

# ECE 2400 Computer Systems Programming

## Spring 2026

### Topic 15: Tables

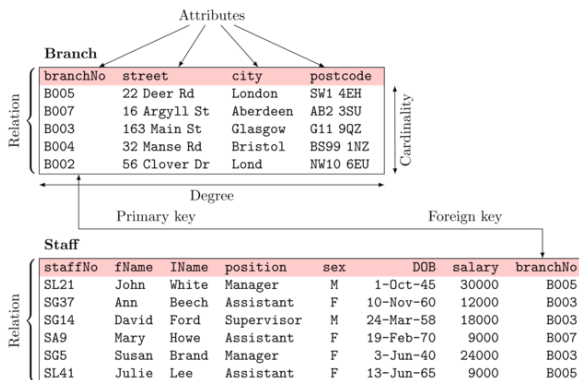
School of Electrical and Computer Engineering  
Cornell University

revision: 2026-04-22-12-02

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# 1. Table Basics

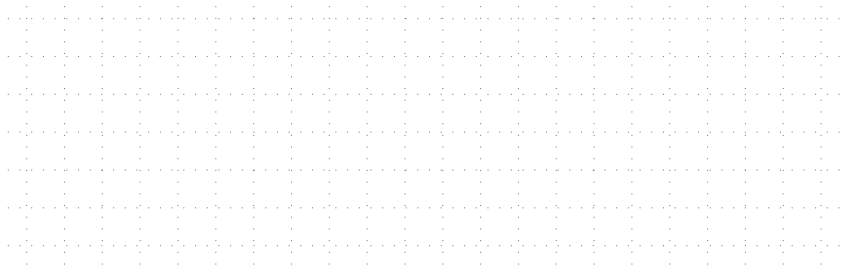
## Common use case: Relational Databases



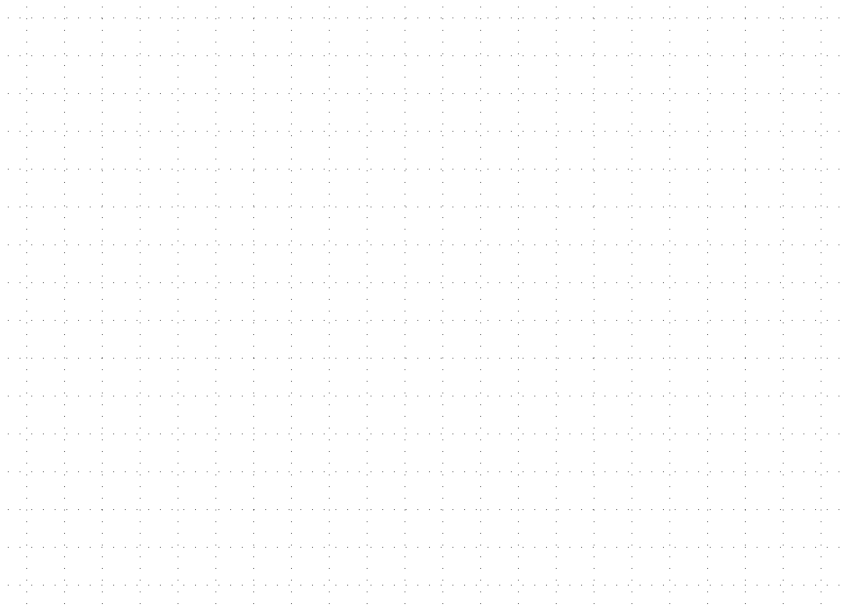
Tables can be ADTs with operations insert row|column, modify cell, sort rows|columns, etc. However, in this class, we use **tables as efficient implementations of other ADTs:**

ADT	Implementation					
	List	Vector	Binary Search Tree	Binary Heap Tree	Lookup Table	Hash Table
Stack	★	★				
Queue	★	★				
Priority Queue	✓	✓		★		
Set	✓	✓	★		★	★
Map	✓	✓	★		★	★

## 2. Table Concepts



## 3. Table Storage



## 4. Lookup Tables

- Recall that sets provide `add` and `contains` member functions
- Recall that maps provide `add` and `lookup` member functions
- Consider implementing a set/map with a list, vector, or tree

<b>Time Complexity</b>	<code>add</code> ( <i>no duplicates: must do contains first!</i> )	<code>contains</code> / <code>lookup</code>
list		
vector (sorted)		
binary search tree		
lookup table		

- A **lookup table** is a table where the value is *directly* used to index into the table
- Focus on object-oriented array-based lookup tables for storing positive ints or Strings to implement sets
  - Could apply same approach to implementing a map
  - Could use object-oriented programming and dynamic polymorphism
  - Could use generic programming and static polymorphism
  - Later: use concurrent programming to analyze table in parallel

