ADTs
List as an ADT
A List interface

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Abstract Data Types (ADTs)

Abstract data types* describe the behaviour (semantics) of a data type without specifying its implementation. An ADT is thus **abstract**, not concrete.

- A **container** is a very general ADT, a holder of objects.
- A **list** is an example of a more specific container ADT.

* Not to be confused with: *Algebraic* Data Type.

The List ADT

The **list** ADT is a container known mathematically as a finite sequence of elements. A list has these fundamental properties:

- duplicates are allowed
- order is preserved

A list may* support operations such as these:

- *create*: construct an empty list
- *add*: add an element to the list
- *is empty*: test whether the list is empty

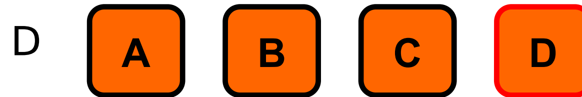
* The operations a given ADT must support will vary depending on the author / library

Our List Interface

We will explore lists using a simple interface:

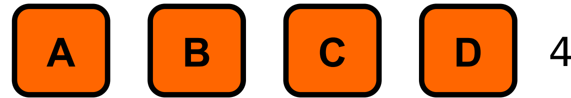
```
public interface List<T> {
    void add(T value);
    T get(int index);
    int size();
    T remove(int index);
    void reverse();
}
```

```java
void add(T value);
```

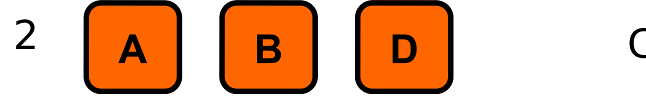



```java
T get(int index);
```

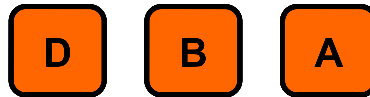
```java
int size();
```




```java
T remove(int index);
```




```java
void reverse();
```




```java
String toString();
```

A02 List Implementations

An array-based implementation
A linked-list-based implementation

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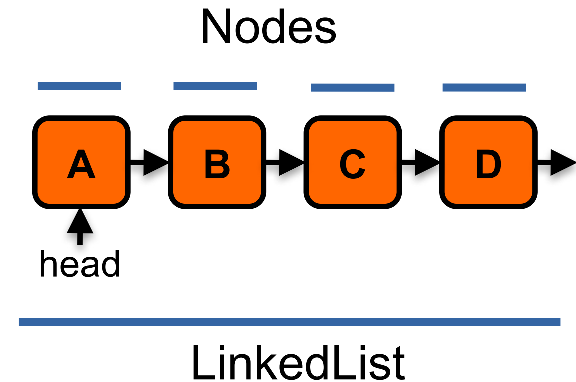
List Implementation Options

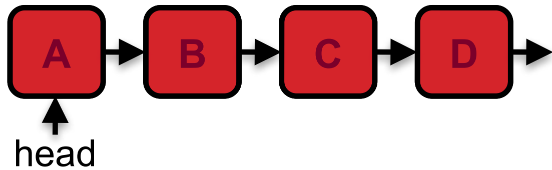
- Arrays
  - Fast lookup of any element
  - A little messy to grow and contract
- Linked list
  - Logical fit to a list, easy to grow, contract
  - Need to traverse list to access elements

Linked Lists: Singly Linked List

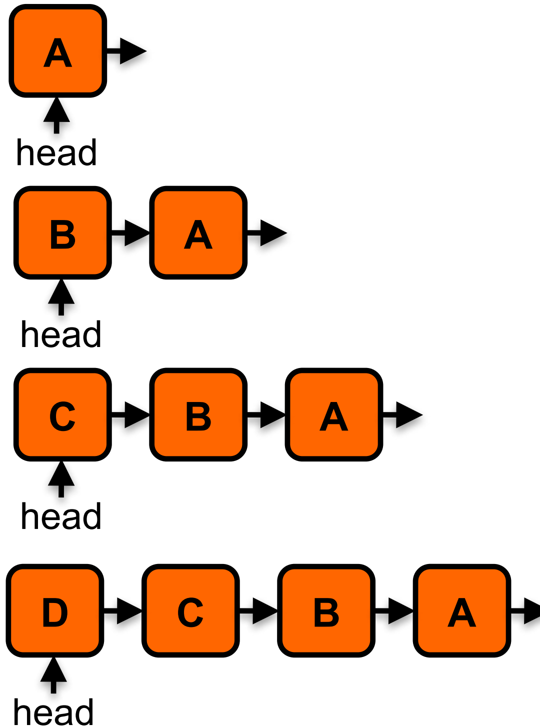
```
public class LinkedList<T> {
  private class Node<T> {
    T value;
    Node<T> next;
  }
  Node<T> head;
}
```



