Hashing

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- Worst-case complexity: $O(n)$;

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  1. Compute the value of **hash function**;
  2. **Collisions resolution**;

Hash Function

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where $key[i]$ is in ASCII or Unicode, and $p[i]$ is a weight.

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In C/C++:

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```
void generateWeights(){
    for (int i = 0; i < n; i++)
        weights[i] = rand() % m + 1;
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Objective: different keys with same characters have different weights to give different results for the hash function.

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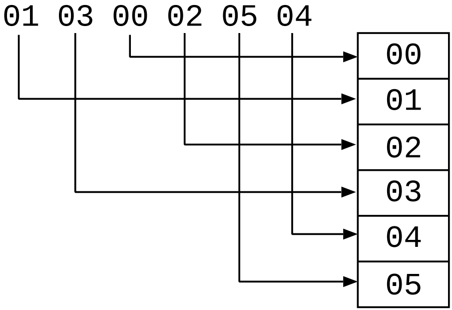
```
int h(char key[ ]){
    int sum = 0;
    for (int i = 0; i < n; i++)
        sum += (unsigned int)key[i] * weights[i];
    return sum % m;
}
```

Trivial Hash Function

Key x is stored in the bucket x:



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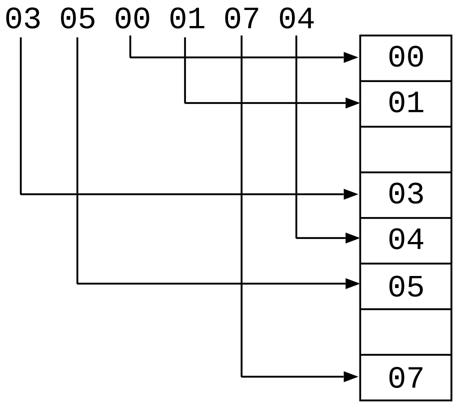

It can be used when $n = m$ or $n < m$ but $m - n$ is small.

Collision resolution

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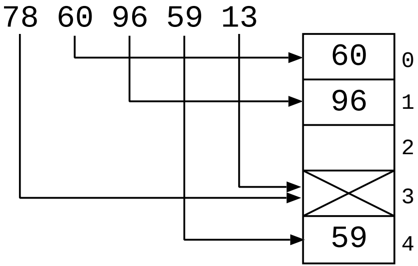

h(x)=x mod 5

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Uniform function: same probability for all slots, i.e., $\frac{1}{m}$ of getting $h(x)$.

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- **If m is odd:**

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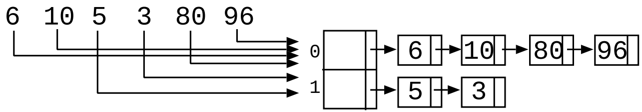

h(x)=x mod 2

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Integer	Binary	Remainder from $2^3 = 8$
0	00000	0
1	00001	1
2	00010	2
3	00011	3
4	00100	4
5	00101	5
6	00110	6
7	00111	7
8	01000	0
9	01001	1
10	01010	2
11	01011	3
12	01100	4
13	01101	5
14	01110	6
15	01111	7
16	10000	0

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7	00**111**	7
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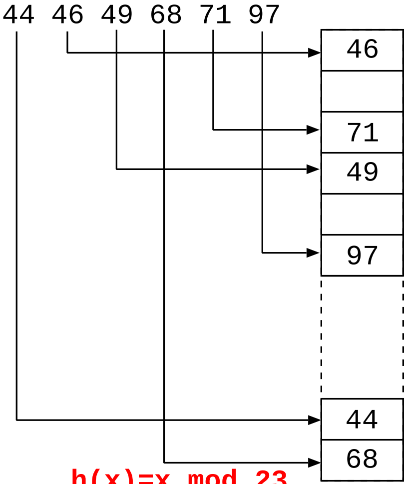

h(x)=x mod 23

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- Even so, there are 50% chance of at least one collision.

