Designing Code for Performance

Choosing and using data structures effectively

Session 224

Quinn Taylor
Internal Applications Engineer

Introduction

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- Huge influx of new developers

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- Diverse backgrounds and experience

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- Data structures performance issues are universal

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- Huge influx of new developers
- Diverse backgrounds and experience
- Data structures performance issues are universal
- Puzzling unless you know what's going on under the hood

“Give a man a fish and you feed him for a day. Teach a man how to fish and you feed him for a lifetime.”

Chinese Proverb

What You Will Learn

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- When to focus on performance

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- How to evaluate computational complexity

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- When to focus on performance
- How to evaluate computational complexity
- How to choose and use data structures
- How to design your code for performance

When to Focus on Performance

“We don’t get a chance to do that many things, and every one should be really excellent. …[W]e’ve all chosen to do this with our lives. So it better be damn good. It better be worth it.”

Steve Jobs (2008)

“You have to pick carefully. Innovation is saying no to 1,000 things.”

Steve Jobs (1997)

Premature optimization is the root of all evil.

Donald Knuth (1974)

“We should forget about small efficiencies ... about 97% of the time. Premature optimization is the root of all evil. Yet we should not pass up our opportunities in that critical 3%.”

Donald Knuth (1974)

“Optimize performance when it will make a meaningful difference.”

Me (just now)

Picking Your Battles

Amdahl's Law

Picking Your Battles

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- Maximum improvement from speeding up code
  - Depends on percentage of execution time
  - Payoff is bigger for dominant pieces

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Amdahl's Law

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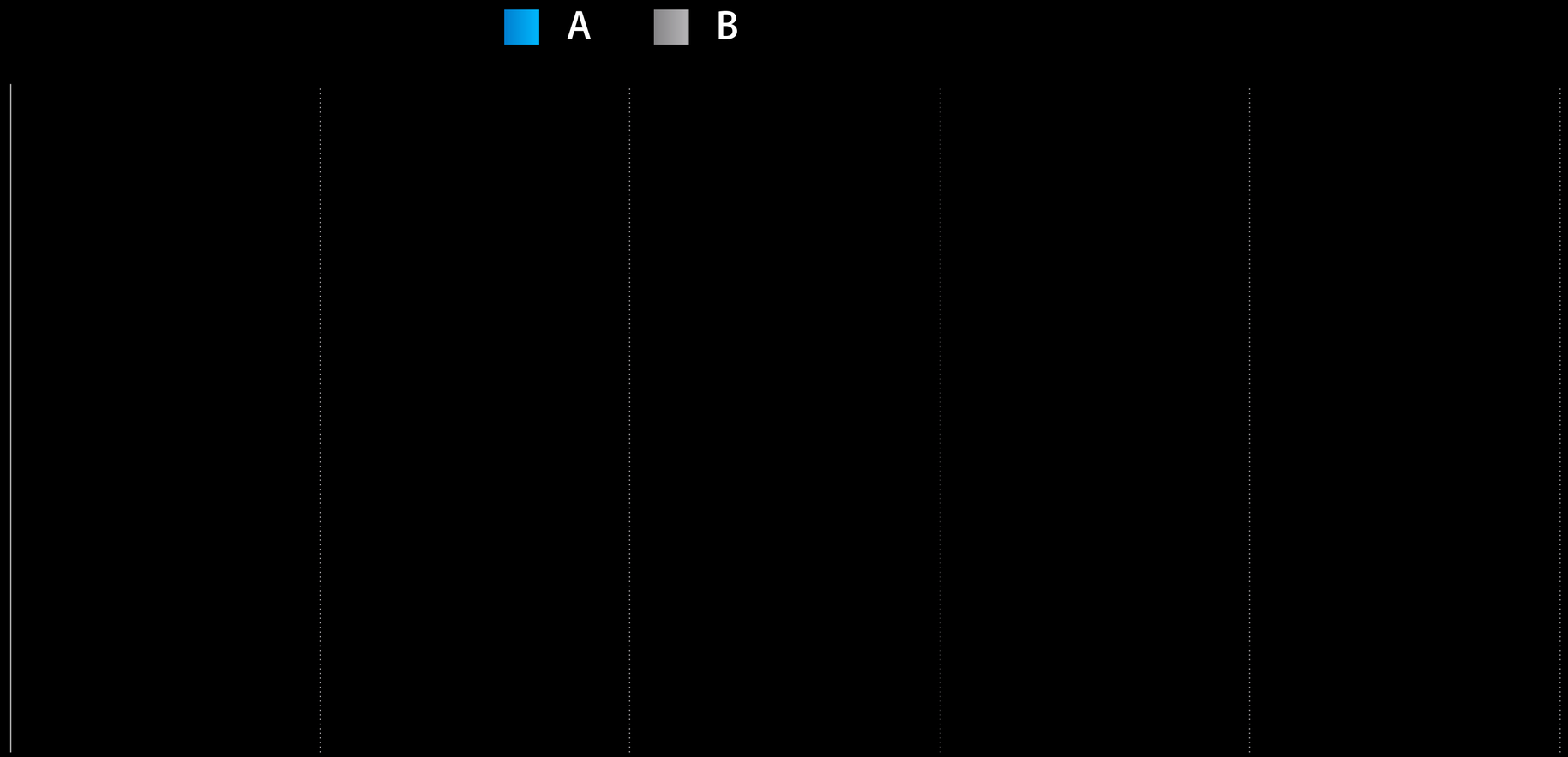
  - Depends on percentage of execution time
  - Payoff is bigger for dominant pieces
- Will the payoff be worth the effort?
- Applies directly to concurrency

Picking Your Battles

Amdahl's Law example

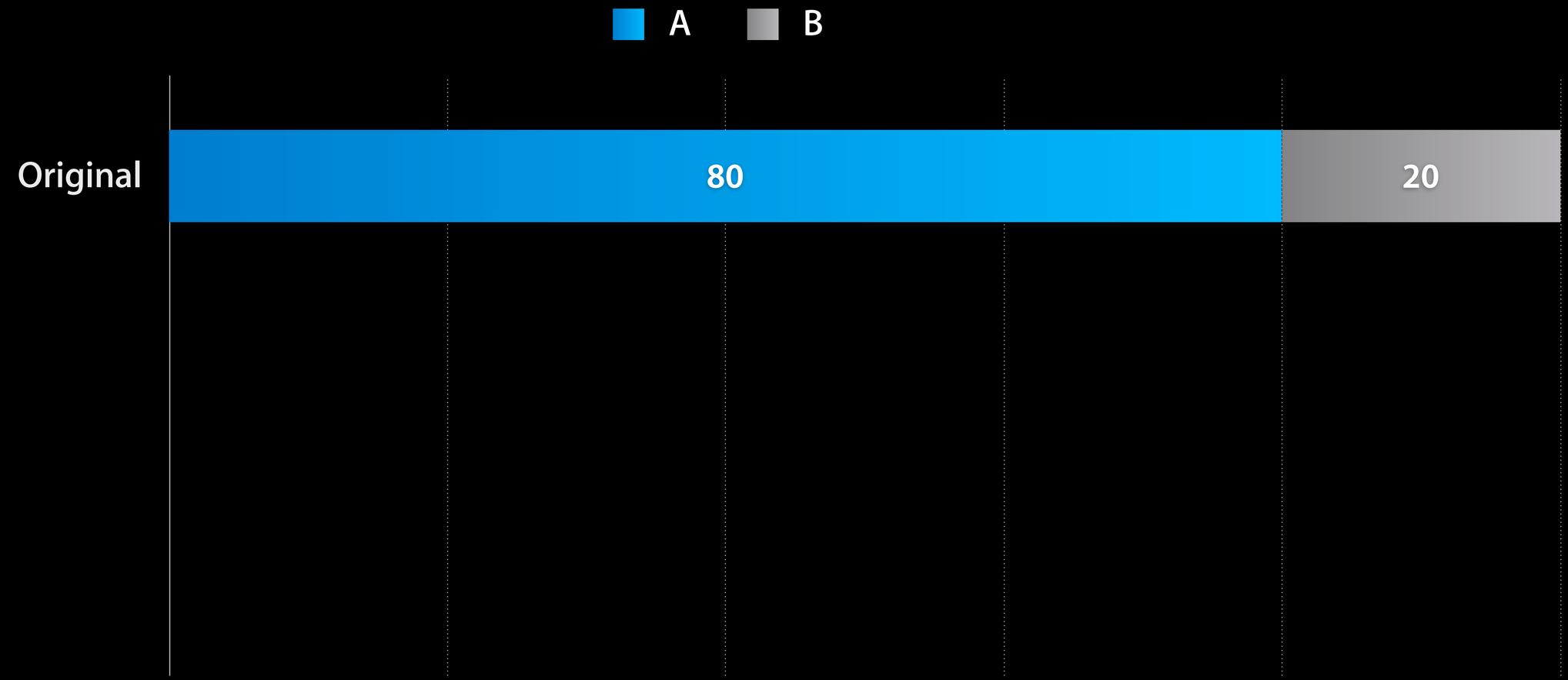
Picking Your Battles

Amdahl's Law example



Picking Your Battles

Amdahl's Law example



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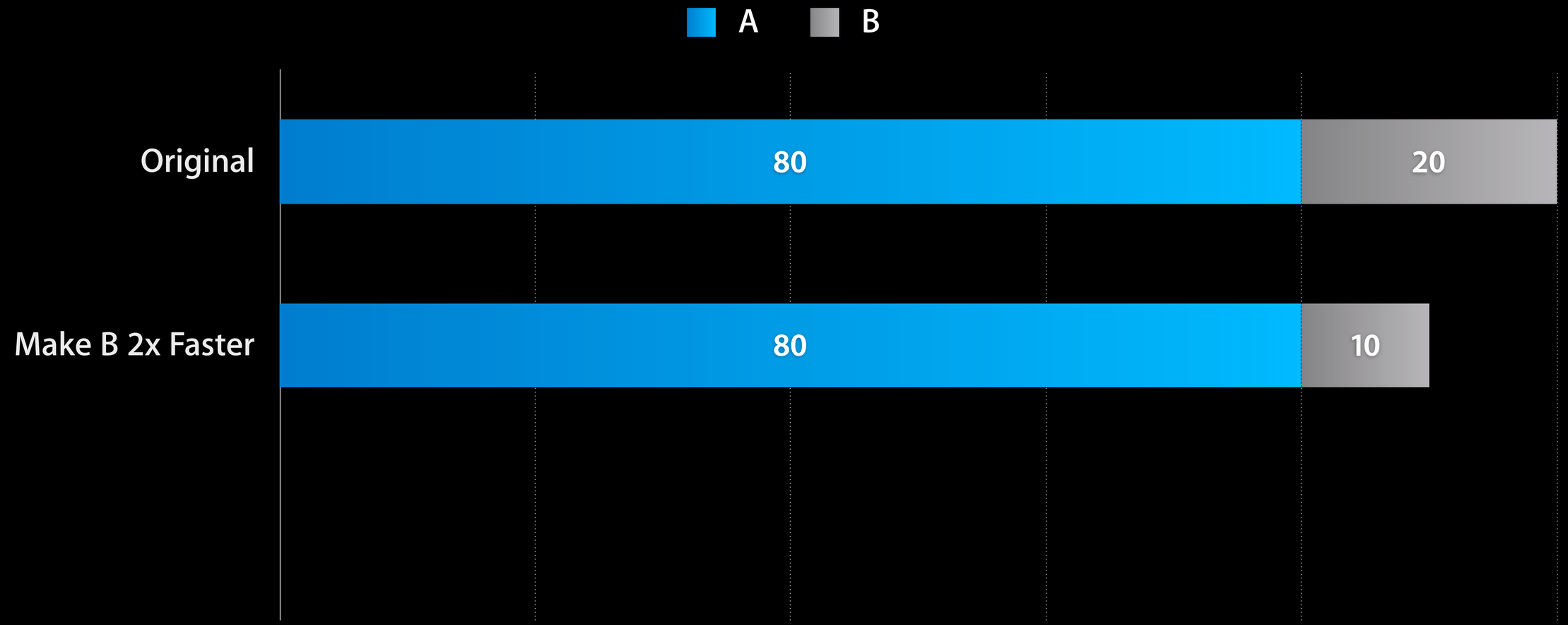

