Week04

- array list

Today is...
✨ **No-Laptop Monday!** ✨

2023 Midterm and Final on website

WARMUP
what is data?
what is a data structure?
why are data structures?

TODO: record lecture

where are we?

the finest lecture hall in all of Williams College

at the **turning point** of CS136

- ~~**part A:** programming fundamentals in Java~~
- **part B:** data structures
  - one data structure per week here we gooo 😀 👍

data structures

data

data is numbers

a **data structure** helps you organizes your data...

...the right data structure for a task is...
- easy to work with -- **programmer time**
- runs fast -- **runtime** (user time)

array list

motivation

arrays are super useful, but...

arrays are super useful, but...
🧠

main limitation of arrays: can't change length

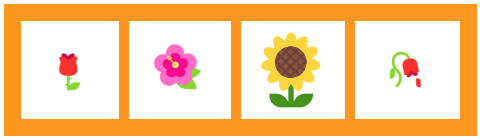
- an **array** is a fixed-length sequence of elements all of the same type
- very fast ($O(1)$ access), very simple
- but what if we don't know how many elements we need?
  - **solution A:** make a BIG array
    - `pool = new Thing[256]; // from HW03`
    - simple
    - might end up being...
      - **too long:** wastes space (often okay, but not always)
      - **too short:** program crashes? (bad bad very bad)
  - **solution B:** *grow the array* as needed (an **array list**)
    - pretty simple
    - pretty fast

review: array metaphor

an array is like a very organized person's flower planter

- one flower per square
- the planter can't change size

(it is made of artisinal woods or something)

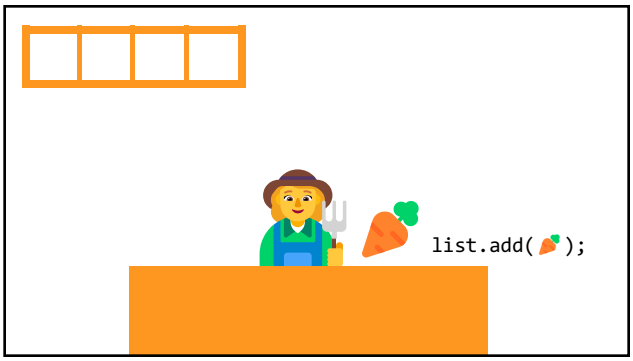


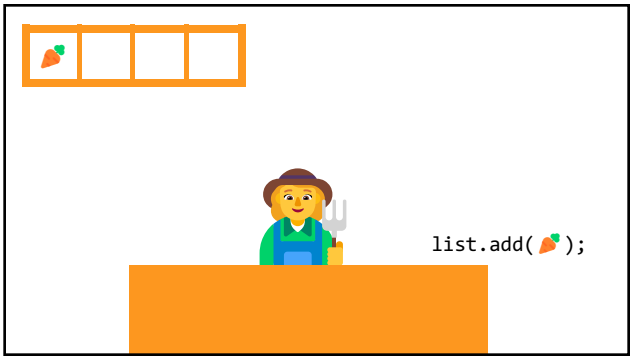
how an array list works (metaphor)

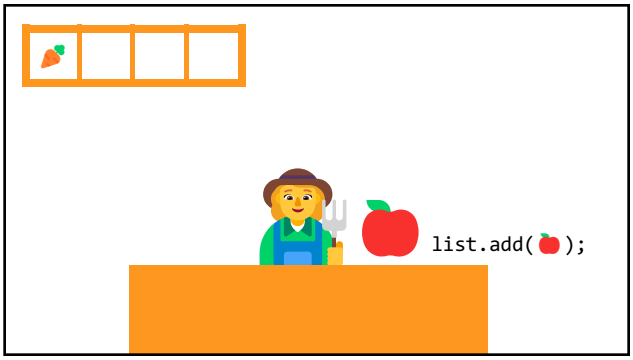
let us imagine...

