Speaking Data:

Simple, Functional Programming with Clojure

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Overview

- Clojure in ten ideas
  - “The key to understanding Clojure is ideas, not language constructs” - Stu Halloway
  - Everything I say about Clojure is true for ClojureScript too
- Software engineering with Clojure
  - Why Clojure? Why now?
  - Community / Ecosystem / Support
- Clojure applied
  - Walmart eReceipts / “Savings Catcher”
  - Boeing 737 MAX diagnostics system
  - DRW Trading

Overview: Clojure

- Getting Started / Docs / Tutorials - https://clojure.org/
- A Lisp dialect (Lisp-1), small core, code-as-data
- Functional, emphasis on immutability, a language for data manipulation
- Symbiotic with an established platform
- Designed for concurrency, managed state
- Compiled, strongly typed, dynamic
- Powerful polymorphic capabilities
- Specifications are first-class
- Clojure programs are composed of expressions

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Extensible Data Notation (edn)

- Extensible data format for the conveyance of values
- Rich set of built-in elements, generic dispatch/extension character
  - Domain can be fully captured and expressed in extensions
- Extensions to the notation are opt-in
- Clojure programs are expressed in edn; Serializable form of Clojure
- https://github.com/edn-format/edn

Extensible Data Notation (edn)

```
{ :firstName "John"
  :lastName "Smith"
  :age 25
  :address {
    :streetAddress "21 2nd Street"
    :city "New York"
    :state "NY"
    :postalCode "10021" }
  :phoneNumber
    [ {:type "name" :number "212 555-1234"}
      {:type "fax" :number "646 555-4567" } ] }
```

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Extensible Data Notation (edn)

type	examples
string	`"foo"`
character	`\f`
integer	`42, 42N`
floating point	`3.14, 3.14M`
boolean	`true`
nil	`nil`
symbol	`foo, +`
keyword	`:foo, ::foo`

Extensible Data Notation (edn)

type	properties	examples
list	sequential	`(1 2 3)`
vector	sequential and random access	`[1 2 3]`
map	associative	`{:a 100 :b 90}`
set	membership	`#{:a :b}`

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Extensible Data Notation: Clojure

