

Clojure

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COSC 3P93

Material Covered

- What is Clojure?
- Why do we care?
- What isn't it?
- Intro to Functional Programming
- Concurrency Support
- Conclusions

What is Clojure?

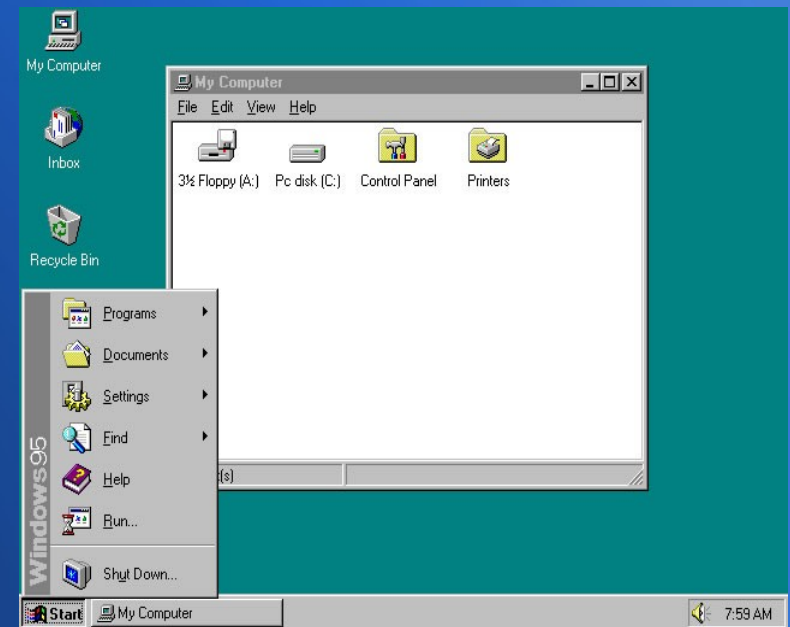
The Clojure Rationale

- Created by Rich Hickey in 2007
- A LISP
 - LISt Processing (or Lots of Irritating Superfluous Parentheses)
- For functional programming
 - Immutable Data
 - First Class Functions
- Exploiting Java
 - Compiles to bytecode (JVM run)
- Concurrency built-in
 - Not an after thought or library

Ok... So what?

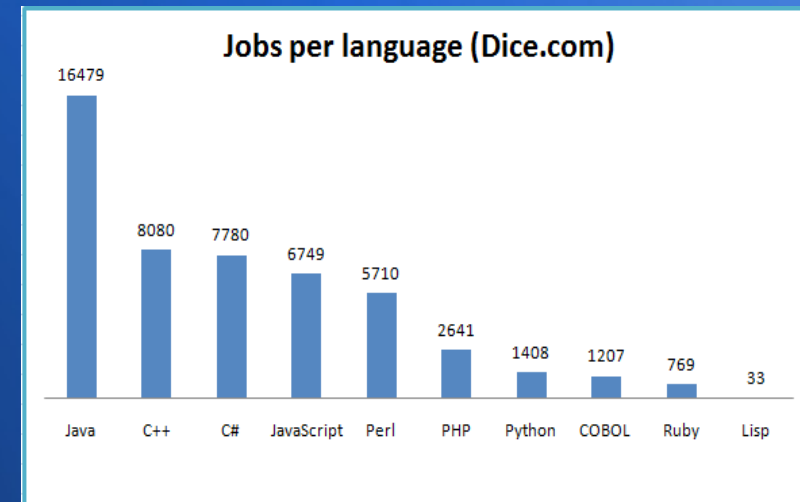
Backwards is Forwards

- Backwards compatibility matters
 - You already have programmers
 - You already have applications & libraries
 - You already have hardware
- Need concurrency? Now what?
 - Retrain, rewrite, replace, make do?
- Need to be realistic
 - A stepping stone to concurrent bliss



Exploit the Market

- Java is well established in the programming industry
 - Lots of trained programmers
 - Lots of applications, libraries and support
 - “Write once, run anywhere”
- Java Virtual Machine (JVM)
 - Incredibly well tested
 - Over 10 years of optimization and tuning
- Already established as a platform for non-Java languages
 - Jython, Jruby, Jscheme, Groovy, Scala, etc
 - Join the party. Bring a “j”.