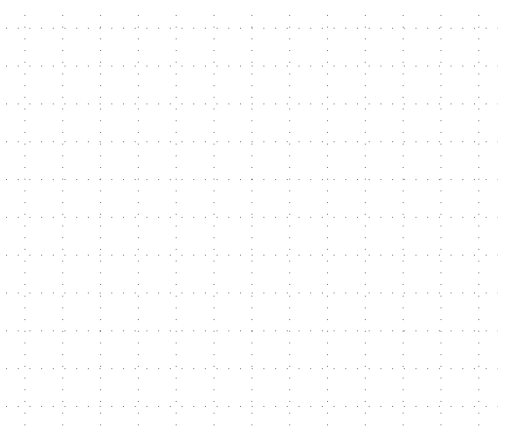
## 4. Lookup Tables

---

```
1 class LookupTableInt
2 {
3     public:
4         LookupTableInt();
5
6         void add( int v );
7         bool contains( int v );
8
9     private:
10        bool m_tbl[8];
11 };
12
13 LookupTableInt::
14     LookupTableInt()
15 {
16     for (int i=0; i<8; i++)
17         m_tbl[i] = false;
18 }
19 void LookupTableInt::add( int v ) {
20
21     bool LookupTableInt::
22         contains( int v ) {
```

Draw the table resulting  
from this code sequence:

```
1 LookupTableInt tbl;
2 tbl.add(3);
3 tbl.add(2);
4 tbl.add(3);
5 tbl.add(5);
6 tbl.add(6);
```



## 4. Lookup Tables

---

```
1 class LookupTableStr                20 void LookupTableStr::add( String v ) {
2 {
3 public:
4     LookupTableStr();
5
6     void add( String v );
7     bool contains( String v );
8
9 private:
10    int idx( String v );
11    bool m_tbl[5];
12 };
13
14 LookupTableStr::
15     LookupTableStr()
16 {
17     for (int i=0; i<5; i++)
18         m_tbl[i] = false;
19 }
20
21 bool LookupTableStr::
22     contains( String v ) {
23
24     int LookupTableStr::idx( String v )
25     {
26         if ( v == "apple" ) return 0;
27         else if ( v == "banana" ) return 1;
28         else if ( v == "cherry" ) return 2;
29         else if ( v == "grape" ) return 3;
30         else if ( v == "kiwi" ) return 4;
31         assert( false );
32     }
```

Draw the table resulting  
from this code sequence:

```
1 LookupTableStr tbl;
2 tbl.add("cherry");
3 tbl.add("banana");
4 tbl.add("apple");
5 tbl.add("cherry");
```

## 5. Hash Tables

- How can we maintain advantages of lookup table while mitigating the disadvantages?

<b>Time Complexity</b>	add ( <i>no duplicates: must do contains first!</i> )	contains / lookup
list		
vector (sorted)		
binary search tree		
lookup table		
hash table		

- A **hash table** is a table where the value is used as input to a *hash function* which returns a positive integer which is then used to index into the table (with a mod (%) operation)
- Focus on object-oriented array-based hash table storing ints to implement a set
  - Could apply same approach to implementing a map
  - Could use object-oriented programming and dynamic polymorphism
  - Could use generic programming and static polymorphism
  - Later: use concurrent programming to analyze table in parallel

## Good Hash Functions

- What makes a hash function a “good” hash function?
- Property 1: We want a *valid* hash function
  - Returns the same value on subsequent calls to the same item
  - For any equivalent objects  $a == b$ , their hashes are also equal
- Property 2: We want a hash function that provides *uniformity*
  - Maps the expected inputs as evenly as possible over the output range
  - Specifically, the hash result should not be a value (e.g., 100) more often
- Property 3: We want a hash function with  $O(1)$  time complexity

## Example Hash Functions

```
1  int hash( int v ) {
2      return (v < 0) ? -v : v;
3  }
4
5  int hash( String v ) {
6      int h = 0;
7      for ( int i = 0; i < v.size(); i++ )
8          h = h + (int) v[i];
9      return h;
10 }
11
12 int hash( float v ) {
13     return (int) ((v < 0) ? -v : v); // truncate to integer
14 }
15
16 int hash( const Vector<int>& v ) {
17     int sum = 0;
18     for ( int e : v )
19         sum += e;
20     return (sum < 0) ? -sum : sum;
21 }
```

```
1 class HashTableInt
2 {
3     public:
4         HashTableInt();
5
6         void add( int v );
7         bool contains( int v );
8
9     private:
10        int hash( int v );
11        int idx( int v );
12        bool m_tbl[4];
13 };
14
15 HashTableInt::
16     HashTableInt()
17 {
18     for ( int i=0; i<4; i++ )
19         m_tbl[i] = false;
20 }
21 void HashTableInt::add( int v ) {
22
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28
29 }
22 bool HashTableInt::contains( int v ) {
23
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27
28
29 }
23 int HashTableInt::hash( int v ) {
24     return (v < 0) ? -v : v;
25 }
26
27 int HashTableInt::idx( int v ) {
28     return hash(v) % 4;
29 }
```