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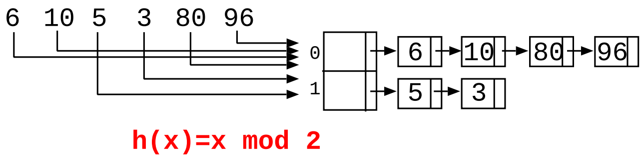

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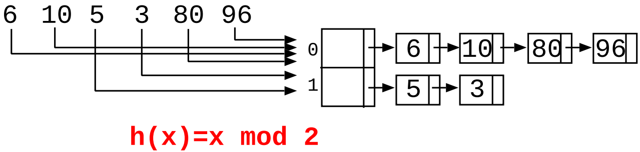

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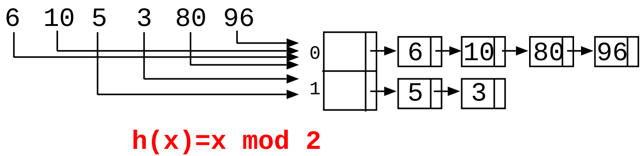

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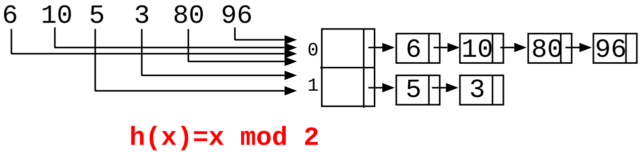

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- linked list can be replace by an AVL tree for optimization;

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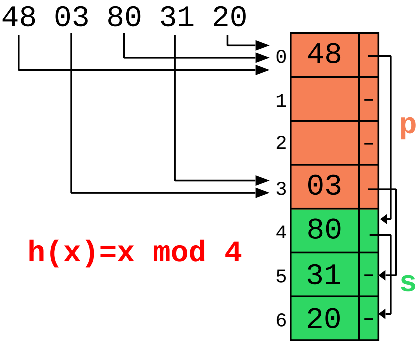

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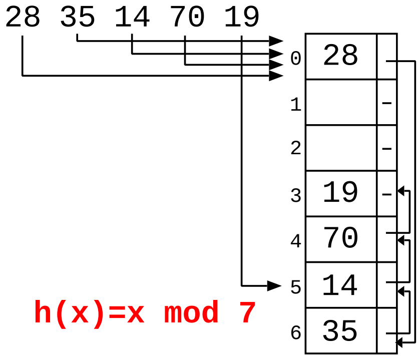

h(x)=x mod 7

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- **If collision:** $h(x, 0)$, $h(x, 1)$, $h(x, 2), \ldots, h(x, m - 1)$;

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Pseudocode for searching in Open Addressing:

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Pseudocode for searching in Open Addressing:

```
searchOpenAd(x, end, a):
    a ← 3; k ← 0;
    while k < m do
        end ← h(x, k);
        if (T[end].key = x) then
            a ← 1;
            k ← m;
        else if (T[end].key = null) then
            a ← 2;
            k ← m;
        else k ← k + 1;
```

where $a = 1$ means the key was found, $a = 2$ or 3 means not found key. If $a = 2$, *end* gives an empty position.

Open Addressing: Linear Probing

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Linear Probing:

- Suppose address of key x is $h'(x)$, i.e., $h'(x) = h(x, 0)$;
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Example:

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\begin{array}{lllcl}
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h(x,1) & = (h(x,0)+1) \pmod{m} & & = & 2 \\
h(x,2) & = (h(x,1)+1) \pmod{m} & & = & 3 \\
h(x,3) & = (h(x,2)+1) \pmod{m} & & = & 4 \\
\vdots & = & \vdots & = & \vdots
\end{array}
$$

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- **Primary grouping:** long consecutive part of memory occupied;
- the larger the primary grouping, the more likely it is to increase it more;

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h(x,3) & = (h(x,2)+3) & \pmod{m} & = & 7 \\
h(x,4) & = (h(x,3)+4) & \pmod{m} & = & 11 \\
h(x,5) & = (h(x,4)+5) & \pmod{m} & = & 16 \\
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- avoids primary groupings;
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- degradation produced by secondary groupings is still smaller than the one produced by primary groupings;

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- No retrieval of elements in sequential order (sorted elements);
- No retrieval of the predecessor or successor of an element;
- For optimization of hash function, it's essential to know the nature of keys;
- In the worst case, the order of operations can be $O(n)$ when all added elements collide.

Applications

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Questions?