Functional, or Dysfunctional?

- Immutable data perfect for concurrency
 - If you can't change it, you never need to worry
 - Synchronization, deadlock, etc
- “First class” functions
 - Make functions on the fly
 - Pass them around as data.
 - No “side effects”
- “Homoiconic”
 - Programs represented in the language's own datastructure
 - Code is data, data is code.
- “If you don't think carefully, you might believe that programming is just typing statements in a programming language.” - W. Cunningham

Threads and Locking? No thanks

- Threads and Locking
 - Complex!
 - Error prone
 - A debug nightmare
 - Potentially slow
- Concurrent from the start
 - Protect all memory
 - Higher level abstractions (like Ada's Tasking)



Too good to be true?

(defn fits-all? [x] (if (= x 'one-size) nil))

- No panaceas
 - one language isn't going to work for any and all applications
 - The benefits of the JVM come with drawbacks
 - Real hardware hidden.
 - Little control of operating system
 - No clusters or “bare metal” execution
 - Still LISP-y in syntax
 - New = Scary
-
- “There are only two kinds of programming languages: those people always bitch about and those nobody uses.” - B. Stroustrup

A Matter of Perspective

Java

C

PHP

Ruby

as seen by...

Java fanboys

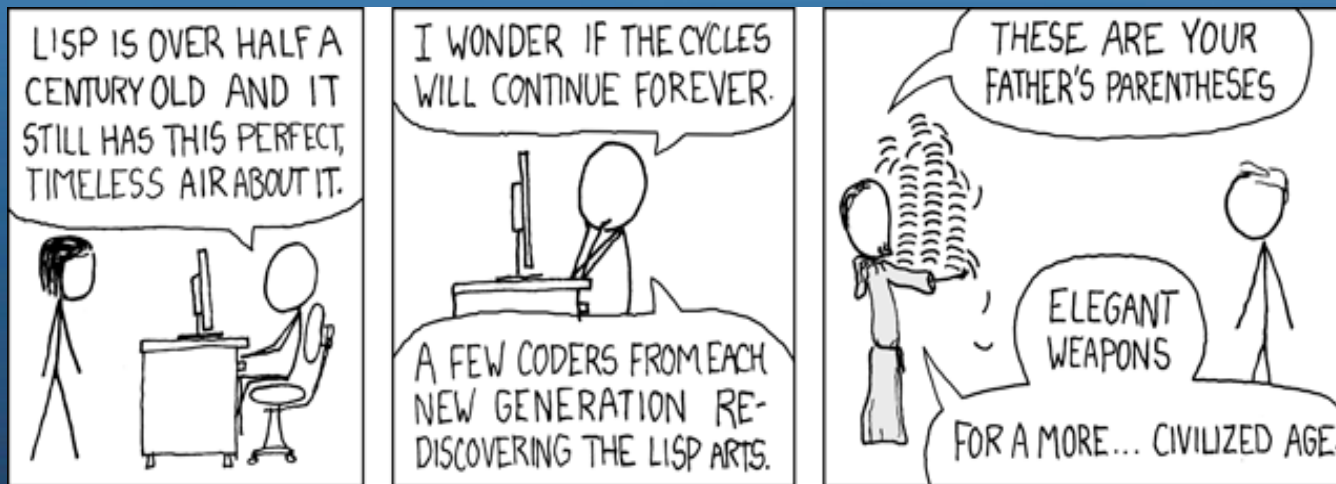
C fanboys

PHP fanboys

Ruby fanboys



LISP?