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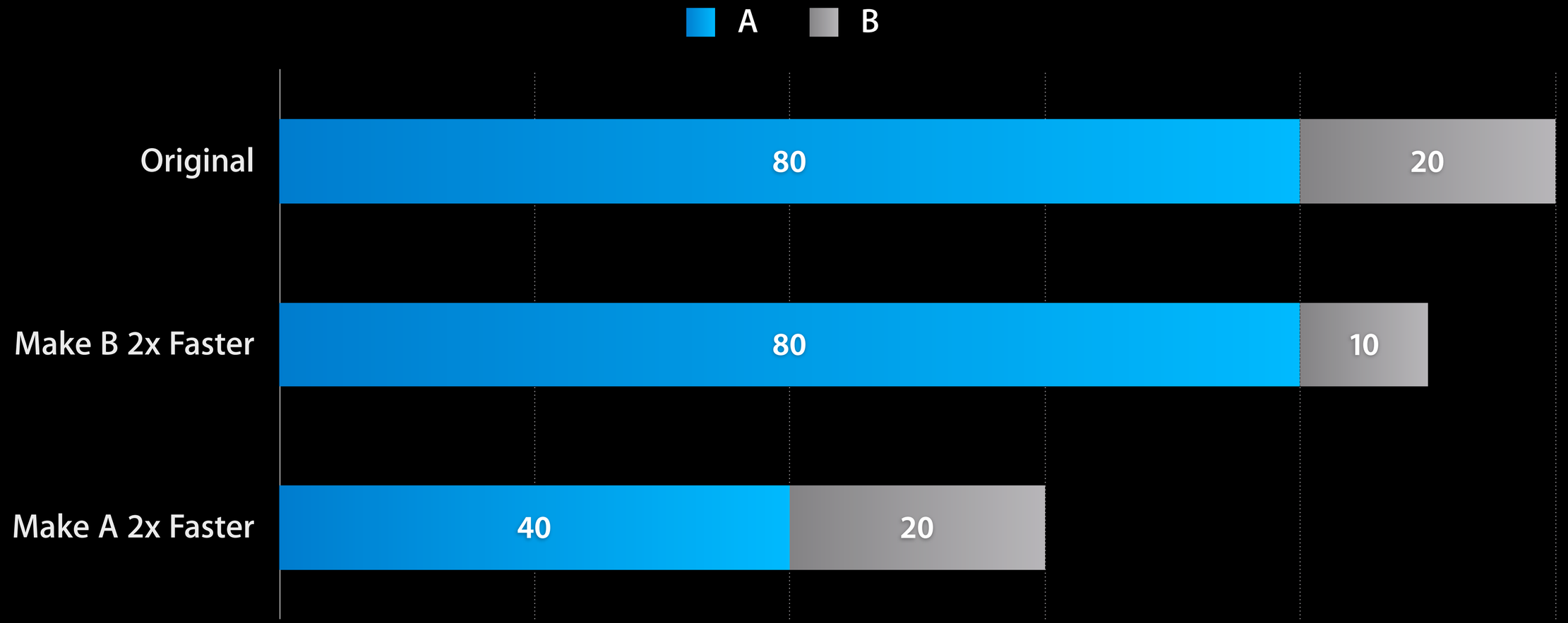

Premature Optimization vs. Informed Design

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- Premature optimization leads to unnecessary complexity
  - “If it ain’t broke, don’t fix it.”
  - Use Instruments to focus on bottlenecks

Premature Optimization vs. Informed Design

- Premature optimization leads to unnecessary complexity
  - "If it ain't broke, don't fix it."
  - Use Instruments to focus on bottlenecks
- Informed design leads to elegant, efficient code
  - Consider performance during design
  - Intelligently avoid real performance pitfalls
  - Why design in slowness you can easily avoid?

How to Design for Performance

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- Resolving a performance issue
  - Don’t do it
  - Do it as rarely as possible
  - Do it as efficiently as possible

How to Design for Performance

- Resolving a performance issue
  - Don’t do it
  - Do it as rarely as possible
  - Do it as efficiently as possible
- Improvement requires context
  - Is this work necessary?
  - Is redundant work being done?
  - Is there a more efficient way?

How do I know if I can do better?

Computational Complexity and Cost

The Cost of Code

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The Cost of Code

- Code takes time to run
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  - Short code may be work-intensive
- Effects of data growth can vary dramatically
  - Work may grow disproportionately
  - Small tests won’t reveal scaling problems
- Can be analyzed even without running code
  - Understanding algorithm complexity is key
  - Computer Science has entire courses about this

Complexity and “Big O” Notation

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  - Ignore coefficients and lower-order terms (e.g. $6n^2+3n+2 \approx n^2$)
  - Ignore logarithm bases (e.g. $\log_{10} n \approx \log_2 n \approx \log n$)
- For any given task, there are inherent limits
  - Some things just take time

“Nine women can’t
make a baby in one month.”

Fred Brooks — *“The Mythical Man-Month”* (1975)

“Big O” Complexity

Order functions

“Big O” Complexity

Order functions

Notation	Name	Examples
O(1)	constant time	simple expressions, indexed/hashed lookup
O(log n)	logarithmic time	search of sorted data
O(n)	linear time	search of unsorted data, enumeration, “for each” loop
O(n log n)	log-linear time	efficient sorting algorithms
$O(n^2)$	quadratic time	nested iteration of data
$O(c^n)$	exponential time	combinatorial explosion, high-dimensional data

“Big O” Complexity

Order functions

- Some are much more common

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Order functions comparison

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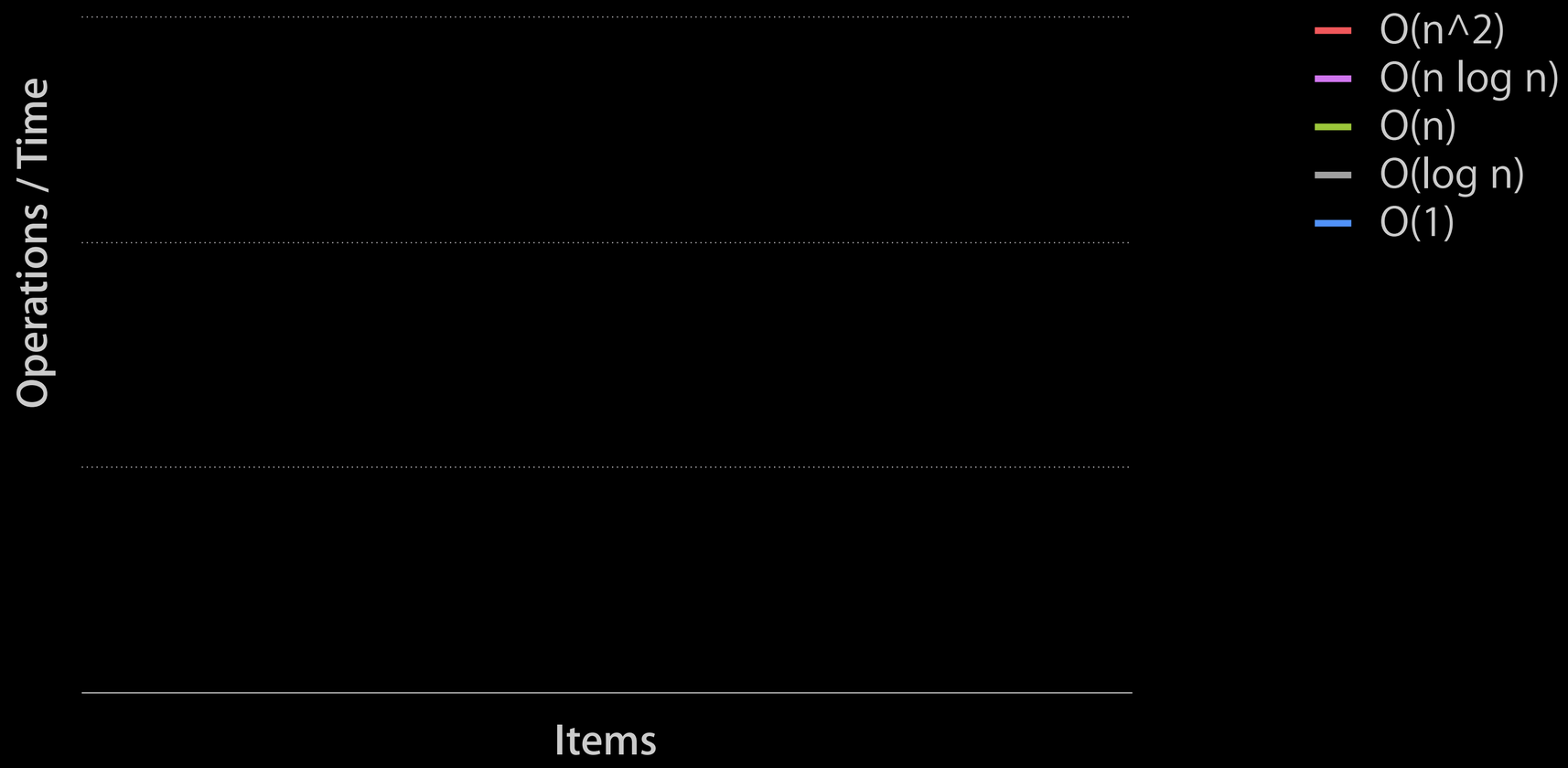

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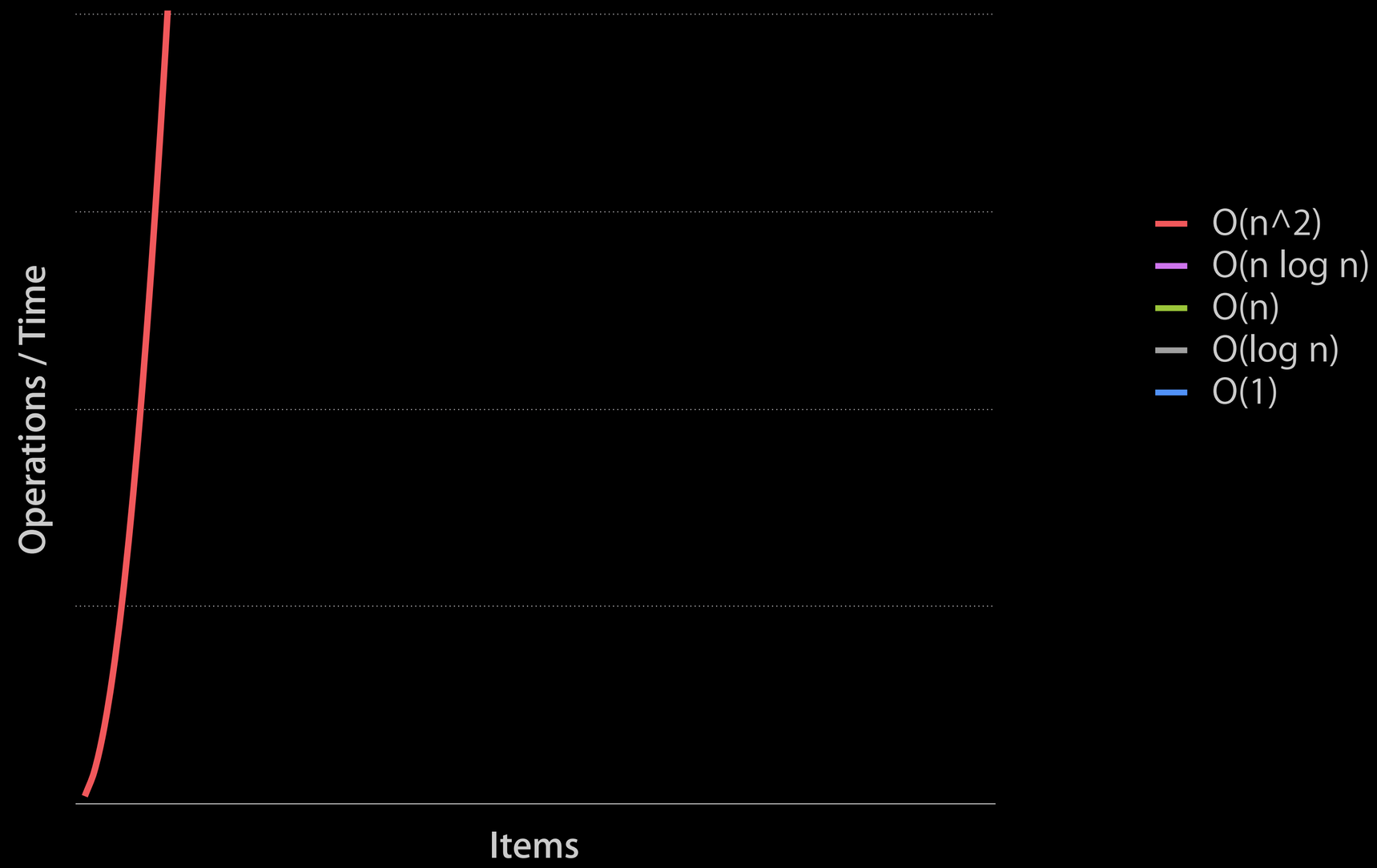

