Introduction to Functional Programming and Clojure

Jan-Willem van de Meent

Anatomy of a Clojure Program

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(ns examples.factorial
  (:gen-class))

(defn factorial
  "computes n * (n-1) * ... * 1"
  [n]
  (if (= n 1)
    1
    (* n (factorial (- n 1)))))

(defn -main
  [& args]
  (doseq [arg args]
    (let [n (Long/parseLong arg)]
      (println "the factorial of" arg
               "is" (factorial n)))))
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Namespace declaration

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Recursive function

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Main function

How do I run this?

```
# get source code for this tutorial
git clone git@bitbucket.org:probprog/ppaml-summer-school-2016.git
cd ppaml-summer-school-2016/exercises/
```

```
# option 1: compile to jar and run via java
lein uberjar
java -cp target/uberjar/exercises-0.1.0-SNAPSHOT-standalone.jar \
  examples.factorial 1 2 5 20

# option 2: run using leiningen
lein run -m examples.factorial 1 2 5 20

# => the factorial of 1 is 1
# => the factorial of 2 is 2
# => the factorial of 5 is 120
# => the factorial of 20 is 2432902008176640000
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Interactive Shell: the REPL

```
$ lein repl
# => nREPL server started on port 50240 on host
     127.0.0.1 - nrepl://127.0.0.1:50240
# => REPL-y 0.3.7, nREPL 0.2.12
# => Clojure 1.8.0
# => Java HotSpot(TM) 64-Bit Server VM 1.8.0-b132
# =>      Docs: (doc function-name-here)
# =>            (find-doc "part-of-name-here")
# =>    Source: (source function-name-here)
# =>   Javadoc: (javadoc java-object-or-class-here)
# =>      Exit: Control+D or (exit) or (quit)
# =>   Results: Stored in vars *1, *2, *3,
                an exception in *e

examples.core=>
```

Interactive Shell: the REPL

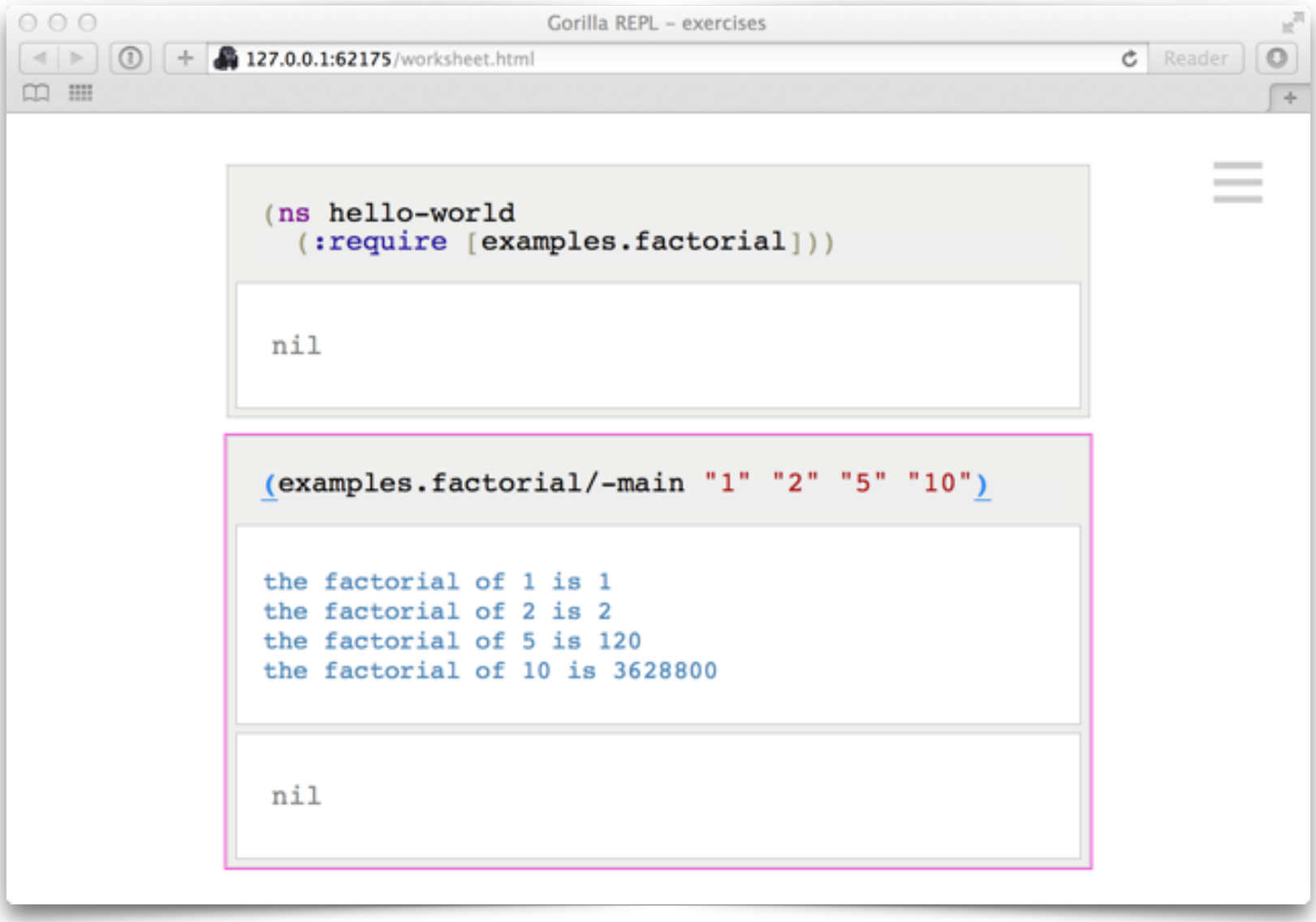
```
examples.core=> (require 'examples.factorial)
;; => nil

