JavaScript Immutability

Don't Go Changing

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https://github.com/mvolkmann/react-examples/Immutable

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Intro.

- What is **OCI**?
  - new home of **Grails**,
    "An Open Source high-productivity framework for building fast and scalable web applications"
  - Open Source Transformation Services, IIoT, DevOps
  - offsite development, consulting, training
  - **handouts** available (includes Grails sticker)
- What does this talk have to do with **Billy Joel** and the song "Just the Way You Are"?
- **Three parts**
  - What is immutability and how is it implemented?
  - What are the options in JavaScript?
  - Overview of API for one option and examples

Immutability Defined

- Immutable values cannot be modified after creation
- In many programming languages, strings are immutable
  - methods on them return new versions rather than modifying original
- Data structures can also be immutable
- Rather than modifying them, create a new version
- Naive approach - copying original and modify copy
- We can do better!

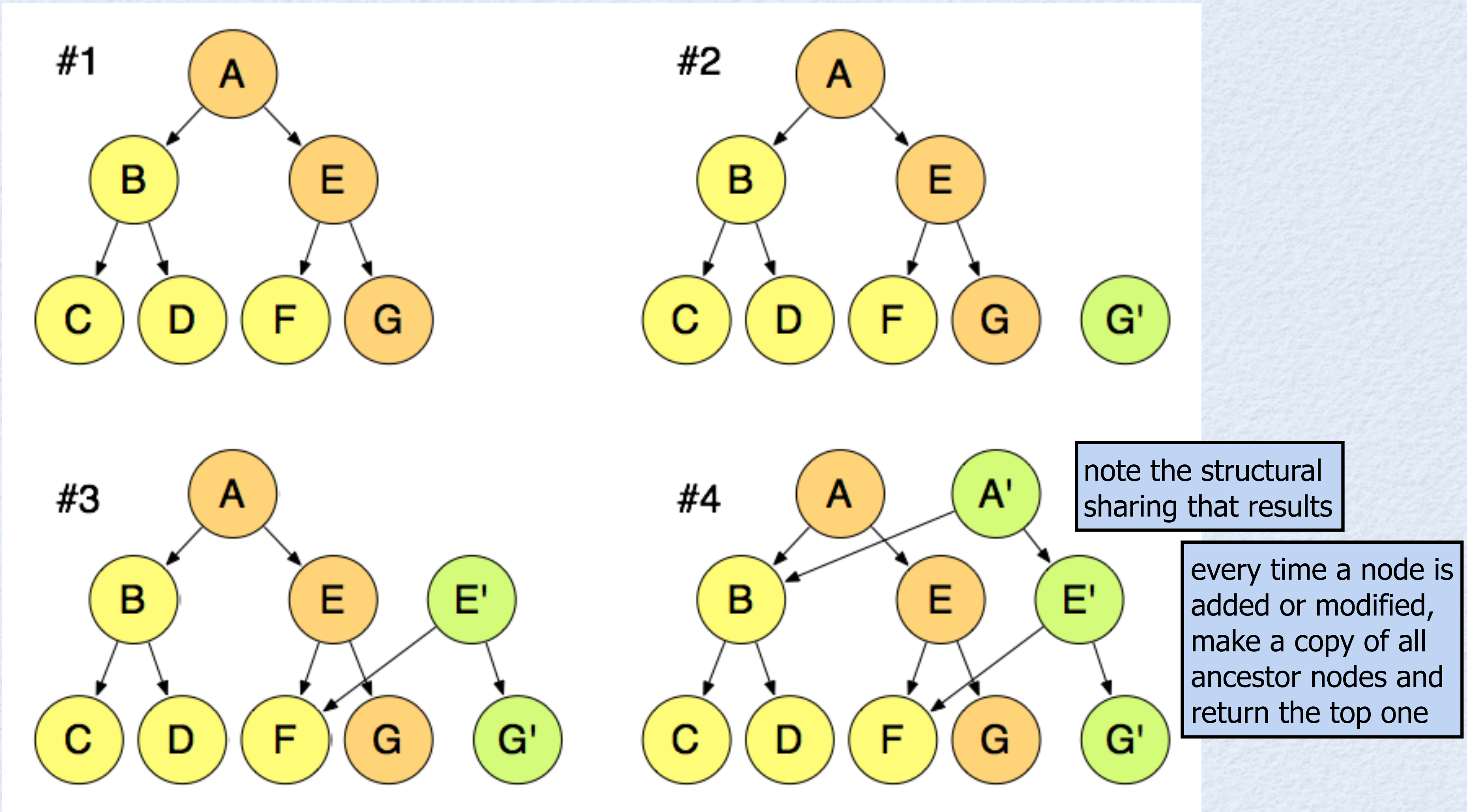
Persistent Data Structures

It's not necessary to understand how these work to take advantage a library that uses them.