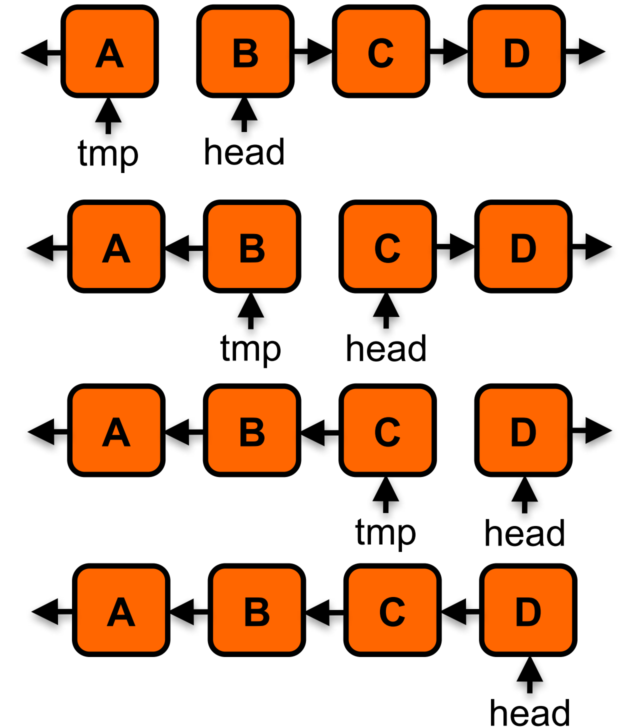
Linked List Reversal: Two Approaches



- Add each item to start:



- Pointer reversal:



Complexity

```
void add(T value);
T get(int index);
int size();
T remove(int index);
void reverse();
```

ArrayList

- `add` – **Time O(1) amortized, O(n) worst**
- `get` – **Time O(1)**
- `size` – **Time O(1)**
- `remove` – **Time O(n)**
- `reverse` – **Time O(n)**

Space O(n)

LinkedList

- `add` – **Time O(1)**
  - if explicitly tracking last node
- `get` – **Time O(n)**
- `size` – **Time O(1)**
  - if explicitly tracked
- `remove` – **Time O(n)**
- `reverse` – **Time O(n)**

Space O(n)

A03 Sets

Set ADT
A Set interface

The Set ADT

The **set** ADT corresponds to a mathematical set. A set has these fundamental properties:

- duplicates are not allowed
- order is not preserved

A **set** may support operations such as these:

- *create*: construct an empty set
- *add*: add an element to the set
- *contains*: does the set contain a given element
- *remove*: remove an element from the set

Our Set Interface

We will explore sets using a simple interface:

```
public interface Set<T> {
    boolean add(T value);
    boolean contains(T value);
    int size();
    boolean remove(T value);
}
```

Hash tables
A hash-table-based Set implementation

Hash Tables

Stores **keys**, using a hash function to map a key into a table entry. Optionally, **values** can be associated with keys and stored alongside them in the table.

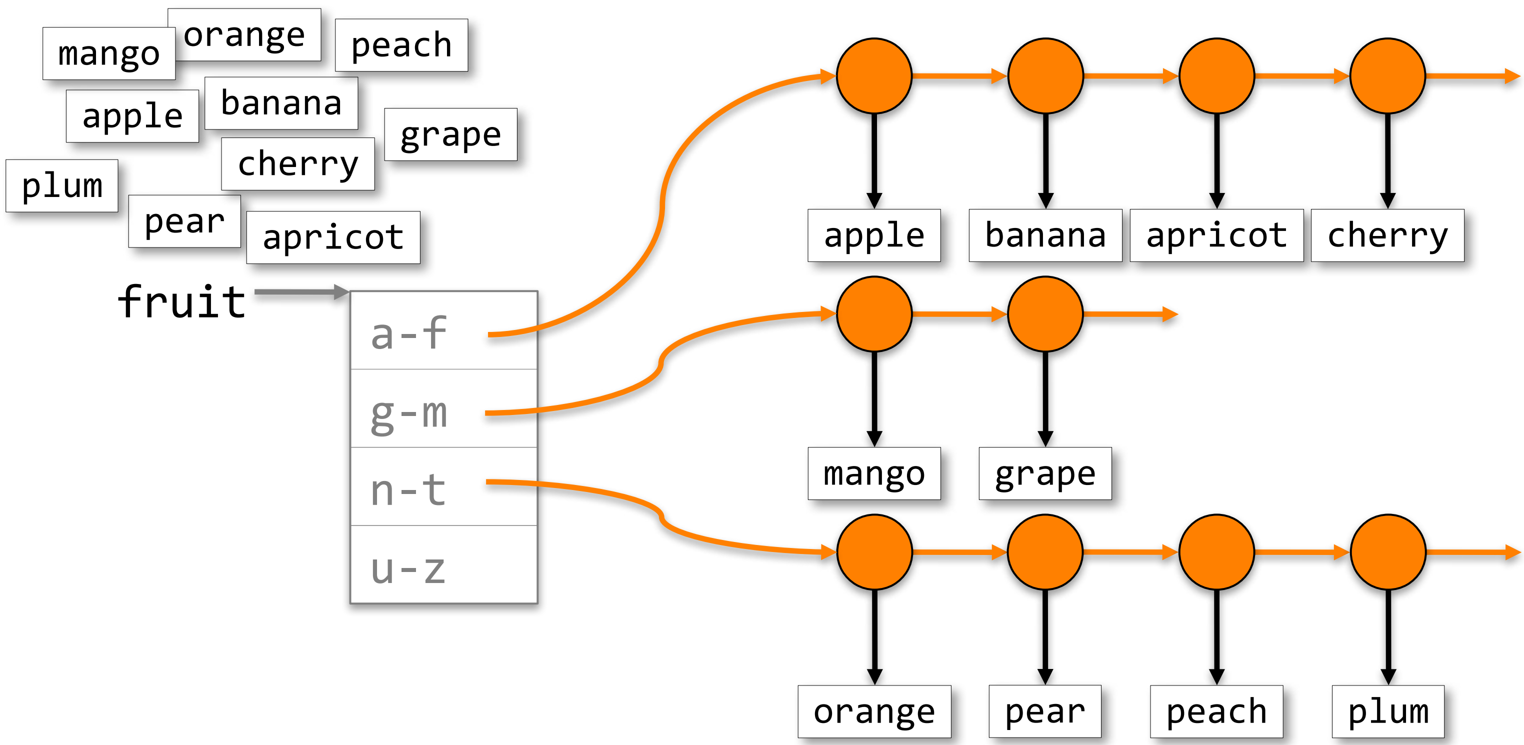
Main challenges are: a) dealing with **hash collisions** and dealing with **load** (how big to make the table).