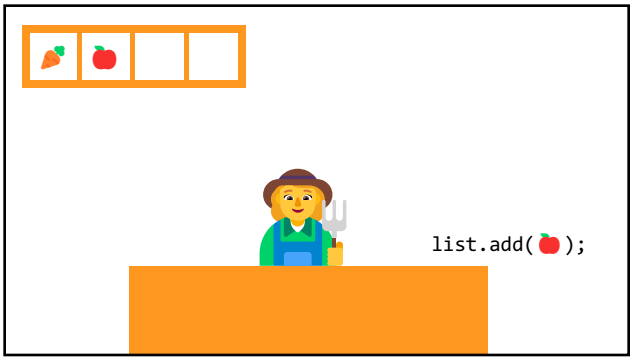
you have a bunch of pieces of produce you need to put somewhere for quick access, but you don't know how many

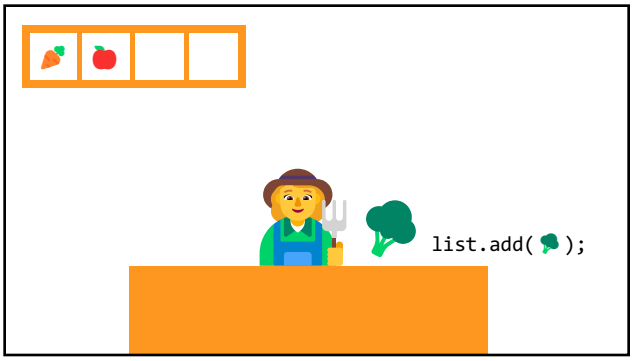
...off to the produce bank we go!

