

Lecture 4

Solving Recurrences (contd.), Hashing

Another Recurrence

Another Recurrence

$$T(n) = \begin{cases} c, & \text{if } n \leq 1 \\ 3.T(n/4) + c'n^2, & \text{otherwise} \end{cases}$$

Another Recurrence

$$T(n) = \begin{cases} c, & \text{if } n \leq 1 \\ 3.T(n/4) + c'n^2, & \text{otherwise} \end{cases}$$

Computing $T(n)$:

Another Recurrence

$$T(n) = \begin{cases} c, & \text{if } n \leq 1 \\ 3.T(n/4) + c'n^2, & \text{otherwise} \end{cases}$$

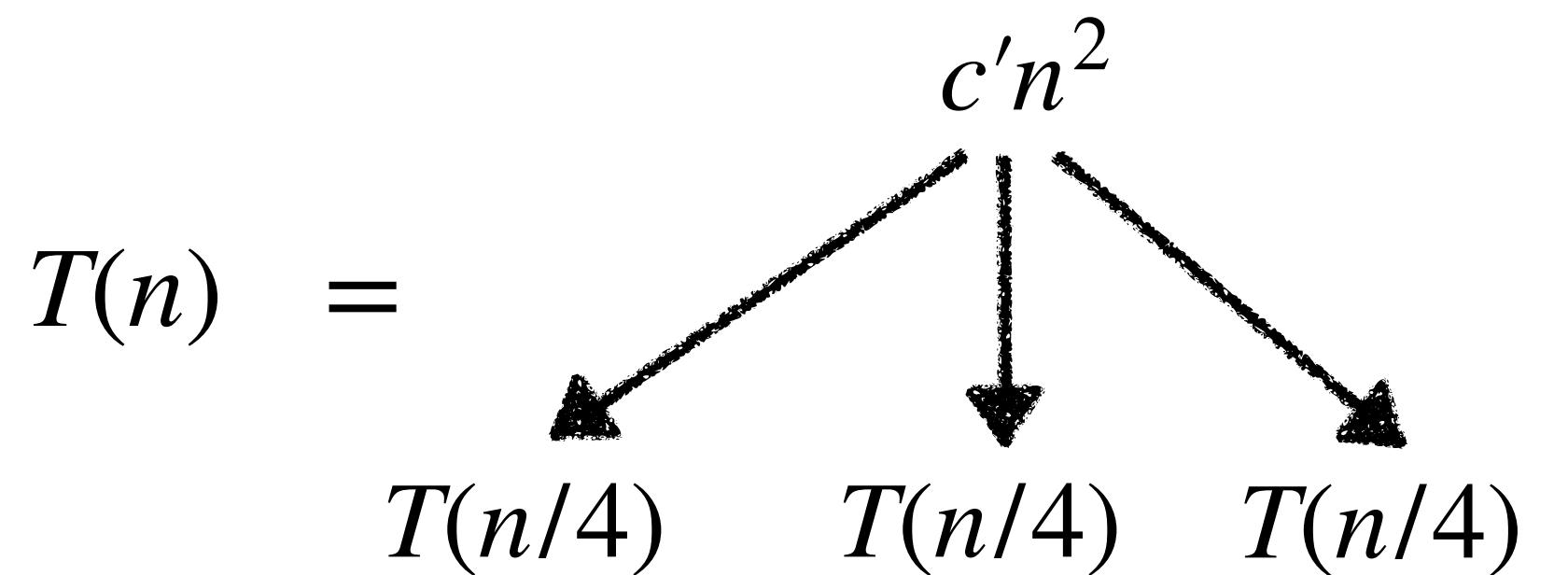
Computing $T(n)$:

$$T(n)$$

Another Recurrence

$$T(n) = \begin{cases} c, & \text{if } n \leq 1 \\ 3.T(n/4) + c'n^2, & \text{otherwise} \end{cases}$$

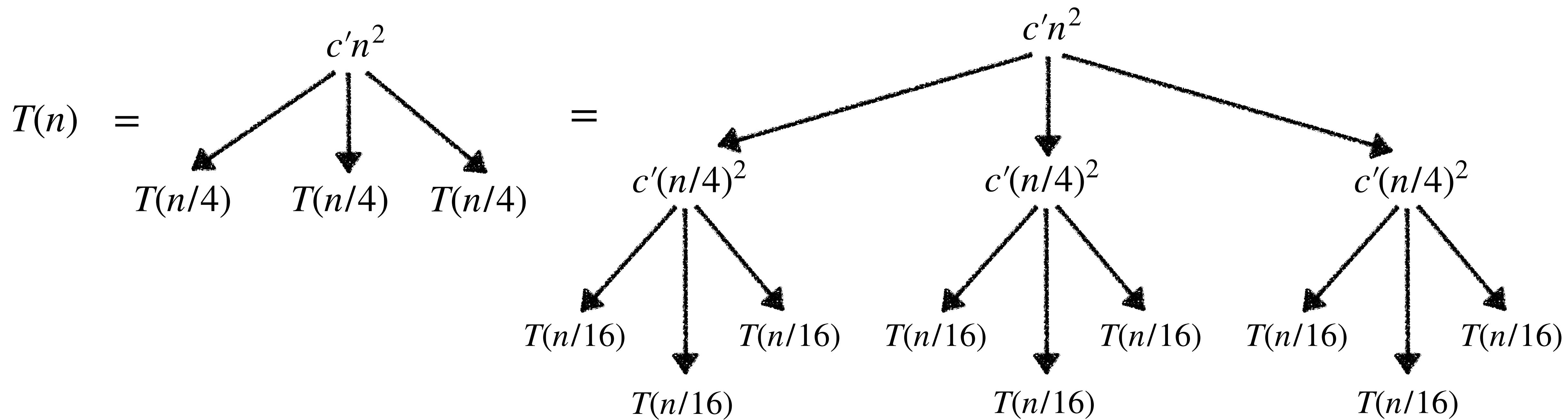
Computing $T(n)$:



Another Recurrence

$$T(n) = \begin{cases} c, & \text{if } n \leq 1 \\ 3.T(n/4) + c'n^2, & \text{otherwise} \end{cases}$$

Computing $T(n)$:



Another Recurrence

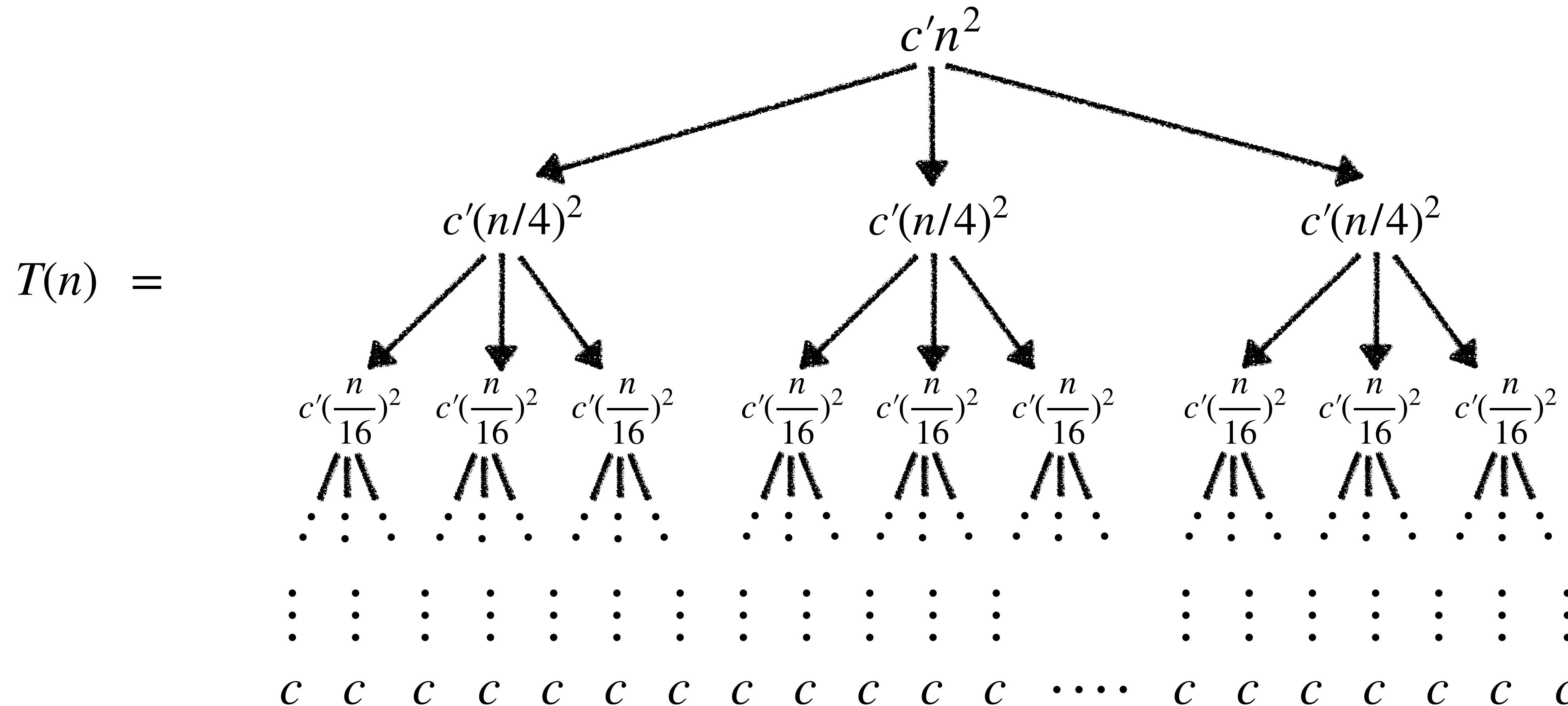
Another Recurrence

$T(n)$

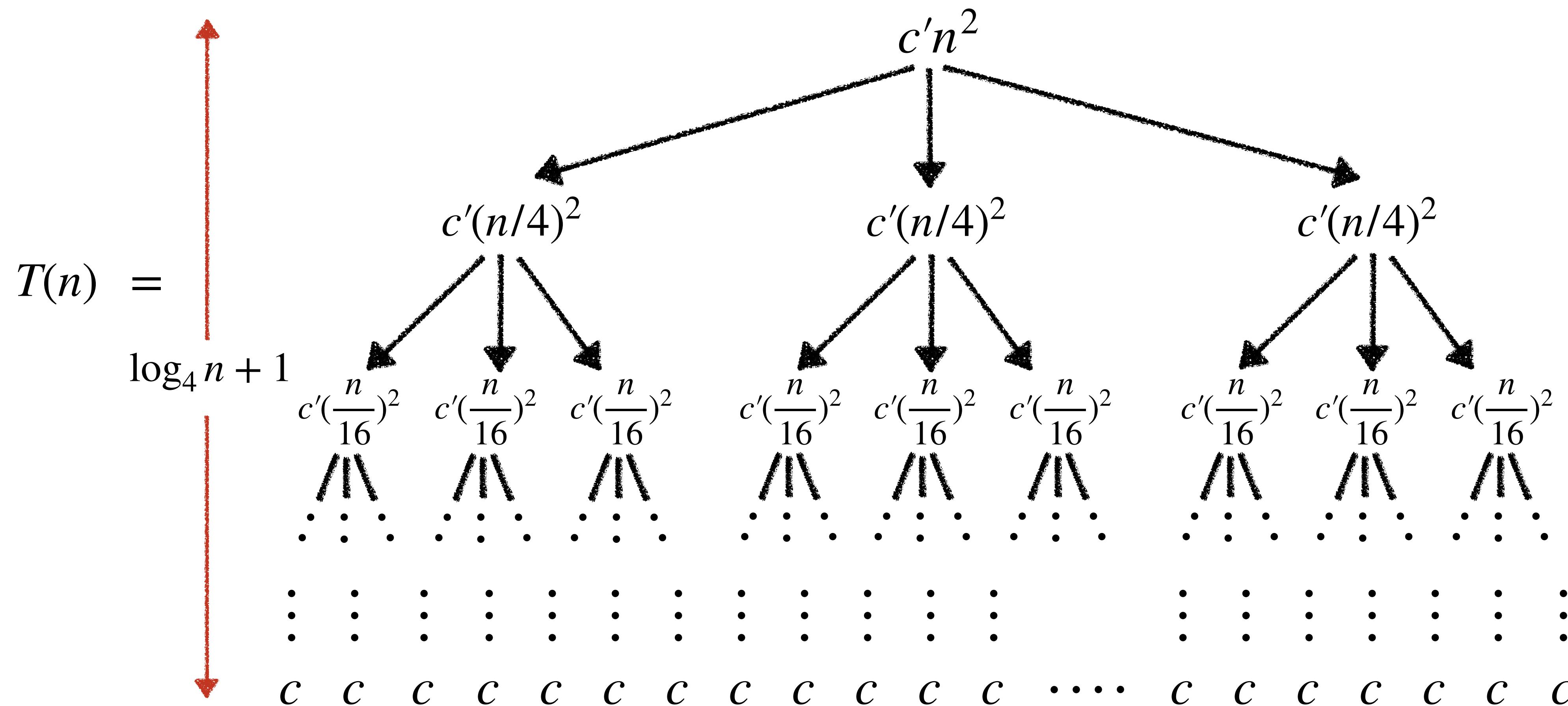
Another Recurrence

$$T(n) =$$

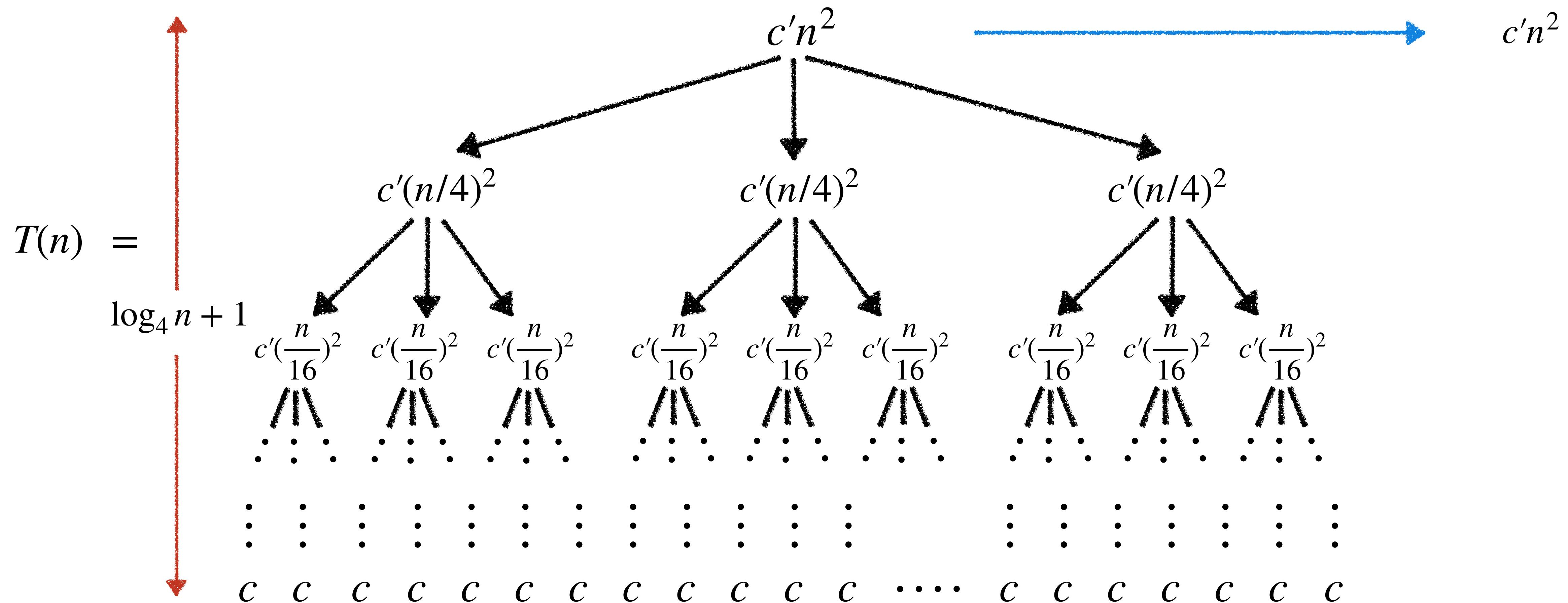
Another Recurrence



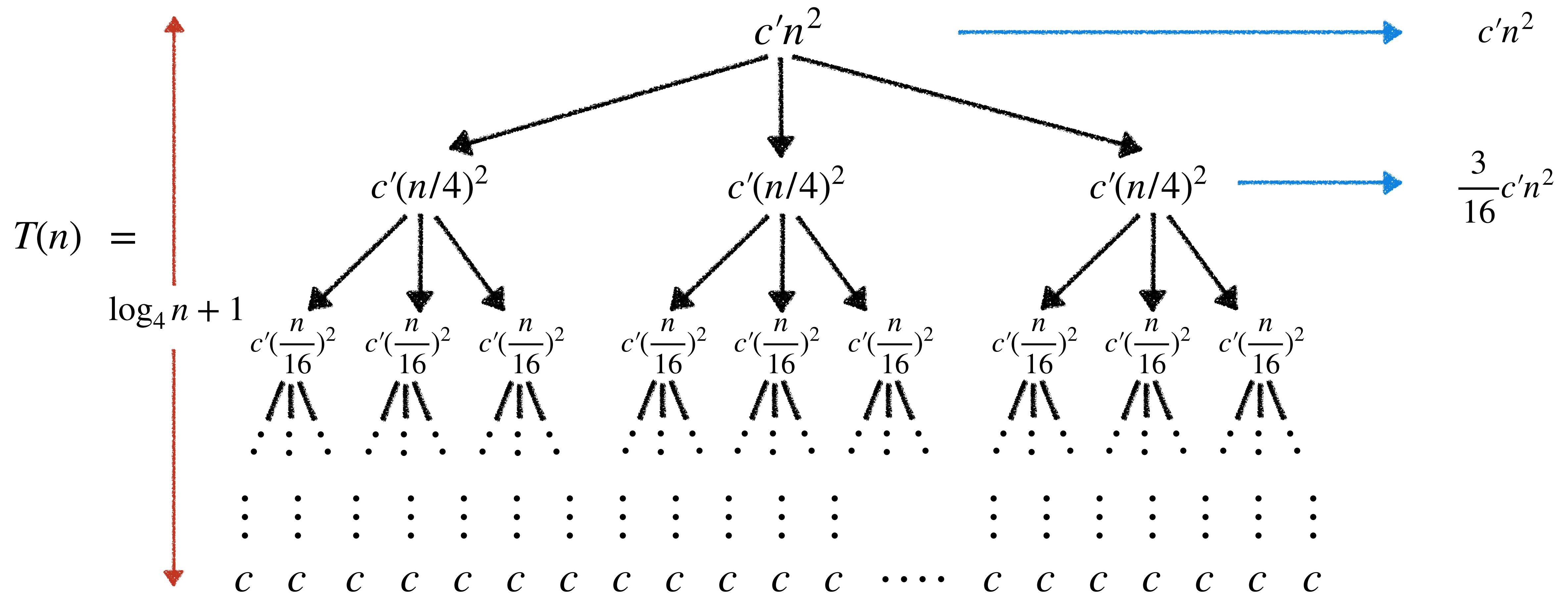
Another Recurrence



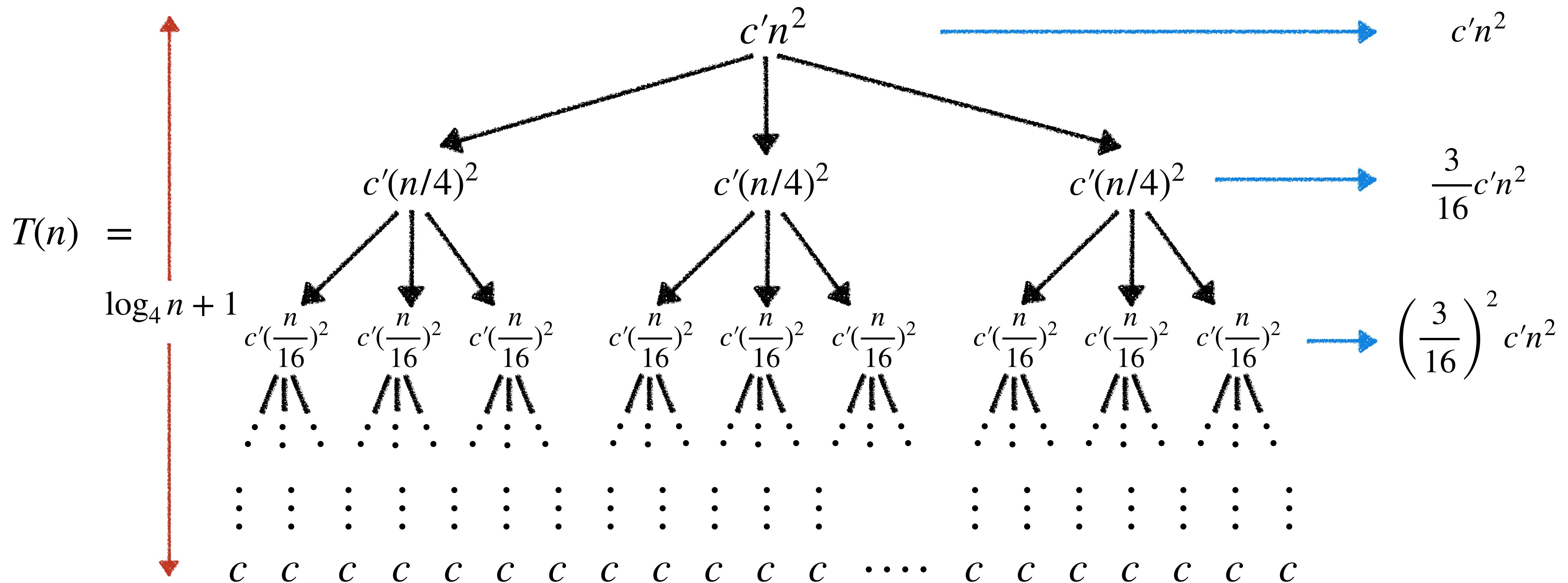
Another Recurrence



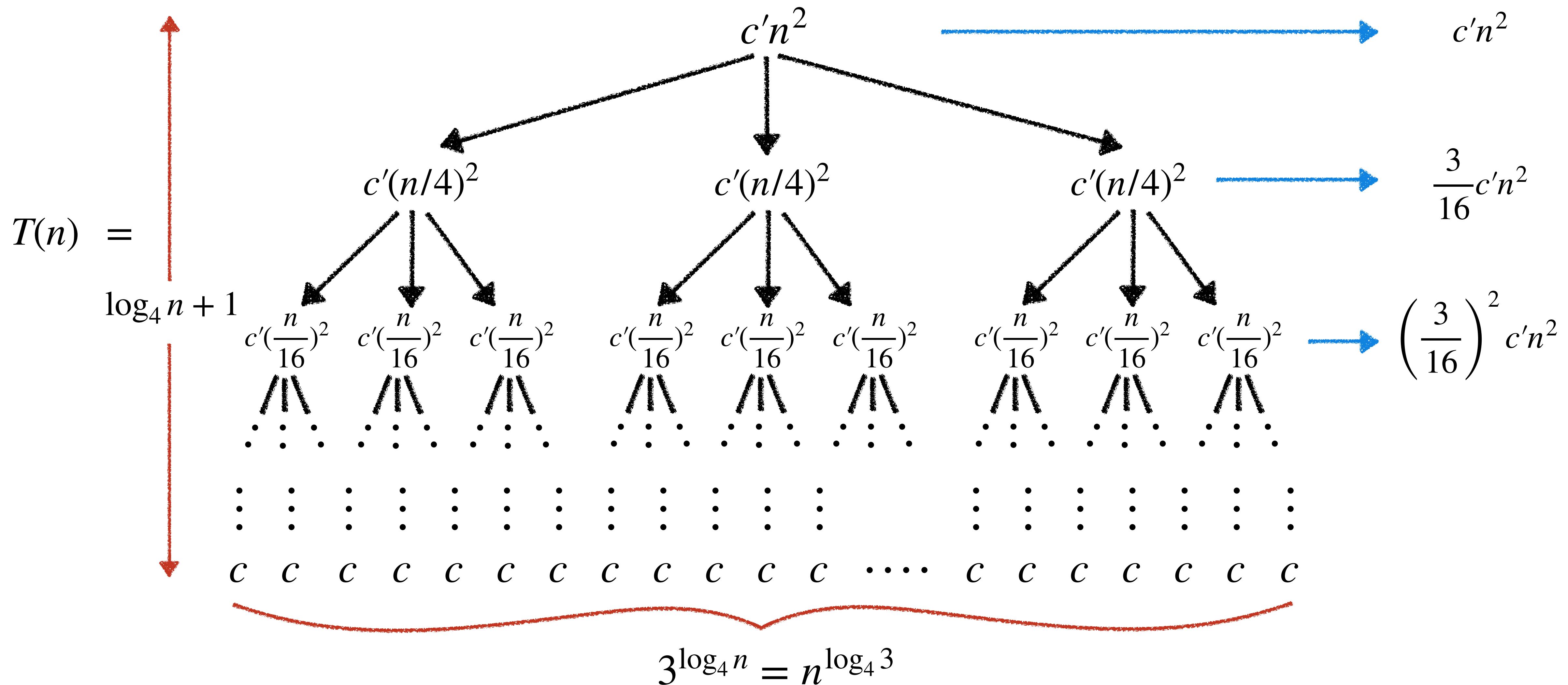
Another Recurrence



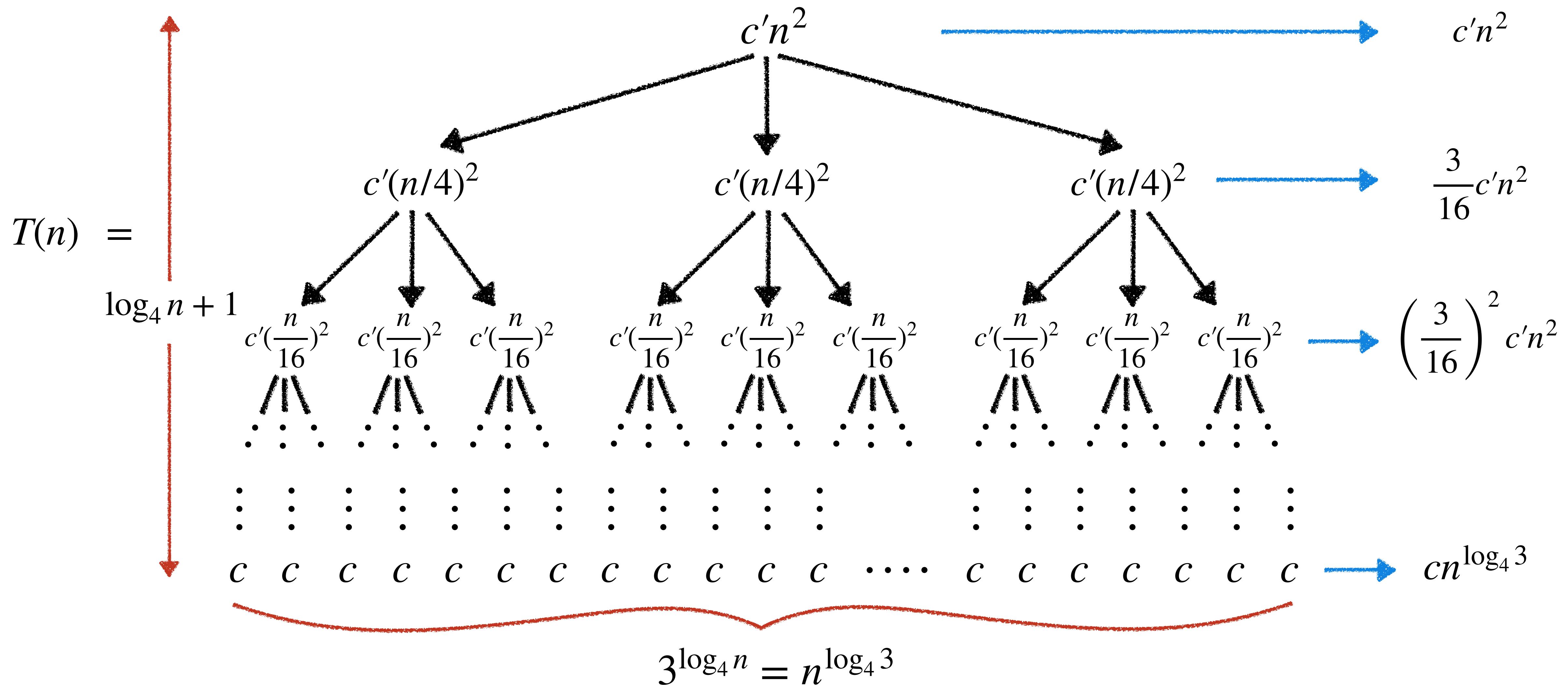
Another Recurrence



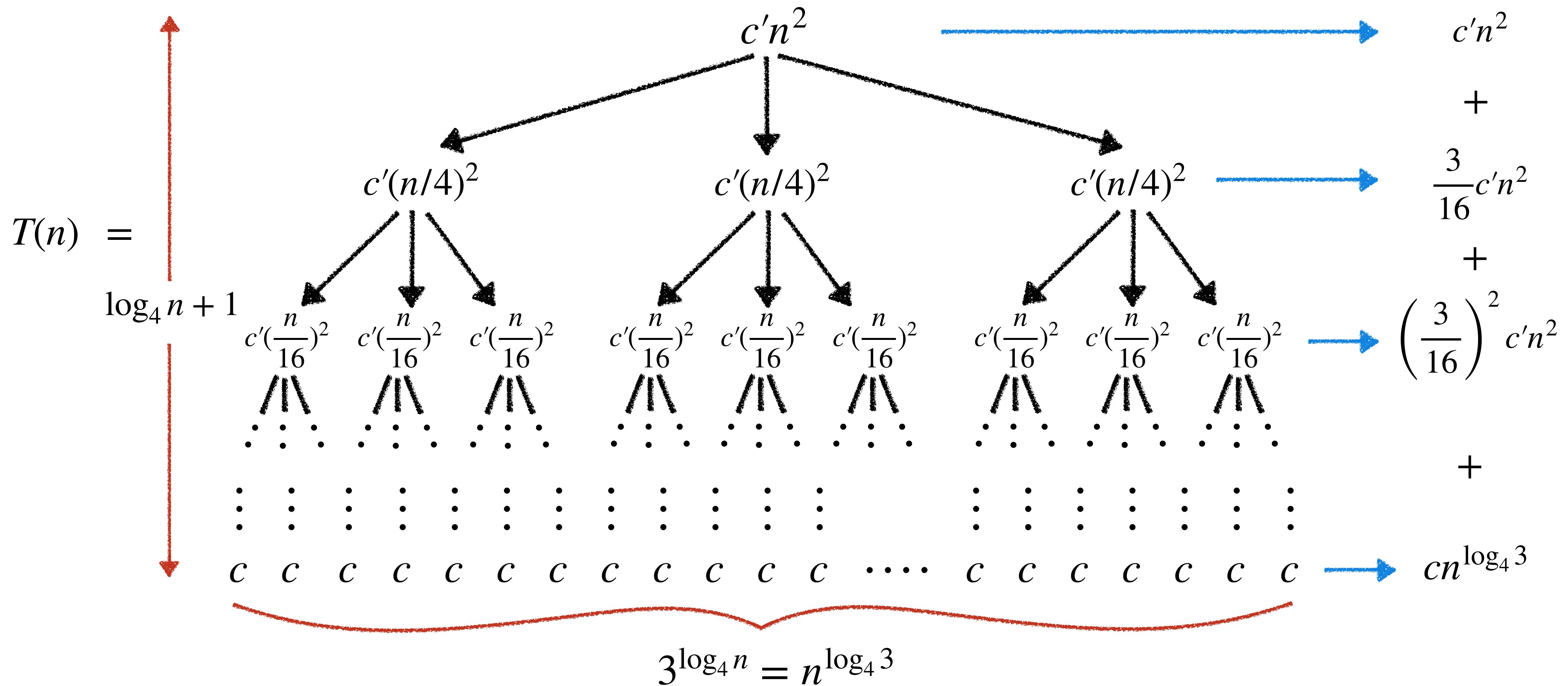
Another Recurrence



Another Recurrence



Another Recurrence



Another Recurrence

Another Recurrence

$$T(n) = c'n^2 + \frac{3}{16}c'n^2 + \left(\frac{3}{16}\right)^2 c'n^2 + \dots + \left(\frac{3}{16}\right)^{\log_4 n} c'n^2 + cn^{\log_4 3}$$

Another Recurrence

$$\begin{aligned} T(n) &= c'n^2 + \frac{3}{16}c'n^2 + \left(\frac{3}{16}\right)^2 c'n^2 + \dots + \left(\frac{3}{16}\right)^{\log_4 n} c'n^2 + cn^{\log_4 3} \\ &= c'n^2 \sum_{i=0}^{\log_4 n} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \end{aligned}$$

Another Recurrence

$$\begin{aligned} T(n) &= c'n^2 + \frac{3}{16}c'n^2 + \left(\frac{3}{16}\right)^2 c'n^2 + \dots + \left(\frac{3}{16}\right)^{\log_4 n} c'n^2 + cn^{\log_4 3} \\ &= c'n^2 \sum_{i=0}^{\log_4 n} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \\ &< c'n^2 \sum_{i=0}^{\infty} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \end{aligned}$$

Another Recurrence

$$\begin{aligned} T(n) &= c'n^2 + \frac{3}{16}c'n^2 + \left(\frac{3}{16}\right)^2 c'n^2 + \dots + \left(\frac{3}{16}\right)^{\log_4 n} c'n^2 + cn^{\log_4 3} \\ &= c'n^2 \sum_{i=0}^{\log_4 n} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \\ &< c'n^2 \sum_{i=0}^{\infty} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \\ &= c'n^2 \left(\frac{16}{13}\right) + cn^{\log_4 3} \end{aligned}$$

Another Recurrence

$$\begin{aligned} T(n) &= c'n^2 + \frac{3}{16}c'n^2 + \left(\frac{3}{16}\right)^2 c'n^2 + \dots + \left(\frac{3}{16}\right)^{\log_4 n} c'n^2 + cn^{\log_4 3} \\ &= c'n^2 \sum_{i=0}^{\log_4 n} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \\ &< c'n^2 \sum_{i=0}^{\infty} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \\ &= c'n^2 \left(\frac{16}{13}\right) + cn^{\log_4 3} \quad (\because a + ar + ar^2 + \dots = \frac{a}{1-r}, \text{ when } |r| < 1) \end{aligned}$$

Another Recurrence

$$\begin{aligned} T(n) &= c'n^2 + \frac{3}{16}c'n^2 + \left(\frac{3}{16}\right)^2 c'n^2 + \dots + \left(\frac{3}{16}\right)^{\log_4 n} c'n^2 + cn^{\log_4 3} \\ &= c'n^2 \sum_{i=0}^{\log_4 n} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \\ &< c'n^2 \sum_{i=0}^{\infty} \left(\frac{3}{16}\right)^i + cn^{\log_4 3} \\ &= c'n^2 \left(\frac{16}{13}\right) + cn^{\log_4 3} \quad (\because a + ar + ar^2 + \dots = \frac{a}{1-r}, \text{ when } |r| < 1) \\ &= O(n^2) \end{aligned}$$

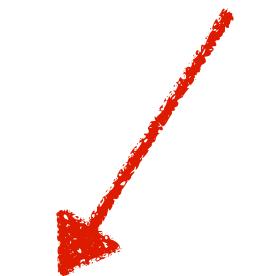
Hashing: Introduction

Hashing: Introduction

Hashing is typically used to maintain a dynamic set that supports three operations:

Hashing: Introduction

Set of elements where every element has a key.



Hashing is typically used to maintain a **dynamic set** that supports three operations:

Hashing: Introduction

Set of elements where every element has a key.



Hashing is typically used to maintain a **dynamic set** that supports three operations:

- **Insert** an element.

Hashing: Introduction

Set of elements where every element has a key.



Hashing is typically used to maintain a **dynamic set** that supports three operations:

- **Insert** an element.
- **Search** for an element with the key k .

Hashing: Introduction

Set of elements where every element has a key.



Hashing is typically used to maintain a **dynamic set** that supports three operations:

- **Insert** an element.
- **Search** for an element with the key k .
- **Delete** an element.

Direct-address Tables

Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**

Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent

Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

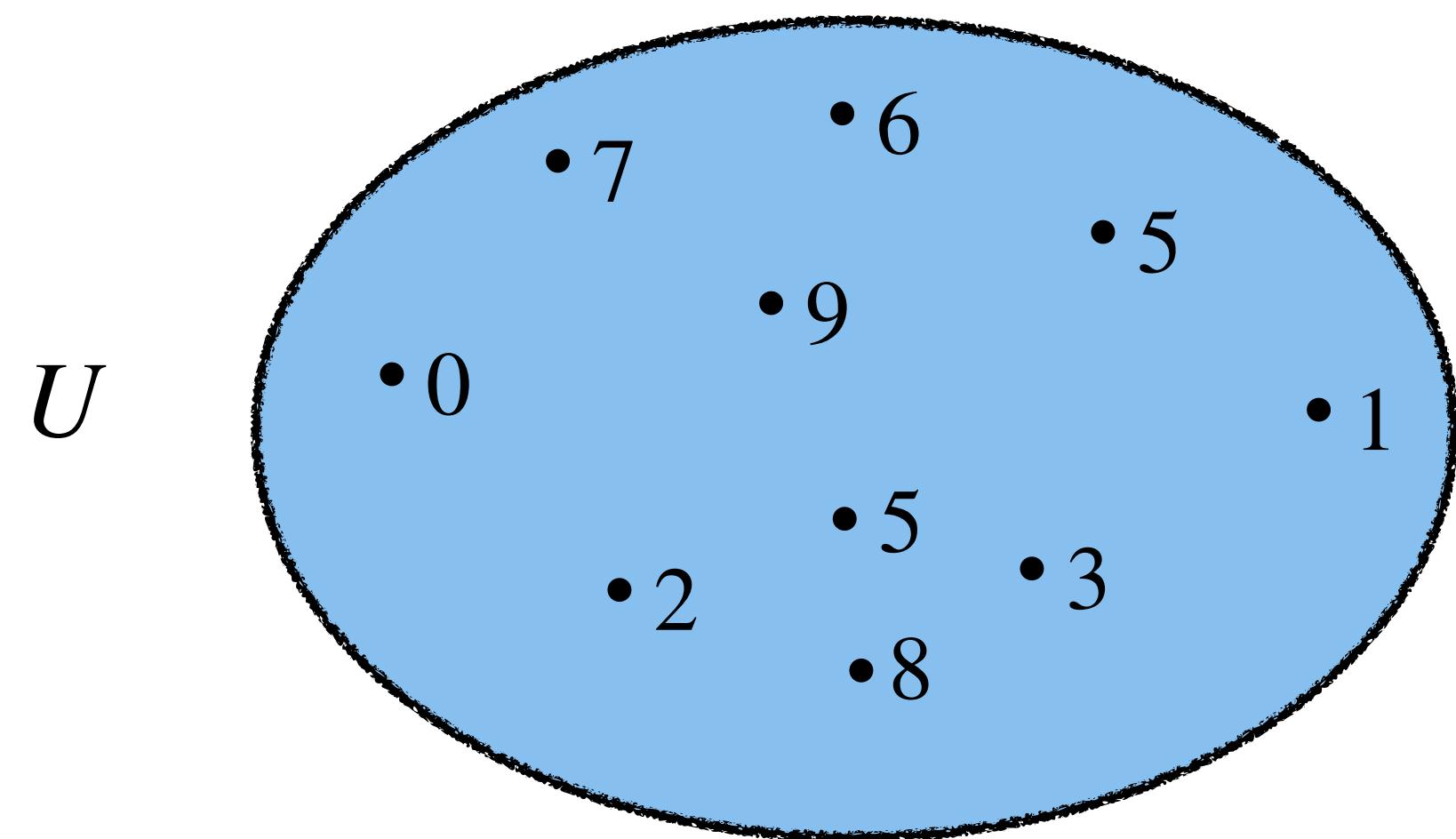
Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.key]$.

Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.

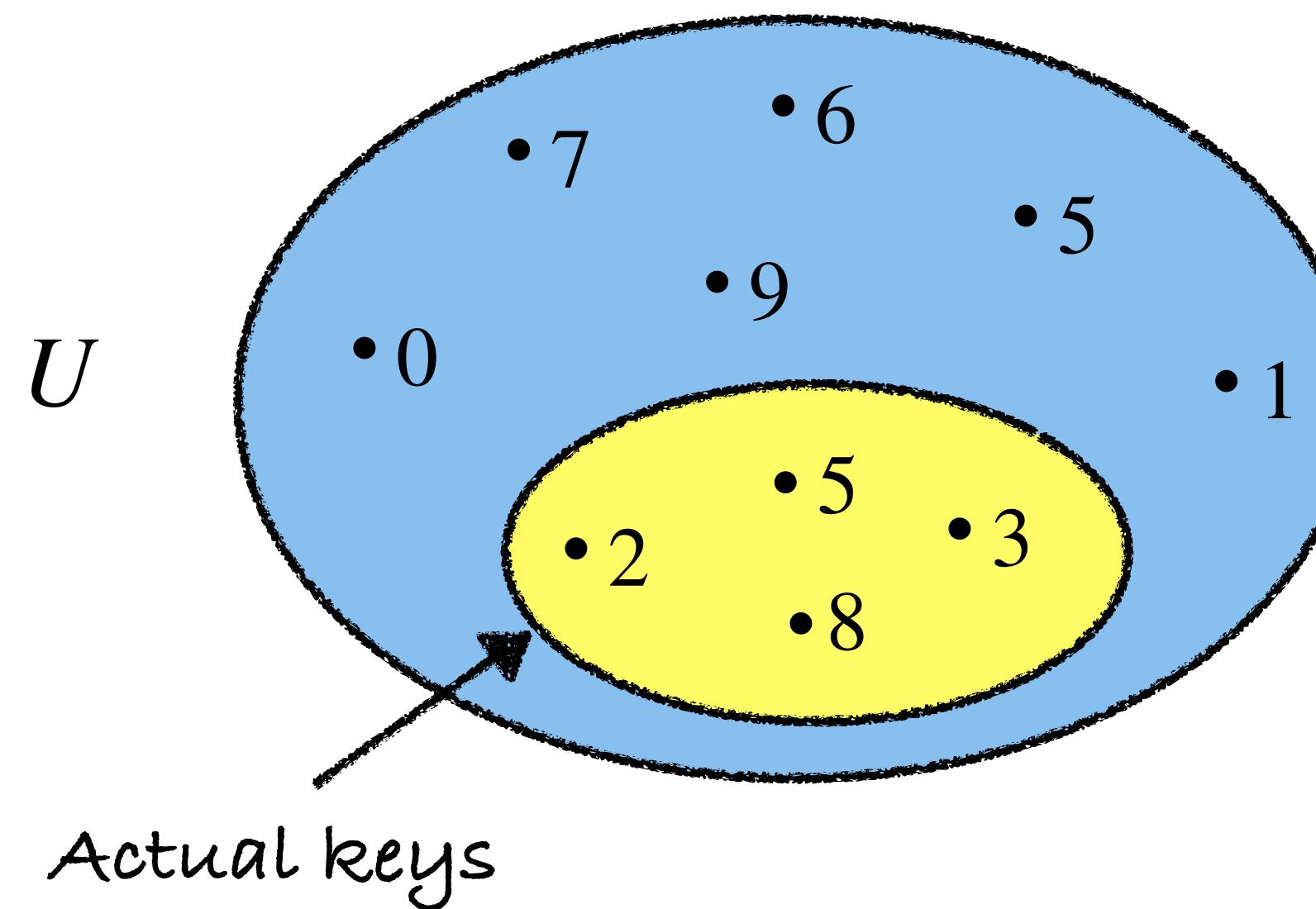


Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.

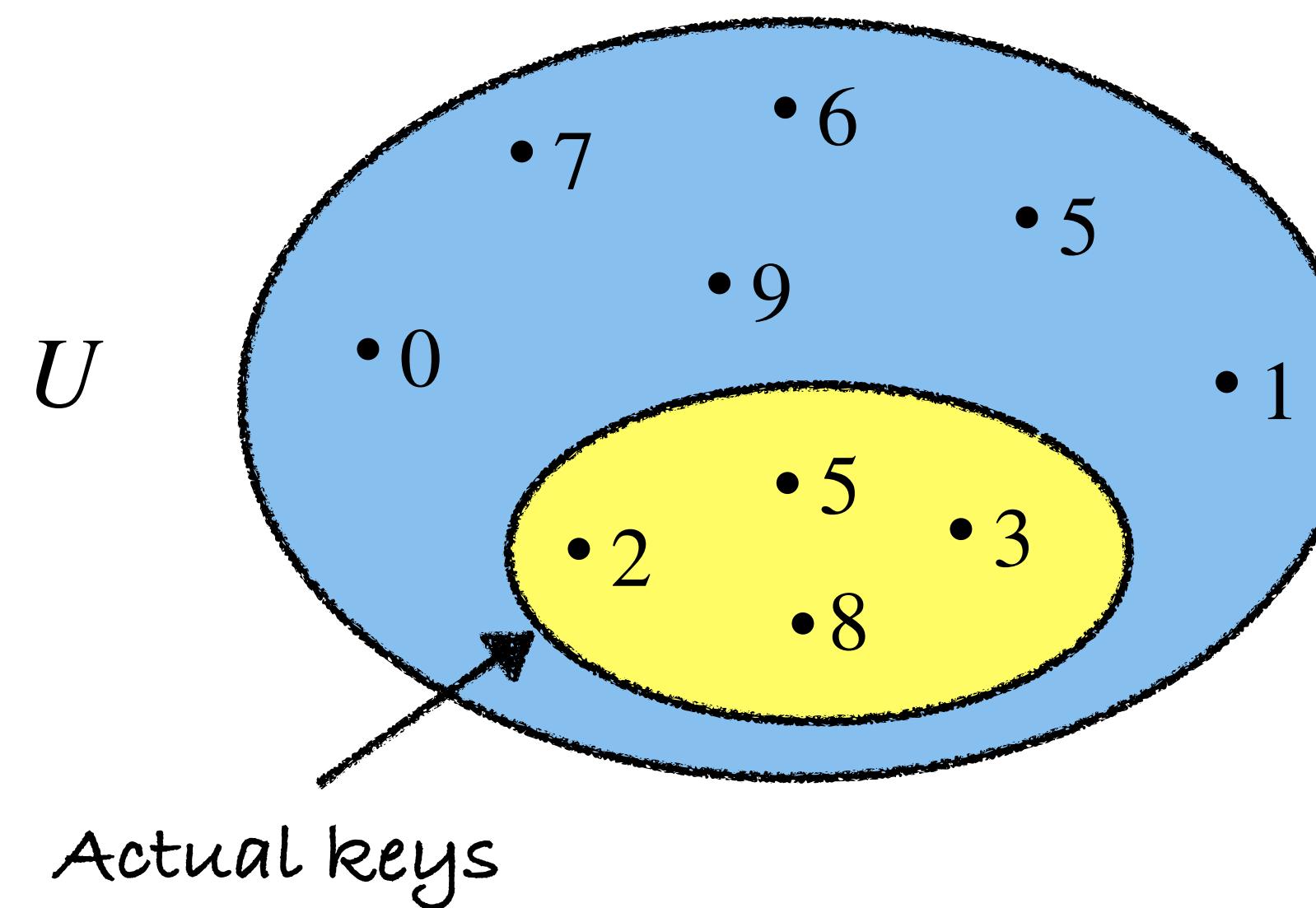


Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.