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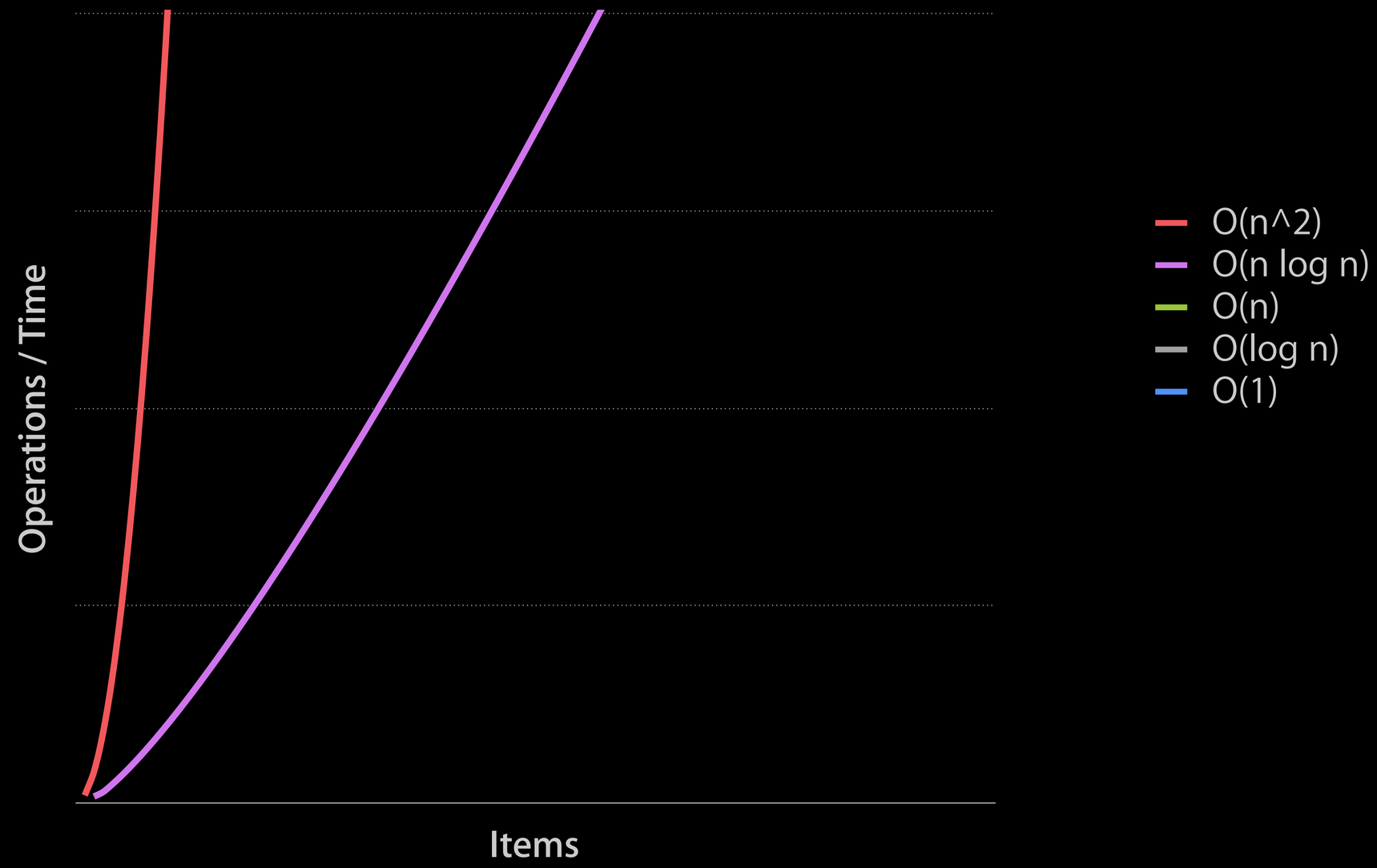

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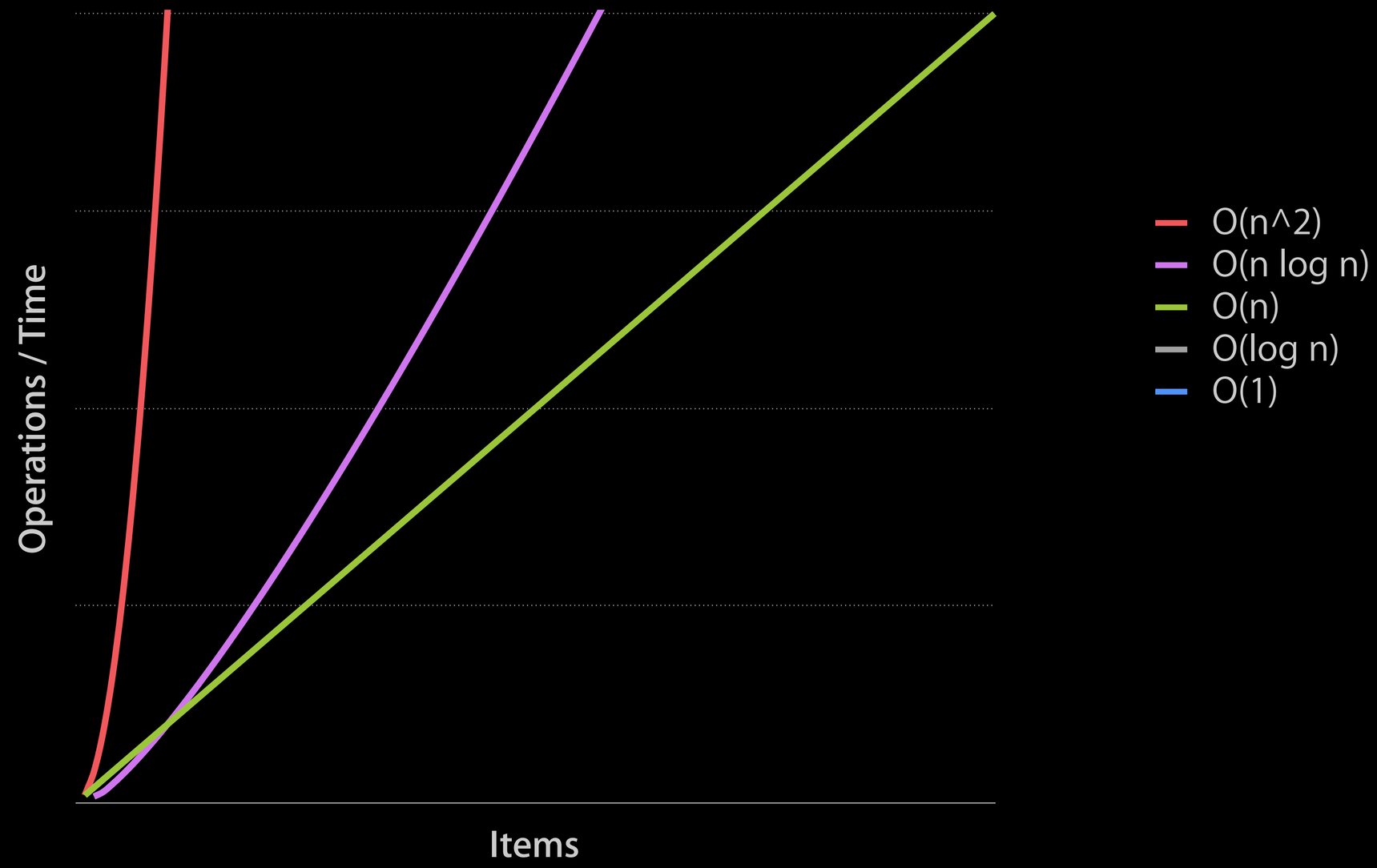

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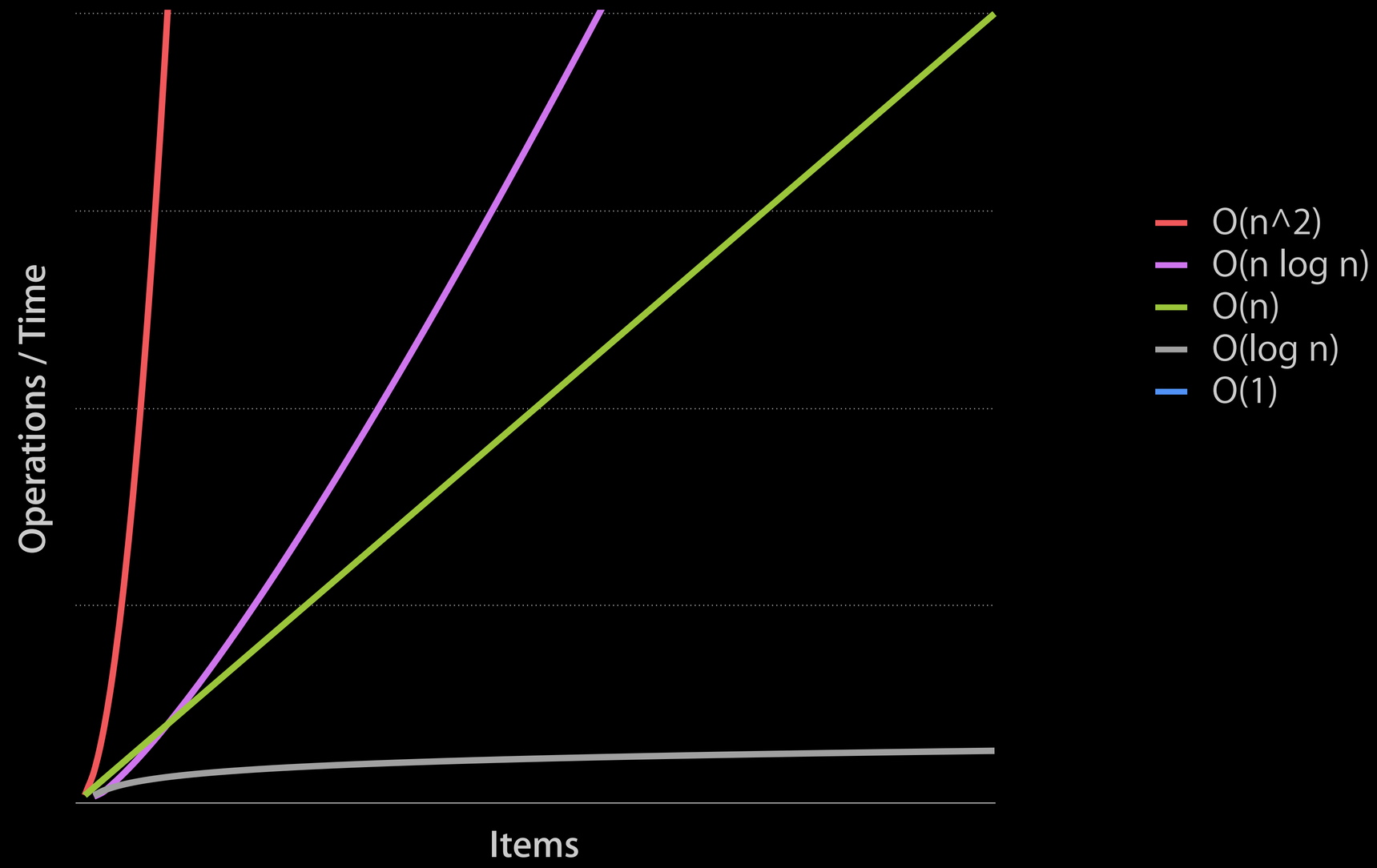