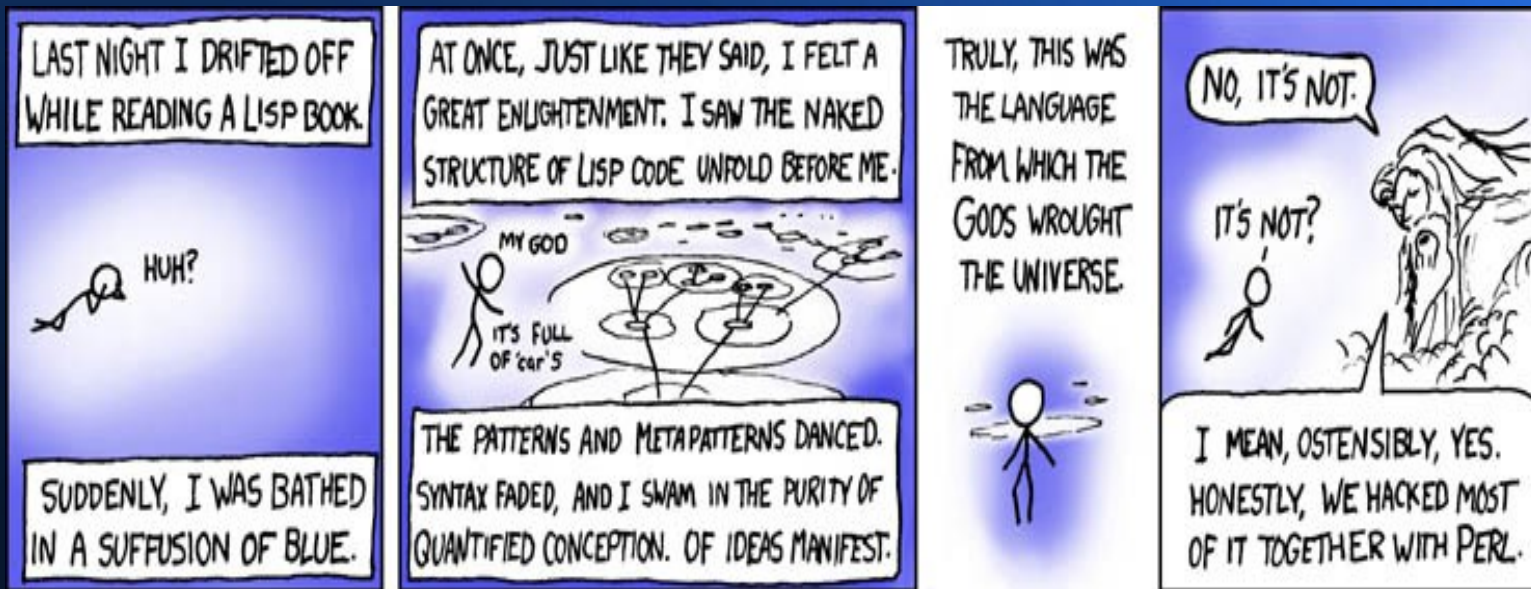


LISP!?! Why LISP?

- LISP will not die
 - John McCarthy, ~1958. Second oldest high level language.
 - Almost no core syntax to learn
 - Able to adapt to every new programming paradigm.
 - Code is data is code -> homoiconic
 - A “programmable programming language”
- Ahead of the curve
 - Read-Execute-Print model
 - “Often emulated, never duplicated”
- Math doesn't get stale!
 - “Recursive Functions of Symbolic Expressions and Their Computation by Machine, Part I”
 - Turing-complete algorithm language

Borrowing Credibility

- “A language that doesn't affect the way you think about programming is not worth knowing.” - A. Perlis
- “The tools we use have a profound (and devious!) influence on our thinking habits, and, therefore, on our thinking abilities.” - E. Dijkstra



Functional Programming

- A light-speed introduction to FP using Clojure
- If you've taken COSC2P90 – pretend you haven't...
- Resources at the end for the curious