semantics: fn call arg

```
(println "Hello World")
```

structure: list symbol string

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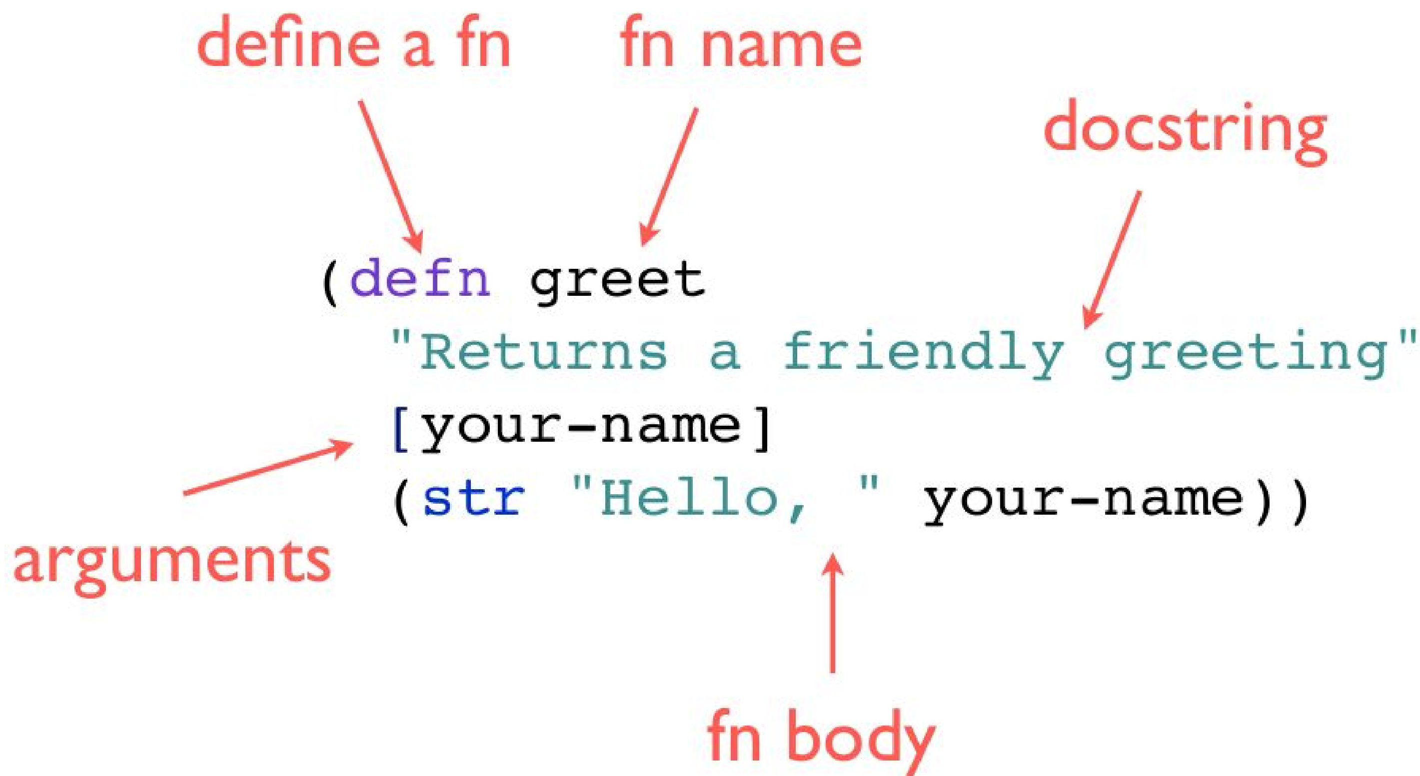
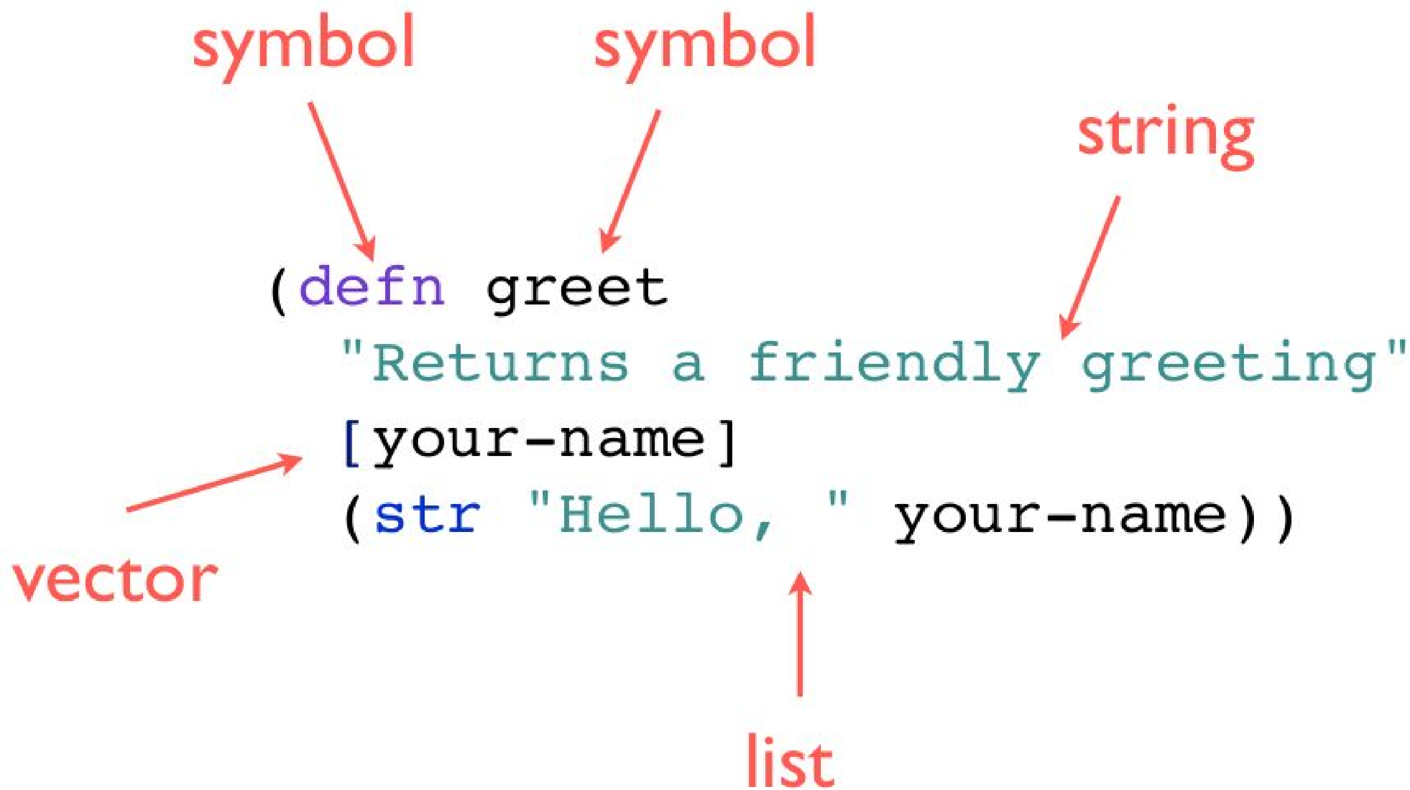
Extensible Data Notation: Clojure



Extensible Data Notation: Clojure



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Extensible Data Notation: Generic Extension

- #name edn-form
  - *name* describes the interpretation/domain of the element that follows
  - Recursively defined
- Built-in tags
  - #inst “rfc-3339-format”
    - Tagged element string in RFC-3339 Format
    - #inst “1985-04-12T23:20:50.52Z”
  - #uuid “canonical-uuid-string”
    - Tagged element is a UUID string
    - #uuid “f81d4fae-7dec-11d0-a765-00a0c91e6bf6”

