A05 Sets: TreeSet

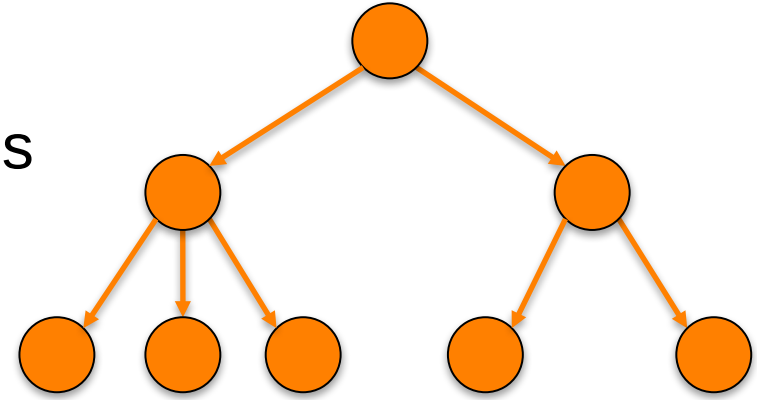
Tree as an ADT
A tree-based Set implementation

Tree as an ADT

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

A tree is defined recursively in terms of nodes:

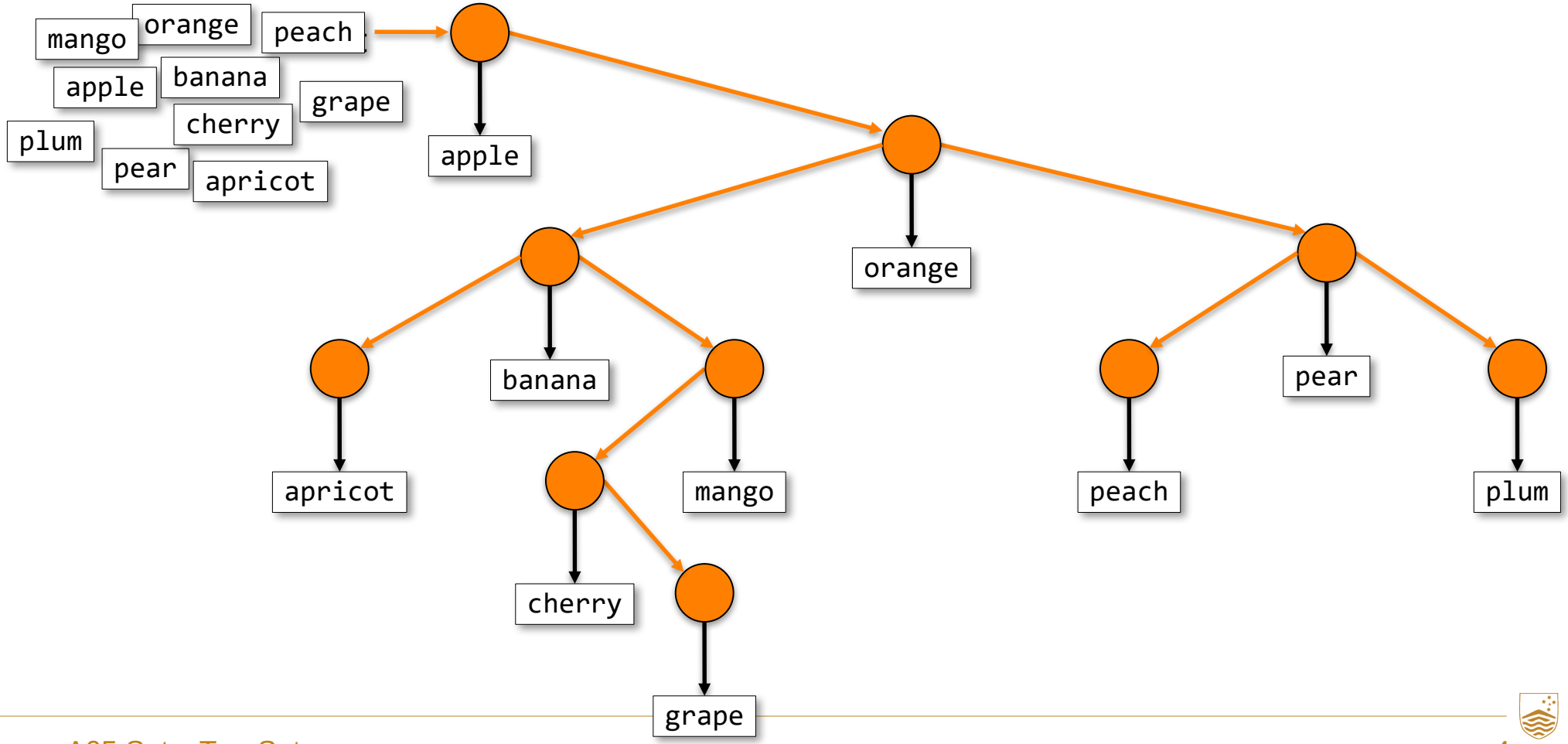
- A tree is a node
- A node contains a value and a list of trees
- No node is duplicated