Two broad approaches:

- Separate chaining
  - Hash table entries are lists: (key, value) pairs are in lists.
- Open addressing
  - Hash table entries are (key, value) pairs.
  - Collisions resolved by probing – e.g. find next entry slot

HashSet Implementation of a Set

- Special case of hash table where we only have **key** (it is not associated with any *value*).
- We'll demonstrate **separate chaining** where our lists only needs to store a single item rather than a pair.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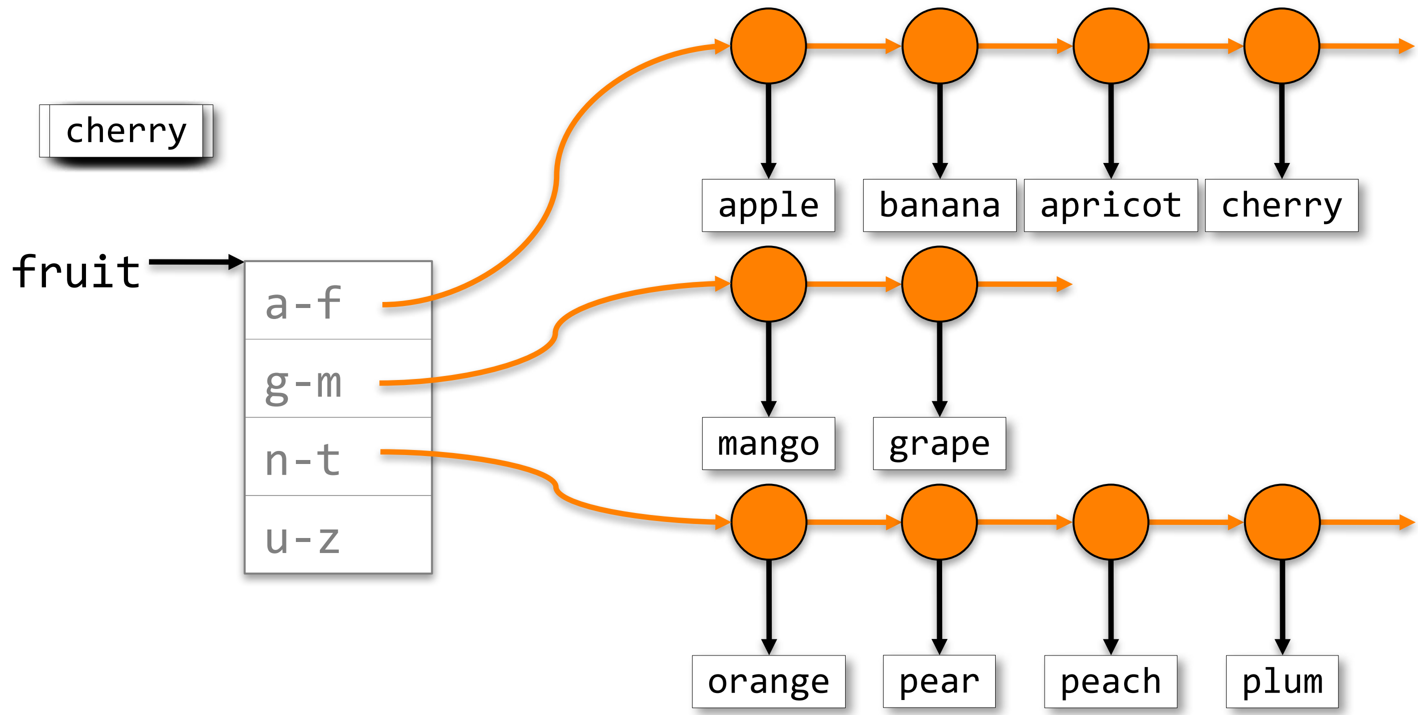
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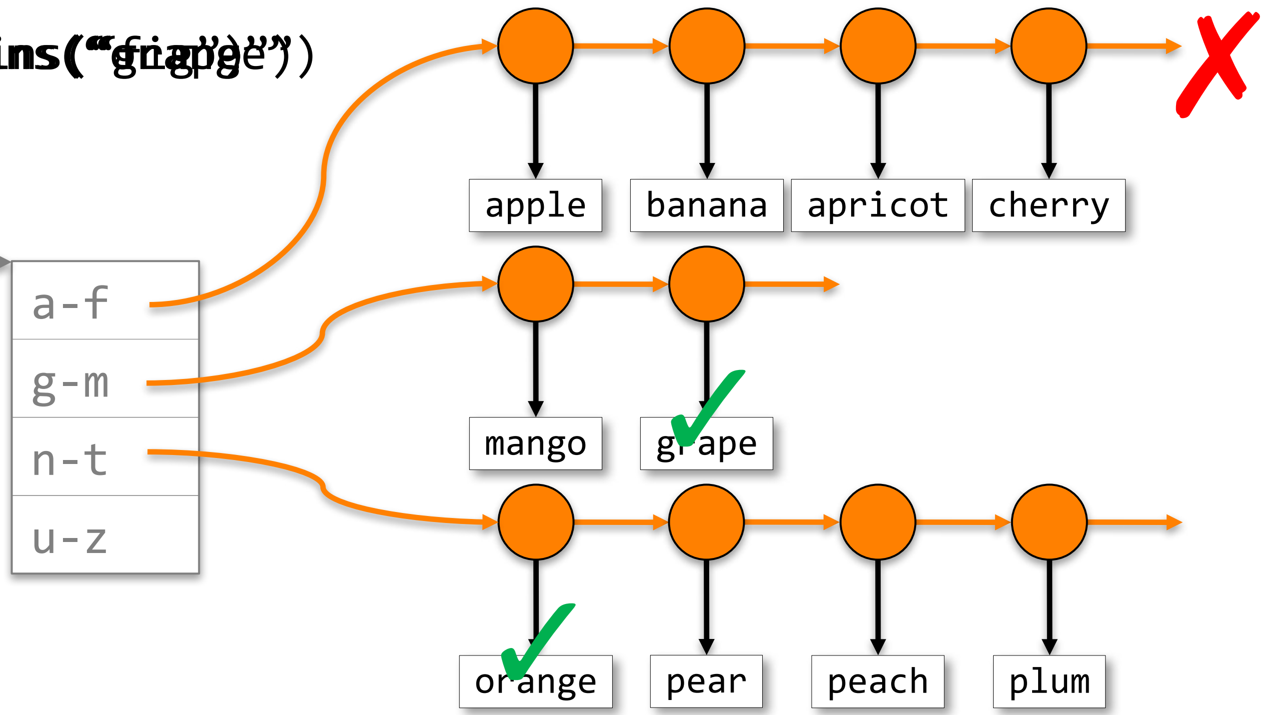
```
fruit.contains("grape")
```