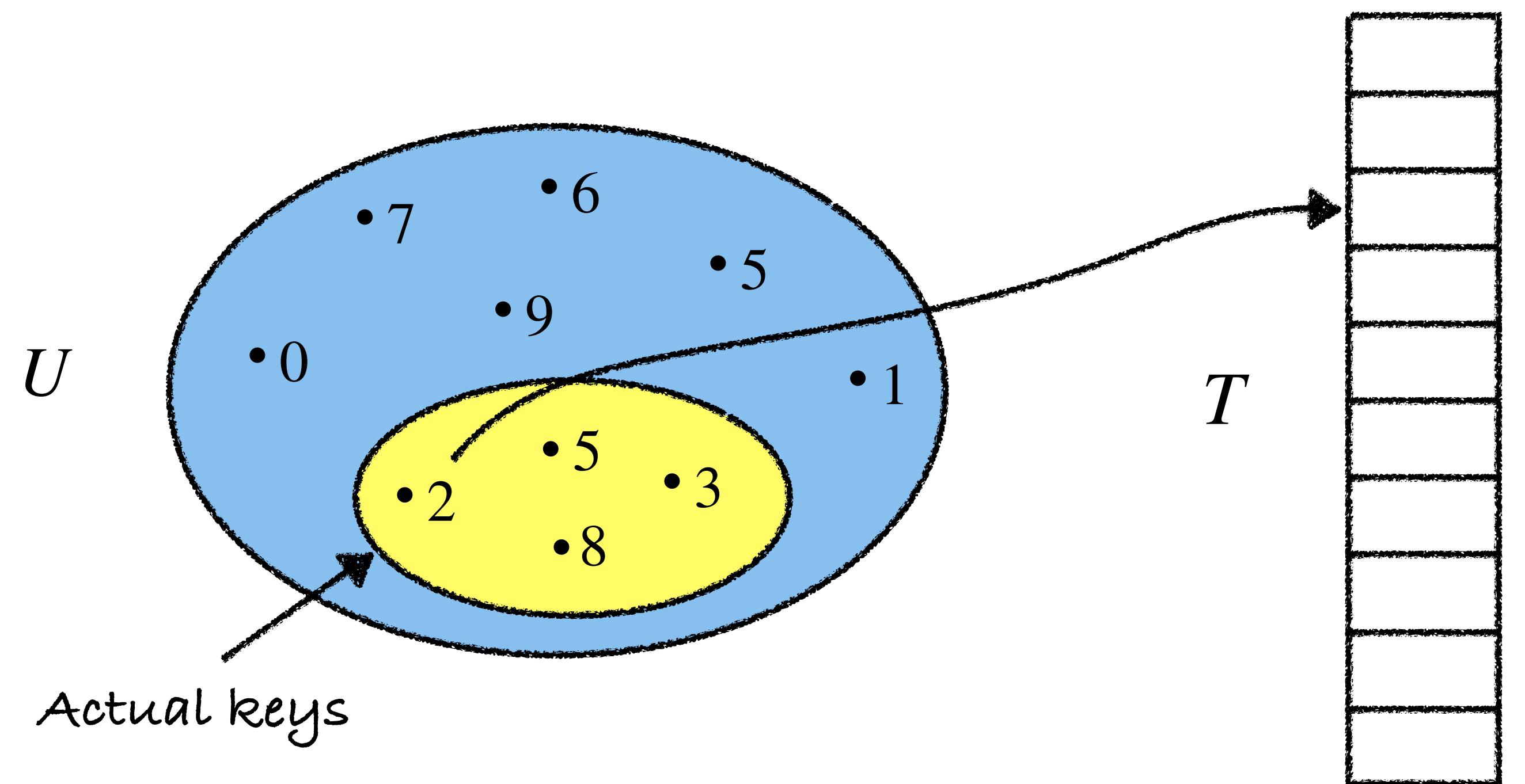
T	0
	1
	2
	3
	4
	5
	6
	7
	8
	9

Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.

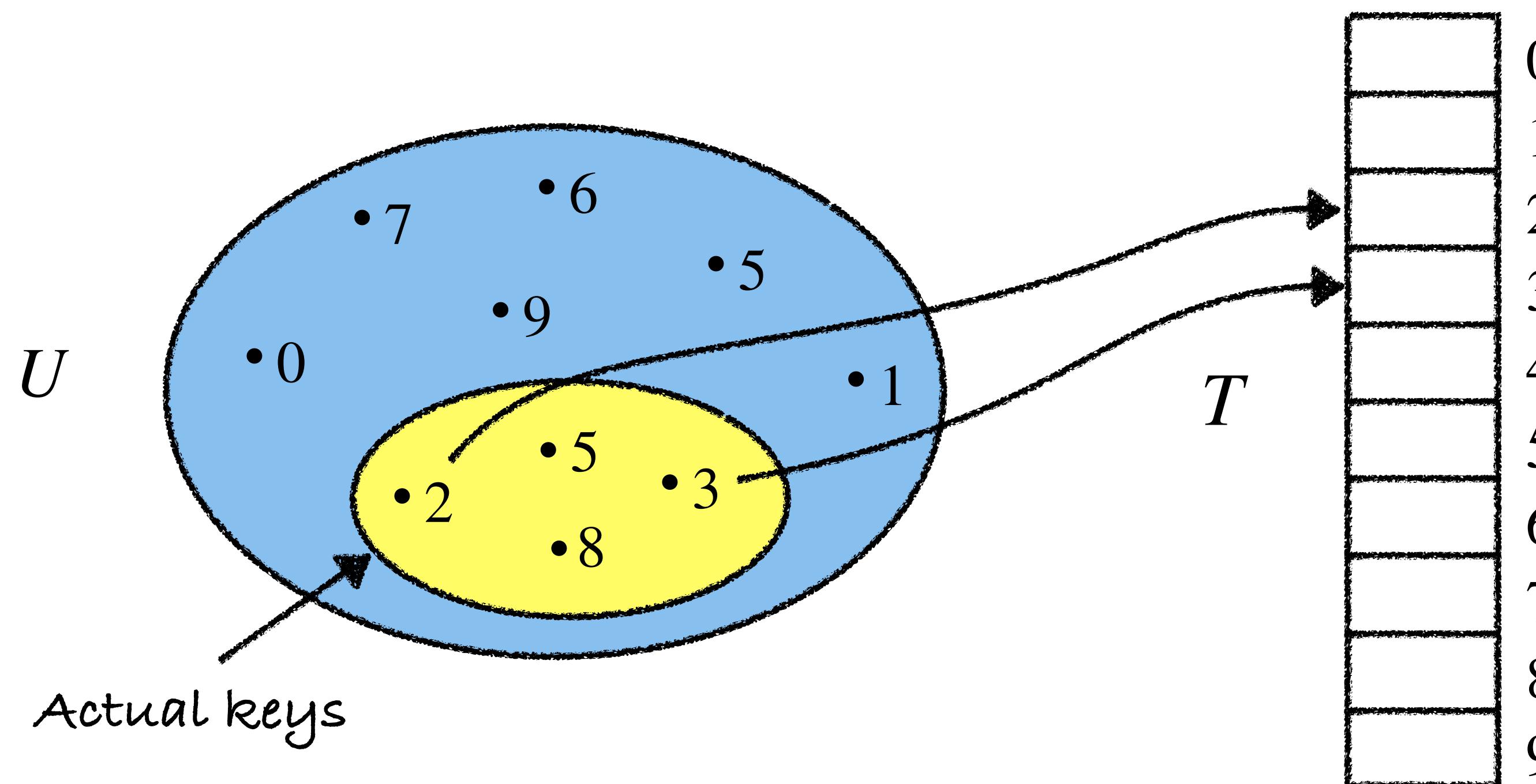


Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.

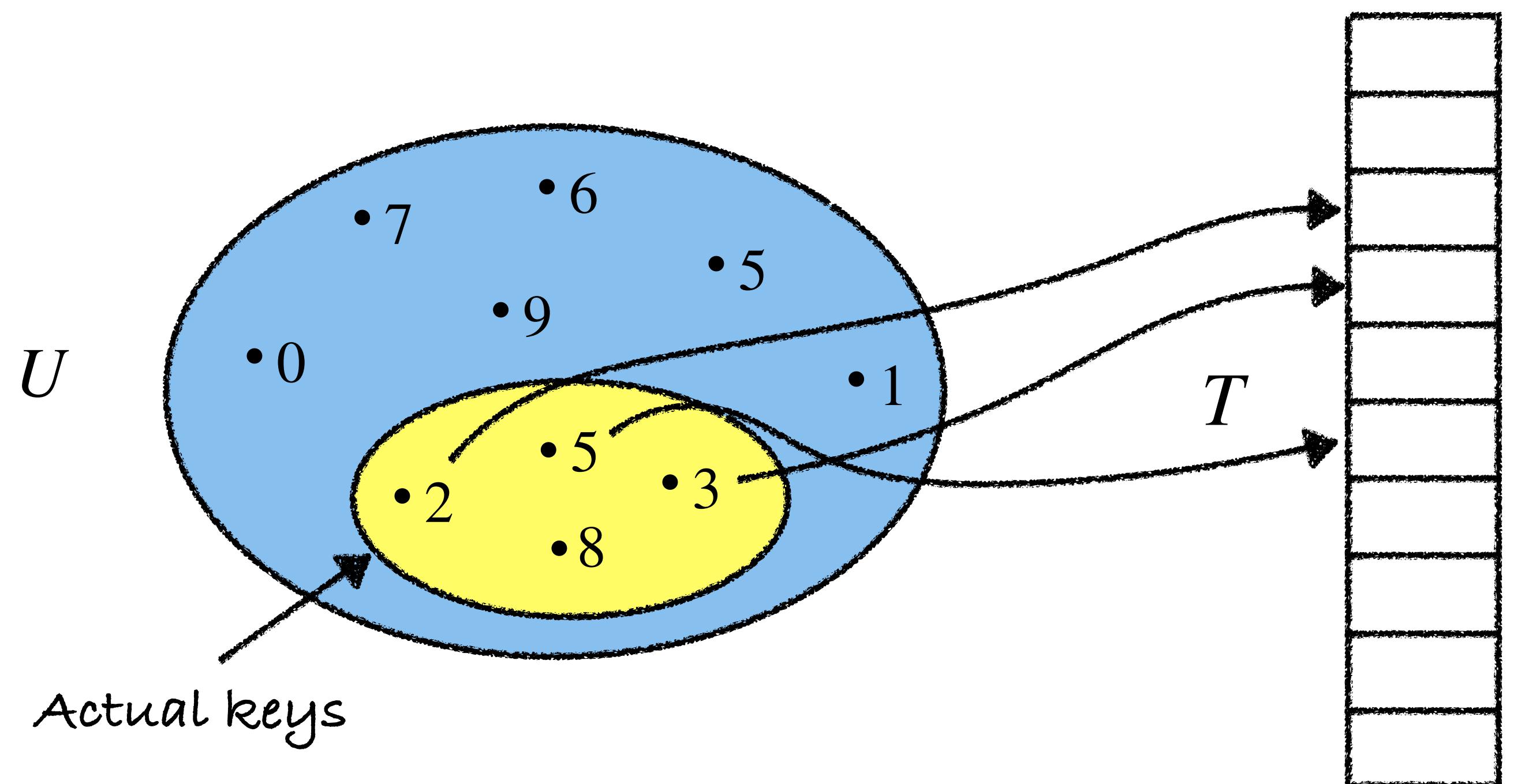


Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.

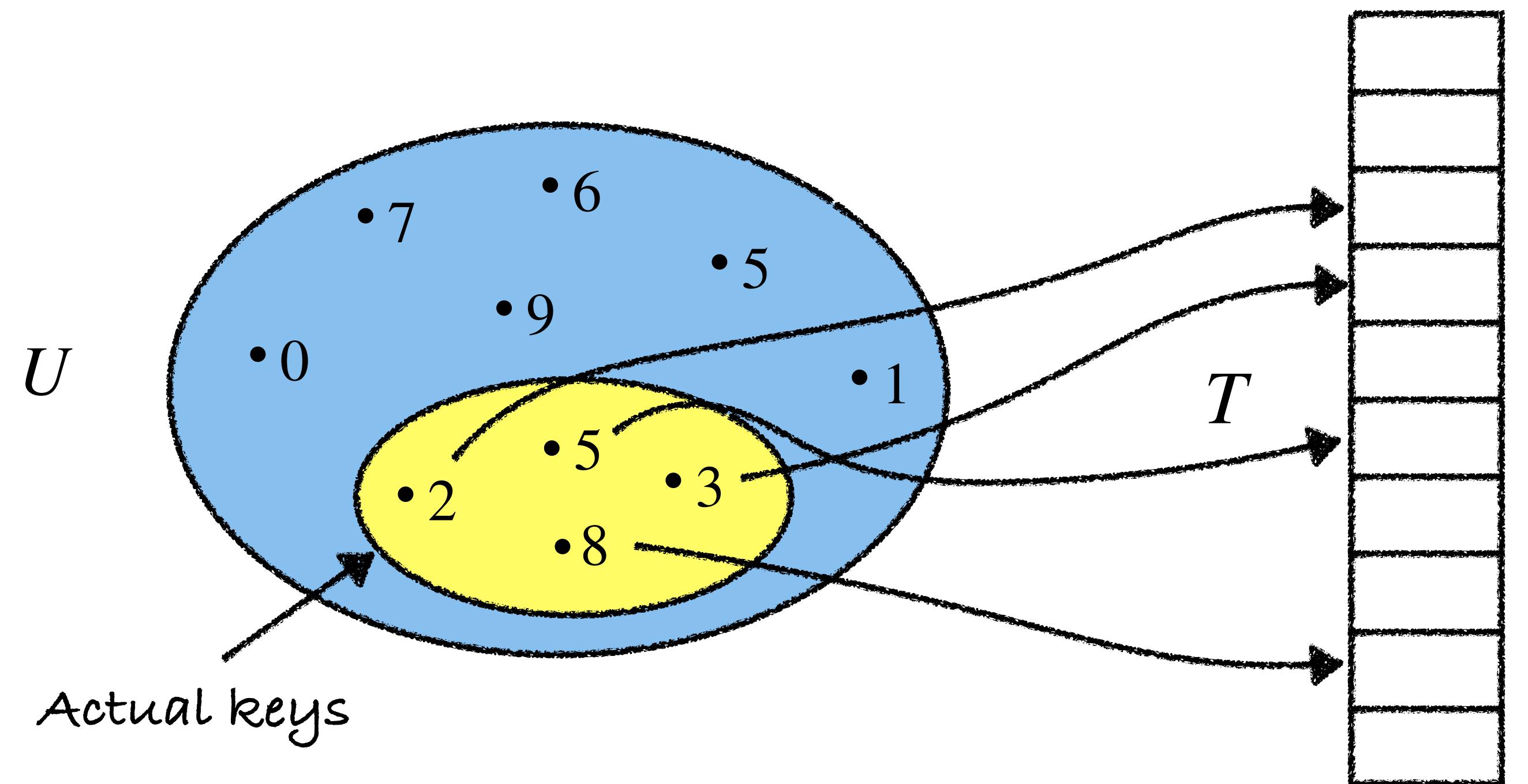


Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.

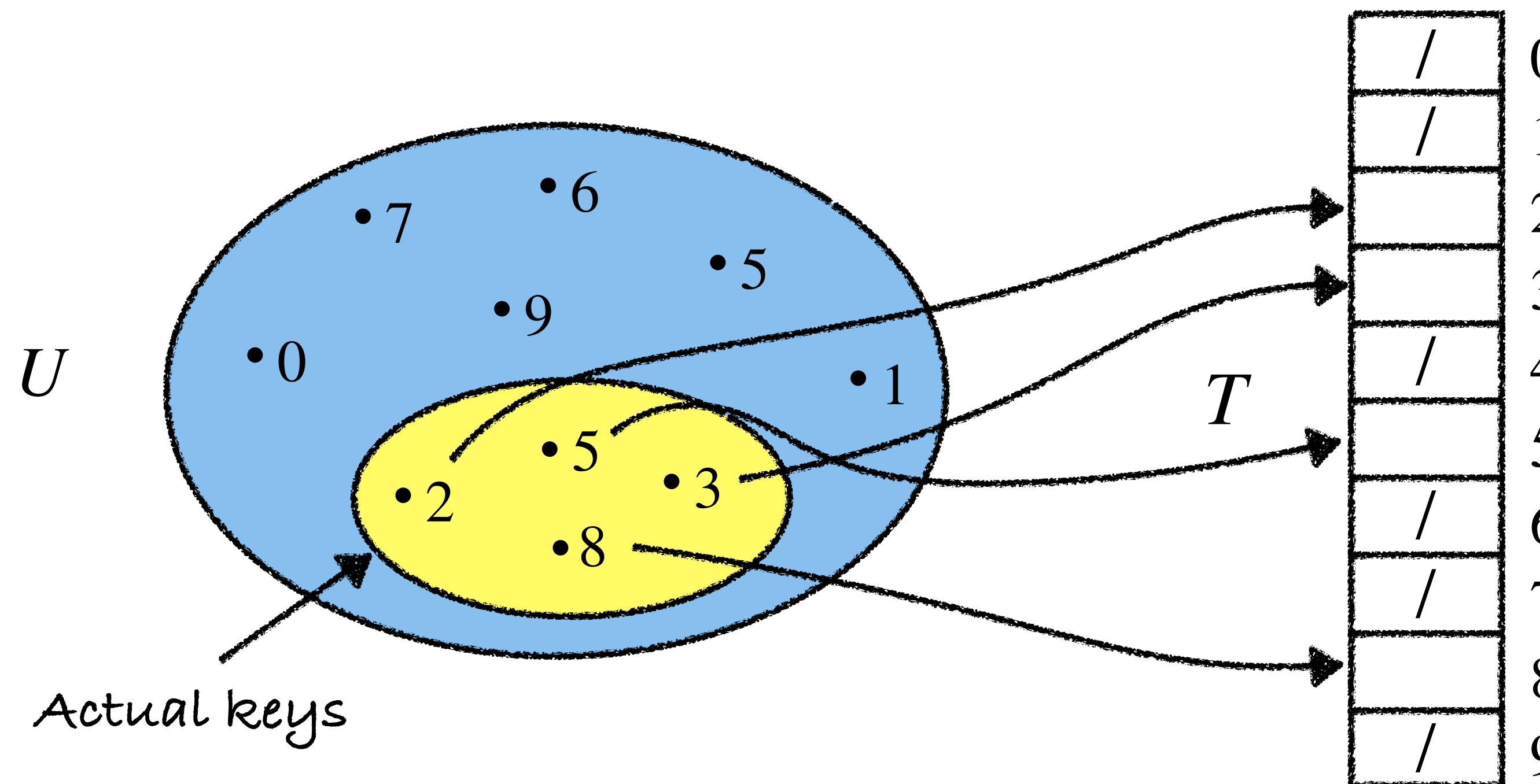


Direct-address Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, m - 1\}$$

Then, we can use an array or a **direct-address table**, denoted by $T[0 : m - 1]$, to represent the dynamic set, in which element x resides in $T[x.\text{key}]$.



Direct-address Tables: Operations

Direct-address Tables: Operations

DAT-INSERT(T, x):

Direct-address Tables: Operations

DAT-INSERT(T, x):

1. $T[x.key] = x$

Direct-address Tables: Operations

DAT-INSERT(T, x):

1. $T[x.key] = x$

DAT-SEARCH(T, k):

Direct-address Tables: Operations

DAT-INSERT(T, x):

1. $T[x.key] = x$

DAT-SEARCH(T, k):

1. **return** $T[k]$

Direct-address Tables: Operations

DAT-INSERT(T, x):

1. $T[x.key] = x$

DAT-SEARCH(T, k):

1. **return** $T[k]$

DAT-DELETE(T, x):

Direct-address Tables: Operations

DAT-INSERT(T, x):

1. $T[x.key] = x$

DAT-SEARCH(T, k):

1. **return** $T[k]$

DAT-DELETE(T, x):

1. $T[x.key] = NIL$

Direct-address Tables: Operations

DAT-INSERT(T, x):

1. $T[x.key] = x$

Time complexity: $O(1)$

DAT-SEARCH(T, k):

1. **return** $T[k]$

Time complexity: $O(1)$

DAT-DELETE(T, x):

1. $T[x.key] = NIL$

Time complexity: $O(1)$

Direct-address Tables: Cons

Direct-address Tables: Cons

A downside of direct-address tables:

Direct-address Tables: Cons

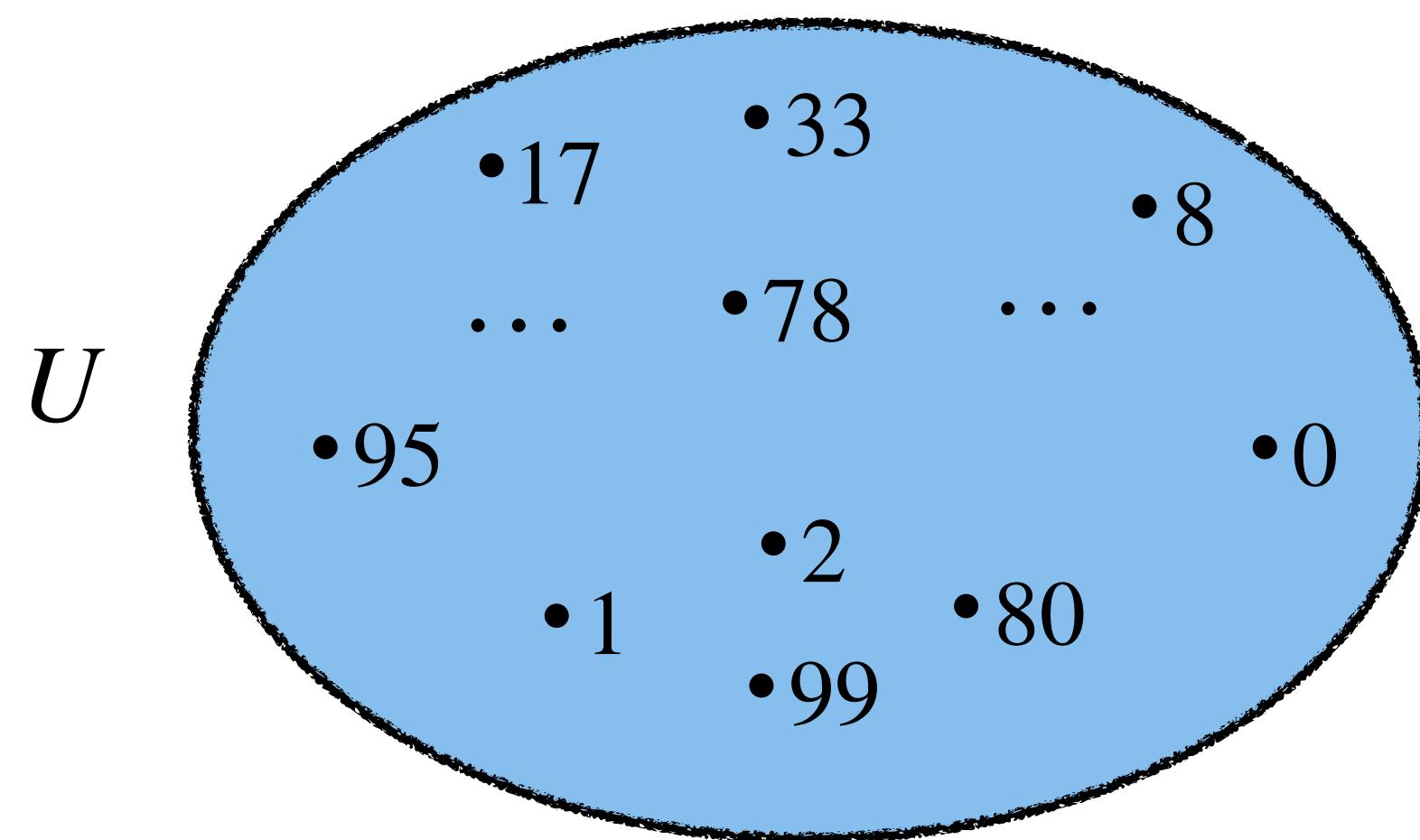
A downside of direct-address tables:

Large universe of keys but small number of elements causes wastage of space.