examples.core=> (ns examples.factorial)
;; => #object[clojure.lang.Namespace 0x42cd2abe
"examples.factorial"]

examples.factorial=> (-main "1" "2" "5" "20")
;; => the factorial of 1 is 1
;; => the factorial of 2 is 2
;; => the factorial of 5 is 120
;; => the factorial of 20 is 2432902008176640000
;; => nil
```

Gorilla REPL

```
$ lein gorilla
```



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```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    if n == 1:
        return 1
    else:
        return n * factorial(n - 1)
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Name

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Docstring

```python
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Function body

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S-expression

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Block statement

Anatomy of an Expression

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Data Types

Atomic

```
;; symbols
(symbol "ada"), ada

;; keywords
:ada

;; integers, doubles, ratios
1234, 1.234, 12/34

;; strings, characters
"ada", \a \d \a

;; booleans, null
true, false, nil

;; regular expressions
#"a*b"
```

Collections

```
;; lists
(list 1 2 3), (1 2 3)

;; hash maps
{:a 1 :b 2}

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{:a [[1 2] [3 4]]
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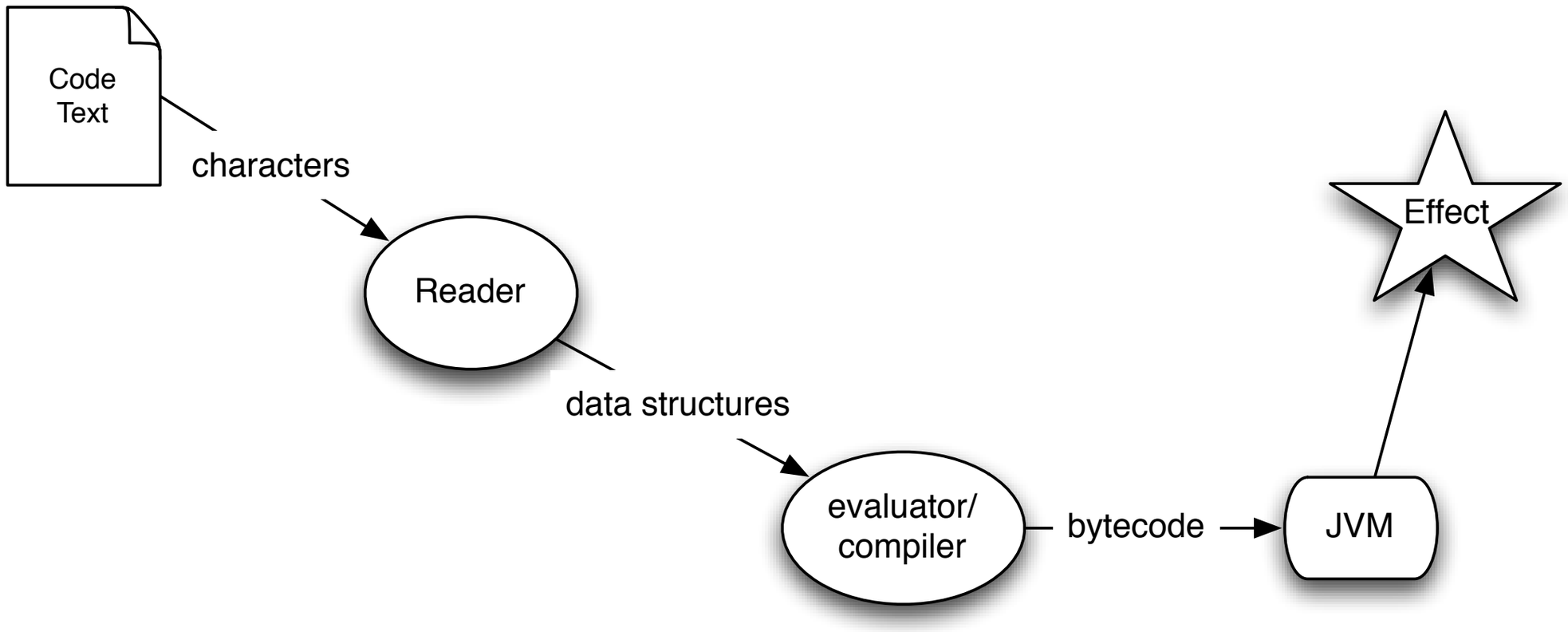
Evaluation in Clojure

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(let [expr (read-string "(+ 1 2)")]
  (prn expr) ; => (+ 1 2)
  (prn (class expr)) ; => clojure.lang.Persistentlist
  (prn (class (first expr))) ; => clojure.lang.Symbol
  (eval expr)) ; => 3
```

(image credit: Rich Hickey)