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


mango
orange
peach
apple
banana
grape
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orange
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mango
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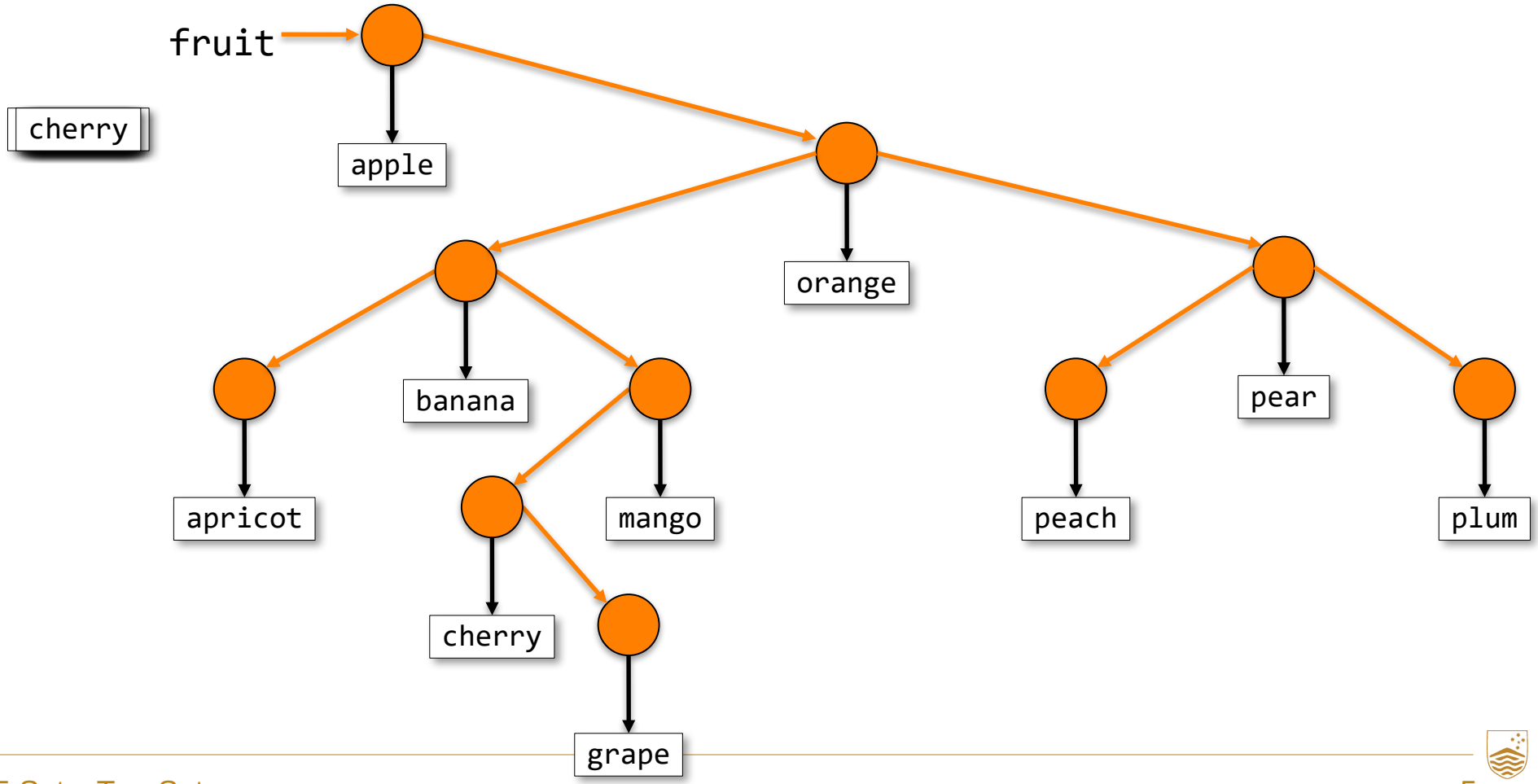
pear
plum
cherry
grape