Direct-address Tables: Cons

A downside of direct-address tables:

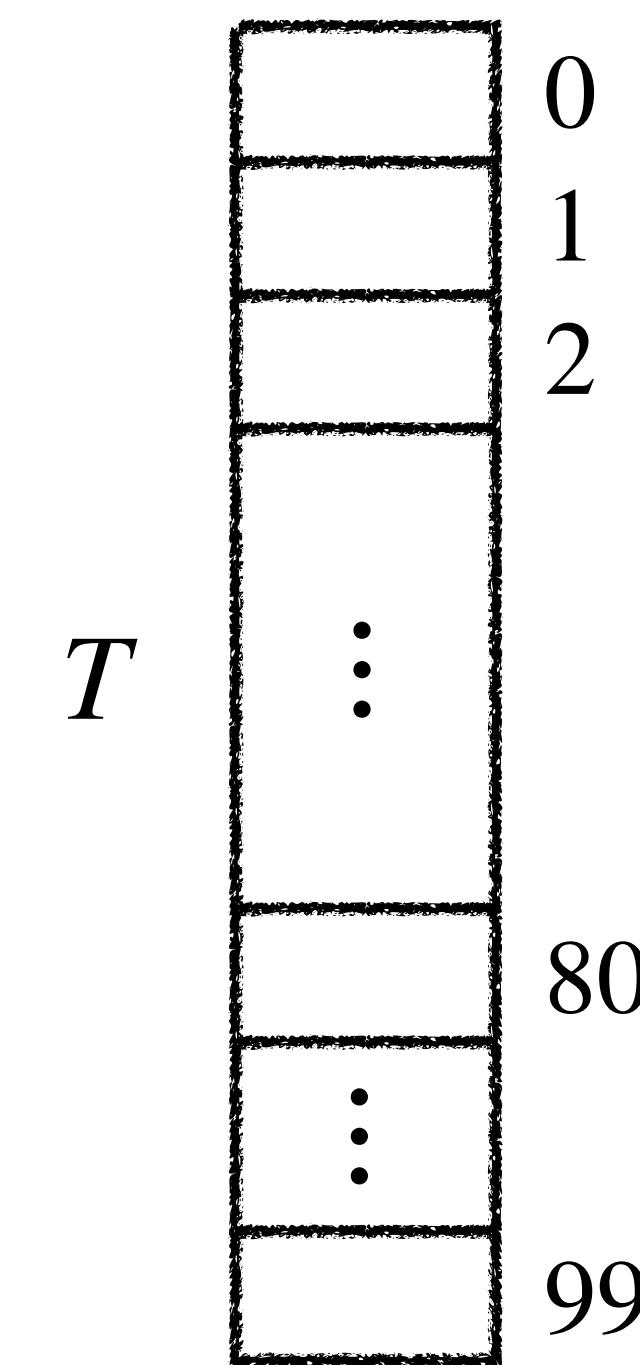
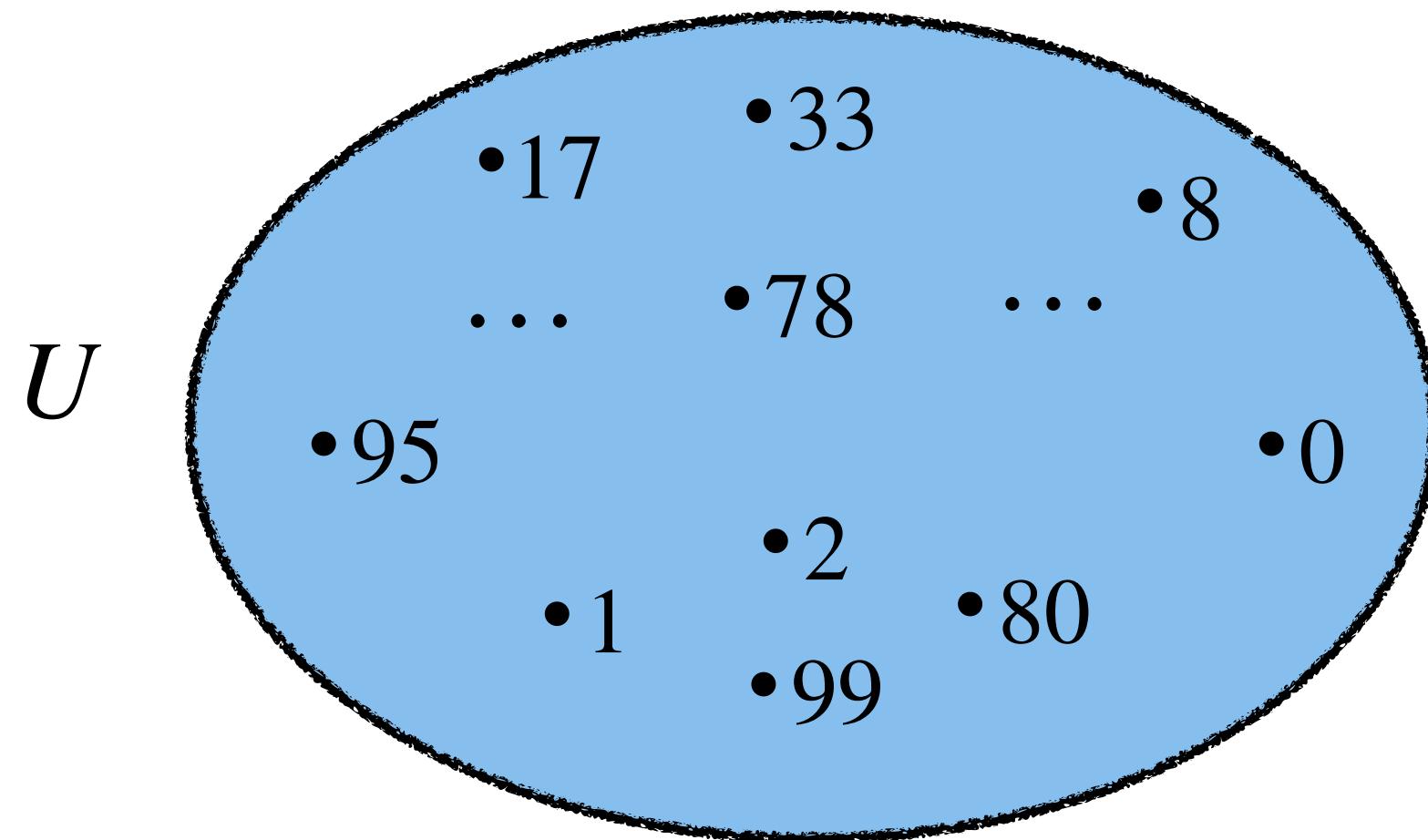
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

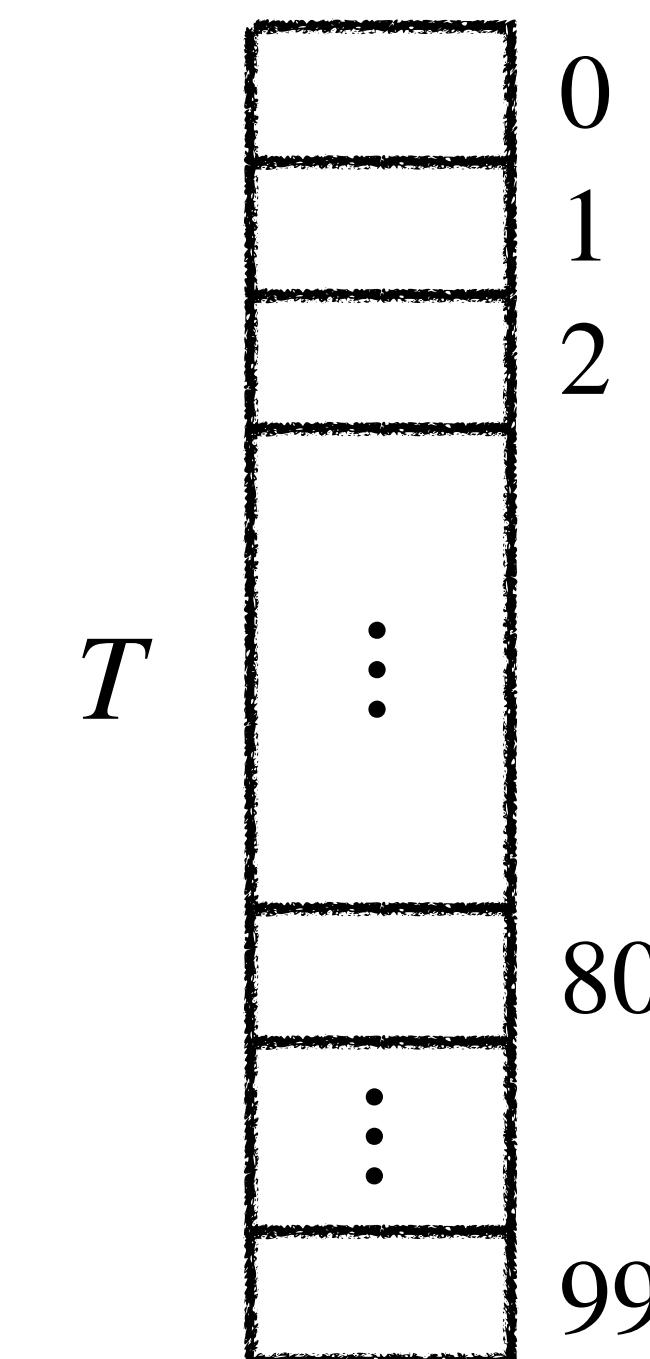
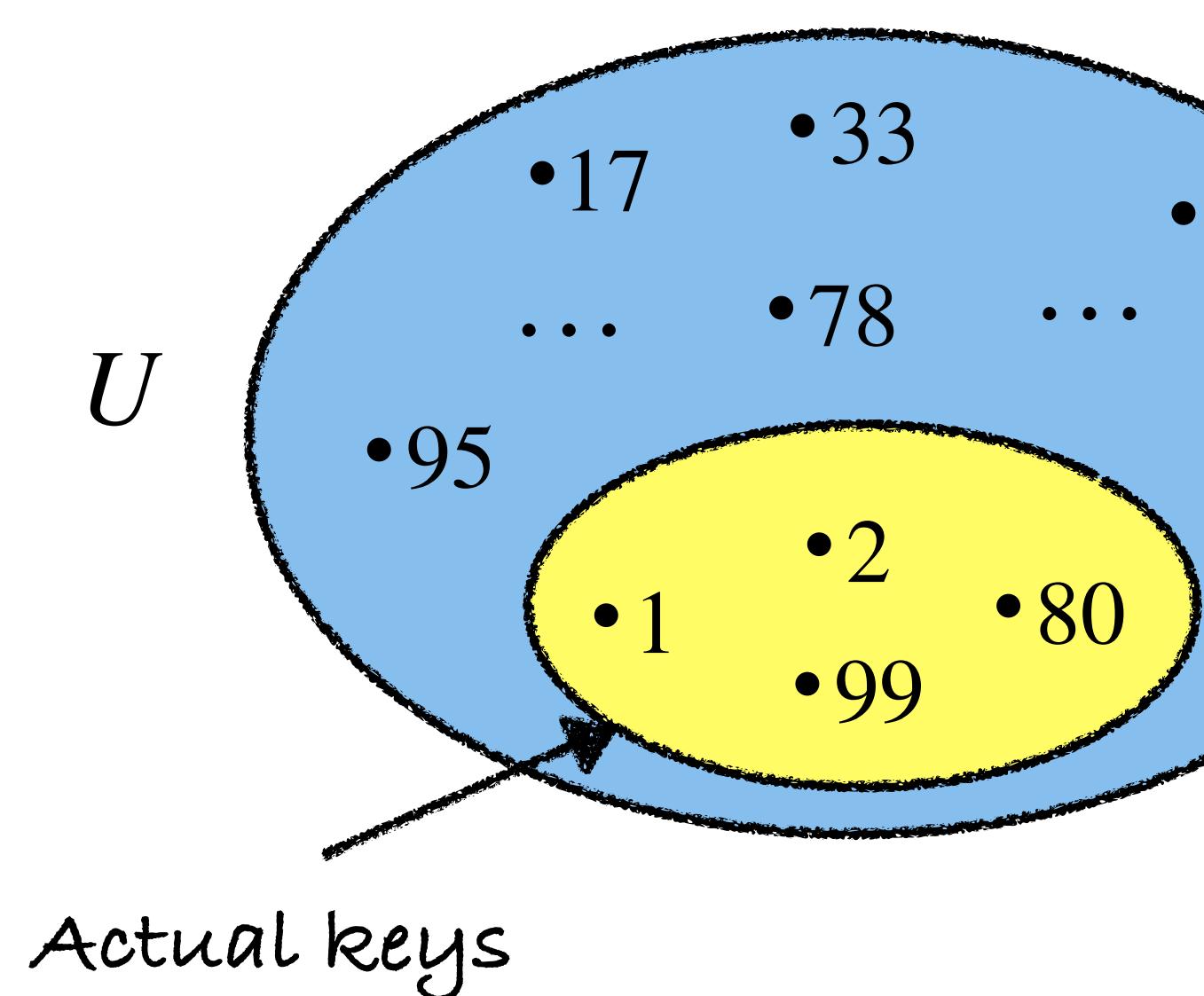
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

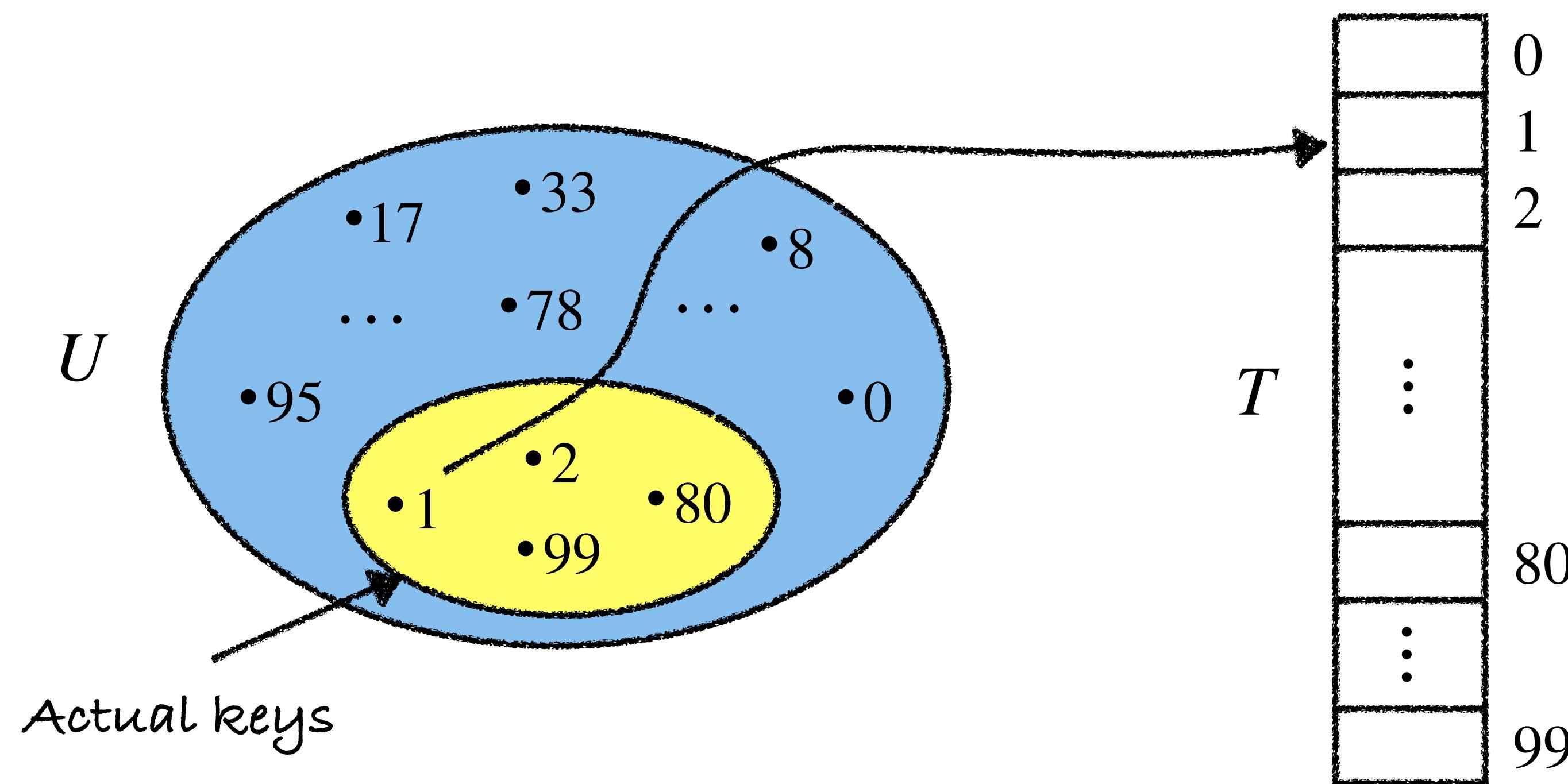
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

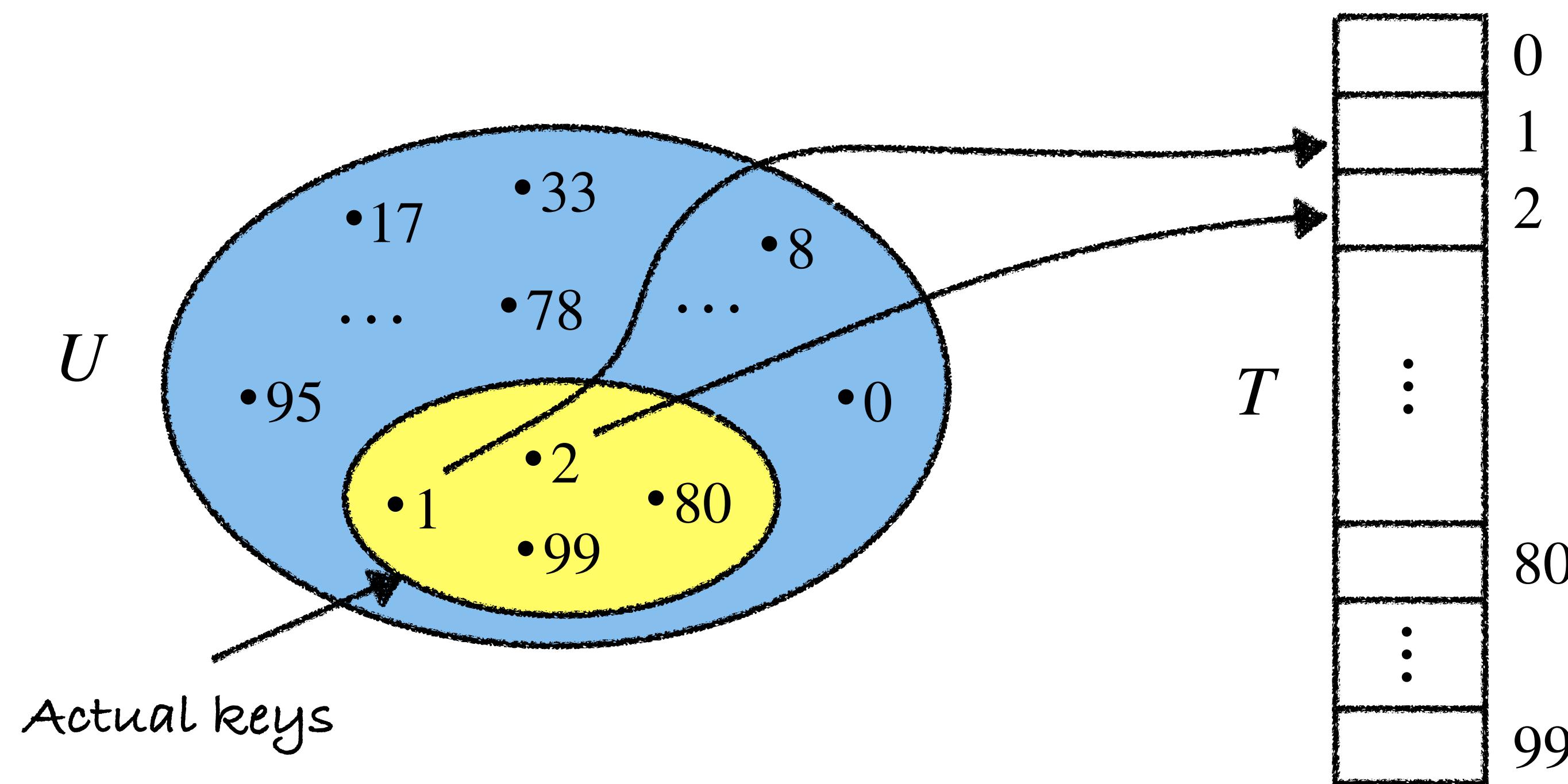
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