Persistent Data Structures

- Immutable
- “Change” is by function application
- “Change” produces a new collection; structurally shared
  - Full-fidelity old version remains available
- Maintains performance guarantees
- Built upon linked lists and hash array mapped tries (HAMTs)

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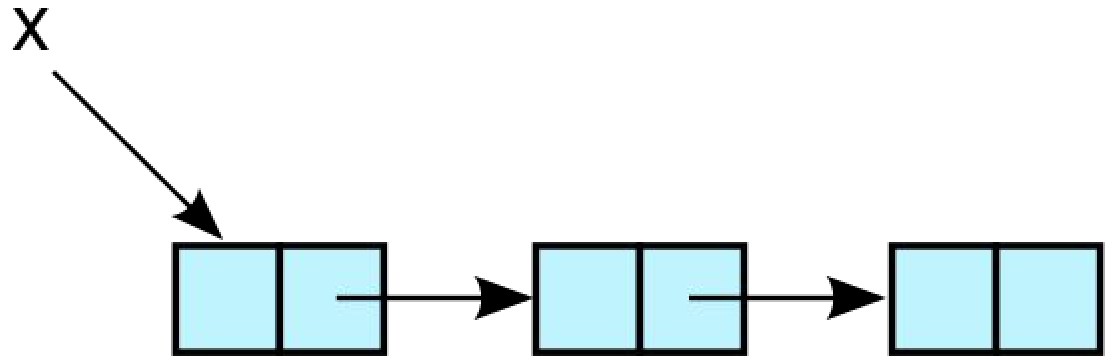
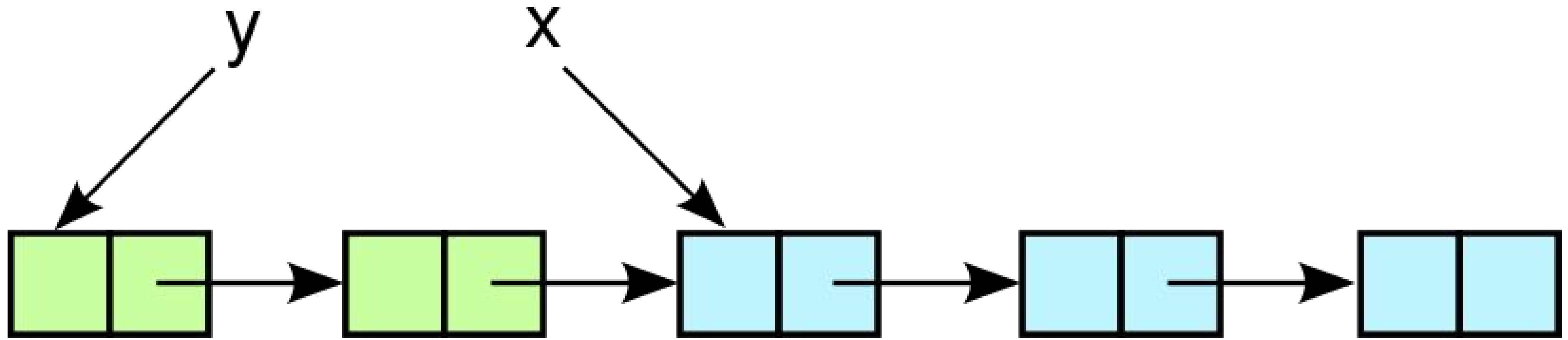
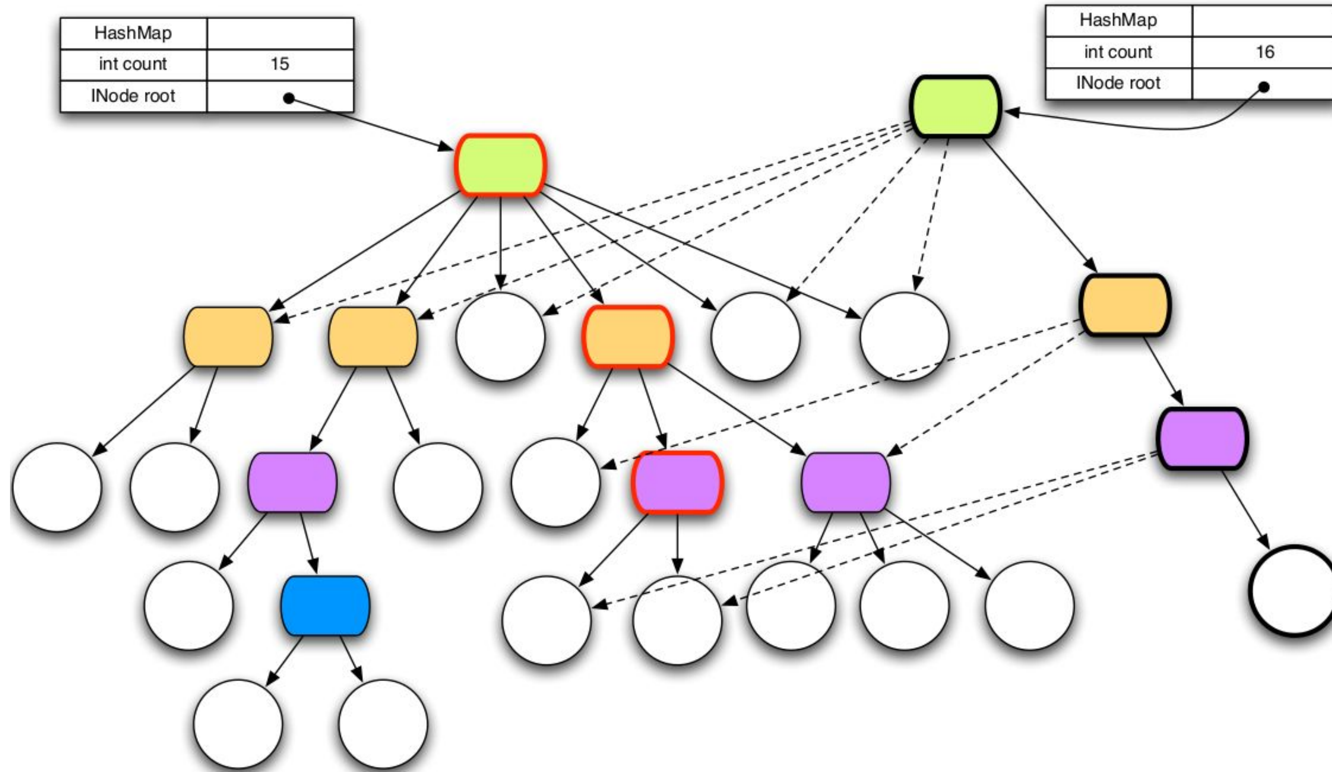
Persistent Data Structures



