JavaScript Immutability

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

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 - copy original and modify copy
- We can do better!

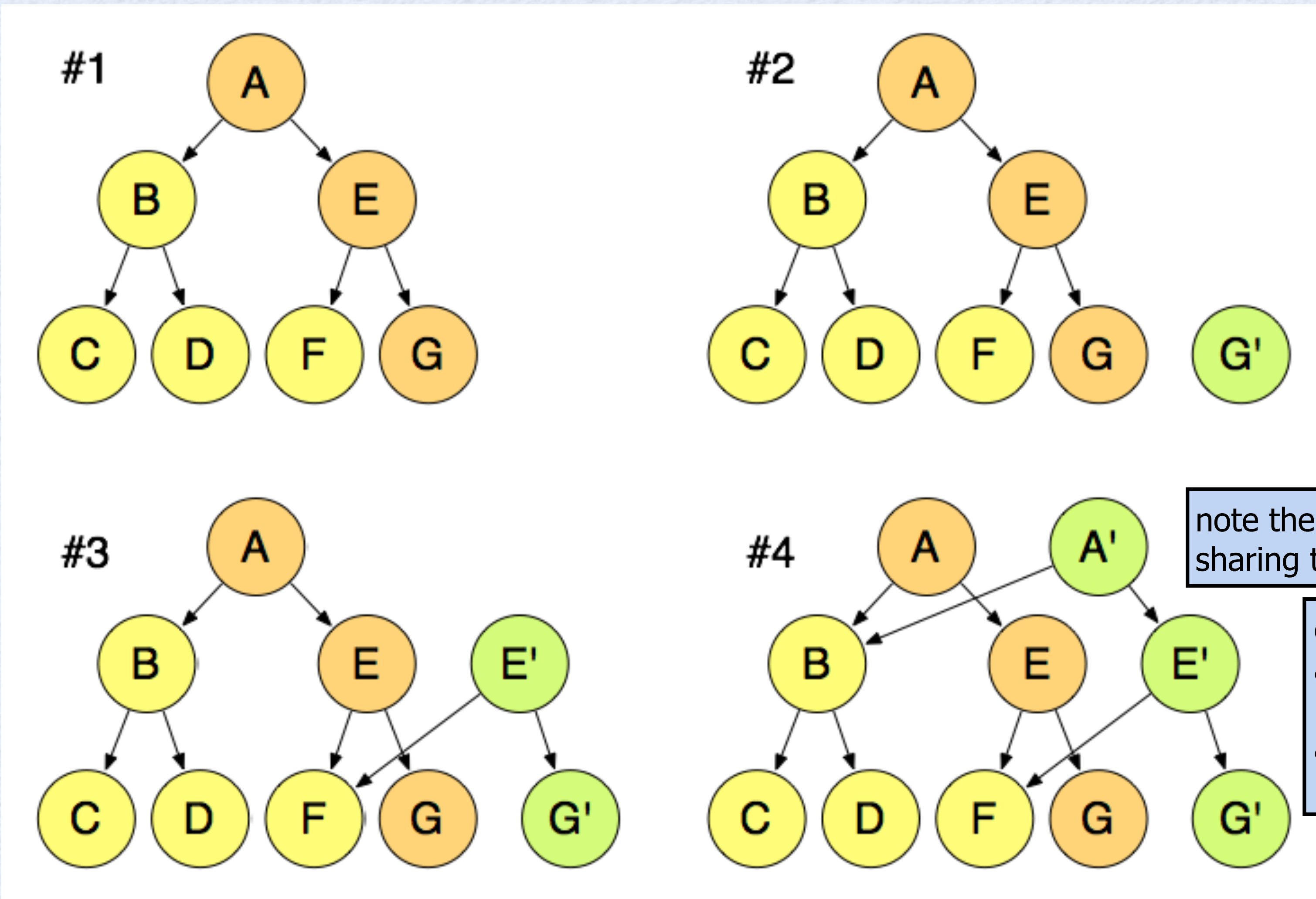
Persistent Data Structures

It’s not necessary to understand how these work
to take advantage a library that uses them.
Skip to slide 12 if not interested in details.

