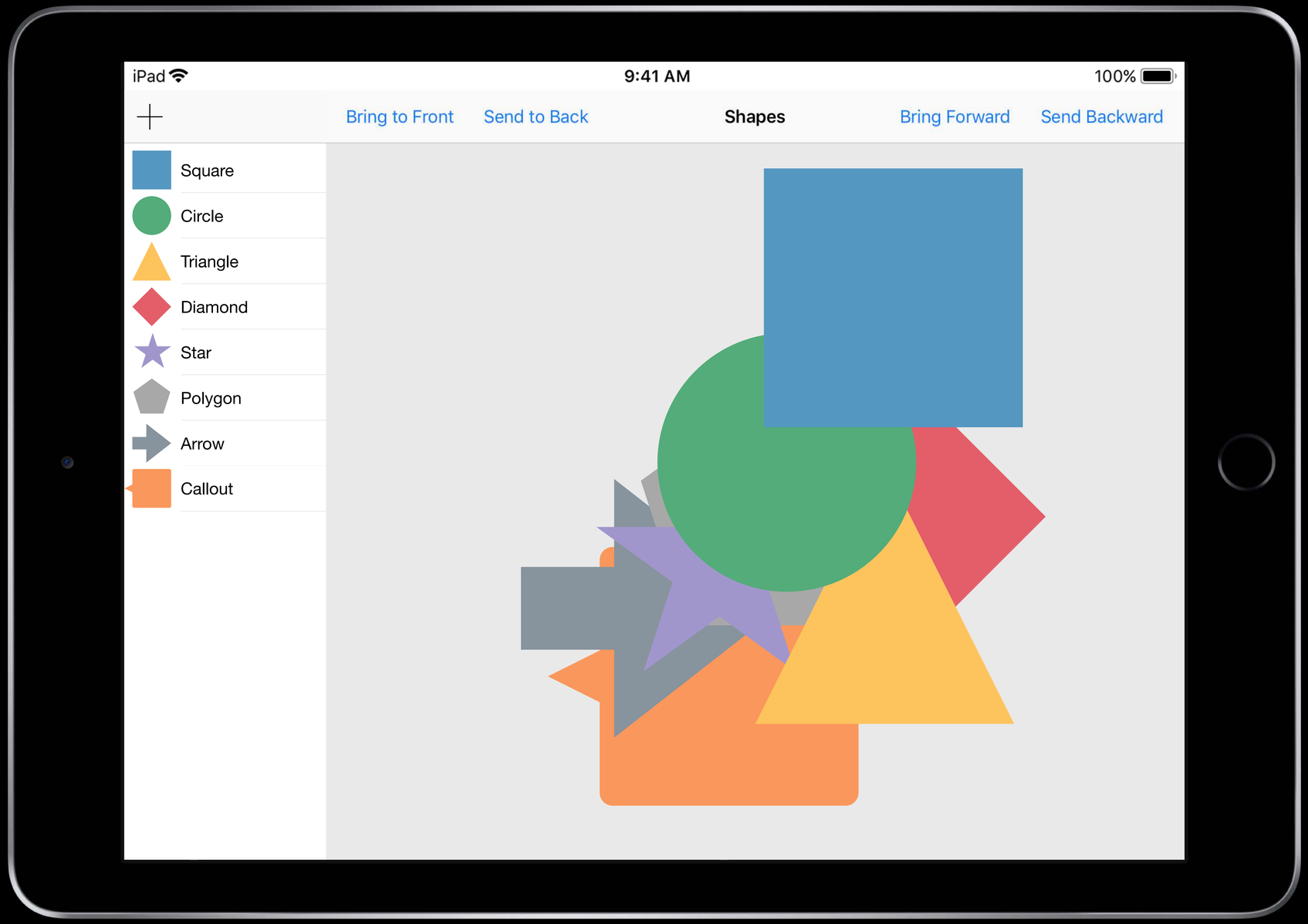
#WWDC18

Embracing Algorithms

Dave Abrahams

Meet Crusty

Mind your own business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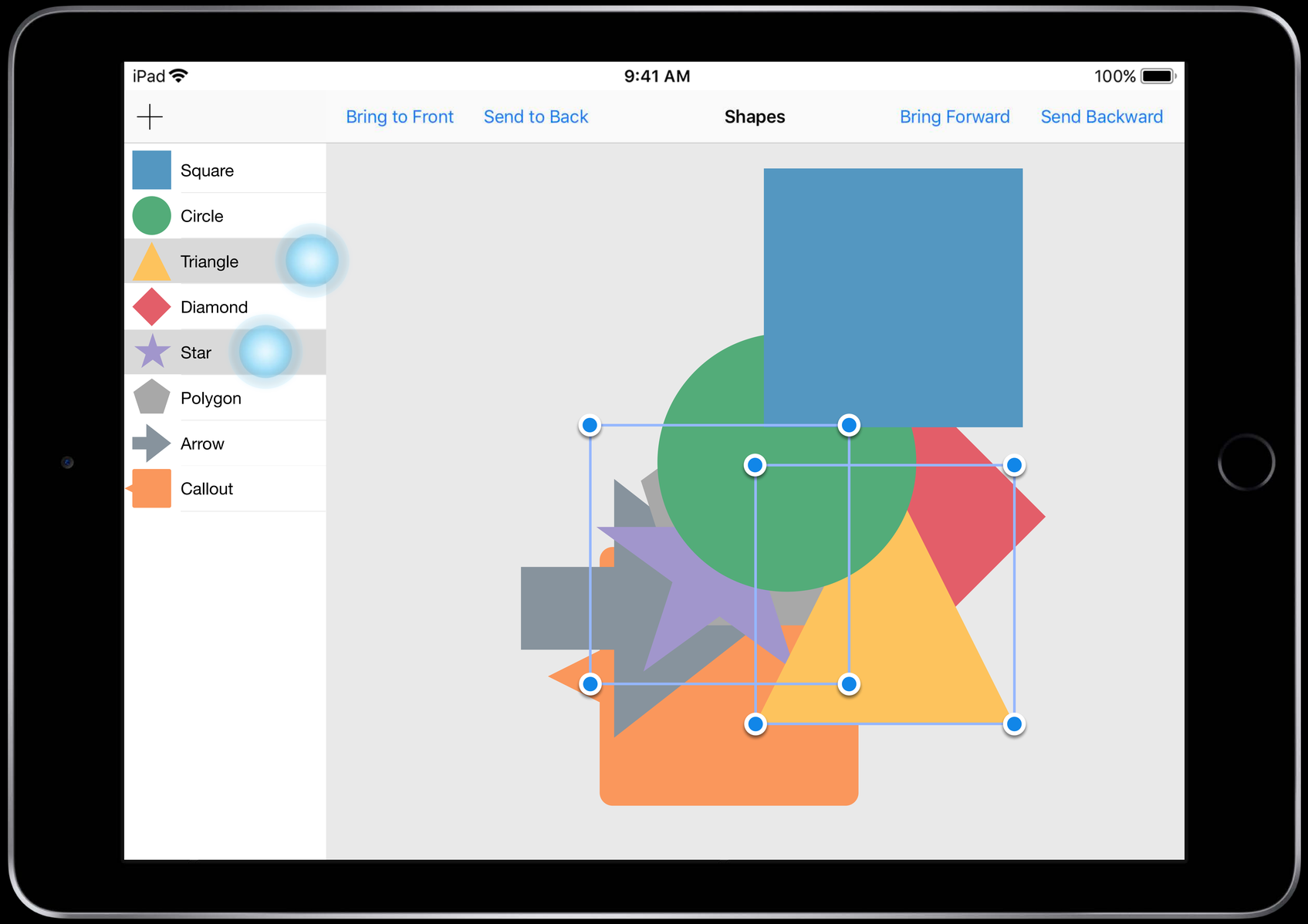
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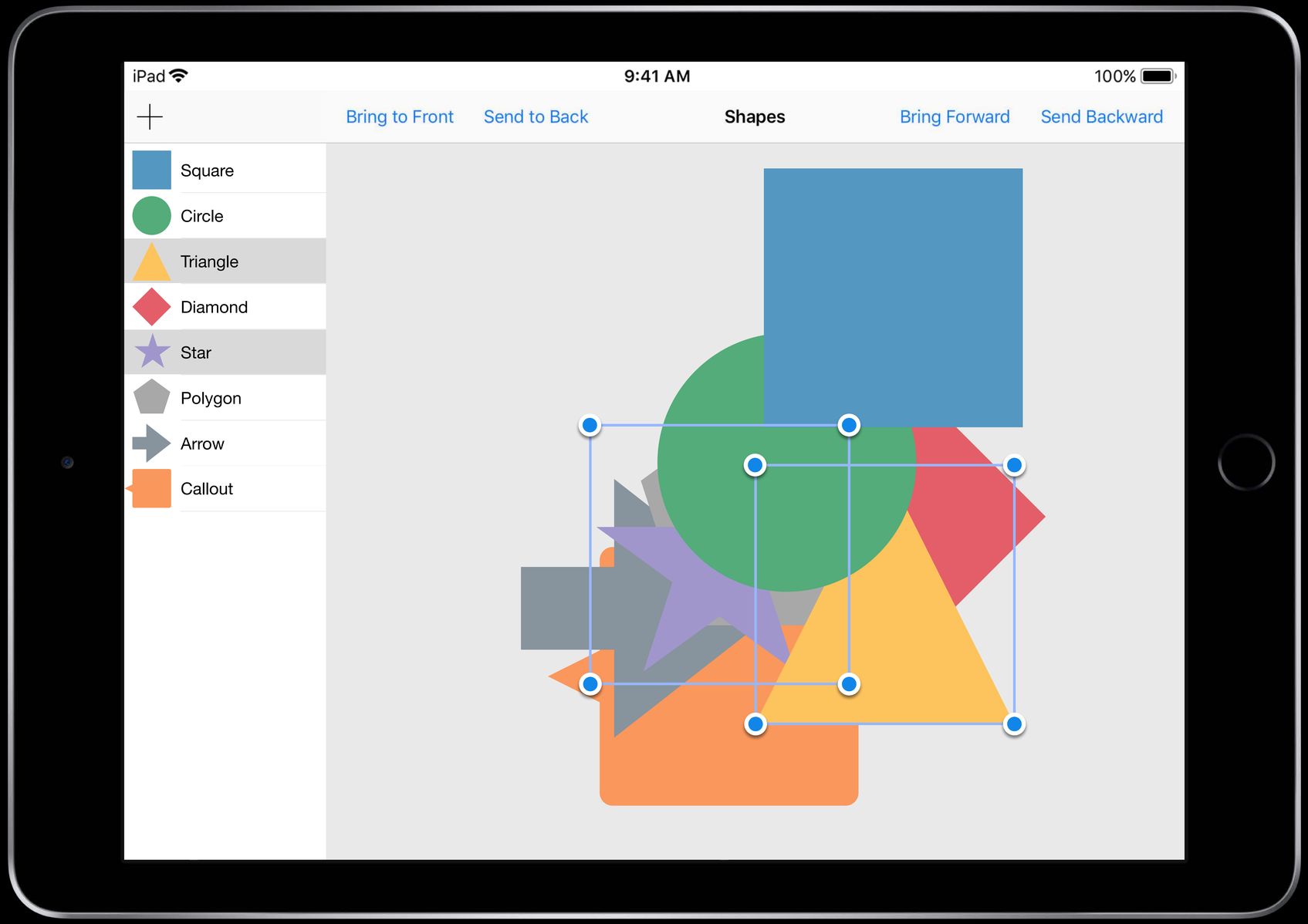
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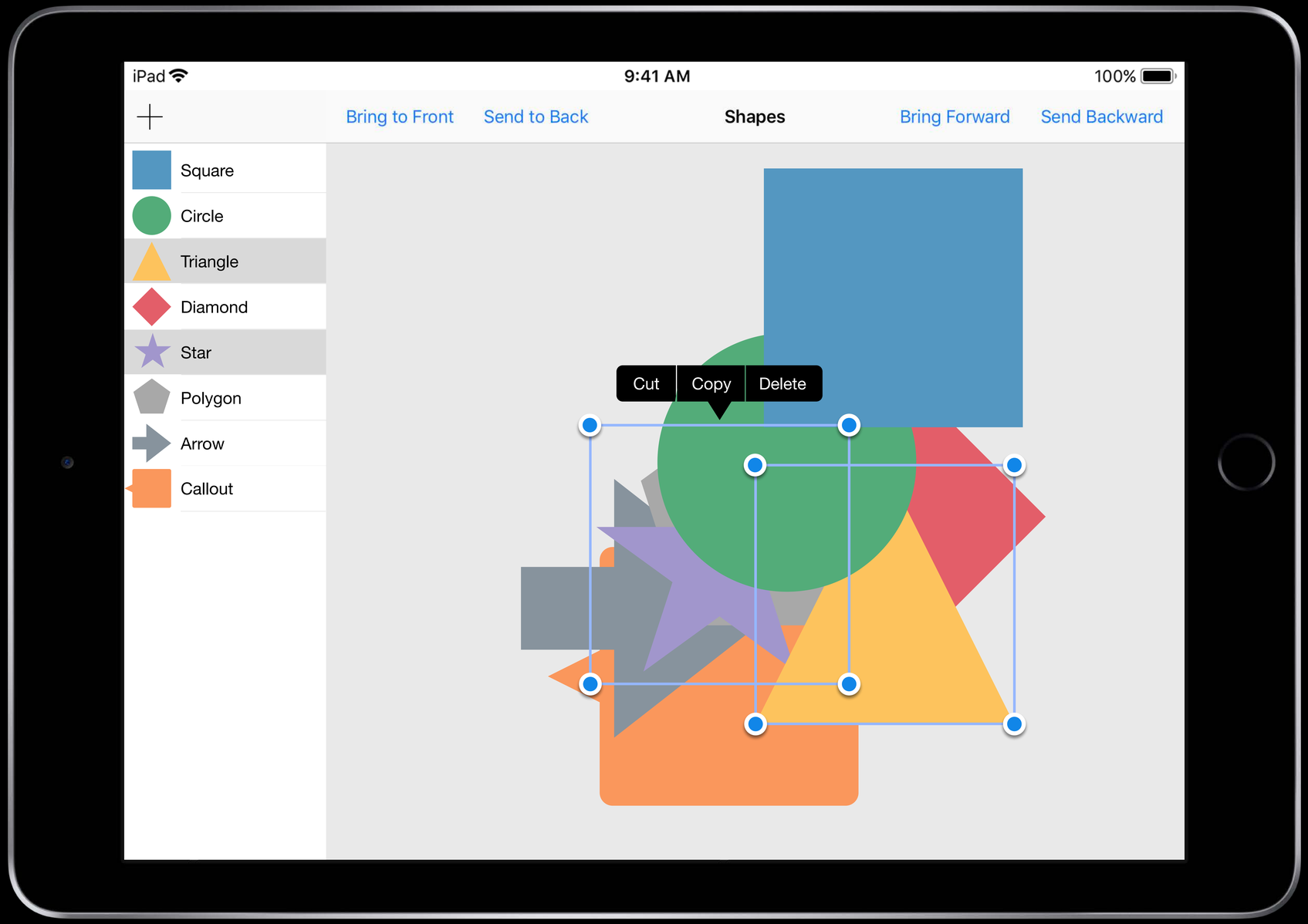
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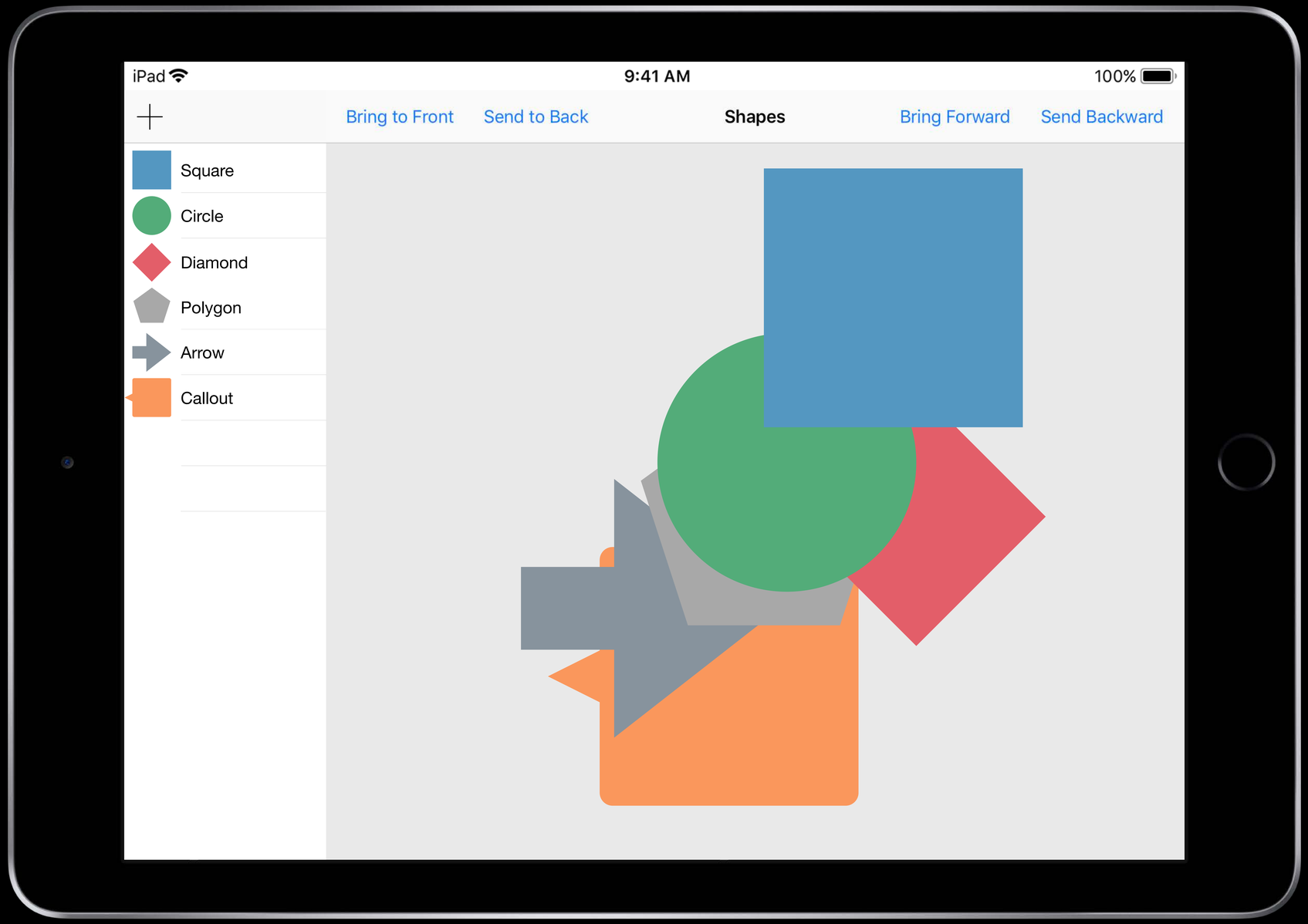
Delete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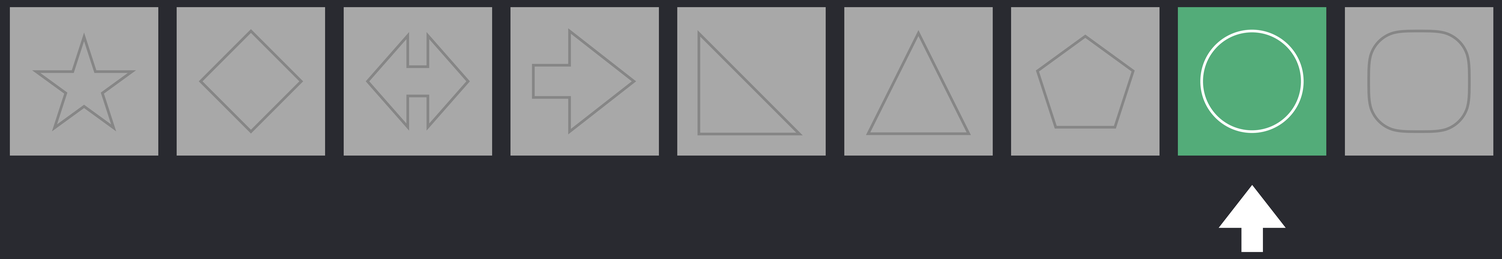

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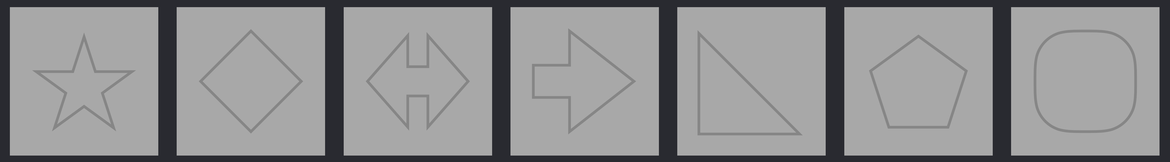

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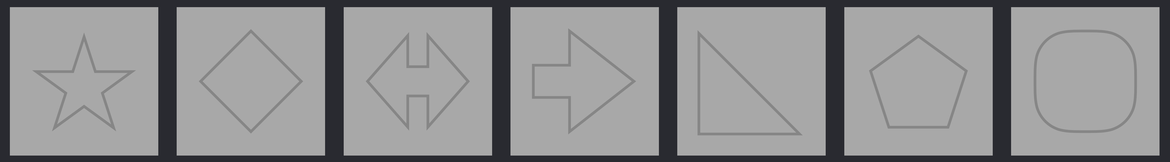

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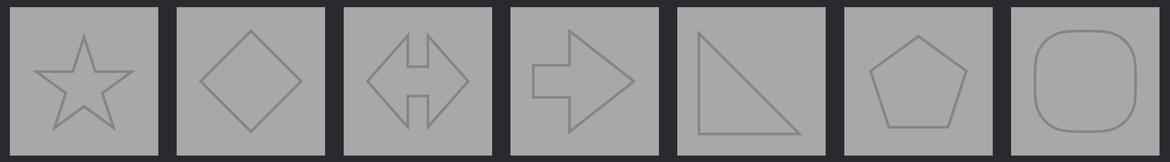

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Removes and returns the element at the specified position.

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```
mutating func remove(at index: Int) -> Shape
```

Discussion

All the elements following the specified position are moved up to close the gap.

```
var measurements: [Double] = [1.1, 1.5, 2.9, 1.2, 1.5, 1.3, 1.2]
let removed = measurements.remove(at: 2)
print(measurements)
// Prints "[1.1, 1.5, 1.2, 1.5, 1.3, 1.2]"
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Complexity

O(*n*), where *n* is the length of the array.

Parameters

`index`	The position of the element to remove. `index` must be a valid index of the array.

Returns

The element at the specified index.

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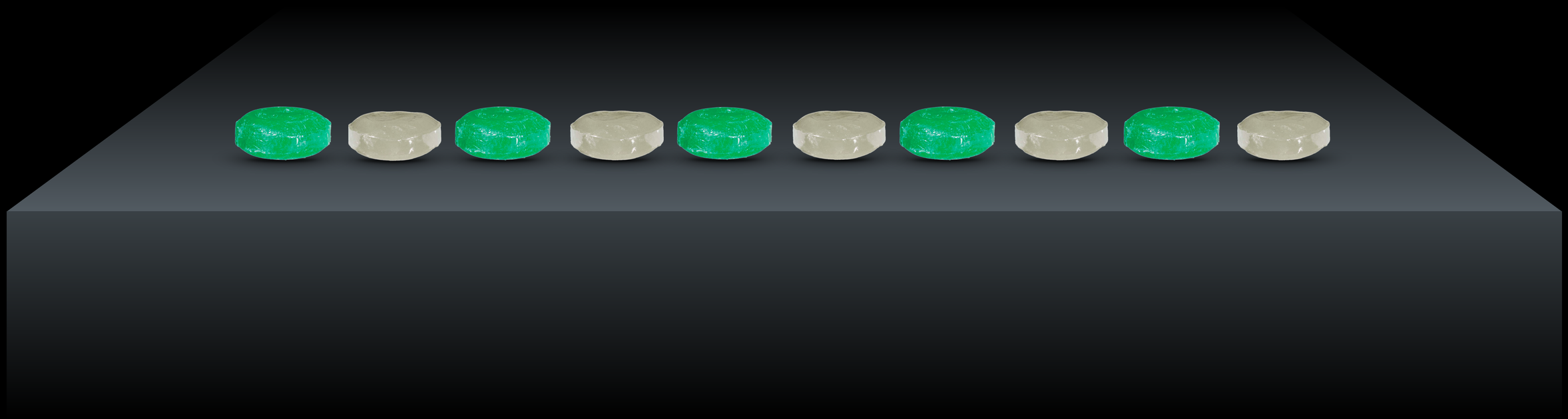
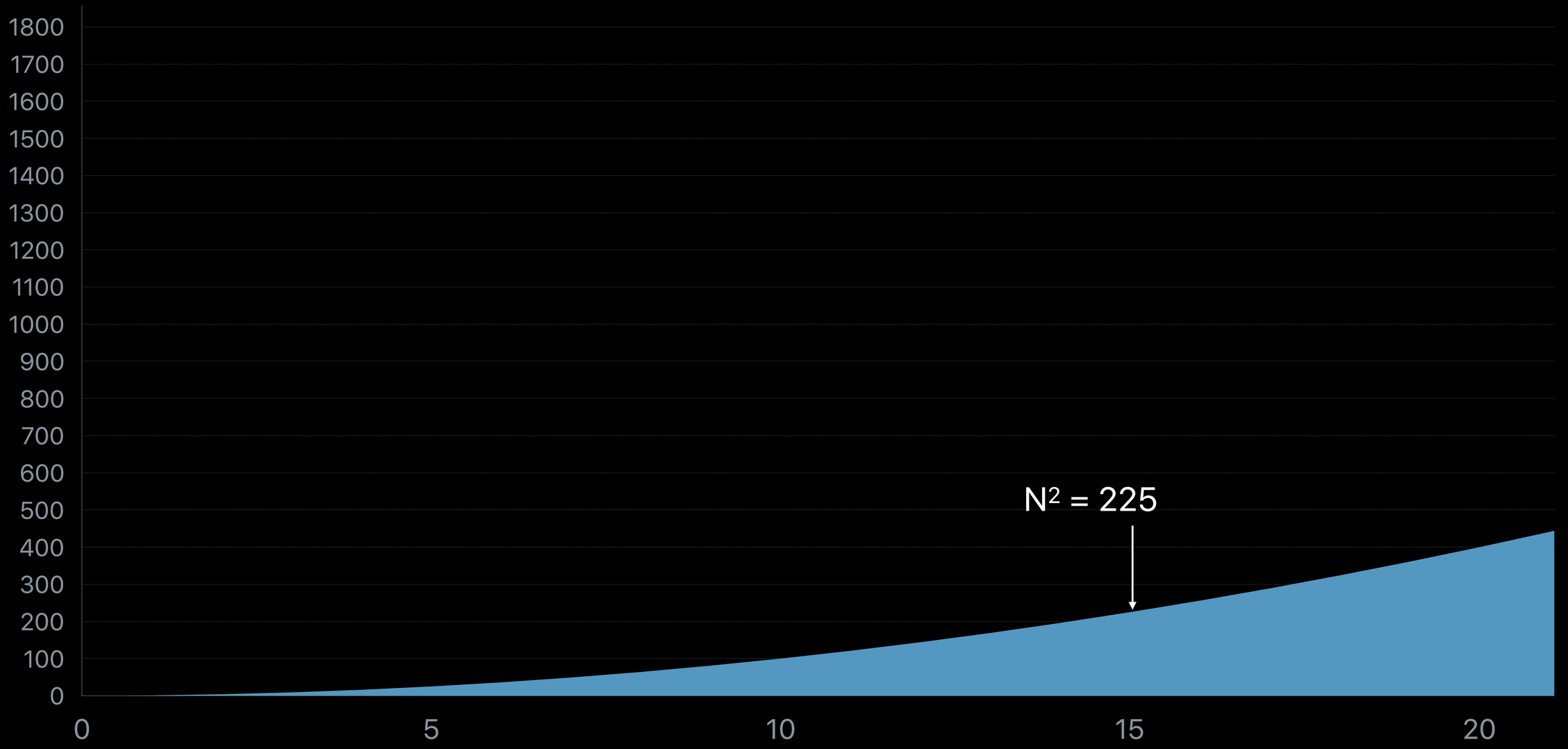


Delete the Green Ones

Scalability Matters



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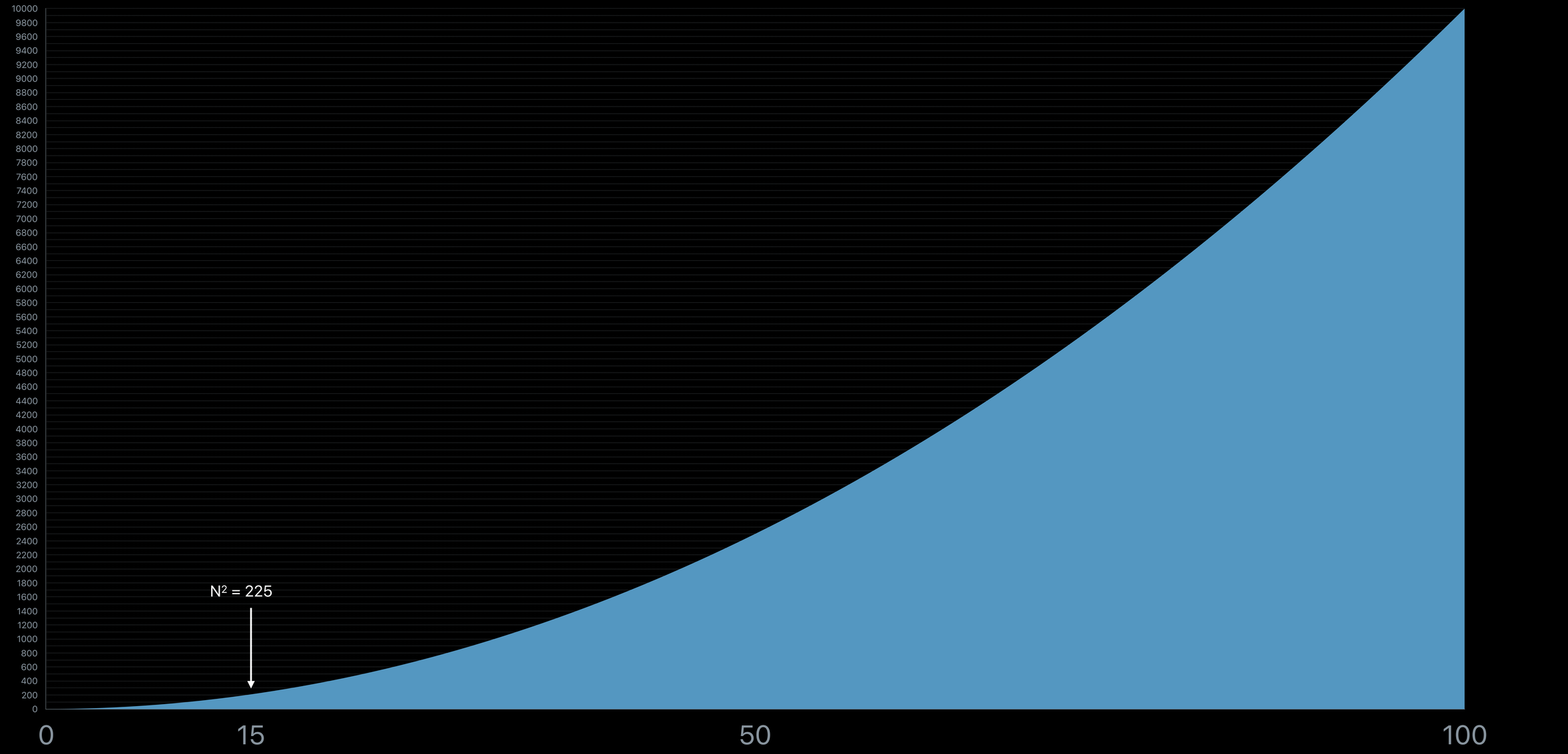

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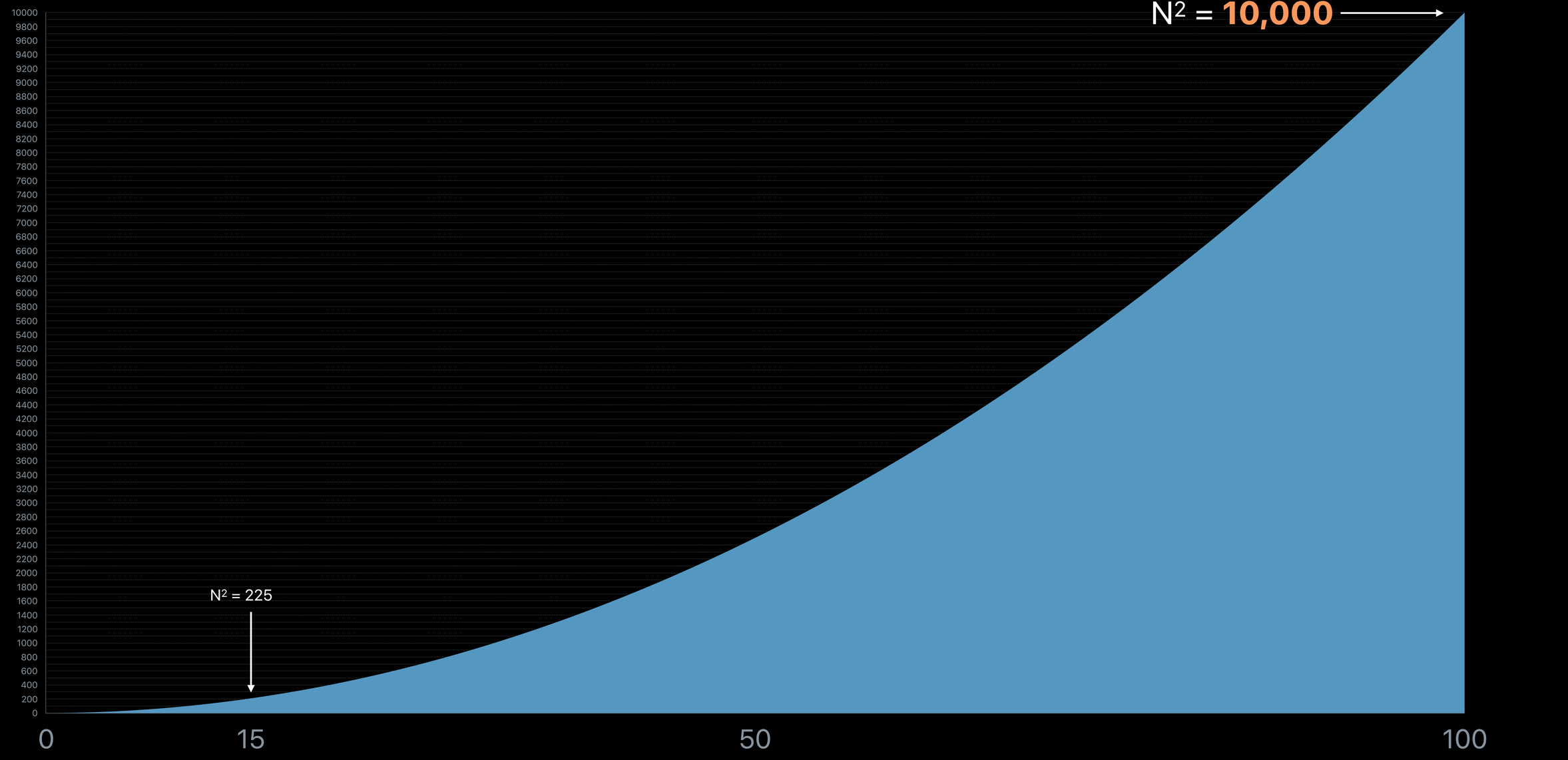