- Wikipedia says "**a data structure that always preserves the previous version of itself when it is modified**"
- Uses **structural sharing** to efficiently create new versions of data structures like lists and maps
- Typically implemented with
  - **index tries**
  - **hash array map tries** (HAMT)
- **Slower** and uses **more memory** than operating on mutable data structures
  - but fast enough for most uses
- Explained well in video "Tech Talk: Lee Byron on Immutable.js"
  - Lee Byron is at Facebook
  - https://www.youtube.com/watch?v=kbnUIhsX2ds&list=WL&index=34
- Uses **Directed Acyclic Graphs** (DAGs)

DAGs

- Can be used to represent a list
- Diagrams show new version of list created for new value of node G



Tries

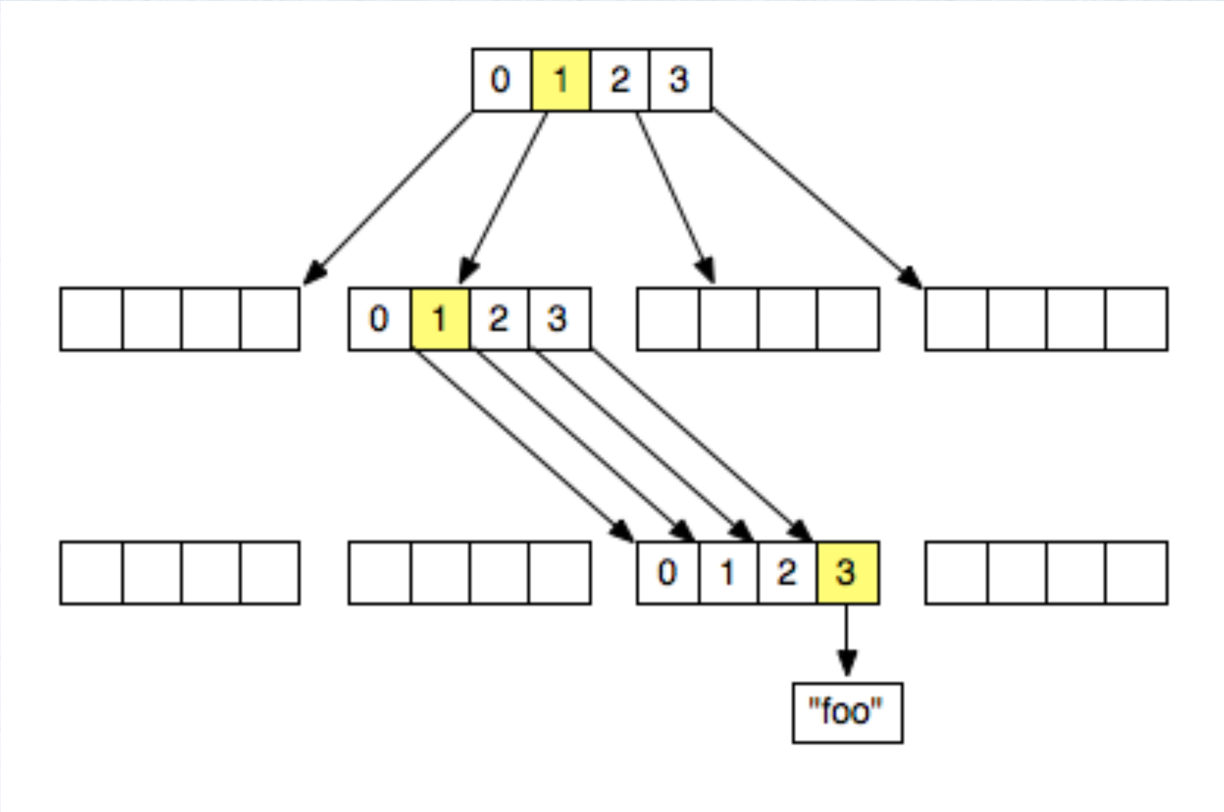
- A **trie** is a special kind of DAG
  - name taken from "re**TRIE**val"
  - correct pronunciation is "tree",
    but many say "try" because
    computer science already has something called a tree
- We'll discuss two types
  - **index trie** used to model arrays
  - **hash array mapped trie** (HAMT) used to model sets and maps

Index Trie ...

- Nodes are fixed-size arrays of pointers to other nodes or values
  - store value "foo" at index 53
  - 53 in binary is 110101
  - starting from least significant bits,
    the pairs are 01, 01, and 11
    or node indexes 1, 1, and 3

    least significant bits tend to be more random

  - use same process to lookup a value at a given index
  - typically node size is 64 instead of 4 to match hardware "word" size



... Index Trie

- To set a new value at a given index, use the DAG approach described earlier to create new versions of existing nodes so those remain unchanged
- Ditto for marking a value "undefined" or popping a value from end
- Values can only be efficiently removed or inserted at end
  - not at beginning or in middle because indexes of other values would have to change

> Recall that JS arrays are modeled as objects. The `Array` `shift` method is not efficient. See pseudocode at https://tc39.github.io/ecma262/#sec-array.prototype.shift.