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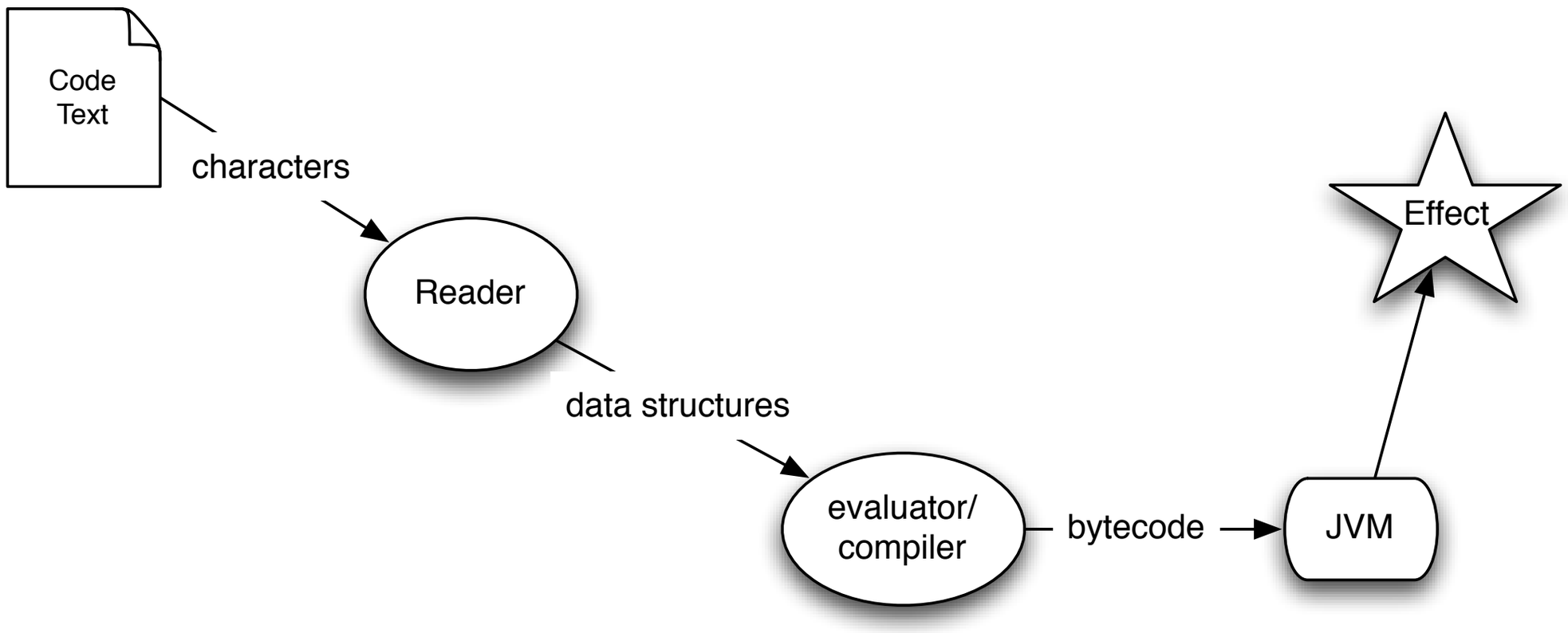


