Hash Table Collision Exercises

Similar to the first three questions on Homework 6

Quadratic Probing

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	
7	
8	
9	
10	
11	
12	
13	
14	14

- Using Quadratic Probing, insert 21, 25, 18, 76, 36, and 12 into the hash table in the given order
- Then, search and remove 36 from the table
- Reminder:
  - Quadratic probing uses the following formula to determine an item's placement in the hash table
  - $(H + c1 * i + c2 * i^2)\ \%\ (tablesize)$
    - H is the result of the hash function
    - i starts out at 0 and increments by 1 for each collision encountered when trying to insert the item into the table

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	
7	
8	
9	
10	
11	
12	
13	
14	14

- Insert 21 into the hash table
- h(21) = 21 % 15 = 6
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(6 + 1 * 0 + 1 * 0^2) \% 15$$
$$(6 + 0 + 0) \% 15$$
$$6 \% 15$$
$$6$$

- So, we will try inserting into bucket 6

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	
11	
12	
13	
14	14

- Insert 21 into the hash table
- h(21) = 21 % 15 = 6
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(6 + 1 * 0 + 1 * 0^2) \% 15$$
$$(6 + 0 + 0) \% 15$$
$$6 \% 15$$
$$6$$

- So, we will try inserting into bucket 6
- Bucket 6 is empty, so we can insert 21 in it
- No collisions

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	
11	
12	
13	
14	14

- Insert 25 into the hash table
- h(25) = 25 % 15 = 10
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(10 + 1 * 0 + 1 * 0^2) \% 15$$

$$(10 + 0 + 0) \% 15$$

$$10 \% 15$$

$$10$$

- So, we will try inserting into bucket 10

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	25
11	
12	
13	
14	14

- Insert 25 into the hash table
- h(25) = 25 % 15 = 10
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(10 + 1 * 0 + 1 * 0^2) \% 15$$
$$(10 + 0 + 0) \% 15$$
$$10 \% 15$$
$$10$$

- So, we will try inserting into bucket 10
- Bucket 10 is empty, so we can insert 25 in it
- No collisions

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	25
11	
12	
13	
14	14

- Insert 18 into the hash table
- h(18) = 18 % 15 = 3
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(3 + 1 * 0 + 1 * 0^2) \% 15$$
$$(3 + 0 + 0) \% 15$$
$$3 \% 15$$
$$3$$

- So, we will try inserting into bucket 3

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	25
11	
12	
13	
14	14

- Insert 18 into the hash table
- h(18) = 18 % 15 = 3
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(3 + 1 * 0 + 1 * 0^2) \% 15$$
$$(3 + 0 + 0) \% 15$$
$$3 \% 15$$
$$3$$

- So, we will try inserting into bucket 3
- There is already an item in bucket 3
- So, we must handle the collision using Quadratic Probing

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	25
11	
12	
13	
14	14

- Increment *i* by 1 and find next bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(3 + 1 * 1 + 1 * 1^2) \% 15$$

$$(3 + 1 + 1) \% 15$$

$$5 \% 15$$

$$5$$

- So, we will try inserting into bucket 5

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	25
11	
12	
13	
14	14

- Increment *i* by 1 and find next bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(3 + 1 * 1 + 1 * 1^2) \% 15$$
$$(3 + 1 + 1) \% 15$$
$$5 \% 15$$
$$5$$

- So, we will try inserting into bucket 5
- There is already an item in bucket 5
- So, we must handle the collision using Quadratic Probing

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	
10	25
11	
12	
13	
14	14

- Increment *i* by 1 and find next bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(3 + 1 * 2 + 1 * 2^2) \% 15$$

$$(3 + 2 + 4) \% 15$$

$$9 \% 15$$

$$9$$

- So, we will try inserting into bucket 9

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	18
10	25
11	
12	
13	
14	14

- Increment *i* by 1 and find next bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(3 + 1 * 2 + 1 * 2^2) \% 15$$

$$(3 + 2 + 4) \% 15$$

$$9 \% 15$$

$$9$$

- So, we will try inserting into bucket 9
- Bucket 9 is empty, so we insert 18 in it

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	
2	
3	3
4	
5	5
6	21
7	
8	
9	18
10	25
11	
12	
13	
14	14