Persistent Data Structures



Persistent Data Structures



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Persistent Data Structures

Characteristic	Mutable, Transient	Immutable, Persistent
Sharing	difficult	trivial
Distribution	difficult	easy
Concurrent Access	difficult	trivial
Access Pattern	eager	eager or lazy
Caching	difficult	easy
Examples	Java, .Net Collections Relational DBs Place-Oriented Systems	Clojure, F# Collections Datomic DB Value-Oriented Systems

Persistent Data Structures

Functions:

Action	List	Vector	Map	Set
Create	list , list*	vector, vec	hash-map, sorted-map	set, hash-set, sorted-set
Examine	peek, pop, list?	get, nth, peek, vector?	get, contains?, find, keys, vals, map?	get, contains?
“Change”	conj	conj, assoc, subvec, replace	assoc, dissoc, merge, select-keys	conj, disj

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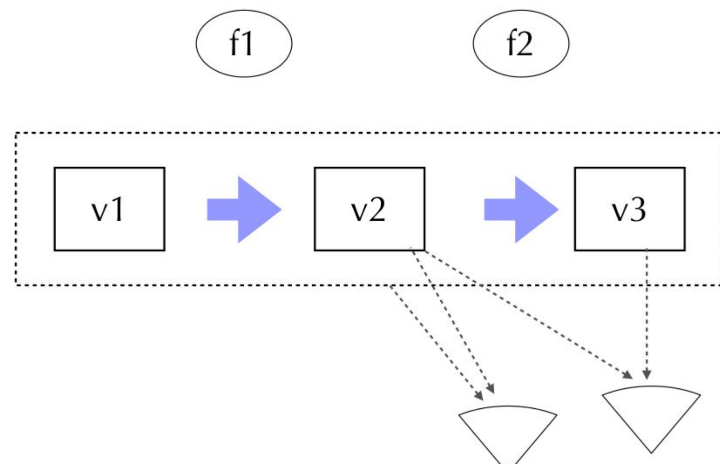
Unified Succession Model

- Separation of State and Identity
  - Identities are managed references to immutable values
    - References refer to point-in-time value
  - Values aren't updated in-place
  - Function application moves state forward in "time"
  - References see a succession of values
  - (*change-state* reference function args*)
- Clojure provides reference types
  - Synchronous
    - Var, Atom (uncoordinated)
    - Ref (coordinated; Uses STM)
  - Asynchronous
    - Agent



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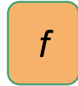
Unified Succession Model