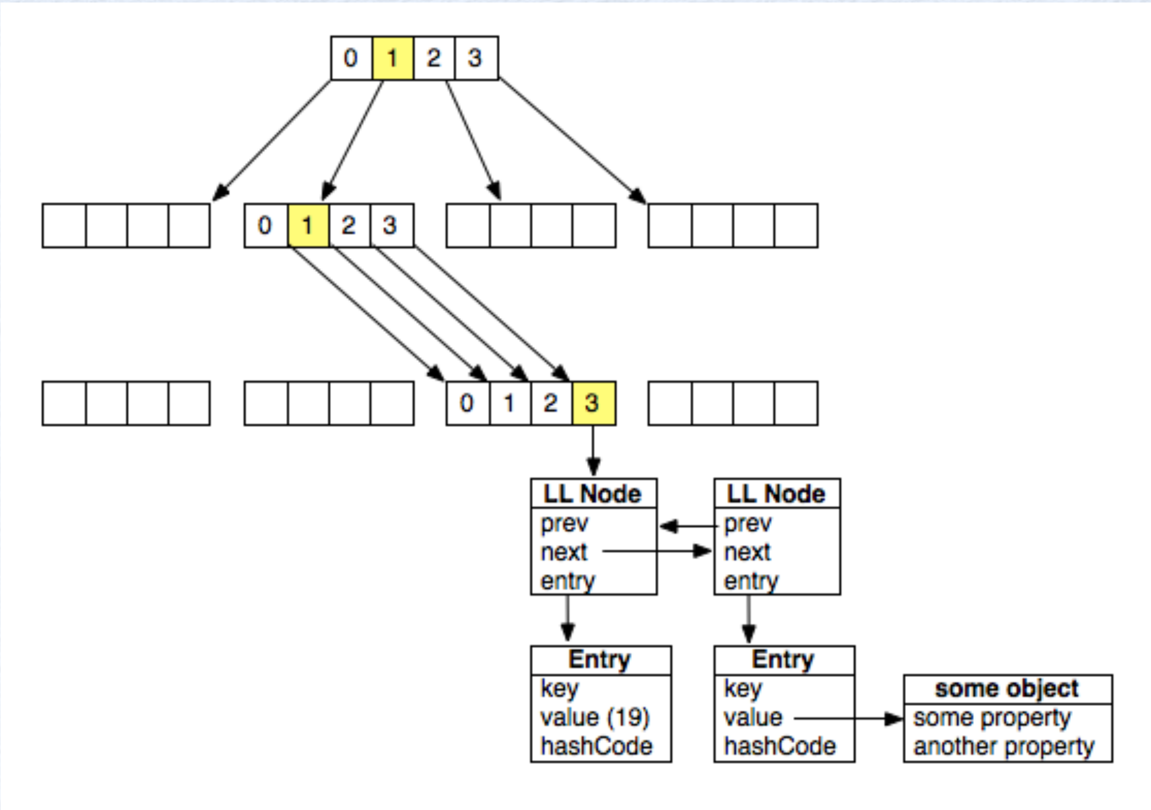
Hash Array Mapped Trie ...

- Used to model sets, maps, and objects
  - maps are collections of key/value pairs
  - think of sets as collections of keys
- Similar to an index trie
- Invented by Phil Bagel and iterated on by Rich Hickey
- Instead of array indexes, hash codes of keys are used
  - need way to compute hash code for strings
    - no hash code functions are provided by JavaScript
    - some approaches are documented at http://erlycoder.com/49/javascript-hash-functions-to-convert-string-into-integer-hash-
  - if keys of other primitive types (boolean and number) are allowed, can use `toString` method to convert to a string and hash that
  - if object keys are allowed, hash code can be computed by some combination of hash codes of its property values

... Hash Array Mapped Trie ...

- Node array values ("slots") have three possibilities
  - **empty** (undefined)
  - reference to another **trie node**
  - reference to **linked list node** see picture on next slide
    - holds **previous**/**next** references to other linked list nodes and **entry** reference
    - previous/next references support having a linked list of objects for when more than one key has **same hash code** (shouldn't happen frequently, but can't rule out)
    - **entry objects** hold **key**, **value**, and **hash code** of key
  - when traversal leads to a list of objects, linear search finds correct one by key
- Adding or removing an entry
  - results in a new HAMT that uses structural sharing with previous version
  - when copying a trie node, can copy references to existing linked list nodes

… Hash Array Mapped Trie



- Level optimization
  - when storing a value,
    if an empty slot is reached,
    store value there,
    using a subset of hash code bits
  - later if another value
    ends up at that same slot,
    move both along deeper
    until subset of hash code bits differ
  - but need to compare
    key value on lookup
- Existing value optimization
  - if a key is set to its existing value,
    return same structure