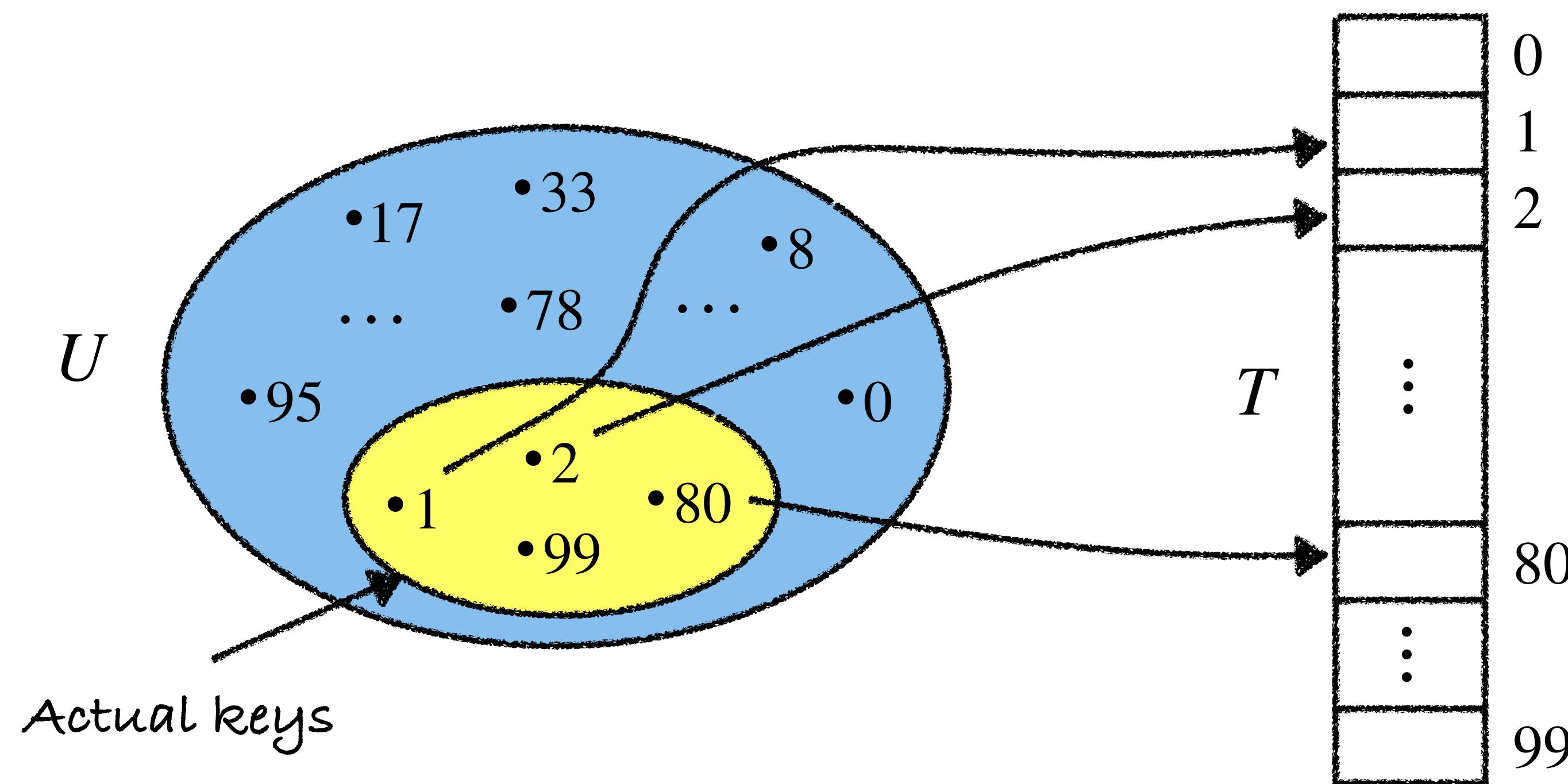
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

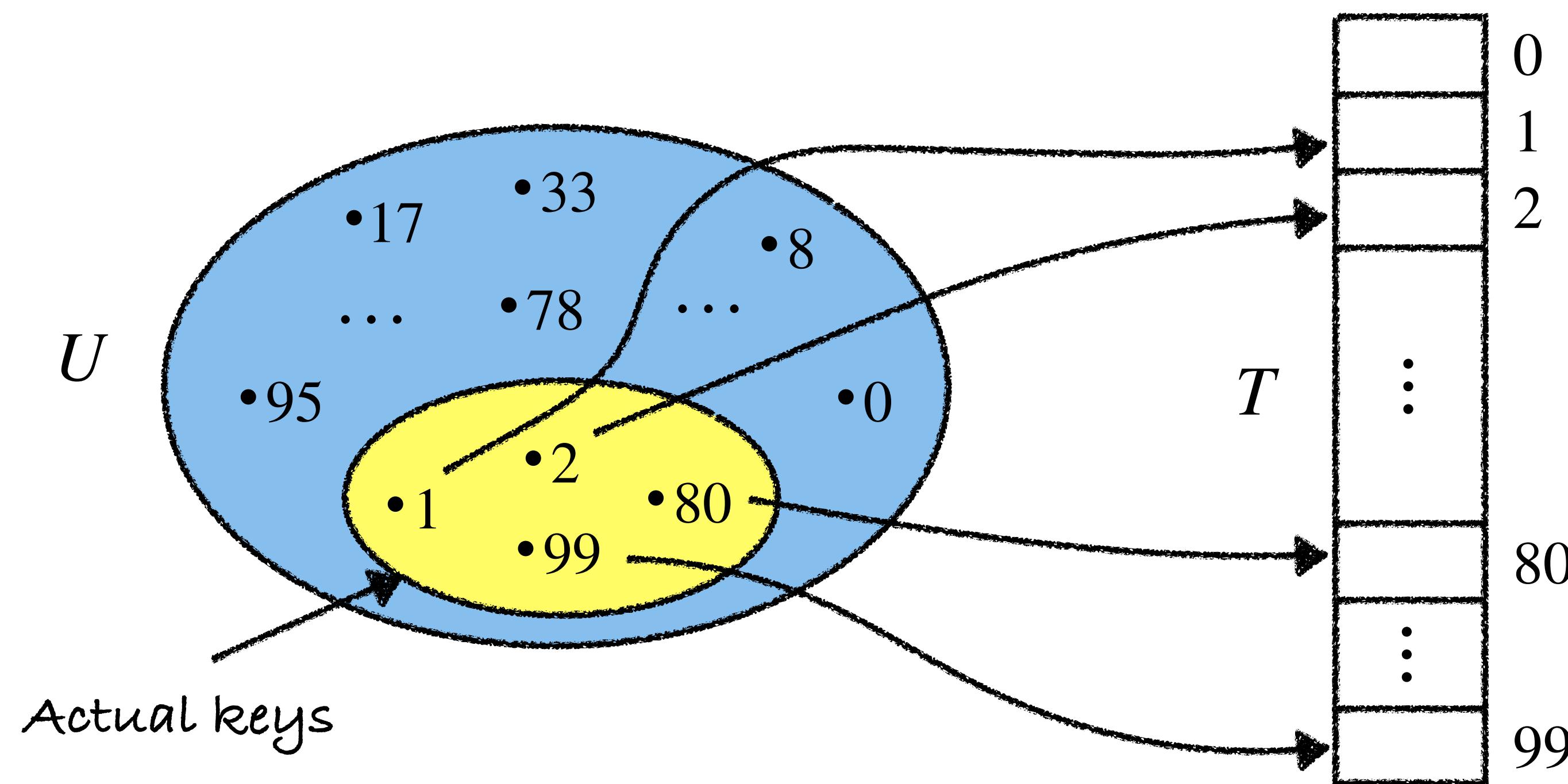
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

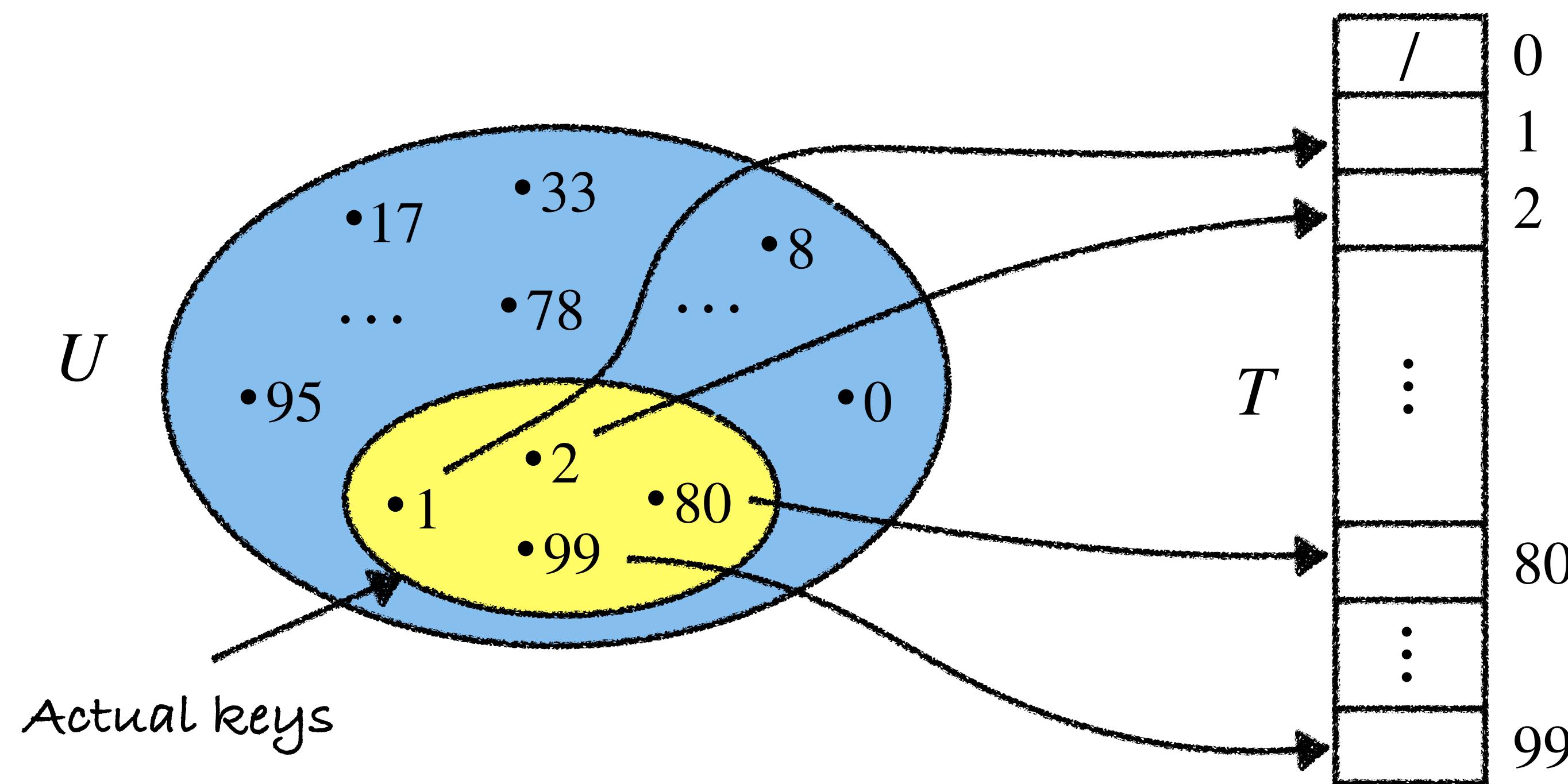
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

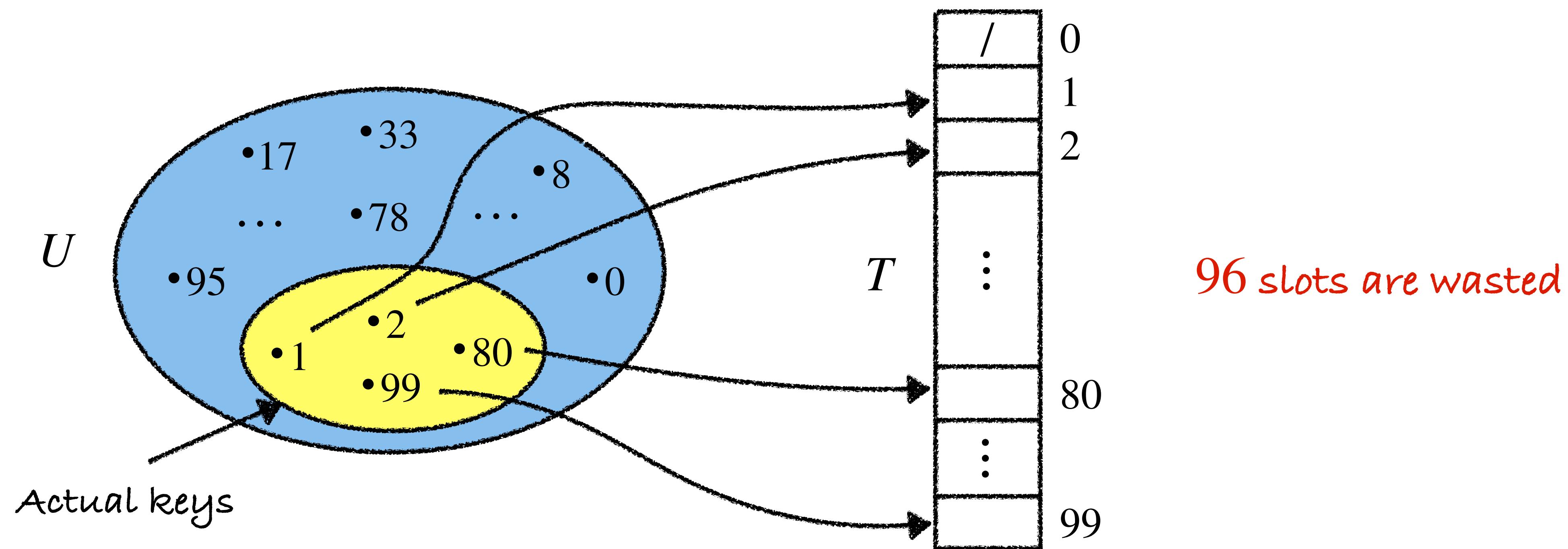
Large universe of keys but small number of elements causes wastage of space.



Direct-address Tables: Cons

A downside of direct-address tables:

Large universe of keys but small number of elements causes wastage of space.



Hash Tables

Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$,

Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$,

Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.

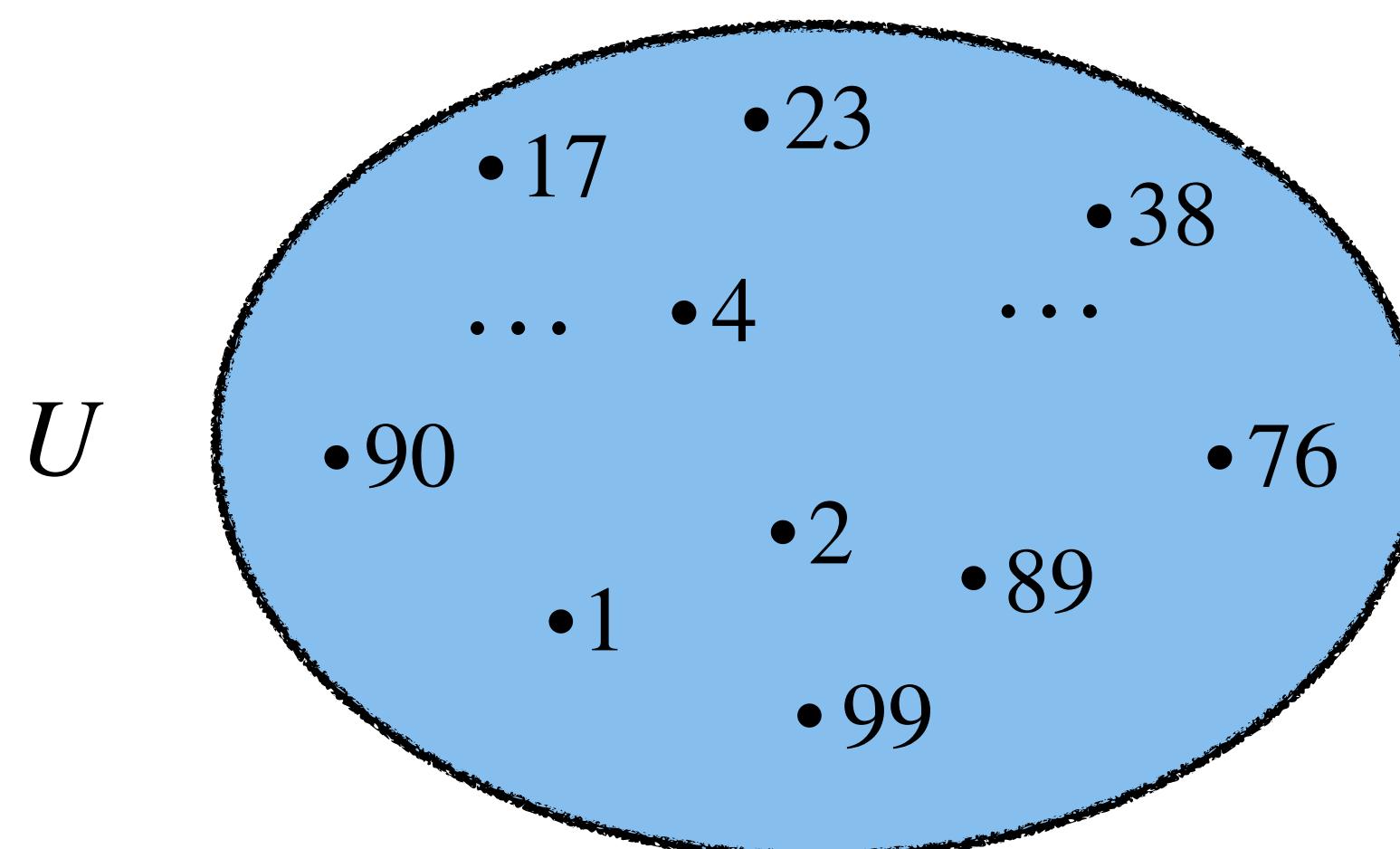
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



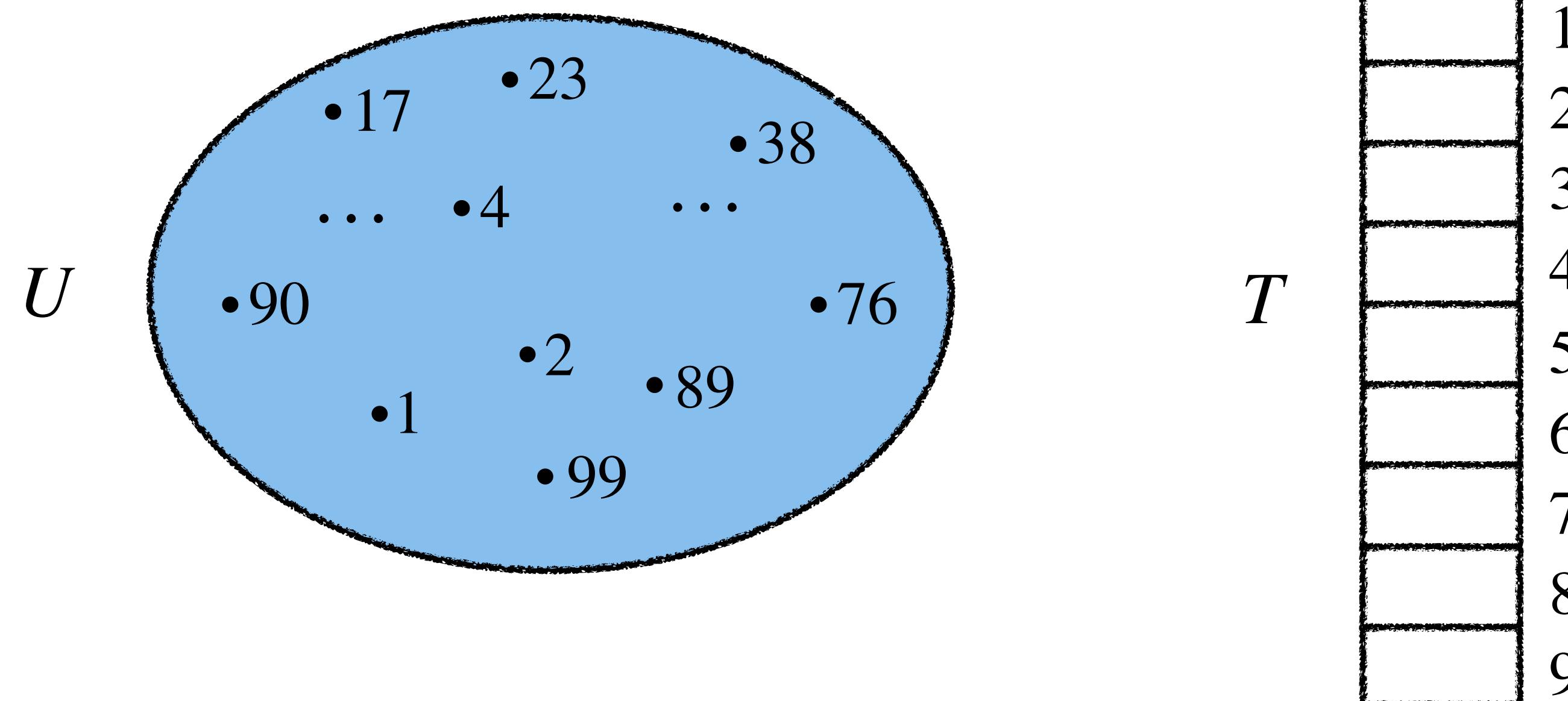
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



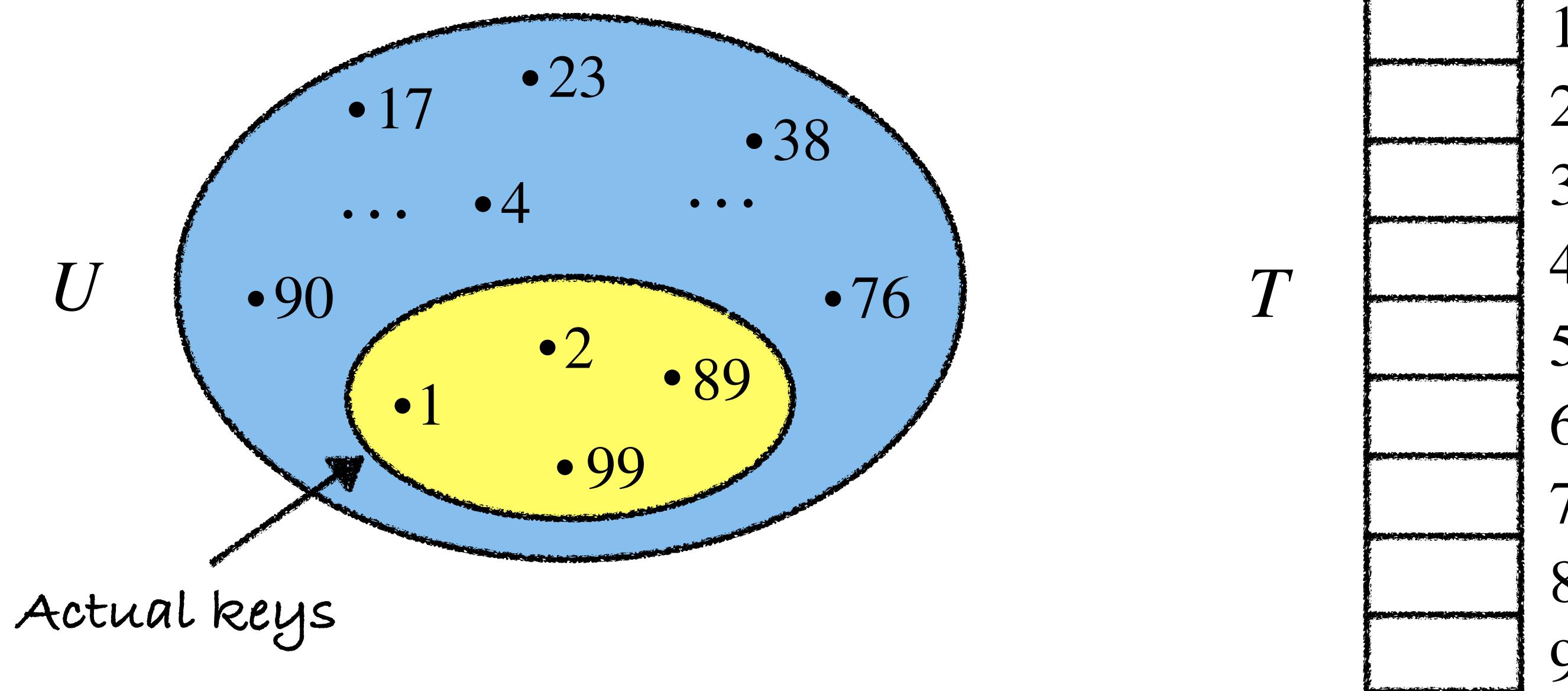
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