The REPL

- LISP – the origin of iterative development
- A shell for experimental coding
- Read -> Evaluate -> Print -> Loop
- A programmer's best friend
- Code, Documentation, Testing, and Debugging in one.

```
daniel : screen
File Edit View Scrollback Bookmarks Settings Help
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65 (defn normalize-edges [edges]
66   "Removes any duplicate edges. Edges will be returned as a distinct
67   set of ordered edge connections indexed by the source node."
68   (letfn [(fixNode [nodes nodesLeft]
69     (if (empty? nodesLeft)
70         nodes
71         (recur (assoc nodes (first (first nodesLeft)) (set (second (first nodesLeft))
72           )) (drop 1 nodesLeft)))
73     (fixNode {} edges)
74   )
75 )
76
77 (defn make-graph [nodes edgeMap]
78   "Create a graph structure from a node list and an edge mapping"
79   (struct-map graph :nodes nodes :edgeMap (normalize-edges edgeMap) :synonyms 0)
80 )
81
82 (defn countEdges [g]
83   "Count the edges leading out of each node in a graph. The number of out
84   going edges for each node in the graph is returned in sorted order"
85   (sort (map #(count (second %)) (get-edge-map g))))
86
87 (defn same-graph? [graphA graphB]
88   "Two graphs are the same iff:
89   A) they have the same # of nodes
90   B) each has the same connection structure"
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```

Core Datatypes

- Numbers: `4`, `1.0`, `22/7`, `-9999999999999999`
 - Convert to `BigDecimal` as required
 - Built in ratio type
- Strings & Chars: `"Foo"`, `\f`
 - Unicode, pretty much the same as Java.
- List: `(+ 5 9 9.0)`
 - Used for function calls.
