Clojure

pronounced the same as "closure"

"It (the logo) was designed by my brother, Tom Hickey. I don't think we ever really discussed the colors representing anything specific. I always vaguely thought of them as earth and sky." - Rich Hickey

"It I wanted to involve c (c#), l (lisp) and j (java). Once I came up with Clojure, given the pun on closure, the available domains and vast emptiness of the googlespace, it was an easy decision.." - Rich Hickey

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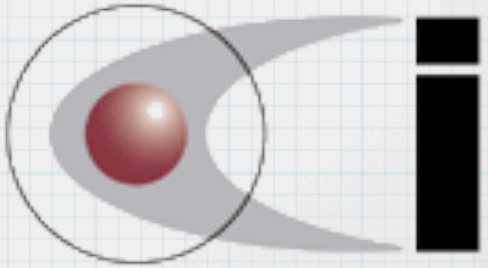


Core Beliefs ...

- Functional programming is important
  - helps with concurrency issues
    - emergence of multi-core processors makes this an issue for all kinds of applications
    - locking is too hard to use correctly
    - immutable data along with other mechanisms is easier
  - provides performance optimization
    - through code reordering by compiler
  - can make code easier to understand and test
    - the result of functions with no side-effects only depends on arguments
- Java platform (JVM) is the place to be
  - portability, stability, performance, security
  - access to existing Java libraries
    - no need to reinvent libraries for file I/O, database access, XML, and so on

Side-effects include:
changing values of global variables
and performing any kind of I/O

... Core Beliefs

* Dynamic types and polymorphism are good
  * see multimethods
* Lisp-like syntax is good
  * code and data have same representation
  * transformation from Java syntax to Lisp syntax
    * move { in method definitions to beginning
    * replace { with (and } with)
    * remove types (can specify type hints)
    * remove commas from argument lists
    * remove semicolon statement terminators
  * less "noise" than Java (4 -> 2 below)

```
myFunction(arg1, arg2); -> (myFunction arg1 arg2)
```

```
// Java
public void hello(String name) {
    System.out.println("Hello, " + name);
}

; Clojure
(defn hello [name]
  (println "Hello," name))
```

Side Effects

- In general, functions should not
  - rely on global data values (only their arguments)
  - modify global data values
  - perform I/O
- Especially for functions invoked in a transaction
  - because they may be invoked more than once if the transaction must be rerun
- Some benefits
  - makes functions easier to understand and test
  - allows their execution to be reordered and parallelized
- It's up to you to avoid side effects
  - Clojure doesn't prevent them

"using purely functional programming is also not very useful since, if we allow no side effects, our program will do nothing except heat up the CPU" - Simon Peyton Jones

Clojure does provide the function `io!` which takes a set of expressions to execute. If it is executed inside a transaction, an `IllegalStateException` is thrown.

Clojure Key Features ...

- Functional, inspired by other languages
  - Lisp (syntax), Haskell (lazy evaluation), ML, Erlang
- Concise
  - results in shorter programs which are easier to write and maintain
- Lisp syntax
  - with enhancements
  - code is data; can modify the language using the language
- Runs on JVM
  - popular, efficient platform that is constantly being improved
  - large number of available libraries
- Java interop
  - can call Java methods from Clojure code and Clojure code from Java

... Clojure Key Features

- Sequences - logical lists
  - examples include all Clojure and Java collections, streams, directory structures and more
- Concurrency without locks
  - important for multi-threaded, multi-processor applications
  - see refs, agents and atoms

Getting Clojure

- Prebuilt
  - download from http://clojure.org
- From source
  - `svn co http://clojure.googlecode.com/svn/trunk/ clojure-read-only`
  - `cd clojure-read-only`
  - `ant clean jar`
- clojure-contrib from source
  - the "standard library"
  - not well-documented yet; see examples in source
  - `svn co http://clojure-contrib.googlecode.com/svn/trunk/ \ clojure-contrib-read-only`
  - `cd clojure-contrib-read-only`
  - `ant clean jar`

REPL

- Read Eval Print Loop
  - an interactive shell for experimenting with Clojure code
  - like Ruby's irb
  - the "reader" reads program text and produces data structures (mostly lists)
  - these are evaluated to obtain results that are printed
- To start, run clj script - see next slide
- To load code from a file, `(load-file "file-path")`
- Special variables
  - result of last three evaluations are saved in `*1`, `*2` and `*3`
  - last exception is saved in `*e`
    - to see stack trace `(.printStackTrace *e)`
- To exit, press ctrl-d or ctrl-c