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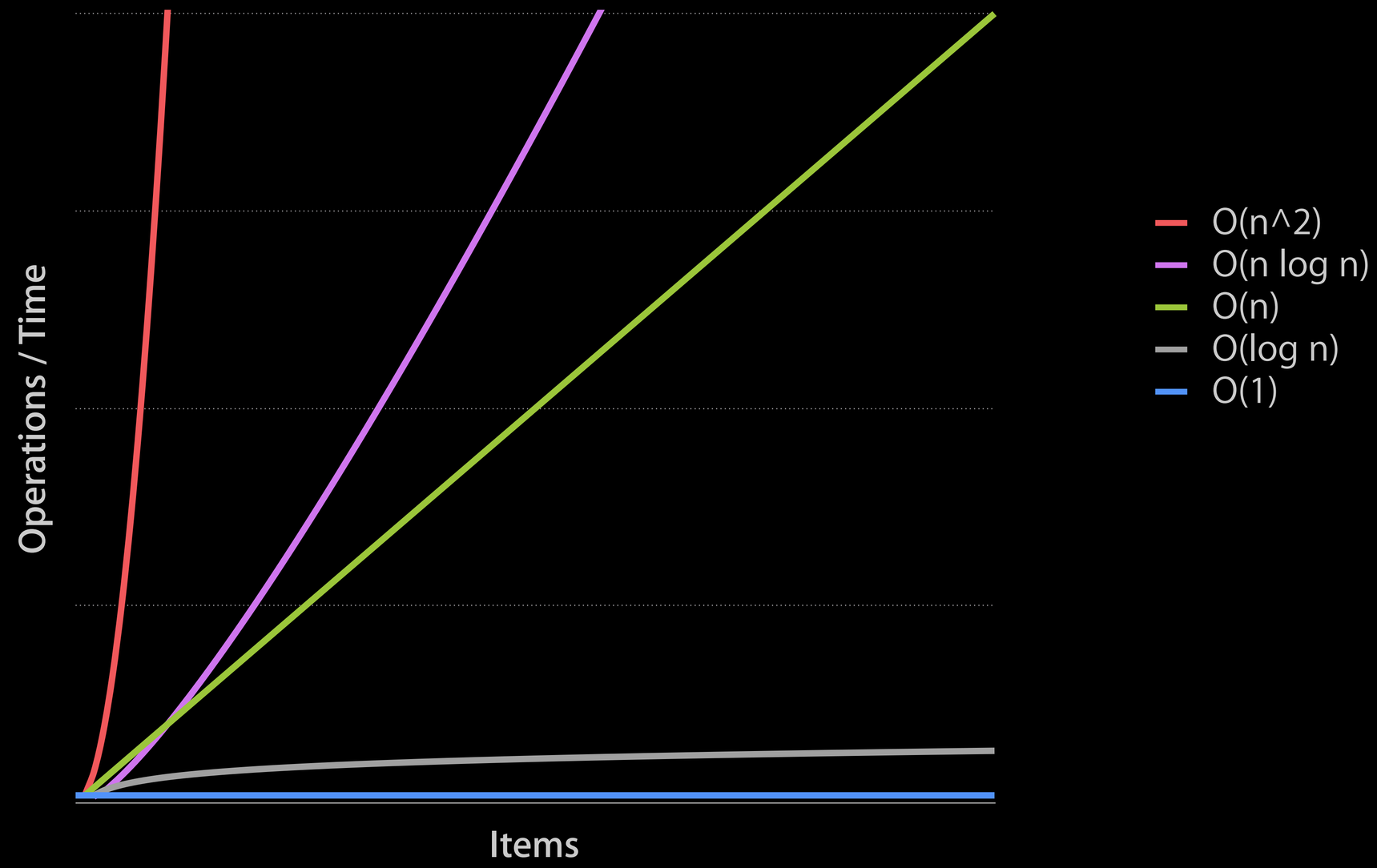

“Big O” Complexity

Examples

- Determine complexity from source code
- Growth of work with size is key

“Big O” Complexity

Example: O(1)

```
BOOL ContainsValueAtIndex(int[] array, int count, int value, int idx) {
    return (idx < count && array[idx] == value);
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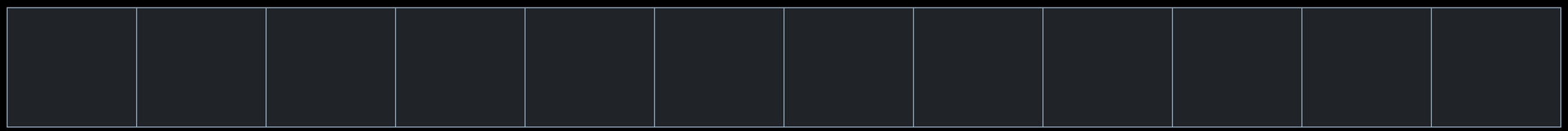

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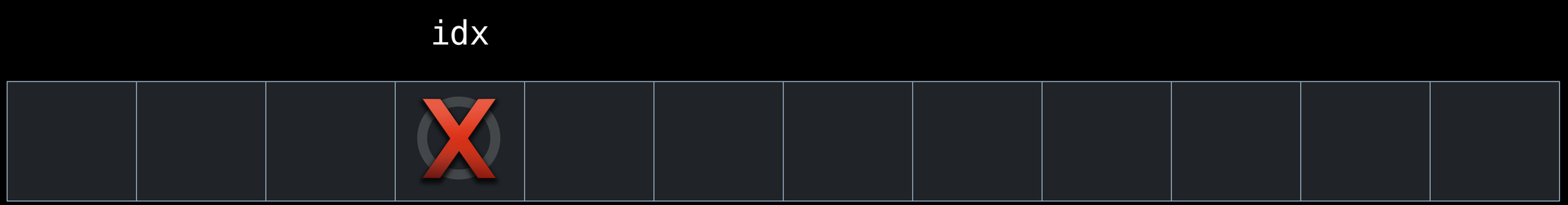

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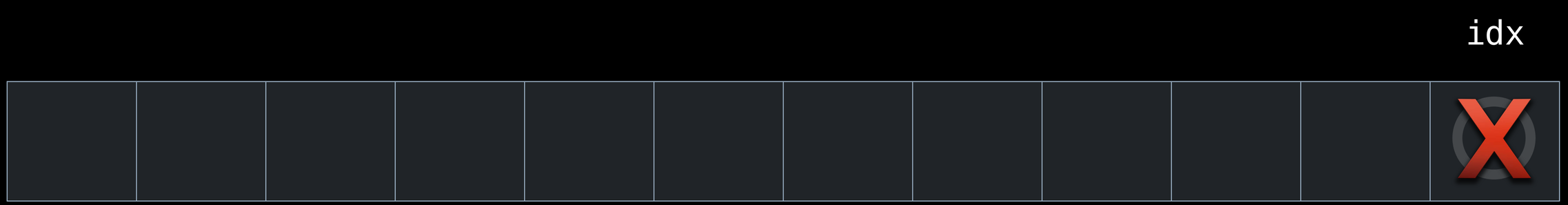

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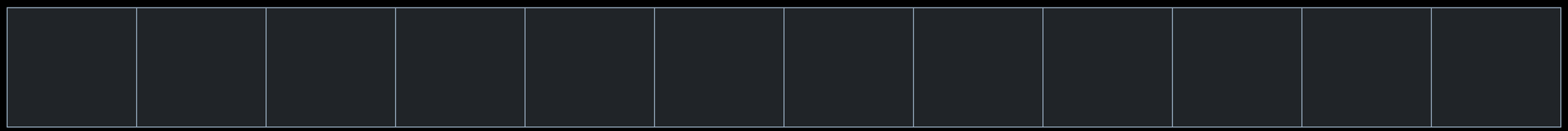
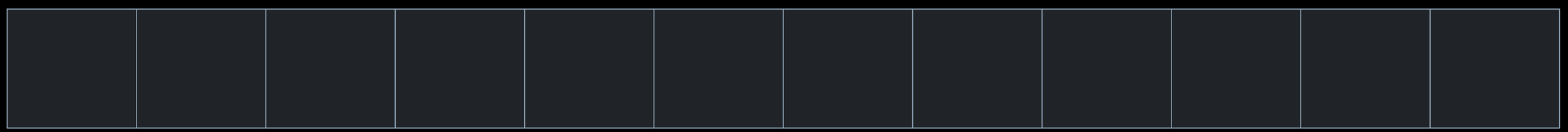


“Big O” Complexity

Example: O(n)

```
BOOL ContainsValue(int[] array, int count, int value) {
    for (int i = 0; i < count; i++) {      // O(n)
        if (array[i] == value) {
            return YES;
        }
    }
    return NO;
}
```



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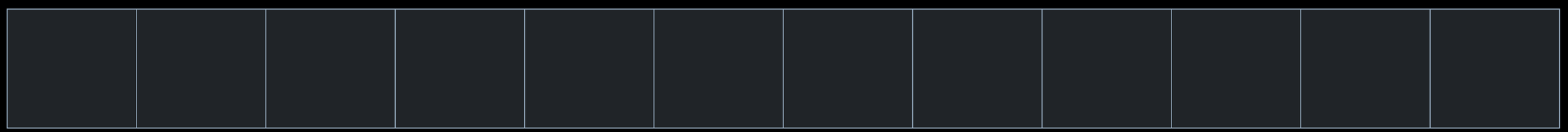
“Big O” Complexity

Example: $O(n^2)$

```
BOOL ContainsDuplicateValues(int[] array, int count) {
    for (int i = 0; i < count; i++) {       // O(n)
        for (int j = 0; j < count; j++) {   // O(n)
            if (i != j && array[i] == array[j]) {
                return YES;
            }
        }
    }
    return NO;
}
```



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            }
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```
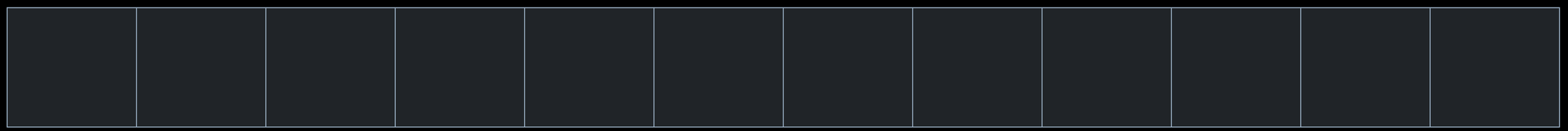

i

j



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Calculating Complexity

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- Order functions can be combined
  - Multiply nested complexities
  - Add sequential complexities

Calculating Complexity

- Order functions can be combined
  - Multiply nested complexities
  - Add sequential complexities
- This function reduces to $O(n^2)$