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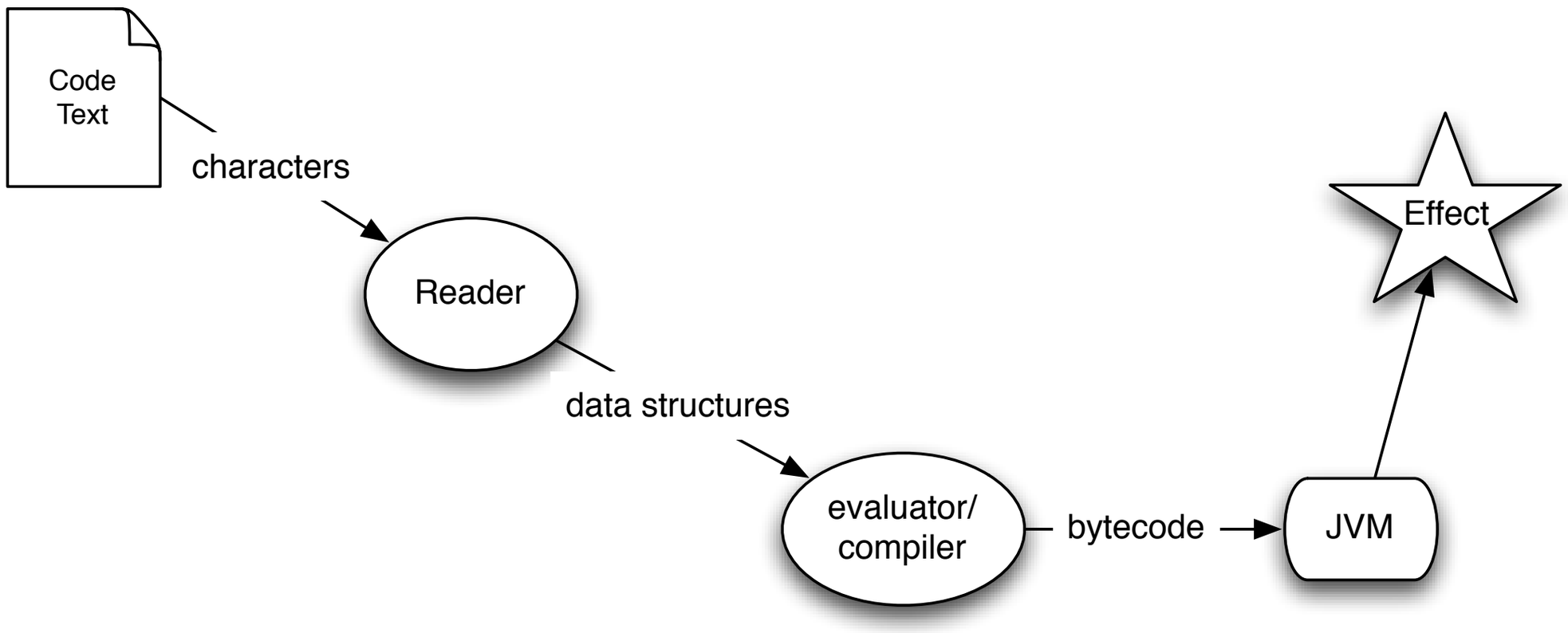