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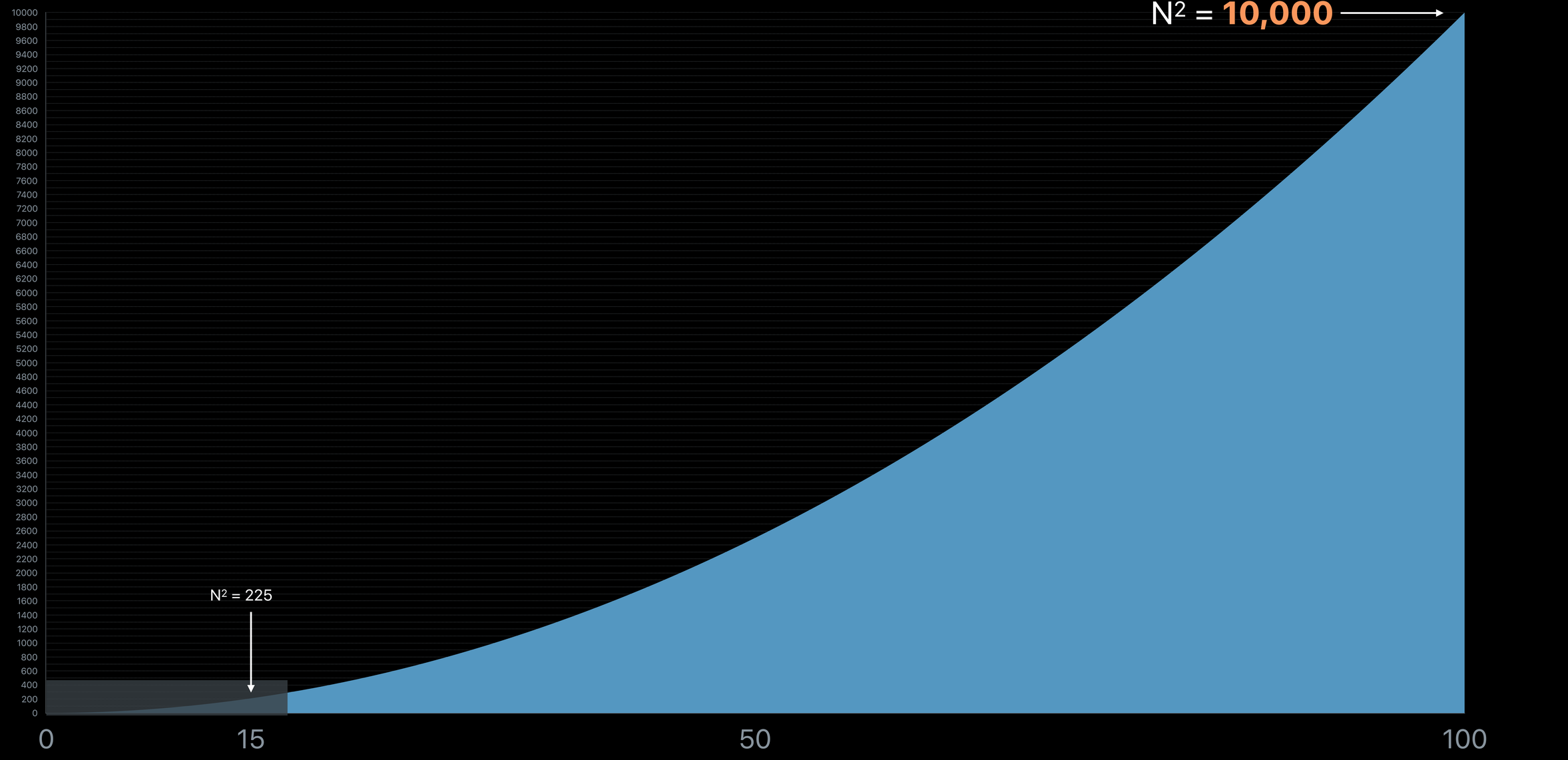

The Application Architect Speaks

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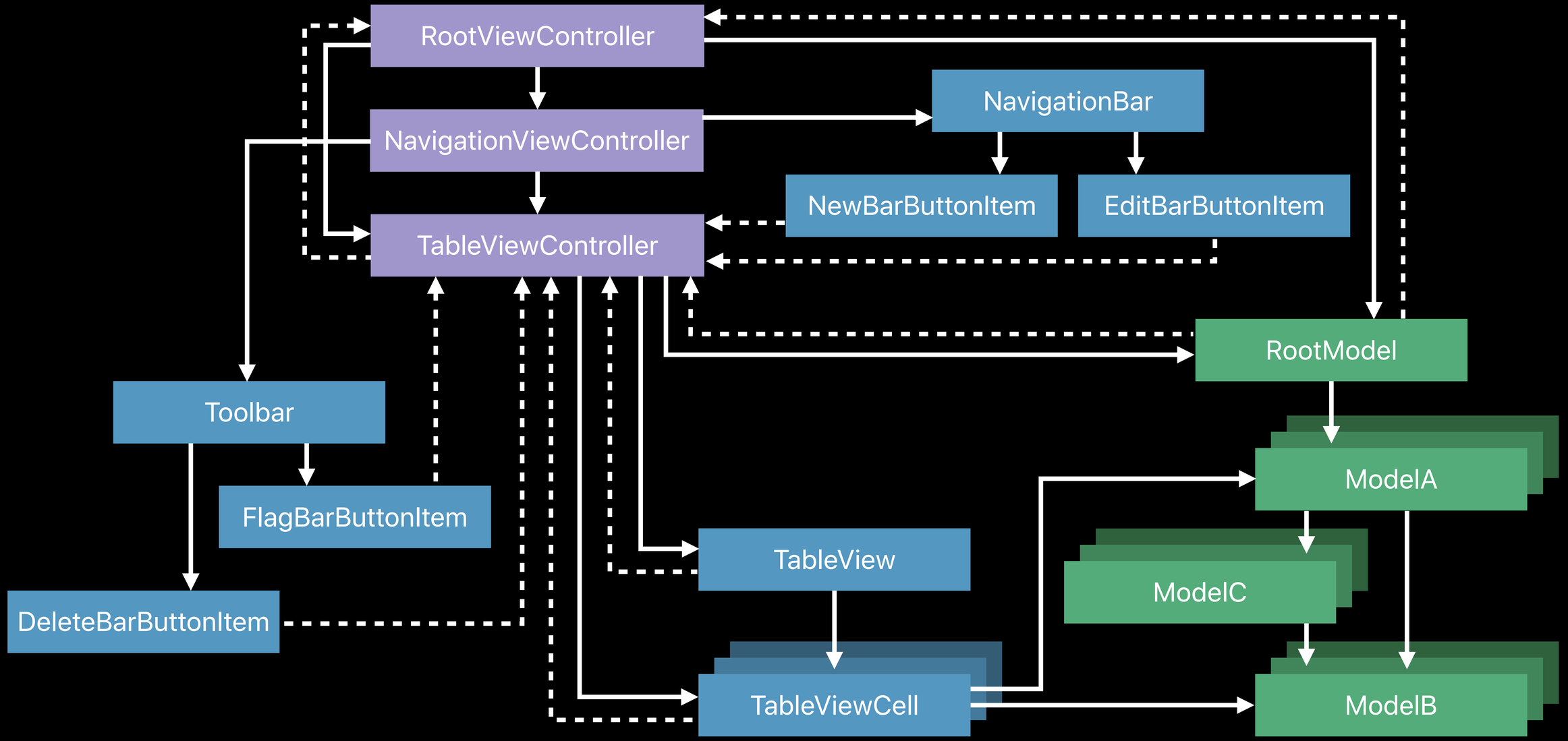

Algorithm: Look it Up

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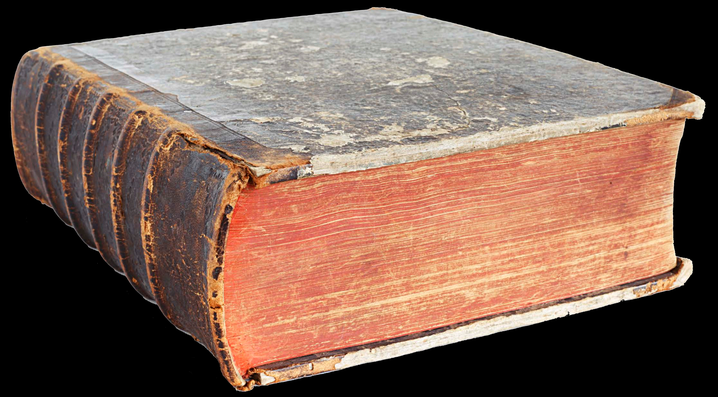

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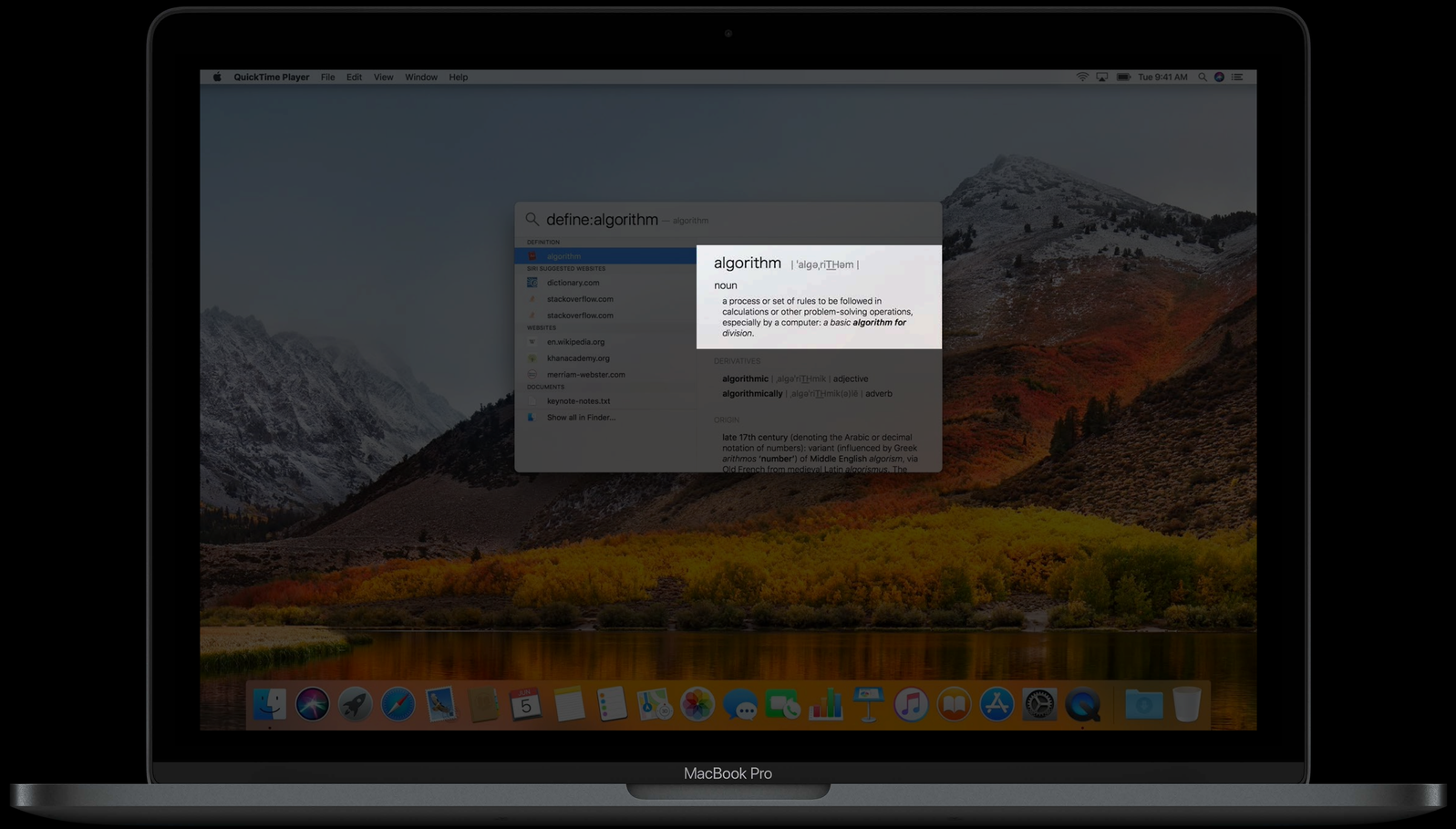

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Summary

Removes from the collection all elements that satisfy the given predicate.

Declaration

```
mutating func removeAll(where predicate: (Self.Element) throws ->
Bool) rethrows
```

Discussion

Complexity

O(*n*), where *n* is the length of the collection.

Parameters

`predicate`	A closure that takes an element of the sequence as its argument and returns a Boolean value indicating whether the element should be removed from the collection.

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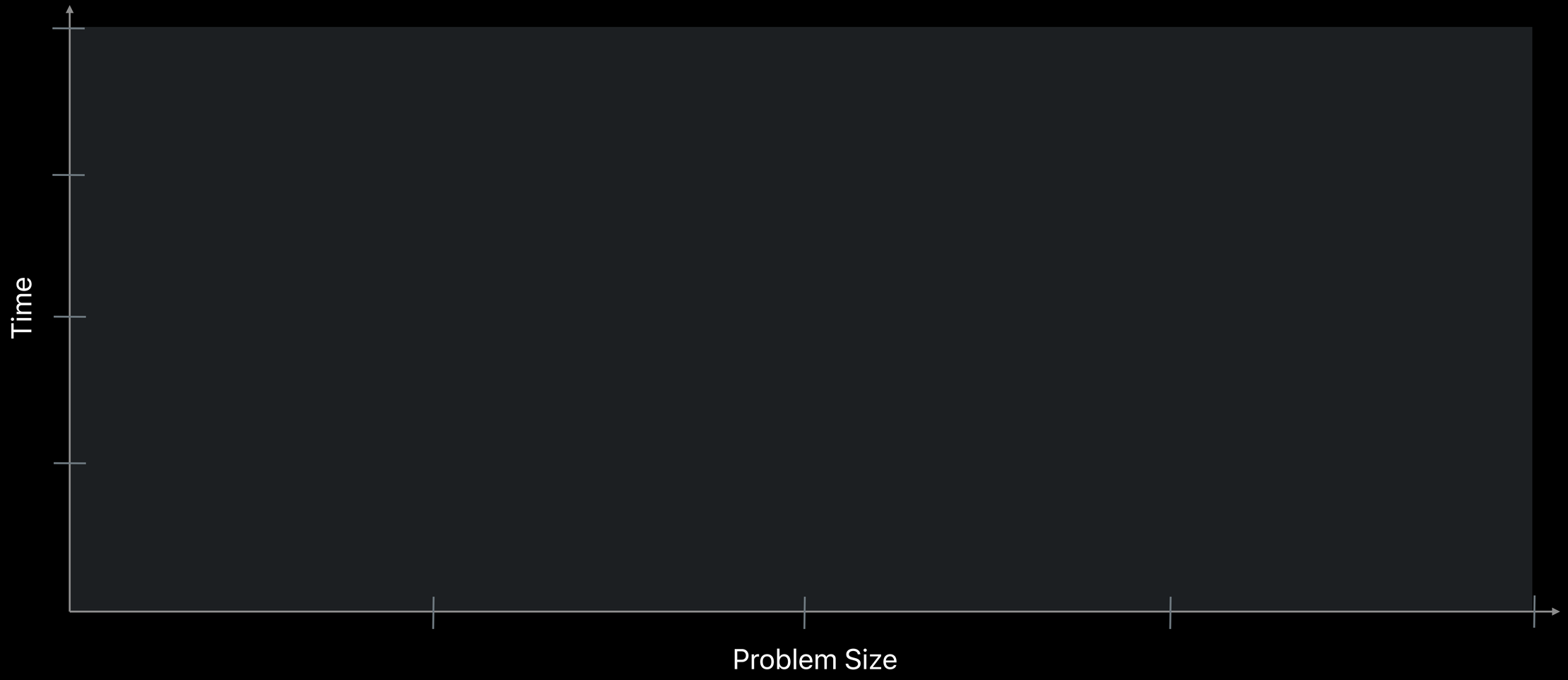

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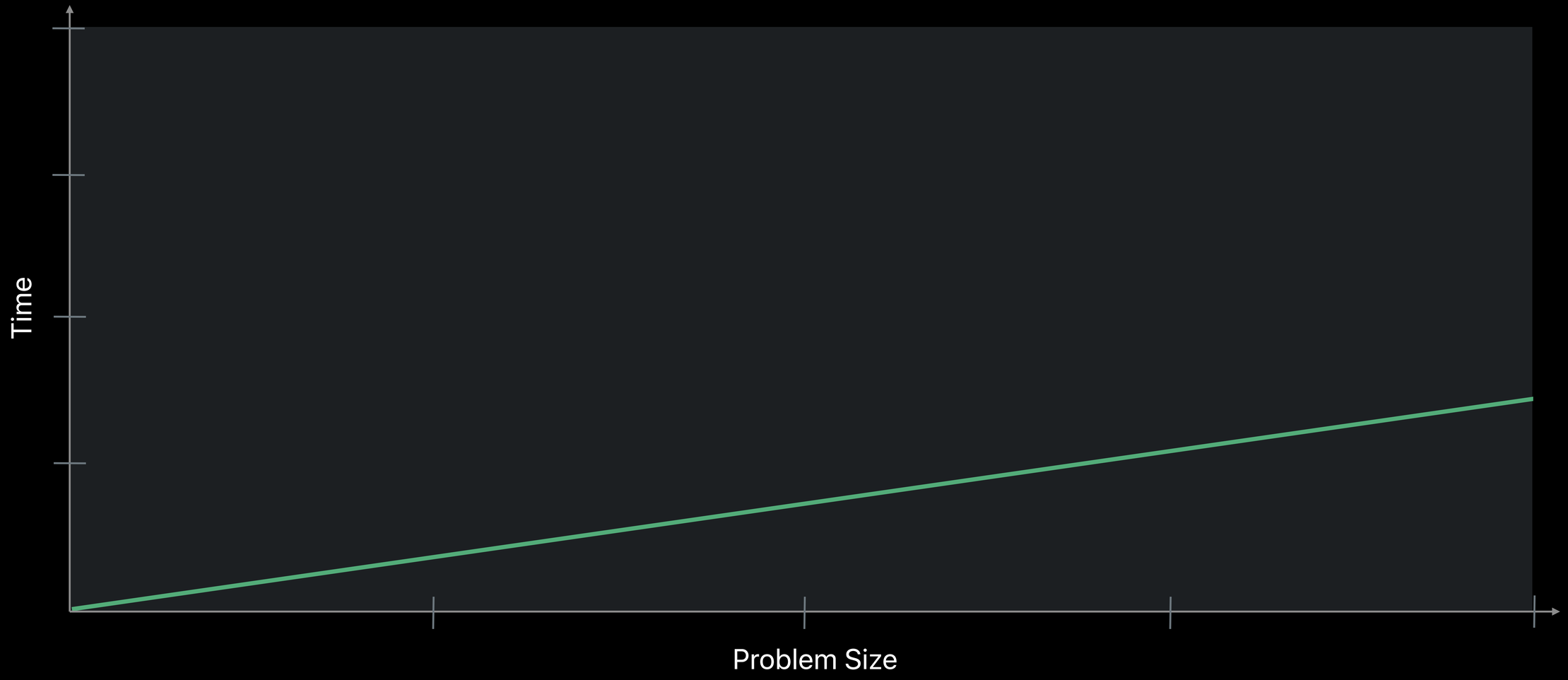

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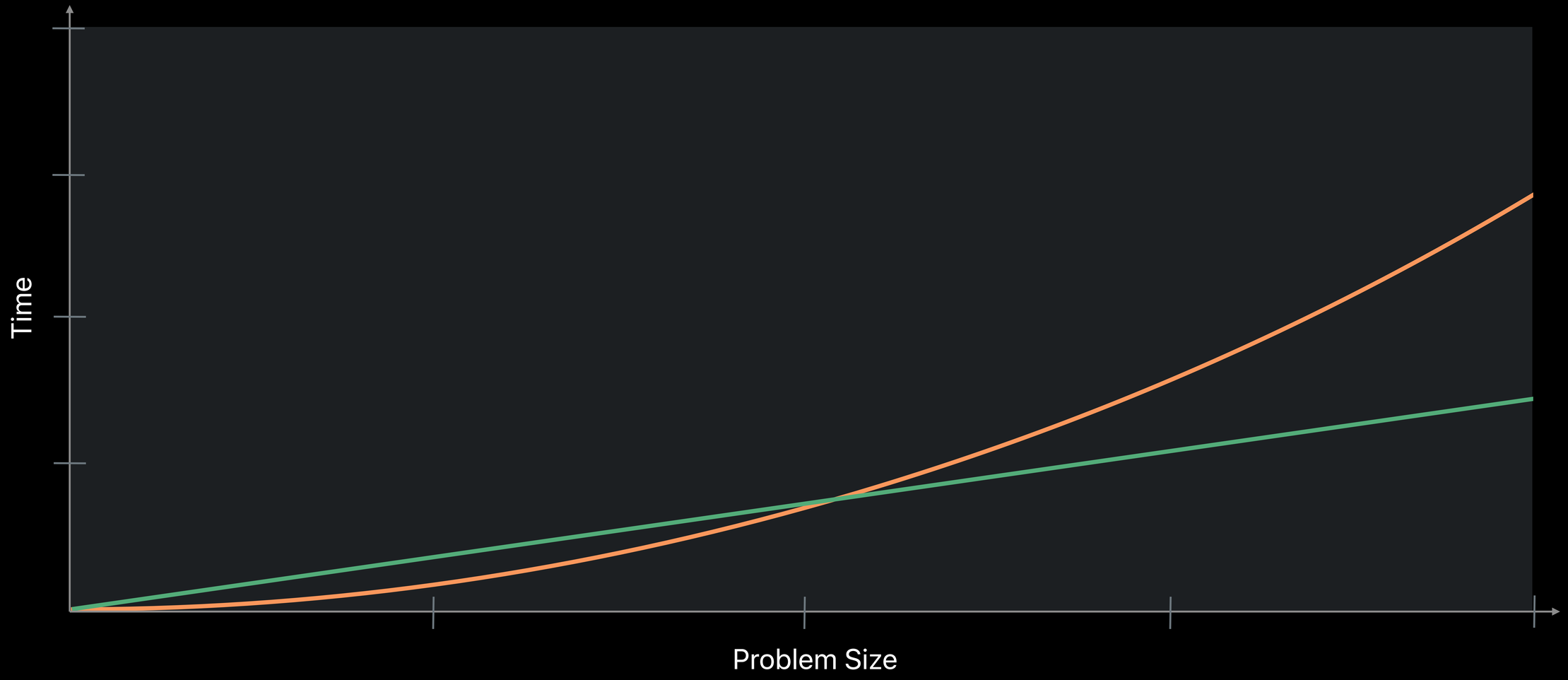

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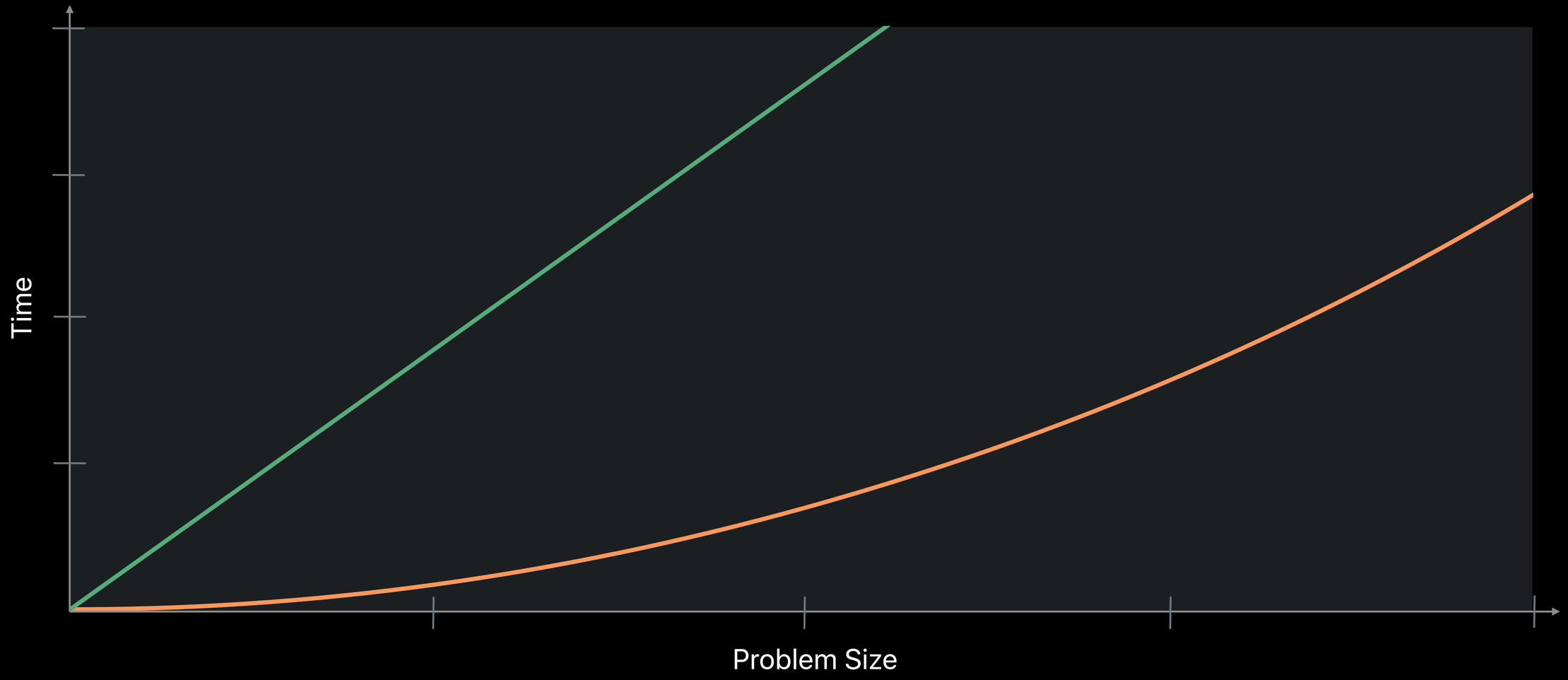

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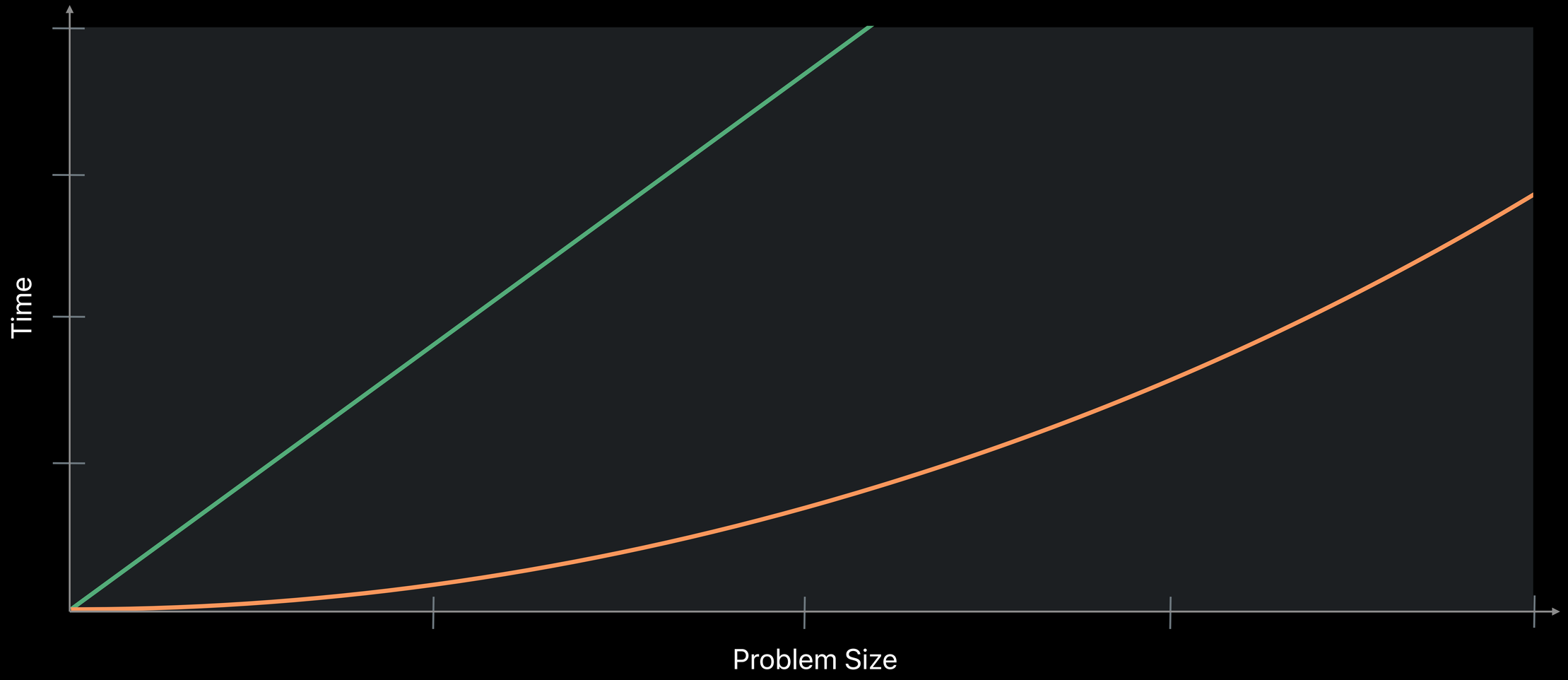

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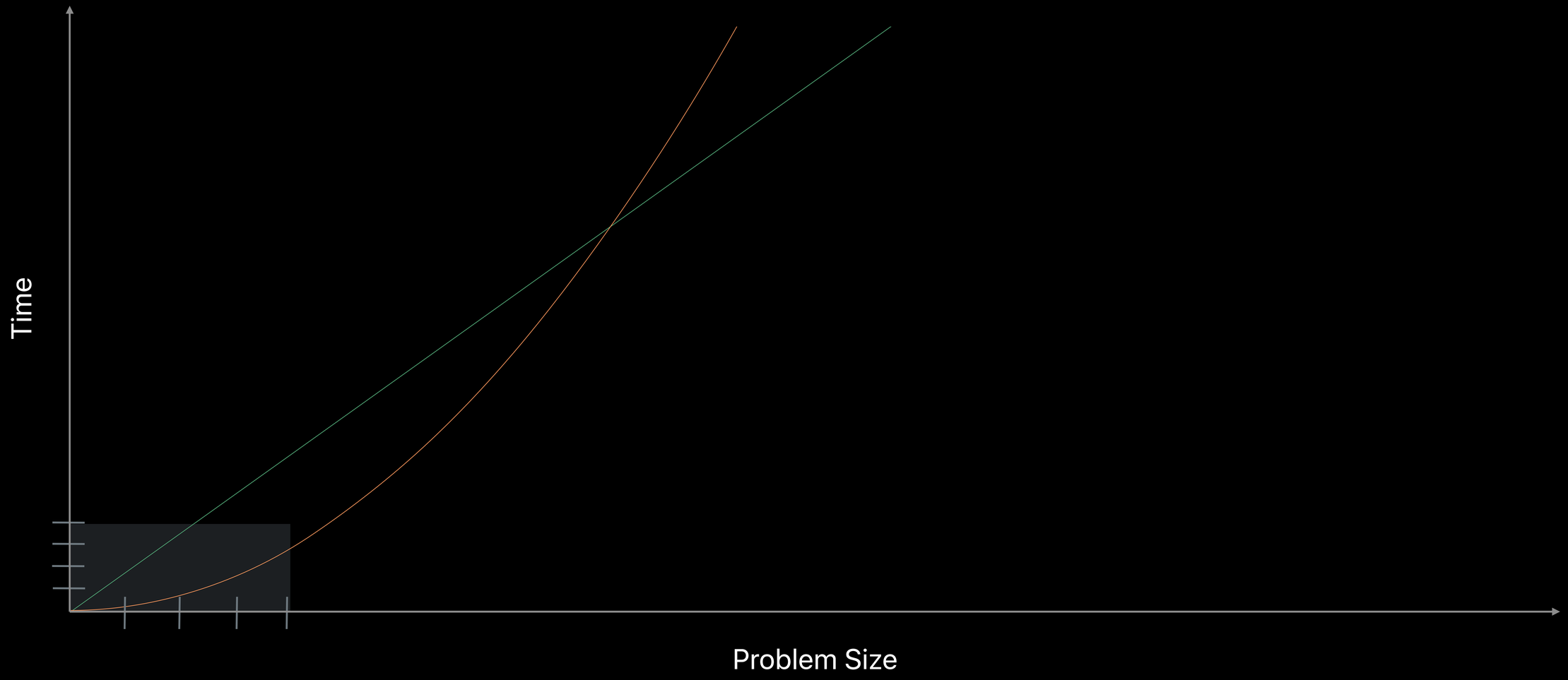

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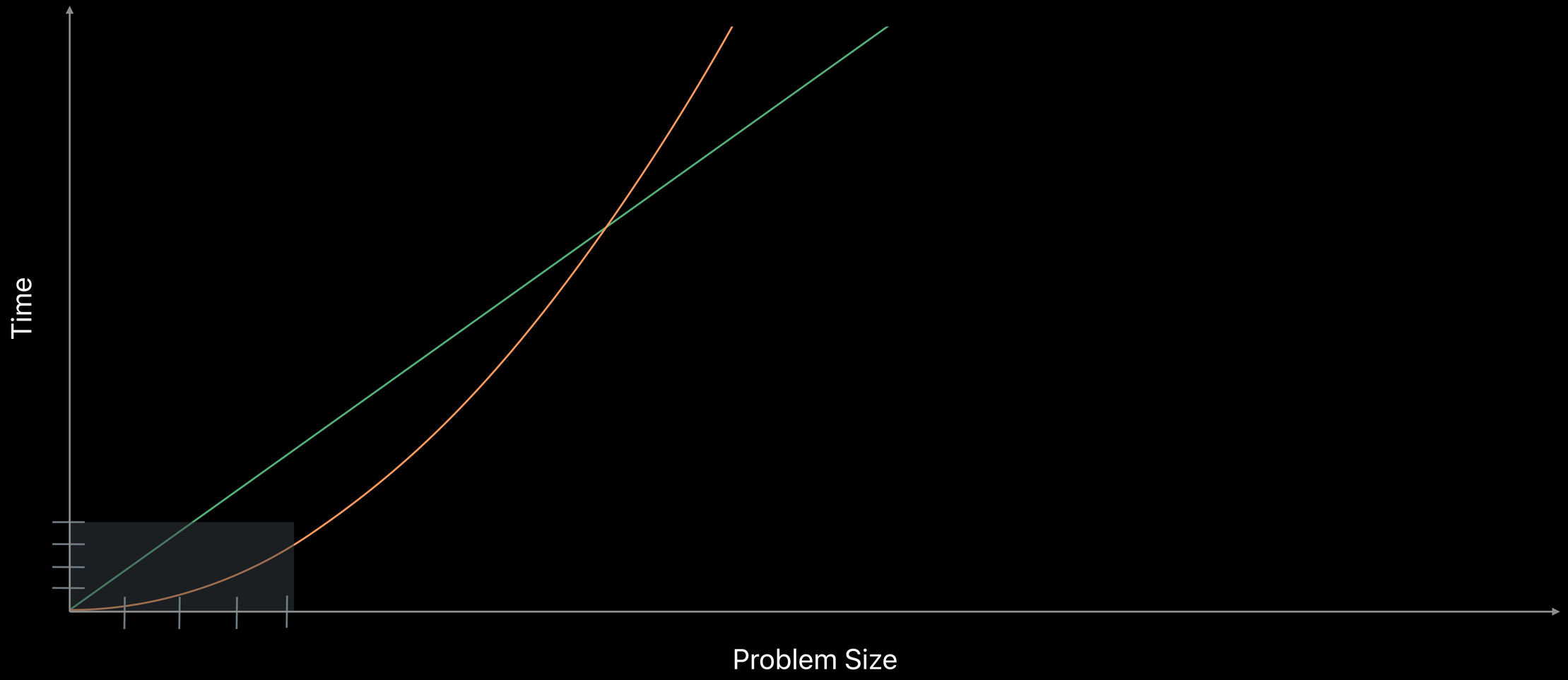