Value

Given some value

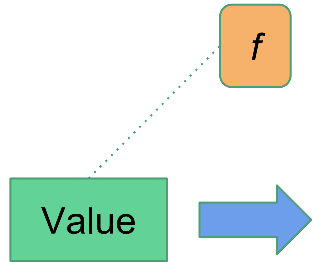
Unified Succession Model



Value

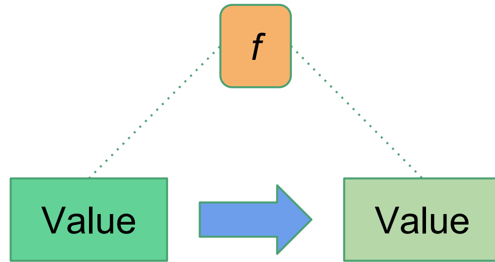
Given some function

Unified Succession Model



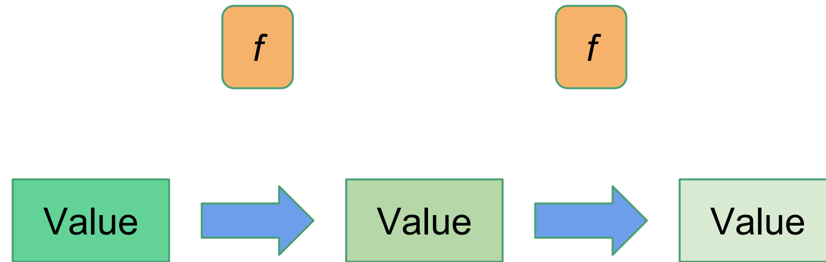
Atomically apply the function to the value; “Atomic Succession”

Unified Succession Model

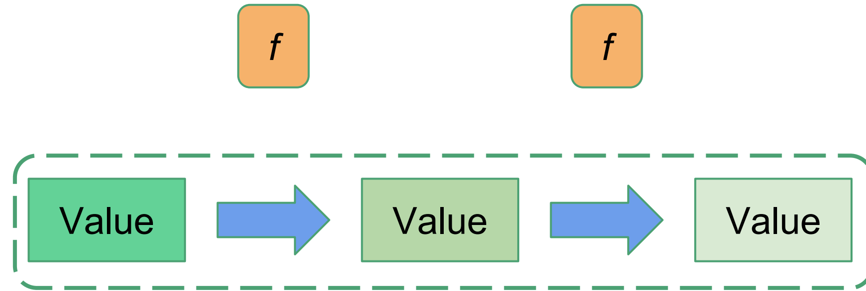


Which results in a new value, at a new point in time

Unified Succession Model

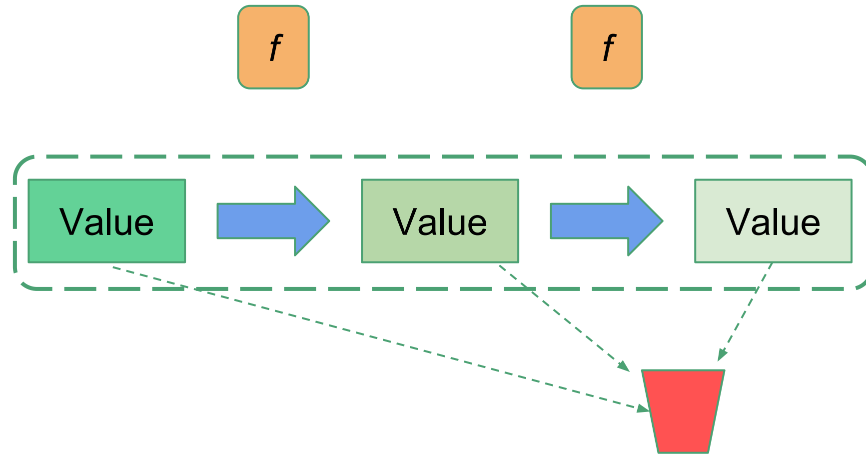


Unified Succession Model



A reference sees a succession of values

Unified Succession Model



Observers perceive identity; can see each value, can remember and record

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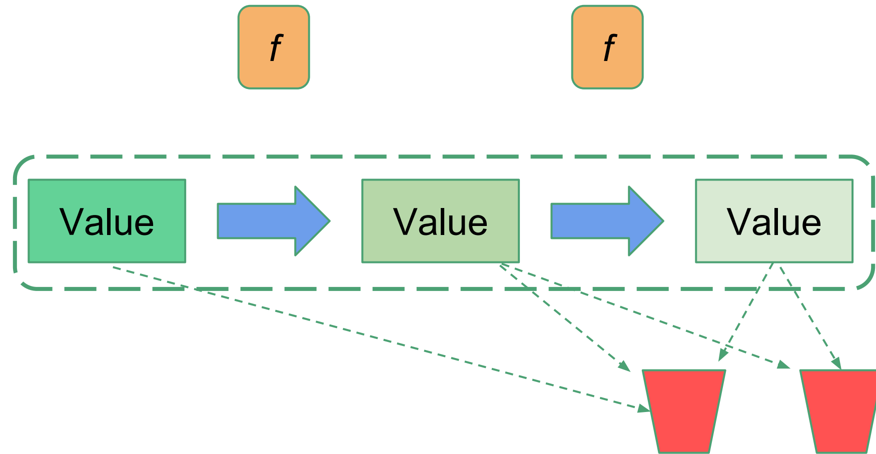
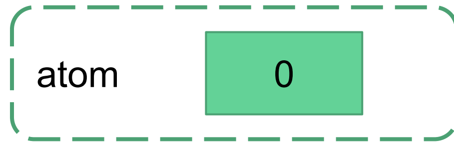
Unified Succession Model



Observers do not coordinate

Unified Succession Model



(def counter (atom 0))