Running Clojure Code

* Create a script like this named clj - why isn't this supplied?
  * see http://en.wikibooks.org/wiki/Clojure_Programming/Getting_Started

```
#!/bin/bash
# Runs Clojure on a script file or interactively using a REPL.
CLOJURE_JAR=$CLOJURE_DIR/clojure-read-only/clojure.jar
CONTRIB_JAR=$CLOJURE_DIR/clojure-contrib-read-only/clojure-contrib.jar
BREAK_CHARS="(){}[],^%$#@\"\";:''|\\"
CP=$CLOJURE_JAR:$CONTRIB_JAR:$JLINE_JAR

# If there are no command-line arguments ...
if [ -z "$1" ]; then
  rlwrap --remember -c -b $BREAK_CHARS -f $HOME/.clj_completions \
  java -cp $CP clojure.main --init ~/user.clj --repl
else
  java -cp $CP clojure.lang.Script $1 -- $*
fi
```

rlwrap supports tab completion, paren matching, command recall across sessions, and vi or emacs keystrokes. See http://utopia.knoware.nl/~hlub/uck/rlwrap/. Another option is JLine.

For more options, run
`java -jar ./clojure/trunk/clojure.jar -help`

Hello World!

* hello.clj

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

* To run

```
$ clj hello.clj
```

Alternative
Add `#!/usr/bin/env clj` as first line of .clj files.
Run with `./hello.clj`

* To get documentation on any function, even ones you wrote

```
$ clj
user=> (doc function-name)
```

The `doc` function generates a description of the allowed arguments from the code and outputs the function doc-string if one was provided.

* To get documentation on all functions whose name or documentation match a given regex

```
$ clj
user=> (find-doc "regex-string")
```

For example, to find all the predicate functions,
`(find-doc "\\?$")`

Invoking From Java - Option 1

* From a Java application, read a text file containing Clojure code and invoke specific functions it defines

```
import clojure.lang.RT;
import clojure.lang.Var;
...
// path must be in CLASSPATH
RT.loadResourceScript("path/name.clj");
Var function = RT.var("namespace", "function-name");
function.invoke("arg1", "arg2", ...);
```

Invoking From Java - Option 2

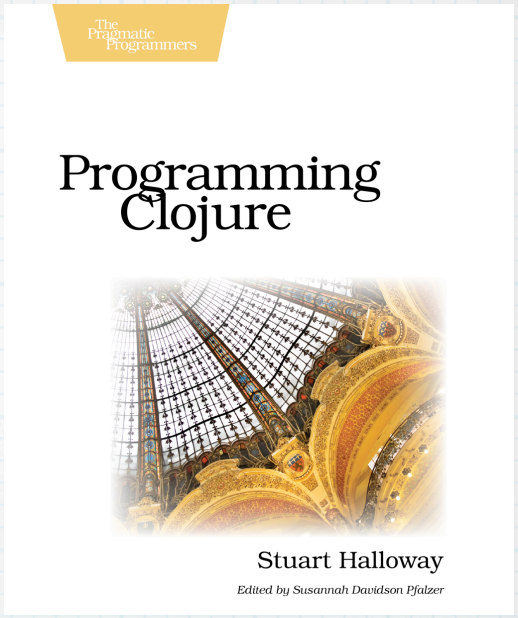
* Compile Clojure code to bytecode and use it from a Java application just like any other Java code
  * easy if your Clojure code implements an existing Java interface

```
(ns namespace
  (:gen-class :implements [java-interface]))

(defn -function-defined-in-interface [this arg1 arg2 ...]
  ...)
```

* Note
  * `defn` names for functions defined in the interface begin with "-"
  * every method takes an extra, first "this" argument
  * to generate the .class file, use `(compile namespace)` or `clojure.lang.Compile`

Books



- Only one now ... "Programming Clojure"
  - Stuart Halloway, Pragmatic Programmers
- Website
  - http://pragprog.com/titles/shcloj/programming-clojure
  - has example code, errata and a forum
- Running example code

```
$ clj
user=> (require 'examples.introduction)
user=> (take 10 examples.introduction/fibs)
```

  - `take` returns a lazy sequence of the first n items in a collection
  - namespaces are separated from names by a `/`
    - `examples.introduction` is the namespace of the `fibs` function

Processing Order

- Read-time
  - reader macros and "normal" macros are converted to non-macro forms
  - macros only evaluate their arguments if and when directed to do so
- Compile-time
  - forms, including function calls, are compiled to Java bytecode
  - not interpreted
- Run-time
  - Java bytecode is executed
  - functions evaluate all their arguments before running

