# Data Structures: Part 1

# Immutable state

- Major difference between Clojure and all other dialects of Lisp

# Immutable state

## What is it?

- Data is not modified
- So what happens when state is updated?
  - New data is created.
  - Old data still remains.

# Immutable state

## Why?

- Makes program easier to reason about (static analysis)
- Reduces dependence between functions: more modularity + code reuse
- Shorter and more legible code == less bugs.
- Everything is threadsafe, allowing for implicit parallelism (no need for locks)

# Immutable state

Alan Kay

Xerox PARC, Creator of Smalltalk

The last thing you wanted any programmer to do is mess with internal state even if presented figuratively. It is unfortunate that much of what is called "object-oriented programming" today is simply old style programming with fancier constructs.

"The Early History of Smalltalk"

- Alan Kay, Lisp hacker and inventor of Object-Oriented Programming

# Immutable state

## Does it affect performance?

- The short answer: no!
- Garbage collection on the JVM is now highly optimized
- Memory usage is controlled by eliminating intermediate copies of data
  - In other languages as a compiler optimization (fusion)
  - In Clojure by not creating them in the first place (tranducers...more on this later)

# Immutable State

**In Clojure immutability is encouraged, but not enforced.**

- Functional programming avoids variable assignment
- Functions are referred to as "pure" or having "referential transparency" if:
  - No global state passed in
  - No local state
  - They cannot modify other parts of the program (referred to as "side effects")

- Pure functions are "idempotent"— applying multiple times to same input does nothing (like mathematical functions)
- Most built-in functions in Clojure are pure
- Impure functions end with a ! ("bang")

# The Collection Abstraction

> "It is better to have 100 functions operate on one data structure than 10 functions on 10 data structures."

- Alan Perlis, first recipient of the Turing Award

- Clojure extends the "list processing" paradigm to other data structures by abstracting over them with a consistent API
- All data structures implement the "Collection" abstraction ("coll" for short)

# The Collection Abstraction

Abstracing data structures based on shared APIs allows Clojure to optimize them under the hood.

- Even the same data structure may implement functions differently based on the number of elements
- It's often faster to implement higher order functions with Java methods than recursive Clojure functions.

- The Clojure compiler is a mix of Clojure and Java code, with APIs managed by Java interfaces
- Clojure encapsulates this using parametric polymorphism in the form of *protocols* (covered later)
- It's important to understand what particular implementation is being used in order to write performant code, but more specific details are beyond the scope of this workshop
- If you're interested, there's a link to the source for every function in the cheatsheet. Don't be afraid, the Clojure compiler is very accessible!

# Types of Collections

## Lists

- S-expresions starting with `list` or `quote`
- Example: `'(1 2 3)`

# Types of Collections

## Vectors

- Ordered, like lists but more performant
- Square brackets
- Example: `["foo" "bar" "baz"]`

# Types of Collections

## Maps

- Associates keys with values
- Unordered, except for `sorted-map` and `array-map`
- Curly brackets
- Example:
  `{:language "Clojure", :creator "Rich Hickey"}`

# Types of Collections

## Sets

- Unordered
- Elements can only appear once
- Curly brackets preceded with hashtag
- Example:

  ```
  #{"clojure" "scheme" "haskell" "ocaml" "scala"}
  ```

- Not covered in this workshop

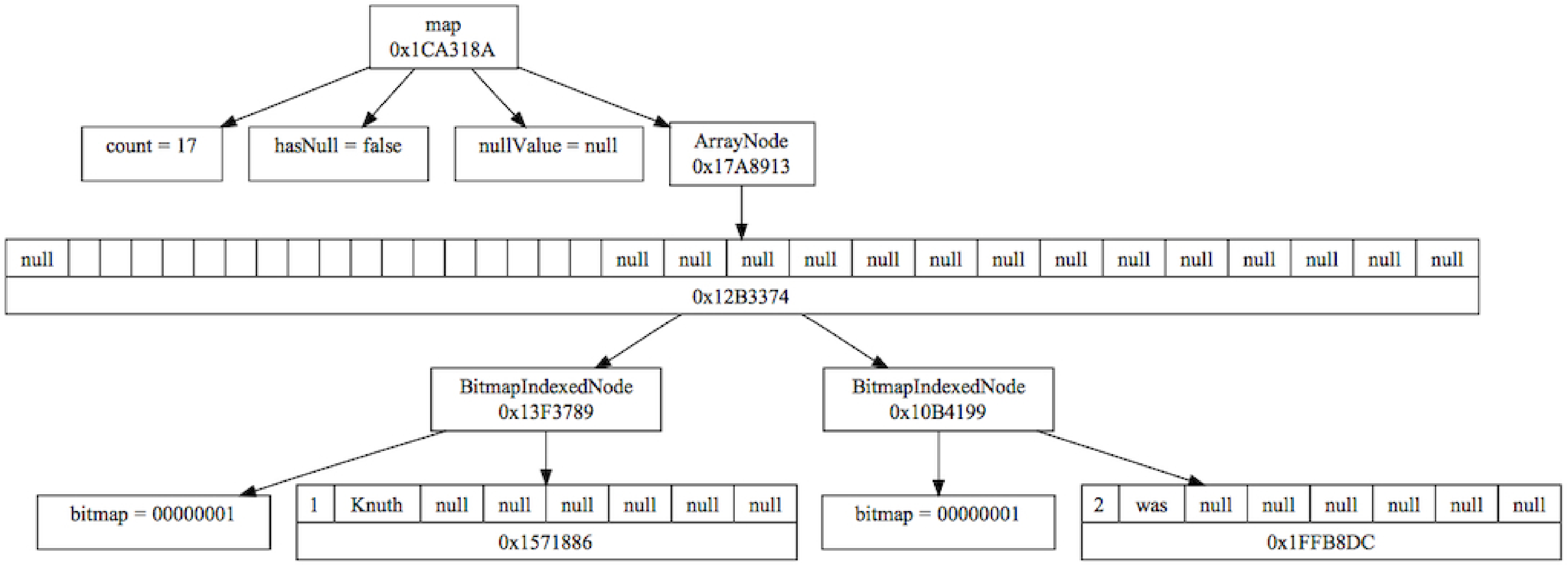
# Under the Hood

All collections except for linked lists are "tries."