For even more detail, see the book
"**Purely Functional Data Structures**"
by Chris Okazaki

Immutable Pros

- **Some side effects avoided**
  - can pass immutable values to a function and know it cannot modify them
- **Pure functions easier to write**
  - can pass an object and return an efficiently modified version
- **Fast change detection**
  - rather than deep comparison, can just compare object references
  - in JavaScript, use ===
- **Immutable data can be safely cached**
  - no possibility of code changing it after it has been cached
- **Easier to implement undo**
  - keep a list of past values and reset to one of them
  - but doesn't undo changes to persistent stores like databases
- **Concurrency**
  - can share data between threads without concern over concurrent access

not a concern in JavaScript

Immutable Cons

- **Performance**
  - takes longer to create a new version of a persistent data structure than to mutate a mutable data structure like an array or map
  - takes longer to lookup a value in a persistent data structure than in a mutable data structure like an array or map
- **Memory**
  - structural sharing uses more memory than mutable data structures
- **Learning curve**
  - can't use standard JavaScript API for collections (`Array`, `Object`, `Set`, `Map`)
  - must learn new API

React and Immutability

- React ("JavaScript library for building user interfaces") favors immutable objects
- Should not modify properties in state objects
- Instead, create a new object and pass to `setState` method of components
  - or use Redux to manage state
- Manually creating a modified copy of state is tedious, error prone, and expensive in terms of memory
- Better to use an immutability library that utilizes structural sharing

Options ...

- **Be careful**
  - write code that avoids mutations
- **Immutability helpers**
  - from React team
  - https://facebook.github.io/react/docs/update.html
  - **doesn’t use structural sharing** (a.k.a. persistent data structures)
- **seamless-immutable**
  - from Richard Feldman
  - https://github.com/rtfeldman/seamless-immutable
  - **doesn’t use structural sharing**

... Options

- **Mori**
  - from David Nolan
  - https://github.com/swannodette/mori
    and http://swannodette.github.io/mori/
  - **uses structural sharing**
  - Clojure persistent data structures ported to JavaScript
- **Immutable**
  - from Lee Byron at Facebook
  - https://facebook.github.io/immutable-js/
  - **uses structural sharing**
  - great overview from React.js Conf 2015
    "Immutable Data and React" by Lee Byron of Facebook
    https://www.youtube.com/watch?v=I7IdS-PbEgI
  - **we will mainly focus on this**

Being Careful

This road leads to madness!

- Add element to end of array
  - ES6: `newArr = [...oldArr, elem]`
- Insert element at index in array
  - ES6: `newArr = [...oldArr.slice(0, index), elem, ...oldArr.slice(index)]`
- Remove element at index from array
  - ES6: `newArr = [...oldArr.slice(0, index), ...oldArr.slice(index + 1)]`
- Modify element at index in array
  - ES6: `newArr = [...oldArr.slice(0, index), newElem, ...oldArr.slice(index + 1)]`
- Modify or add property in object
  - ES6: `newObj = Object.assign({}, oldObj, {propName: propValue});`
  - ES7: `newObj = {...oldObj, propName: propValue};` uses object spread operator

consider using **deep-freeze** to prevent accidental mutations
https://github.com/substack/deep-freeze

Immutability Helpers

- https://facebook.github.io/react/docs/update.html
  - see examples here
- Install with **`npm install --save-dev react-addons-update`**
- Usage

```
const update = require('react-addons-update');
const newObj = update(oldObj, changes);
```

- Object commands
  - **`$set:`** ***`value`*** - replaces target value with specified ***`value`*** (no **`$unset`**, but it has been proposed)
  - **`$merge:`** ***`obj`*** - replace target object with result of merging properties in ***`obj`*** with current value
  - **`$apply:`** ***`fn`*** - replaces target value with result of ***`fn`*** when passed current value
- Array Commands
  - **`$push:`** ***`arr`*** - adds all elements in ***`arr`*** to end of target array
  - **`$unshift:`** ***`arr`*** - adds all elements in ***`arr`*** to beginning of target array
  - **`$splice:`** ***`arr`*** - each ***`arr`*** element is an array of splice arguments;
    creates new array from target by calling splice with each set of arguments

seamless-immutable

- **Creates objects that are backward-compatible with JS Arrays and Objects**
- Efficiently copies objects by reusing existing nested objects whose properties aren't changed
- Operates differently depending whether built for development or production
  - **development** - objects are frozen; overrides methods that normally mutate to throw
  - **production** - assumes code has been tested in development mode and favors performance by not doing these things
- `Immutable` function takes any object and returns a backward-compatible, immutable version
- **Doesn't work with objects that contain circular references**
- Adds methods to immutable objects: `merge`, `without`, `asMutable`
- Adds methods to immutable arrays: `flatMap`, `asObject`, `asMutable`

