Elementary Symbol Tables

Reference: Chapter 12, Algorithms in Java, 3rd Edition, Robert Sedgewick.

Symbol Table

Symbol table: key-value pair abstraction.

- Insert a value with specified key.
- Given a key, search for the corresponding value.

DNS lookup.

- Insert URL with specified IP address.
- Given URL, find corresponding IP address.

URL	IP address
www.cs.princeton.edu	128.112.136.11
www.princeton.edu	128.112.128.15
www.yale.edu	130.132.143.21
www.harvard.edu	128.103.060.55
www.simpsons.com	209.052.165.60

key value

Symbol Table Applications

Application	Purpose	Key	Value
Phone book	Look up phone number	Name	Phone number
Bank	Process transaction	Account number	Transaction details
File share	Find song to download	Name of song	Computer ID
File system	Find file on disk	Filename	Location on disk
Dictionary	Look up word	Word	Definition
Web search	Find relevant documents	Keyword	List of documents
Book index	Find relevant pages	Keyword	List of pages
Web cache	Download	Filename	File contents
Genomics	Find markers	DNA string	Known positions
DNS	Find IP address given URL	URL	IP address
Reverse DNS	Find URL given IP address	IP address	URL
Compiler	Find properties of variable	Variable name	Value and type
Routing table	Route Internet packets	Destination	Best route

Symbol Table Client: DNS Lookup

DNS lookup client program.

- `st.put(key, val)` inserts a key-value pair into symbol table.
- `st.get(key)` searches for the given key and returns the value.

```
public static void main(String[] args) {
   ST<String, String> st = new ST<String, String>();

   st.put("www.cs.princeton.edu",  "128.112.136.11");
   st.put("www.princeton.edu",     "128.112.128.15");
   st.put("www.yale.edu",          "130.132.143.21");
   st.put("www.simpsons.com",      "209.052.165.60");
          ↖ st["www.simpsons.com"] = "209.052.165.60"

   System.out.println(st.get("www.cs.princeton.edu"));
   System.out.println(st.get("www.harvardsucks.com"));
   System.out.println(st.get("www.simpsons.com"));
}                        ↖
                      st["www.simpsons.com"]
```

```
128.112.136.11
null
209.052.165.60
```

Symbol Table Client: Frequency Counter

Frequency counter. [e.g., web traffic analysis]

- Read in a key.
- If key is in symbol table, increment counter by one;
  If key is not in symbol table, insert it with count = 1.

```
public static void main(String[] args) {
   ST<String, Integer> st = new ST<String, Integer>();

   while (!StdIn.isEmpty()) {
      String key = StdIn.readString();
      if (st.contains(key)) st.put(key, st.get(key) + 1);
      else                  st.put(key, 1);
   }                                         calculate frequencies

   for (String s : st)                   print results
      System.out.println(st.get(s) + " " + s);
}
```

Symbol Table API

Associative array abstraction. Unique value associated with each key.

Symbol table API.

`put(key, val)`	insert the key-value pair
`get(key)`	return value associated with given key
`remove(key)`	remove the key
`contains(key)`	is given key present?
`iterator()`	return iterator over all keys

Our conventions.

- Values are not `null`.
- Method `get()` return `null` if key not present.
- Method `put()` overwrites old value with new value.

Keys and Values

Key type.

- Some implementations assumes keys are a generic `Comparable` type, and use the `compareTo()` method.
- Other implementations assume keys are any generic type, and use the `equals()` and `hashCode()` methods.

Value type. Any generic type.

Best practices. Use immutable types for symbol table keys.

- Immutable in Java: `String`, `Integer`, `BigInteger`.
- Mutable in Java: `Date`, `GregorianCalendar`, `StringBuilder`.

Sorted Array Implementation

Symbol Table: Sorted Array Implementation

Maintain array of keys and values.

- Store in sorted order by key.
- `keys[i]` = i^{th} largest key.
- `vals[i]` = value associated with i^{th} largest key.

```
public class SortedST<Key extends Comparable, Val> {
implements Iterable<Key>
   private int N;
   private Key[] keys;
   private Val[] vals;
```

4	6	14	20	26	32	47	55	56	58	82	▨	▨	▨

Symbol Table Search: Sorted Array Implementation

Binary search.

- Examine the middle key.
- If it matches, return the value.
- Otherwise, search either the left or right half.

```
public Val get(Key key) {
   int l = 0;
   int r = N-1;
   while (l <= r) {
      int m = l + (r - l) / 2;
      if (  eq(key, keys[m])) return vals[m];
      if (less(key, keys[m])) r = m - 1;
      else                    l = m + 1;
   }
   return null;
}
```

Symbol Table Insert: Sorted Array Implementation

Insert.