 - If you think of an "add" method in Java how do you call it? `add (5, 9);`
 - Put the function name inside the brackets too, more orthogonal `(add 5 9)`
 - Now understand that clojure's built in operators are functions too `(+ 5 9)`
- Vector: `[5, 9, 9.0]`

Core Datatypes (Cont'd)

- Dictionary/Mapping: `{ :key "value1" :key2 "value2" }`
 - Key to Value lookup table.
 - Allows for key missing default values, access to just values, just keys.
- Keyword: `:key`
 - Evaluate to themselves, used for fast equality checks
 - `(:key2 { :key "value1" :key2 "value2" })` results in `"value2"`
- Symbol: `'(someFunc 2 4)`
 - Code is data, we need a way to express code so it won't be run
 - Without the `'` shorthand for `quote()` Clojure will run `someFunc(2, 4)`

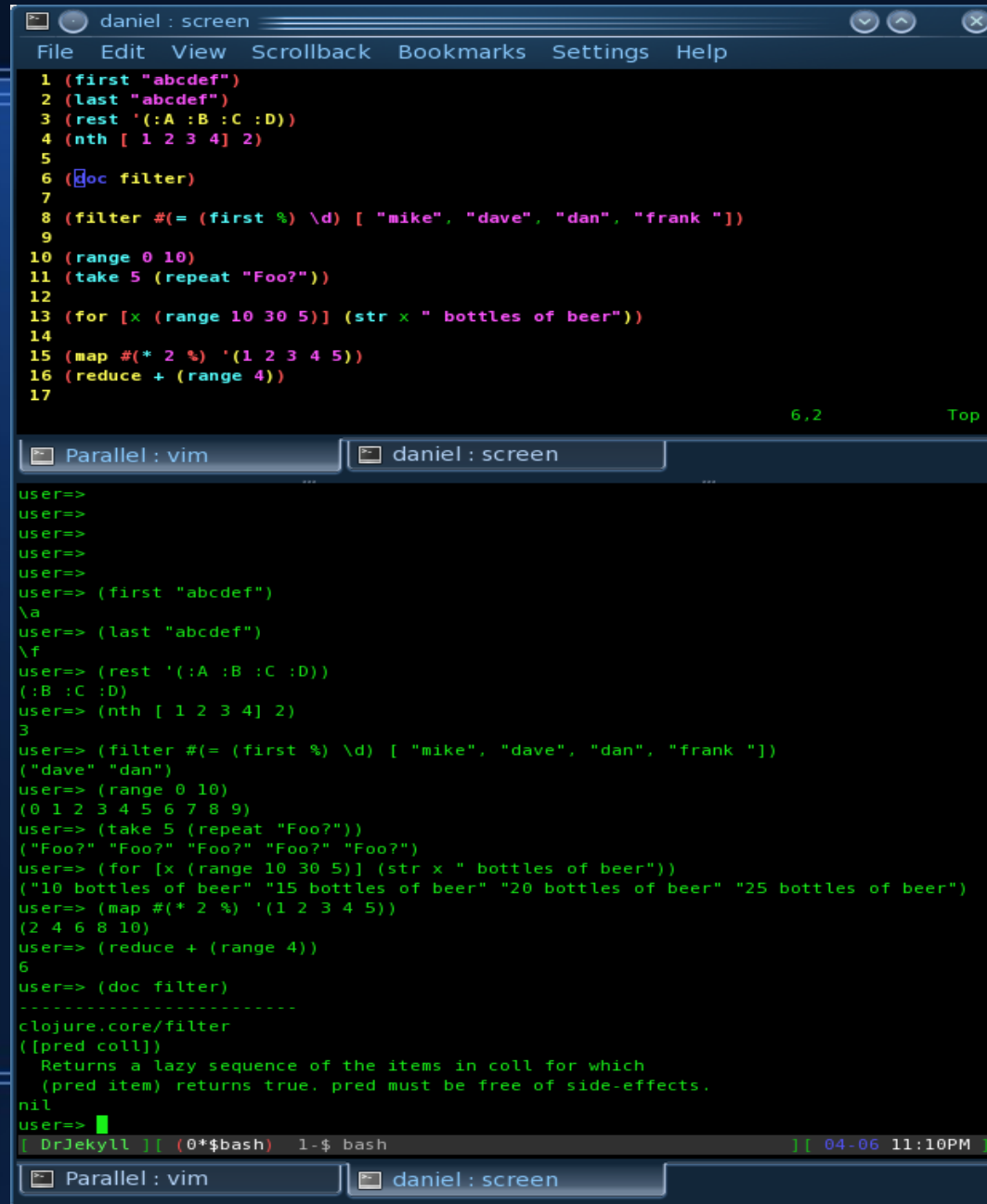
“One sequence to access them all, and in the bytecode bind them”

- Clojure *unifies* the majority of the mentioned data types under the Sequence interface.
- Accessing vectors, lists, maps, sets, and strings uniformly
 - `first`, `rest`, `cons`, `next`, `conj`, `into`
- Create sequences on the fly:
 - `Range`, `repeat`, `cycle`, `interleave`
 - “for” (see: python list comprehension)
- “Filter” sequences to find elements with specific properties
 - `filter`, `take-while`, `drop-while`
- Transform sequences
 - `map`, `reduce`, `sort`



- “Any sufficiently advanced technology is indistinguishable from magic.” - A. Clarke

Pies Code or it didn't happen.



The image shows a terminal window titled "daniel : screen" with a menu bar (File, Edit, View, Scrollback, Bookmarks, Settings, Help). The terminal contains Clojure code and its execution results. The code is as follows:

```
1 (first "abcdef")
2 (last "abcdef")
3 (rest '(:A :B :C :D))
4 (nth [ 1 2 3 4] 2)
5
6 (doc filter)
7
8 (filter #(= (first %) \d) [ "mike", "dave", "dan", "frank "])
9
10 (range 0 10)
11 (take 5 (repeat "Foo?"))
12
13 (for [x (range 10 30 5)] (str x " bottles of beer"))
14
15 (map #(* 2 %) '(1 2 3 4 5))
16 (reduce + (range 4))
17
```

The execution results are as follows:

```
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user=>
user=>
user=>
user=>
user=> (first "abcdef")
\ a
user=> (last "abcdef")
\ f
user=> (rest '(:A :B :C :D))
(:B :C :D)
user=> (nth [ 1 2 3 4] 2)
3
user=> (filter #(= (first %) \d) [ "mike", "dave", "dan", "frank "])
("dave" "dan")
user=> (range 0 10)
(0 1 2 3 4 5 6 7 8 9)
user=> (take 5 (repeat "Foo?"))
("Foo?" "Foo?" "Foo?" "Foo?" "Foo?")
user=> (for [x (range 10 30 5)] (str x " bottles of beer"))
("10 bottles of beer" "15 bottles of beer" "20 bottles of beer" "25 bottles of beer")
user=> (map #(* 2 %) '(1 2 3 4 5))
(2 4 6 8 10)
user=> (reduce + (range 4))
6
user=> (doc filter)
-----
clojure.core/filter
([pred coll])
  Returns a lazy sequence of the items in coll for which
  (pred item) returns true. pred must be free of side-effects.
nil
user=>
```

The terminal window also shows a taskbar at the bottom with tabs for "Parallel : vim" and "daniel : screen". The system tray at the bottom right shows the user "DrJekyll", the shell "(0*\$bash)", and the time "04-06 11:10PM".

The Art of Lazy

- **A lazy sequence:**
 - Elements not calculated until needed
 - Postpones expensive computations, delays I/O
 - Work with data sets bigger than your memory capacity
- Create “lazy sequences” on the fly out of function results
 - See “*yield*” in some other languages. Concept of a “**generator**”
- Other sequences already provided “lazy”
- Lazy sequences make it possible to have “infinite sequences”
 - If the next value is computable into infinity...
 - Compute the ones you need on a lazy basis

Of Wizards and Lambdas

- First class functions mean that we can pass them around as data
 - See `(reduce + (range 5))`
 - Passes the `+` function to the higher order function `reduce`
- Further, functions can be nested within other functions
- Functions can be created on the fly.
 - A `lambda` is an unnamed function. Similar to an anon. inner class in Java
 - Can use the `fn` function to specify a function with formal parameter names
 - Can use the `%()` reader macro to create a function that uses `%1` style tokens to access arguments
- Returning a function created on the fly to wrap a piece of data is “closing over” the data. Think: abstraction in OO terms (*private member scope*).

A while() before loops...

- Looping requires mutable state
 - Counter variables (i,j,k), boolean status flags (is_done, has_data)
- Functional programming uses recursion
- Clojure has no loops, only advanced recursion options.
- But what of performance?
 - Language support for Memoization
 - Partial tail-recursion
 - Libraries for easily “trampolining”



Java Inter-op

- Create new Java objects
 - `(new Random)`
- Call methods on the object
 - `(. (new Random) nextInt)`
- Masquerade as a subclass or an interface implementer
 - Runtime **proxy** function
 - Lets you take a binding of functions and get an object
 - Can save runtime computed bytecode to a .class file
- Clojure functions **all** implement the **Runnable & Callable** interfaces
 - Can immediately be run on their own thread. No changes required.

"Syntactic sugar causes cancer of the semicolon" - A. Perlis

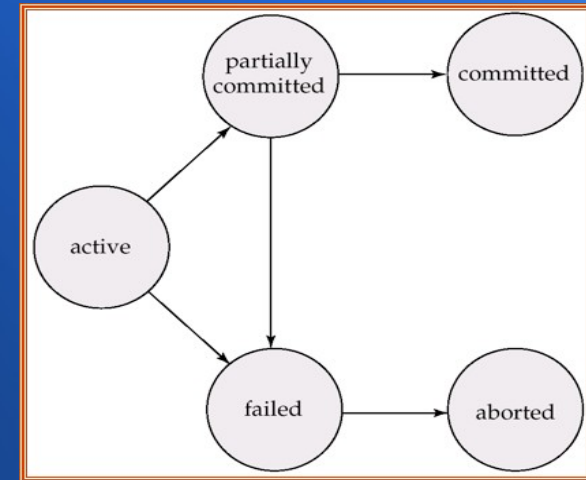
Concurrency

A problem

- Traditional concurrent programming (in particular Java) requires the programmer manage data access **very** carefully.