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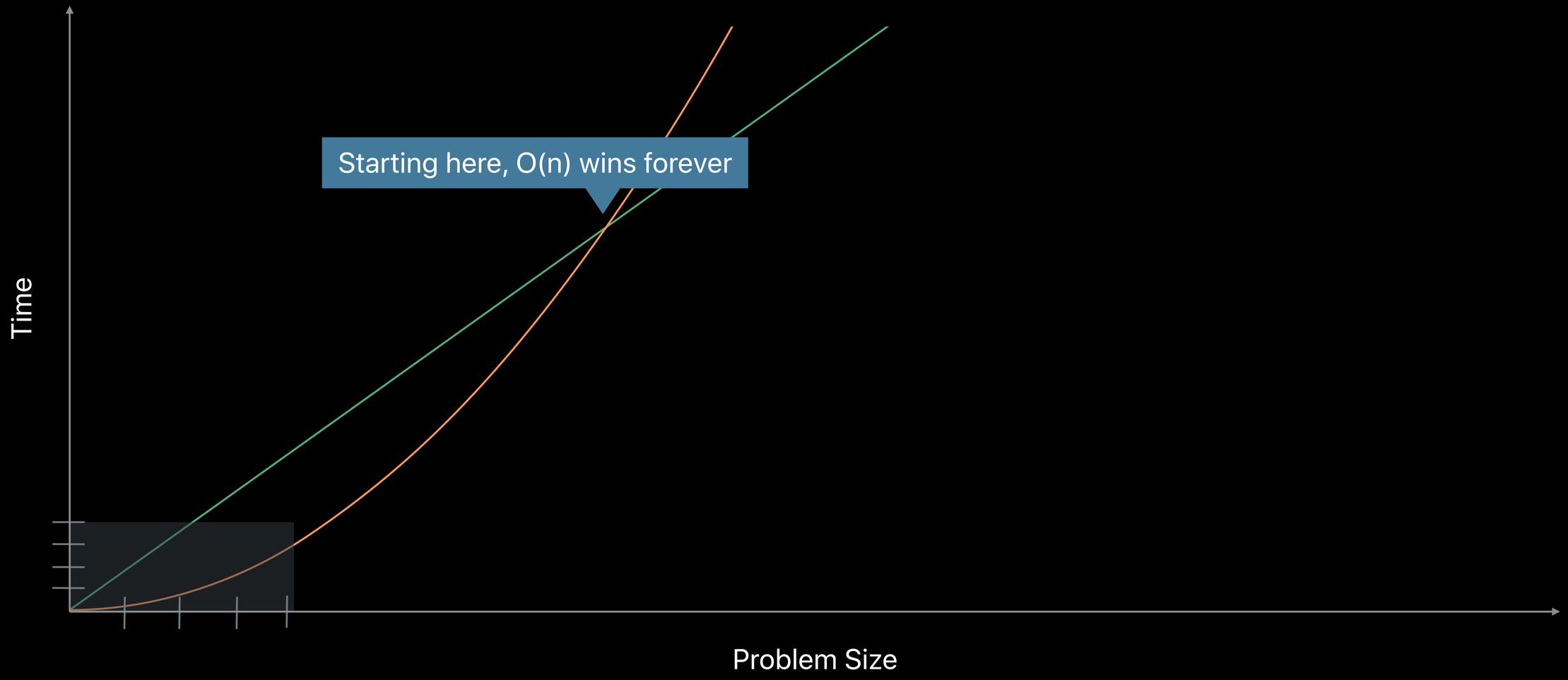

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    /// Removes all elements satisfying `shouldRemove`.
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    /// - Complexity: O(n) where n is the number of elements.
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        let suffixStart = halfStablePartition(isSuffixElement: shouldRemove)
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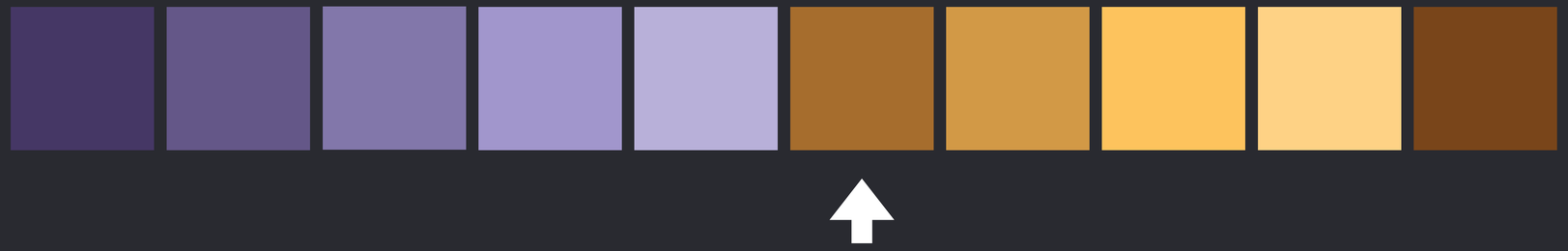
    mutating func removeAll(where shouldRemove: (Element)->Bool) {
        let suffixStart = halfStablePartition(isSuffixElement: shouldRemove)
        removeSubrange(suffixStart...)
    }
}
```



```
extension MutableCollection where Self : RangeReplaceableCollection {
    /// Removes all elements satisfying `shouldRemove`.
    ///
    /// - Complexity: O(n) where n is the number of elements.
    mutating func removeAll(where shouldRemove: (Element)->Bool) {
        let suffixStart = halfStablePartition(isSuffixElement: shouldRemove)
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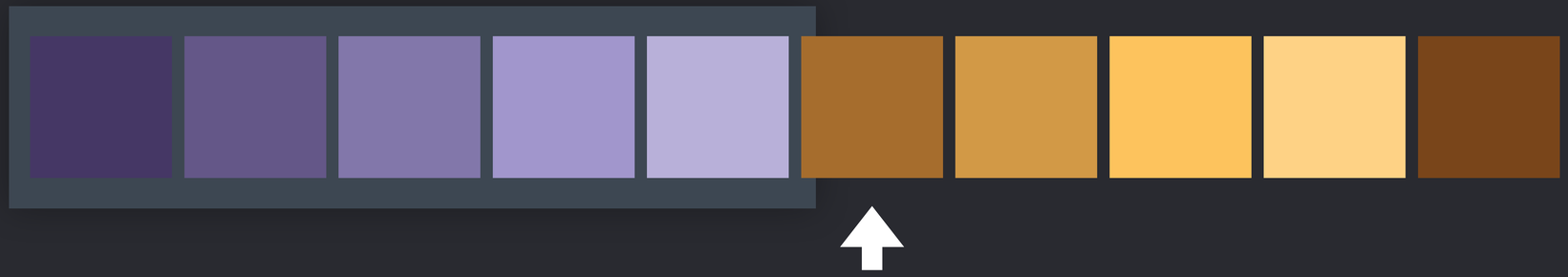

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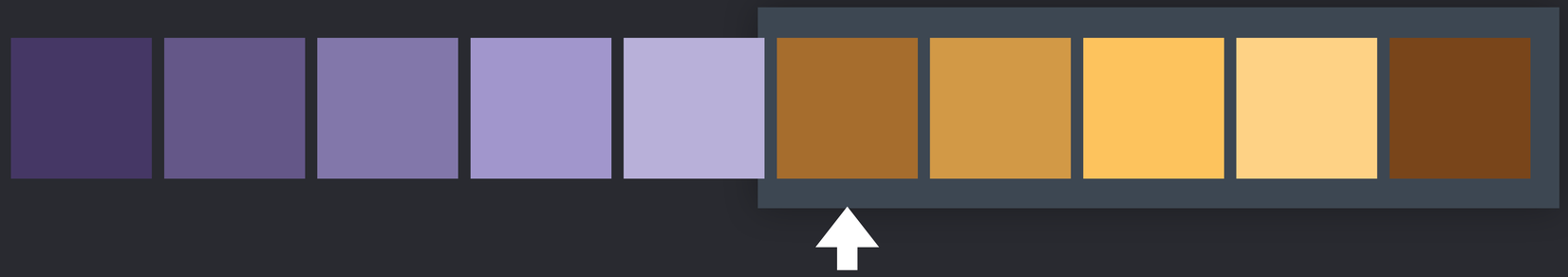

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        let suffixStart = halfStablePartition(isSuffixElement: shouldRemove)
        removeSubrange(suffixStart...)
    }
}
```

Means the same as
`suffixStart..<endIndex`

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extension MutableCollection {
    /// Moves all elements satisfying `isSuffixElement` into a suffix of the collection,
    /// returning the start position of the resulting suffix.
    ///
    /// - Complexity: O(n) where n is the number of elements.
    mutating func halfStablePartition(isSuffixElement: (Element) -> Bool) -> Index {
        guard var i = firstIndex(where: isSuffixElement) else { return endIndex }
        var j = index(after: i)
        while j != endIndex {
            if !isSuffixElement(self[j]) { swapAt(i, j); formIndex(after: &i) }
            formIndex(after: &j)
        }
        return i
    }
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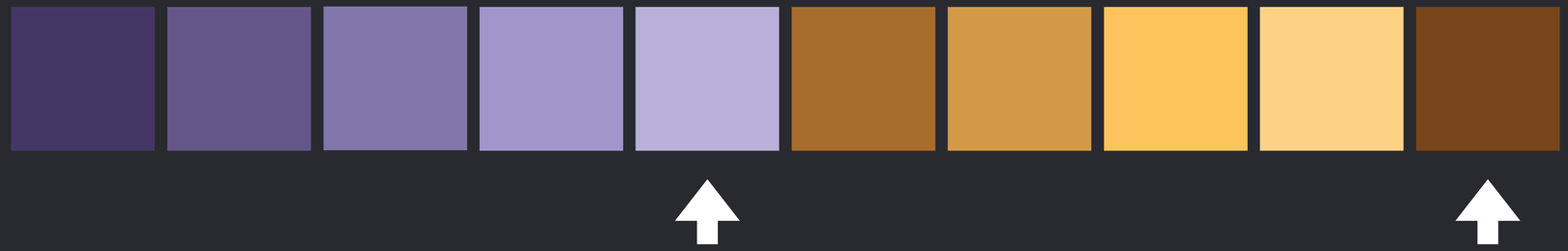

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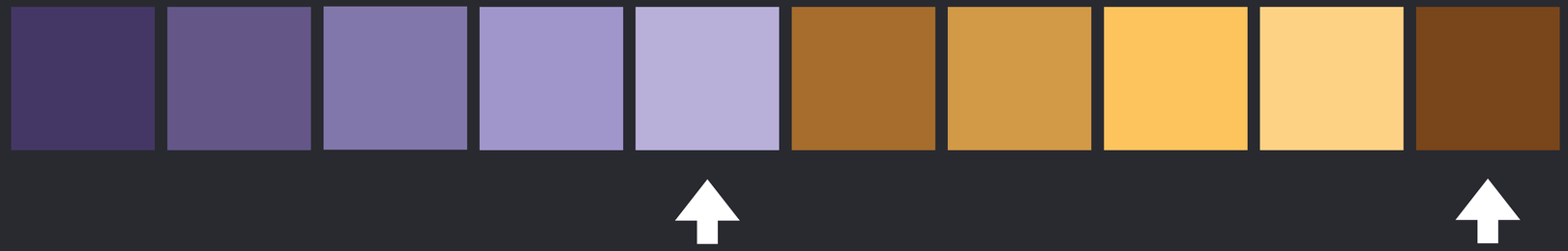
```



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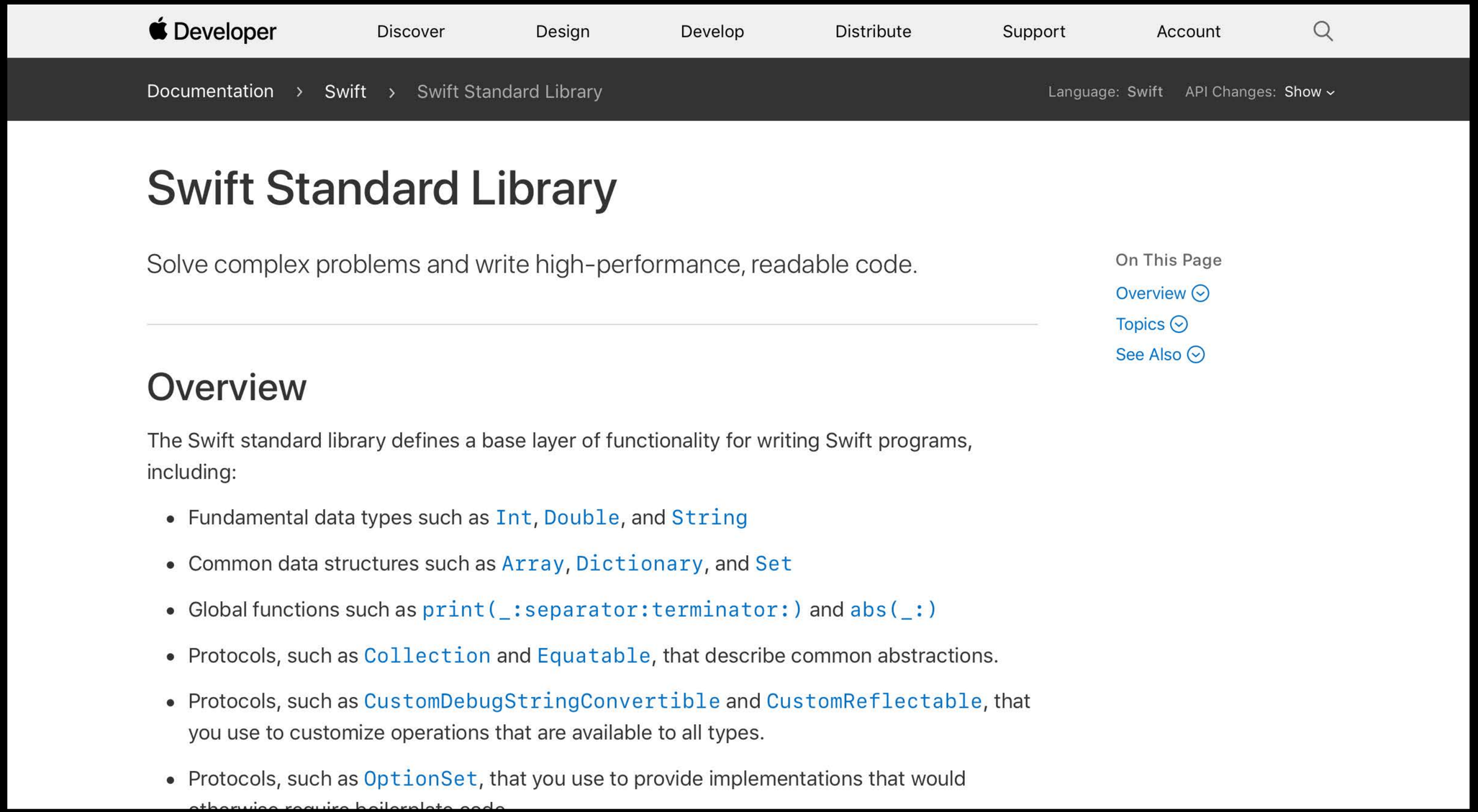
Get to know your standard library



https://developer.apple.com/documentation/swift/swift_standard_library

Readability and Maintainability

Before

```
for i in (0..<shapes.count).reversed() {
    if shapes[i].isSelected {
        shapes.remove(at: i)
    }
}
```

After

```
shapes.removeAll(where: { $0.isSelected })
```

Readability and Maintainability

Before

```
// Remove each selected item.
for i in (0..<shapes.count).reversed() {
    if shapes[i].isSelected {
        shapes.remove(at: i)
    }
}
```

After

```
shapes.removeAll(where: { $0.isSelected })
```

Readability and Maintainability

Before

```
// Remove each selected item.
// Go backward to avoid shifting
// as-yet-unprocessed elements.
for i in (0..<shapes.count).reversed() {
    if shapes[i].isSelected {
        shapes.remove(at: i)
    }
}
```

After

```
shapes.removeAll(where: { $0.isSelected })
```

Readability and Maintainability

Before

```
// Remove each selected item.
// Go backward to avoid shifting
// as-yet-unprocessed elements.
for i in (0..<shapes.count).reversed() {
    if shapes[i].isSelected {
        shapes.remove(at: i)
    }
}
```

After

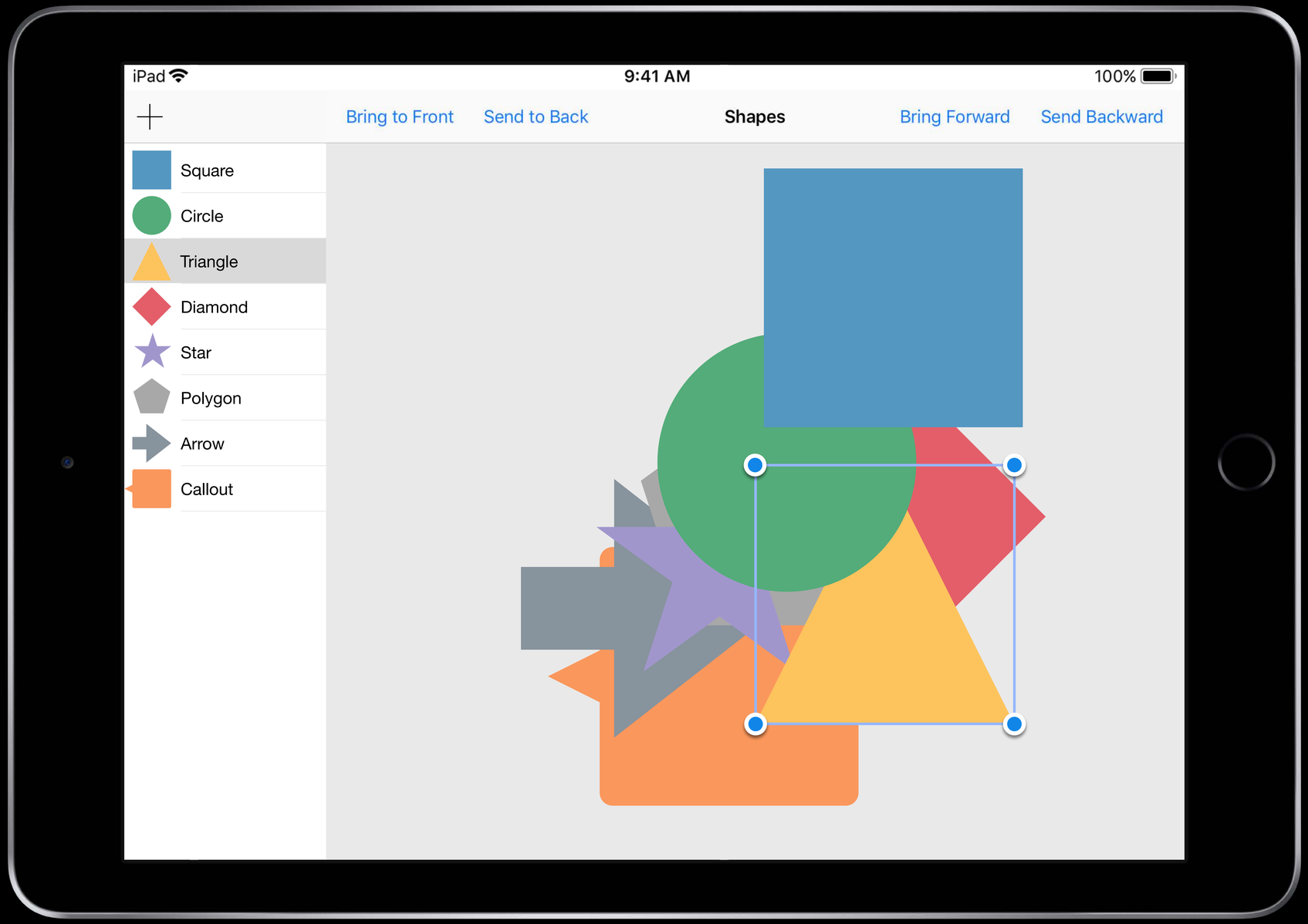
```
shapes.removeAll { $0.isSelected }
```

“No Raw Loops”