Mori

- **Uses Clojure terminology**
  - such as `assoc`, `dissoc`, `conj`, `transduce`, and `vector`
- Used in ClojureScript
  - can also be used in JavaScript
- **Uses structural sharing**
- Faster than other libraries
- Has a functional API
  - data structures are passed to functions
    rather than having methods on them in OO-style
- Larger library than Immutable
  - after gzipping both, Mori **2.4 times as large as Immutable**

Immutable

- "Inspired by inspired by Clojure, Scala, Haskell and other functional programming environments"
- API mirrors ES6 `Array`, `Map`, and `Set` methods
  - but methods that mutate in ES6 return an immutable copy instead
  - ex. Array methods `push`, `pop`, `unshift`, `shift`, `splice`
- **Uses structural sharing**
  - makes copying more efficient in both performance and memory usage
- Provides many immutable classes
  - listed on "Collection Types" slide ahead
- Remaining slides focus on this library

Setup

- To install,
  ```
  npm install --save immutable
  ```
- To use in ES5 browser code,
  ```
  <script src="node-modules/immutable/dist/immutable.min.js"></script>
  ```
- To use in ES6 browser code,
  ```
  import Immutable from 'immutable';
  ```
- To use in Node code,
  ```
  const Immutable = require('immutable');
  ```

Collection Types

see documentation at http://facebook.github.io/immutable-js/docs

- `Map` and `OrderedMap`
  - similar to ES6 `Map`
  - `OrderedMap` iteration order matches order added
- `List`
  - similar to JavaScript `Array`
- `Set` and `OrderedSet`
  - similar to ES6 `Set`
  - `OrderedSet` iteration order matches order added
- `Stack`
  - singly linked list
  - efficient addition and removal at front
- `Record`
  - "creates a new class which produces `Record` instances ... similar to a JS object"
- Iterables
  - `Iterable`, `KeyedIterable`, `IndexedIterable`, `SetIterable`
  - all are ES6 iterables
- Sequences
  - `Seq`, `KeyedSeq`, `IndexedSeq`, `SetSeq`
  - support lazy evaluation
- Collection base classes
  - `Collection`, `KeyedCollection`, `IndexedCollection`, `SetCollection`

Nesting

- Can nest immutable objects
  - ex. immutable `Map` with properties whose values are immutable `List` objects
- It can be confusing and error prone
  to use non-immutable values
  (such as standard JavaScript objects and arrays)
  as values in immutable structures
  - be consistent!

JS to Immutable

- To convert an `Object` or `Array` to an immutable `Map` or `List`,

```
const immObj = Immutable.fromJS(mutObj);
```

- To customize the conversion and choose the collection types to be used,

```
const immObj = Immutable.fromJS(mutObj, (key, value) => {
  // Only called for non-primitive values.
  // value will be a Seq object.
  // Return an immutable object.
});
```

Immutable to JS

- To convert an immutable object to a JavaScript `Object` or `Array`,
  `const mutObj = immObj.toJS();`
- Resist the urge to do this just so values can be accessed in a standard JavaScript way
  - less efficient than using methods on immutable objects

Working With Maps ...

- To create
  - `const map = Immutable.Map();`
    - can pass many kinds of things to initialize
  - `const map = Immutable.fromJS(jsObject);`
    - makes deep copy where all values are immutable
    - objects -> `Map`s; arrays -> `List`s
- To set top-level key value
  - `const newMap = map.set(key, value);`
- To set deeper key value
  - `const newMap = map.setIn([key-path], value);`
- To get top-level key value
  - `const value = map.get(key);`
- To get deeper key value
  - `const value = map.getIn([key-path]);`

> `key-path` is an ordered array of keys;
> ex. `['work', 'address', 'city']`

... Working With Maps ...

- To update top-level key value
  - `const newMap = map.update(key, fn);`
  - value at **`key`** is passed to **`fn`** and return value becomes new value
- To update deeper key value
  - `const newMap = map.updateIn([key-path], fn);`
  - value at **`key-path`** is passed to **`fn`** and return value becomes new value
- To delete top-level key/value pair
  - `const newMap = map.delete(key);`
- To delete deeper key/value pair
  - `const newMap = map.deleteIn([key-path]);`

... Working With Maps

- To iterate over
  - keys - `const iter = map.keys();`
  - values - `const iter = map.values();`
  - entries - `const iter = map.entries();` entries are `[key, value]` arrays
  - value returned from each of these is an ES6 iterable,
    so can use with ES6 for-of loop

    ```
    for (const entry of teams.entries()) { ... }
    ```
- There are MANY more methods on **`Map`** listed later
- Working with other kinds of collections is similar