- Need to maintain entries in ascending order.
- Find insertion point and move larger keys to the right.

4	6	14	20	26	32	47	55	56	58	82	▨	▨	key = value = int
4	6	14	20	26	28	32	47	55	56	58	82	▨	Insert 28

Performance Cost Summary

	Worst Case		Average Case	
Implementation	Search	Insert	Search	Insert
Sorted array	log N	N	log N	N/2

Sorted array. Fast search, slow insert.

Equals

Equivalence relation. For any references `x`, `y` and `z`:

- Reflexive: `x.equals(x)` is `true`.
- Symmetric: `x.equals(y)` iff `y.equals(x)`.
- Transitive: If `x.equals(y)` and `y.equals(z)`, then `x.equals(z)`.
- Non-null: `x.equals(null)` is `false`.
- Consistency: Multiple calls to `x.equals(y)` return same value.

Default implementation. `(x == y)`

Customized implementations. `String, URL, Integer.`

User-defined implementations. Some care needed.

Implementing Equals: US Phone Numbers

Phone numbers. (609) 867-5309.

helps enforce immutability

```
public final class WrongPhoneNumber {
   private final int area;    // 609
   private final int exch;    // 867
   private final int ext;     // 5309

   public WrongPhoneNumber(int area, int exch, int ext) {
      this.area = area;
      this.exch = exch;
      this.ext  = ext;
   }

   public boolean equals(WrongPhoneNumber b) {
      WrongPhoneNumber a = this;
      return (a.ext == b.ext) && (a.exch == b.exch)
                              && (a.area == b.area);
   }
}
```

broken implementation of equals
(won't get called by java.util.HashMap)

Implementing Equals: US Phone Numbers

Phone numbers. (609) 867-5309.

```
public final class PhoneNumber {
   private final int area, exch, ext;

   public PhoneNumber(int area, int exch, int ext) {
      this.area = area;
      this.exch = exch;
      this.ext  = ext;
   }

   public boolean equals(Object y) {
      if (y == this) return true;
      if (y == null) return false;
      if (y.getClass() != this.getClass()) return false;
      PhoneNumber a = this;
      PhoneNumber b = (PhoneNumber) y;
      return (a.area == b.area) && (a.exch == b.exch)
                                && (a.ext == b.ext);
   }
}
```

must be `Object`, not `PhoneNumber`

can't throw an exception

Best Practices

Comparable. If class implements `Comparable` interface, make `equals()` consistent with `compareTo()`.

Hashcode. If class overrides `equals()`, also override `hashCode()`.

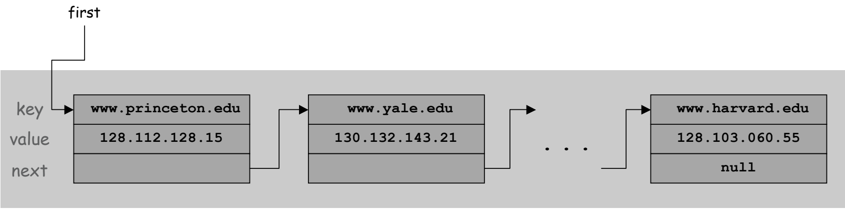
stay tuned

Linked List Implementation

Symbol Table: Linked List Implementation

Maintain a linked list of key-value pairs.

- Insert new key-value pair at beginning of list.
- Use exhaustive search to find a given key.



Symbol Table: Linked List Implementation

```
public class ListST<Key, Val> implements Iterable<Key> {
   private Node first;

   private class Node {
      Key  key;
      Val  val;
      Node next;
      Node(Key key, Val val, Node next)  {
         this.key  = key;
         this.val  = val;
         this.next = next;
      }
   }

   public Iterator<Key> iterator()  {
      return new ListIterator();
   }
```

similar to Sequence iterator

Symbol Table: Linked List Implementation (cont)

```
   public Val get(Key key)  {
      for (Node x = first; x != null; x = x.next)
         if (key.equals(x.key))
            return x.val;
      return null;
   }

   public void put(Key key, Val val)  {
      for (Node x = first; x != null; x = x.next)  {
         if (key.equals(x.key))  {
            x.val = val;
            return;
         }
      }
      first = new Node(key, val, first);
   }
}
```

if key is already present, replace value

Performance Cost Summary

	Worst Case		Average Case	
Implementation	Search	Insert	Search	Insert
Sorted array	log N	N	log N	N / 2
Unsorted list	N	N	N / 2	N

Sorted array. Fast search, slow insert.
Linked list. Slow insert, slow search.

Q. Can we achieve O(log N) for all ops?