- Insert 76 into the hash table
- h(76) = 76 % 15 = 1
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(1 + 1 * 0 + 1 * 0^2) \% 15$$

$$(1 + 0 + 0) \% 15$$

$$1 \% 15$$

$$1$$

- So, we will try inserting into bucket 1

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	
9	18
10	25
11	
12	
13	
14	14

- Insert 76 into the hash table
- h(76) = 76 % 15 = 1
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(1 + 1 * 0 + 1 * 0^2) \% 15$$
$$(1 + 0 + 0) \% 15$$
$$1 \% 15$$
$$1$$

- So, we will try inserting into bucket 1
- Bucket 1 is empty, so we insert 76 into it
- No collisions

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	
9	18
10	25
11	
12	
13	
14	14

- Insert 36 into the hash table
- h(36) = 36 % 15 = 6
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(6 + 1 * 0 + 1 * 0^2) \% 15$$

$$(6 + 0 + 0) \% 15$$

$$6 \% 15$$

$$6$$

- So, we will try inserting into bucket 6

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	
9	18
10	25
11	
12	
13	
14	14

- Insert 36 into the hash table
- h(36) = 36 % 15 = 6
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(6 + 1 * 0 + 1 * 0^2) \% 15$$
$$(6 + 0 + 0) \% 15$$
$$6 \% 15$$
$$6$$

- So, we will try inserting into bucket 6
- There is already an item in bucket 5
- So, we must handle the collision using Quadratic Probing

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	
9	18
10	25
11	
12	
13	
14	14

- Increment i by 1 and find next bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(6 + 1 * 1 + 1 * 1^2) \% 15$$

$$(6 + 1 + 1) \% 15$$

$$8 \% 15$$

$$8$$

- So, we will try inserting into bucket 8

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	36
9	18
10	25
11	
12	
13	
14	14

- Increment i by 1 and find next bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(6 + 1 * 1 + 1 * 1^2) \% 15$$

$$(6 + 1 + 1) \% 15$$

$$8 \% 15$$

$$8$$

- So, we will try inserting into bucket 8
- Bucket 8 is empty, so we insert 36 into it

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	36
9	18
10	25
11	
12	
13	
14	14

- Insert 12 into the hash table
- h(12) = 12 % 15 = 12
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(12 + 1 * 0 + 1 * 0^2) \% 15$$
$$(12 + 0 + 0) \% 15$$
$$12 \% 15$$
$$12$$

- So, we will try inserting into bucket 12

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	36
9	18
10	25
11	
12	12
13	
14	14

- Insert 12 into the hash table
- h(12) = 12 % 15 = 12
- Find bucket to insert into:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(12 + 1 * 0 + 1 * 0^2) \% 15$$
$$(12 + 0 + 0) \% 15$$
$$12 \% 15$$
$$12$$

- So, we will try inserting into bucket 12
- Bucket 12 is empty, so we insert 12 into it
- No collisions

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	36
9	18
10	25
11	
12	12
13	
14	14

- Search and remove 36 from the table
- h(36) = 36 % 15 = 6
- Find bucket to remove from:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(6 + 1 * 0 + 1 * 0^2) \% 15$$
$$(6 + 0 + 0) \% 15$$
$$6 \% 15$$
$$6$$

- So, we will check bucket 6 to see if 36 is in it

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	36
9	18
10	25
11	
12	12
13	
14	14

- Search and remove 36 from the table
- h(36) = 36 % 15 = 6
- Find bucket to remove from:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(6 + 1 * 0 + 1 * 0^2) \% 15$$
$$(6 + 0 + 0) \% 15$$
$$6 \% 15$$
$$6$$

- So, we will check bucket 6 to see if 36 is in it
- Bucket 6 is non-empty and does not contain 36
- So, search for next place 36 could be with Quadratic Probing

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	36
9	18
10	25
11	
12	12
13	
14	14

- Increment i by 1 and find next bucket to remove from:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$

$$(6 + 1 * 1 + 1 * 1^2) \% 15$$

$$(6 + 1 + 1) \% 15$$

$$8 \% 15$$

$$8$$

- So, we will check bucket 8 to see if 36 is in it

- Assume that c1 = 1 and c2 =1 and that you are given the following hash table and the hash function is h(key) = key % 15