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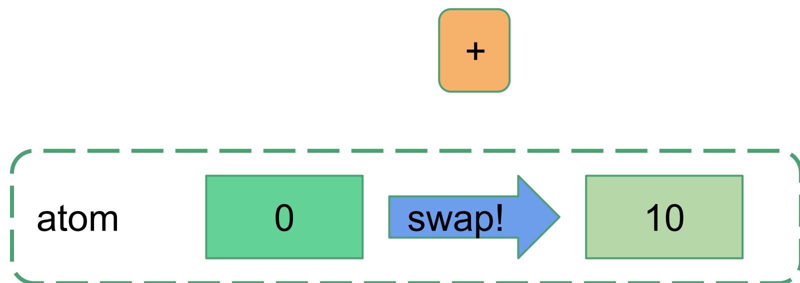
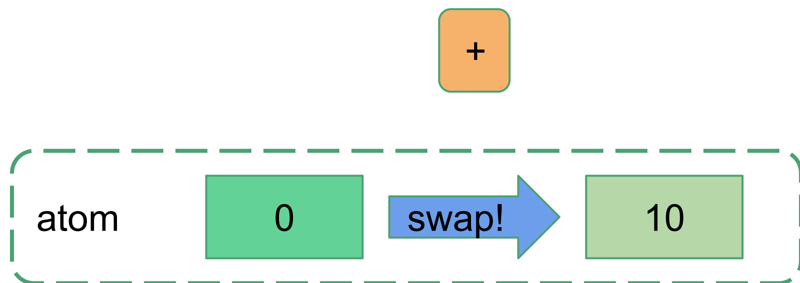
Unified Succession Model




```
(def counter (atom 0))
(swap! counter + 10)
```

Unified Succession Model




```
(def counter (atom 0))
(swap! counter + 10)
```

Atomic Succession

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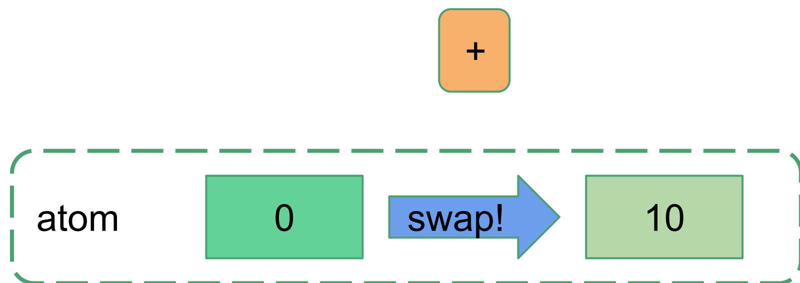
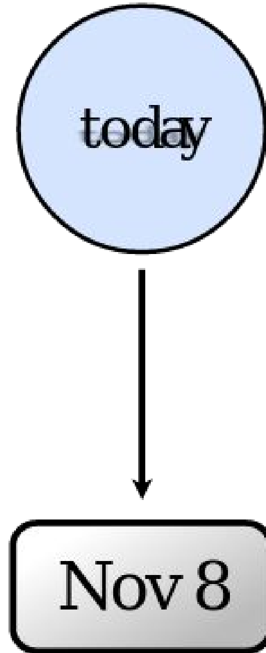
Unified Succession Model



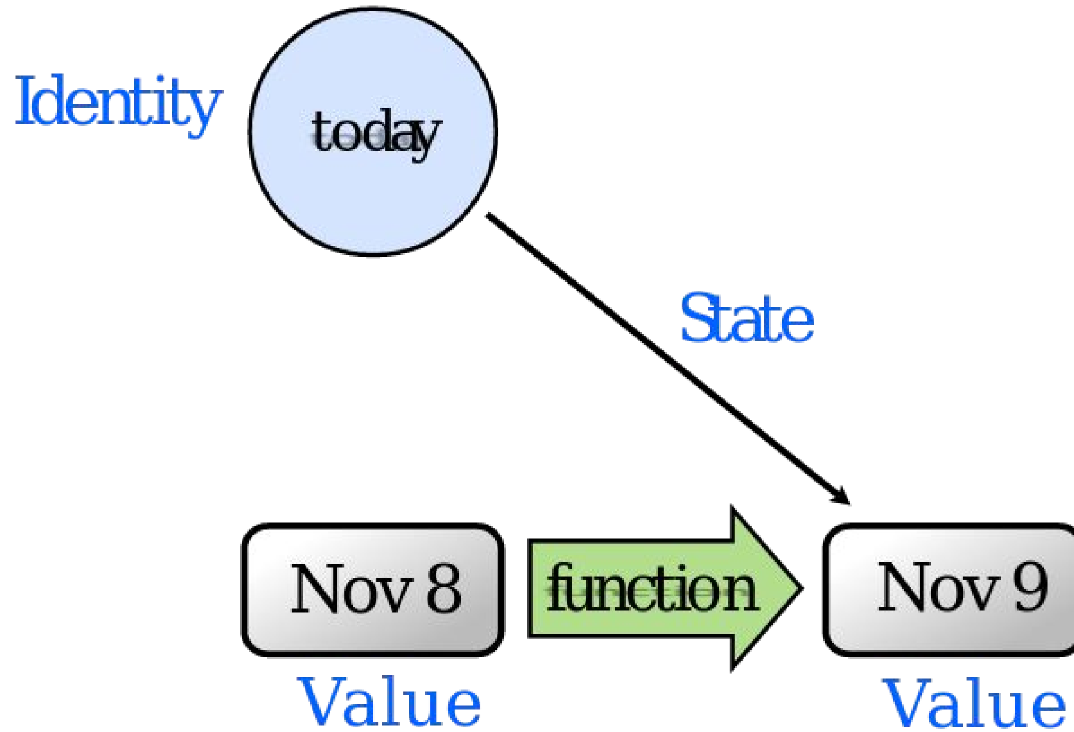

```
(def counter (atom 0))
(swap! counter + 10)
```