Map API Examples

```
import Immutable from 'immutable';

let person = Immutable.fromJS({
  name: 'Moe Howard',
  address: {
    street: '123 Some Street',
    city: 'Somewhere',
    state: 'MO',
    zip: 12345
  }
});

person = person.set('name', 'Larry Fine');
person = person.setIn(['address', 'city'], 'Los Angeles');
console.log('name =', person.get('name'));
console.log('city =', person.getIn(['address', 'city']));
person = person.deleteIn(['address', 'street']);
person = person.updateIn(['address', 'zip'], zip => zip + 1);
console.log(person.toJS());
```

Output

```
name = Larry Fine
city = Los Angeles
{
  name: 'Larry Fine',
  address: {
    zip: 12346,
    city: 'Los Angeles',
    state: 'MO'
  }
}
```

can chain all calls that create a new version

Multiple Mutations

- When modifying multiple properties in an immutable object, it can be more efficient to make them on a mutable version and then create an immutable version from that
  - avoids creating multiple new, immutable objects
- **`withMutations`** method does this
  - call on an immutable object
  - pass a function that will be invoked with a mutable version of it
  - returns a new, immutable object

```
person = person.withMutations(mutPerson =>
  mutPerson.set('name', 'Larry Fine').
    setIn(['address', 'city'], 'Los Angeles').
    deleteIn(['address', 'street']).
    updateIn(['address', 'zip'], zip => zip + 1));
```

alternate version of code on previous slide

Working With Lists

- See example code on next slide
- `List` class has MANY more methods than are demonstrated

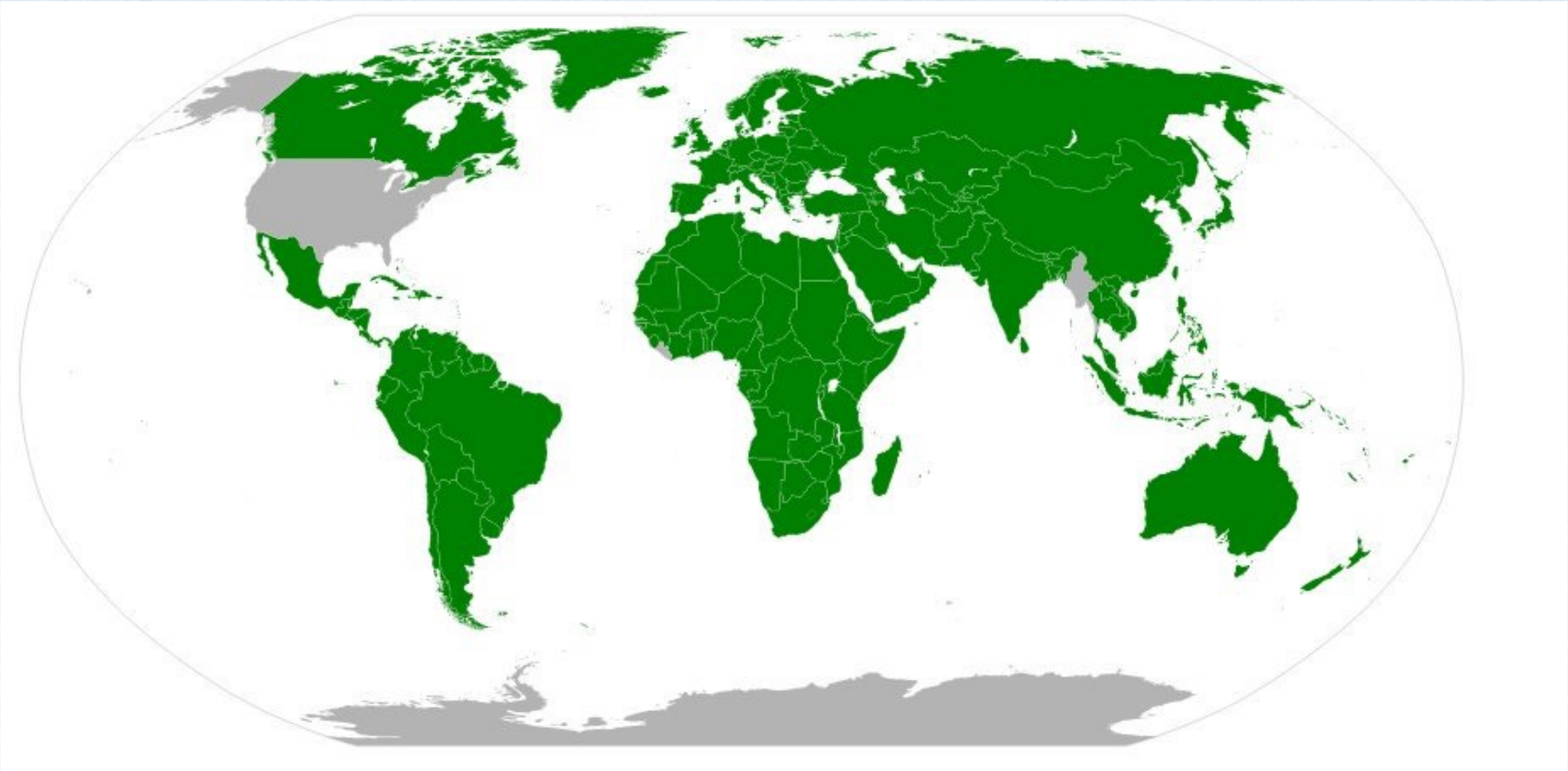
List API Examples

```
let numbers = Immutable.fromJS([10, 20, 30]);
console.log(numbers.get(1)); // 20
console.log(numbers.first()); // 10
console.log(numbers.last()); // 30
console.log(numbers.has(2), numbers.includes(2)); // true, false
console.log(numbers.has(20), numbers.includes(20)); // false, true
numbers = numbers.push(40); // [10, 20, 30, 40]
numbers = numbers.pop(); // [10, 20, 30]
numbers = numbers.unshift(0); // [0, 10, 20, 30]
numbers = numbers.shift(); // [10, 20, 30]
numbers = numbers.set(1, 7); // [10, 7, 30]
numbers = numbers.delete(1); // [10, 30]
numbers = numbers.update(1, n => n * 2); // [10, 60]
numbers = numbers.splice(1, 0, 20, 30, 40, 50); // [10, 20, 30, 40, 50, 60]

let people = Immutable.fromJS([
  {name: 'Mark', height: 74, occupation: 'software engineer'},
  {name: 'Tami', height: 64, occupation: 'vet receptionist'}
]);
console.log(people.getIn([0, 'occupation'])); // software engineer
people = people.setIn([1, 'occupation'], 'retired'); // Tami is retired
people = people.deleteIn([1, 'occupation']); // Tami has no occupation
people = people.updateIn([1, 'height'],
  height => height + 1); // Tami's height is 65

// Lists are iterable!
for (const person of people) {
  console.log(person);
}
```