- 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



note the structural sharing that results

every time a node is added or modified, make a copy of all ancestor nodes and return the top one

Tries

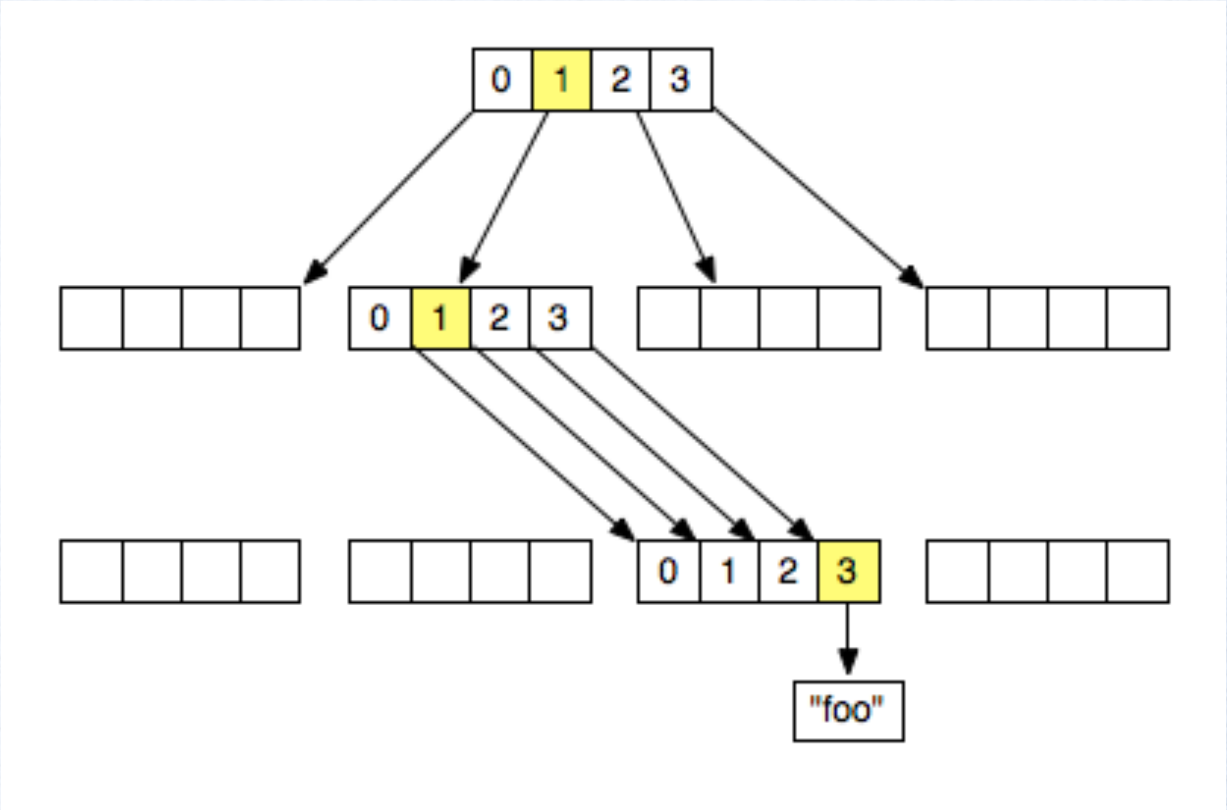
- A **trie** is a special kind of DAG
  - name taken from "re**TRIE**val"
  - correct pronunciation is "tree",
    but many say "try" because
    computer science already has something called a tree
- We'll discuss two types
  - **index trie** used to model arrays
  - **hash array mapped trie** (HAMT)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



... 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.