```
void AnalyzeArray(int[] array, int count) {
    ContainsDuplicateValues(array, count);    // O(n^2)
    ContainsValue(array, count, 0);           // O(n)
    ContainsValue(array, count, 1);           // O(n)
    ContainsValueAtIndex(array, count, 1, 0); // O(1)
    ContainsValueAtIndex(array, count, 0, 1); // O(1)
    ContainsValueAtIndex(array, count, 1, 1); // O(1)
}
```

Estimating Complexity

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- When you don’t know, estimate
  - Consider what the code does
  - Profile with Instruments

Estimating Complexity

- When you don’t know, estimate
  - Consider what the code does
  - Profile with Instruments
- Some APIs appear similar, but don’t assume
  - For example, `-containsObject:` on NSArray and NSSet

Estimating Complexity

Reading between the lines

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- Consider `-[NSArray containsObject:]`
  - What does it do?
  - Documentation says it sends `-isEqual:` to each object

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Reading between the lines

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- This sounds like O(n)
- Concurrency would only reduce by some factor

Estimating Complexity

Jumping to the wrong conclusion

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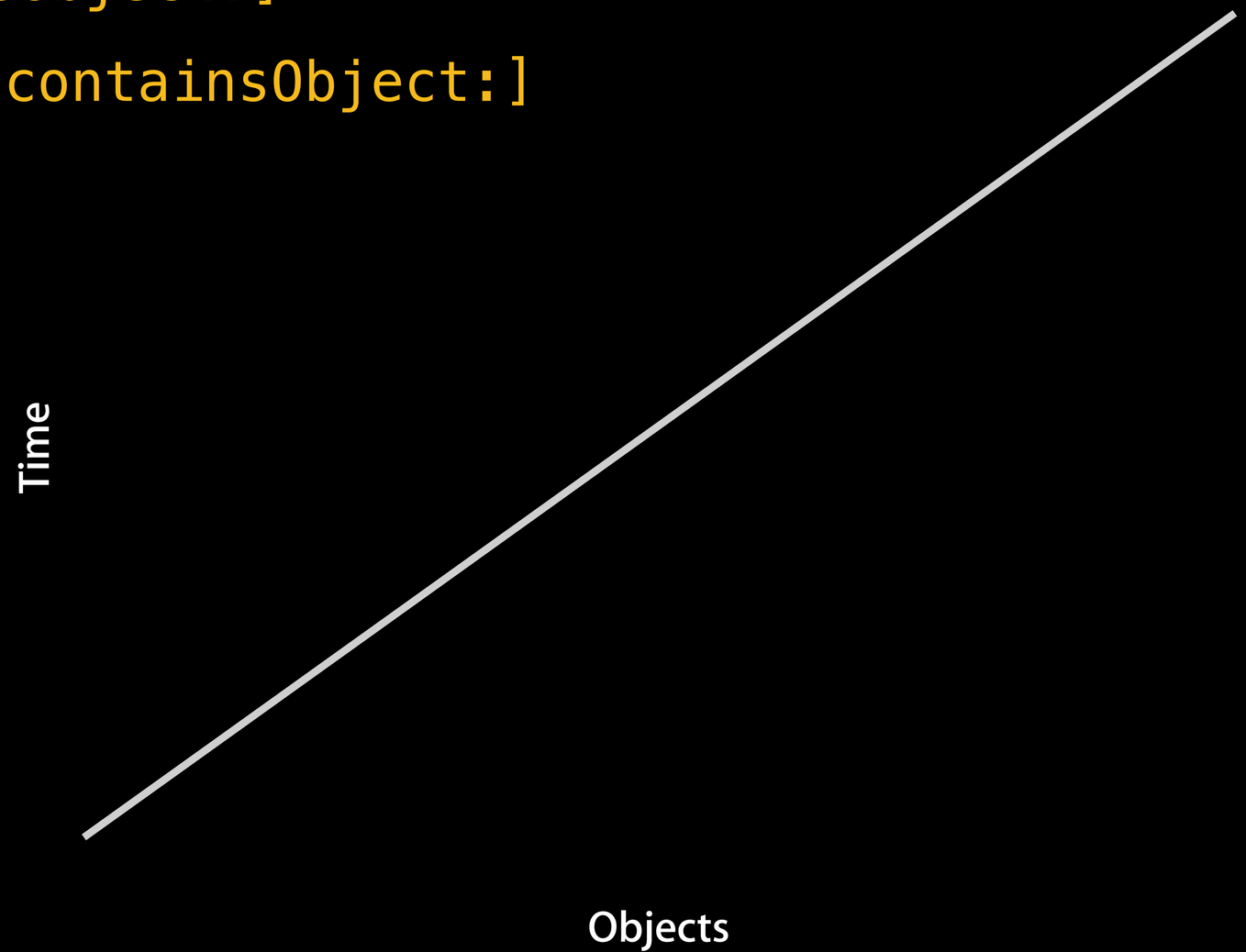

Estimating Complexity

Jumping to the wrong conclusion

- Consider `–[NSSet containsObject:]`
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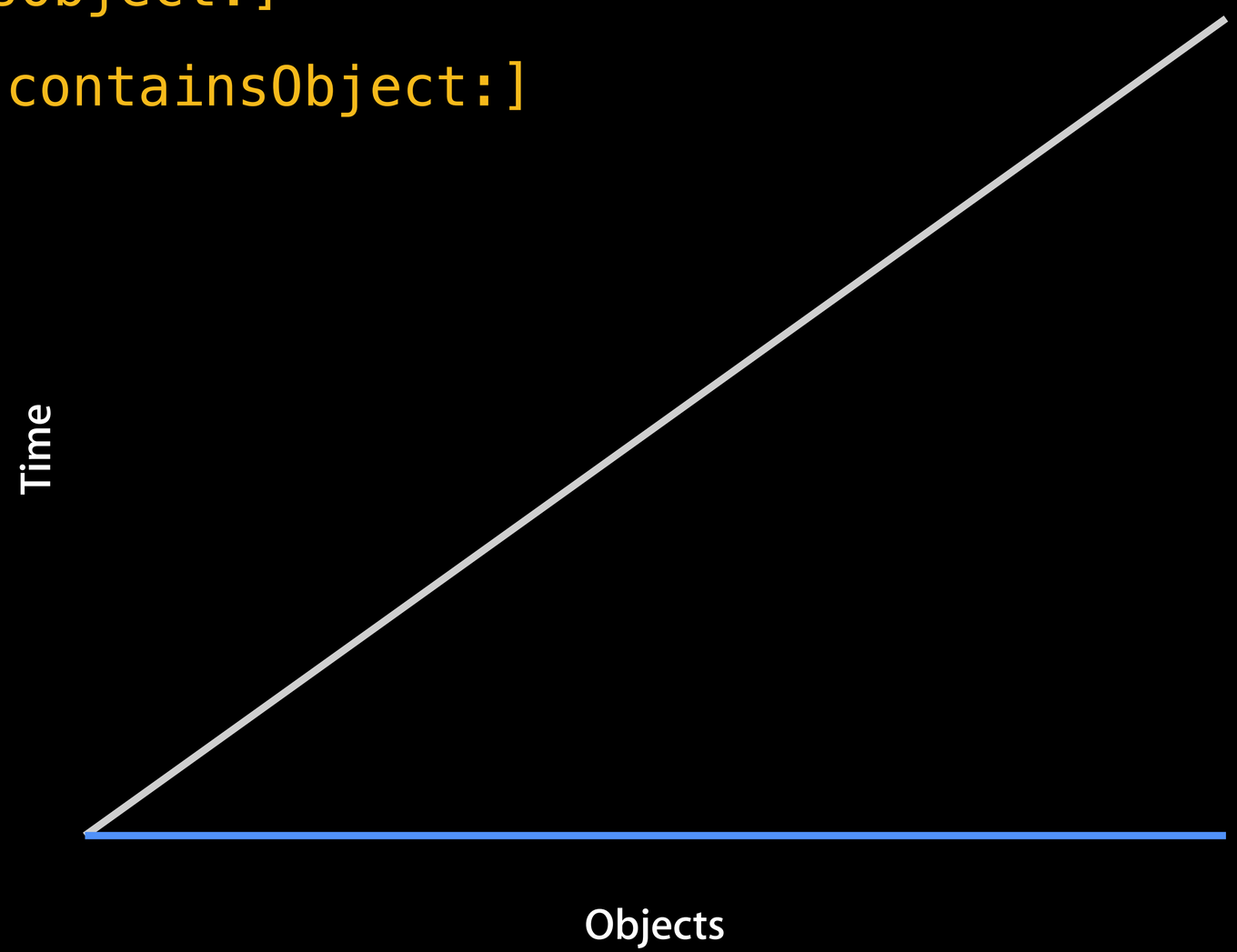
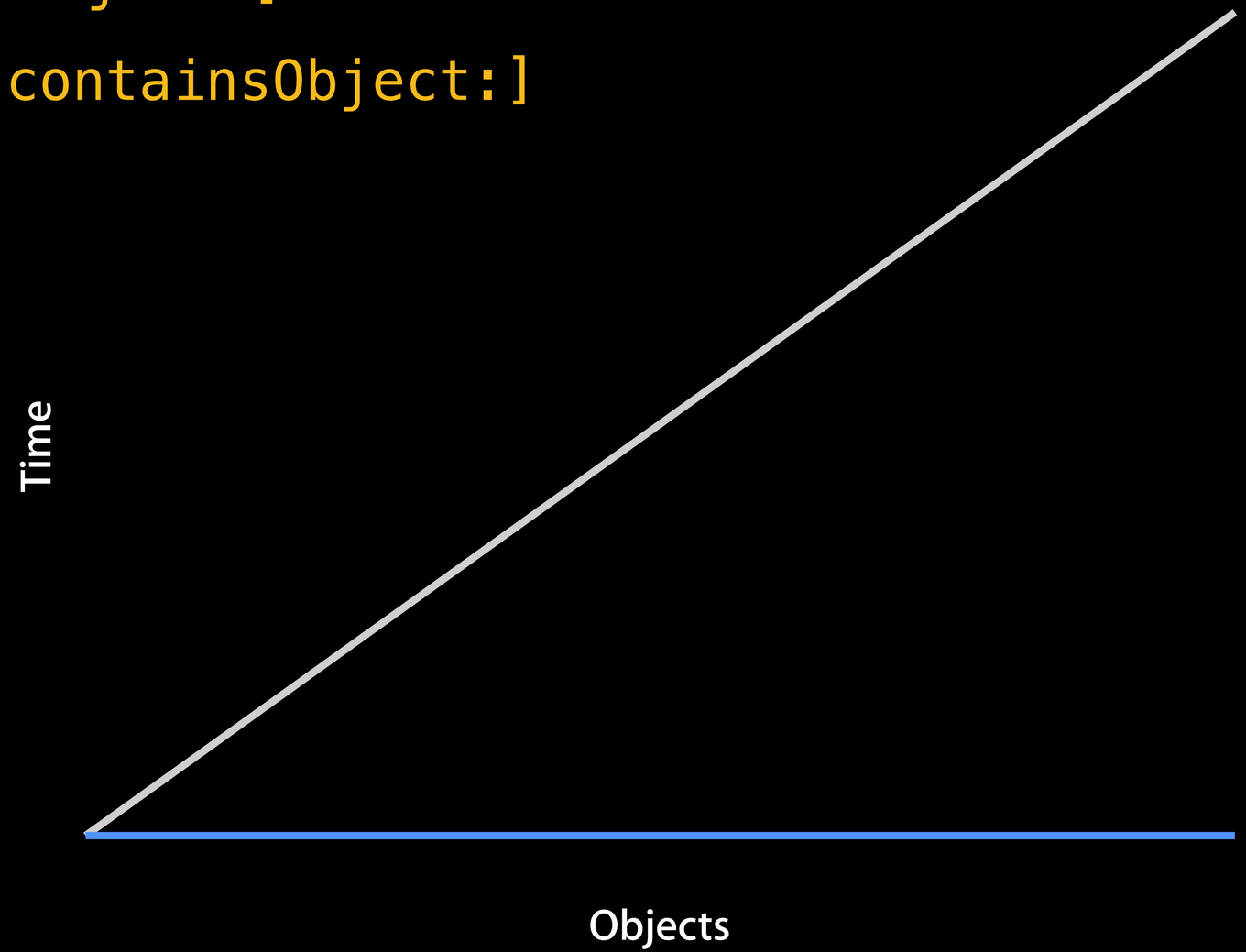
- Is it also O(n)?
- It's actually O(1)



Estimating Complexity