- Locking based schemes used to synchronize access to key resources.
 - Allows one one thread access at a time (*see: bottleneck*)
 - Not being careful leads to hard to reproduce deadlock and concurrent memory access issues.
- Clojure has a natural advantage due to it's pure functions and immutable data.
- For everything else Clojure provides a layer above memory that acts as a controller for concurrent modification without explicit programmer interaction.
- This layer is based on the concept of ACID transactions from enterprise database servers.

ACID (hallucination free)

- ACID is defined:
 - Atomicity
 - Consistency
 - Isolation
 - Durability
- Atomicity defines “all or nothing” behavior
- Consistency ensures that the system is always in a known state.
- Isolation requires that no other operations can access/view data from an in-progress transaction
- Durability ensures that once a user has been notified of a successful transaction result, the transaction will not be lost in the result of a crash.



Software Transactional Memory

- Clojure adapts the concept of ACID transactions to main memory
- References to mutable state created
- The reference can only be changed inside of a transaction
- Transactions are managed in an ACID fashion. If a transaction is queued, it will retry until successful. STM loses the “Durability aspect”. RAM Only.
- Very optimistic locking
 - Read-only access will never block writers or other readers.
 - “Speculative evaluation”, things may be undone, or re-tried inside of a transaction. Changes are isolated and can be undone if required.
- More noticeable overhead on small # of processors

Clojure Concurrency Library

- Clojure provides several options for concurrent code
- At the most fine grain level is the STM implementation and *refs*.
- *Atoms* manage *uncoordinated, synchronous* changes to shared state.
- *Agents* manage *asynchronous* changes to shared state.
- *Vars* manage *thread-local* state. (Dynamic rebinding)

Clojure Concurrency Library Contd.

- **Atoms**
- Protect a single ref from uncoordinated synchronous changes.
- Because they protect a singular reference an atom does not need to be updated inside of a transaction.
- As a side-effect, you can not update two atoms at once in a coordinated fashion.
- Lighter weight than directly using refs and transactions. Less for Clojure to protect you from.
- **Agents**
- Specialized for tasks that can proceed independently - minimal coordination.
- Comparable to Ada's tasking approach.
- Wrap an initial state and accept functions to update this state. Update funcs are queued, eventually run on their own thread.

Some Code

If time has permitted...

Counting node edges

```
(defn countEdges [g]
  "Count the edges leading out of each node in a graph. The number of out
  going edges for each node in the graph is returned in sorted order"
  (sort (map #(count (second %)) (get-edge-map g))))
```

- Extracts a map of node to edge connections from graph g
{ :0 [:1 :2], :1 [:0], :2 [:0] }
- Counts the second element of each keypair (i.e. the value)
(count [:1 :2]) (count [:0]) and (count [:0])
- Creates a list from those count results
- Sorts that list
(1, 1, 2)

Questions?

Resources

<http://clojure.org> specifically:
<http://clojure.org/rationale>
http://clojure.org/concurrent_programming
http://clojure.org/getting_started

<http://norvig.com/>
<http://www.paulgraham.com/icad.html>
<http://mitpress.mit.edu/sicp/>

<http://groups.csail.mit.edu/mac/classes/6.001/abelson-sussman-lectures/>
“Programming Clojure” - <http://bit.ly/dAaKrW>
<http://kotka.de/projects/clojure/vimclojure.html>