`has` method looks for index;
`includes` method looks for value

74″ ~= 188 cm
64″ ~= 163 cm

Metric System Usage



Seqs

- Represent a sequence of values
  - backed by another data structure when created with `toSeq`, `toKeyedSeq`, `toIndexedSeq`, and `toSetSeq` methods
  - can create directly with `Seq`, `KeyedSeq`, `IndexedSeq`, and `SetSeq` constructors
  - values can be primitives and objects, including other immutable data structures
- Immutable
  - many methods create a new, immutable version: `concat`, `map`, `reverse`, `sort`, `sortBy`, `groupBy`, `flatten`, `flatMap`
  - many methods create immutable subsets: `filter`, `filterNot`, `slice`, `rest` (all but first), `butLast`, `skip`, `skipLast`, `skipWhile`, `skipUntil`, `take`, `takeLast`, `takeWhile`, `takeUtil`

`Seq` has a large API.
This scratches the surface.

- Lazy
  - "does as little work as necessary to respond to any method call"
  - see example on next slide

Seq Example

Range returns an IndexedSeq of numbers
from start (inclusive, defaults to 0)
to end (exclusive, defaults to infinity),
by step (defaults to 1)

Infinity is a predefined
global variable in JavaScript

```
const result =
  Immutable.Range(1, Infinity). // all positive integers
  filter(n => n % 7 === 0). // all numbers divisible by 7
  take(3). // just first three: 7, 14, 21
  map(n => n * 2). // double them: 14, 28, 42
  reduce((sum, n) => sum + n); // sum them: 84
```

Comparing Objects

- To determine if two immutable objects contain the same data, `Immutable.is(immObj1, immObj2)`
  - performs a **deep equality check** that works as expected when comparing nested, immutable objects
  - unlike `Object.is` added in ES6 which does **not** perform a **deep** equality check
- If one immutable object was created by potential modifications on another, this can be simplified to `immObj1 === immObj2`

API Summary

- The remaining slides summarize the methods available in each of the collection types
- It's a large API!

skip to slide 57

Persistent Changes

	Map/OrderedMap	List	Set/OrderedSet	Stack	Seq
set	X	X			
delete	X	X	X		
clear	X	X	X	X	
update	X	X			
merge	X	X			
mergeWith	X	X			
mergeDeep	X	X			
mergeDeepWith	X	X			
push		X		X	
pop		X		X	
unshift		X		X	
shift		X		X	
setSize		X			
add			X		
union			X		
intersect			X		
subtract			X		
pushAll				X	
unshiftAll				X	

Deep Persistent Changes

	Map/OrderedMap	List	Set/OrderedSet	Stack	Seq
setIn	X	X			
deleteIn	X	X			
updateIn	X	X			
mergeIn	X	X			
mergeDeepIn	X	X			

Transient Changes

	Map/OrderedMap	List	Set/OrderedSet	Stack	Seq
withMutations	X	X	X	X	
asMutable	X	X	X	X	
asImmutable	X	X	X	X	