Jumping to the wrong conclusion

- Consider `-[NSSet containsObject:]`
- It looks just like `-[NSArray containsObject:]`
- Is it also O(n)?
- It's actually O(1)
- It must do less work



Hash-Based Organization

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  - `–hash` returns an NSUInteger
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- Objects are grouped in “buckets”
  - A hash function maps hashes to buckets
  - Goal is uniform distribution
- Lookup only considers objects in one bucket
  - Check `–isEqual:` for very few objects (or none)

Hash-Based Organization

Hash Function

Buckets

0	
1	
2	
3	
4	
5	

Hash-Based Organization

@"Tim Cook"

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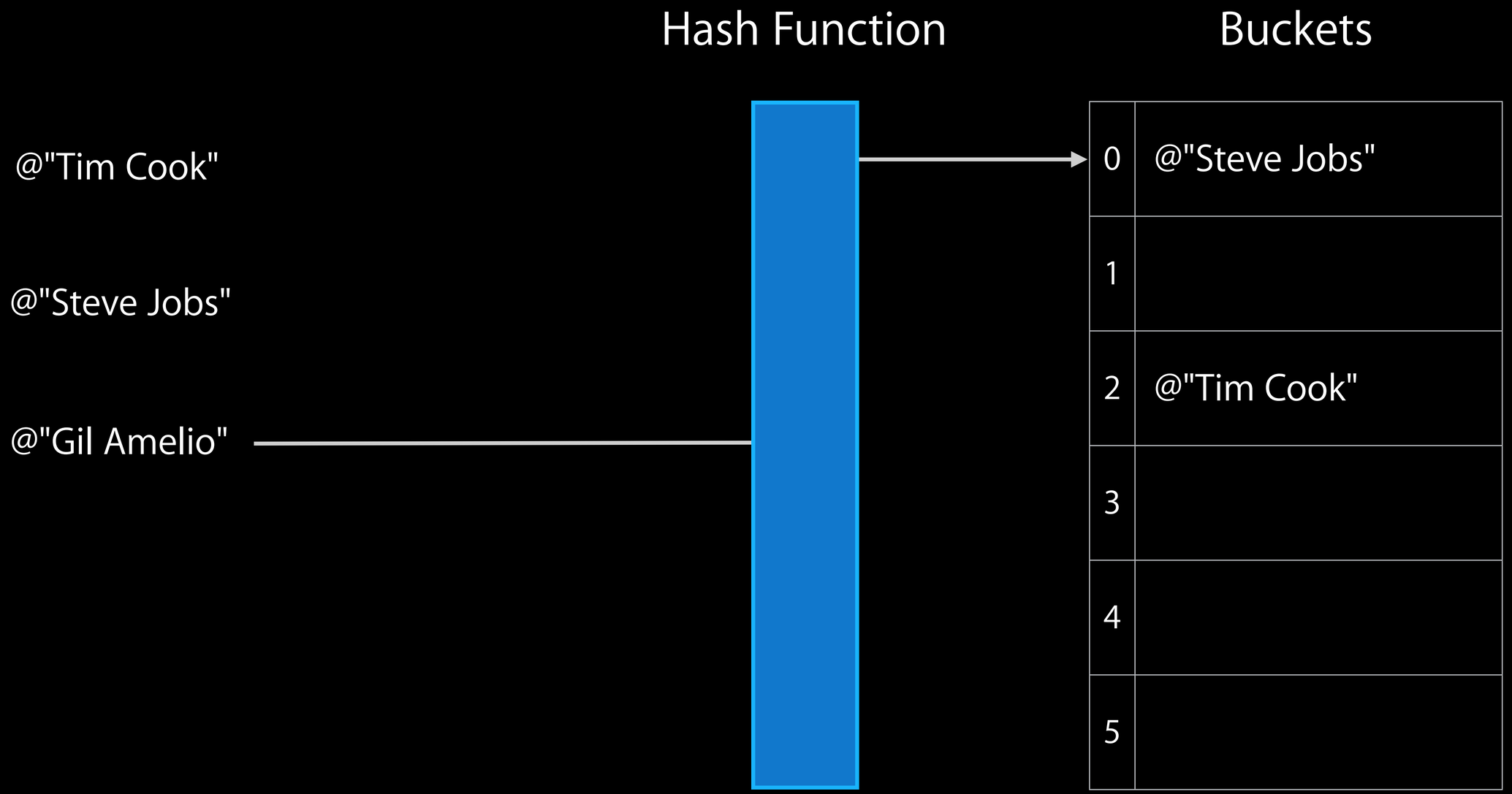

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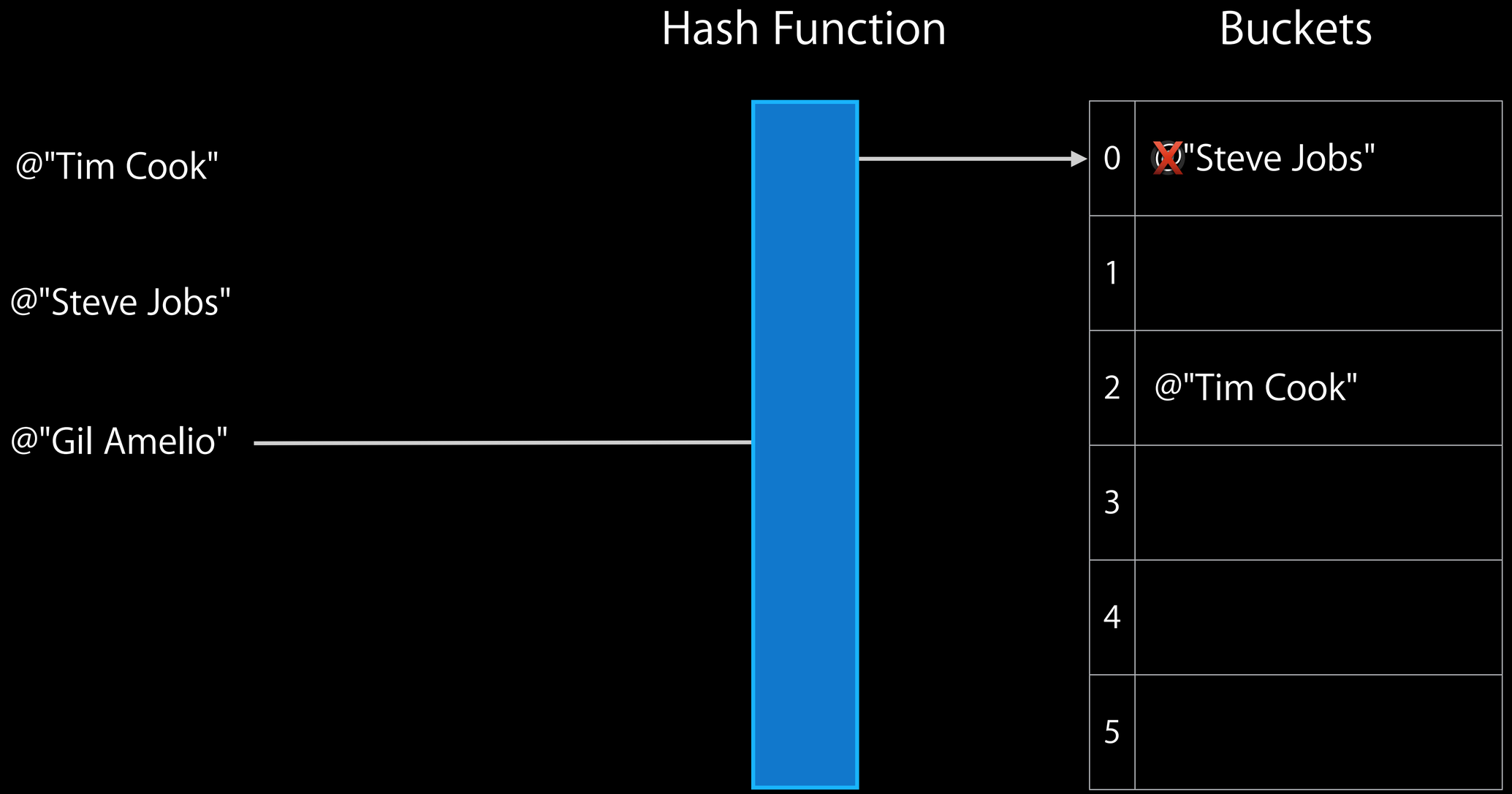

Hash-Based Organization

@"Tim Cook"

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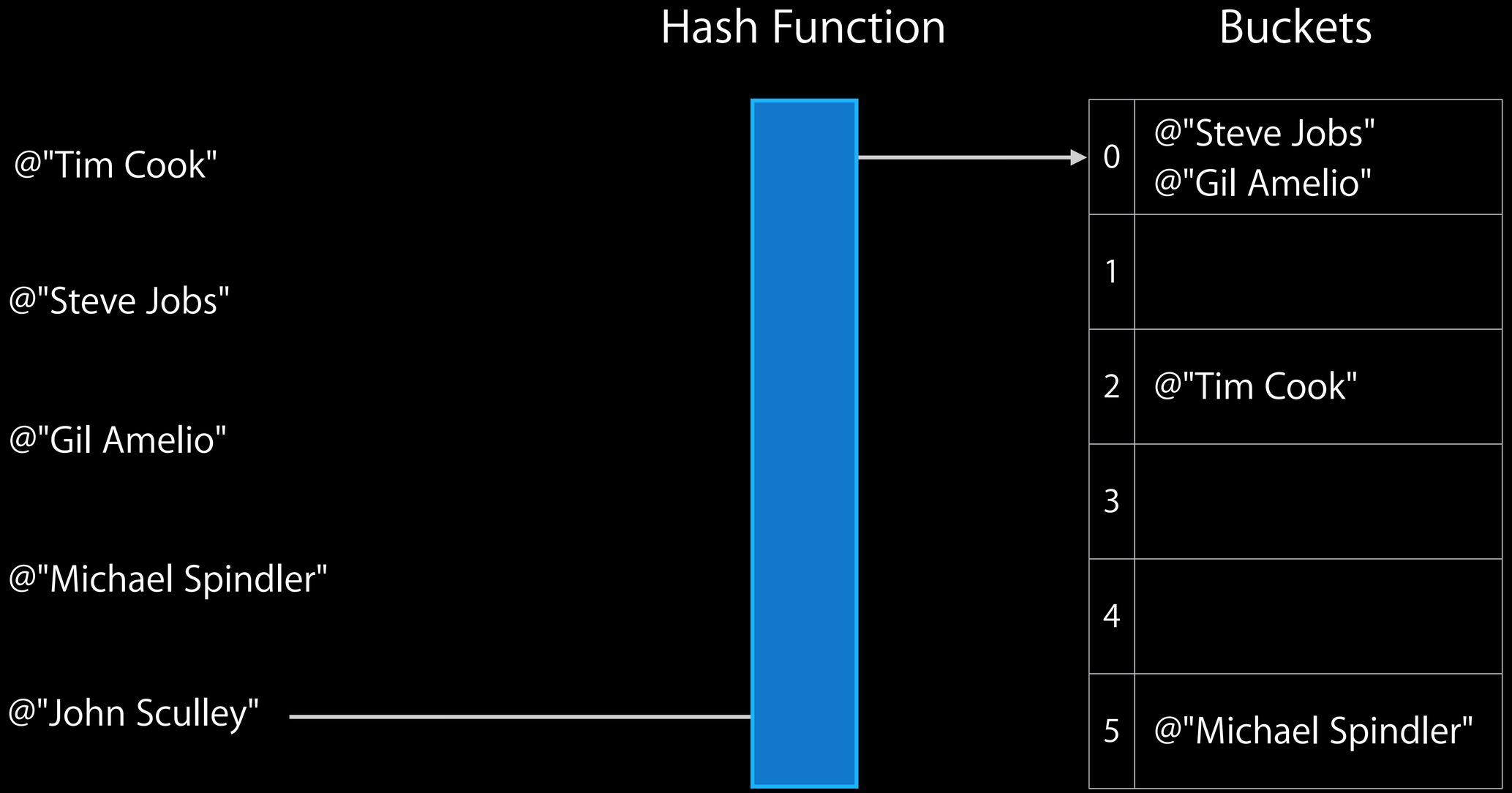

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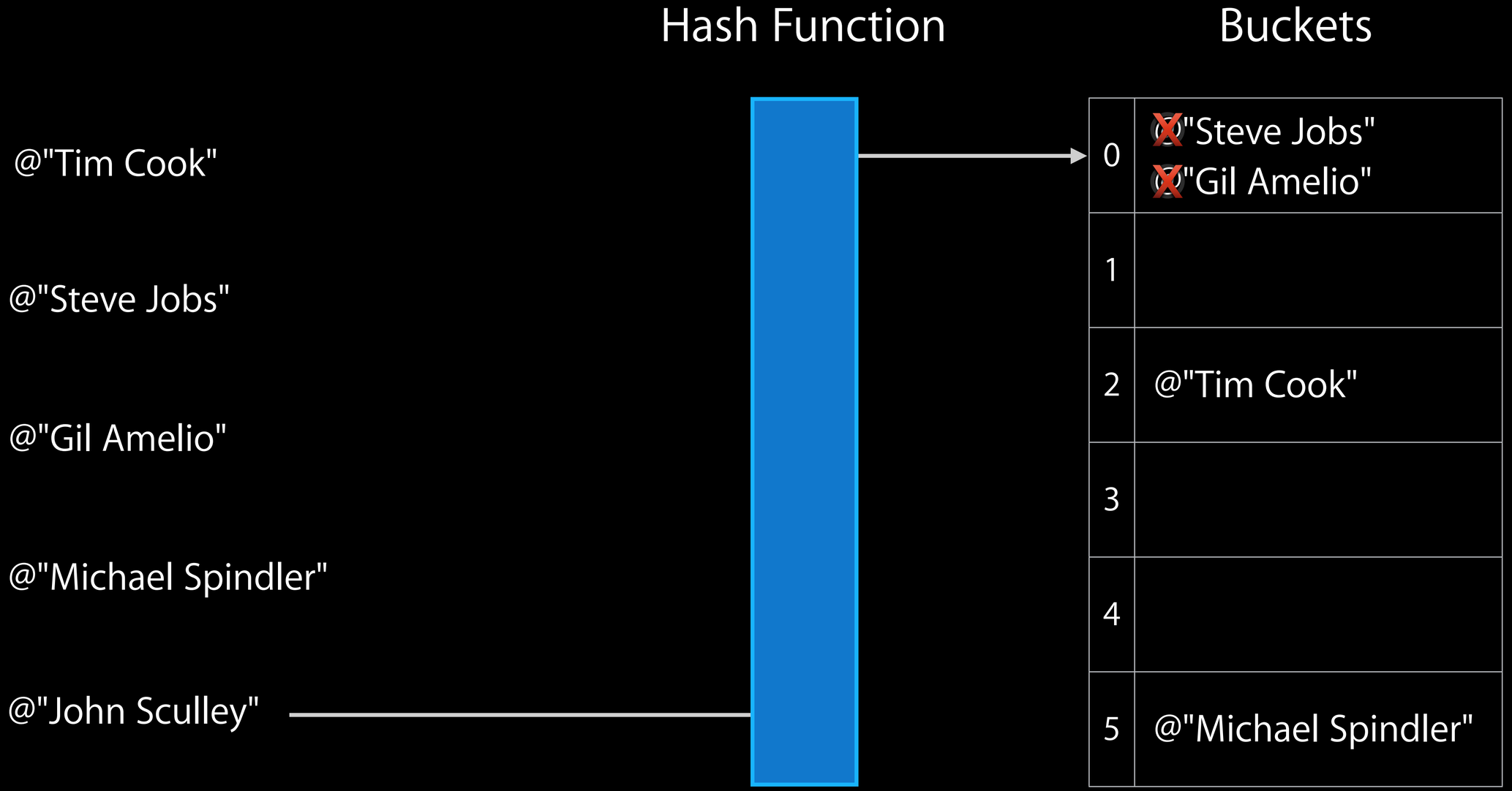

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@”Bill Gates”?

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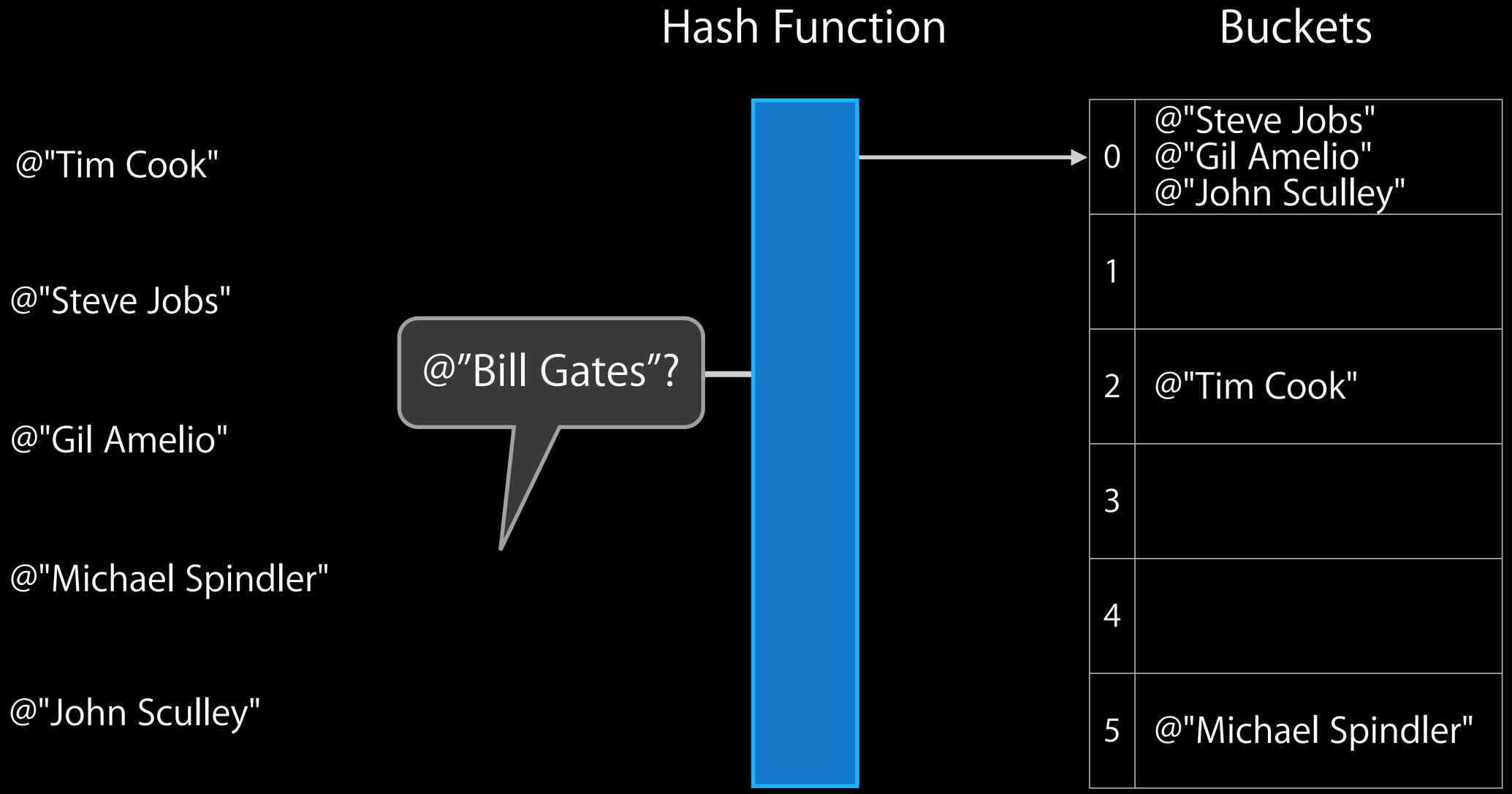

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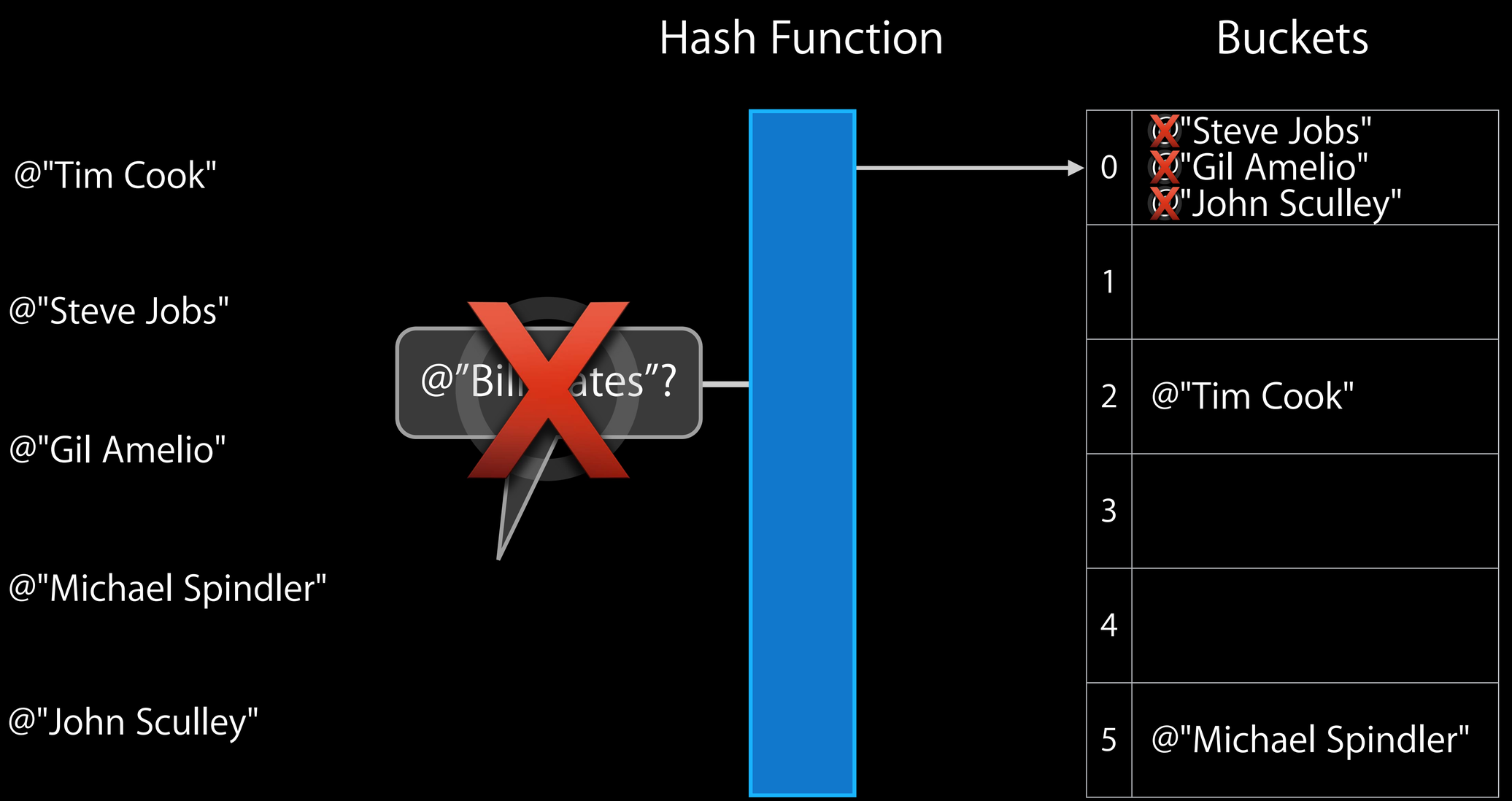

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2	@"Steve Jobs"
3	@"Michael Spindler"
4	@"Tim Cook"
5	@"Gil Amelio"

Hash-Based Organization

Define your identity

Hash-Based Organization

Define your identity

- NSObject's `-isEqual:` and `-hash` are functionally equivalent to:

```
- (BOOL) isEqual:(id)other
{
    return self == other;
}

- (NSUInteger) hash
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- http://developer.apple.com/documentation/General/Conceptual/DevPedia-CocoaCore/ObjectComparison.html

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Rules of the road

- If `-isEqual:` returns true, `-hash` must be equal for both objects
  - The same hash value does not imply equality
- If you define `-isEqual:`, also define `-hash`
- A good hash should minimize collisions
  - Poor hashes will degrade performance
- Hash lookup + unpredictable hash = disaster
  - Option 1: Don't modify object in a collection
  - Option 2: Don't base hash on mutable state

Hash-Based Organization

Sample implementation

```
@interface WWDCNews : NSObject <NSCopying>
@property (readonly, copy) NSString *title;
@property (readonly, copy) NSDate *timestamp;
@end

@implementation WWDCNews
- (NSUInteger) hash {
    return [self.title hash];
}

- (BOOL) isEqual:(id)object {
    return ([object isKindOfClass:[WWDCNews class]]
         && [self.title isEqual:[object title]]
         && [self.timestamp isEqual:[object timestamp]]);
}
...
@end
```

Hash-Based Organization

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Data Structures Performance

Example: Organizing Books

Choosing a strategy

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- Sort by topic, author, title, size, color, etc.