Sean Parent (a.k.a. “Crusty's cousin”), *C++ Seasoning*

```
// Done, and done!

extension Canvas {
    mutating func deleteSelection() {
        shapes.removeAll { $0.isSelected }
    }
}
```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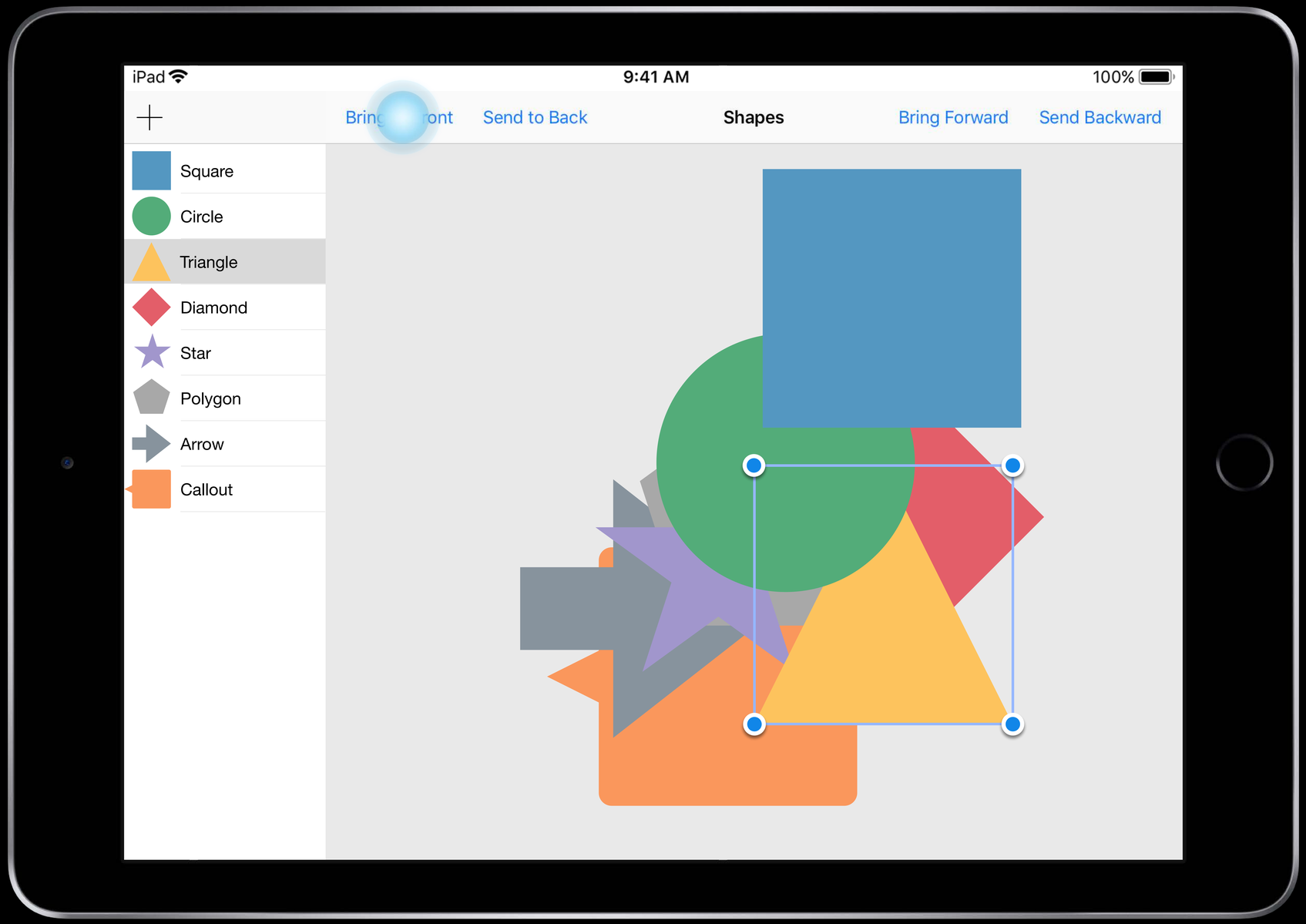
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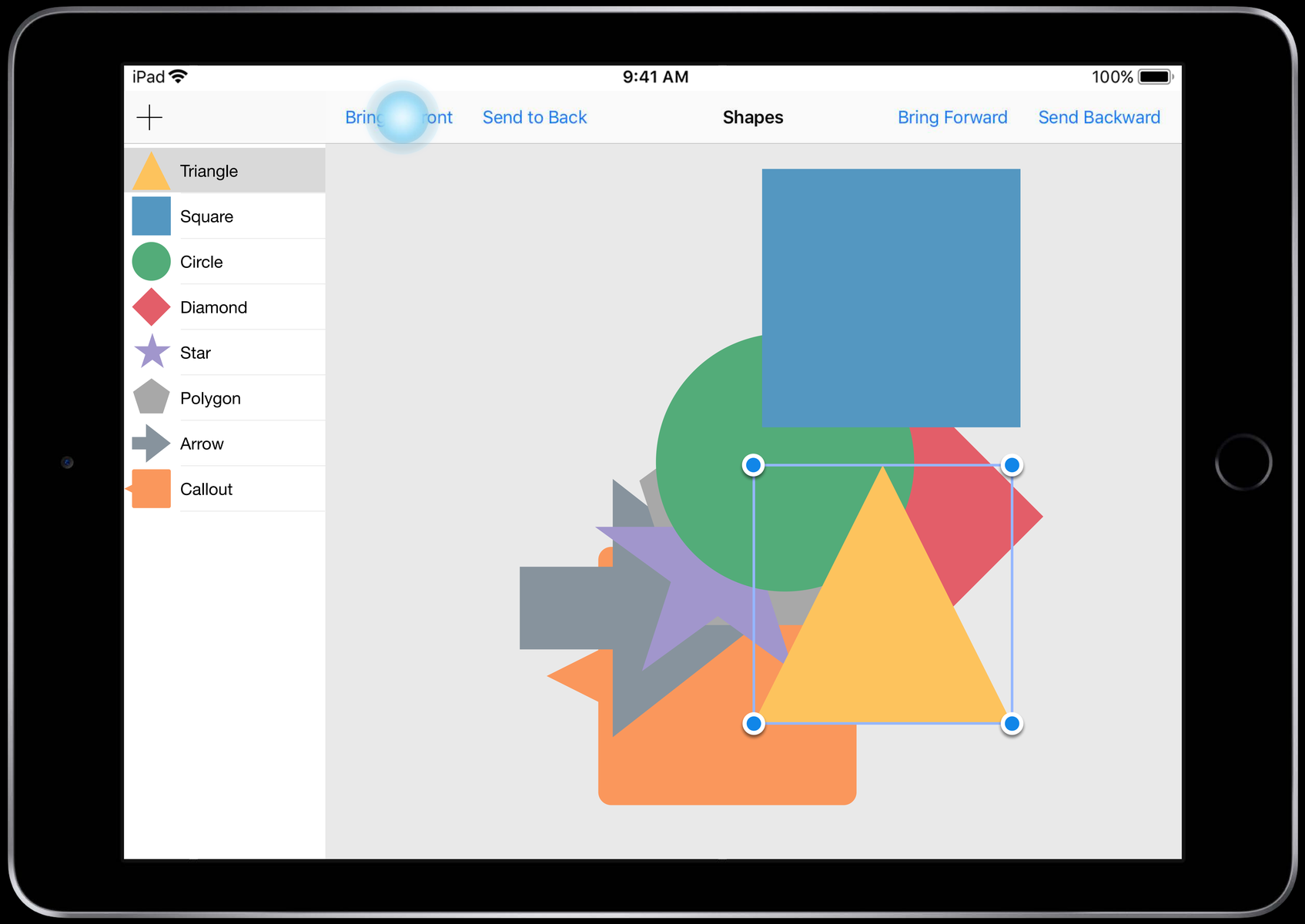
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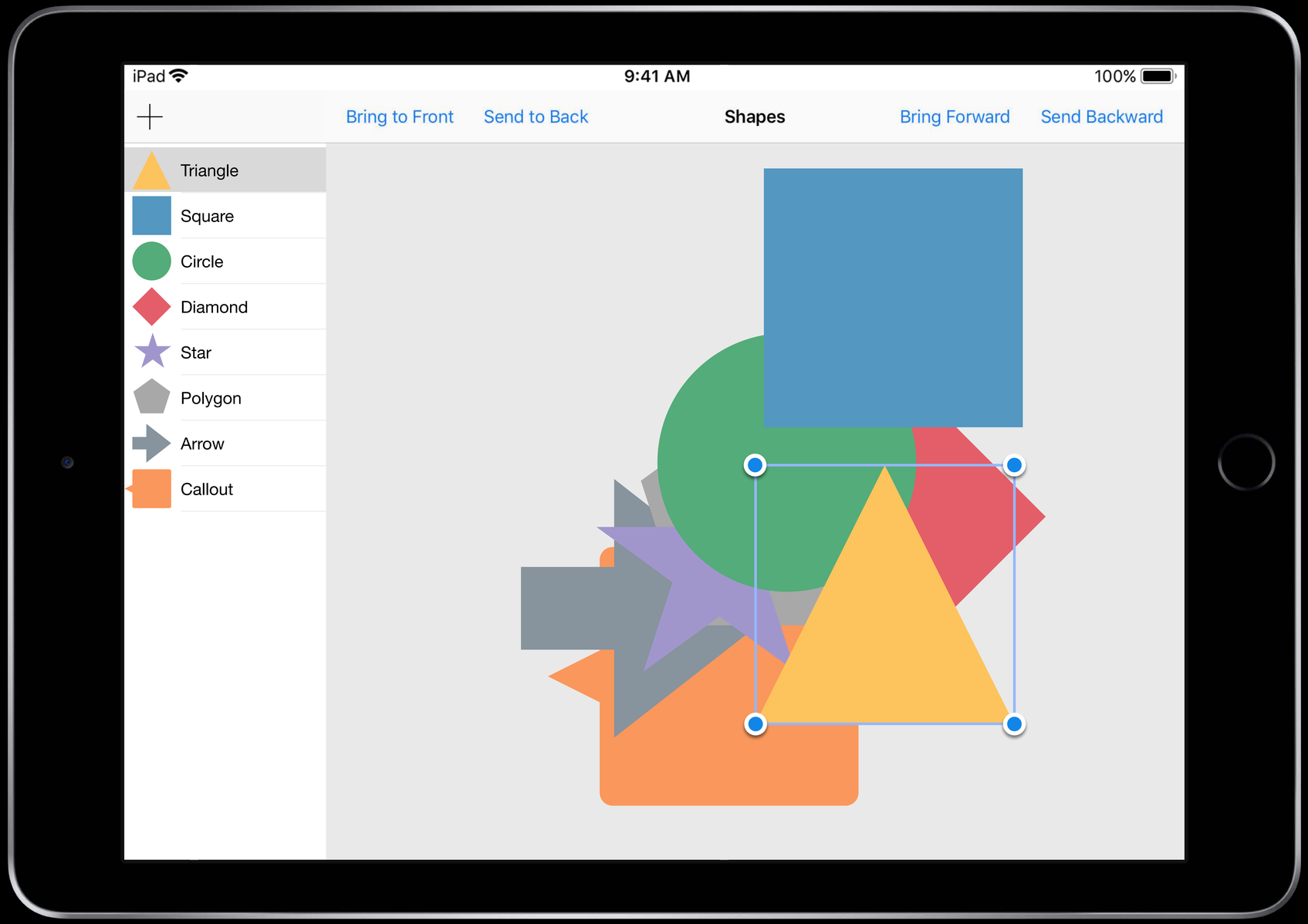
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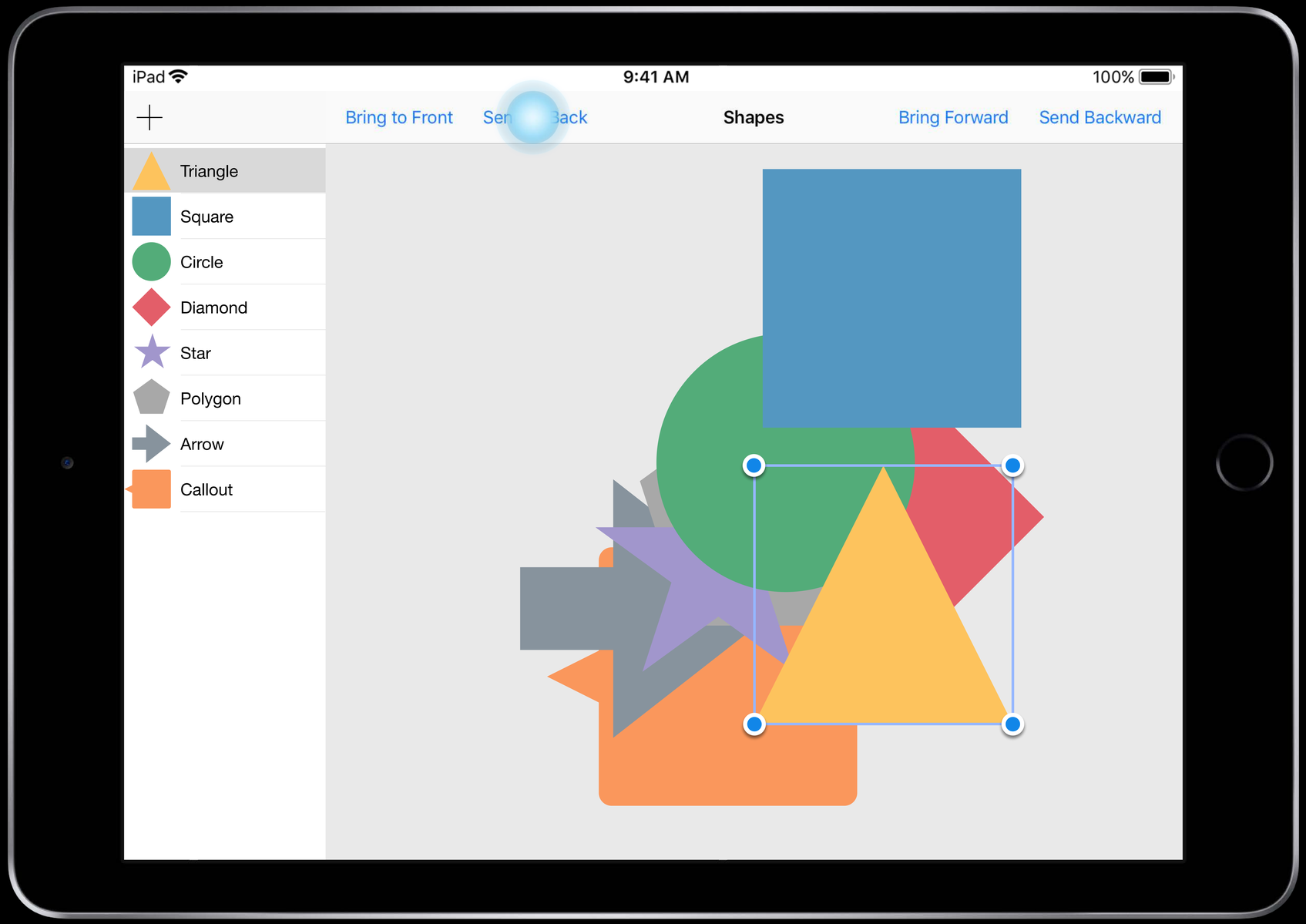
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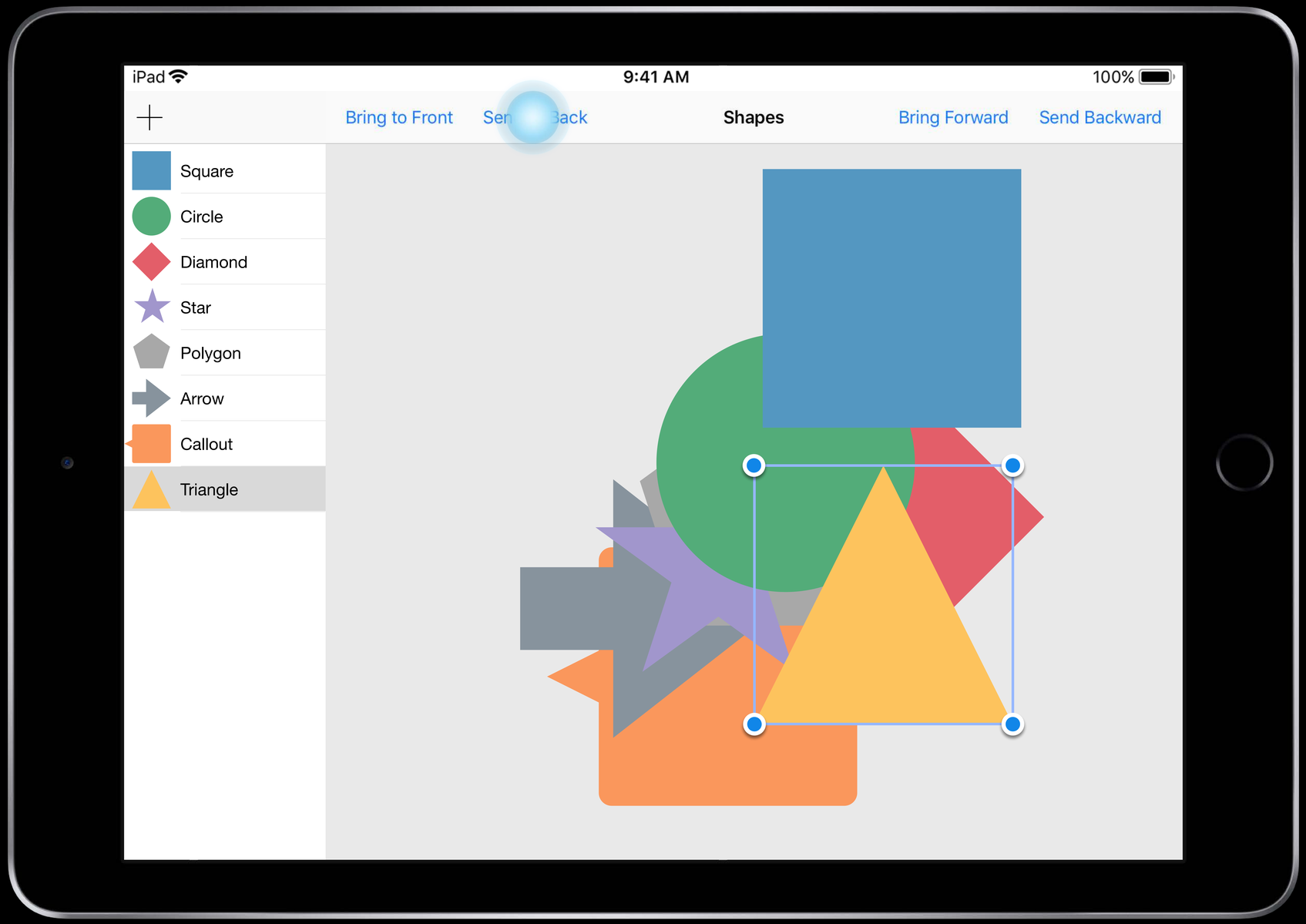
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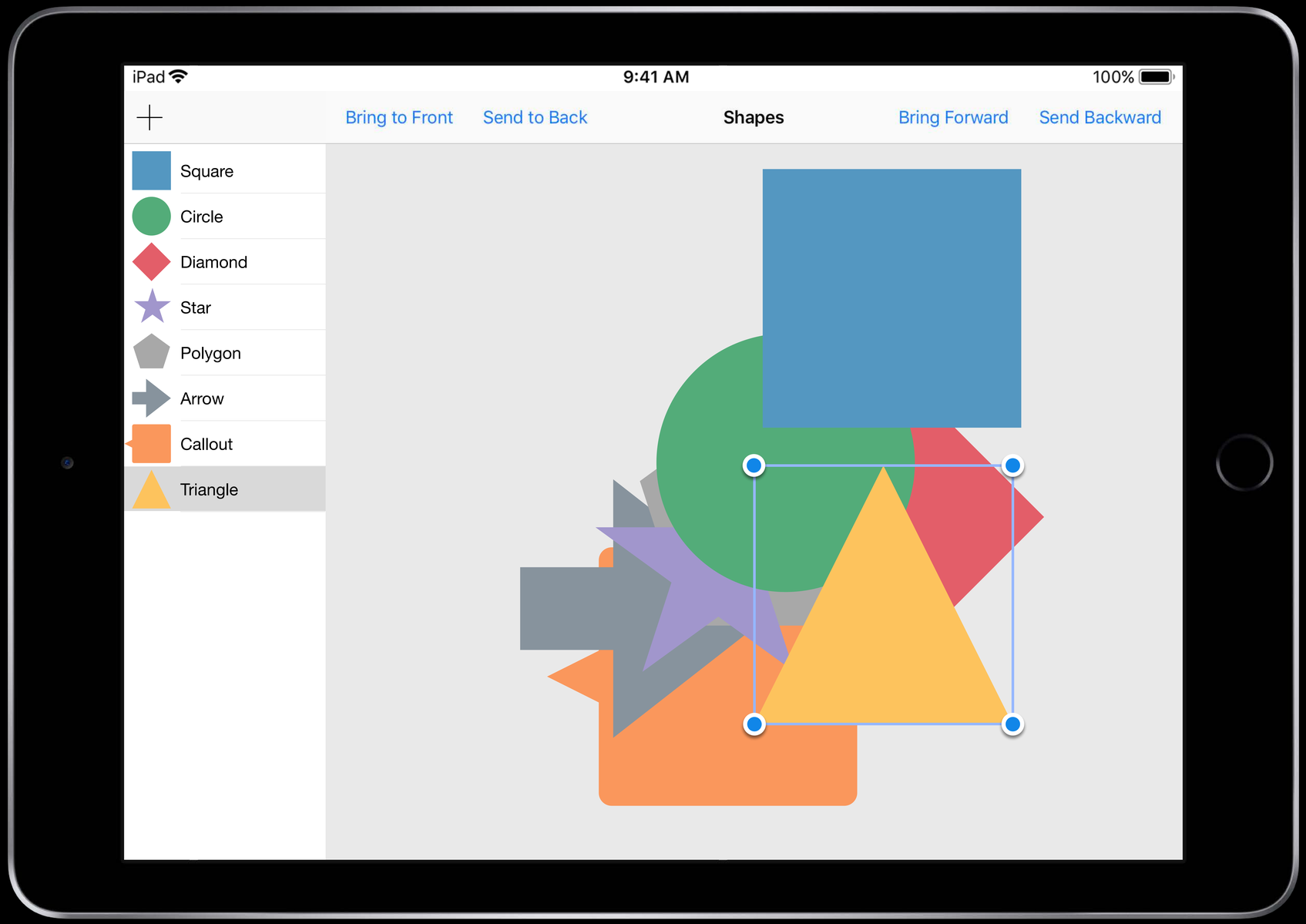
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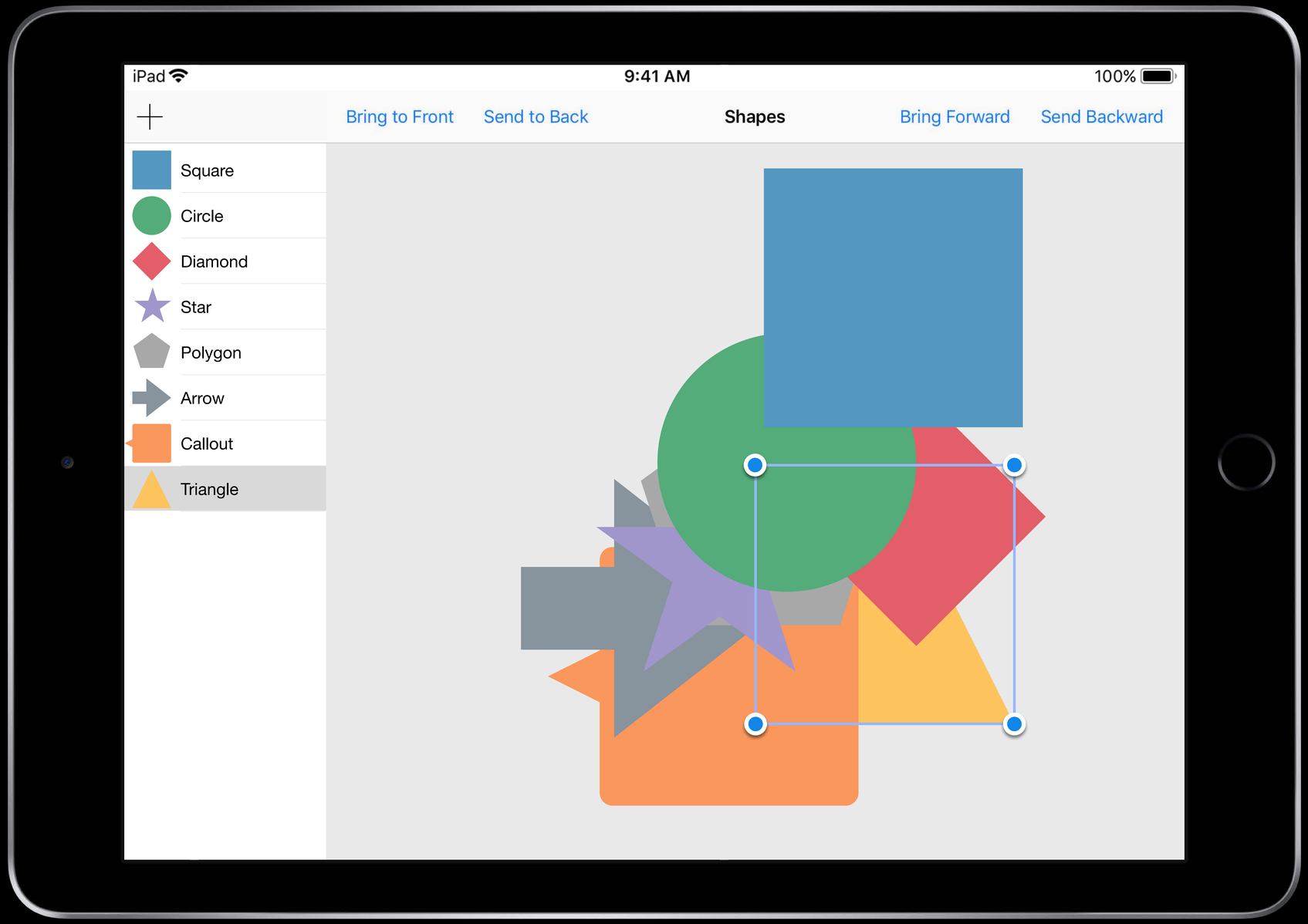
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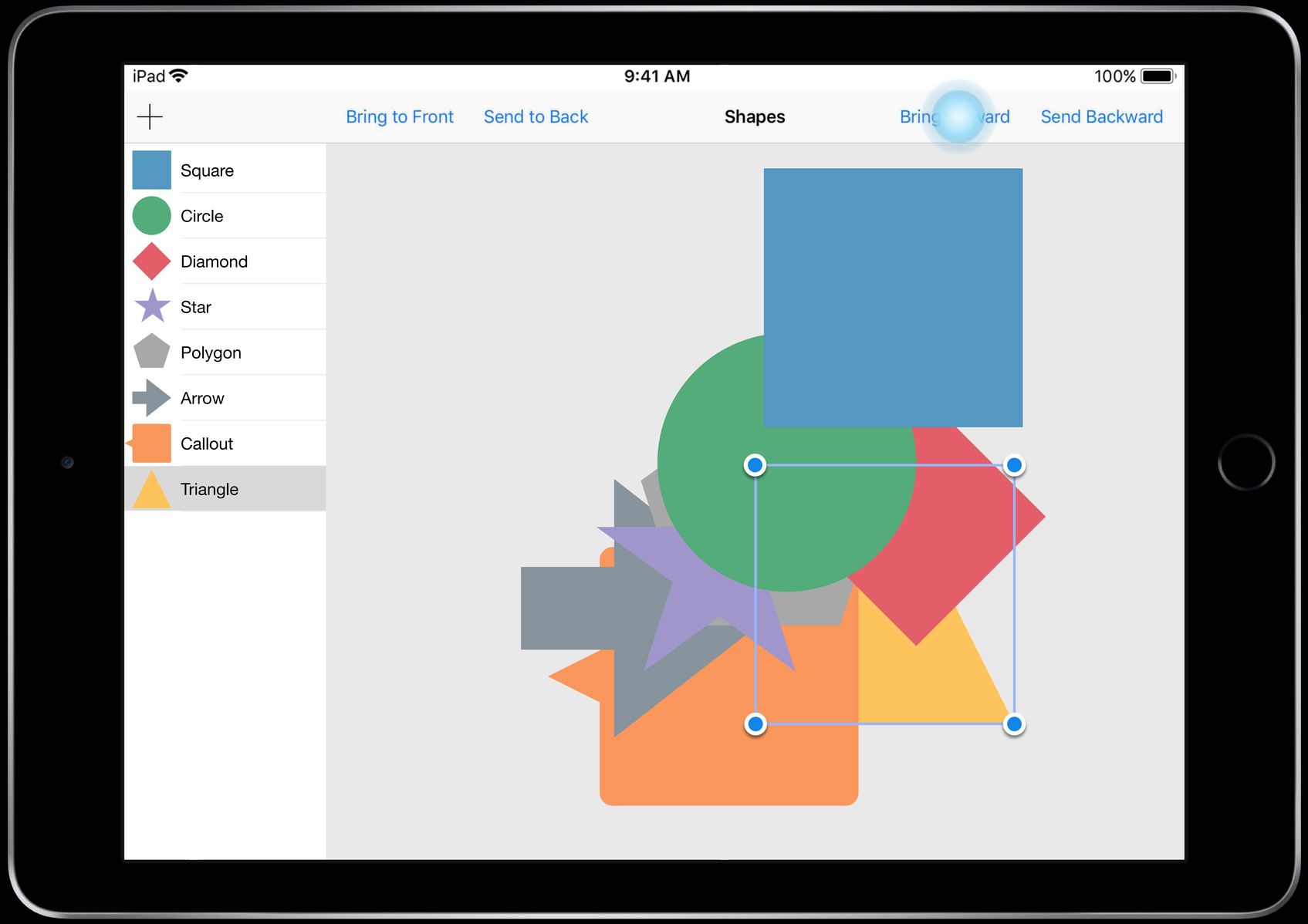
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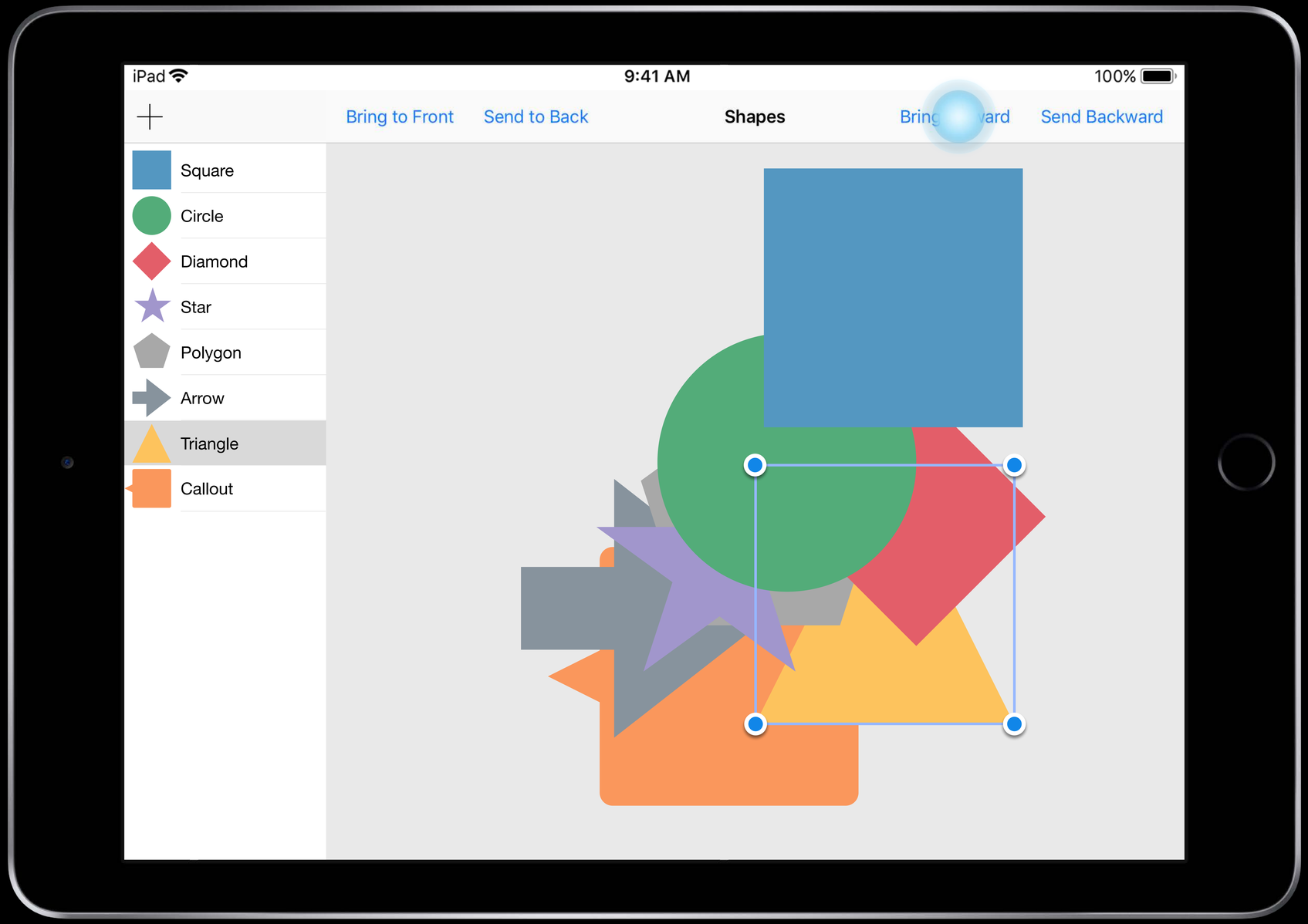
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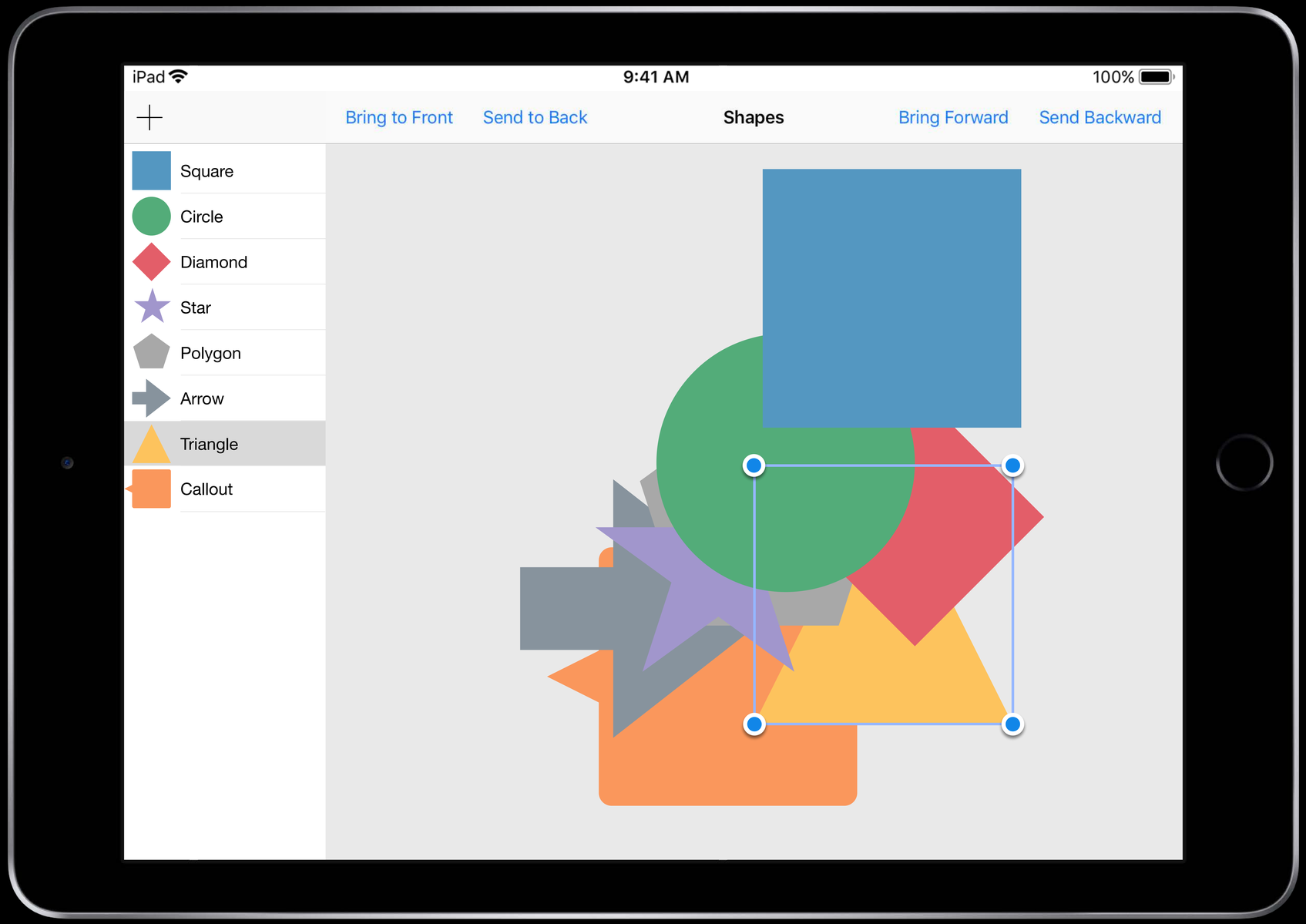
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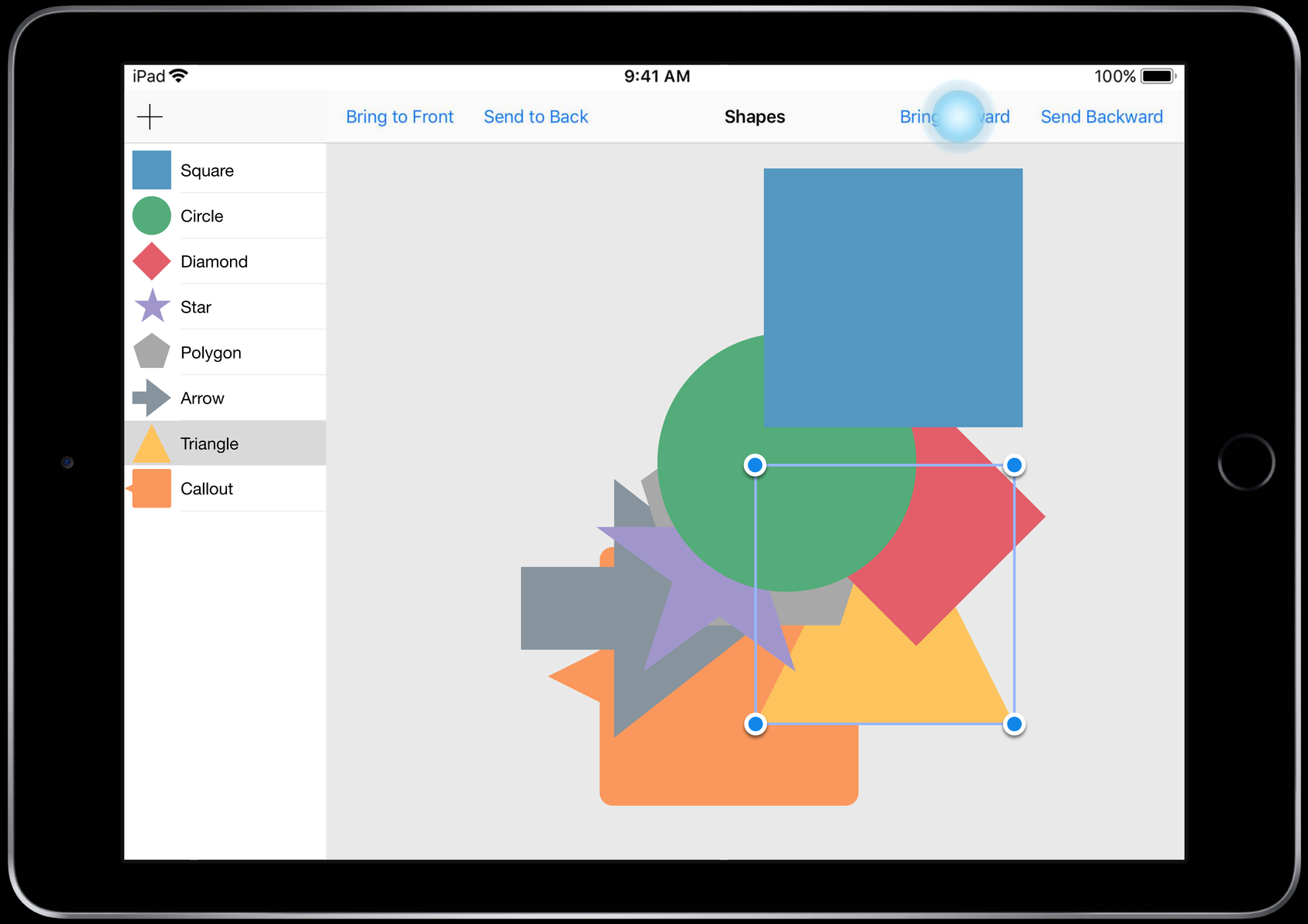
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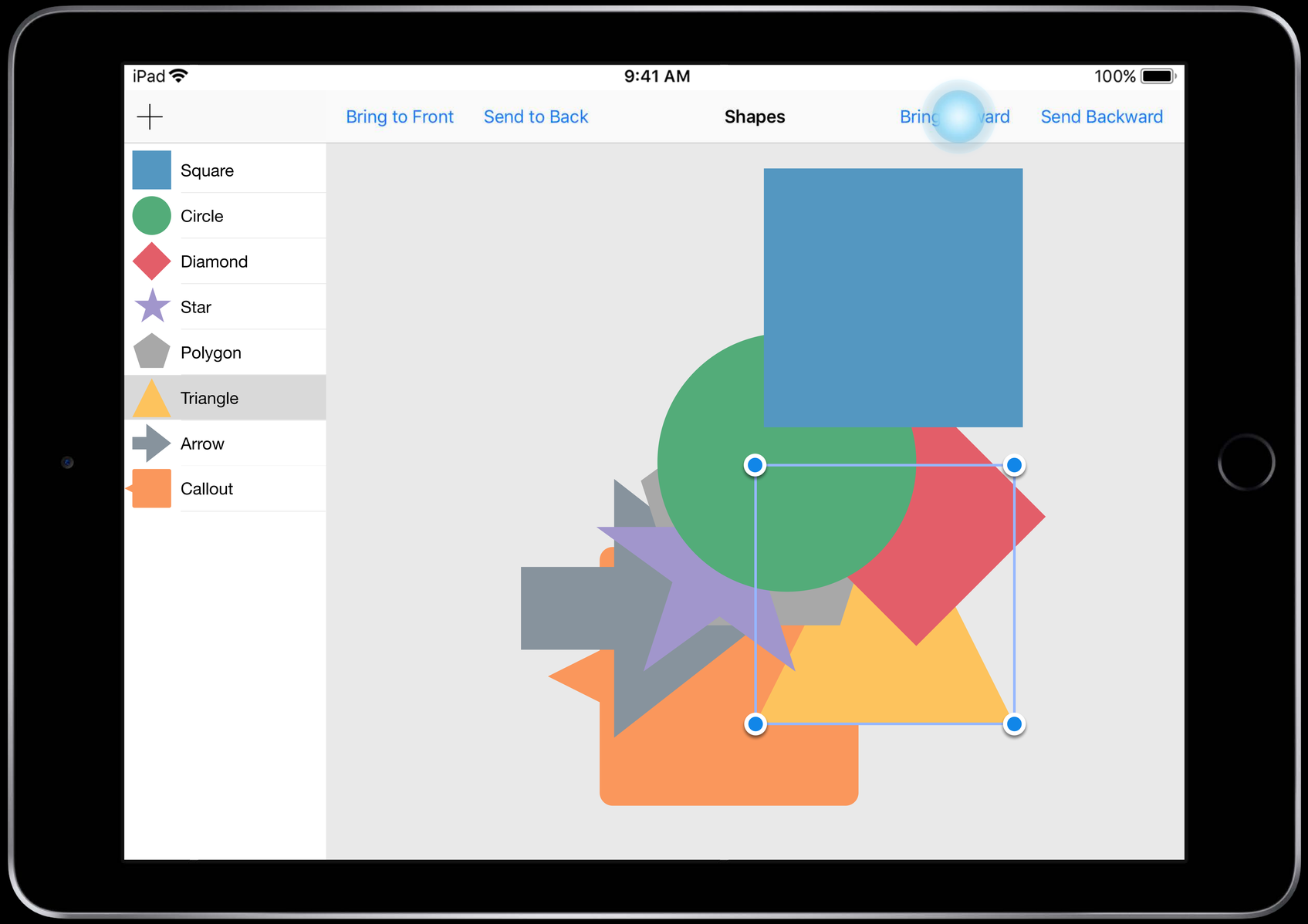
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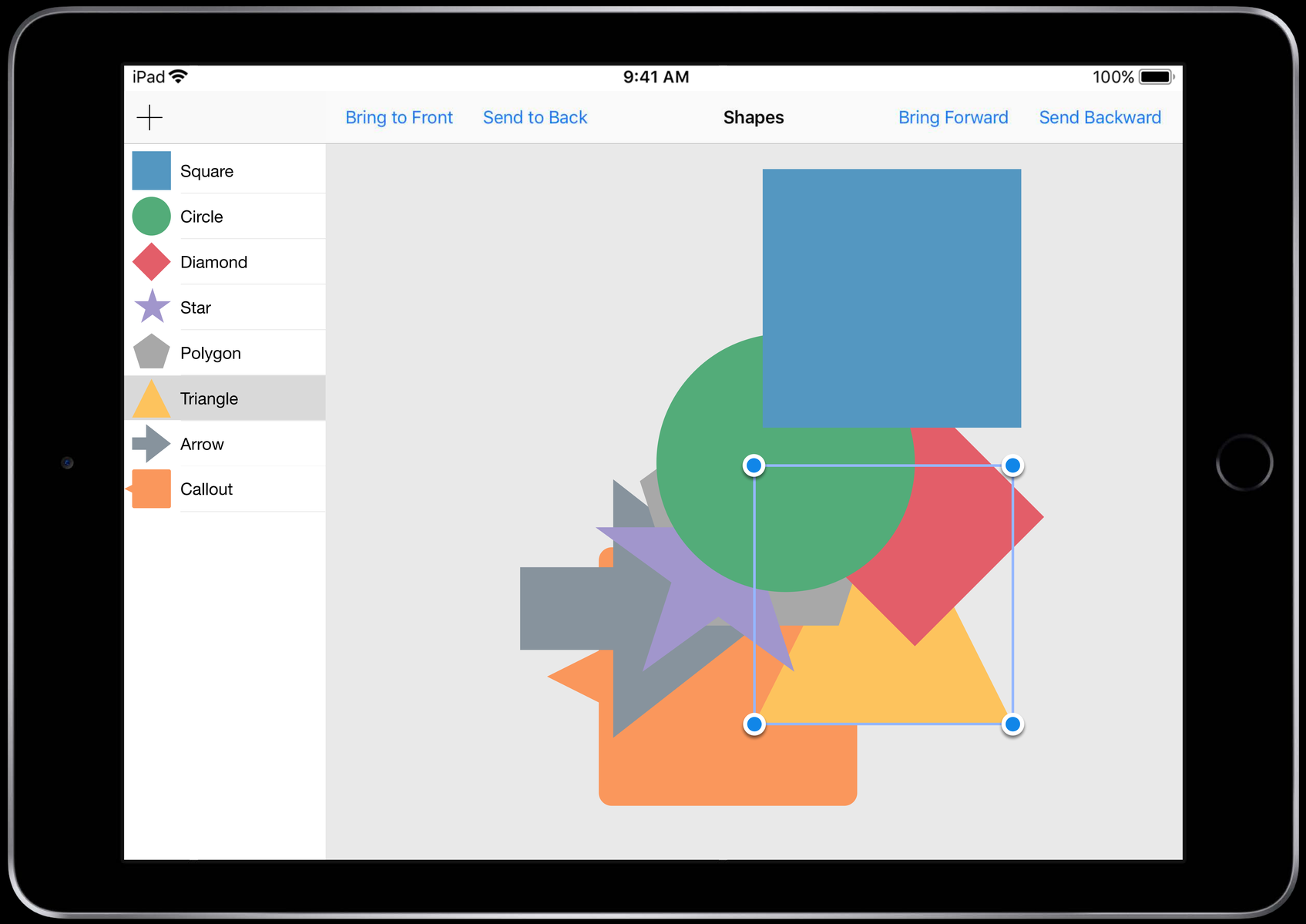
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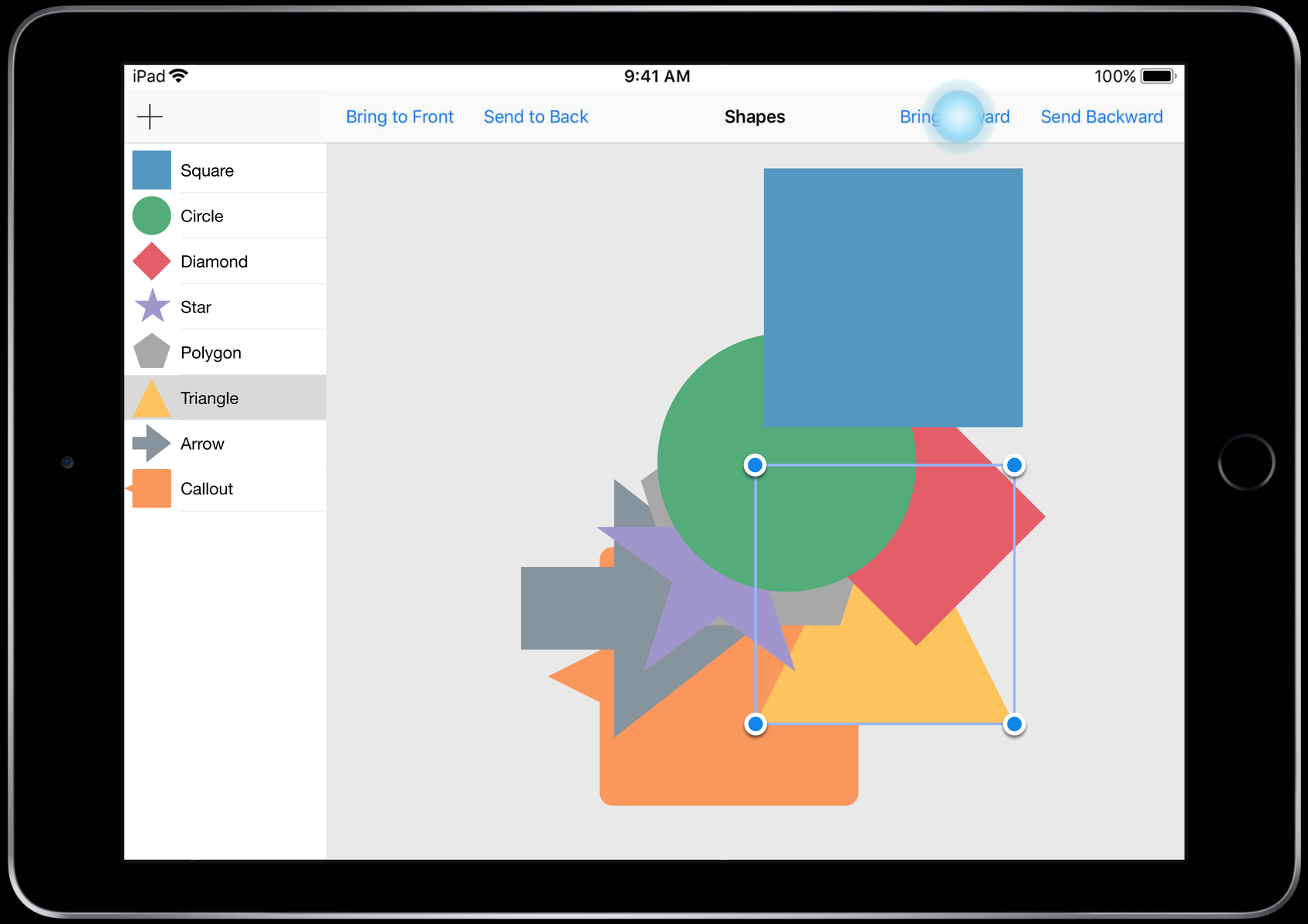
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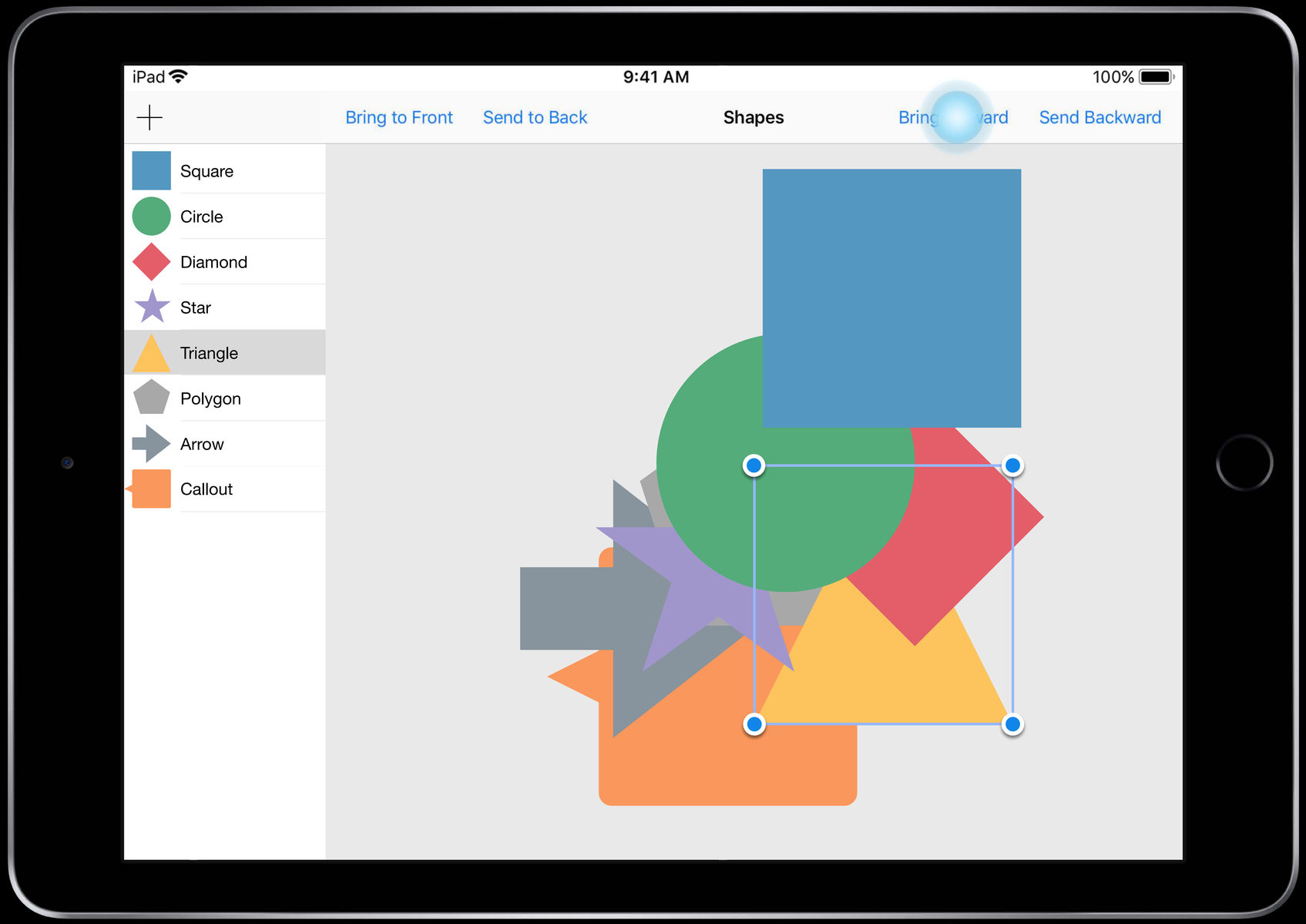
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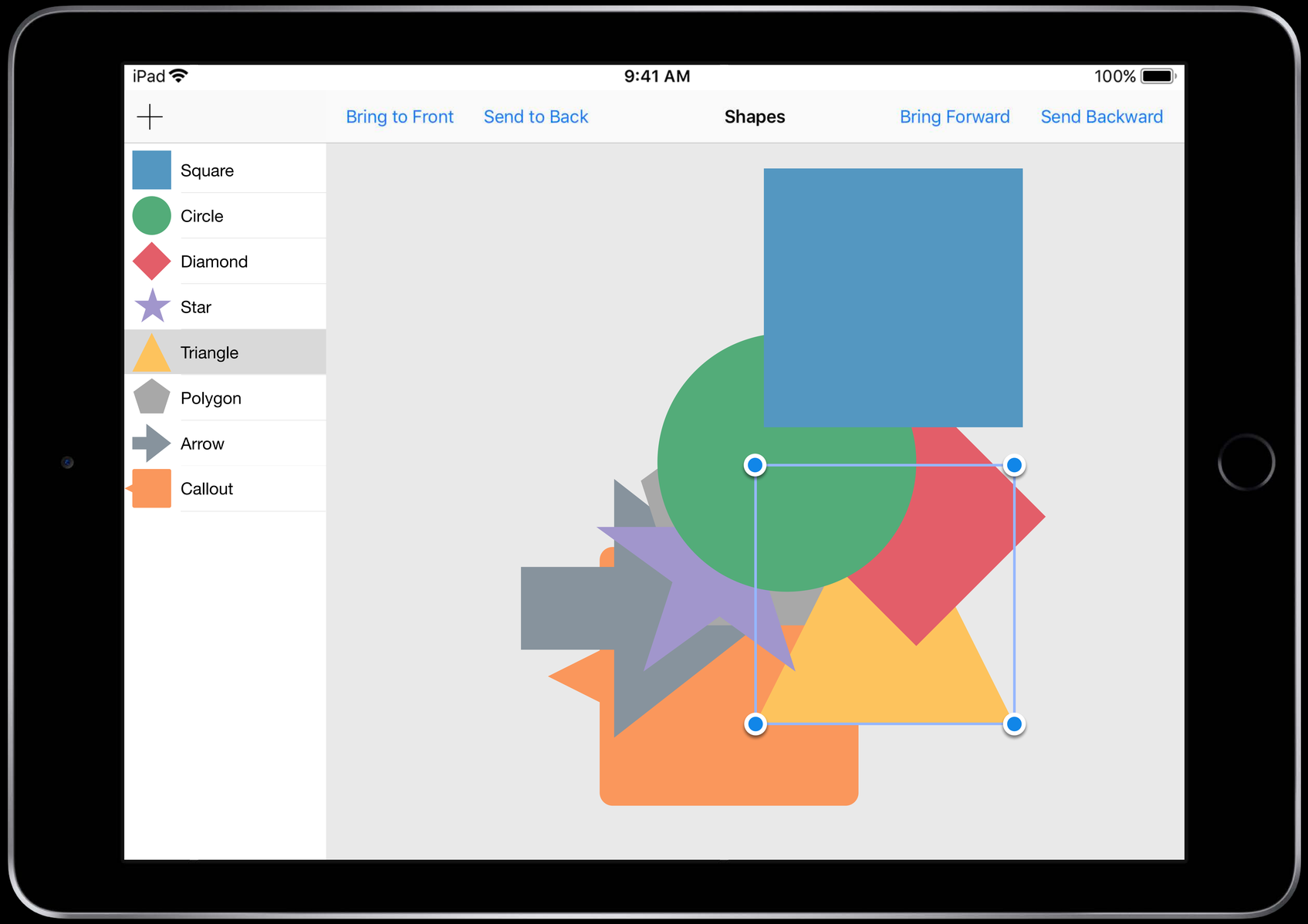
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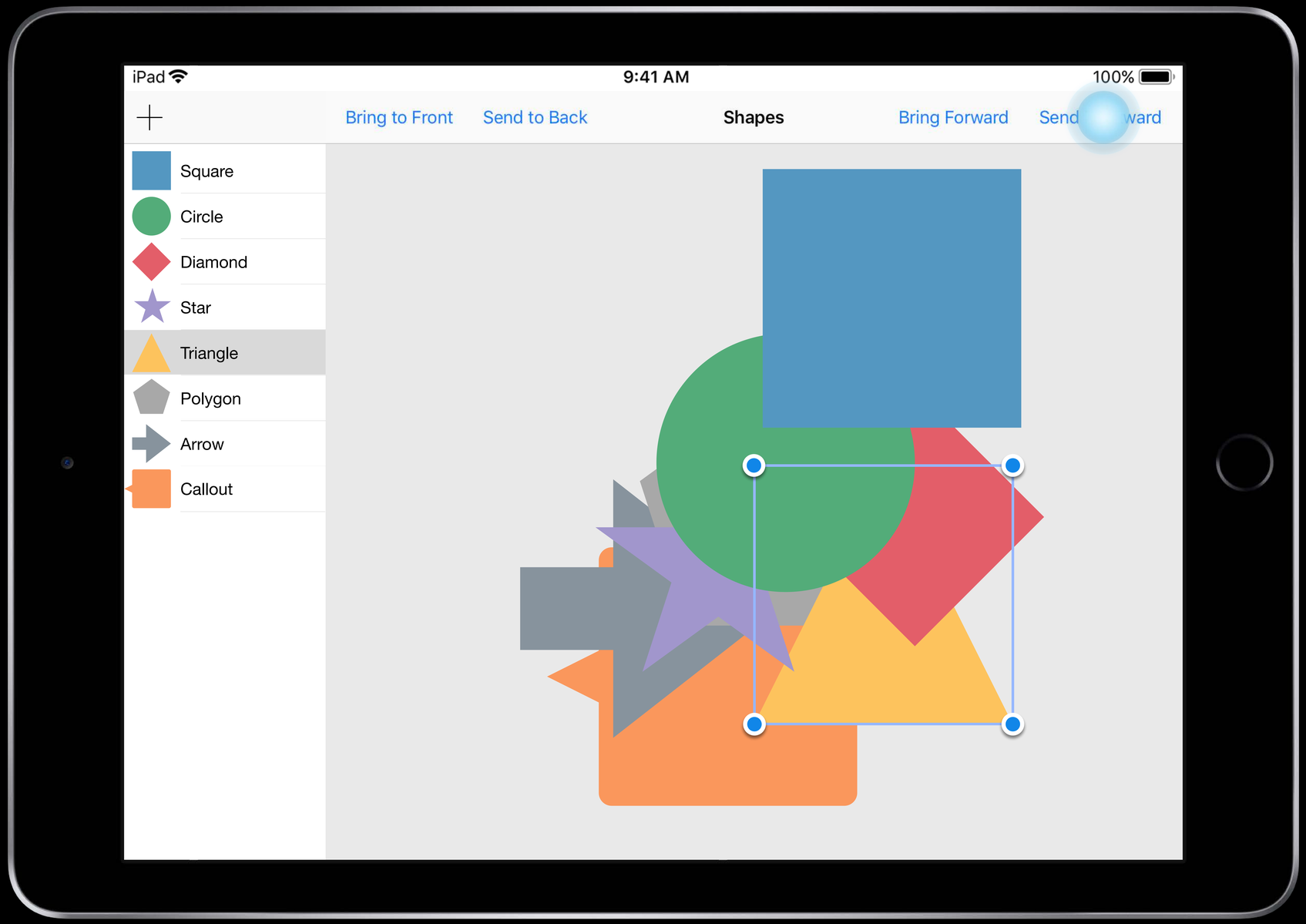