fruit
cherry
apple
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grape
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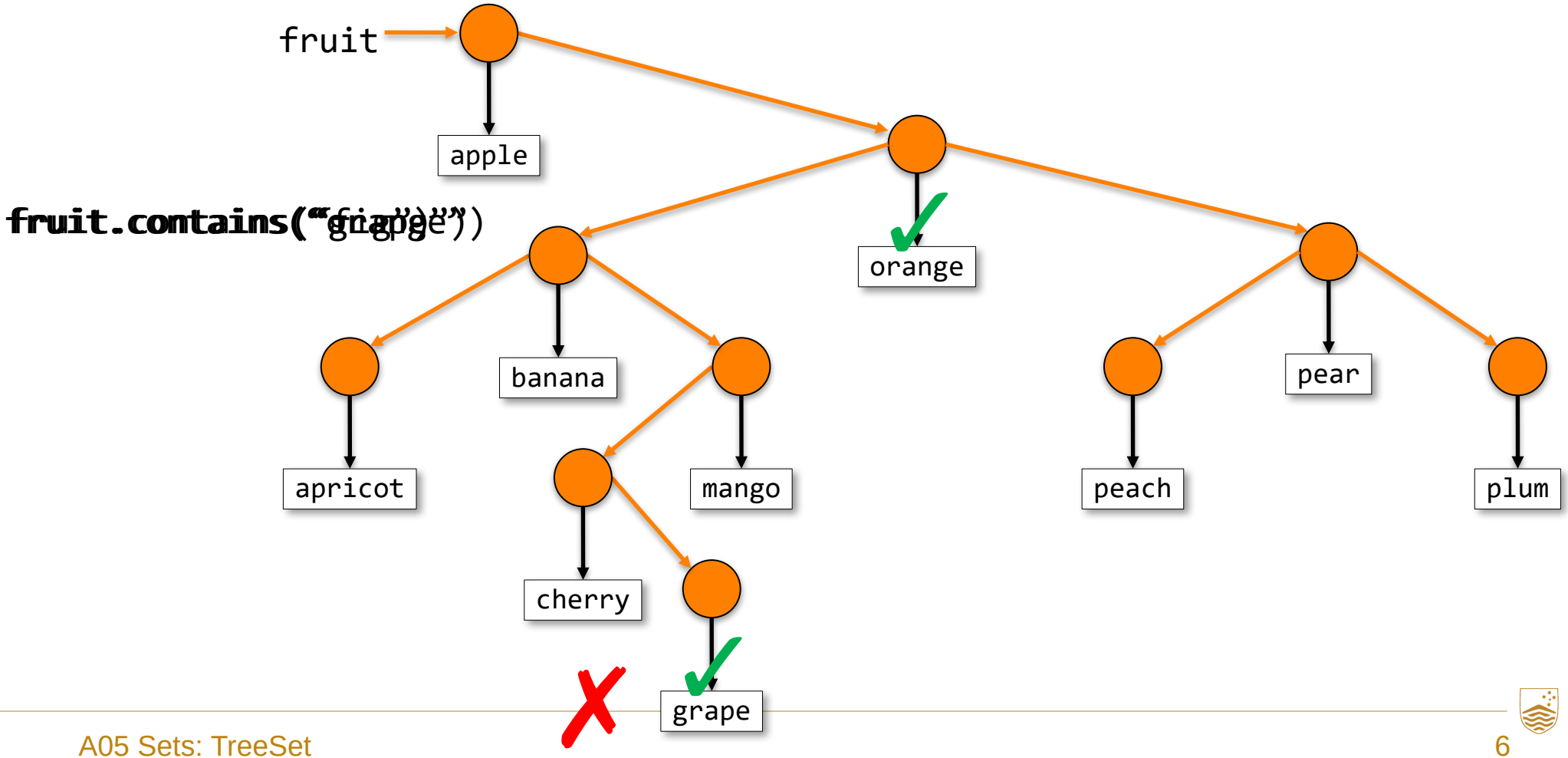
plum


fruit
apple
orange
banana
apricot
mango
cherry
grape
peach
pear
plum
fruit.contains("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)