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  - Use one that best fits your needs

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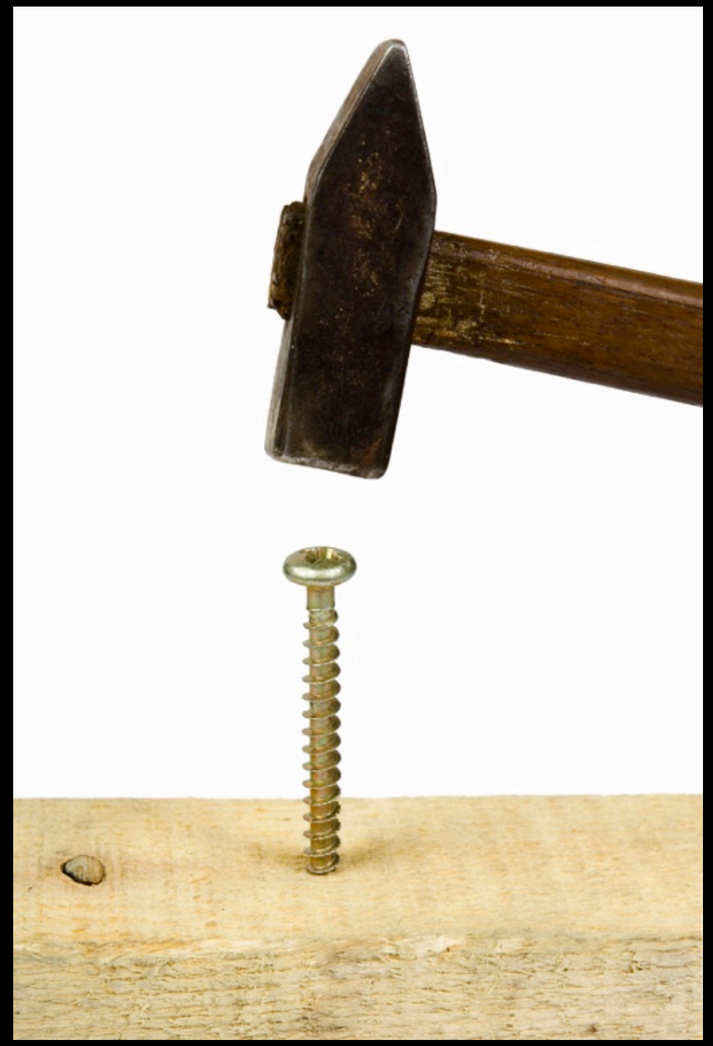
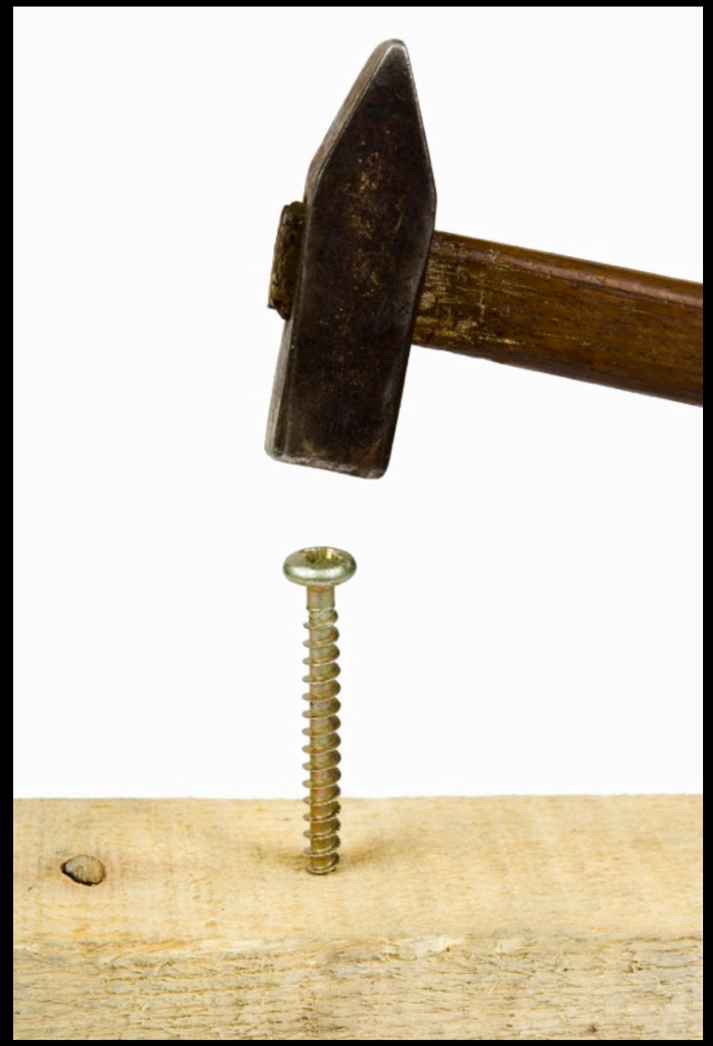
- A bad fit hurts performance
  - The wrong tool
  - The wrong approach



Data Structures Performance

Choosing a strategy

- All data structures have tradeoffs
  - Use one that best fits your needs
- A bad fit hurts performance
  - The wrong tool
  - The wrong approach
- Always prefer to use the built-in API
  - Extensively tested and optimized
  - Automatic future improvements



Data Structures

Context is key

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- Know what you need
  - Is order important?
  - Will I have duplicates?
  - Is mutability required?
  - What operations are most critical?
  - Where will data come from and go to?

Data Structures

Context is key

- Know what you need
  - Is order important?
  - Will I have duplicates?
  - Is mutability required?
  - What operations are most critical?
  - Where will data come from and go to?
- Know what to expect
  - Getting the count is O(1)
  - Enumerating all objects is O(n)
  - Other operations vary by collection

Mutability

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Mutability

- Use it when you need it
- Immutable collections have benefits
  - Thread safety
  - Memory and speed optimizations
- Make immutable copy afterward?
- Help us help you
  - You know how it will be used
  - Hints can enhance performance
  - Consider using `-initWithCapacity:`

Foundation Collection MVPs

- NSArray / NSMutableArray
- NSSet / NSMutableSet / NSCountedSet
- NSDictionary / NSMutableDictionary
- NSOrderedSet / NSMutableOrderedSet
- NSIndexSet / NSMutableIndexSet
- NSMapTable
- NSHashTable
- NSCache

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  - Add / remove, arbitrary index (e.g. `-insertObject:atIndex:`)
- Specialty operations
  - Binary search (requires a sorted range of an array)
    - `-indexOfObject:inSortedRange:options:usingComparator:`

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  - Set math: modify (e.g. `-intersectSet:`, `-minusSet:`, `-unionSet:`)
- Caveats
  - Converting array to set loses ordering and duplicates
  - Cannot be stored in a property list or JSON

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NSCountedSet

- Unordered, no duplicates, hash lookup
- Subclass of NSMutableSet, same operations and caveats
- Tracks net insertion count for each object
  - Incremented on insert, decremented on remove
  - `-countForObject:` returns individual count
  - `-count` still returns number of objects, not sum of insertions

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  - Property list file I/O
  - `+sharedKeySetForKeys:`, `+dictionaryWithSharedKeySet:` (10.8, iOS 6)
- Caveats
  - Keys must conform to NSCopying (“copy in”)
  - NEVER mutate an object that is a dictionary key

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  - Property list support requires conversions

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  - Use caution with indexes for mutable arrays

NSMapTable / NSHashTable

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  - Optional copy on insert
- Caveats
  - Can’t convert non-object contents to dictionary/set
  - Beware of premature optimization!

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- Doesn’t copy keys
- Auto-removal under memory pressure
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- NSKeyedArchiver / NSKeyedUnarchiver

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- Works with a few Foundation classes
  - NSArray, NSDictionary, NSNull, NSNumber, NSString
  - Some restrictions on hierarchy and values
- NSJSONSerialization (10.7 / iOS 5.0)
  - Reading, writing, object validation
  - Optional mutability on read
  - Fast, built-in, dynamically linked

Real-World Applications

WWDC App — Refreshing Sessions

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- Profiling reveals non-linear growth

WWDC App — Refreshing Sessions

Approach 1

WWDC App — Refreshing Sessions

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```
NSArray *sessionsToImport = ...; // Fetched from server
NSManagedObjectContext *context = ...;

for (WWDCSession *session in sessionsToImport) {
    NSFetchRequest *r = [NSFetchRequest fetchRequestWithEntityName:@"WWDCSession"];
    r.predicate = [NSPredicate predicateWithFormat:@"sessionID = %@", session.sessionID];
    NSArray *results = [context executeFetchRequest:r error:nil];

    WWDCSession *existingSession = [results firstObject];
    if (existingSession != nil) {
        // Merge into existingSession
    } else {
        // Insert into context
    }
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WWDC App — Refreshing Sessions

Approach 2

```
NSArray *sessionsToImport = ...; // Fetched from server
NSManagedObjectContext *context = ...;

NSArray *sessionIDs = [sessionsToImport valueForKey:@"sessionID"];
NSFetchRequest *r = [NSFetchRequest fetchRequestWithEntityName:@"WWDCSession"];
r.predicate = [NSPredicate predicateWithFormat:@"sessionID in %@", sessionIDs];
NSArray *results = [context executeFetchRequest:r error:nil];

for (WWDCSession *session in sessionsToImport) {
    NSInteger existingSessionIndex = [results indexOfObject:session];
    if (existingSessionIndex != NSNotFound) {
        WWDCSession *existingSession = results[existingSessionIndex];
        // Merge into existingSession
    } else {
        // Insert into context
    }
}
```

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WWDC App — Refreshing Sessions

Approach 3

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NSManagedObjectContext *context = ...;

NSArray *sessionIDs = [sessionsToImport valueForKey:@"sessionID"];
NSFetchRequest *r = [NSFetchRequest fetchRequestWithEntityName:@"WWDCSession"];
r.predicate = [NSPredicate predicateWithFormat:@"sessionID in %@", sessionIDs];
NSArray *results = [context executeFetchRequest:r error:nil];
NSDictionary *sessionsKeyedByID = [NSDictionary dictionaryWithObjects:results forKeys:
[results valueForKey:@"sessionID"]];

for (WWDCSession *session in sessionsToImport) {
    WWDCSession *existingSession = sessionsKeyedByID[session.sessionID];
    if (existingSession != nil) {
        // Merge into existingSession
    } else {
        // Insert into context
    }
}
```

WWDC App — Refreshing Sessions

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NSArray *sessionsToImport = ...; // Fetched from server
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for (WWDCSession *session in sessionsToImport) {
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WWDC App — Refreshing Sessions

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Eliminating Extra Work

- Minimize redundancy, especially "expensive" code
  - Particularly within loops
- Take advantage of faster lookup when possible
  - Dictionaries and sets
- Use mutable collections (and strings) when it makes sense
- Streamline how you access your data
- Don't reinvent the wheel
  - e.g. `-[NSArray componentsJoinedByString:]`

Eliminating Extra Work

Example

Eliminating Extra Work

Example

```
- (NSArray*) doSomethingWithArray:(NSArray*)array
{
    NSArray *newArray = [NSArray array];
    for (id object in array) {
        id newObject = [self doSomethingWithObject:object];
        if (newObject != nil) {
            newArray = [newArray arrayByAddingObject:newObject];
        }
    }
    return newArray;
}
```

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```

Eliminating Extra Work

Example

```
- (NSArray*) doSomethingWithArray:(NSArray*)array
{
    NSMutableArray *newArray = [NSMutableArray array];
    for (id object in array) {
        id newObject = [self doSomethingWithObject:object];
        if (newObject != nil) {
            [newArray addObject:newObject];
        }
    }
    return [newArray copy]; // Copy is immutable
}
```

Eliminating Extra Work

Example

```
- (NSArray*) doSomethingWithArray:(NSArray*)array
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    NSMutableArray *newArray = [NSMutableArray array];
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            [newArray addObject:newObject];
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    }
    return [newArray copy]; // Copy is immutable
}
```

- Similarly, appending to an NSMutableString

Don’t leave performance on the table

More Information

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Apple Developer Forums
http://devforums.apple.com

Collections Programming Topics
http://developer.apple.com/documentation/Cocoa/Conceptual/Collections/

Property List Programming Guide
http://developer.apple.com/documentation/Cocoa/Conceptual/PropertyLists/

Archives and Serializations Programming Guide
http://developer.apple.com/documentation/Cocoa/Conceptual/Archiving/

Related Sessions

Building Efficient OS X Apps	Nob Hill Tuesday 4:30PM
Hidden Gems in Cocoa and Cocoa Touch	Nob Hill Friday 10:15AM

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