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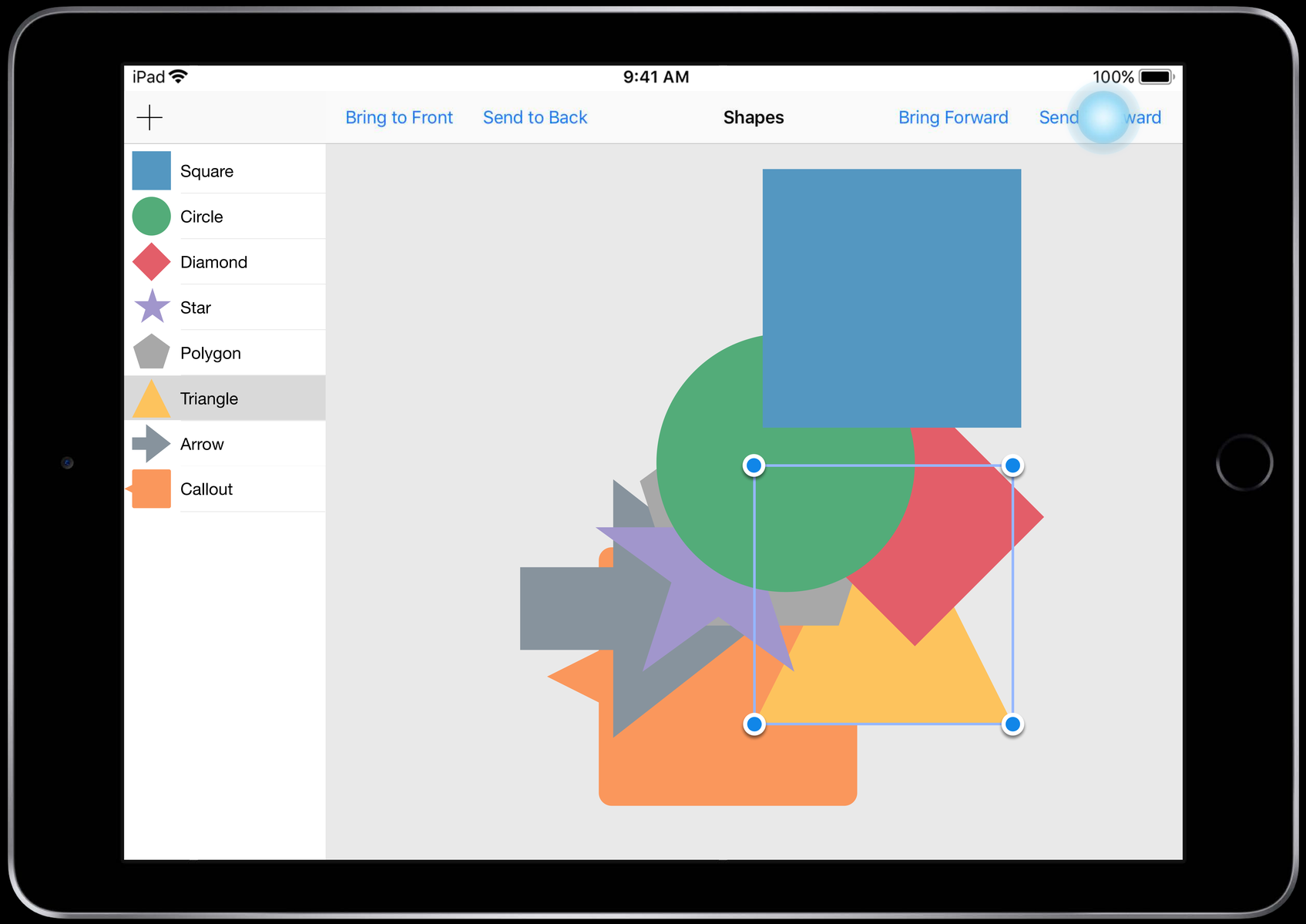
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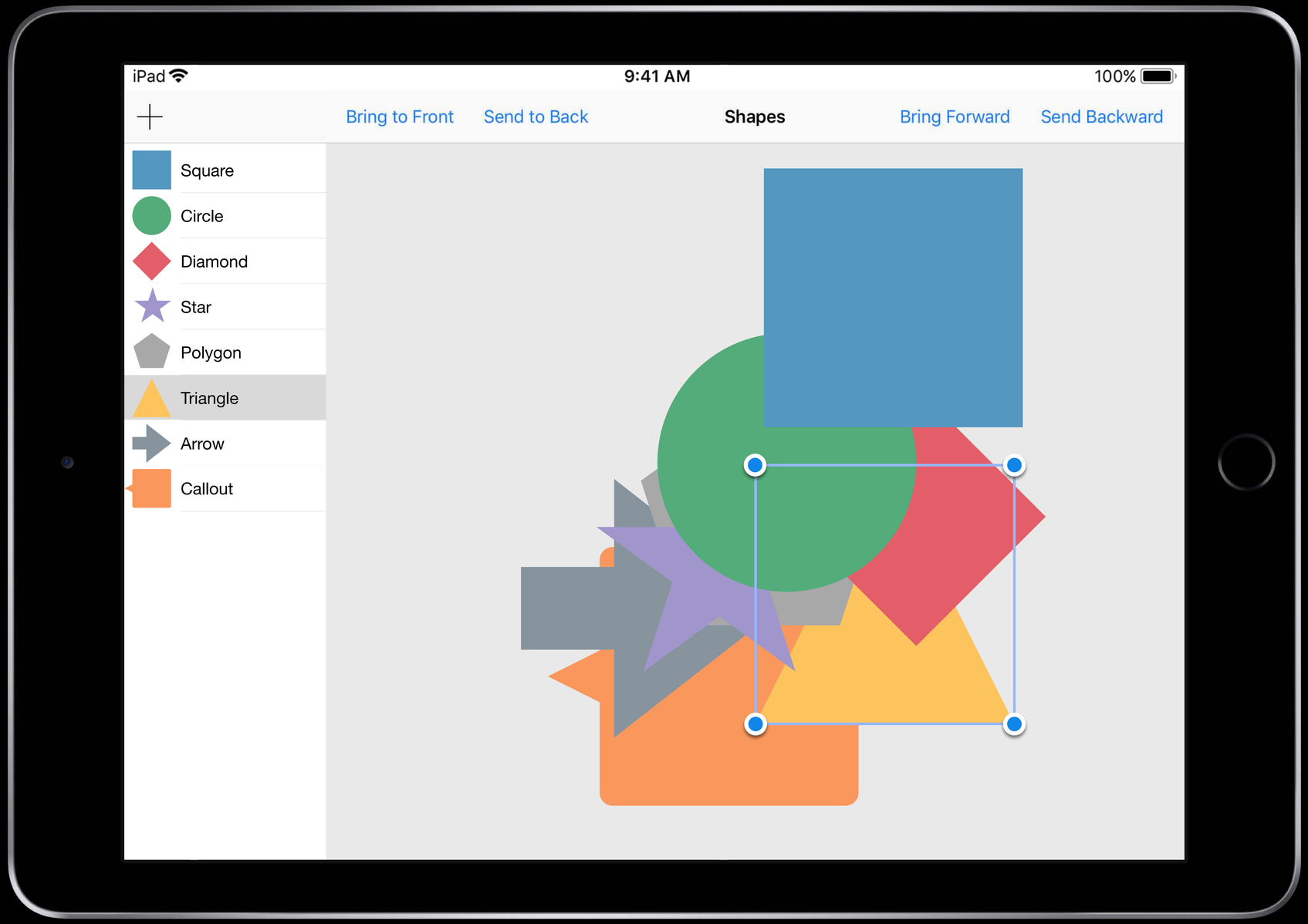
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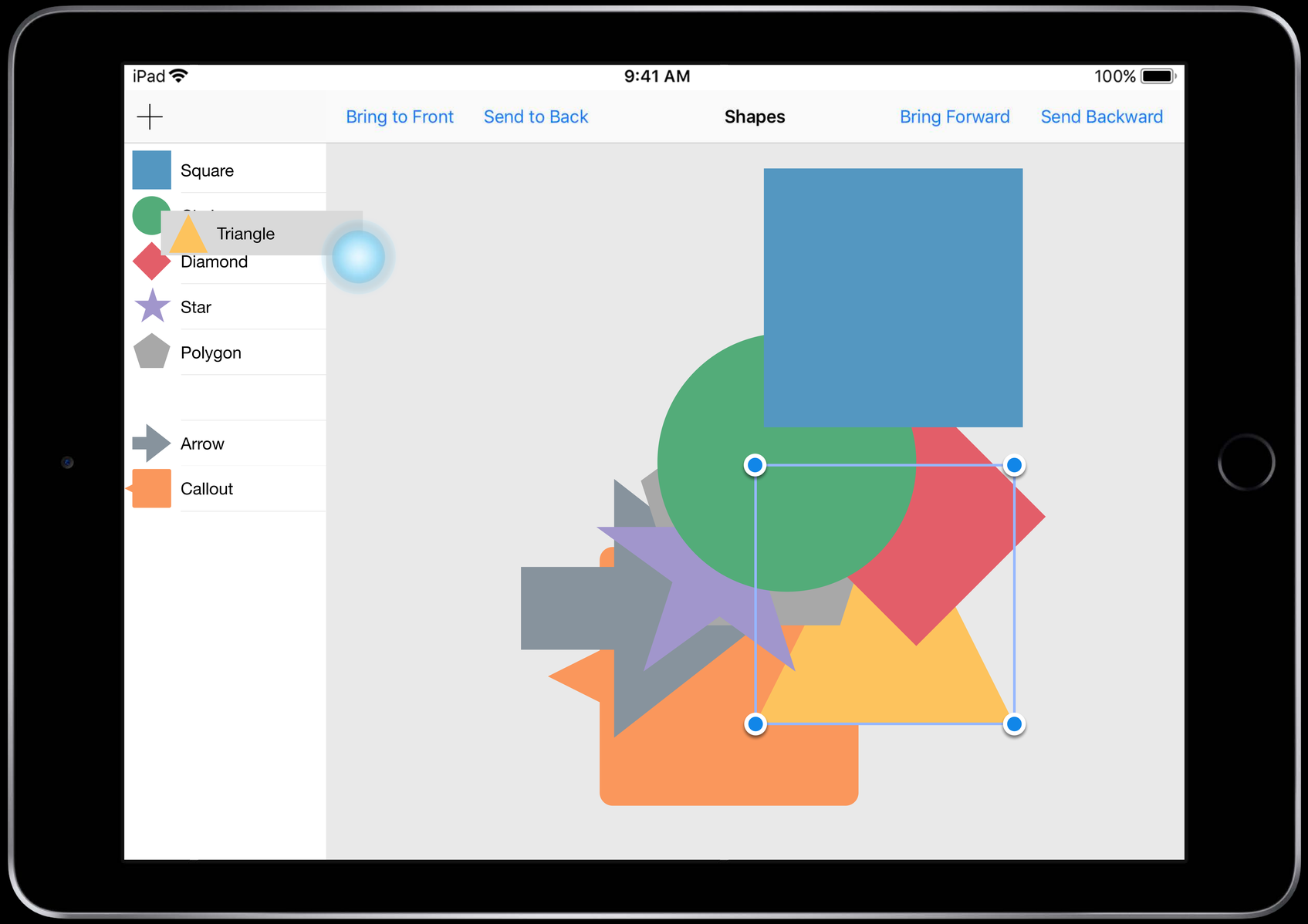
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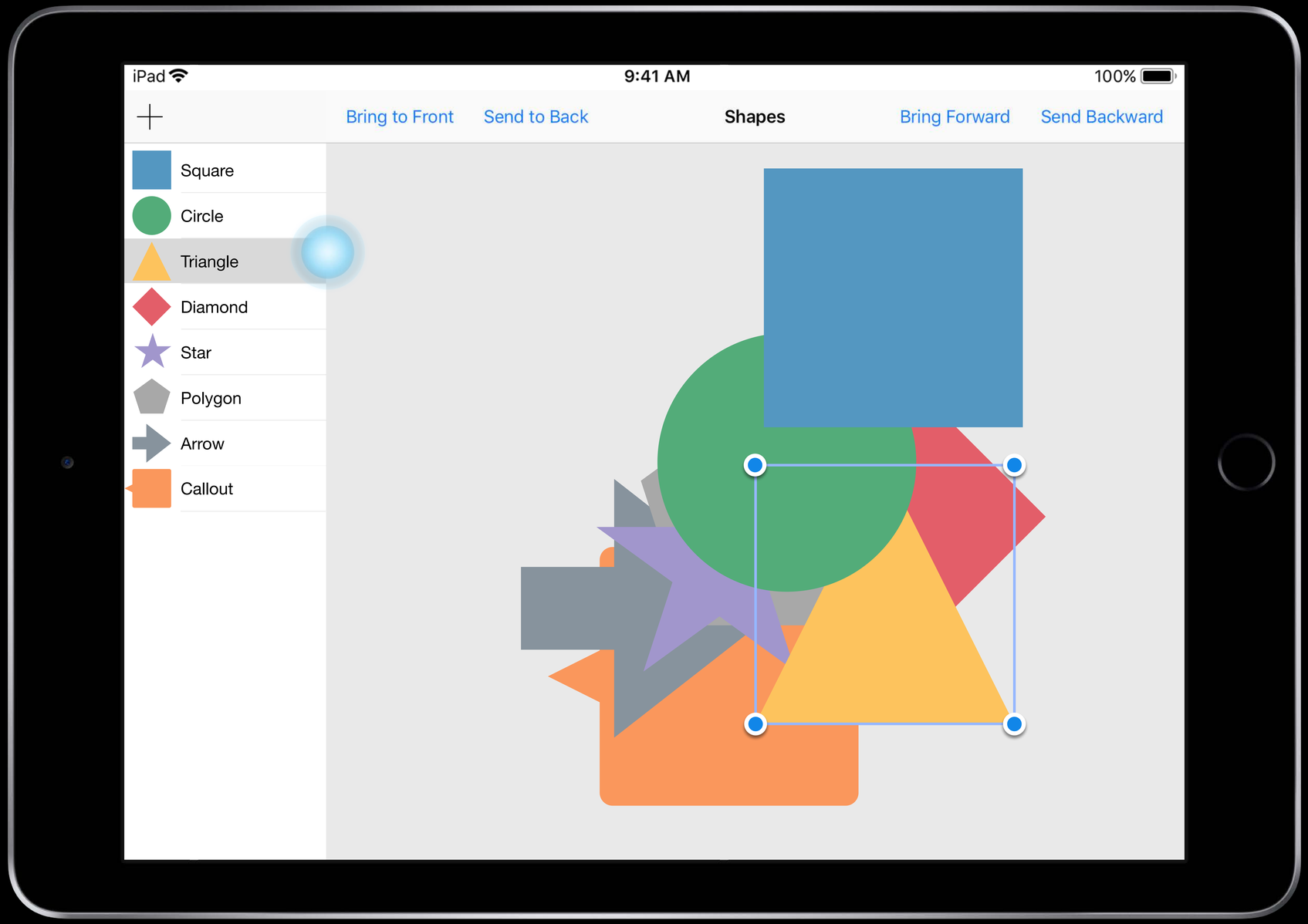
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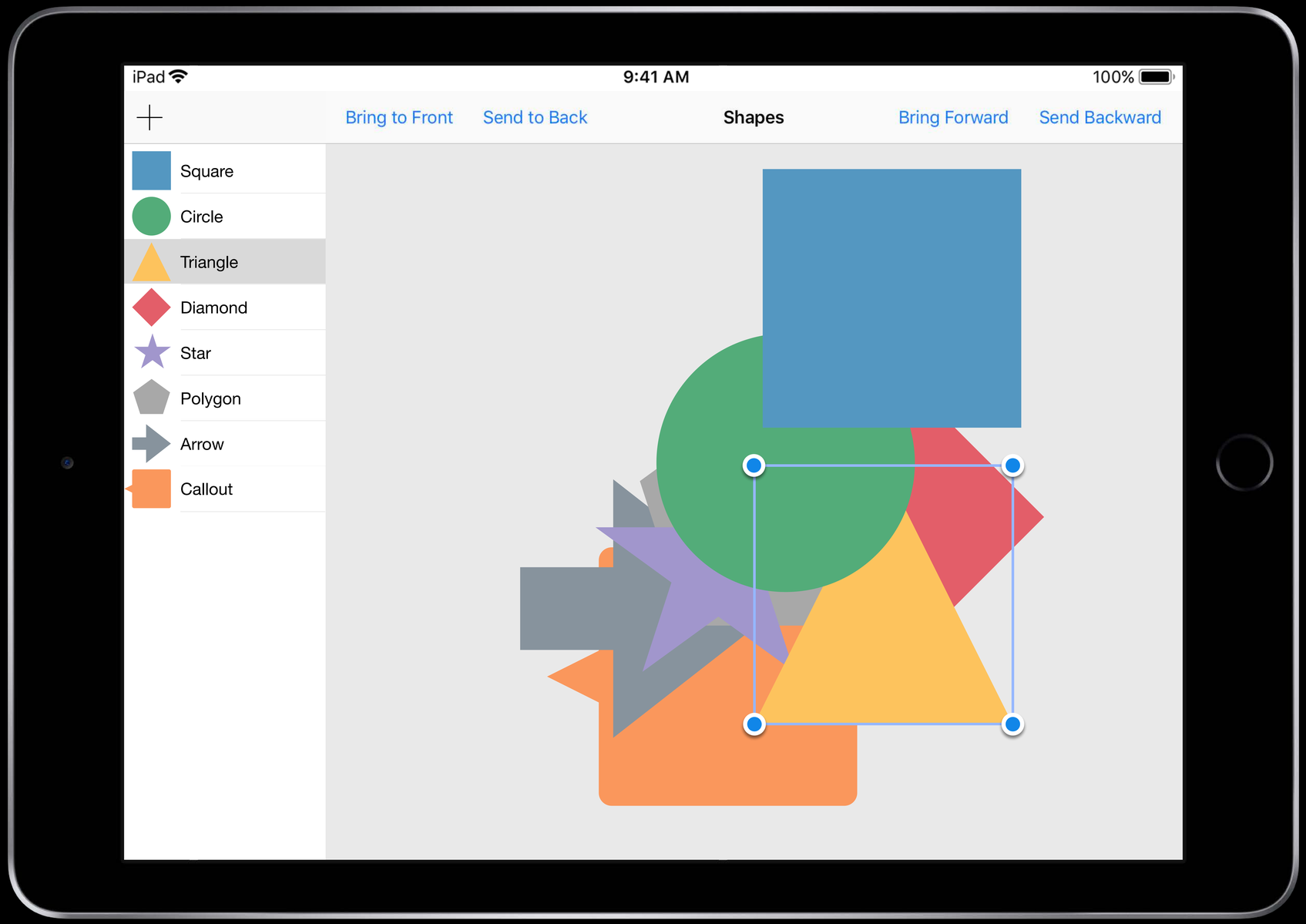
iPad
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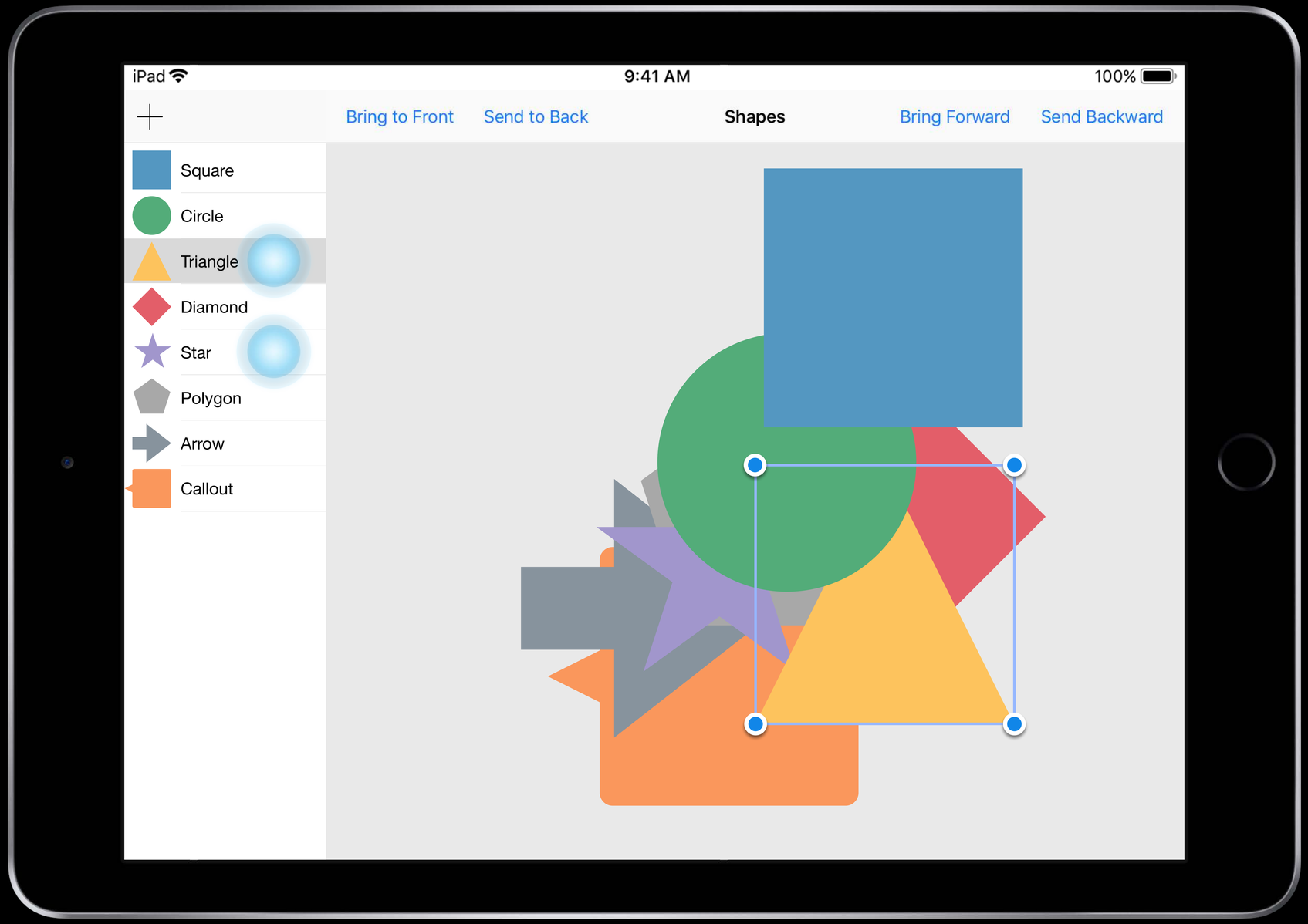
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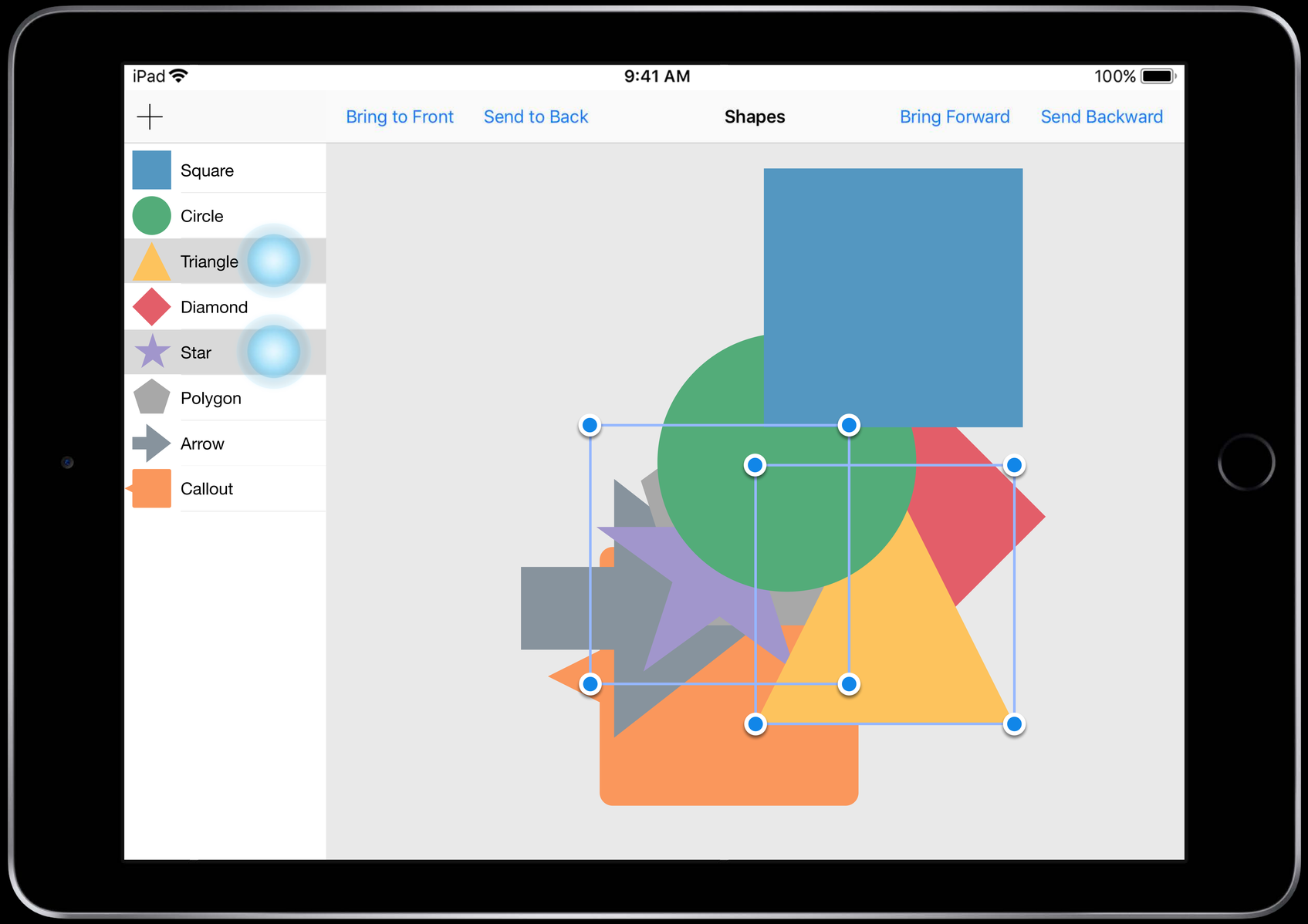
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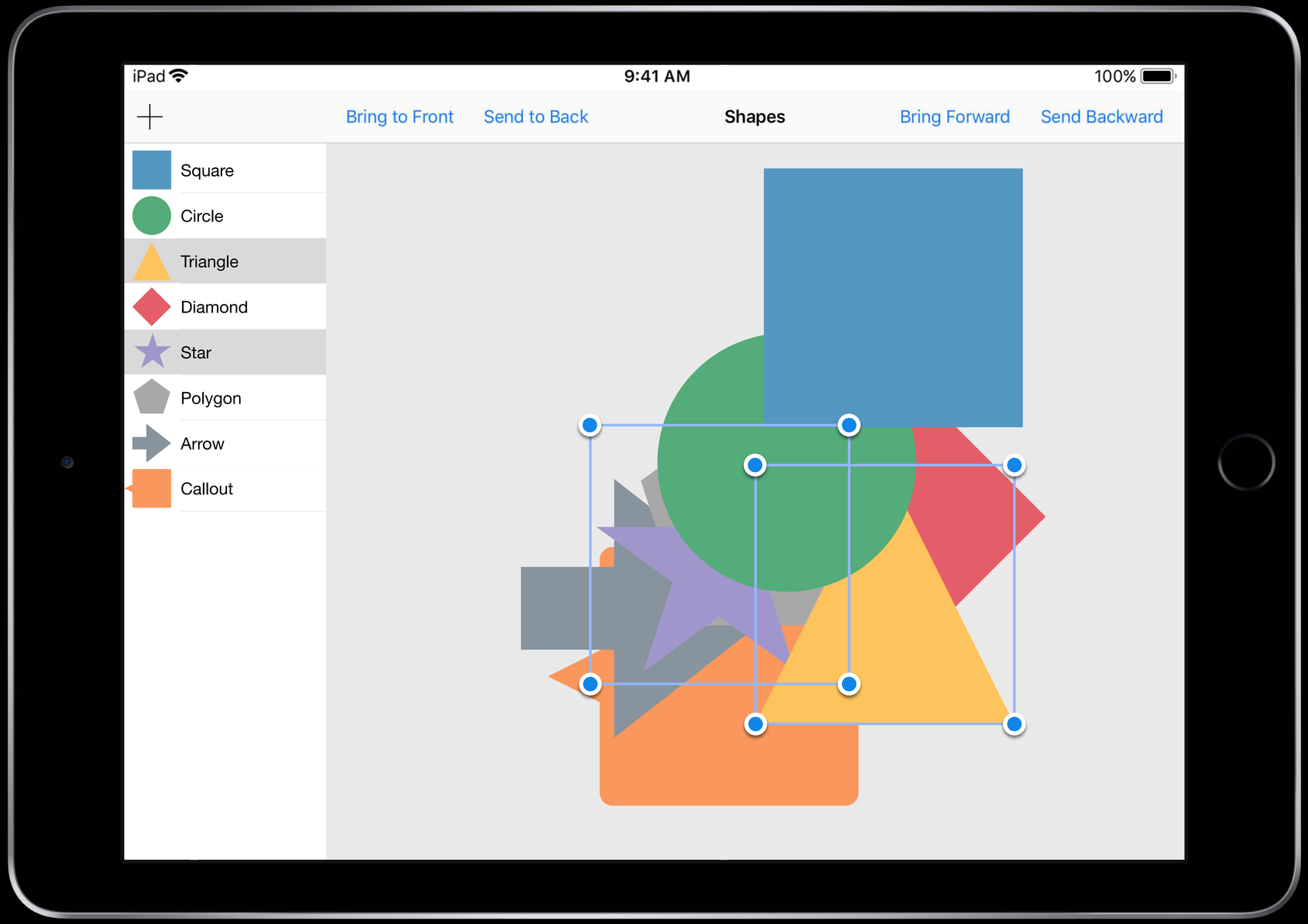
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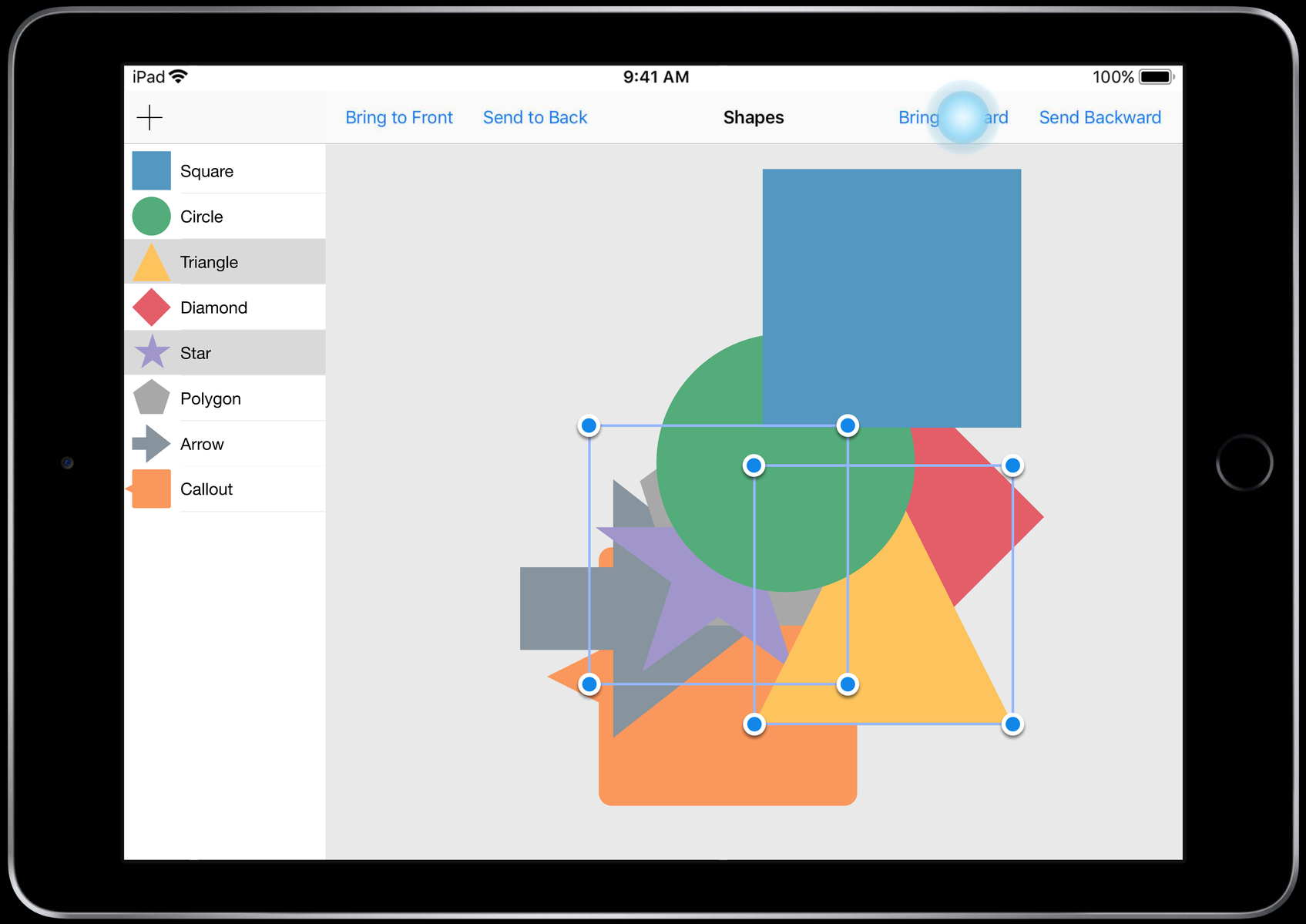
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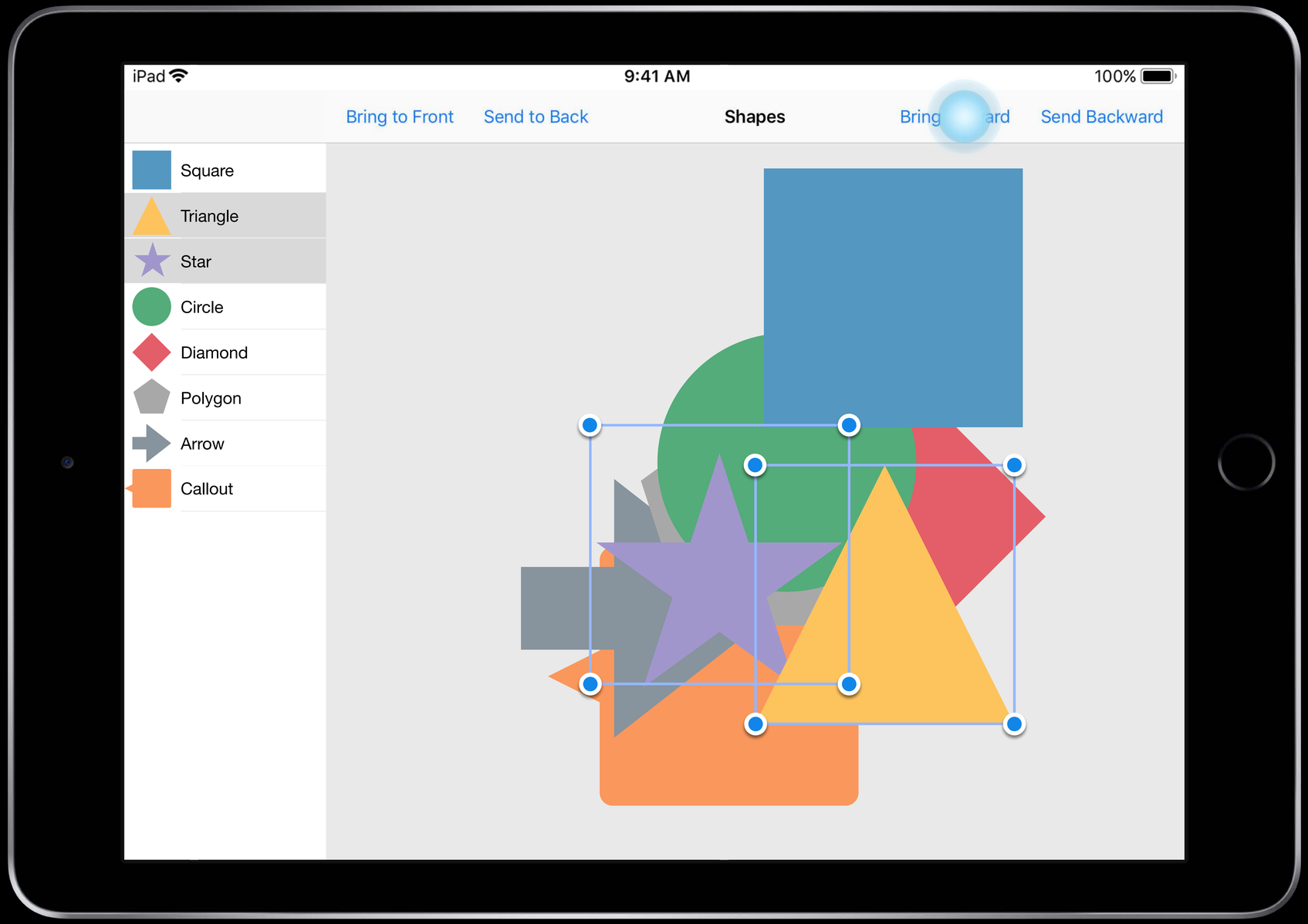
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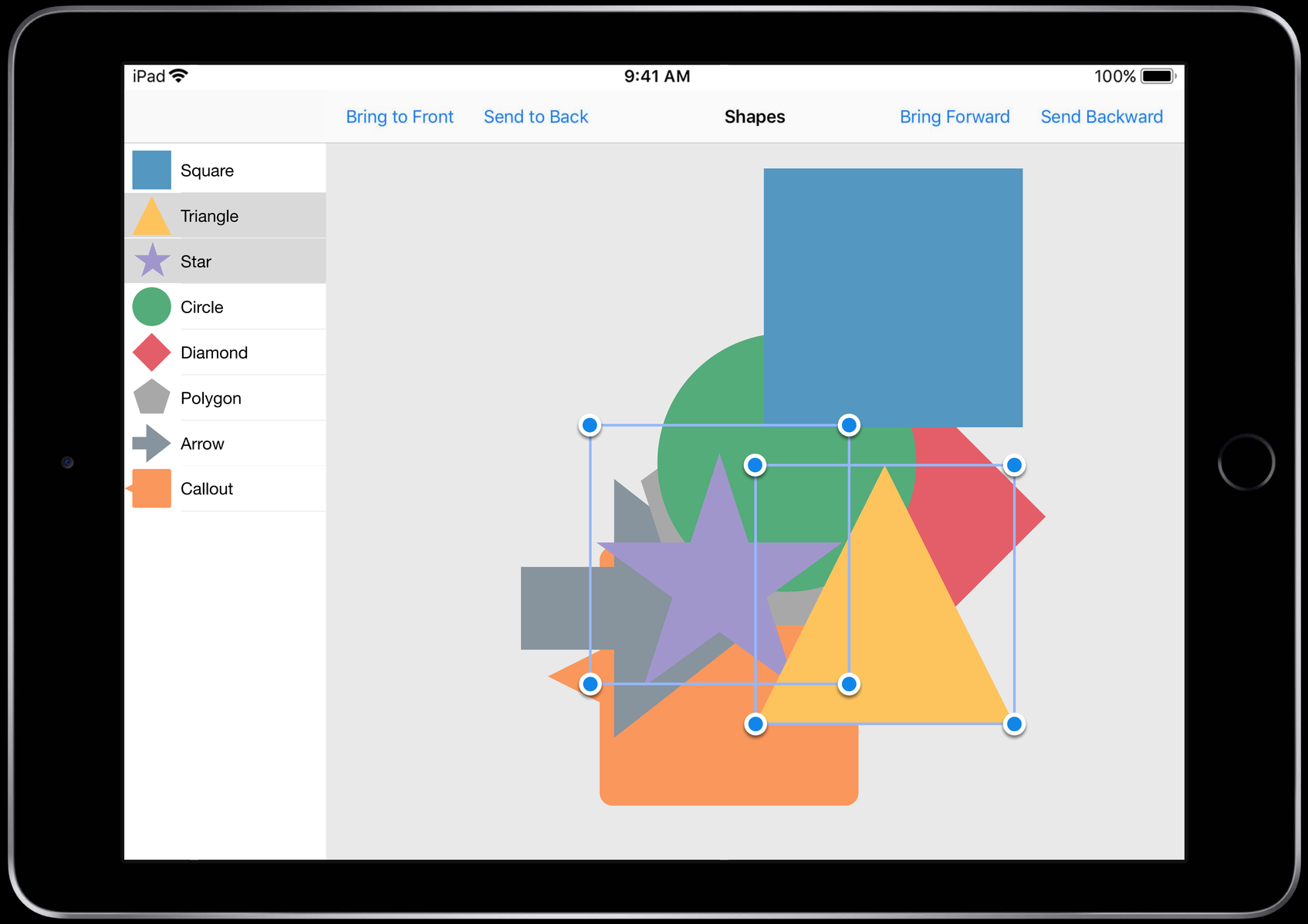
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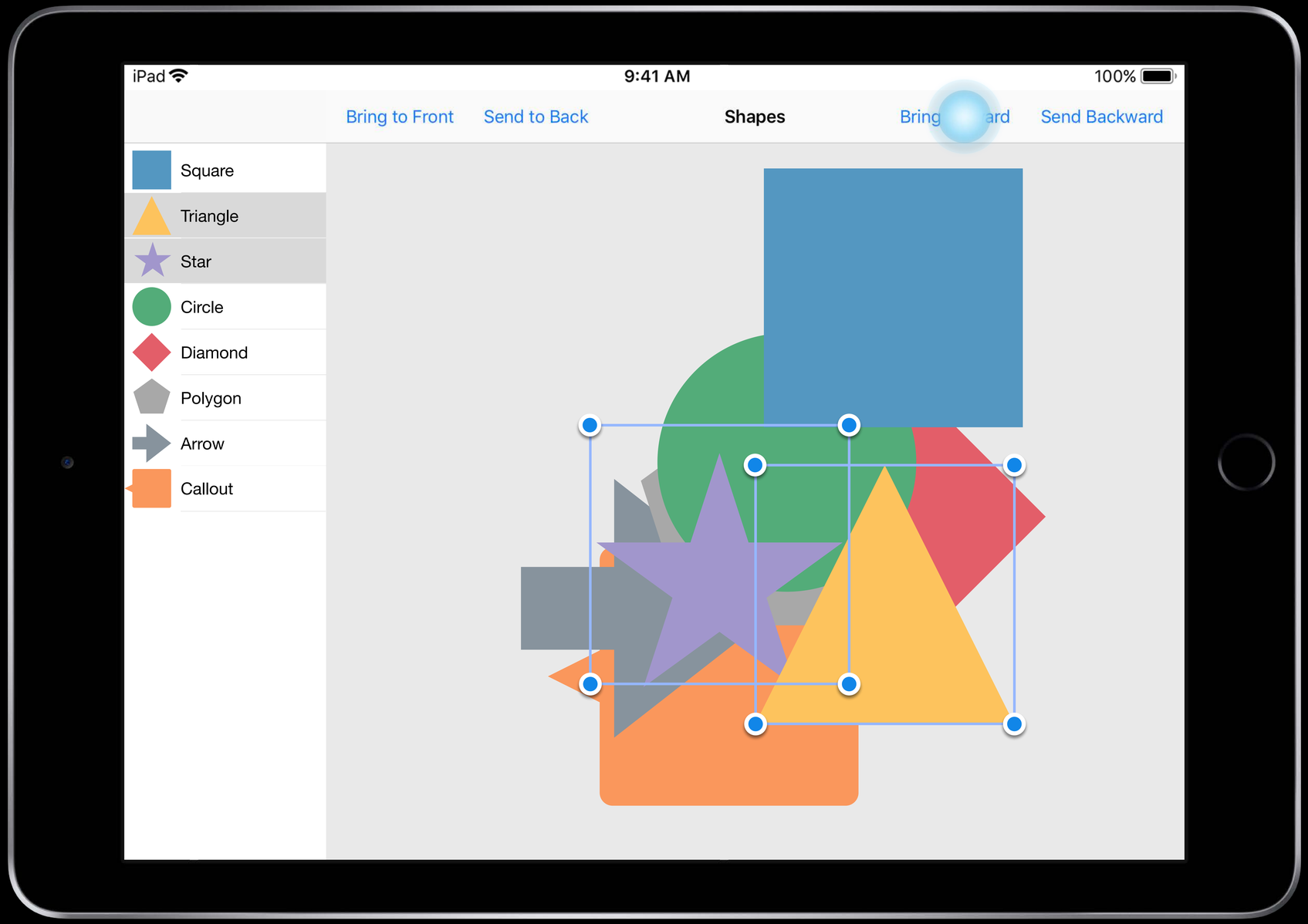
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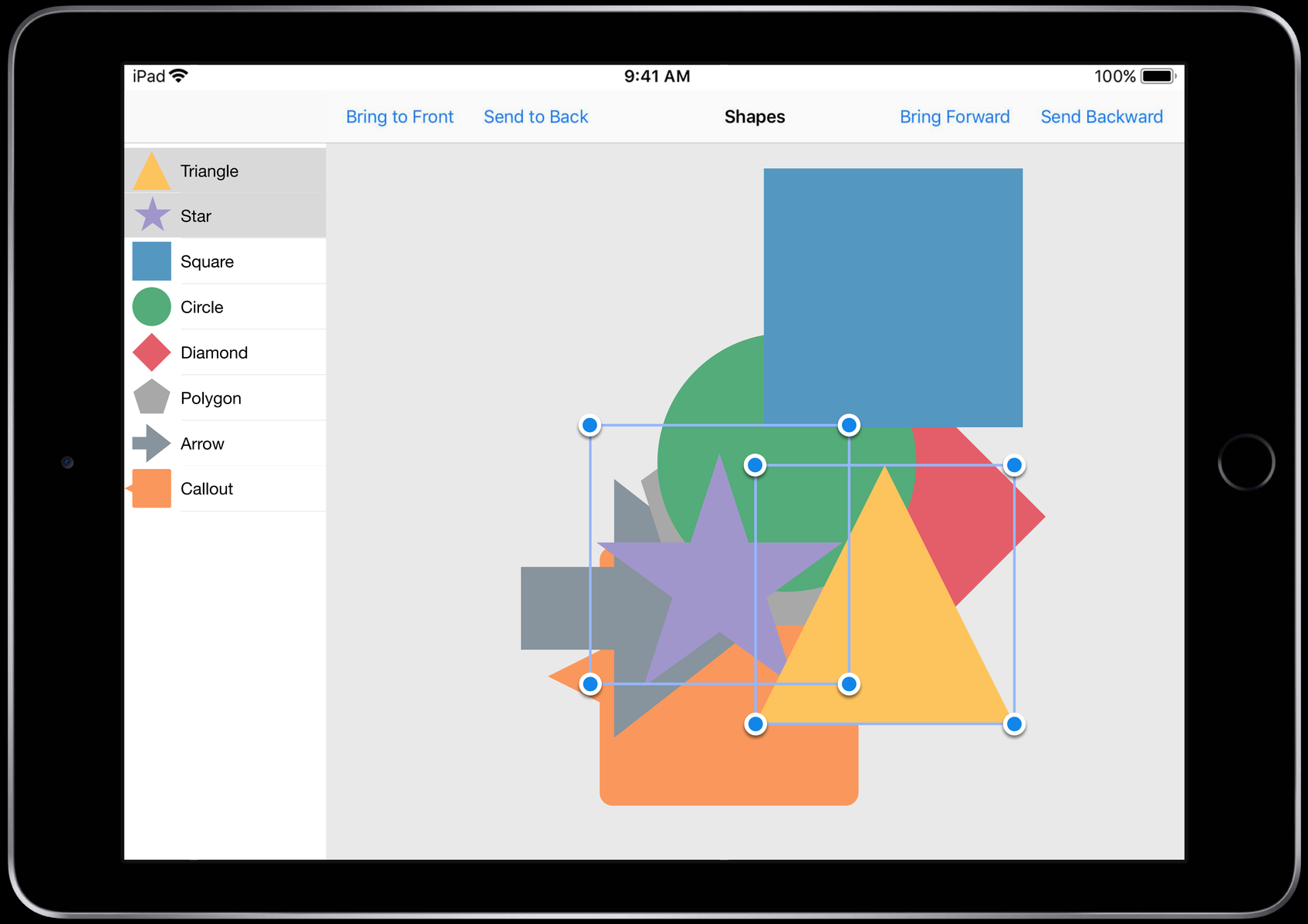
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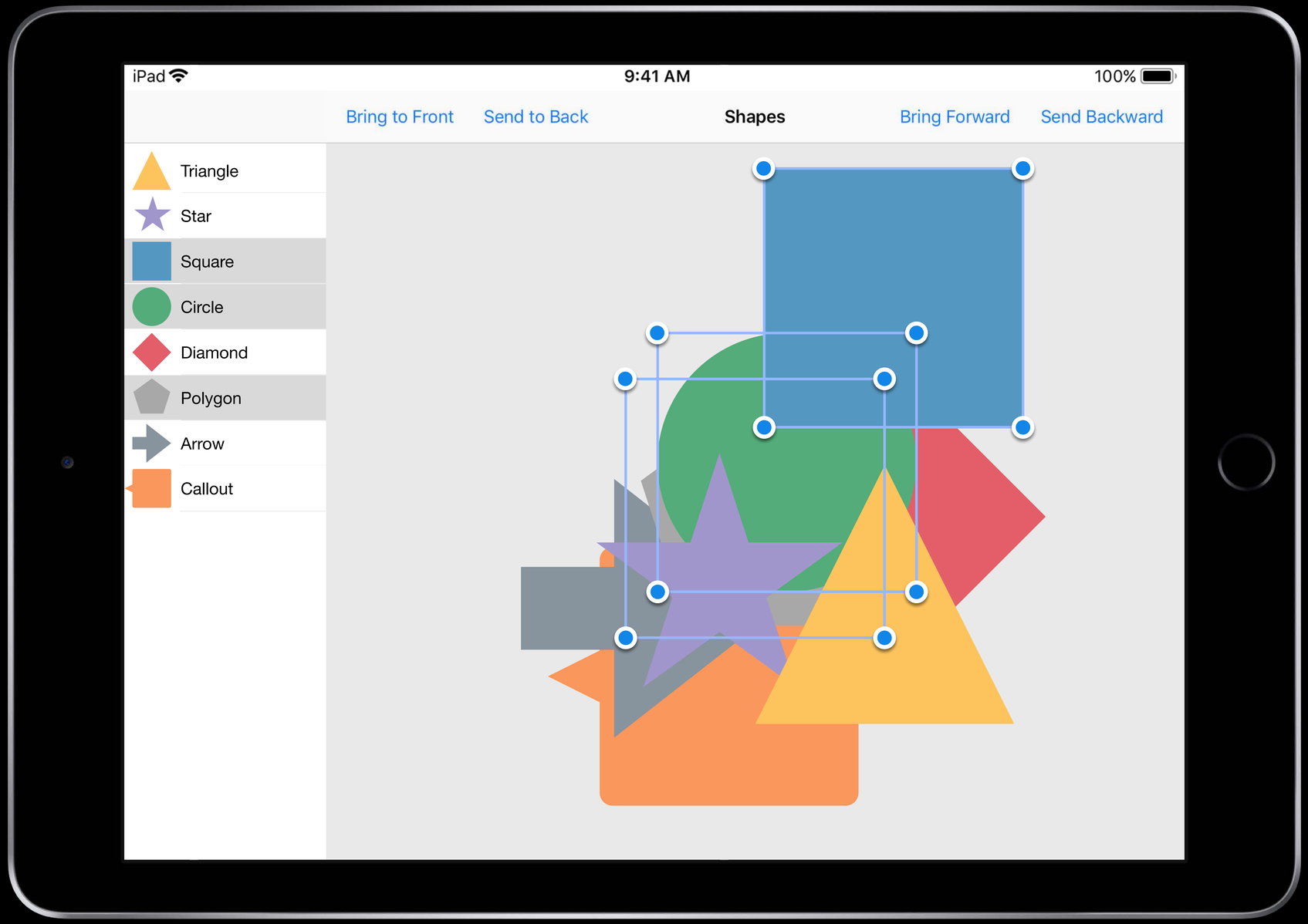
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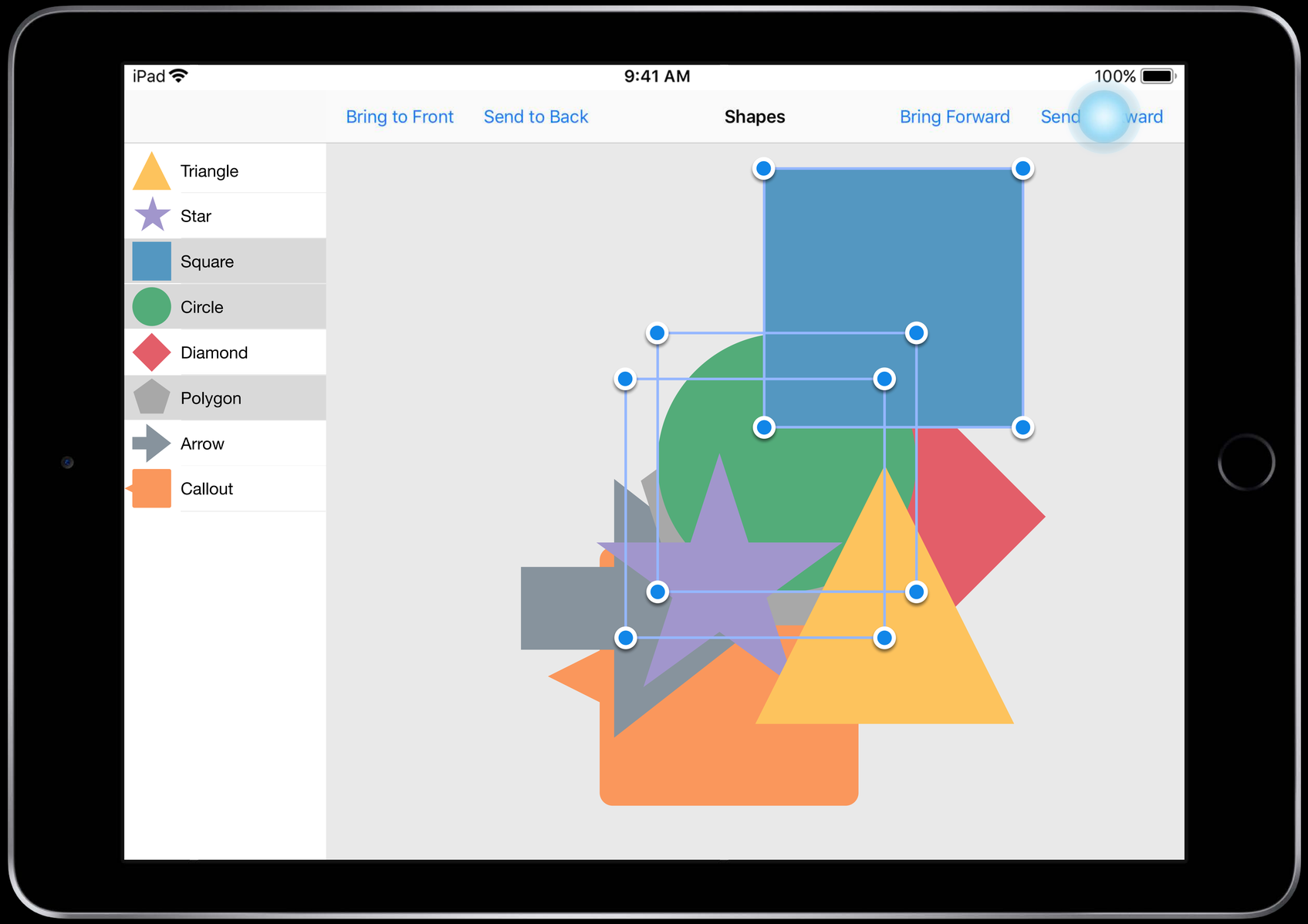
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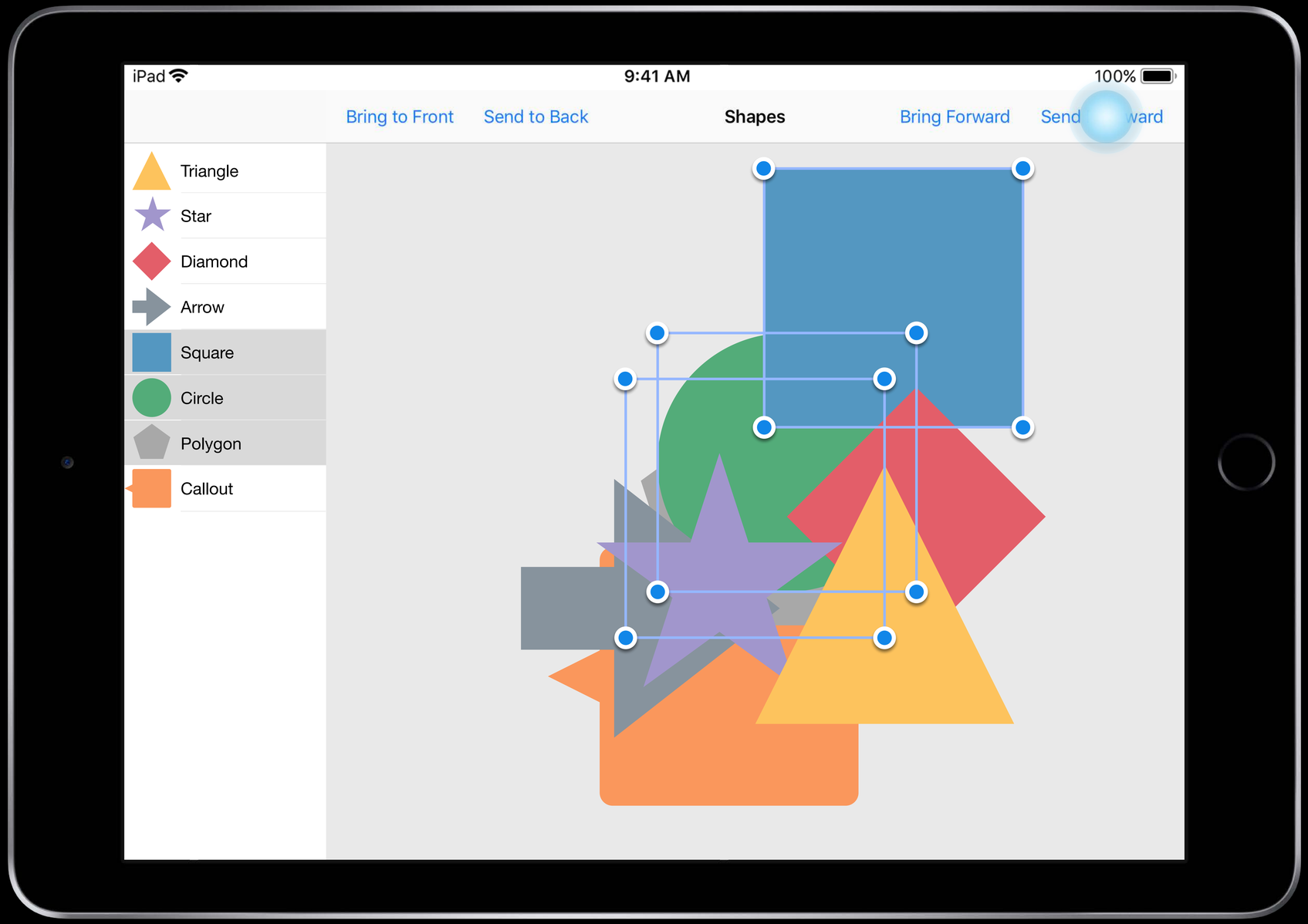
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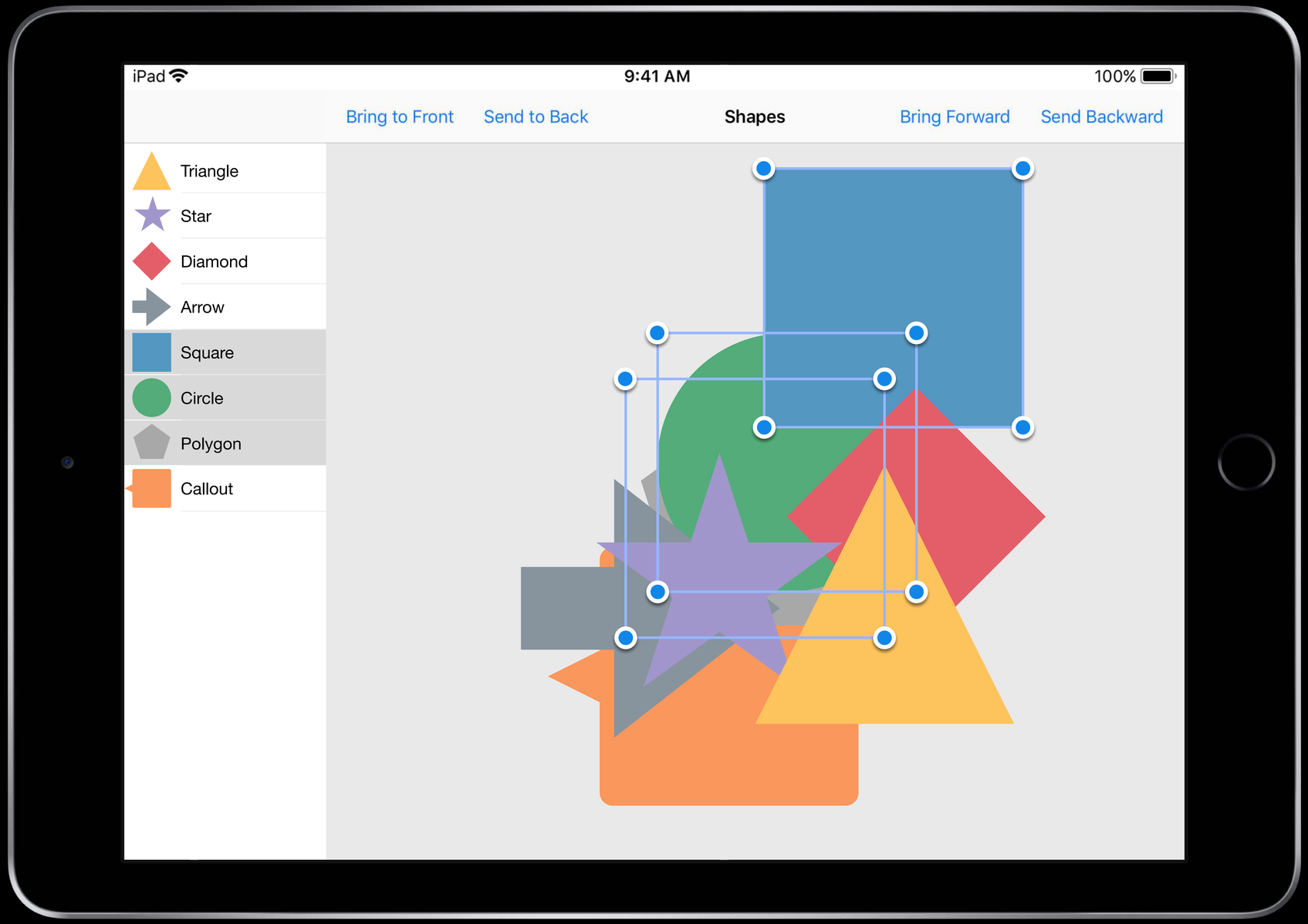
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Bring to Front
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Triangle
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```
// Layering Operations
// bringToFront()