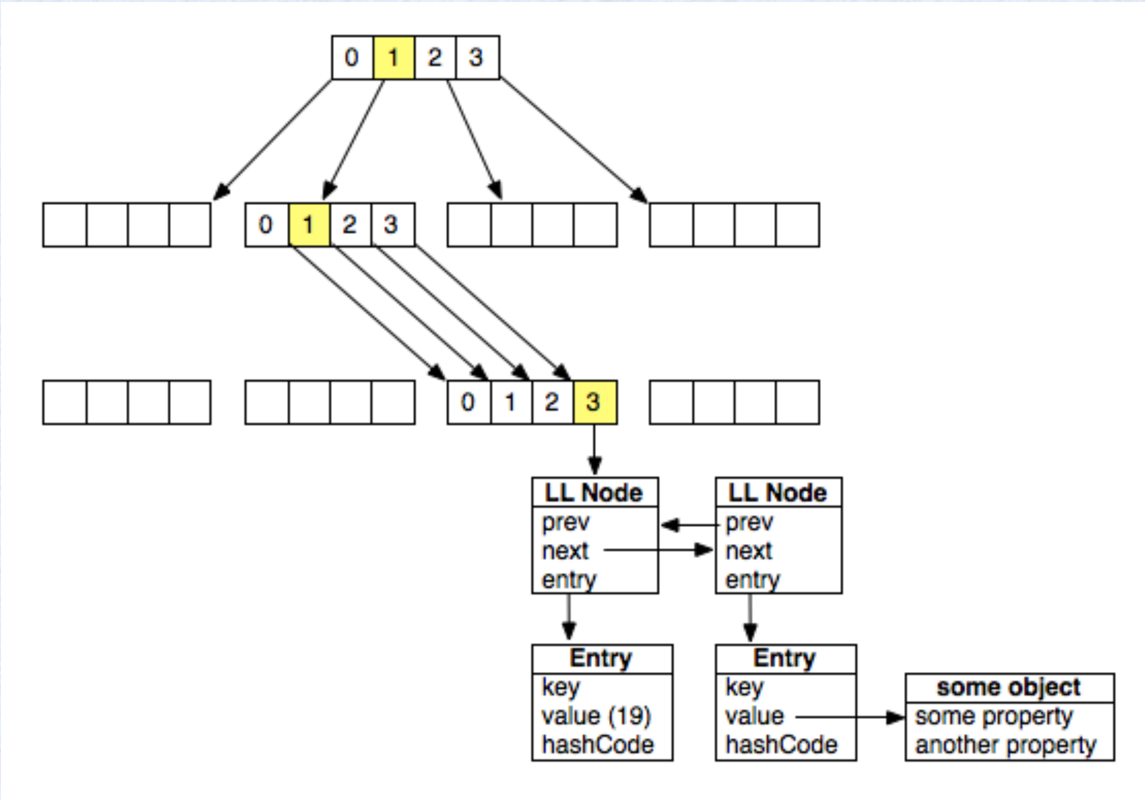
Hash Array Mapped Trie ...

- 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 an **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
    - **value** can be a primitive (like 19) or a reference to an object
  - 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 and time)
- 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;
"calls `Object.freeze(obj)` recursively on
all unfrozen properties of `obj` that are objects";
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);
```

changes is an object where each key specifies a property to be changed and the corresponding value describes the change using a command object below

- 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

a weak variant of structural sharing

- 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 is **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

- `List`
  - similar to JavaScript `Array`
- `Stack`
  - singly linked list
  - efficient addition and removal at front
- `Set` and `OrderedSet`
  - similar to ES6 `Set`
  - `OrderedSet` iteration order matches order added

    not a sorted set!
- `Map` and `OrderedMap`
  - similar to ES6 `Map`
  - `OrderedMap` iteration order matches order added

    not a sorted map!

- `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`, `Collection.Keyed`, `Collection.Indexed`, `Collection.Set`

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.
  });
  ```

  called once for each key/value pair in `mutObj`

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);`

    `key` can be any type
- To set deeper key value
  - `const newMap = map.setIn([key-path], value);`

    `key-path` is an ordered array of keys;
    ex. `['work', 'address', 'city']`
- To get top-level key value
  - `const value = map.get(key);`
- To get deeper key value
  - `const value = map.getIn([key-path]);`

... 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');
console.log('name =', person.get('name'));
person = person.setIn(['address', 'city'], 'Los Angeles');
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.get('name')); // Mark then Tami
}
```

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

74″ ~= 188 cm
64″ ~= 163 cm

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
    - when passed two objects, only tests whether they are the same object
- 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 56

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 the 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