0	
1	76
2	
3	3
4	
5	5
6	21
7	
8	
9	18
10	25
11	
12	12
13	
14	14

- Increment i by 1 and find next bucket to remove from:

$$(H + c1 * i + c2 * i^2) \% (tablesize)$$
$$(6 + 1 * 1 + 1 * 1^2) \% 15$$
$$(6 + 1 + 1) \% 15$$
$$8 \% 15$$
$$8$$

- So, we will check bucket 8 to see if 36 is in it
- 36 is in bucket 8
- Remove the entry in bucket 8
- Mark bucket 8 as empty-after-removal

Double Hashing

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	
2	
3	
4	
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Using Double Hashing, insert 4, 12, 21, 17, and 31 into the hash table in the given order
- Then, search and remove 17 from the table
- Reminder:
  - Double hashing uses the following formula to determine an item's placement in the hash table
  - $(h1(key) + i * h2(key)) \% (tablesize)$
    - i starts out at 0 and increments by 1 for each collision encountered when trying to insert the item into the table

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	
2	
3	
4	
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 4 into the hash table
- h1(4) = 4 % 10 = 4
- h2(4) = 4 % 3 = 1
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(4) + 0 * h2(4)) \% 15$$
$$(4 + 0) \% 15$$
$$4 \% 15$$
$$4$$

- So, we try inserting into bucket 4

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	
2	
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 4 into the hash table
- h1(4) = 4 % 10 = 4
- h2(4) = 4 % 3 = 1
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(4) + 0 * h2(4)) \% 15$$
$$(4 + 0) \% 15$$
$$4 \% 15$$
$$4$$

- So, we try inserting into bucket 4
- Bucket 4 is empty, so we can insert 4 into it
- No collisions

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	
2	
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 12 into the hash table
- h1(12) = 12 % 10 = 2
- h2(12) = 12 % 3 = 0
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(12) + 0 * h2(12)) \% 15$$
$$(2 + 0) \% 15$$
$$2 \% 15$$
$$2$$

- So, we try inserting into bucket 2

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	
2	12
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 12 into the hash table
- h1(12) = 12 % 10 = 2
- h2(12) = 12 % 3 = 0
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(12) + 0 * h2(12)) \% 15$$
$$(2 + 0) \% 15$$
$$2 \% 15$$
$$2$$

- So, we try inserting into bucket 2
- Bucket 2 is empty, so we can insert 12 into it
- No collisions

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	
2	12
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 21 into the hash table
- h1(21) = 21 % 10 = 1
- h2(21) = 21 % 3 = 0
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(21) + 0 * h2(21)) \% 15$$
$$(1 + 0) \% 15$$
$$1 \% 15$$
$$1$$

- So, we try inserting into bucket 1

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 21 into the hash table
- h1(21) = 21 % 10 = 1
- h2(21) = 21 % 3 = 0
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(21) + 0 * h2(21)) \% 15$$
$$(1 + 0) \% 15$$
$$1 \% 15$$
$$1$$

- So, we try inserting into bucket 1
- Bucket 1 is empty, so we can insert 21 into it
- No collisions

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 17 into the hash table
- h1(17) = 17 % 10 = 7
- h2(17) = 17 % 3 = 2
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 0 * h2(17)) \% 15$$
$$(7 + 0) \% 15$$
$$7 \% 15$$
$$7$$

- So, we try inserting into bucket 7

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 17 into the hash table
- h1(17) = 17 % 10 = 7
- h2(17) = 17 % 3 = 2
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 0 * h2(17)) \% 15$$
$$(7 + 0) \% 15$$
$$7 \% 15$$
$$7$$

- So, we try inserting into bucket 7
- There is already an item in bucket 7
- So, we must handle the collision using Double Hashing

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 1 * h2(17)) \% 15$$
$$(7 + 1 * 2) \% 15$$
$$(7 + 2) \% 15$$
$$9 \% 15$$
$$9$$

- So, we try inserting into bucket 9

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 1 * h2(17)) \% 15$$
$$(7 + 1 * 2) \% 15$$
$$(7 + 2) \% 15$$
$$9 \% 15$$
$$9$$