- Name comes from "retrieval"
- Officially pronounced like "tree," but commonly pronounced like "try" so as to avoid confusion
- Invented in 1959, but became popularized in Chris Okasaki's *Purely Functional Data Structures* (1998)

- Trees with data *only* stored in leaves
- Location in tree determines location (index or key) of value
- Grow dynamically when new values are added (preallocation unnecessary)

# Under the Hood: Maps & Sets



map
0x1CA318A

count = 17

hasNull = false

nullValue = null

ArrayNode
0x17A8913

null null null null null null null null null null null null null null null

0x12B3374

BitmapIndexedNode
0x13F3789

BitmapIndexedNode
0x10B4199

bitmap = 00000001

1 Knuth null null null null null null

0x1571886

bitmap = 00000001

2 was null null null null null null

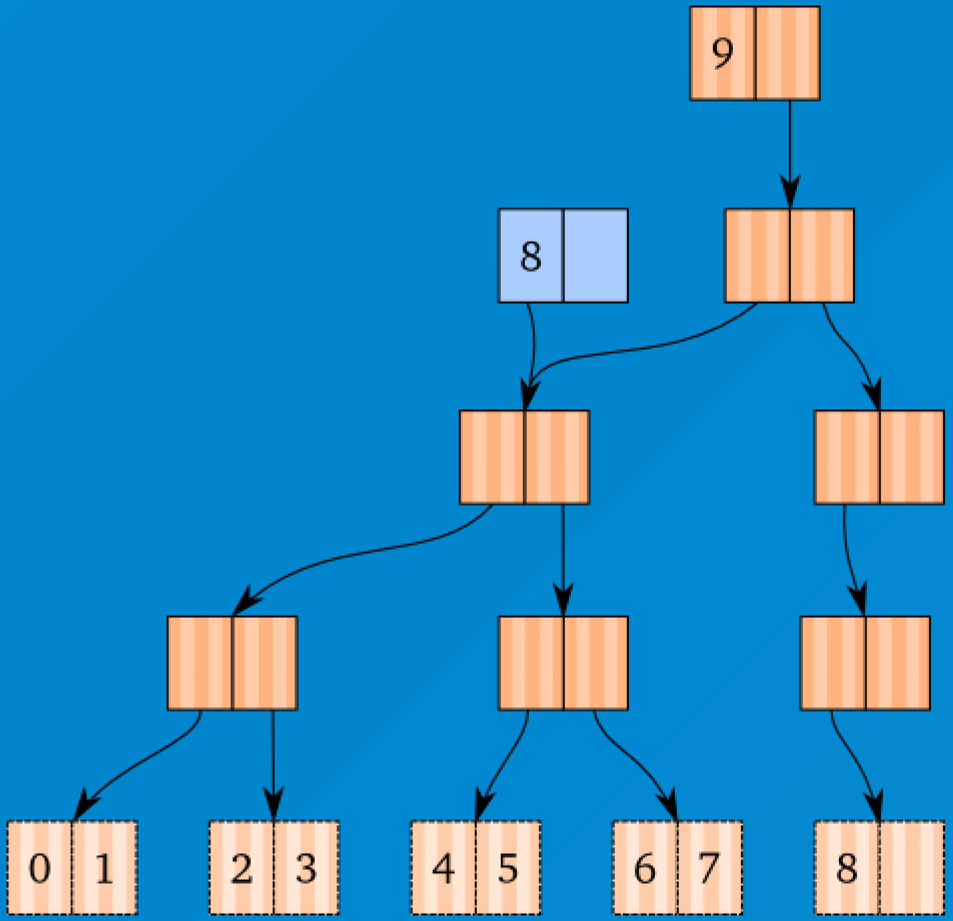
0x1FFB8DC

Maps and Sets are "hash array mapped tries" (HAMTs)

# HAMTs

- Invented by Phil Bagwell in "Ideal Hash Trees" (2000) then implemented in Scala
- Optimized for immutable key-value storage
- As name implies, keys are hashed to ensure constant length
- *Most of the time* faster for all common operations than hash-tables using buckets
- Lookup can often be done in constant time, although worst-case is linear

# Under the Hood: Vectors



Clojure vectors are 32-array binary search tries

## Clojure Vectors

- Invented by Rich Hickey
- Binary structure means logarithmic time from root to leaf…
- …except in this case each node has up to 32 children (unlike image above)…
- …meaning log32 time, which is *effectively* constant

- This makes large vectors extremely efficient, even into millions of elements
- Time complexity applies for most common operations: append, update, lookup, and taking subvectors
- However, *not* for prepending: unlike lists, new elements go at the end
- Vectors make ideal stacks: `conj`, `pop`, `peek`

# Collection Functions

All collections share a basic API

- `=`: checks value equality of a collection compared to other collections
- `count`: returns number of elements in a collection
  - Takes linear time so use sparingly!

- `conj`: adds an item to a collection in the most efficient way (short for "conjoin")
    - Note: "most efficient" means in a different place for each collection type. Be careful!
- `empty`: returns an empty collection of the same type as the argument
- `seq`: gets a sequence of a collection

# How to Work With Lists, Vectors, and Maps Coming Up in Part II...