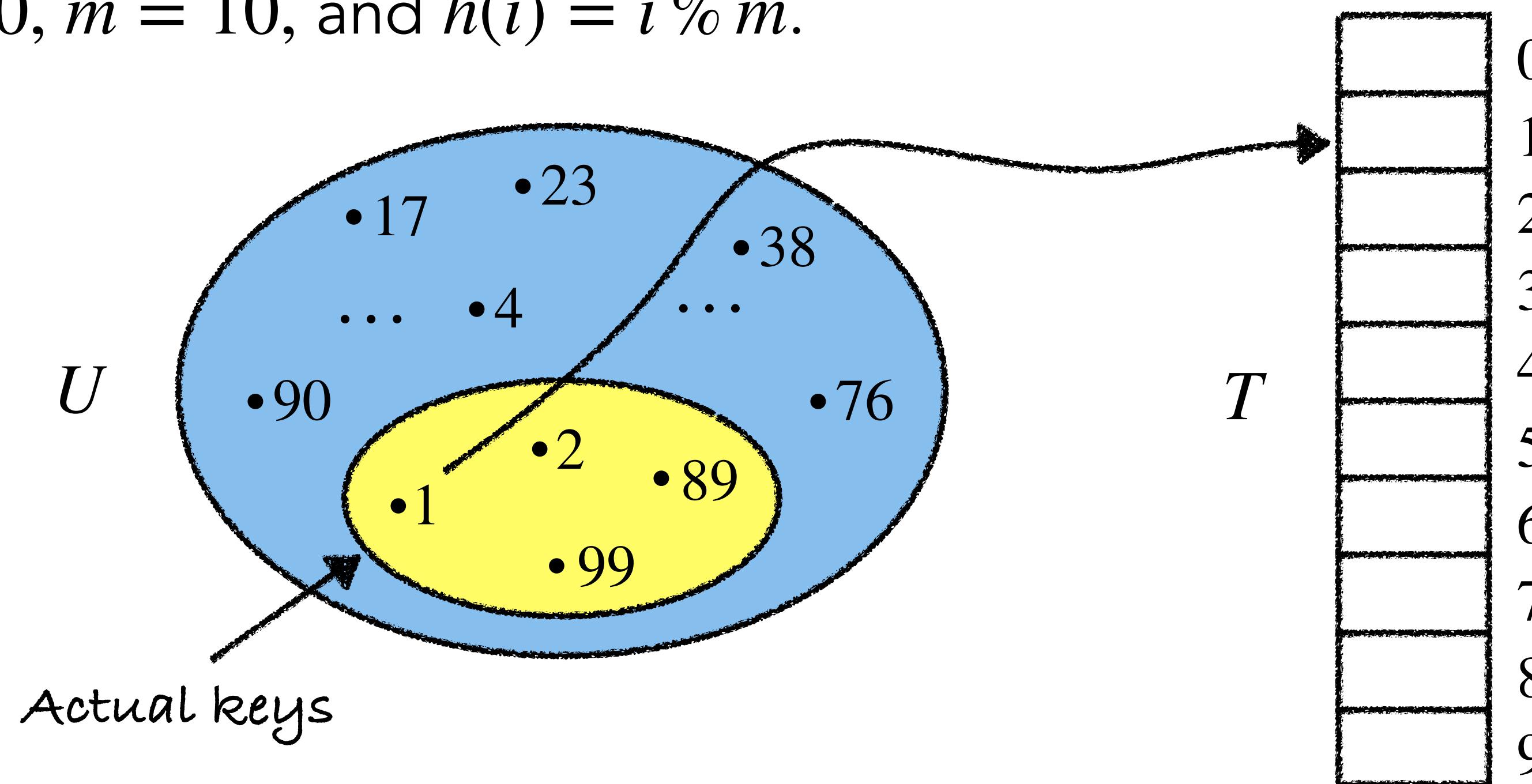
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



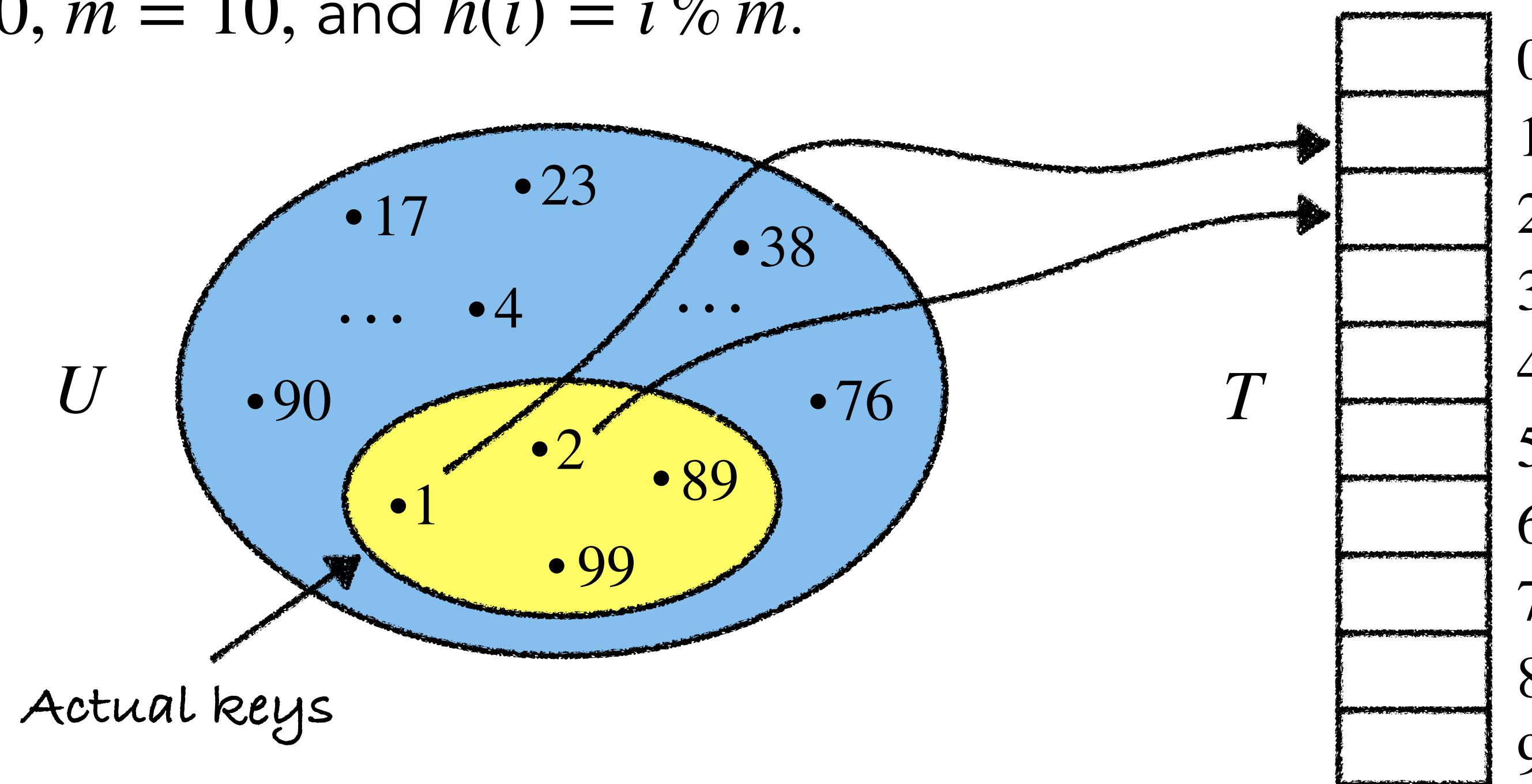
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



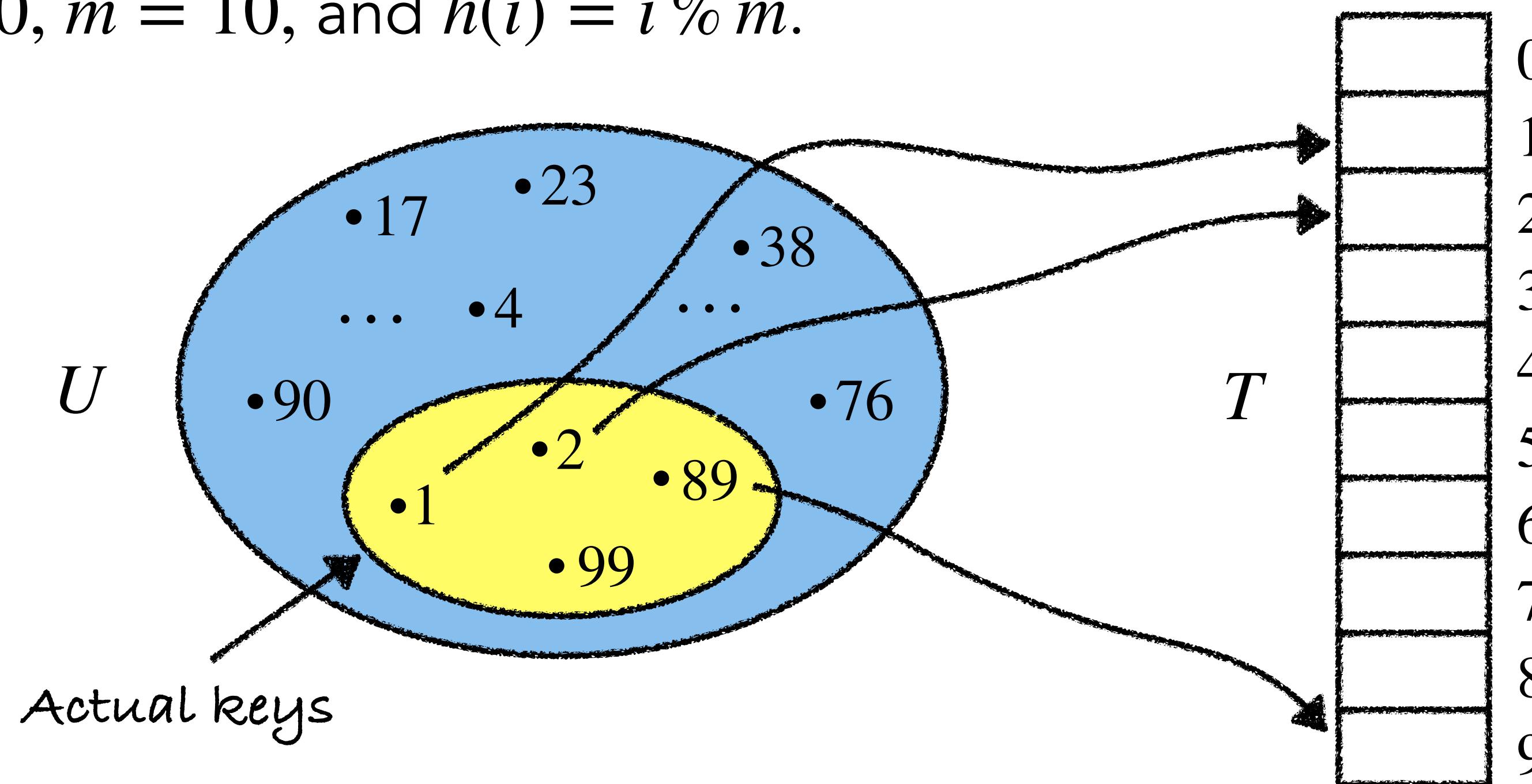
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



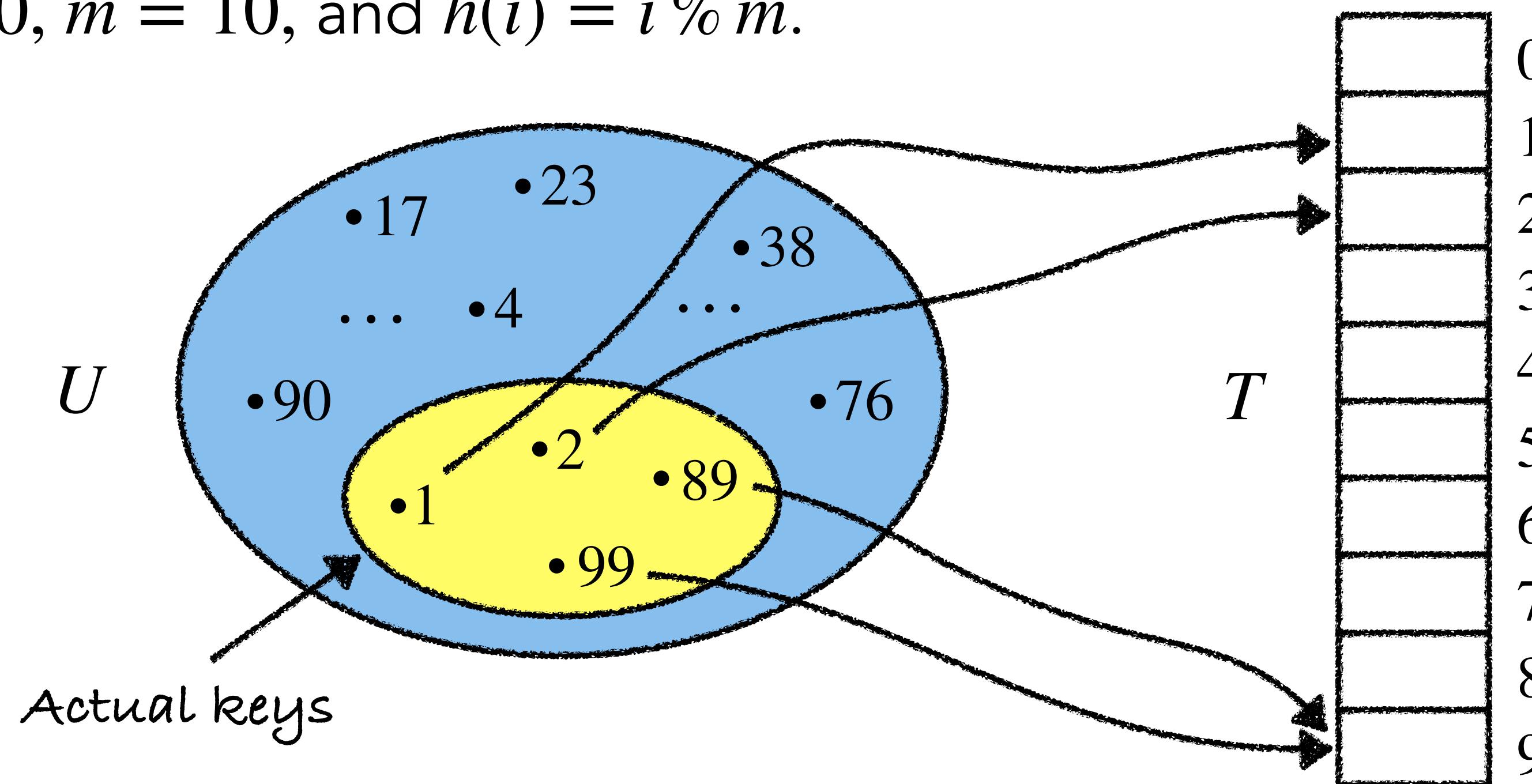
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



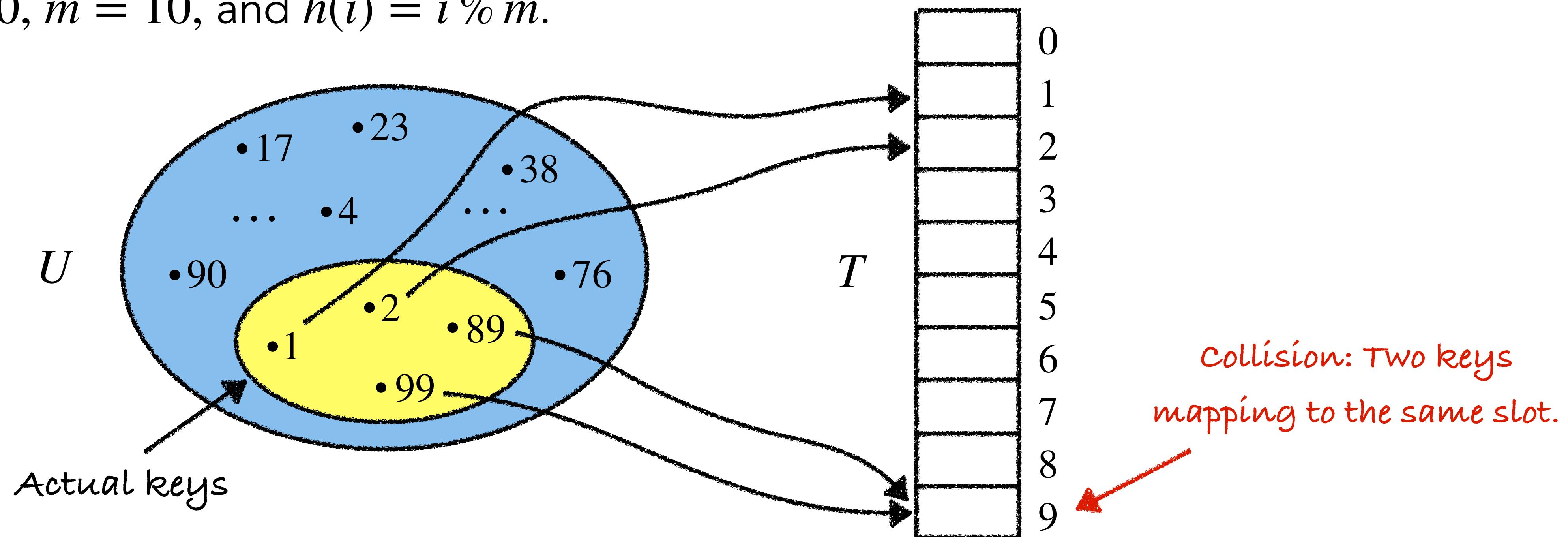
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



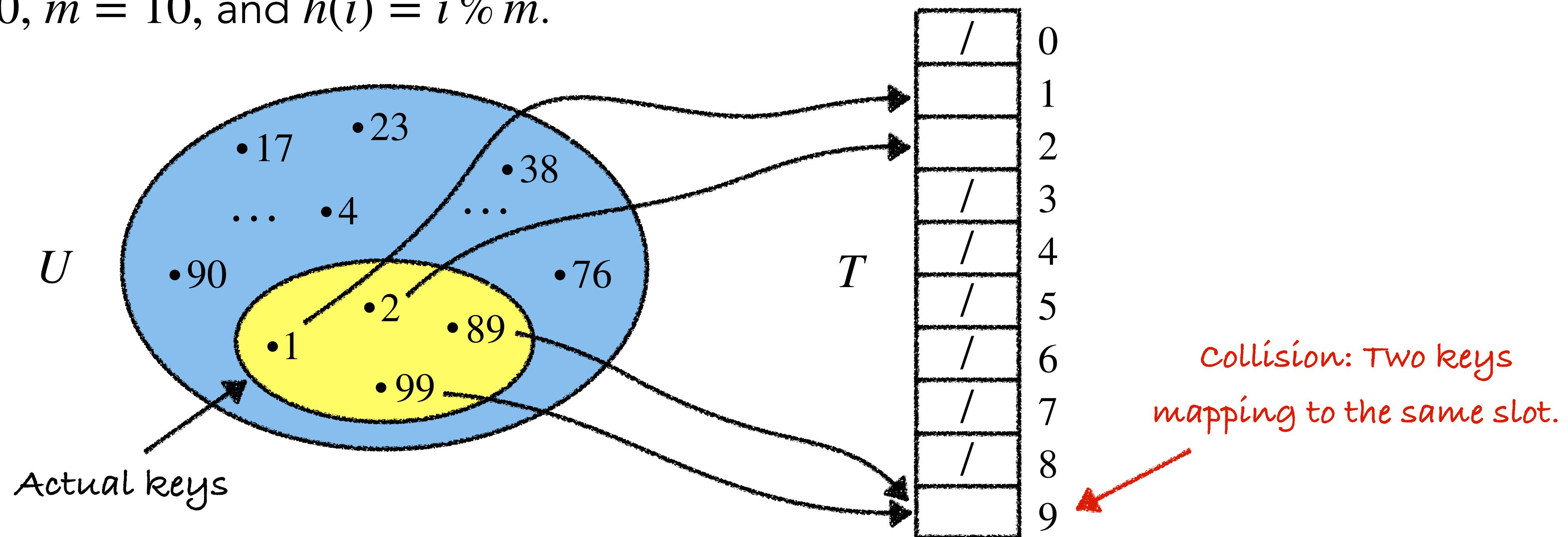
Hash Tables

Suppose every element of the dynamic set has a **distinct key** from the universe U .

$$U = \{0, 1, \dots, n - 1\}$$

In a **hash table**, denoted by $T[0 : m - 1]$, where $m < n$, element x resides in $T[h(x.key)]$, where $h: U \rightarrow \{0, 1, \dots, m - 1\}$ is a **hash function**.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Hash Tables: Chaining

Chaining is a way to handle collisions,

Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a [linked list](#) consisting of

Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a **linked list** consisting of elements whose key hashes to the i th slot.

Hash Tables: Chaining

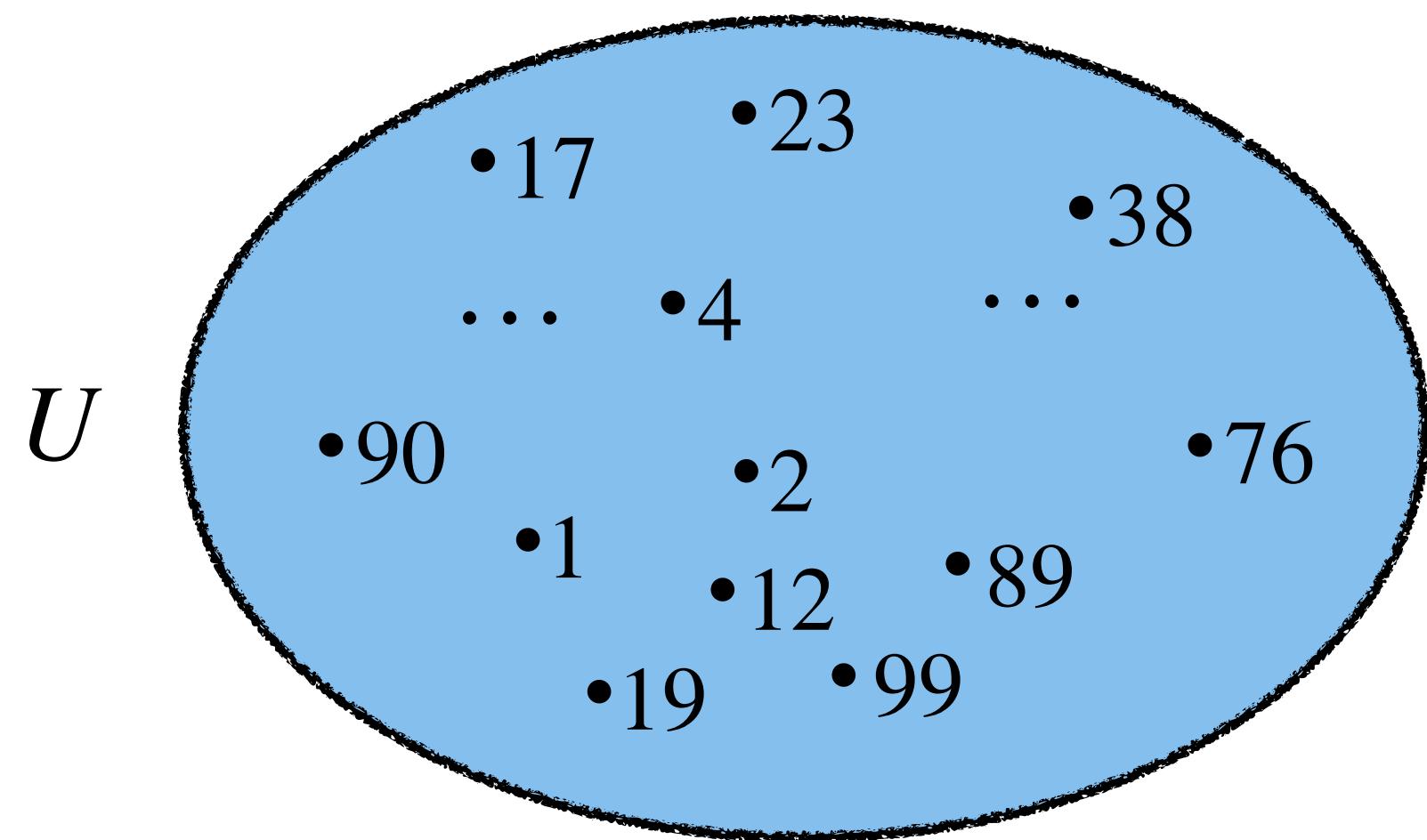
Chaining is a way to handle collisions, in which every slot $T[i]$ points to a **linked list** consisting of elements whose key hashes to the i th slot.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.

Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a **linked list** consisting of elements whose key hashes to the i th slot.

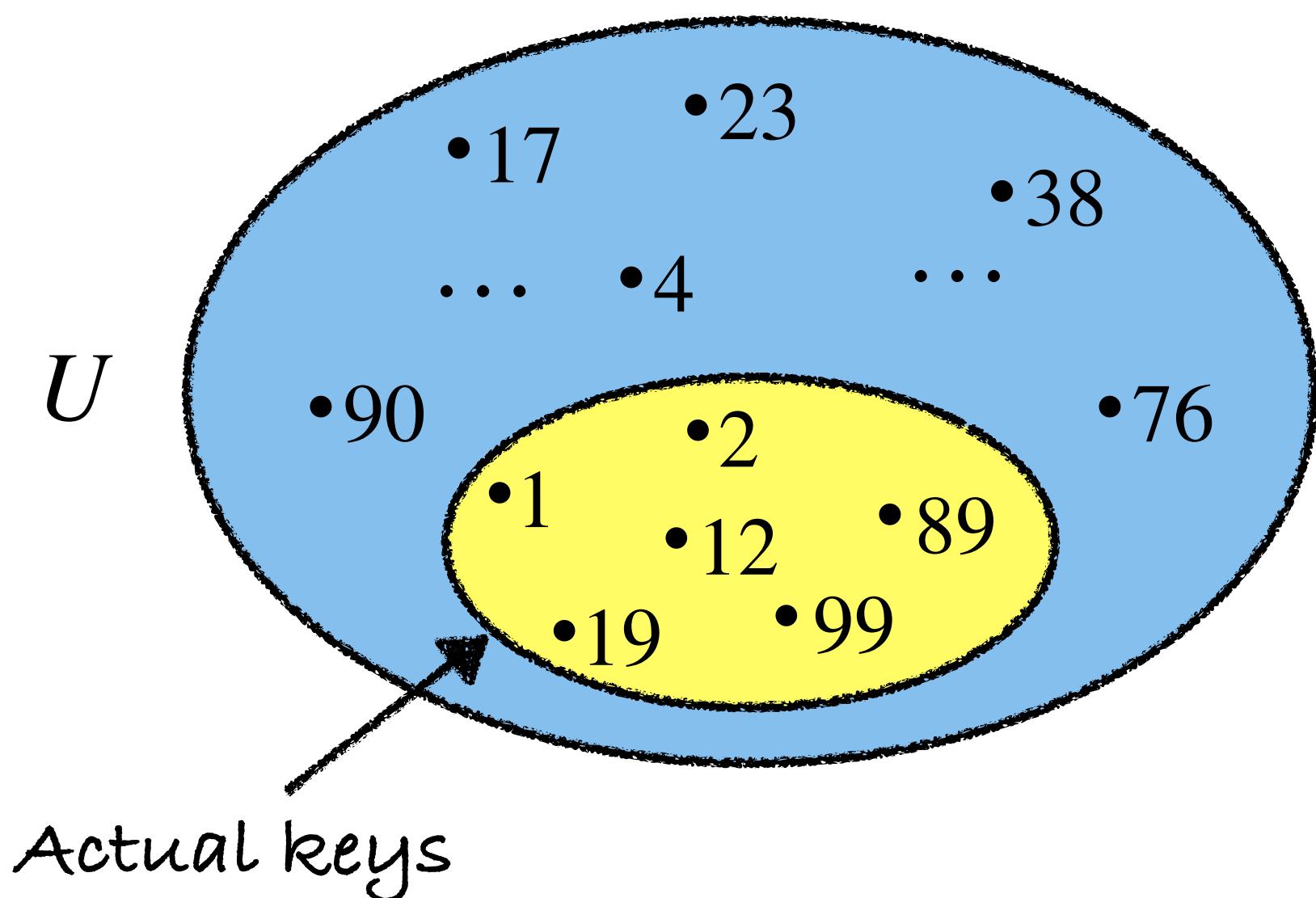
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

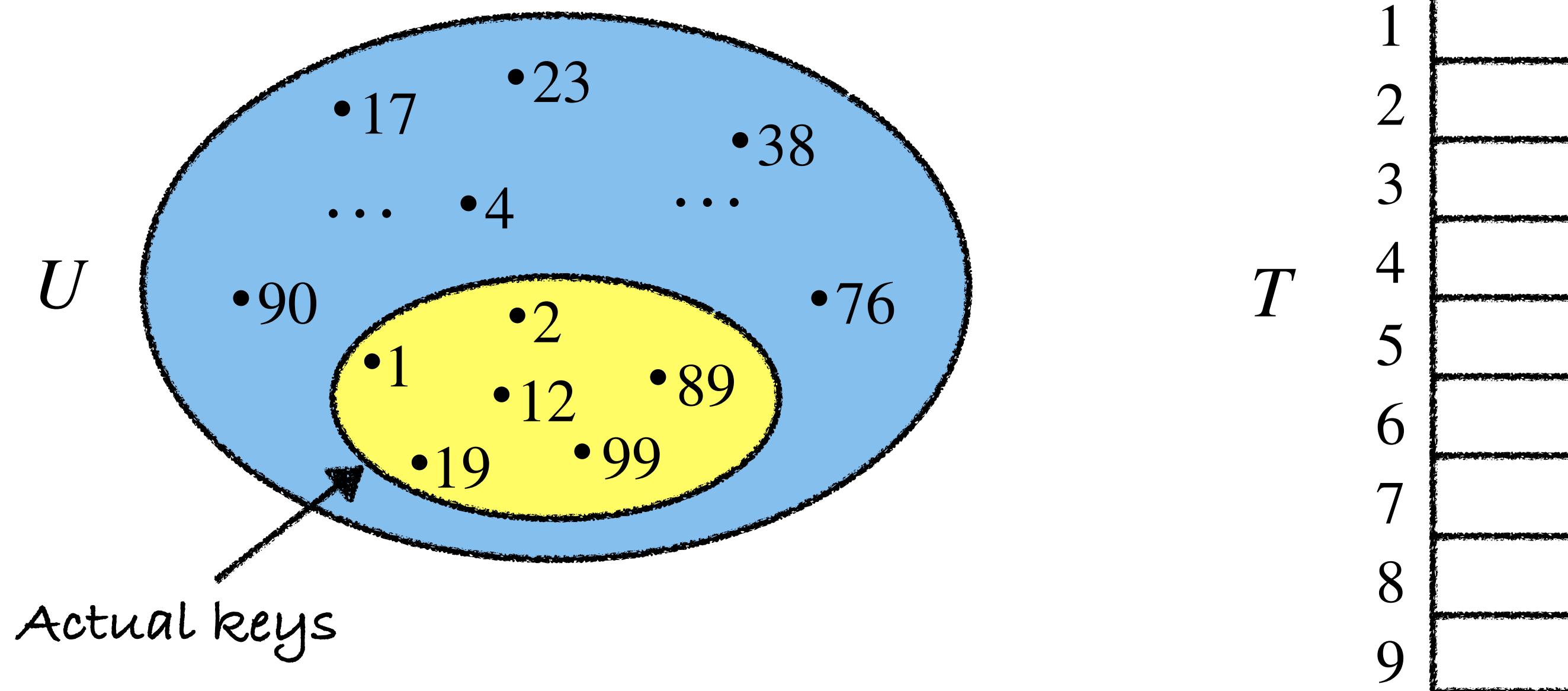
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

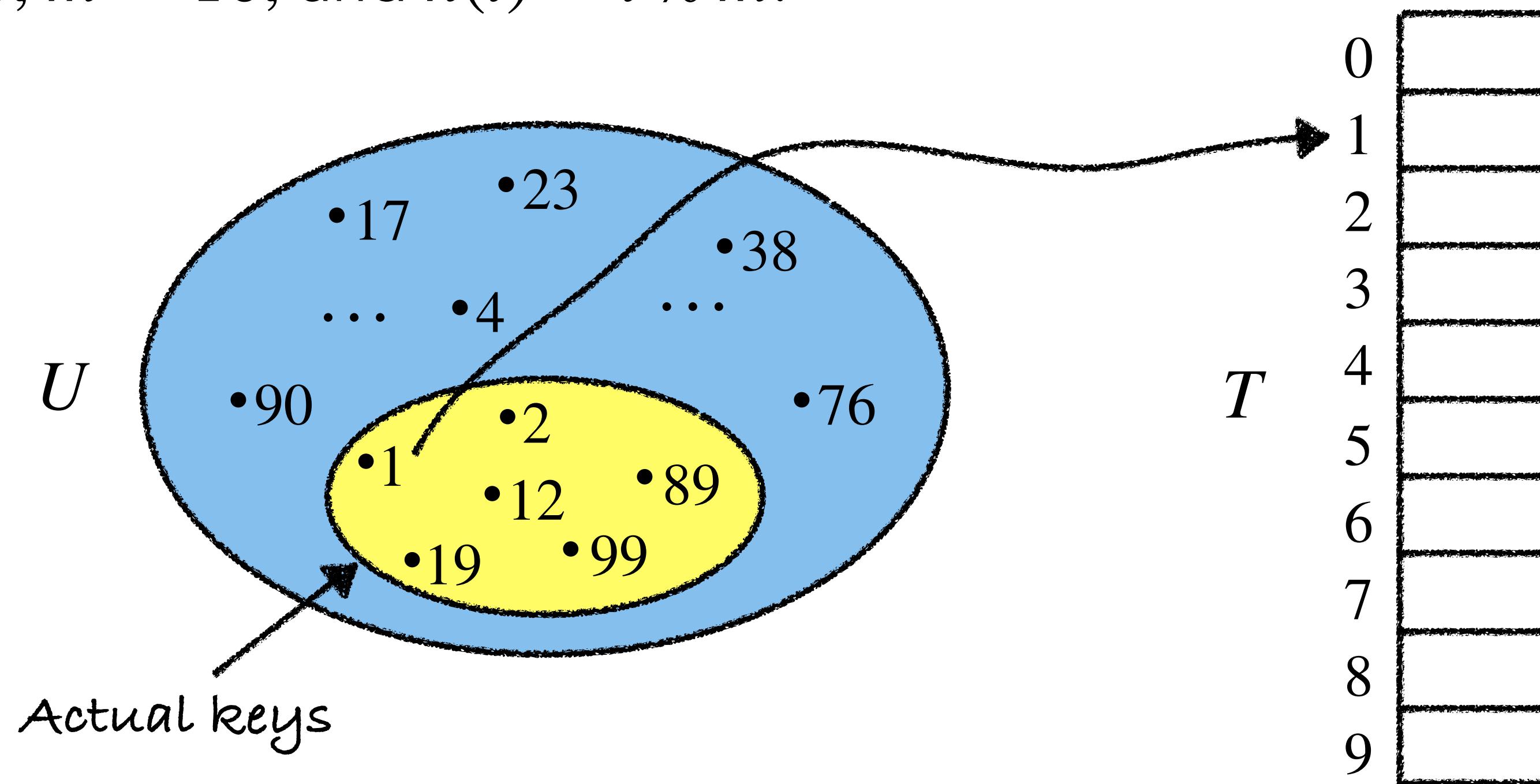
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

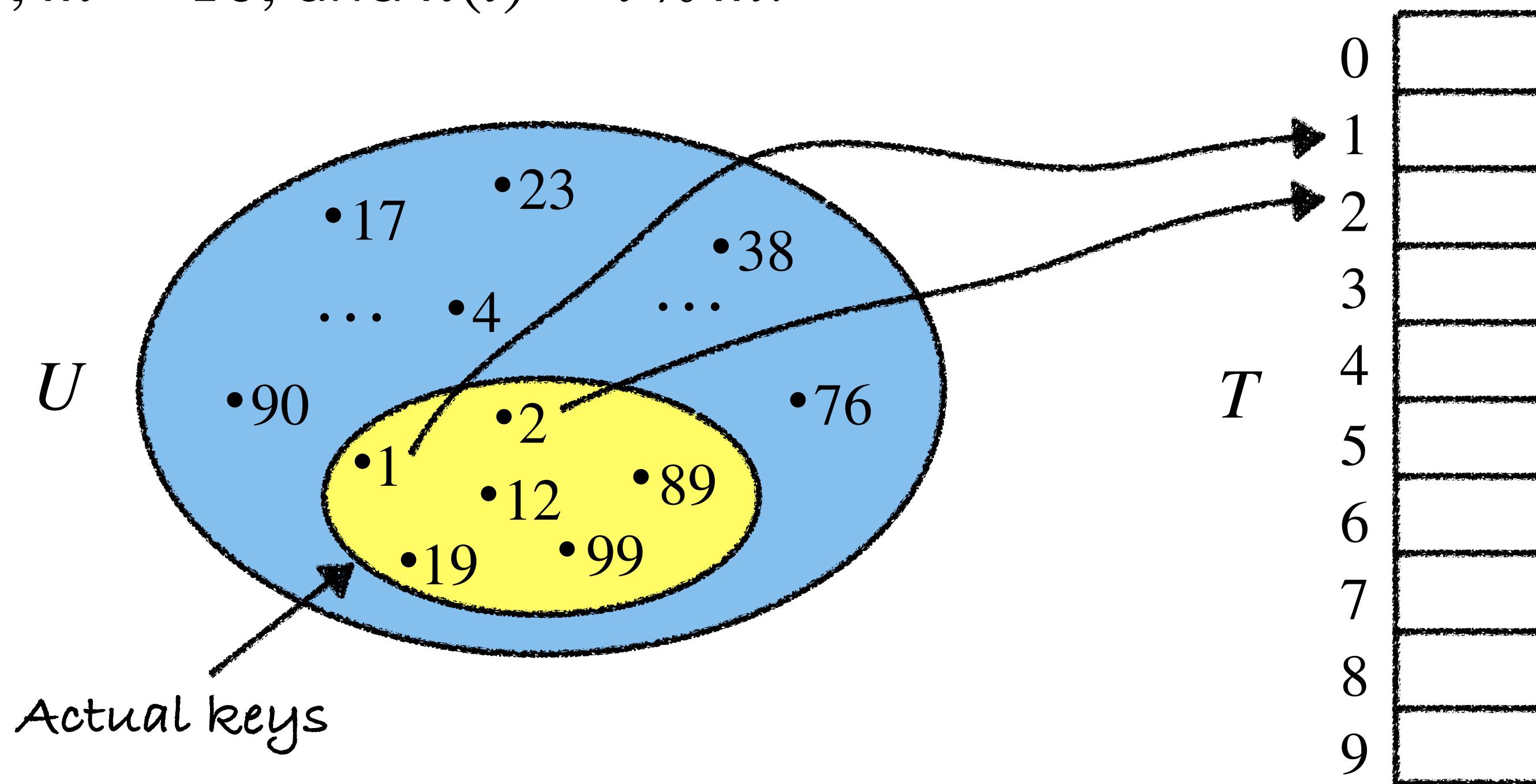
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

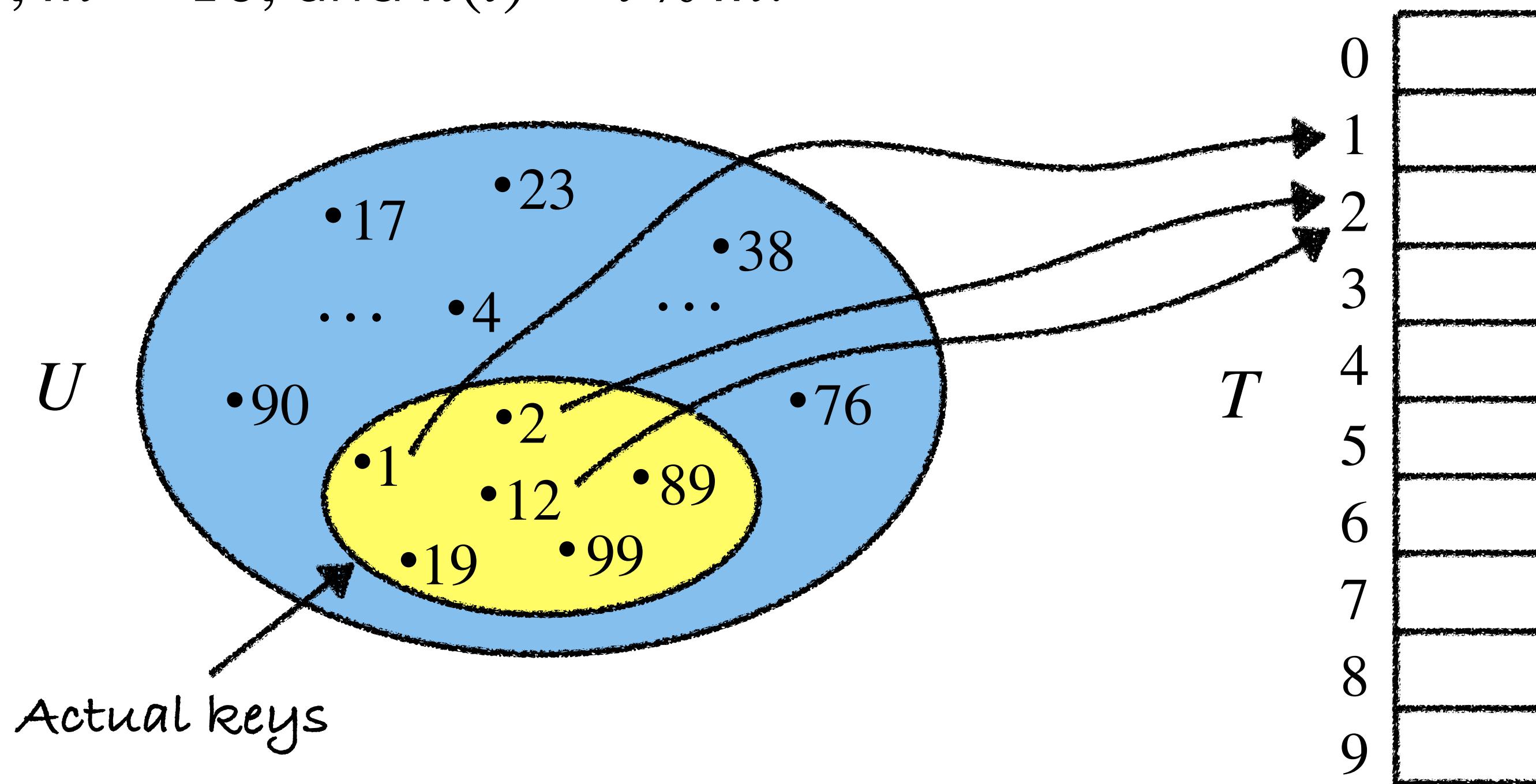
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

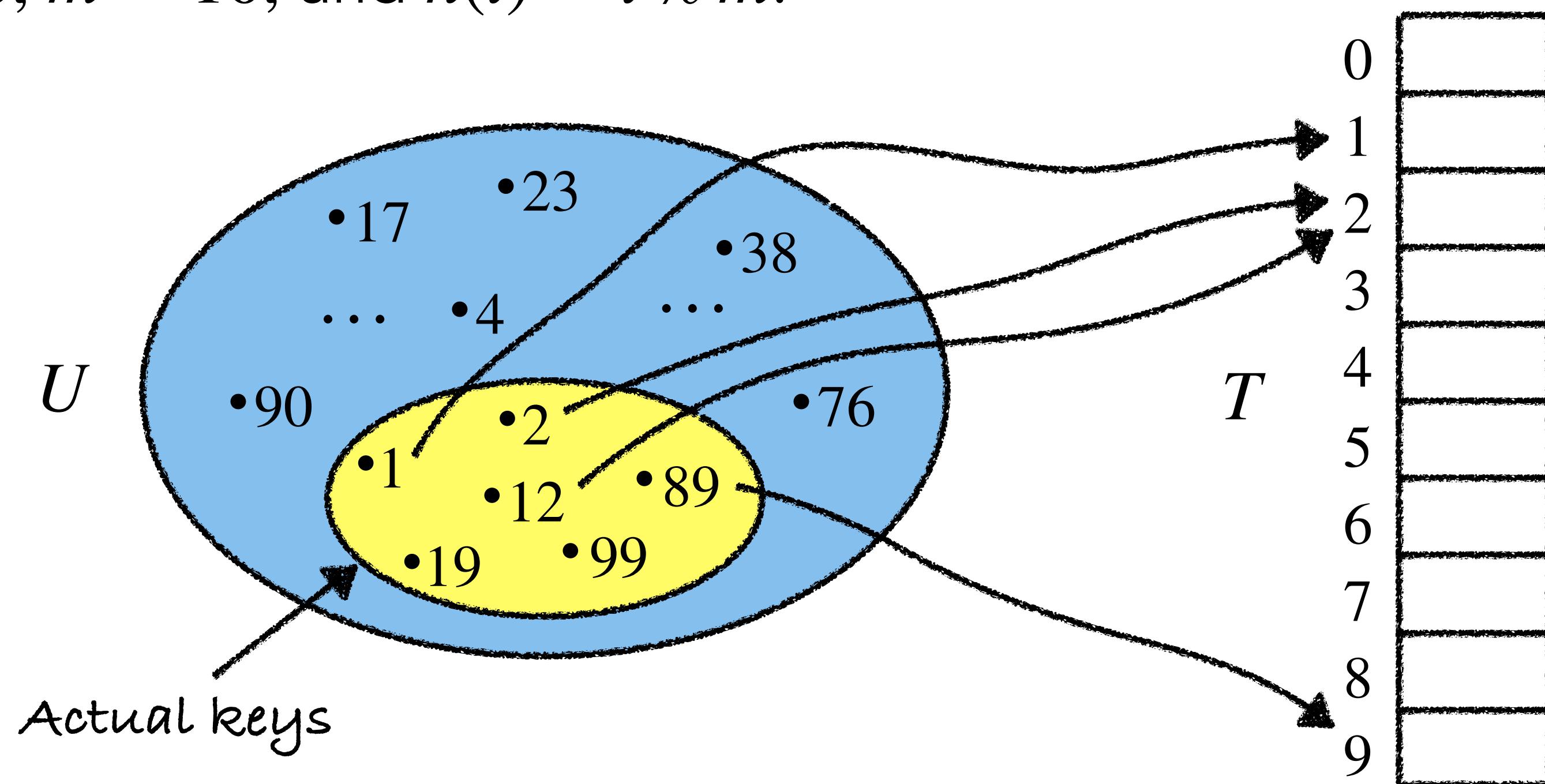
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a **linked list** consisting of elements whose key hashes to the i th slot.