grape

fruit



Load Factor

The **load factor** is the ratio of number of elements to the number of "buckets" (size of table).

By resizing (doubling) table capacity when lists grow "too long", `add` and `contains` can run in amortised constant time (assuming a good hash function).

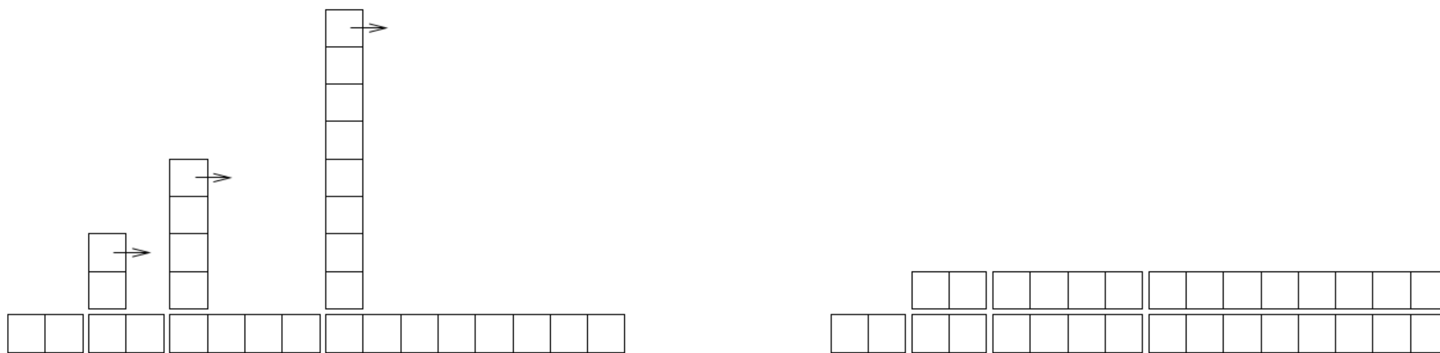


Figure B.1: The cost of a hashtable add.

(Illustration from "Think Python: How to think like a computer scientists" (2nd ed) by Allen B. Downey.)