extension Canvas {
   mutating func bringToFront() {
        var i = 0, j = 0
        while i < shapes.count {
            if shapes[i].isSelected {
                let selected = shapes.remove(at: i)
                shapes.insert(selected, at: j)
                j += 1
            }
            i += 1
        }
    }
}
```

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```

O(n) loop, containing...

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O(n) loop, containing...

O(n) operations

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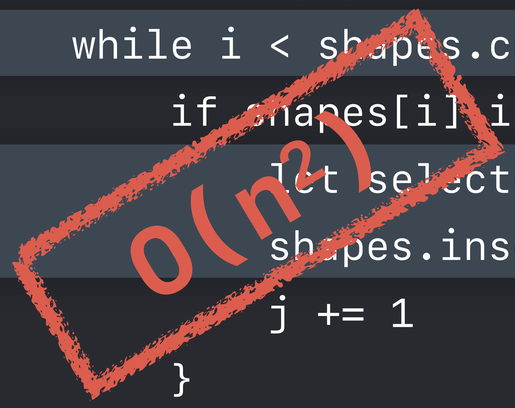
O(n) loop, containing...

O(n) operations



```
extension Canvas {
    mutating func bringToFront() {
        var i = 0, j = 0
        while i < shapes.count {
            if shapes[i].isSelected {
                let selected = shapes.remove(at: i)
                shapes.insert(selected, at: j)
                j += 1
            }
            i += 1
        }
    }

    mutating func sendToBack() {
        var i = 0, j = shapes.count
        while i < j {
            if shapes[i].isSelected {
                let selected = shapes.remove(at: i)
                shapes.append(selected)
                j -= 1
            }
            else {
                i += 1
            }
        }
    }
}
```

O(n²)