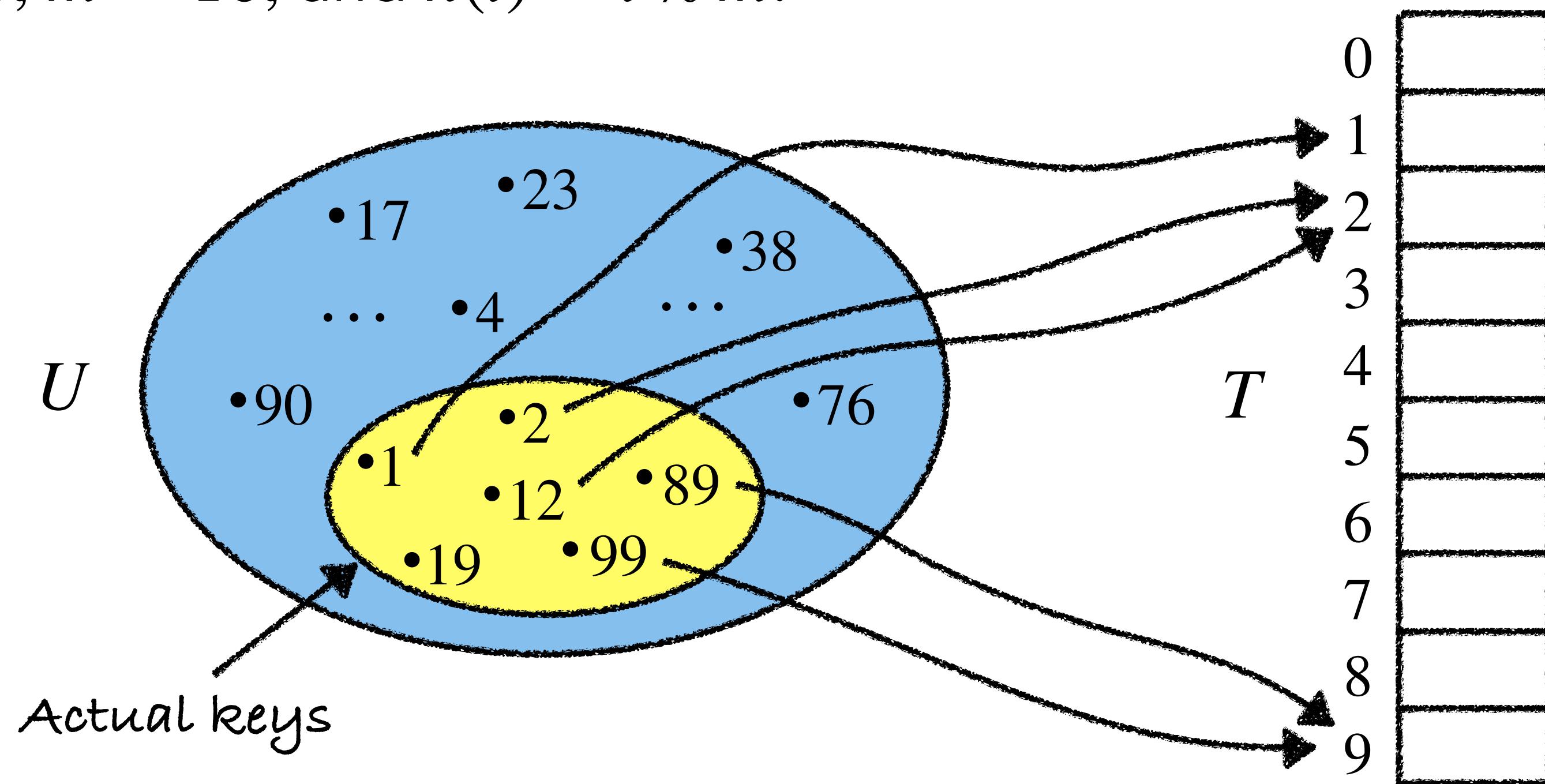
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

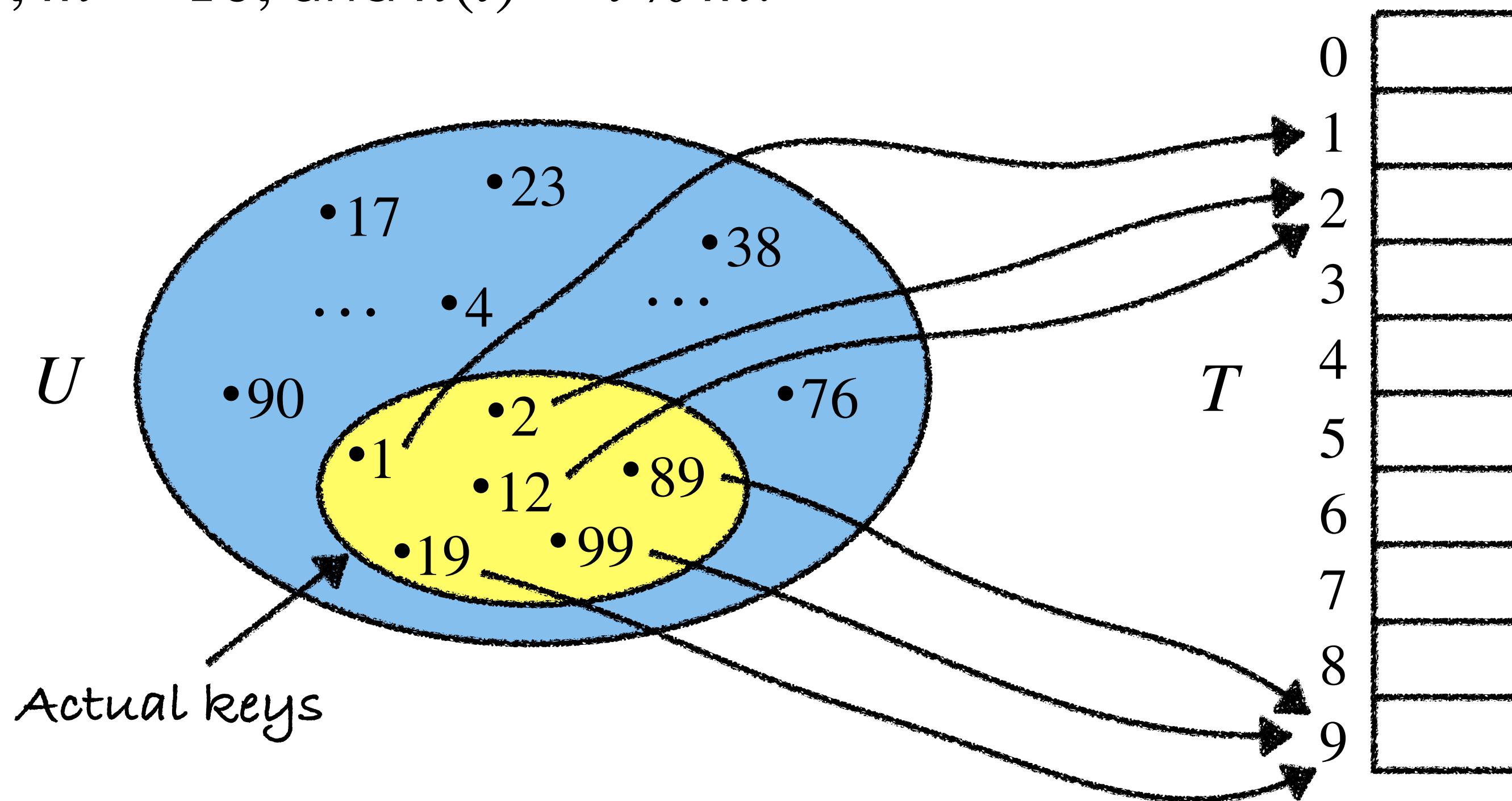
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

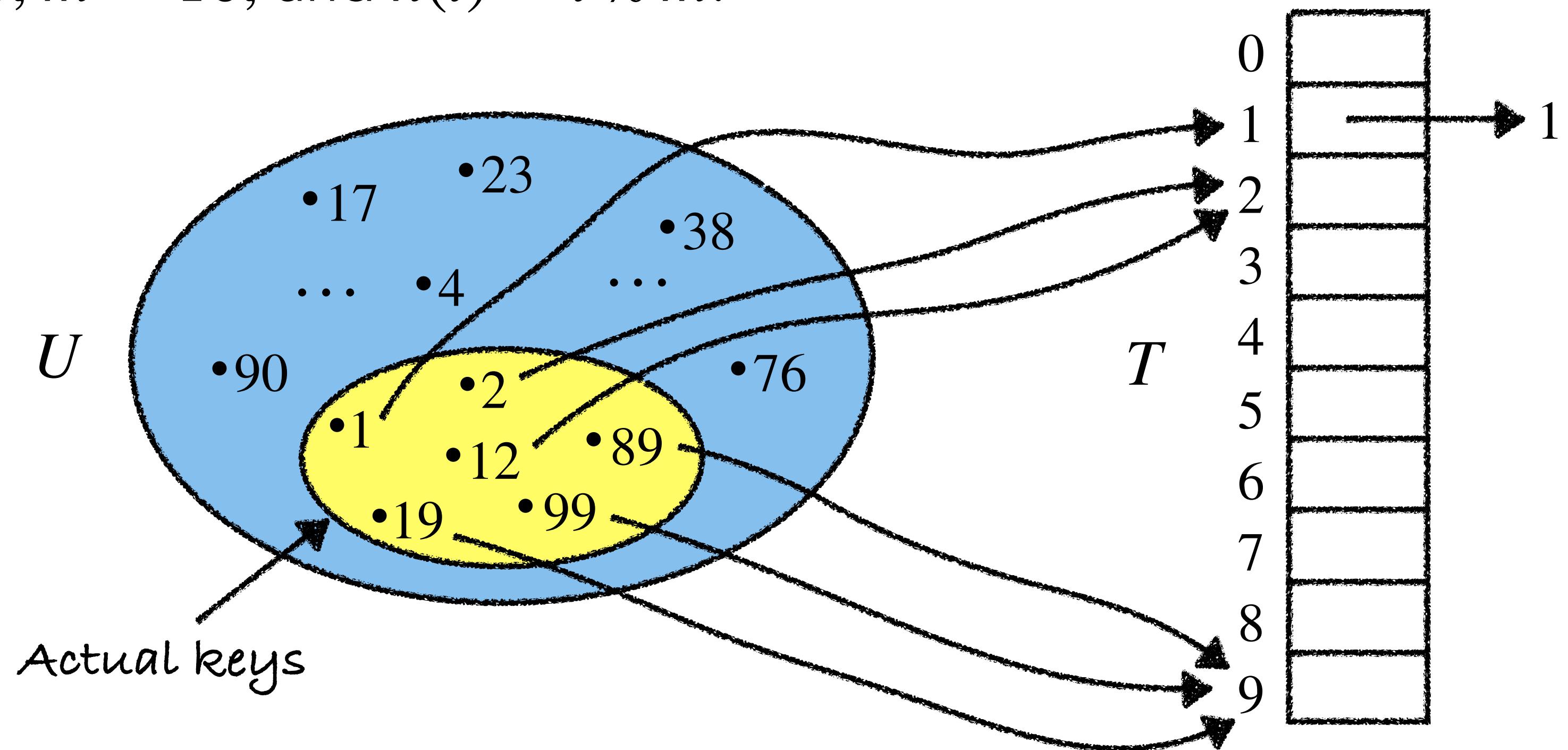
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

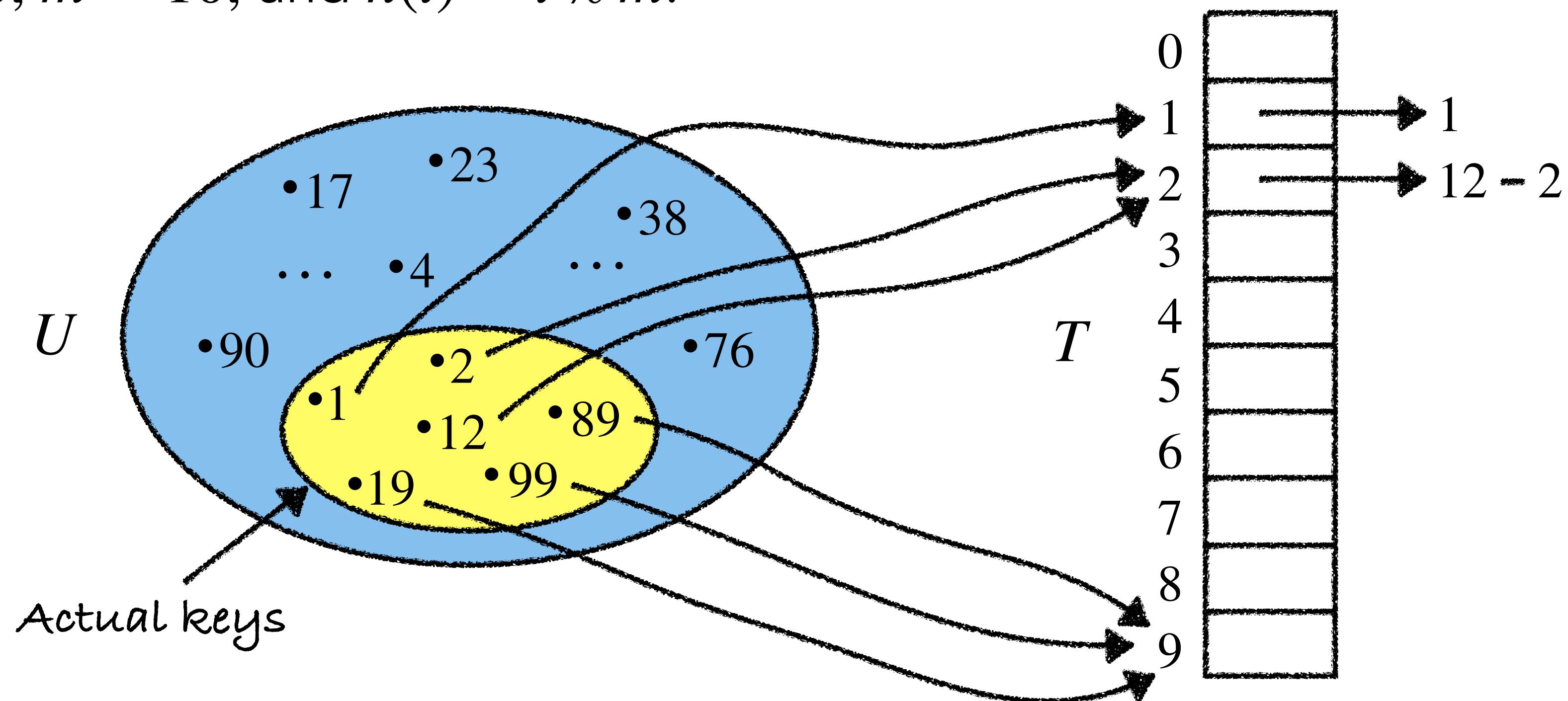
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

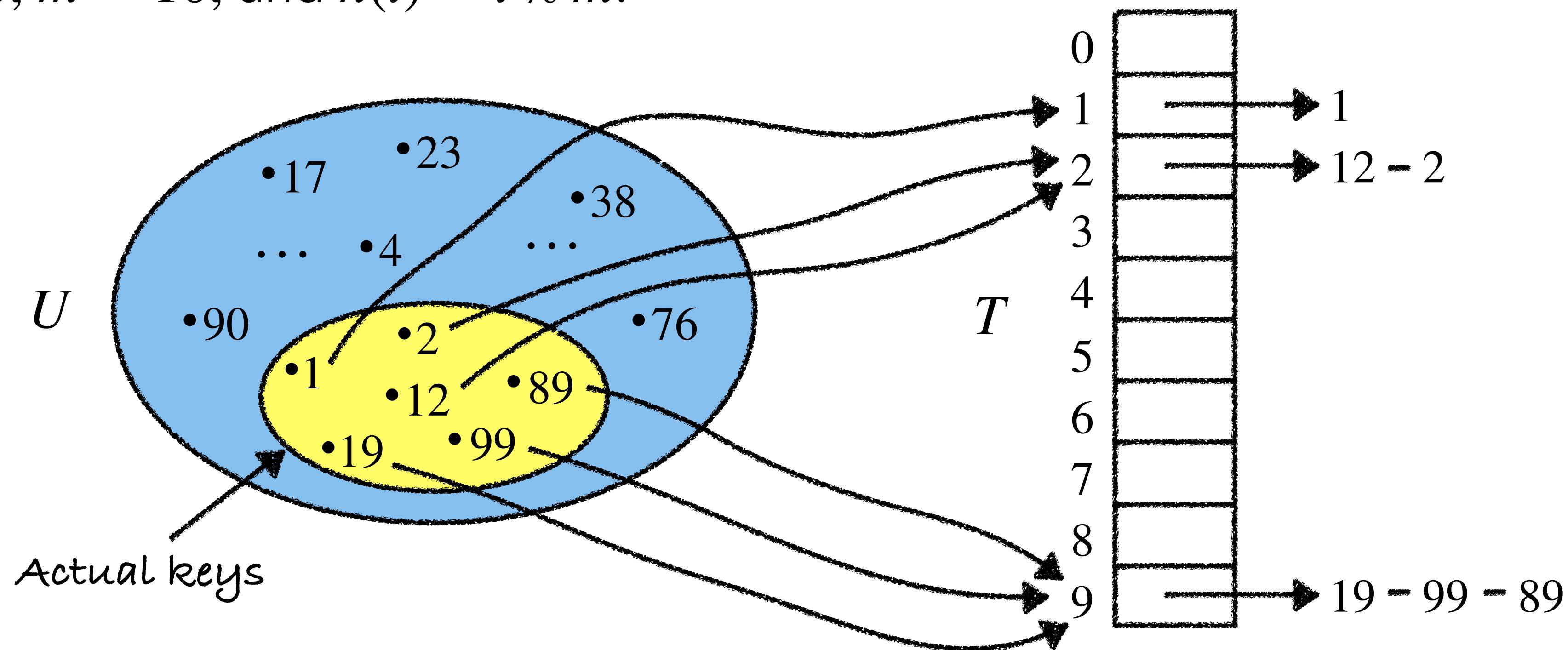
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

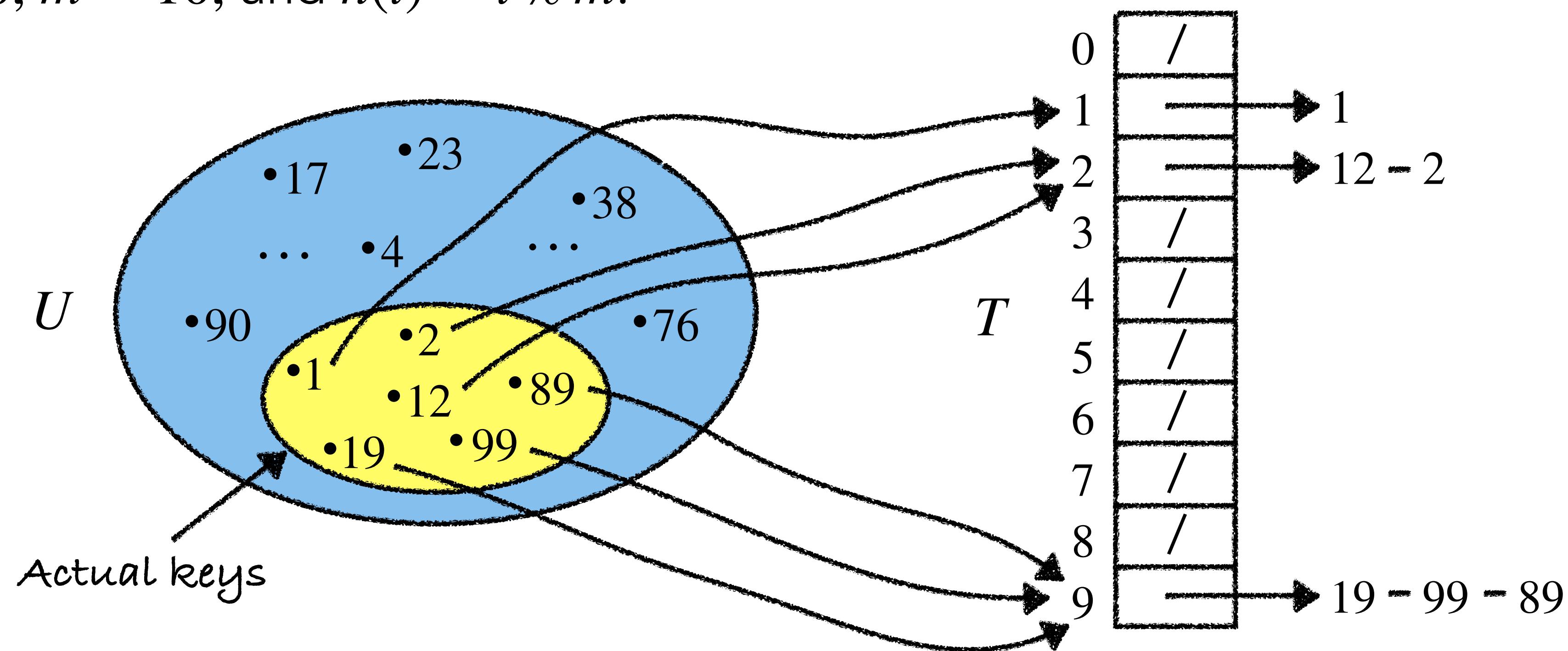
Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Hash Tables: Chaining

Chaining is a way to handle collisions, in which every slot $T[i]$ points to a linked list consisting of elements whose key hashes to the i th slot.

Example: $n = 100$, $m = 10$, and $h(i) = i \% m$.



Chained Hash Tables: Operations

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. LIST-PREPEND($T[h(x \cdot key)]$, x)

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. LIST-PREPEND($T[h(x \cdot key)]$, x)

CHAINED-HASH-SEARCH(T, k):

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. **LIST-PREPEND($T[h(x \cdot key)]$, x)**

CHAINED-HASH-SEARCH(T, k):

1. **return LIST-SEARCH($T[h(k)]$, k)**

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. **LIST-PREPEND($T[h(x \cdot key)]$, x)**

CHAINED-HASH-SEARCH(T, k):

1. **return LIST-SEARCH($T[h(k)]$, k)**

CHAINED-HASH-DELETE(T, x):

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. **LIST-PREPEND($T[h(x \cdot key)]$, x)**

CHAINED-HASH-SEARCH(T, k):

1. **return LIST-SEARCH($T[h(k)]$, k)**

CHAINED-HASH-DELETE(T, x):

1. **LIST-DELETE($T[h(x \cdot key)]$, x)**

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. **LIST-PREPEND($T[h(x \cdot key)], x$)**

Time complexity: $O(1)$

CHAINED-HASH-SEARCH(T, k):

1. **return LIST-SEARCH($T[h(k)], k$)**

CHAINED-HASH-DELETE(T, x):

1. **LIST-DELETE($T[h(x \cdot key)], x$)**

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. LIST-PREPEND($T[h(x \cdot key)]$, x)

Time complexity: $O(1)$

CHAINED-HASH-SEARCH(T, k):

1. return LIST-SEARCH($T[h(k)]$, k)

Time complexity: $O(n)$ ($n = \text{size of dynamic set}$)

CHAINED-HASH-DELETE(T, x):

1. LIST-DELETE($T[h(x \cdot key)]$, x)

Chained Hash Tables: Operations

CHAINED-HASH-INSERT(T, x):

1. LIST-PREPEND($T[h(x \cdot \text{key})], x$)

Time complexity: $O(1)$

CHAINED-HASH-SEARCH(T, k):

1. return LIST-SEARCH($T[h(k)], k$)

Time complexity: $O(n)$ ($n = \text{size of dynamic set}$)

CHAINED-HASH-DELETE(T, x):

1. LIST-DELETE($T[h(x \cdot \text{key})], x$)

Time complexity: $O(1)$