Complexity

```
boolean add(T value);
boolean contains(T value);
int size();
boolean remove(T value);
```

- `add`, `contains`, `remove` – **Time O(1) amortized, O(n) worst**
  - *good* hash function
  - table resized to keep table *load factor* in a range
- `size` – **Time O(1)**
  - explicitly tracked

Space O(n)

A05 Sets: TreeSet

Tree as an ADT
A tree-based Set implementation

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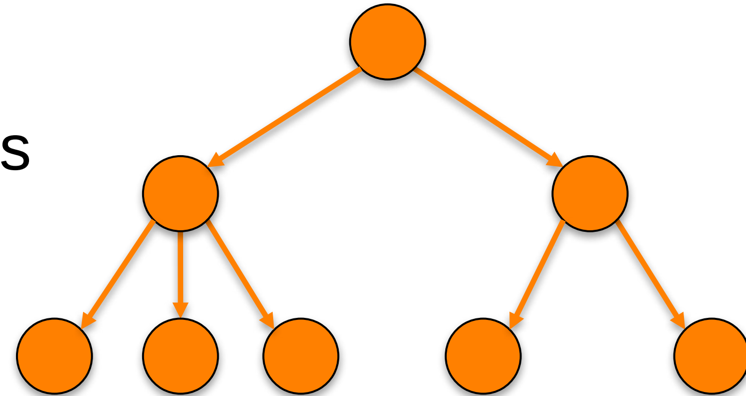
Tree as an ADT

The **tree** ADT corresponds to an ordered tree in mathematics.

A tree is defined recursively in terms of nodes:

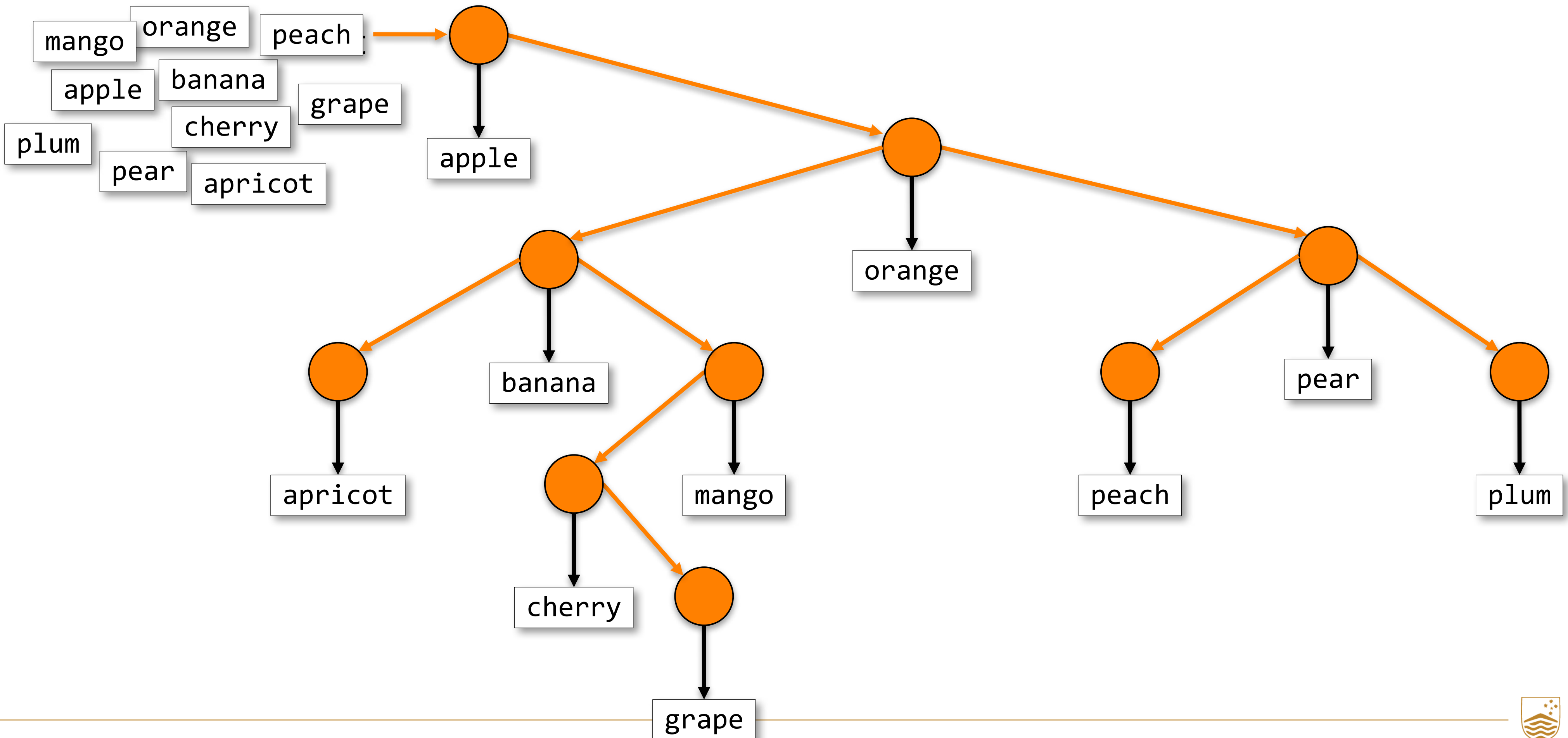
- A tree is a node
- A node contains a value and a list of trees
- No node is duplicated



Binary Search Tree to Implement Set

A **binary** search tree is a tree with the following additional properties:

- Each node has at most **two** sub-trees
- Nodes may contain (key, value) pairs, or just keys
- Keys are ordered within the tree:
  - The left sub-tree only contains keys less than the node’s key
  - The right sub-tree only contains keys greater than the node’s key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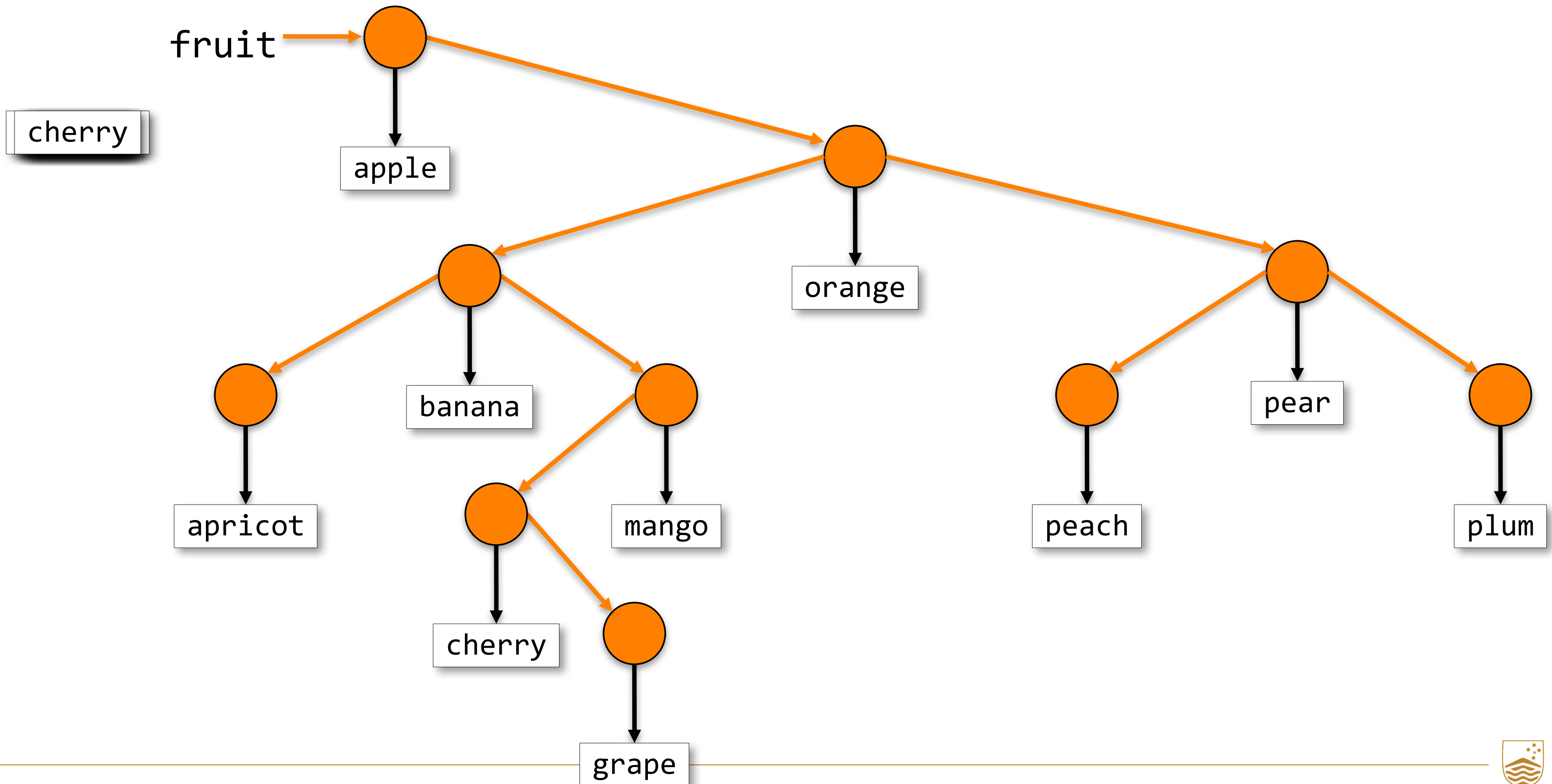
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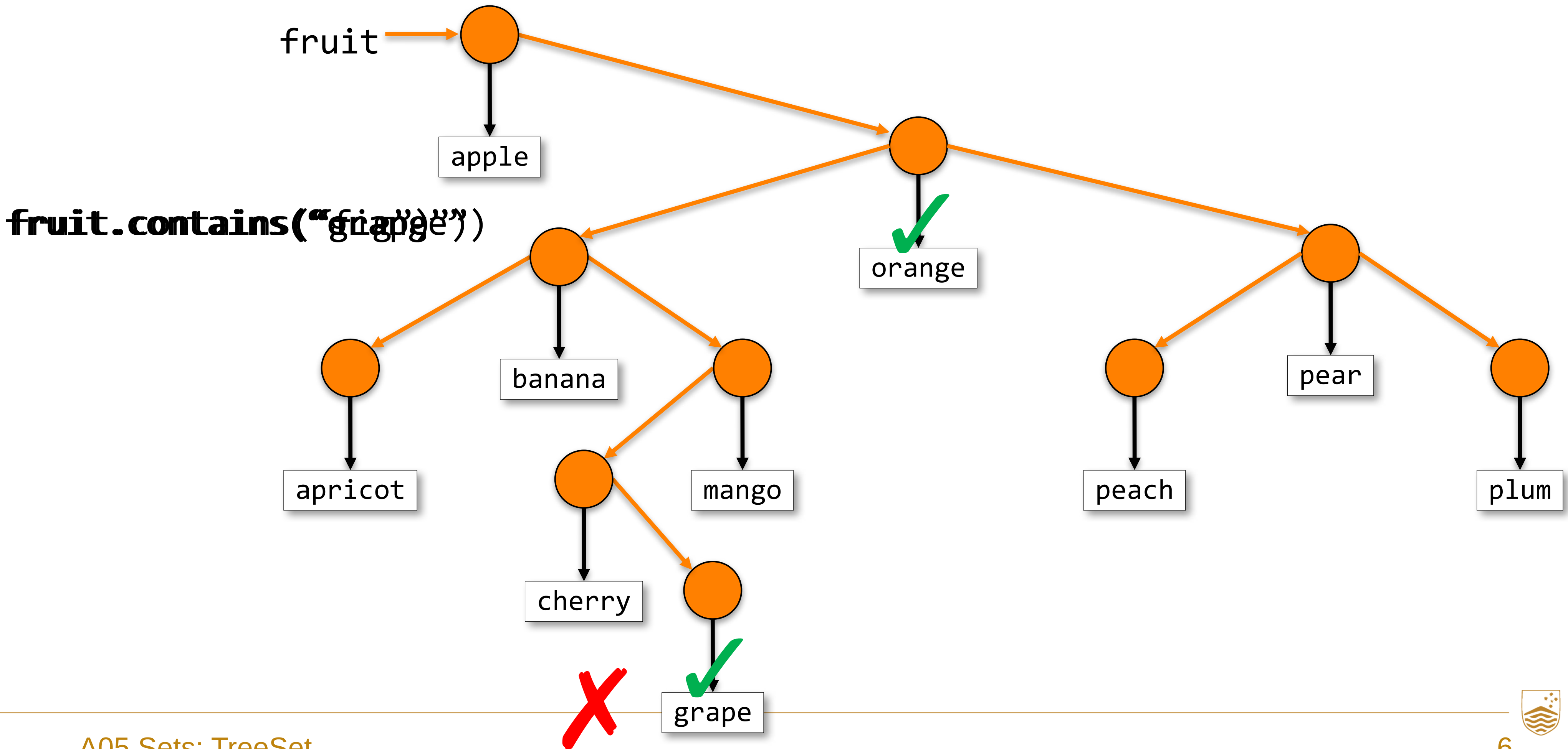
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grape