- So, we try inserting into bucket 9
- Bucket 9 is empty, so we can insert 17 into it

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Insert 31 into the hash table
- h1(31) = 31 % 10 = 1
- h2(31) = 31 % 3 = 1
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(31) + 0 * h2(31)) \% 15$$
$$(1 + 0) \% 15$$
$$1 \% 15$$
$$1$$

- So, we try inserting into bucket 1

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Insert 31 into the hash table
- h1(31) = 31 % 10 = 1
- h2(31) = 31 % 3 = 1
- Find bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(31) + 0 * h2(31)) \% 15$$
$$(1 + 0) \% 15$$
$$1 \% 15$$
$$1$$

- So, we try inserting into bucket 1
- There is already an item in bucket 1
- So, we must handle the collision using Double Hashing

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(31) + 1 * h2(31)) \% 15$$
$$(1 + 1 * 1) \% 15$$
$$(1 + 1) \% 15$$
$$2 \% 15$$
$$2$$

- So, we try inserting into bucket 2

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(31) + 1 * h2(31)) \% 15$$
$$(1 + 1 * 1) \% 15$$
$$(1 + 1) \% 15$$
$$2 \% 15$$
$$2$$

- So, we try inserting into bucket 2
- There is already an item in bucket 2
- So, we must handle the collision using Double Hashing

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(31) + 2 * h2(31)) \% 15$$
$$(1 + 2 * 1) \% 15$$
$$(1 + 2) \% 15$$
$$3 \% 15$$
$$3$$

- So, we try inserting into bucket 3

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	31
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to insert into:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(31) + 2 * h2(31)) \% 15$$
$$(1 + 2 * 1) \% 15$$
$$(1 + 2) \% 15$$
$$3 \% 15$$
$$3$$

- So, we try inserting into bucket 3
- Bucket 3 is empty so we can insert 31 into it

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	31
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Search and remove 17 from the table
- h1(17) = 17 % 10 = 7
- h2(17) = 17 % 3 = 2
- Find bucket to remove from:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 0 * h2(31)) \% 15$$
$$(7 + 0) \% 15$$
$$7 \% 15$$
$$7$$

- So, we will check bucket 7 to see if 17 is in it

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	31
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Search and remove 17 from the table
- h1(17) = 17 % 10 = 7
- h2(17) = 17 % 3 = 2
- Find bucket to remove from:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 0 * h2(31)) \% 15$$
$$(7 + 0) \% 15$$
$$7 \% 15$$
$$7$$

- So, we will check bucket 7 to see if 17 is in it
- Bucket 7 is non-empty and does not contain 17
- So, search for next place 17 could be with Double Hashing

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	31
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to remove from:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 1 * h2(31)) \% 15$$
$$(7 + 1 * 2) \% 15$$
$$(7 + 2) \% 15$$
$$9 \% 15$$
$$9$$

- So, we will check bucket 9 to see if 17 is in it

- Assume h1(key) = key % 10 and h2(key) = key % 3

0	
1	21
2	12
3	31
4	4
5	5
6	
7	7
8	
9	17
10	10
11	
12	
13	
14	

- Increment i by 1 and find next bucket to remove from:

$$(h1(key) + i * h2(key)) \% (tablesize)$$
$$(h1(17) + 1 * h2(31)) \% 15$$
$$(7 + 1 * 2) \% 15$$
$$(7 + 2) \% 15$$
$$9 \% 15$$
$$9$$

- So, we will check bucket 9 to see if 17 is in it
- 17 is in bucket 9
- Remove the entry in bucket 9
- Mark bucket 9 as empty-after-removal

Linear Probing

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Using Linear Probing, insert 6, 25, and 17 into the hash table in the given order
- Then, search and remove 10 from the table
- Then insert 12 and 34 into the hash table in the given order
- Then search and remove 25 from the table
- Reminder:
  - If a collision occurs and Linear Probing is used as the collision resolution method, subsequent buckets will be checked until an empty bucket is found for the insert to occur
  - The search starts from the bucket the collision occurred in

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 6 into the hash table
- h(6) = 6 % 15 = 6
- So, we will try inserting into bucket 6

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 6 into the hash table
- h(6) = 6 % 15 = 6
- So, we will try inserting into bucket 6
- Bucket 6 is empty, so we can insert 6 into it