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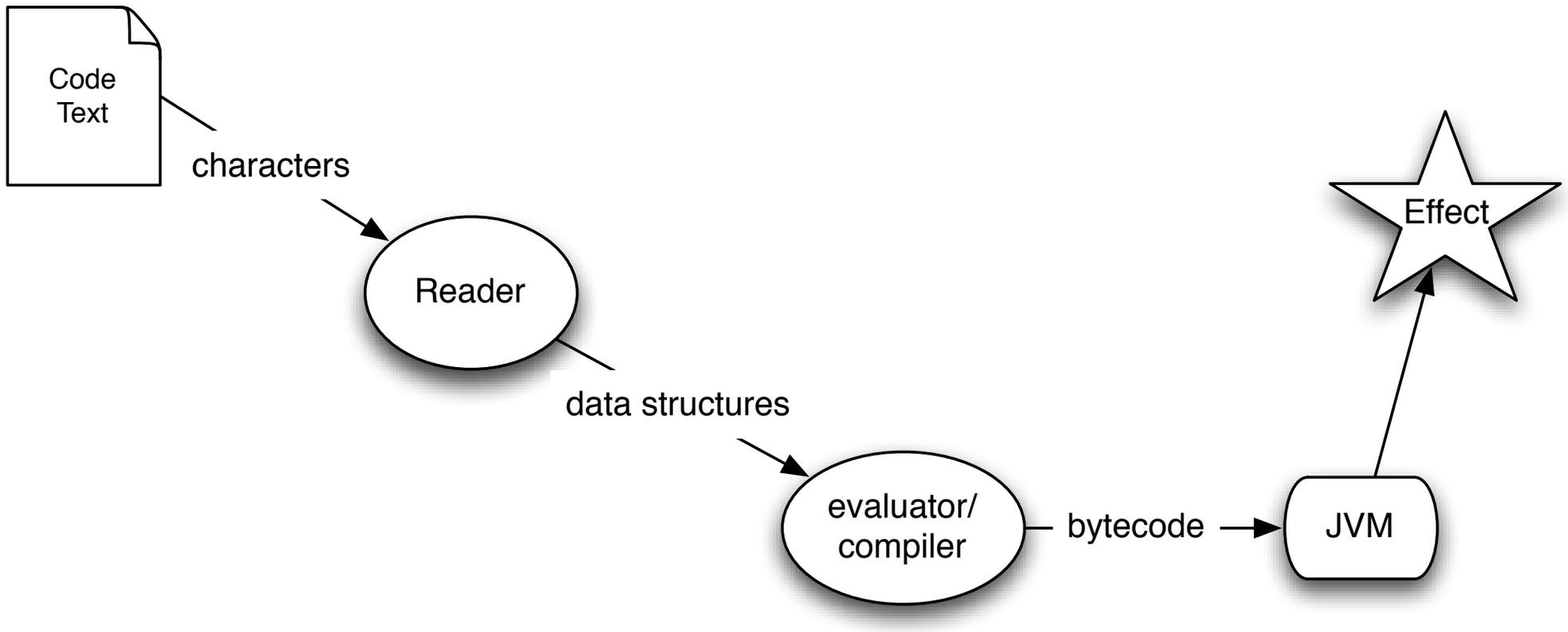