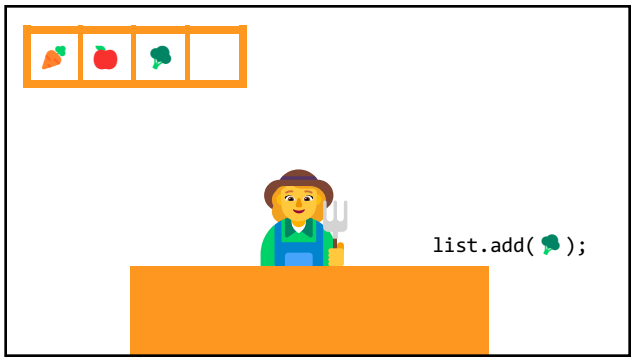


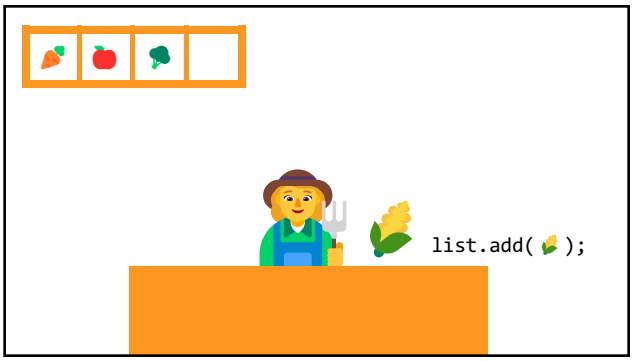









list.add( );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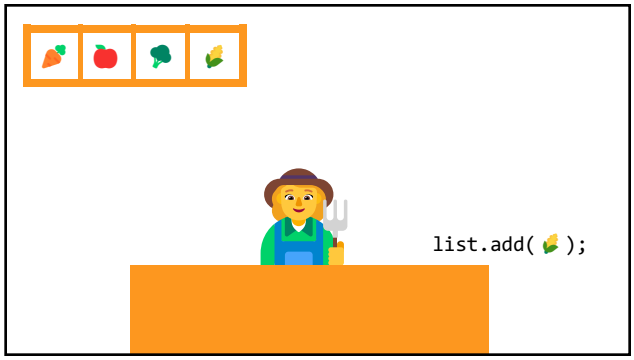
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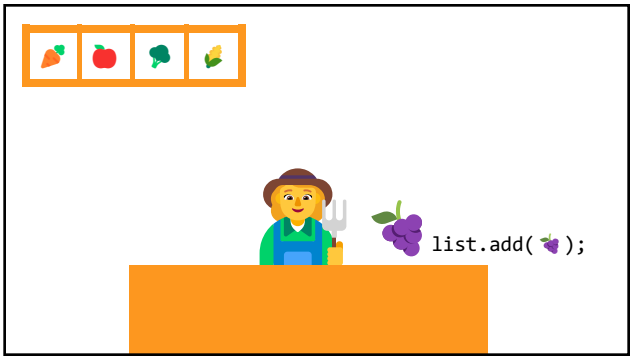
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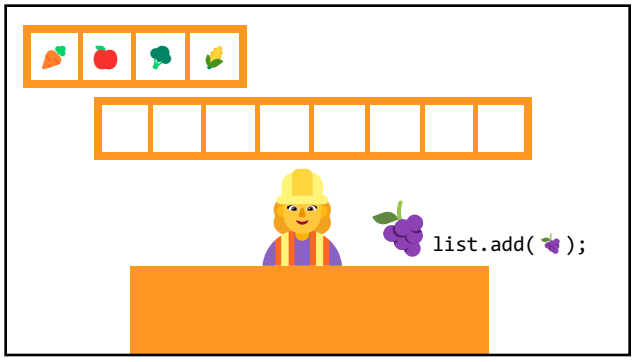
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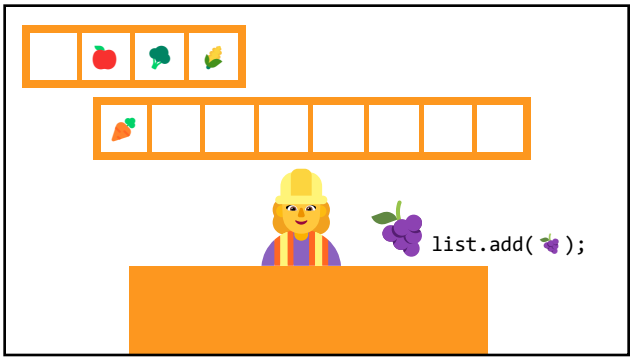
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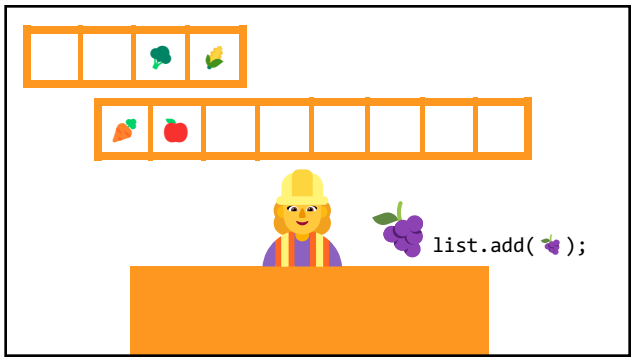
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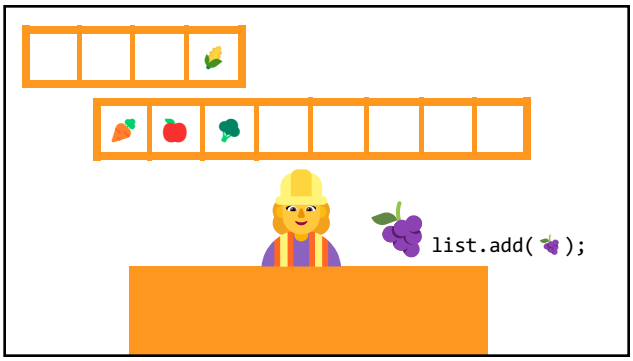
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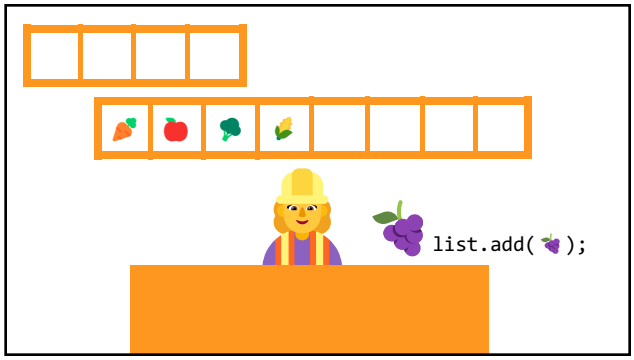
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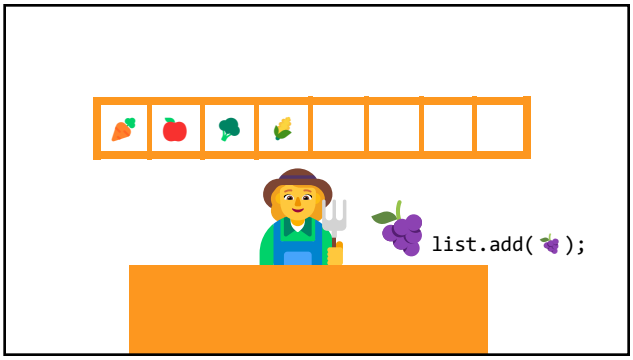
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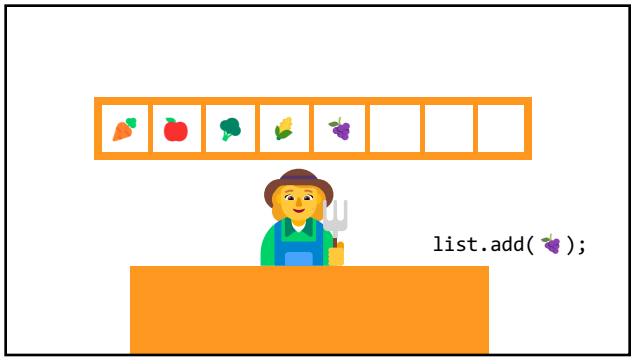
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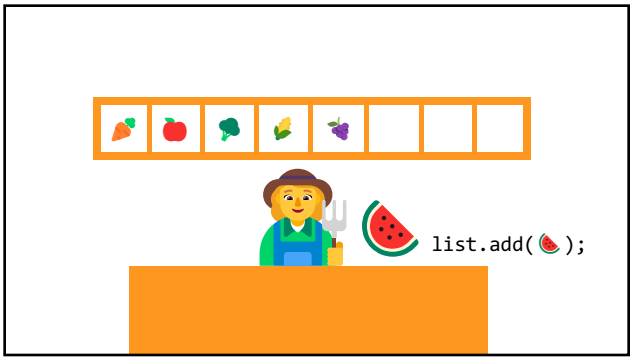
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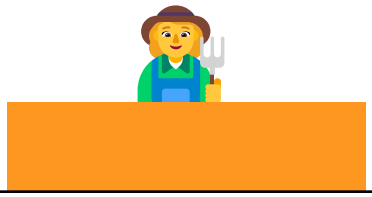