Draw the table resulting from this code sequence:

```
1 HashTableInt tbl;
2 tbl.add(3);
3 tbl.add(2);
4 tbl.add(3);
5 tbl.add(5);
6 tbl.add(6);
7 tbl.add(1);
```



- Two common approaches for handling collisions
  - Separate chaining (usually with linked lists)
  - Open addressing (usually with linear probing) → **zyBooks**

```
1 class HashTableInt
2 {
3     public:
4         HashTableInt();
5
6         void add( int v );
7         bool contains( int v );
8
9     private:
10        int hash( int v );
11        int idx( int v );
12        List<int> m_tbl[4];
13 };
14
15 HashTableInt::
16     HashTableInt()
17 {
18     for ( int i=0; i<4; i++ )
19         m_tbl[i] = List<int>();
20 }
21 void HashTableInt::add( int v ) {
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```

Draw the table resulting from this code sequence:

```
1 HashTableInt tbl;
2 tbl.add(3);
3 tbl.add(2);
4 tbl.add(3);
5 tbl.add(5);
6 tbl.add(6);
7 tbl.add(1);
```

What is the time complexity for add?

```
1 class HashTableInt
2 {
3 public:
4     HashTableInt();
5
6     void add( int v );
7     bool contains( int v );
8
9 private:
10    int hash( int v );
11    int idx( int v );
12    int m_size;
13    Vector<List<int>> m_tbl;
14 };
15
16 HashTableInt::HashTableInt()
17 {
18     m_size = 0;
19     for ( int i=0; i<4; i++ )
20         m_tbl.push_back(List<int>());
21 }
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38
39 void HashTableInt::add( int v )
40 {
41     if ( !contains(v) ) {
42         m_tbl[idx(v)].push_back(v);
43         m_size++;
44     }
45
46     if ( (m_size/(1.0*m_tbl.size())) > 0.5 ) {
47
48         int new_size = 2*m_tbl.size();
49         Vector<List<int>> new_tbl;
50         for ( int i = 0; i < new_size; i++ )
51             new_tbl.push_back( List<int>() );
52
53         for ( int i = 0; i < m_tbl.size(); i++ ) {
54             for ( int x : m_tbl[i] )
55                 new_tbl[hash(x) % new_size].push_back(x);
56         }
57
58         m_tbl = new_tbl;
59     }
60 }
```

See zyBook section 16.1 for runnable code.

## Hash Function for Strings

```

1  int HashTableStr::hash( String v ) {
2      int h = 0;
3      for ( int i = 0; i < v.size(); i++ )
4          h = h + (int) v[i];
5      return h;
6  }
7
8  int HashTableStr::idx( String v ) {
9      return hash(v) % m_tbl.size();
10 }

```

```

40 (   50 2   60 <   70 F   80 P   90 Z   100 d  110 n
41 )   51 3   61 =   71 G   81 Q   91 [   101 e  111 o
42 *   52 4   62 >   72 H   82 R   92 \   102 f  112 p
43 +   53 5   63 ?   73 I   83 S   93 ]   103 g  113 q
44 ,   54 6   64 @   74 J   84 T   94 ^   104 h  114 r
45 -   55 7   65 A   75 K   85 U   95 _   105 i  115 s
46 .   56 8   66 B   76 L   86 V   96 `   106 j  116 t
47 /   57 9   67 C   77 M   87 W   97 a   107 k  117 u
48 0   58 :   68 D   78 N   88 X   98 b   108 l  118 v
49 1   59 ;   69 E   79 O   89 Y   99 c   109 m  119 w

```

String	hash	idx
"bat"		
"tab"		
"elf"		
"ago"		

assume `m_tbl.size()` is 1024

## Good Hash Function for Strings

```

1  int HashTableStr::hash( String v ) {
2      int h = 0;
3      for ( int i = 0; i < v.size(); i++ )
4          h = (29 * h) + (int) v[i];
5      return h;
6  }
7
8  int HashTableStr::idx( String v ) {
9      return hash(v) % m_tbl.size();
10 }

```

```

40 (   50 2   60 <   70 F   80 P   90 Z   100 d  110 n
41 )   51 3   61 =   71 G   81 Q   91 [   101 e  111 o
42 *   52 4   62 >   72 H   82 R   92 \   102 f  112 p
43 +   53 5   63 ?   73 I   83 S   93 ]   103 g  113 q
44 ,   54 6   64 @   74 J   84 T   94 ^   104 h  114 r
45 -   55 7   65 A   75 K   85 U   95 _   105 i  115 s
46 .   56 8   66 B   76 L   86 V   96 `   106 j  116 t
47 /   57 9   67 C   77 M   87 W   97 a   107 k  117 u
48 0   58 :   68 D   78 N   88 X   98 b   108 l  118 v
49 1   59 ;   69 E   79 O   89 Y   99 c   109 m  119 w

```

String	hash	idx
"bat"		
"tab"		
"elf"		
"ago"		

assume `m_tbl.size()` is 1024