Ordering in Java (Recall J14)

Objects of any class that implements the `Comparable` interface can be ordered:

`a.compareTo(b)`

- < 0 iff a is ordered before b
- > 0 iff a is ordered after b
- == 0 if a.equals(b) (but also if a and b are not ordered)

Our `Set` interface does not bound our contained type parameter to be `Comparable`, what to do?

- Bound T in the `TreeSet` class declaration:
  - `class TreeSet<T extends Comparable<T>> implements Set<T>`
- Throw runtime exception on use of non-comparable types (the approach in `java.utils.TreeSet`).
- Force users to provide `Comparator` (e.g., as lambda expression).

https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/Comparable.html

Complexity

```
boolean add(T value);
boolean contains(T value);
int size();
boolean remove(T value);
```

- `add`, `contains`, `remove` – **Time O(log(n)) amortized, O(n) worst**
  - self-balancing trees (e.g., B-Trees) have O(log(n)) worst case
- `size` – **Time O(1)**
  - explicitly tracked

Space O(n)

A06 Maps: HashMap and TreeMap

Map as an ADT
A Map interface
A hash-table-based Map implementation
A tree-based Map implementation

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ADT Recap

First-principles implementation of three Java container types:

- List
  - **`ArrayList`**, **`LinkedList`** implementations (A1, A2)
- Set
  - **`HashSet`**, **`TreeSet`** implementations (A3, A4, A5)
- Map
  - **HashMap**, **TreeMap** implementations (A6)

Introduced **hash tables**, **trees** (A4, A5)

The Map ADT (also known as Associative Array)

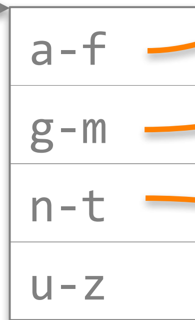
A map consists of **(key, value)** pairs

- Each key may occur only once in the map
- Values are retrieved from the map via the key
- Values may be modified
- Key, value pairs may be removed