interface

an array list is a kind of list

- an **array list** (dynamic array, stretchy buffer, **vector**) is a kind of **list**
  - like an array, the user can **access** the i-th element in an array list
    - **get** the value of an element that is already there
    - **set** the value of an element that is already there
  - unlike an array, the user can always **add** a new element to an array list, no matter how many elements it already contains
    - **append** (push back) a new element to the end (back)
    - **insert** a new element at any valid index
  - the user can also **remove** elements from an array list

ArrayList<ElementType>

```
class ArrayList<ElementType> {
  void add(ElementType element); // to end
  void add(int index, ElementType element);
  ElementType get(int index);
  void set(int index, ElementType element);
  void remove(int index);
  int size();
  boolean isEmpty(); // (list.size() == 0)
}
```

<ElementType>

- Java's **`ArrayList<ElementType>`** is **generic**, which means you choose `ElementType` when you instantiate the class
  - `ArrayList<Thing> list = new ArrayList<>();`
  - `ArrayList<ArrayList<Thing>> lists = new ArrayList<>();`
  - `ArrayList<Integer> numbers = new ArrayList<>();`
    - **NOTE:** In between the angle brackets, use...
      - `Boolean` instead of `boolean`
      - `Character` instead of `char`
      - `Double` instead of `double`
      - `Integer` instead of `int`
      - 🤷

usage code

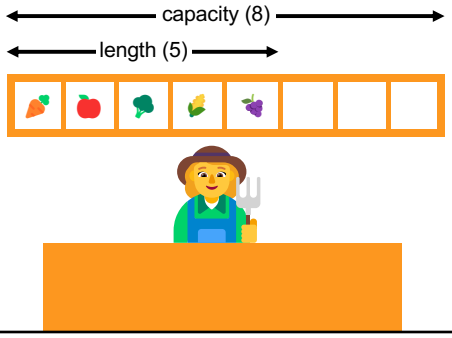
what does this code print? (the home game)

