i, b.get(i) + c.get(i));
   return c;
}
```



## Sparse Matrix Implementation

```
public class SparseMatrix {
   private final int N;
   private SparseVector[] rows;

   public SparseMatrix(int N) {
      this.N  = N;
      rows = new SparseVector[N];
      for (int i = 0; i < N; i++)
         rows[i] = new SparseVector(N);
   }

   public void put(int i, int j, double value) {
      rows[i].put(j, value);
   }

   public double get(int i, int j) {
      return rows[i].get(j);
   }
```

N-by-N matrix of all zeros

A[i][j] = value

A[i][j]



## Sparse Matrix Implementation (cont)

```
// return b = A*x
public SparseVector times(SparseVector x) {
   SparseMatrix A = this;
   SparseVector b = new SparseVector(N);
   for (int i = 0; i < N; i++)
      b.put(i, rows[i].dot(x));
   return b;
}
```

```
// return C = A + B
public SparseMatrix plus(SparseMatrix B) {
   SparseMatrix A = this;
   SparseMatrix C = new SparseMatrix(N);
   for (int i = 0; i < N; i++)
      C.rows[i] = A.rows[i].plus(B.rows[i]);
   return C;
}
```

# A Plan for Spam





Bayesian spam filter.

- Filter based on analysis of previous messages.
- User trains the filter by classifying messages as spam or ham.
- Parse messages into tokens (alphanumeric, dashes, ', $)

Build data structures.

- Hash table A of tokens and frequencies for spam.
- Hash table B of tokens and frequencies for ham.
- Hash table C of tokens with probability p that they appear in spam.

```
double h = 2.0 * ham.freq(word);
double s = 1.0 * spam.freq(word);
double p = (s/spams) / (h/hams + s/spams);
```

bias probabilities to avoid false positives

Reference: http://www.paulgraham.com/spam.html





Identify incoming email as spam or ham.

- Find 15 most interesting tokens (difference from 0.5).
- Combine probabilities using Bayes law.

which data structure?

$$\frac{p_1 \times p_2 \times \cdots \times p_{15}}{(p_1 \times p_2 \times \cdots \times p_{15}) \; + \; ((1-p_1)\times(1-p_2)\times\cdots\times(1-p_{15}))}$$

- Declare as spam if threshold > 0.9.

Details.

- Words you've never seen.
- Words that appear in ham corpus but not spam corpus, vice versa.
- Words that appear less than 5 times in spam and ham corpuses.
- Update data structures.