Forms

* The Clojure "reader" looks for forms in program text and creates data structures from them
* Supported forms include
  * **no value** - `nil`; treated as false in boolean contexts; same as Java's null
  * **boolean** - `true` or `false`
  * **character** - `\char`, `\newline`, `\space`, `\tab` - uses java.lang.Character
  * **number** - integer, decimal or ratio; automatically uses BigInteger when needed
  * **keyword** - name that begins with `:`; like Java interned Strings
  * **symbol** - names things like variables and functions
    * composed of letters, digits (not first), `+ - / | ? . _`
  * **string** - `"char*"` - uses java.lang.String
  * **list** - `'( item* )` - allows duplicates; not indexable
  * **vector** - `[ item* ]` - similar to a list, but indexable like an array (w/ `get`)
  * **set** - `#{ item* }` - like list, but no duplicates
  * **map** - `{ item-pair* }` - each item-pair is a key and value separated by a space

Clojure collections

All forms except symbols and lists are literals, i.e. they evalute to themselves.

`6/9` is a ratio that will be represented by `2/3`. Math with ratios maintains precision.

`'foo` evaluates to the symbol `foo` evaluates to the value

lists are evaluated literally only if they are quoted

empty lists `()` evaluate to themselves

keywords and symbols have a name and an optional namespace

Clojure Collections

See diagram showing relationships at http://tinyurl.com/clojure-classes

- Include
  - lists - `'(items)` or `(list items)`
    - a singly linked list
    - without the quote it is evaluated as a function call
  - vectors - `[items]` or `(vector items)`
    - a dynamic array; can be treated as a map with integer index keys
    - often used in place of lists to avoid need to quote to avoid being evaluated as a function call
  - sets - `#{items}` or `(hash-set items)`
    - items must be unique
  - maps - `#{pairs}` or `(hash-map pairs)`
    - associative array of key/value pairs
  - sorted-set - `(sorted-set items)`
  - sorted-map - `(sorted-map pairs)` and `(sorted-map-by comparator pairs)`
  - and more that are used internally

... Clojure Collections ...

- All are immutable
- All are heterogenous
  - can hold a variety of types
- All are "persistent"
  - "support efficient creation of modified versions by utilizing structural sharing"
    - works because they are immutable
  - not related to persistent storage
    - see http://en.wikipedia.org/wiki/Persistent_data_structure

Vectors

- To create
  - `[:a 2 "three"]`
  - `(vector :a 2 "three")`
  - `(vec another-collection)`
- To access elements
  - indexes are zero-based
  - `(def my-vector [2 5 7])`
  - `(get my-vector 1) -> 5` - returns nil if index is out of bounds
  - `(nth my-vector 1) -> 5` - can throw IndexOutOfBoundsException
  - `(my-vector 1) -> 5` - vectors are a function of their indexes
  - integers are not functions of vectors - can't use `(1 my-vector)`

Sets

- To create
  - `#{}` - an empty set
  - `#{:a 2 "three"}`
  - `(set :a 2 "three")`
- To put an empty set into a variable,

```
(def mySet (ref #{}))
```

- To add a value to the set,

```
(dosync (commute mySet conj value))
```

  - dosync evaluates its argument in an STM
  - yikes that's verbose!
- To dereference the set from the variable
  - `(deref mySet)`

Maps ...

- To create
  - `{ key1 value1 key2 value2 ... }`
  - often keywords are used for keys because comparing them is fast
    - can get the name of a keyword as a string - `(name :foo) -> "foo"`
  - `(def my-map {:a 1 :b 2})`
- To get the value of a key, returning nil if not found
  - `(get map key)` or `(get map key not-found-value)`
  - maps are functions of keys and keys are functions of maps
  - `(map key) or (key map)`
  - `(my-map :b) or (:b my-map)`
- To get an entry, returning nil if not found
  - `(find map key)`
  - `(find my-map :b) -> <:b 2>` (printed form of an entry)

use `key` and `val` functions to get pieces of an entry

... Maps

- To determine if a key is present
  - `(contains? map key)`
- To get a new map with entries added
  - `(assoc map key value key value ...)`
  - `(assoc my-map :c 3 :d 4)`
- To get a new map with entries removed
  - `(dissoc map keys)`
  - `(dissoc my-map :a :c)`
- To get all the keys or all the values as a sequence
  - `(keys map)`
  - `(values map)`

Sequences ...