Pure function

Unified Succession Model



Unified Succession Model



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Sequence Abstraction

- Clojure is a language programmed to interfaces/abstractions
    - Collections are interfaces, Java interfaces for interop, etc.

- Sequence interface unifies the foundation
    - Sequential interface
    - Used like iterators/generators, but immutable and persistent

- "It is better to have 100 functions operate on one ~~data structure~~ abstraction than 10 functions on 10 ~~data structures~~ abstractions."

- Clojure's core is made up of functions of data-oriented interfaces/abstractions
    - Seqs work everywhere: collections, files/directories, XML, JSON, result sets, etc

Sequence Abstraction

- first / rest / cons
  - (first [1 2 3 4])
    -> 1
  - (rest [1 2 3 4])
    -> (2 3 4)
  - (cons 0 [1 2 3 4])
    -> (0 1 2 3 4)

- take / drop
  - (take 2 [1 2 3 4])
    -> (1 2)
  - (drop 2 [1 2 3 4])
    -> (3 4)

- Lazy, infinite
  - (iterate inc 0)
    -> (0 1 2 3 4 5 ...)
  - (cycle [1 2 3])
    -> (1 2 3 1 2 3 1 2 3 ...)
  - (repeat :a)
    -> (:a :a :a :a ...)
  - (repeatedly (fn [ ] (rand-int 10)))
    -> (3 7 1 4 6 7 4 7 ...)

Sequence Abstraction

- map / filter / reduce
  - (range 10)
    -> (0 1 2 3 4 5 6 7 8 9)
  - (filter odd? (range 10))
    -> (1 3 5 7 9)
  - (map inc (range 10))
    -> (1 2 3 4 5 6 7 8 9 10)
  - (reduce + (range 10))
    -> 45
- Fibonacci Sequence
  - (def fibo
    (map first (iterate (fn [[a b]] [b (+ a b)]) [0 1])))
  - (take 7 fibo)
    -> (0 1 1 2 3 5 8)
  - (into [ ] (take 7 fibo))
    -> [0 1 1 2 3 5 8]

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Sequence Abstraction

- What actors are in more than one movie, topping the box office charts?
  - Find the JSON input data of movies
  - Download it
  - Parse the JSON into a value
  - Walk the movies
  - Accumulating all cast members
  - Extract actor names
  - Get the frequencies
  - Sort by the highest frequency

Sequence Abstraction

- What actors are in more than one movie, topping the box office charts?

```
(->> “http://developer.rottentomatoes.com/docs/read/json/v10/Box_Office_Movies”
     slurp
     json/read-json
     :movies
     (mapcat :abridged_cast)
     (map :name)
     frequencies
     (sort-by val >)))
```

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Reducers

```
(->> apples
     (filter :edible?)
     (map #(dissoc % :sticker))
     count)
```

```
(ns ...
  (:require [clojure.core.reducers :as r]))

(->> apples
     (r/filter :edible?)
     (r/map #(dissoc % :sticker))
     (r/fold counter))
```

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Transducers

- Composable algorithmic transformations
    - Independent of/decoupled from their input and output sources
- A single “recipe” can be used many different contexts/processes
    - Collections, streams, channels, observables, etc.
- On-demand transformation characteristics
    - Decide between eager or lazy processing, per use (separate from the “recipe”)
- Same sequence API, without the source sequence

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Transducers

- map / filter
  - (filter odd?) ;; returns a transducer that filters odd
  - (map inc) ;; returns a mapping transducer for incrementing

- take / drop
  - (take 5) ;; returns a transducer that will take the first 5 values
  - (drop 2) ;; returns a transducer that will drop the first 2 values

- Composition is function composition
  - ```
    (def recipe  (comp (filter odd?)
                       (map inc)
                       (take 5))
    ```

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    ```

Protocols

- Named set of generic functions
- Provide a high-performance, dynamic polymorphism construct
  - Polymorphic on the type of the first argument
- Specification only; No implementation
- Open extension after definition

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Protocols

```
(defprotocol AProtocol
  "A doc string for AProtocol abstraction"
  (bar [a b] "bar docs")
  (baz [a] "baz docs"))
```

Protocols

```
(defprotocol AProtocol
  "A doc string for AProtocol abstraction"
  (bar [a b] "bar docs")
  (baz [a] "baz docs"))
```