```
extension Canvas {
    mutating func sendBackward() {
        for i in shapes.indices.reversed()
            where shapes[i].isSelected
        {
            var insertionPoint = i + 1
            if insertionPoint == shapes.count { return }
            for j in (0...i).reversed()
                where shapes[j].isSelected
            {
                let x = shapes.remove(at: j)
                shapes.insert(x, at: insertionPoint)
                insertionPoint -= 1
            }
            return
        }
    }

    mutating func bringForward() {
        for i in shapes.indices
            where shapes[i].isSelected
        {
            if i == 0 { return }
            var insertionPoint = i - 1
            for j in i..<shapes.count
                where shapes[j].isSelected
            {
                let x = shapes.remove(at: j)
                shapes.insert(x, at: insertionPoint)
                insertionPoint += 1
            }
            return
        }
    }
}
```

```
extension Canvas {
    mutating func gatherSelected(at target: Int) {
        var shapesToInsert: [Shape] = []
        var insertionPoint = target
        var i = 0

        while i < insertionPoint {
            if shapes[i].isSelected {
                let x = shapes.remove(at: i)
                shapesToInsert.append(x)
                insertionPoint -= 1
            }
            else {
                i += 1
            }
        }

        while i < shapes.count {
            if shapes[i].isSelected {
                let x = shapes.remove(at: i)
                shapesToInsert.append(x)
            }
            else {
                i += 1
            }
        }

        shapes.insert(
            contentsOf: shapesToInsert,
            at: insertionPoint)
    }
}
```

```
extension Canvas {
    mutating func bringToFront() {
        var i = 0, j = 0
        while i < shapes.count {
            if shapes[i].isSelected {
                let selected = shapes.remove(at: i)
                shapes.insert(selected, at: j)
                j += 1
            }
            i += 1
        }
    }

    mutating func sendToBack() {
        var i = 0, j = shapes.count
        while i < j {
            if shapes[i].isSelected {
                let selected = shapes.remove(at: i)
                shapes.append(selected)
                j -= 1
            }
            else {
                i += 1
            }
        }
    }
}
```

O(n²)

O(n²)

```
extension Canvas {
    mutating func sendBackward() {
        for i in shapes.indices.reversed()
            where shapes[i].isSelected
        {
            var insertionPoint = i + 1
            if insertionPoint == shapes.count { return }
            for j in (0..<i).reversed()
                where shapes[j].isSelected
            {
                let x = shapes.remove(at: j)
                shapes.insert(x, at: insertionPoint)
                insertionPoint -= 1
            }
            return
        }
    }

    mutating func bringForward() {
        for i in shapes.indices
            where shapes[i].isSelected
        {
            if i == 0 { return }
            var insertionPoint = i - 1
            for j in i..<shapes.count
                where shapes[j].isSelected
            {
                let x = shapes.remove(at: j)
                shapes.insert(x, at: insertionPoint)
                insertionPoint += 1
            }
            return
        }
    }
}
```

O(n²)

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O(n²)

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                j += 1
            }
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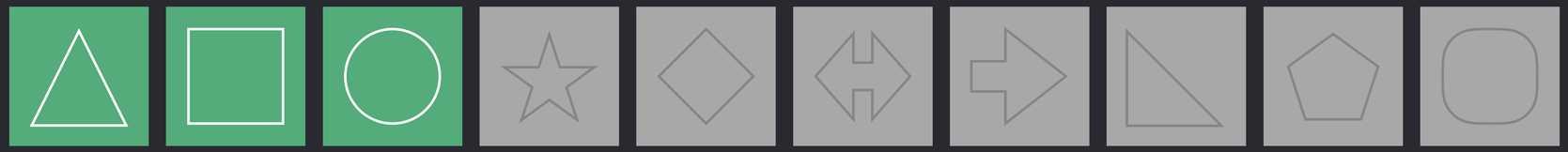
        }
    }
}
```



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        while i < shapes.count {
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                j += 1
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        }
    }
}
```

```
extension Canvas {
    /// Moves the selected shapes to the front, maintaining their relative order.
    mutating func bringToFront() {
        var i = 0, j = 0
        while i < shapes.count {
            if shapes[i].isSelected {
                let selected = shapes.remove(at: i)
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                j += 1
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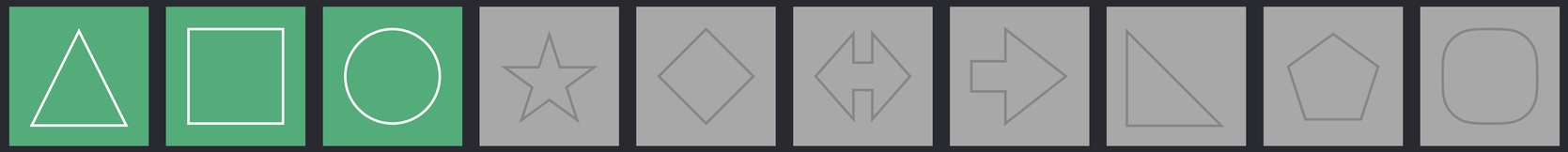
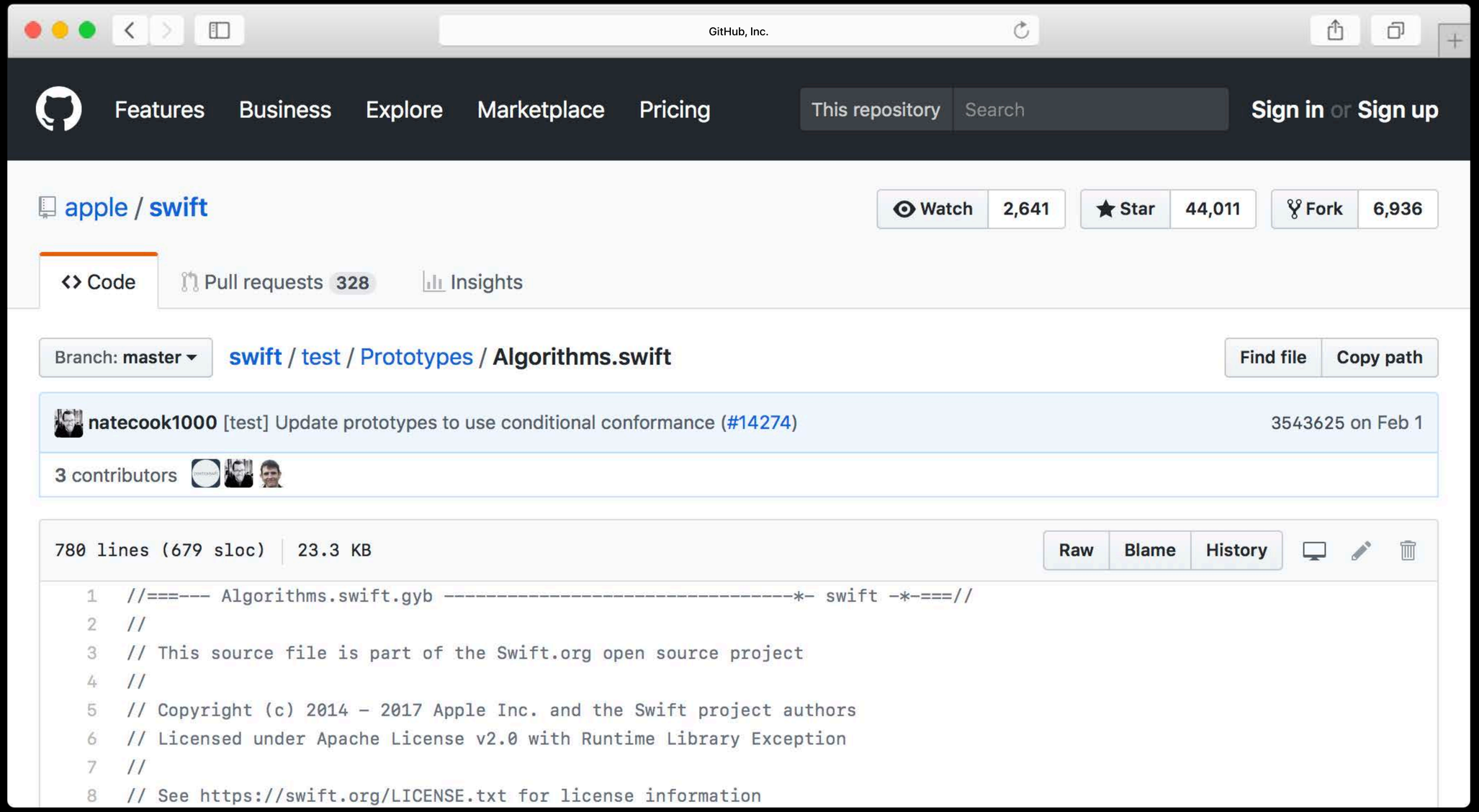
    }
}
```





https://github.com/apple/swift/blob/master/test/Prototypes/Algorithms.swift

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                j += 1
            }
            i += 1
        }
    }
}
```

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extension Canvas {
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    mutating func bringToFront() {

    }
}
```

```
extension Canvas {
    /// Moves the selected shapes to the front, maintaining their relative order.
    mutating func bringToFront() {
        shapes.stablePartition(isSuffixElement: (Shape) -> Bool)
    }
}
```

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extension Canvas {
    /// Moves the selected shapes to the front, maintaining their relative order.
    mutating func bringToFront() {
        shapes.stablePartition(isSuffixElement: (Shape) -> Bool)
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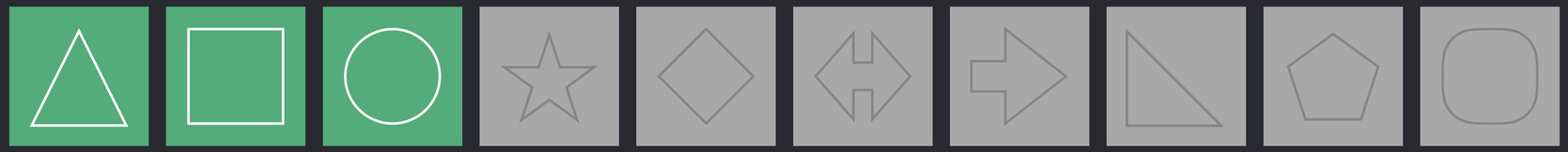
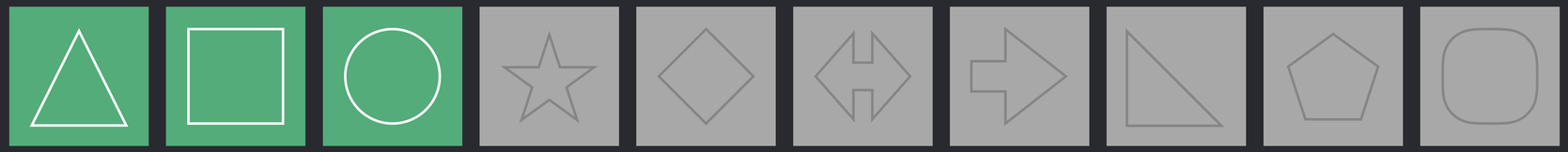


```
extension Canvas {
    /// Moves the selected shapes to the front, maintaining their relative order.
    mutating func bringToFront() {
        shapes.stablePartition(isSuffixElement: { !$0.isSelected })
    }
}
```



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    mutating func bringToFront() {
        shapes.stablePartition(isSuffixElement: { !$0.isSelected })
    }

    /// Moves the selected shapes to the back, maintaining their relative order.
    mutating func sendToBack() {
        shapes.stablePartition(isSuffixElement: { $0.isSelected })
    }
}
```

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```

Summary

Moves all elements satisfying `isSuffixElement` into a suffix of the collection, preserving their relative order, and returns the start of the resulting suffix.

Declaration

```
mutating func stablePartition(isSuffixElement: (Element) -> Bool)
-> Index
```

Discussion

Complexity

O(n log n) where n is the number of elements.

Declared In

Example.playground

```
extension Canvas {
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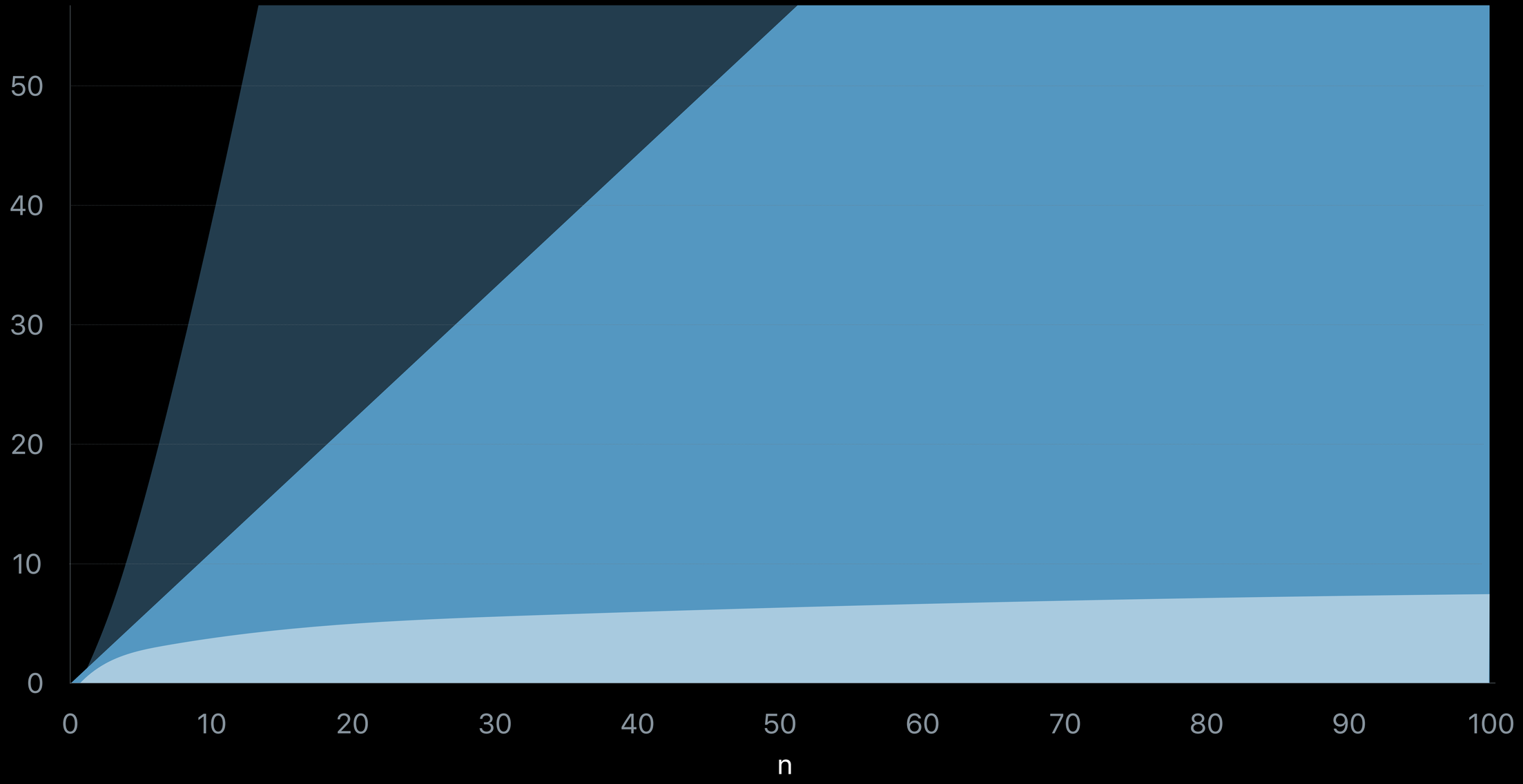
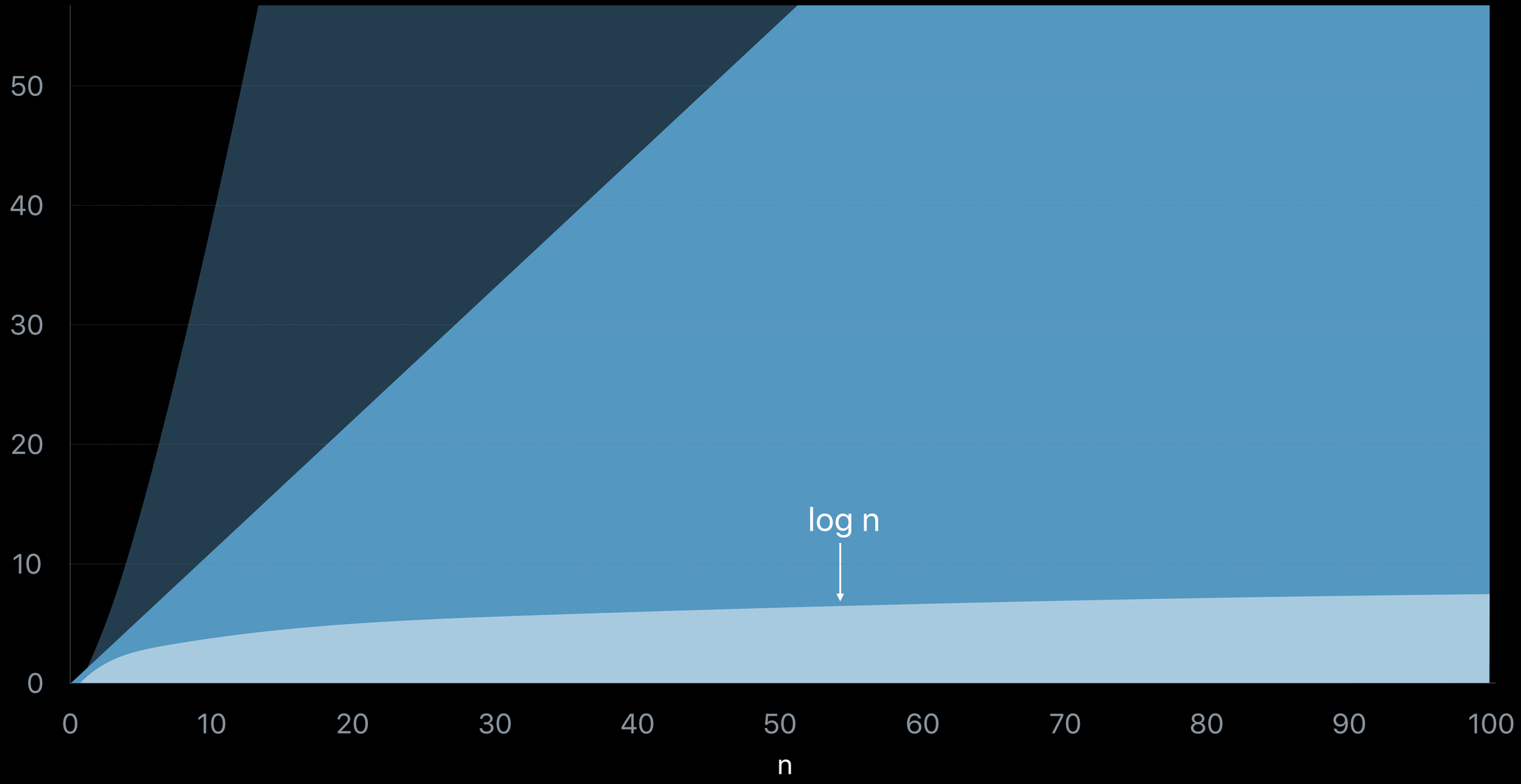
Scalability Redux



Scalability Redux



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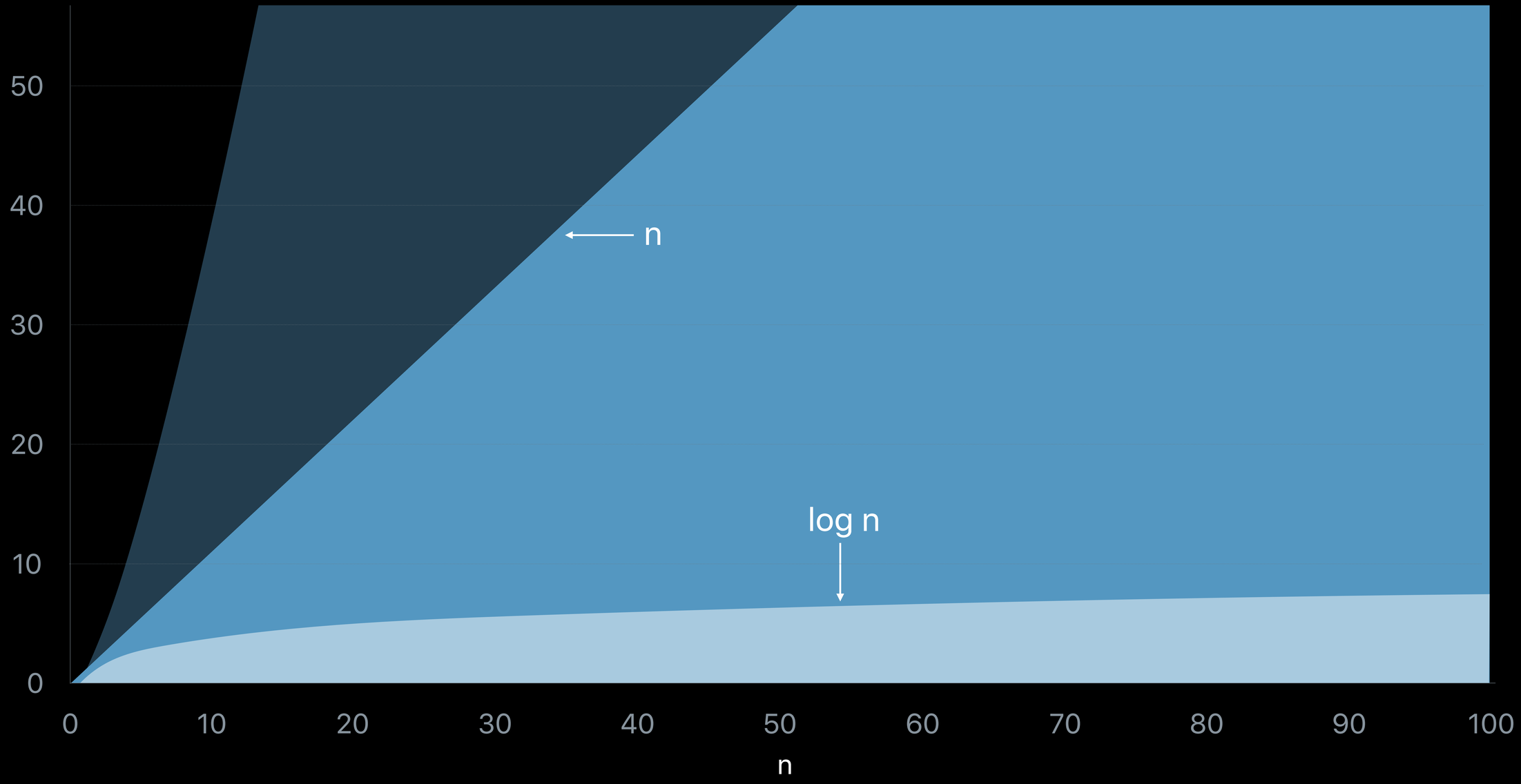

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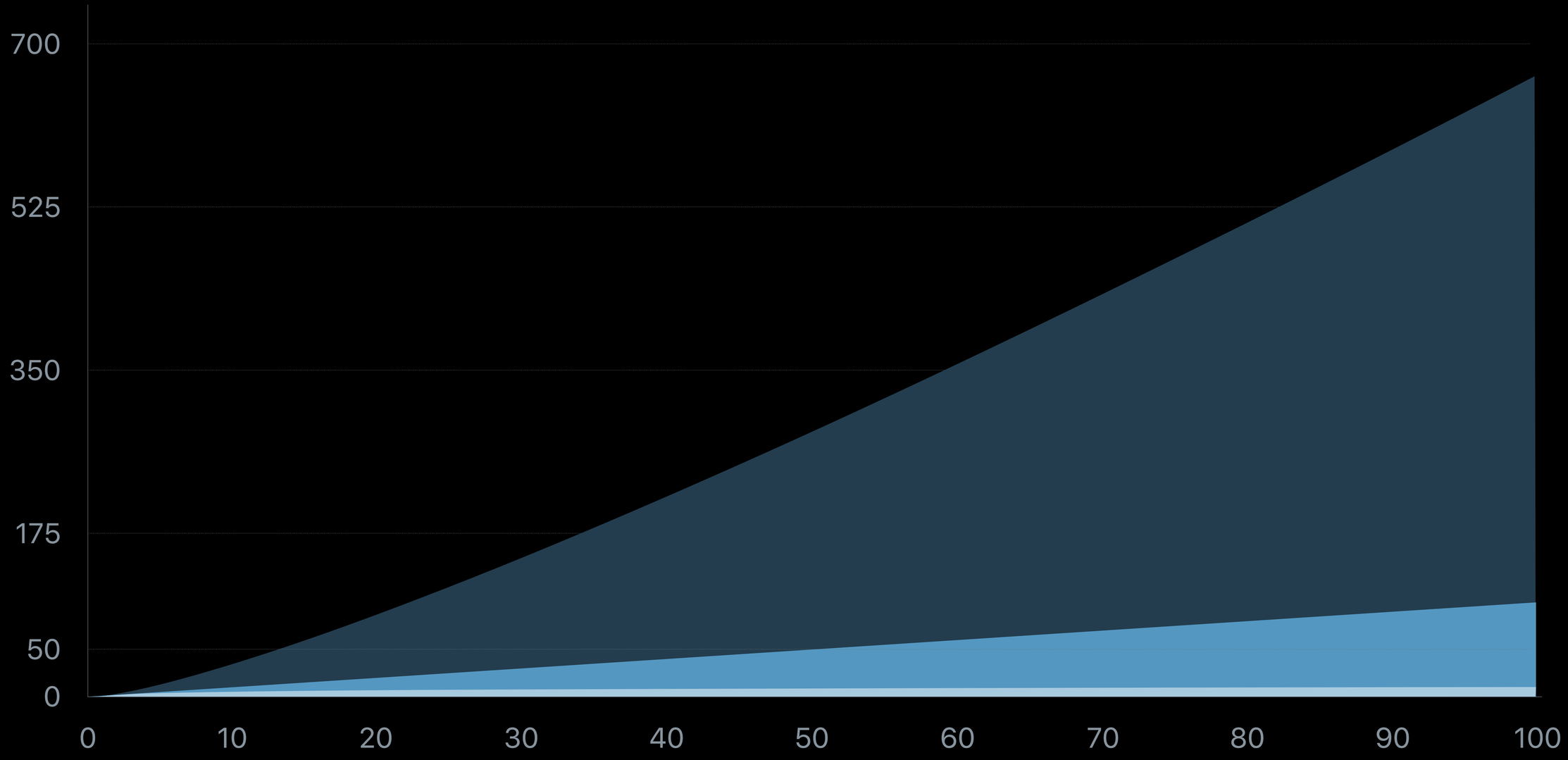
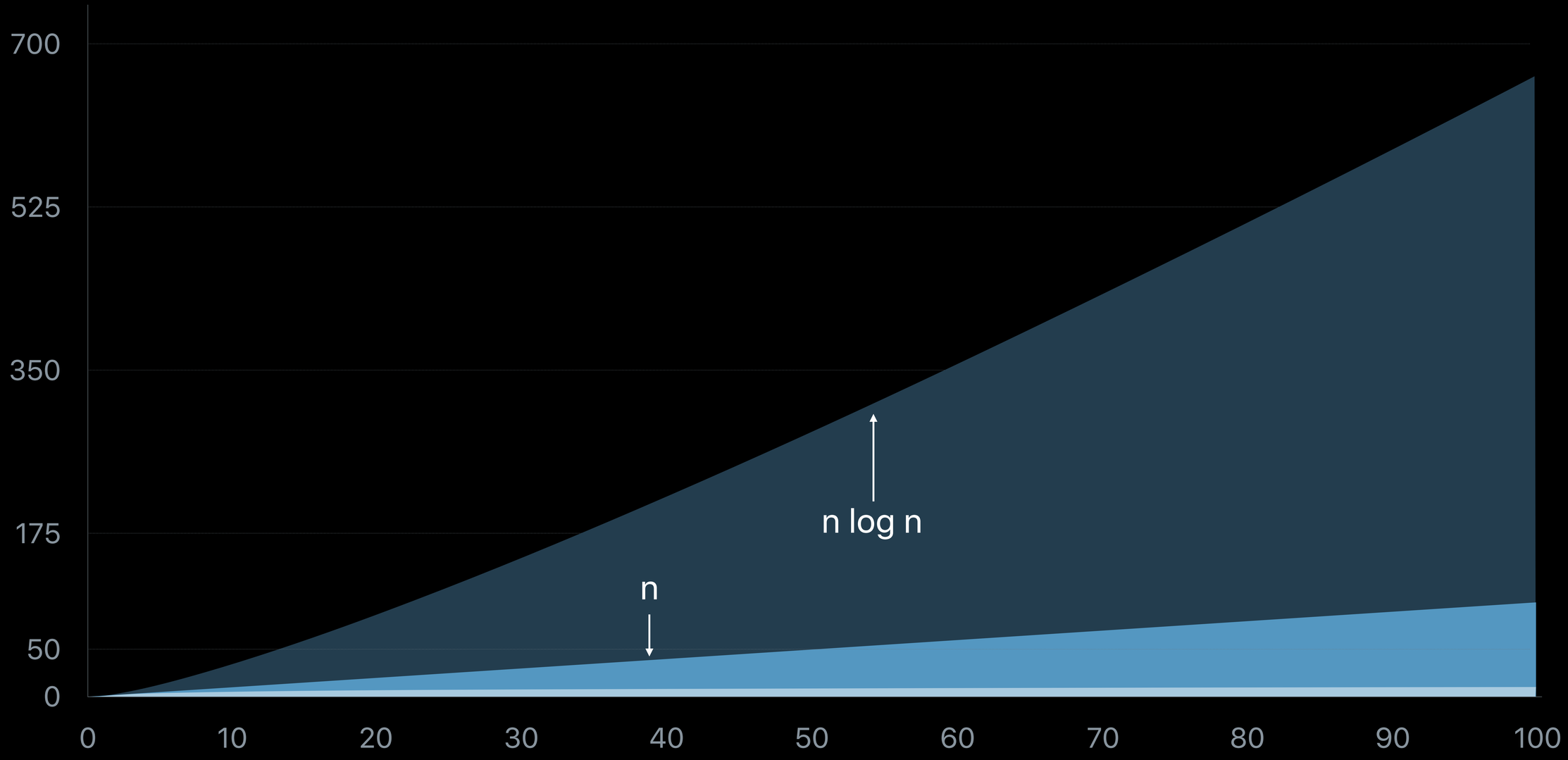


Scalability Redux



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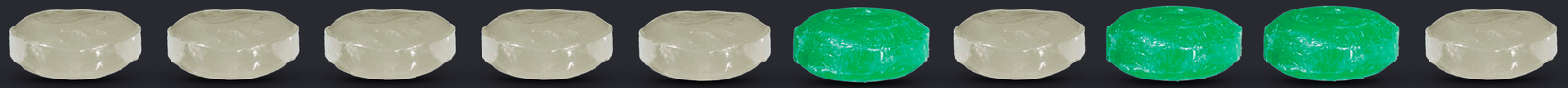

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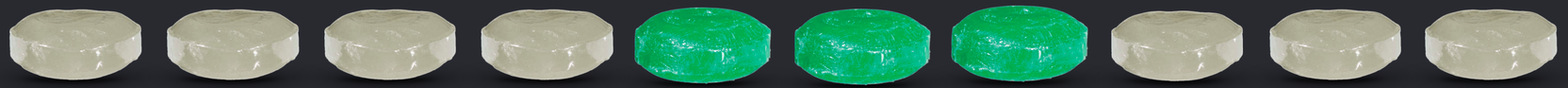

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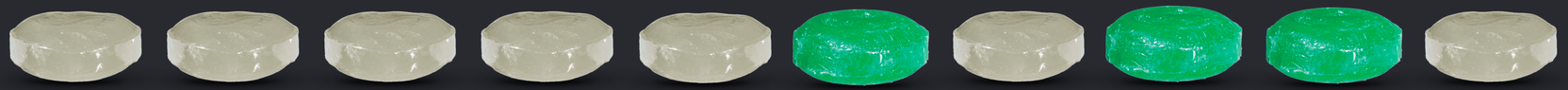

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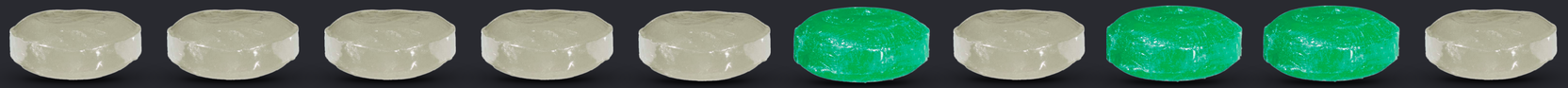

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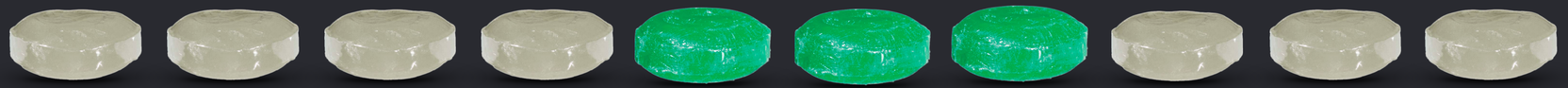

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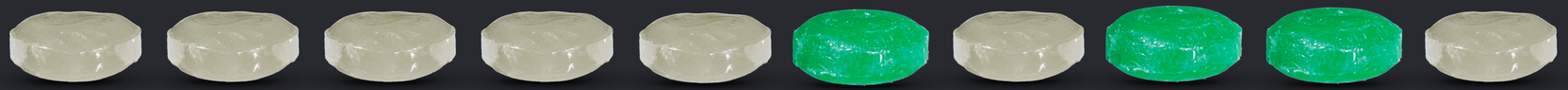

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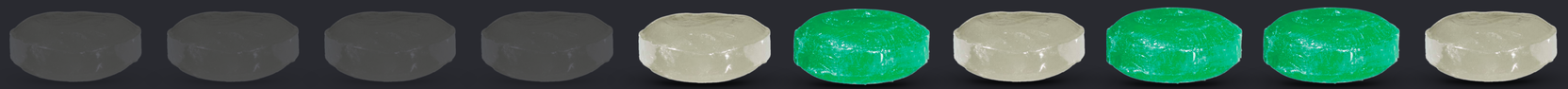

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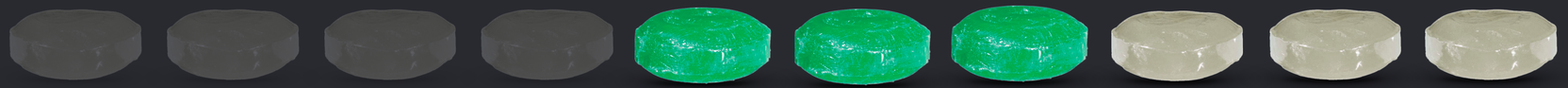

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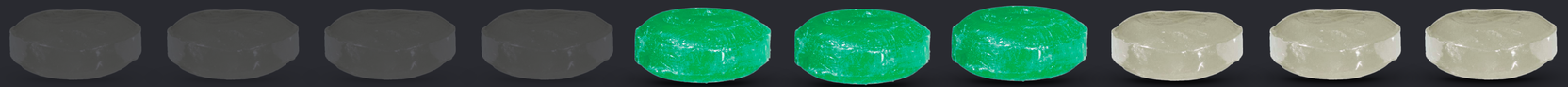

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    }
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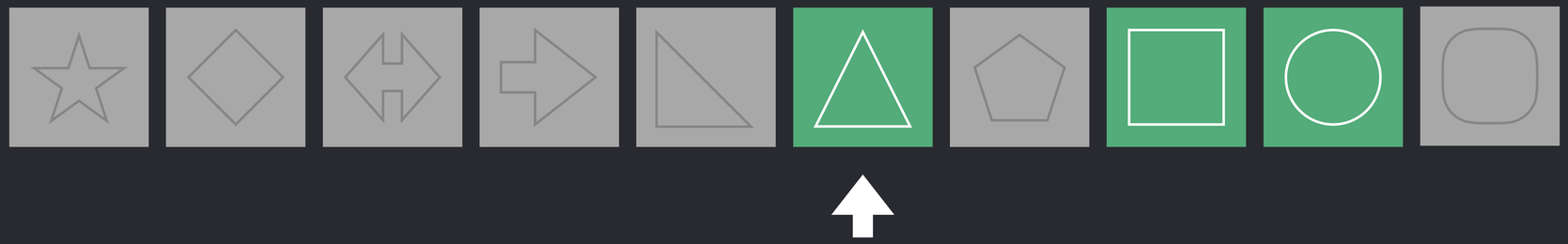

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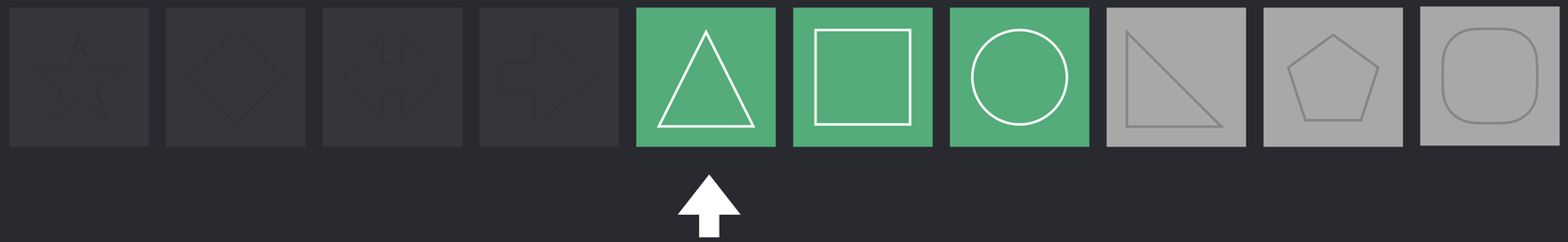

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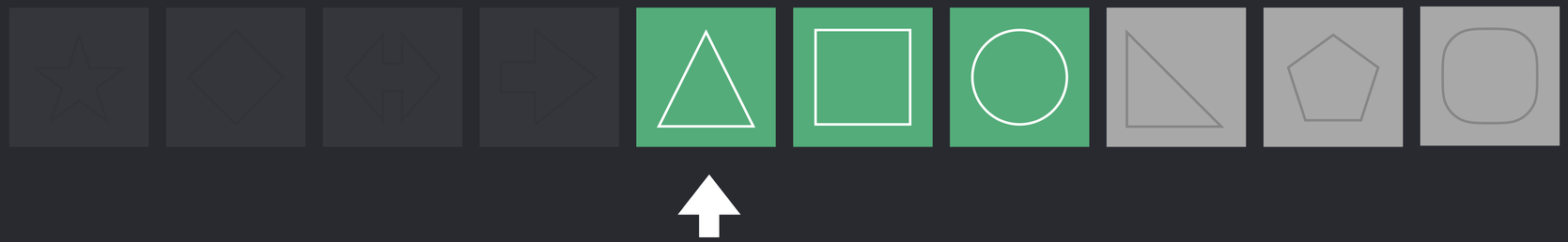
            shapes[predecessor...]
        }
    }
}
```