- Logical list of things; view on a collection
  - not a data structure
  - not a copy of the collection
- Immutable
- Supported by classes that implement the clojure.lang.ISeq interface
  - extends clojure.lang.IPersistentCollection
- Many types can be treated as sequences
  - Clojure and Java collections, strings, regex matches, streams, XML, directory structures, SQL results
  - most functions that operate on "seq-able" things begin by calling seq on their argument
  - when treating a map as a sequence, each key/value pair is a vector containing the key and value

... Sequences

- Operations supported for all sequences
  - get **first** - `(first seq)` instead of Lisp `car`
  - get **rest** - `(rest seq)` instead of Lisp `cdr`
    - returns a new sequences with the first item removed or nil (not an empty sequence; logically false) if the sequence only contains one item
    - nice because nil is logically false whereas an empty list is not
  - "**construct**" new sequence with one item added to front
    - `(cons item seq)` same as Lisp `cons`
    - can usually use `conj` instead
  - "**conjoin**" items to a sequence to create a new sequence
    - where the items are added depends on the collection type
    - `(conj seq items)`
  - get **size** - `(count seq)`
  - create a new, **empty** collection of the same type - `(empty seq)`
  - many sequence function eliminate the need to write loops

The Lisp **car** function stands for "contents of the address register". The Lisp **cdr** function stands for "contents of the decrement register".

Lists **conjoin** at front. Vectors **conjoin** at end. Maps **conjoin** key/value entries or whole other maps.

Lazy Sequences

- Most sequences are lazy
  - items are only evaluated when requested
  - allows processing of sequences that are larger than the available memory
  - can force evaluation of all items with `doall` function
- Examples of creating a lazy sequence

```
(defn f [x] (/ (* x x) 2.0))
(take 5 (map f (iterate inc 0)))
```

Result
```
(0.0 0.5 2.0 4.5 8.0)
```

can also use `lazy-cons`, `lazy-cat` and proxies to implement lazy sequences

```
(defn next-value [x]
  (println "next-value: x =" x) ; so we know if invoked
  (+ x x 1))
(let [start-value 2
      my-sequence (iterate next-value start-value)]
  (doseq [x (take 3 my-sequence)] (println x)))
```

Output
```
2
next-value: x = 2
5
next-value: x = 5
11
```

StructMaps ...

- Immutable maps used in place of Java Beans
- Optimized
  - each instance shares a common set of keys, so doesn't need to repeat them
  - can add entries with new keys not defined for the struct
- To define
  - use keywords for keys (start with a colon)
  - long way - `(def name (create-struct key+))`
  - short way - `(defstruct name key+)`
    - `defstruct` is a macro which can be changed if needed, for example, to add logging of instance creation
  - proper `hashCode` and `equals` methods are generated
  - example
    - `(defstruct car-struct :make :model :year :color)`

... StructMaps ...

* To create an instance
  * `(struct name value+)`
    * where the order of the values matches the order of the keys
  * example

```
(import '(java.awt Color))
```

    * `(def car (struct car-struct "Toyota", "Prius", 2009, Color/YELLOW)`
* To access fields
  * structs are maps
  * `(println (car :year) (car :model)) ; outputs 2009 Prius`

... StructMaps

```java
// Java way

public class Car {
    private String make;
    private String model;
    private int year;

    public Car(String make, String model, int year) {
        this.make = make;
        this.model = model;
        this.year = year;
    }
    public String getMake() { return make; }
    public String getModel() { return model; }
    public String getYear() { return year; }
}

Car c = new Car("BMW", "Z3", 2001);
System.out.println("The year is " + c.getYear);
```

```clojure
; Clojure way

; Define a struct (actually a StructMap) for cars.
(defstruct car :make :model :year)

; Optionally define an accessor function.
(def year (accessor car :year))

(let
  ; Create a struct instance.
  [c (struct car "BMW" "Z3" 2001)]

  (println "The year is" (c :year))

  ; Same using the accessor function.
  (println "The year is" (year c))
)
```

Destructuring

- Functions can take a collection and extract parts of it in the argument list
  - supported by `defn`, `fn`, `let` and `loop`
- With lists

underscore means don't care about corresponding item

```
(defn add-2nd-and-3rd [[_ p2 p3]] (+ p2 p3))
(add-2nd-and-3rd [3 4 5 6]) -> 9
```

- With maps

```
(defstruct car :make :model :year :color)
(defn print-color-and-model [{c :color m :model}]
  (println c m))
(def my-car (struct car "BMW" "Z3" 2001 "yellow"))
  (print-color-and-model my-car)
```

Defining Functions

* Example - need a different example from book

```
(defn greet [name]
  (println (str "Hello " name)))
```

* str converts a list of arguments to strings and concatenates them
* puts the function "greet" into the default namespace "user"
  * full name is user/greet
* Can also have a different body for each arity

```
(defn my-function
  ([] (prn "no ags"))
  ([x] (prn "one arg"))
  ([x y] (prn "two args")))
```