```
(baz “hello”)
```

```
java.lang.IllegalArgumentException:
No implementation of method: :baz
of protocol: #'user/AProtocol
found for class: java.lang.String
```

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Protocols

```
(defprotocol AProtocol
  "A doc string for AProtocol abstraction"
  (bar [a b] "bar docs")
  (baz [a] "baz docs"))

(extend-protocol AProtocol
  String
  (bar [a b] (str a b))
  (baz [a] (str “baz-” a)))

(baz “hello”)  =>  “baz-hello”
```

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Protocols (and other forms of polymorphism)

Closed for Extension	Open for Extension
Dispatch maps	Multiple dispatch / multimethods
Conditional dispatch	Protocols (type of first arg only)
Pattern-matching dispatch	

Programming models are libraries

- “Program in data, not in text”
  - Program manipulation is data manipulation
- Extend the language using the language
  - Functions, macros, extensible reader (edn)
- Build the language up to your domain
  - What’s the ideal way to solve your exact problem?
  - You never need to wait for the language to evolve
- Examples
  - core.async
  - core.logic

Programming models are libraries: core.async

- Async programming using channels and CSP
- No bytecode rewriting, no Clojure modifications -- just a library
- Go blocks, IOC ‘threads’, parking, channels separate from buffers, etc.

```
(let [messages (chan)]
  (put! messages “ping”)
  (go  (println (<! messages))))
```

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Programming models are libraries: core.logic

- Logic programming as a library
- Prolog-like relational programming, constraint logic programming, and nominal logic programming
- Extensible to other forms of logic programming
- Sudoku solver, type inferencer, and more examples

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Programming models are libraries: core.logic

```
(defrel rps winner defeats loser)

(fact rps :scissors :cut :paper)
(fact rps :paper :covers :rock)
...
(fact rps :rock :breaks :scissors)

(run* [verb]
      (fresh [winner]
             (rps winner verb :paper)))
```

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clojure.spec

- Docs are not enough
- Predicative specifications of data
- Values, maps, and sequences
- Validation, error reporting, parsing/destructuring, instrumentation, test data generation, property-based generative test generation

clojure.spec

```
user=> (require '[clojure.spec :as s])
(s/def ::even? (s/and integer? even?))
(s/def ::odd? (s/and integer? odd?))
(s/def ::a integer?)
(s/def ::b integer?)
(s/def ::c integer?)
(def s (s/cat :forty-two #{42}
              :odds (s/+ ::odd?)
              :m (s/keys :req-un [::a ::b ::c])
              :oes (s/* (s/cat :o ::odd? :e ::even?))
              :ex (s/alt :odd ::odd? :even ::even?)))
user=> (s/conform s [42 11 13 15 {:a 1 :b 2 :c 3} 1 2 3 42 43 44 11])
{:forty-two 42,
 :odds [11 13 15],
 :m {:a 1, :b 2, :c 3},
 :oes [{:o 1, :e 2} {:o 3, :e 42} {:o 43, :e 44}],
 :ex {:odd 11}}
```

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Clojure: Software Engineering

- Modern language, built for modern systems, to build modern systems
- First-class specification & instrumentation; Design-by-contract
- Robust testing spans unit, generative property-based, and simulation testing
- Architecturally evident (namespaces), low cognitive load
- Ecosystems and reach

Clojure: Community and Ecosystems

- Mailing list / Slack / IRC / Events - https://clojure.org/community
- Community-driven examples and docs - https://clojuredocs.org
- IDE/Editor support, all with interactive development support
- Project tooling: Maven, Gradle, Boot, Leiningen, etc
- Professional Services, Support, Training from **Cognitect** - http://cognitect.com/
- Robust Web Services with **Pedestal** - http://pedestal.io/
- Rapid Microservices with **Vase** - https://github.com/cognitect-labs/vase
  - Microservices expressed as data/edn

Clojure applied: Walmart “Savings Catcher”

- Process and integrate every purchase
  - 5000+ physical stores
  - Online and mobile purchases
  - Globally distributed system and data

- Savings Catcher, Vudu Instawatch, Black Friday 1-Hour Guarantee

- 8 Developers

Clojure applied: Boeing 737 MAX Diagnostics

- Diagnostic system similar to car's "Check Engine" light
- Hundreds of sensors, streams of data, constant calculation
  - Value validations
  - Interdependent rules evaluation
  - Over 6,000 possible codes
  - Only 34,000 lines of Clojure
- Fully integrated into the flight-deck and ONS system (laptops/tablets/etc)
- "Clojure is a relatively new software language that allowed us to write rules and code capable of handling massive amounts of data under significant hardware limitations"
- Significant cost/time savings; Improved error detection and accuracy

Clojure applied: DRW Trading

- Already on the JVM; Existing systems in Java
- Needed “speed”
  - Execution performance important
  - Time-to-value-delivered
- Interactive-development increased productivity
  - Production debugging
  - Exploratory adaptations
- Domain dominated by data
  - Data-oriented abstractions simplified solutions
  - Whole classes/libraries turned into single Clojure functions