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  (eval expr)) ; => 3
```
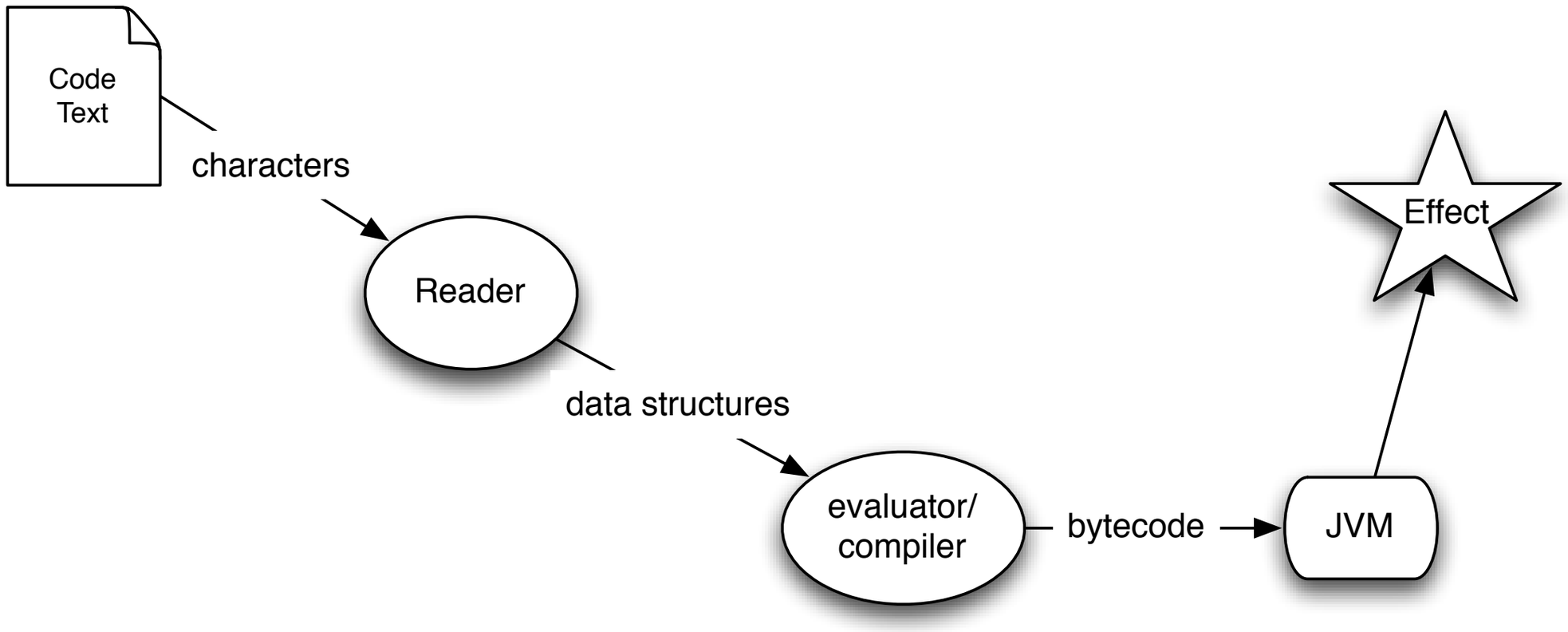

(image credit: Rich Hickey)

Evaluation in Clojure