Conversion to `Seq`

	`Map`/`OrderedMap`	`List`	`Set`/`OrderedSet`	`Stack`	`Seq`
`toSeq`	X	X	X	X	
`toKeyedseq`	X	X	X	X	
`toIndexedSeq`	X	X	X	X	
`toSetSeq`	X	X	X	X	
`fromEntrySeq`		X		X	

Value Equality

- All collection types support these methods
  - `equals`
  - `hashCode`

Reading Values

	Map/OrderedMap	List	Set/OrderedSet	Stack	Seq
get	X	X	X	X	X
has	X	X	X	X	X
includes	X	X	X	X	X
first	X	X	X	X	X
last	X	X	X	X	X
peek				X	

Reading Deep Values

- All collection types support these methods
  - `getIn`
  - `hasIn`

Conversion to JavaScript Types

- Can convert all immutable structures back to standard JS objects
- `toObject` method
  - returns JS object created from top-level properties of immutable object (shallow)
- `toArray` method
  - returns JS array created from top-level properties of immutable object (shallow)
- `toJS` method
  - like `toObject`, but deep
- `toJSON` method
  - just an alias for `toJS`

Conversion to Collections

- All collection types support these methods
  - `toMap`
  - `toOrderedMap`
  - `toSet`
  - `toOrderedSet`
  - `toList`
  - `toStack`

Iterators and Iterables

- All collection types support these methods
  - `keys`
  - `values`
  - `entries`
  - `keySeq`
  - `valueSeq`
  - `entrySeq`

Sequence Algorithms

- All collection types support these methods
  - `map`
  - `filter`
  - `filterNot`
  - `reverse`
  - `sort`
  - `sortBy`
  - `groupBy`

Side Effects

- All collection types support this method
  - `forEach`

Creating Subsets

- All these methods are available on all collection types
  and return an `Iterable` of same type over a subset of the elements
- `slice(begin, end)` - from begin to just before end
- `rest()` - all but first
- `butLast()` - all but last
- `skip(n)` - all but first `n`
- `skipLast(n)` - all but last `n`
- `skipWhile(predicate)` - all starting with first where `predicate` returns `false`
- `skipUntil(predicate)` - all starting with first where `predicate` returns `true`
- `take(n)` - first `n`
- `takeLast(n)` - last `n`
- `takeWhile(predicate)` - initial elements while `predicate` returns `true`
- `takeUntil(predicate)` - initial elements until `predicate` returns `true`

Combination

	Map/OrderedMap	List	Set/OrderedSet	Stack	Seq
concat	X	X	X	X	X
flatten	X	X	X	X	X
flatMap	X	X	X	X	X
interpose		X		X	
interleave		X		X	
splice		X		X	
zip		X		X	
zipWith		X		X	

Reducing

- All these methods are available on all collection types
- `reduce(reducer, initialValue)` - reduces collection to a single value by calling `reducer` with latest value and an element from collection; `reducer` returns next value
- `reduceRight(reducer, initialValue)` - same a reduce, but elements are passed to `reducer` in reverse order
- `every(predicate)` - returns boolean indicating whether `predicate` returns true for every element
- `some(predicate)` - returns boolean indicating whether `predicate` returns true for any element
- `join(separator = ',')` - returns string formed by concatenating the `toString` value of all elements with `separator` string between them
- `isEmpty()` - returns boolean indicating whether collection is empty
- `count(predicate)` - returns count of elements where `predicate` returns `true` or count of all elements if predicate is omitted
- `countBy(grouper)` - returns a KeyedSeq where keys are ? and values are Iterables over elements in the same group; `grouper` is passed each element and returns its group

Search for Value

	Map/OrderedMap	List	Set/OrderedSet	Stack	Seq
find	X	X	X	X	X
findLast	X	X	X	X	X
findEntry	X	X	X	X	X
findLastEntry	X	X	X	X	X
max	X	X	X	X	X
maxBy	X	X	X	X	X
min	X	X	X	X	X
minBy	X	X	X	X	X
keyOf	X				
lastKeyOf	X				
findKey	X				
findLastKey	X				
indexOf		X		X	
lastIndexOf		X		X	
findIndex		X		X	
findLastIndex		X		X	

Comparison

- All collection types support these methods
  - `isSubset`
  - `isSuperset`

Sequence Functions

	Map/OrderedMap	List	Set/OrderedSet	Stack	Seq
flip	X				
mapKeys	X				
mapEntries	X				

Summary

- Immutability has **many benefits** and **few drawbacks**
- **Persistent data structures** are an important feature
  - avoid immutability libraries that don't implement these
- **Immutable** is a great library!
  - learning curve is primarily due to size of API
  - each piece is relatively simple to learn

The End

- Thanks so much for attending my talk!
- Feel free to find me later and ask questions about immutability or anything in the JavaScript world
- Check out my **talk on React tomorrow** at **2 PM** in **room A2**
- **Contact me**

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