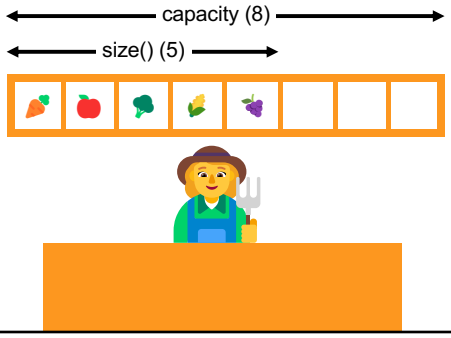
```
ArrayList<String> list = new ArrayList<>();
PRINT(list);
list.add("Hello");
list.add("World");
PRINT(list);
list.add(1, "Cruel"); // NOTE: insert so "Cruel" has index 1
PRINT(list);
PRINT(list.size());
PRINT(list.get(1));
list.remove(0);
PRINT(list);
list.set(1, "Summer");
PRINT(list);
```

usage code

```
ArrayList<String> list = new ArrayList<>();
PRINT(list);          // []
list.add("Hello");
list.add("World");
PRINT(list);          // [Hello, World]
list.add(1, "Cruel");
PRINT(list);          // [Hello, Cruel, World]
PRINT(list.size());   // 3
PRINT(list.get(1));   // Cruel
list.remove(0);
PRINT(list);          // [Cruel, World]
list.set(1, "Summer");
PRINT(list);          // [Cruel, Summer]
```

size (length) of the *list* vs. the *list's capacity*





the internal array

- an array list's **length** (**size**) is the number of elements stored in the list
- an array list stores its elements inside of an internal **array**
  - an array list's **capacity** is the length of this array
  - ✅ **length <= capacity**

```
class ArrayList<ElementType> {
    private int length; // NOTE: call size() to get this

    private ElementType[] internalArray;
    // NOTE: the list's capacity is internalArray.length
}
```

✅ length is not the same thing as capacity

- imagine `ArrayList<String> bestaurants;` with length (size) 3 and capacity 5
- if we could `PRINT(bestaurants.internalArray)`...
  `["Blango", "Sproot", "Sparket", null, null]`
  ...we would see `5 - 3 = 2` "empty slots"

Dinner | $20–30

I ordered general tso's chicken with rice and crab rangoons. Upon biting into the crab rangoon I realized there was absolutely no filling inside of it. Literally the entire thing was bread. When I pay $7 for crab rangoons I 1) expect them to be full of filling 2) there should be more than four. Also the general tso's chicken I got that was almost $15 was not full. My complete order ended up being $30 with tip. And in my opinion was a complete waste of time and money.
0/10 would absolutely never order here again.

implementation continued

`ArrayList() { ... } // constructor`

- a new array list should have...
  - `this.length = 0;`
  - `this.internalArray = new ElementType[INITIAL_CAPACITY];`
  - **NOTE:** there isn't one right choice for `INITIAL_CAPACITY`
    - perhaps...`0`?
    - perhaps `8`?
    - 🤷

`ElementType get(int index) { ... }`

- to **get** an element with a given `index`...
  - `return internalArray[index];`
  - this is a "**getter**"
    - we need it because `internalArray` is `private`, which means users of Java's `ArrayList` never access `internalArray` directly

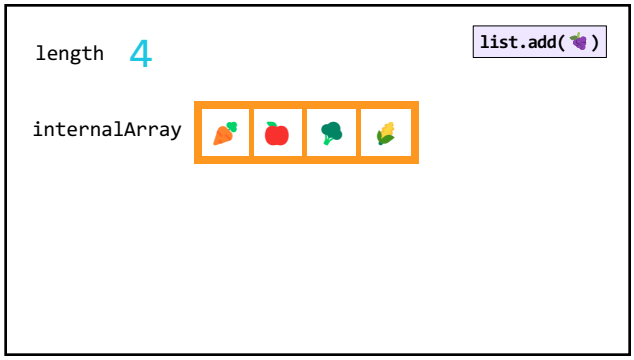
`void add(ElementType element) { ... }`

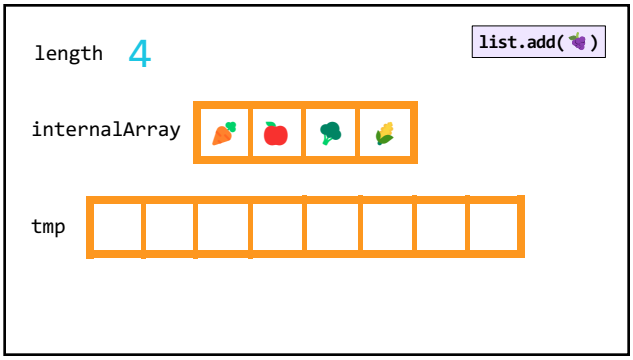
- to **append** (push back) a new element to the back (end) of an array list...
  - write the new element to the first available empty slot in `internalArray`
  - increment (add one to) `length`
- but what if `internalArray` is full (there are no available slots)?