Our Map Interface

We will explore maps using a simple interface:

```
public interface Map<K,V> {
  V put(K key, V value);
  V get(K key);
  V remove (K key);
  int size();
}
```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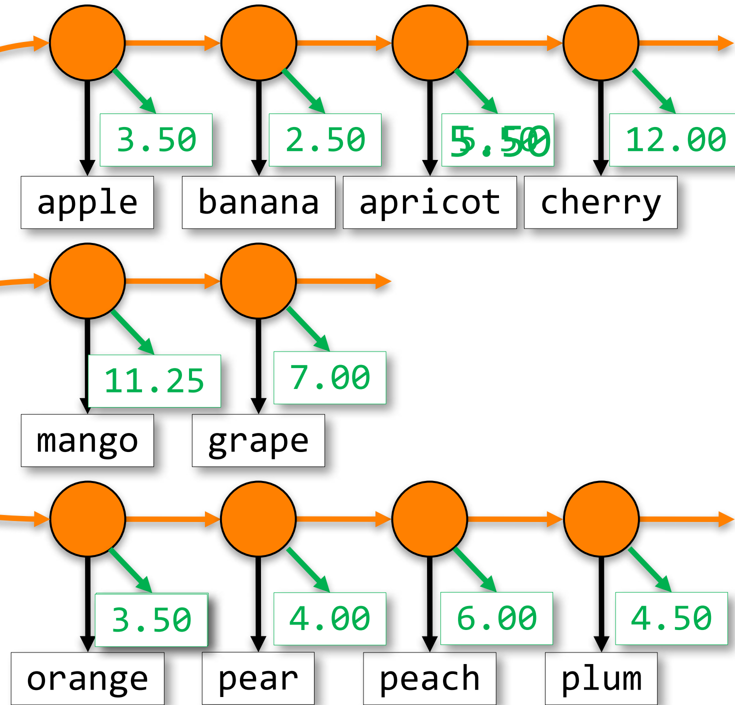
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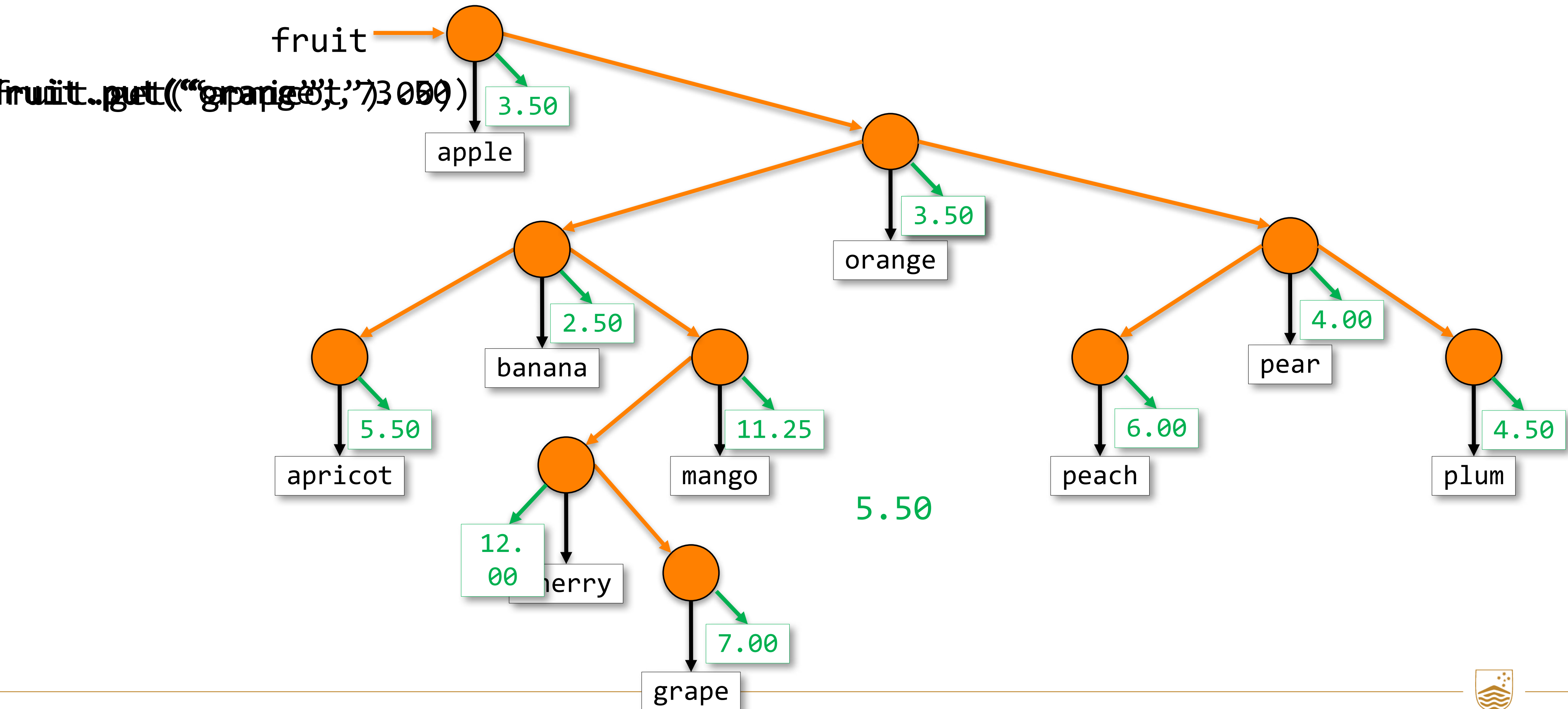
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