Means the same as

`shapes[predecessor..<endIndex]`



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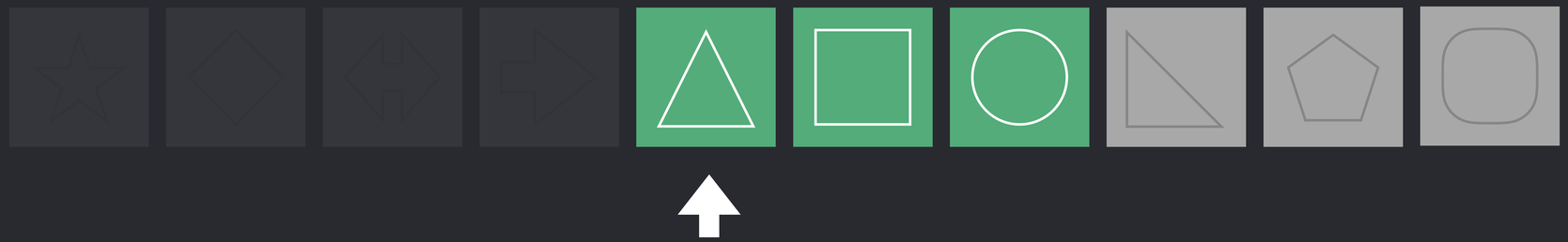

Discover Algorithms

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ArraySlice<Shape>

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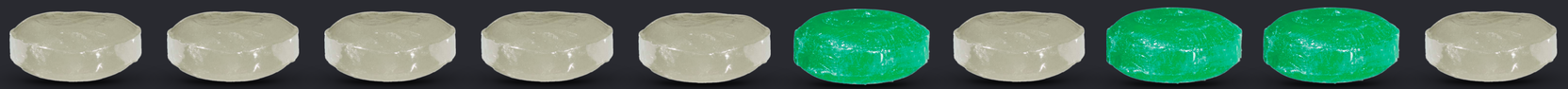
ArraySlice<Shape>



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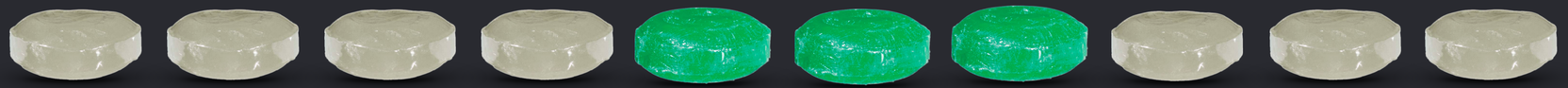
ArraySlice<Shape>



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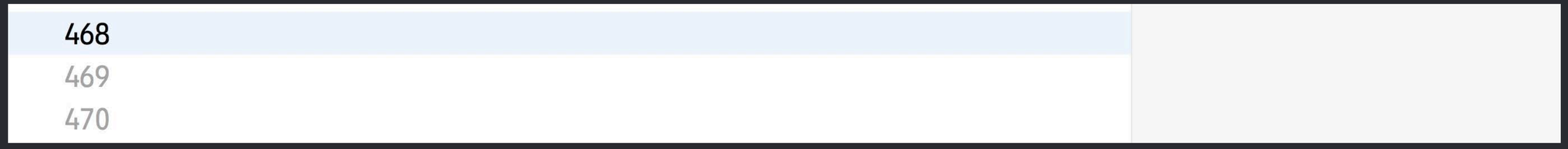

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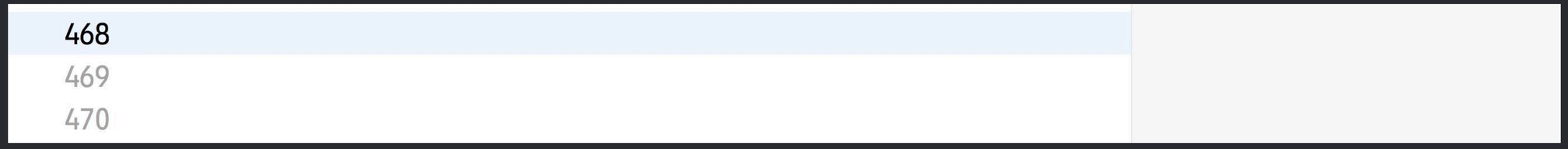

```
extension Array where Element == Shape {
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    }
}
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```
extension Array where Element == Shape {
    mutating func bringForward(elementsSatisfying predicate: (Element) -> Bool) {
        if let i = firstIndex(where: predicate) {
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            let predecessor = i - 1
            self[predecessor...].stablePartition(isSuffixElement: { !predicate($0) })
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}
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```
extension MutableCollection {
    mutating func bringForward(elementsSatisfying predicate: (Element) -> Bool) {
        if let i = firstIndex(where: predicate) {
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    }
}
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```
extension MutableCollection {
    mutating func bringForward(elementsSatisfying predicate: (Element) -> Bool) {
        if let i = firstIndex(where: predicate) {
            if i == 0 { return }   ❗ Binary operator '==' cannot be applied to operands of type 'Self.Index' and 'Int'
            let predecessor = i - 1   ❗ Binary operator '-' cannot be applied to operands of type 'Self.Index' and 'Int'
            self[predecessor...].stablePartition(isSuffixElement: { !predicate($0) })
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}
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extension MutableCollection where Index == Int {
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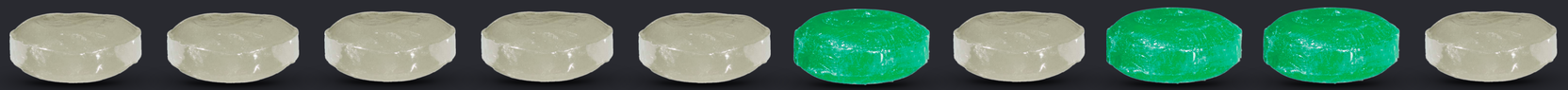

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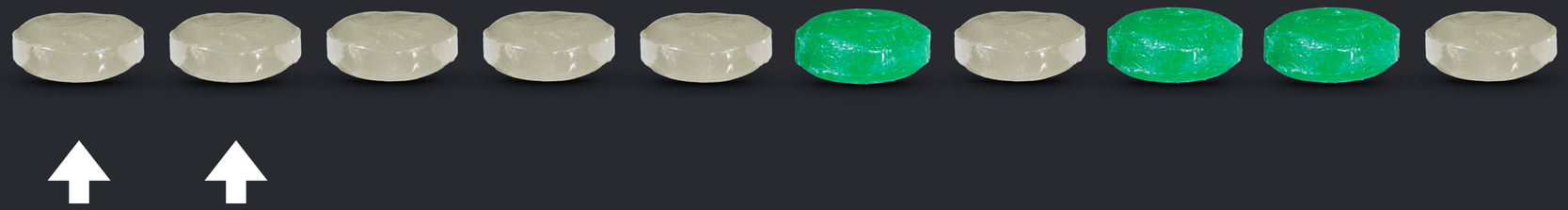

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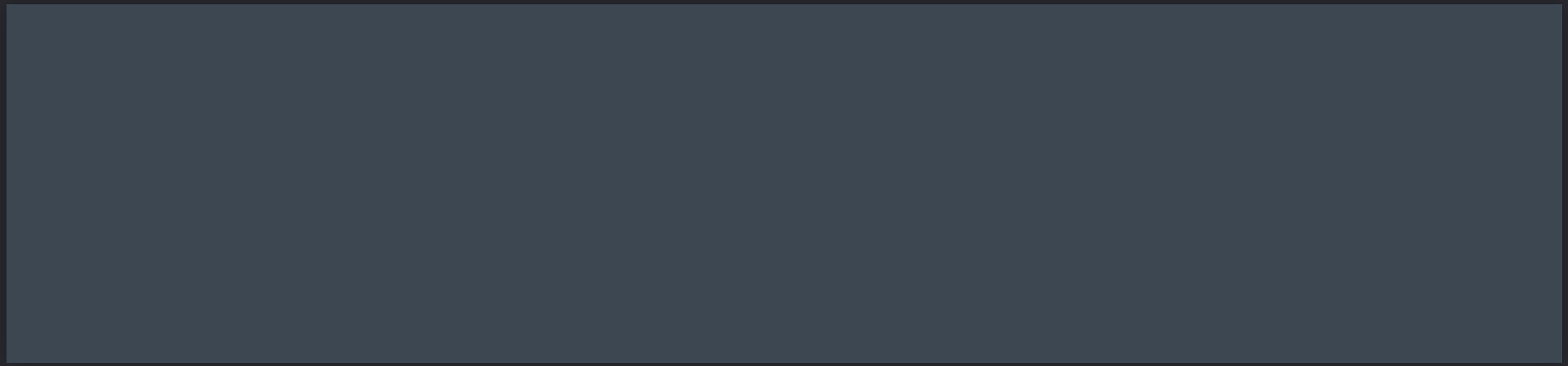

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        }
    }
}

extension Collection {
    func indexBeforeFirst(where predicate: (Element) -> Bool) -> Index? {
        return indices.first {
            let successor = index(after: $0)
            return successor != endIndex && predicate(self[successor])
        }
    }
}
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extension MutableCollection {
    mutating func bringForward(elementsSatisfying predicate: (Element) -> Bool) {
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```

Building Towers Of Abstraction

Building Towers Of Abstraction

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        if let predecessor = indexBeforeFirst(where: predicate) {
            self[predecessor...].stablePartition(isSuffixElement: { !predicate($0) })
        }
    }
}
extension Collection {
    /// Returns the `index` before the first one whose element satisfies `predicate`.
    ///
    /// - Complexity: O(n) where n is the length of the collection.
    func indexBeforeFirst(where predicate: (Element) -> Bool) -> Index? {
        return indices.first {
            let successor = index(after: $0)
            return successor != endIndex && predicate(self[successor])
        }
    }
}
```

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extension MutableCollection {
    mutating func bringForward(elementsSatisfying predicate: (Element) -> Bool) {
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        if let predecessor = indexBeforeFirst(where: predicate) {
            self[predecessor...].stablePartition(isSuffixElement: { !predicate($0) })
        }
    }
}
```

Summary

Returns the `index` before the first one whose element satisfies `predicate`.

Declaration

```
func indexBeforeFirst(where predicate: (Self.Element) -> Bool) ->
Self.Index?
```

Discussion

Complexity

O(n) where n is the length of the collection.

Parameters

`predicate`	No description.

Declared In

Example.playground

```
extension MutableCollection {
    mutating func bringForward(elementsSatisfying predicate: (Element) -> Bool) {
        if let predecessor = indexBeforeFirst(where: predicate) {
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    }
}
```

```
extension MutableCollection {
    /// Gathers the elements satisfying `predicate` at the position preceding
    /// the first element satisfying `predicate`.
    ///
    /// - Complexity: O(n log n) where n is the length of the collection.
    mutating func bringForward(elementsSatisfying predicate: (Element) -> Bool) {
        if let predecessor = indexBeforeFirst(where: predicate) {
            self[predecessor...].stablePartition(isSuffixElement: { !predicate($0) })
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```

```
extension MutableCollection {
    /// Moves all elements satisfying `isSuffixElement` into a suffix of the collection,
    /// preserving their relative order, returning the start of the resulting suffix.
    ///
    /// - Complexity: O(n log n) where n is the number of elements.
    /// - Precondition: `n == self.count`
    mutating func stablePartition(count n: Int, isSuffixElement: (Element) -> Bool) -> Index {
        if n == 0 { return startIndex }
        if n == 1 { return isSuffixElement(self[startIndex]) ? startIndex : endIndex }
        let h = n / 2, i = index(startIndex, offsetBy: h)
        let j = self[..<i].stablePartition(count: h, isSuffixElement: isSuffixElement)
        let k = self[i...].stablePartition(count: n - h, isSuffixElement: isSuffixElement)
        return self[j..<k].rotate(shiftingToStart: i)
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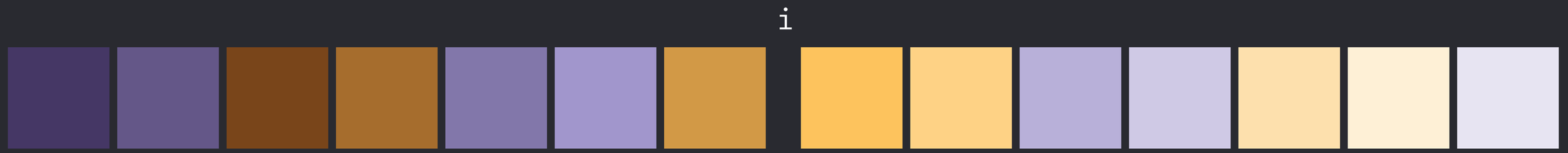

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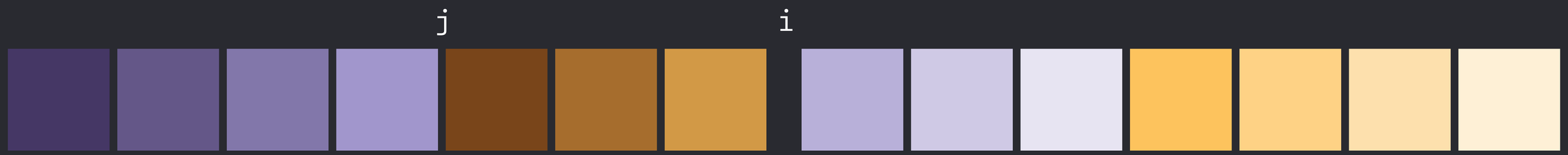

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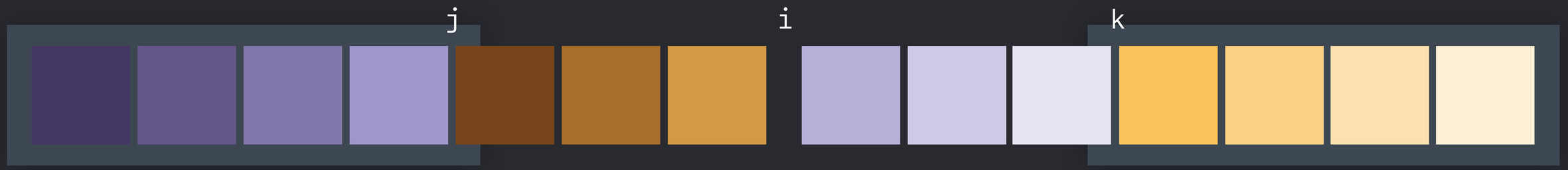

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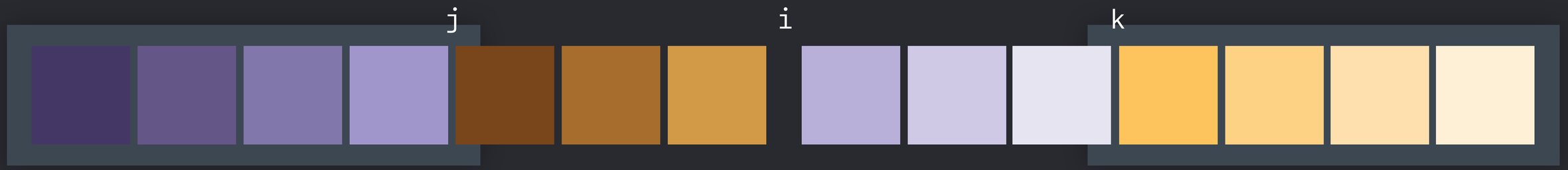

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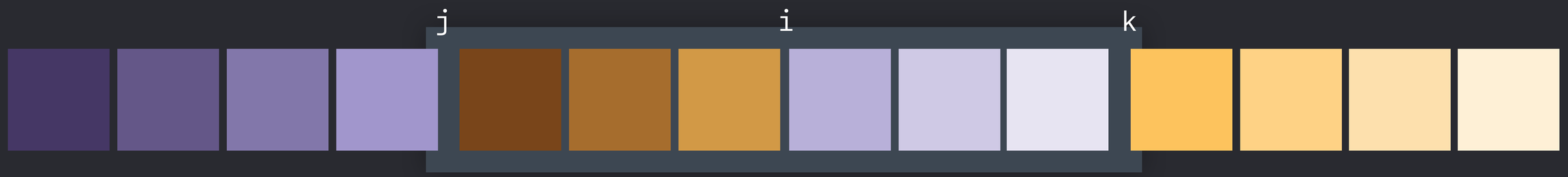

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    }
```

```
extension Canvas {
    mutating func gatherSelected(at target: Int) {
        var buffer: [Shape] = []
        var insertionPoint = target
        var i = 0

        while i < insertionPoint {
            if shapes[i].isSelected {
                let x = shapes.remove(at: i)
                buffer.append(x)
                insertionPoint -= 1
            }
            else {
                i += 1
            }
        }

        while i < shapes.count {
            if shapes[i].isSelected {
                let x = shapes.remove(at: i)
                buffer.append(x)
            }
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                i += 1
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        }

       shapes.insert(contentsOf: buffer, at: insertionPoint)
    }
}
```

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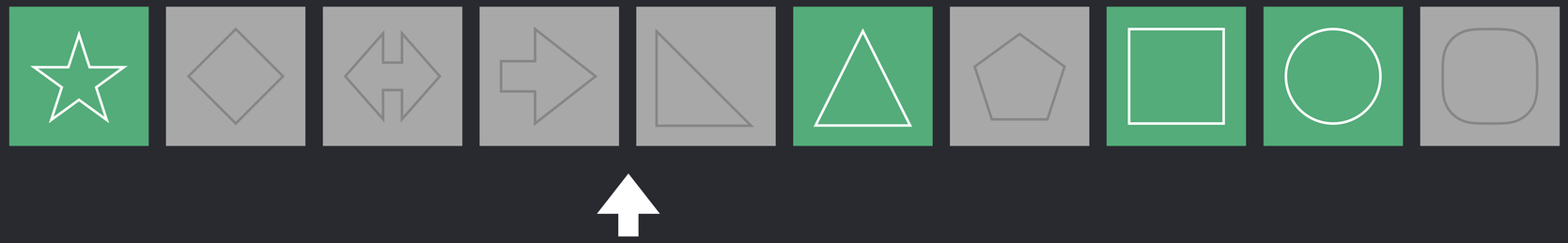

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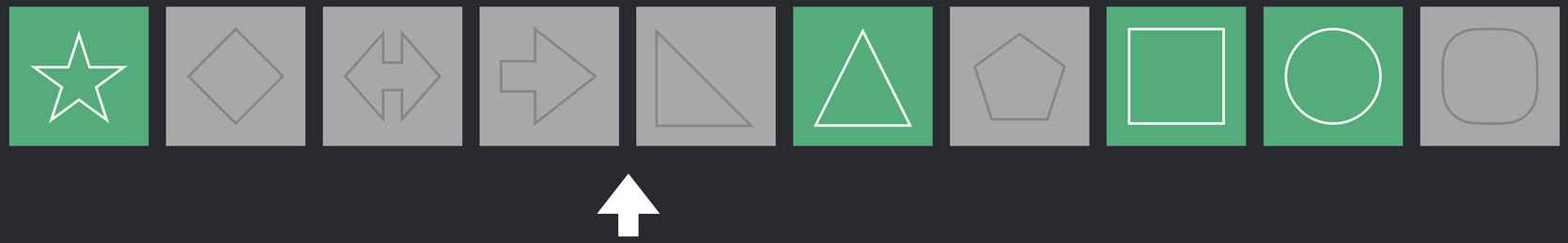

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            }
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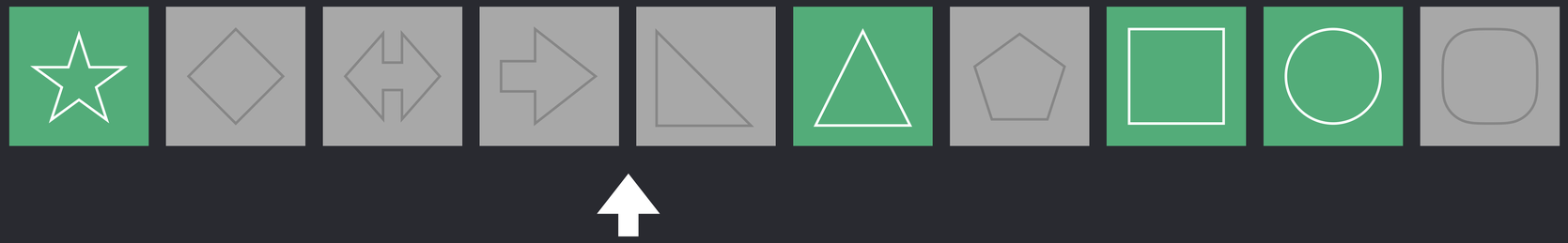

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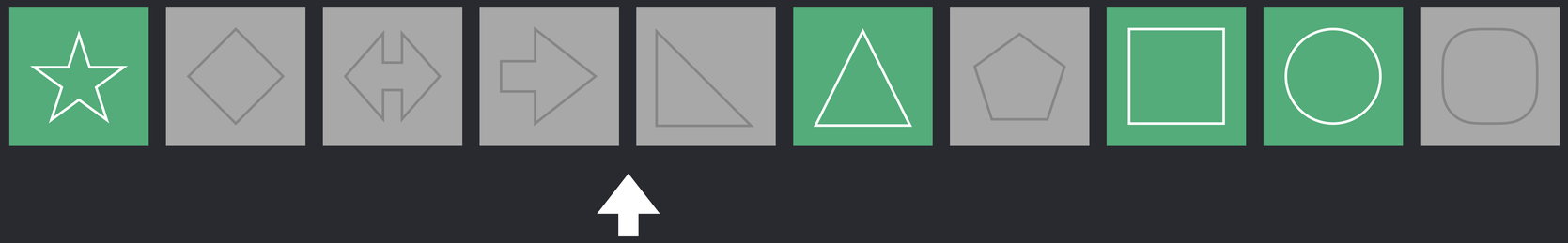

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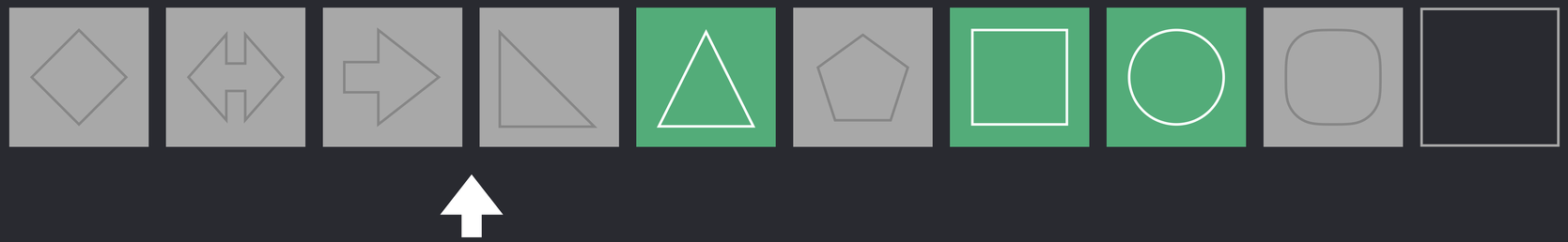

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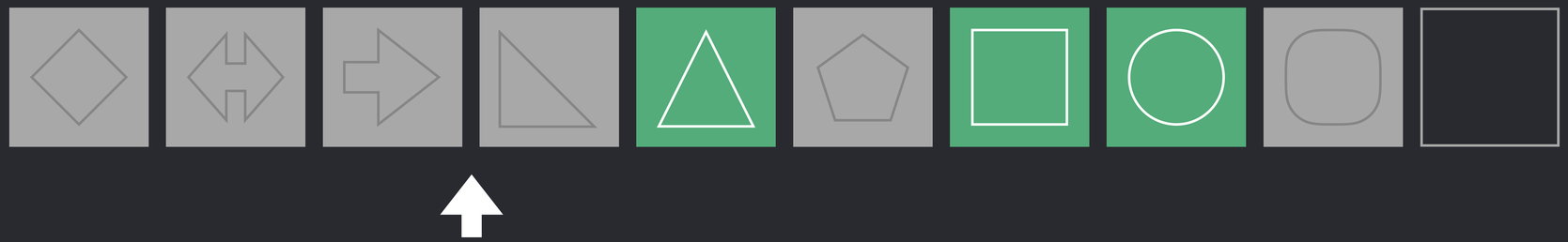

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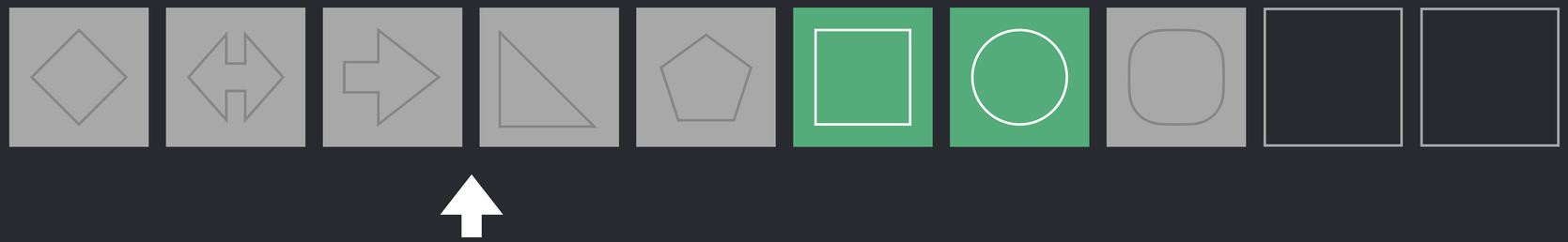

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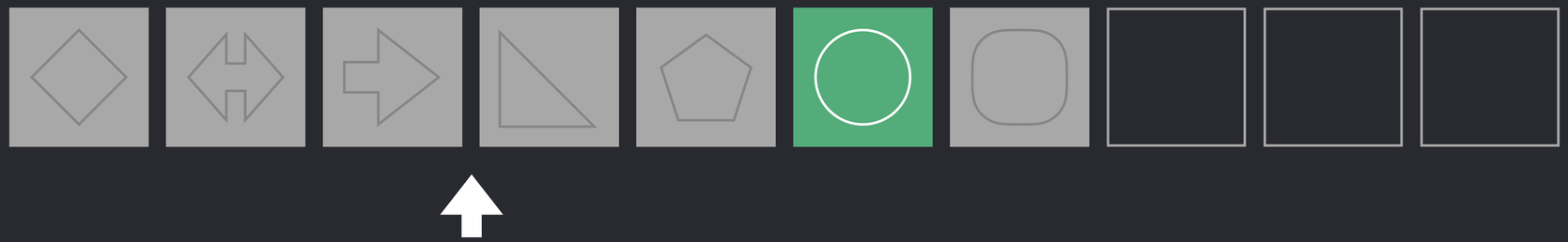

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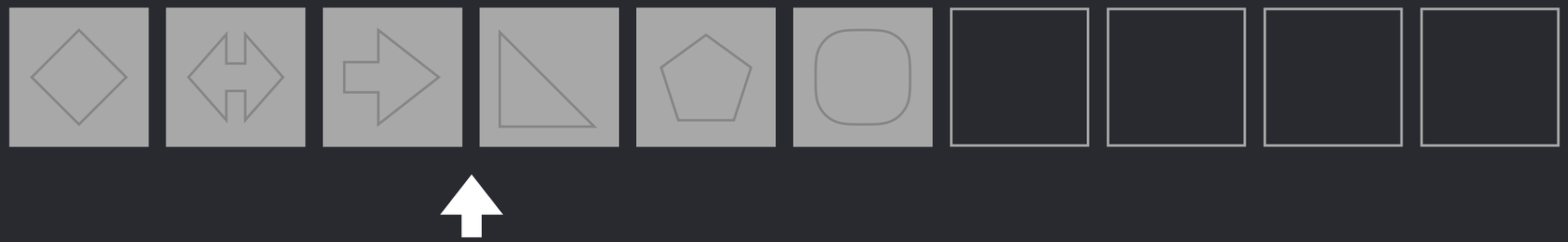

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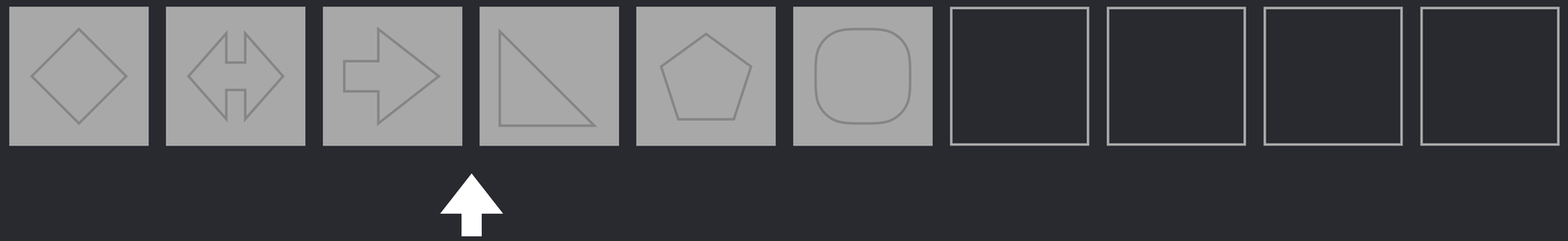

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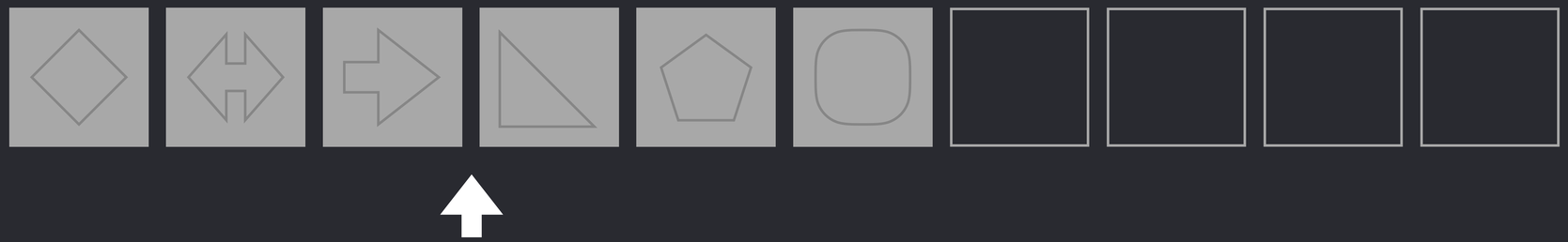

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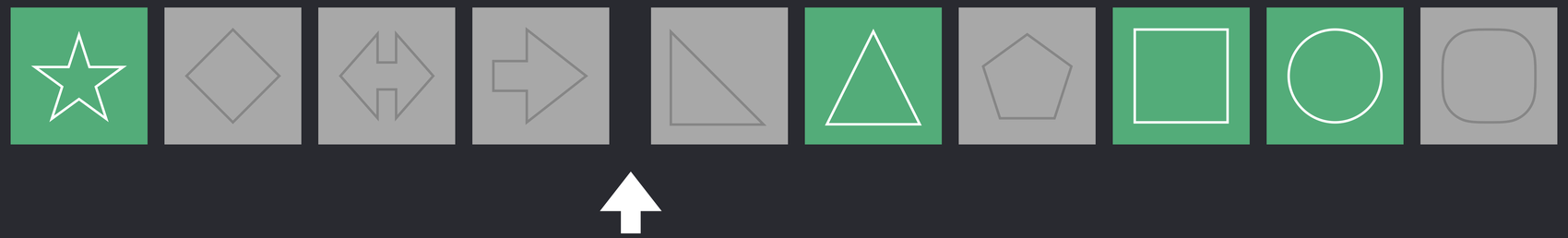

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extension MutableCollection {
    /// Gathers elements satisfying `predicate` at `target`, preserving their relative order.
    ///
    /// - Complexity: O(n log n) where n is the number of elements.
    mutating func gather(at target: Index, allSatisfying predicate: (Element)->Bool) {
        let start = self[..<target].stablePartition(isSuffixElement: predicate)
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Discover Generic Algorithms

“If you want to improve the code quality in your organization, replace all of your coding guidelines with one goal:

No Raw Loops”

Sean Parent, *C++ Seasoning*

More Information

Sean Parent, C++ Seasoning

https://channel9.msdn.com/Events/GoingNative/2013/Cpp-Seasoning

Alexander Stepanov and Paul McJones, Elements of Programming

https://www.youtube.com/watch?v=lh9gpJga4Vc

Swift Algorithms Prototype

https://github.com/apple/swift/blob/master/test/Prototypes/Algorithms.swift

Swift Standard Library Documentation

https://developer.apple.com/documentation/swift/swift_standard_library

More Information

https://developer.apple.com/wwdc18/223

Swift Generics	Hall 2	Wednesday 3:00PM


WWDC18