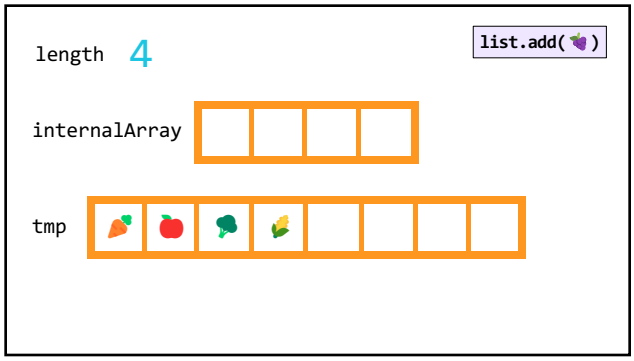
add (details)

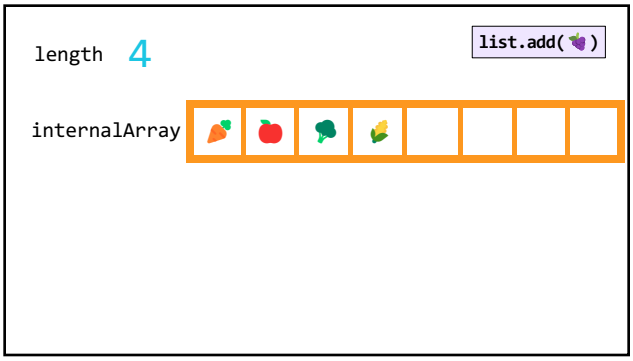
```
void add(ElementType element) { ... }
```

- to **append** (push back) a new element to the back (end) of an array list...
  - if `internalArray` is full...
    - make a new array two times the length of the current internal array
    - copy the elements of the current internal array into this new array (using a for loop)
    - update the `internalArray` reference to refer to this new array
  - write the new element to the first available empty slot in `internalArray`
  - increment `length`









length 5

list.add(🍇)

internalArray

```
void add(int index, ElementType element)
```

- to **insert** a new element so it has a given `index`...
  - `ASSERT` that the given `index` is valid!
    - **NOTE:** `0` is OK (**"prepend"**)
    - **NOTE:** `length` is OK (**append**)
    - **NOTE:** `-1` is BAD BAD VERY BAD (**out of bounds**)
    - **NOTE:** `(length + 1)` is BAD BAD VERY BAD (**out of bounds**)
  - if internal array is full, resize (see previous slide)
  - make room for the new element
    - move elements with indices greater than or equal to index one slot to the right
      ☠️ **like in HW02 (text box), need to iterate backwards**
  - write new element and increment length

length 4

list.add(🍋 , 2)

internalArray

length 4

list.add(🍋 , 2)

internalArray

length 4

list.add(🍋 , 2)

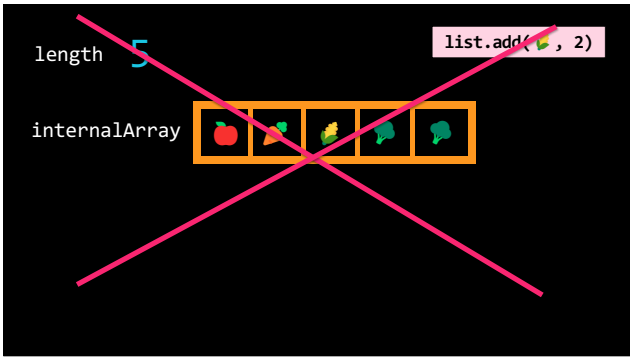
internalArray

length 5

list.add(🍋 , 2)

internalArray

☠️ like in HW02 (text box), need to iterate backwards



final note on add

final note on add

- the special-case add to end (append)
  can be implemented using the general-purpose add (insert)

```
void add(ElementType element) {
    add(length, element);
}
```

- ☠ **however, if i were implementing an array list from scratch,**
  i would implement the less general version first because it is simpler