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 25 into the hash table
- h(25) = 25 % 15 = 10
- So, we will try inserting into bucket 10

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 25 into the hash table
- h(25) = 25 % 15 = 10
- So, we will try inserting into bucket 10
- There is already an item in bucket 10
- To resolve this collision, check for the next empty bucket

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	
12	
13	
14	

- Insert 25 into the hash table
- h(25) = 25 % 15 = 10
- So, we will try inserting into bucket 10
- There is already an item in bucket 10
- To resolve this collision, check for the next empty bucket
- In this case, it is 11

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	25
12	
13	
14	

- Insert 25 into the hash table
- h(25) = 25 % 15 = 10
- So, we will try inserting into bucket 10
- There is already an item in bucket 10
- To resolve this collision, check for the next empty bucket
- In this case, it is 11
- So, we can insert 25 into bucket 11

- Assume h(key) = key % 15

0	
1	
2	
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	25
12	
13	
14	

- Insert 17 into the hash table
- h(17) = 17 % 15 = 2
- So, we will try inserting into bucket 2

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	25
12	
13	
14	

- Insert 17 into the hash table
- h(17) = 17 % 15 = 2
- So, we will try inserting into bucket 2
- Bucket 2 is empty, so we can insert 17 into it

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	
5	5
6	6
7	7
8	
9	
10	10
11	25
12	
13	
14	

- Search and remove 10 from the hash table
- h(10) = 10 % 15 = 10
- So, we will check bucket 10 and see if 10 is in it

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	
5	5
6	6
7	7
8	
9	
10	
11	25
12	
13	
14	

- Search and remove 10 from the hash table
- h(10) = 10 % 15 = 10
- So, we will check bucket 10 and see if 10 is in it
- 10 is in bucket 10, so we can remove the entry
- Mark bucket 10 as empty-after-removal

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	
5	5
6	6
7	7
8	
9	
10	
11	25
12	
13	
14	

- Insert 12 into the hash table
- h(12) = 12 % 15 = 12
- So, we will try inserting into bucket 12

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	
5	5
6	6
7	7
8	
9	
10	
11	25
12	12
13	
14	

- Insert 12 into the hash table
- h(12) = 12 % 15 = 12
- So, we will try inserting into bucket 12
- Bucket 12 is empty, so we can insert 12 into it

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	
5	5
6	6
7	7
8	
9	
10	
11	25
12	12
13	
14	

- Insert 34 into the hash table
- h(34) = 34 % 15 = 4
- So, we will try inserting into bucket 4

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	34
5	5
6	6
7	7
8	
9	
10	
11	25
12	12
13	
14	

- Insert 34 into the hash table
- h(34) = 34 % 15 = 4
- So, we will try inserting into bucket 4
- Bucket 4 is empty, so we can insert 34 into it

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	34
5	5
6	6
7	7
8	
9	
10	
11	25
12	12
13	
14	

- Search and remove 25 from the table
- h(25) = 25 % 15 = 10
- So, we will check Bucket 10 and see if 25 is in it

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	34
5	5
6	6
7	7
8	
9	
10	
11	25
12	12
13	
14	

- Search and remove 25 from the table
- h(25) = 25 % 15 = 10
- So, we will check Bucket 10 and see if 25 is in it
- Bucket 10 is empty but was marked empty-after-removal (from earlier)

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	34
5	5
6	6
7	7
8	
9	
10	
11	25
12	12
13	
14	

- Search and remove 25 from the table
- h(25) = 25 % 15 = 10
- So, we will check Bucket 10 and see if 25 is in it
- Bucket 10 is empty but was marked empty-after-removal (from earlier)
- So, we check the next bucket (11) for 25

- Assume h(key) = key % 15

0	
1	
2	17
3	
4	34
5	5
6	6
7	7
8	
9	
10	
11	
12	12
13	
14	

- Search and remove 25 from the table
- h(25) = 25 % 15 = 10
- So, we will check Bucket 10 and see if 25 is in it
- Bucket 10 is empty but was marked empty-after-removal (from earlier)
- So, we check the next bucket (11) for 25
- 25 is in bucket 11, so we can remove the entry from the bucket
- Mark bucket 11 as empty-after-removal