```clojure
(let [expr (read-string "(+ 1 2)")]
  (prn expr) ; => (+ 1 2)
  (prn (class expr)) ; => clojure.lang.Persistentlist
  (prn (class (first expr))) ; => clojure.lang.Symbol
  (eval expr)) ; => 3
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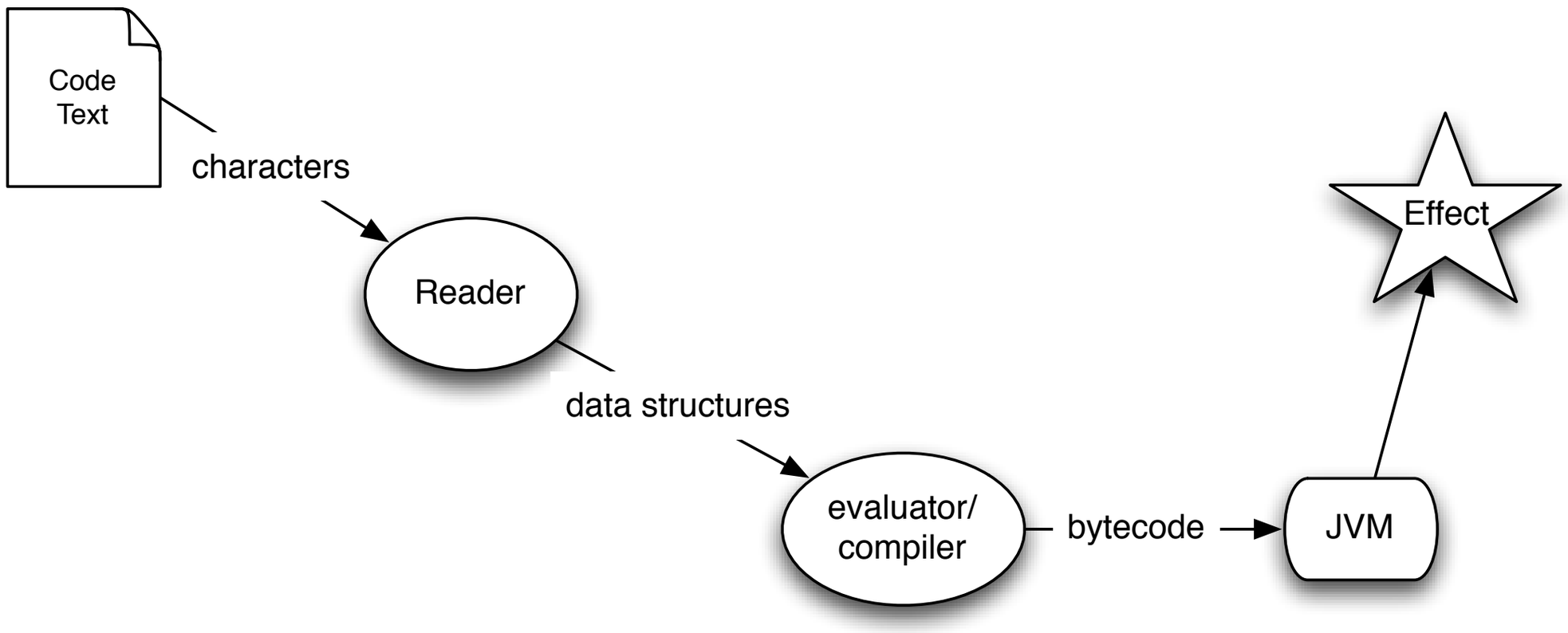
(image credit: Rich Hickey)

Evaluation in Clojure

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(let [expr (read-string "(+ 1 2)")]
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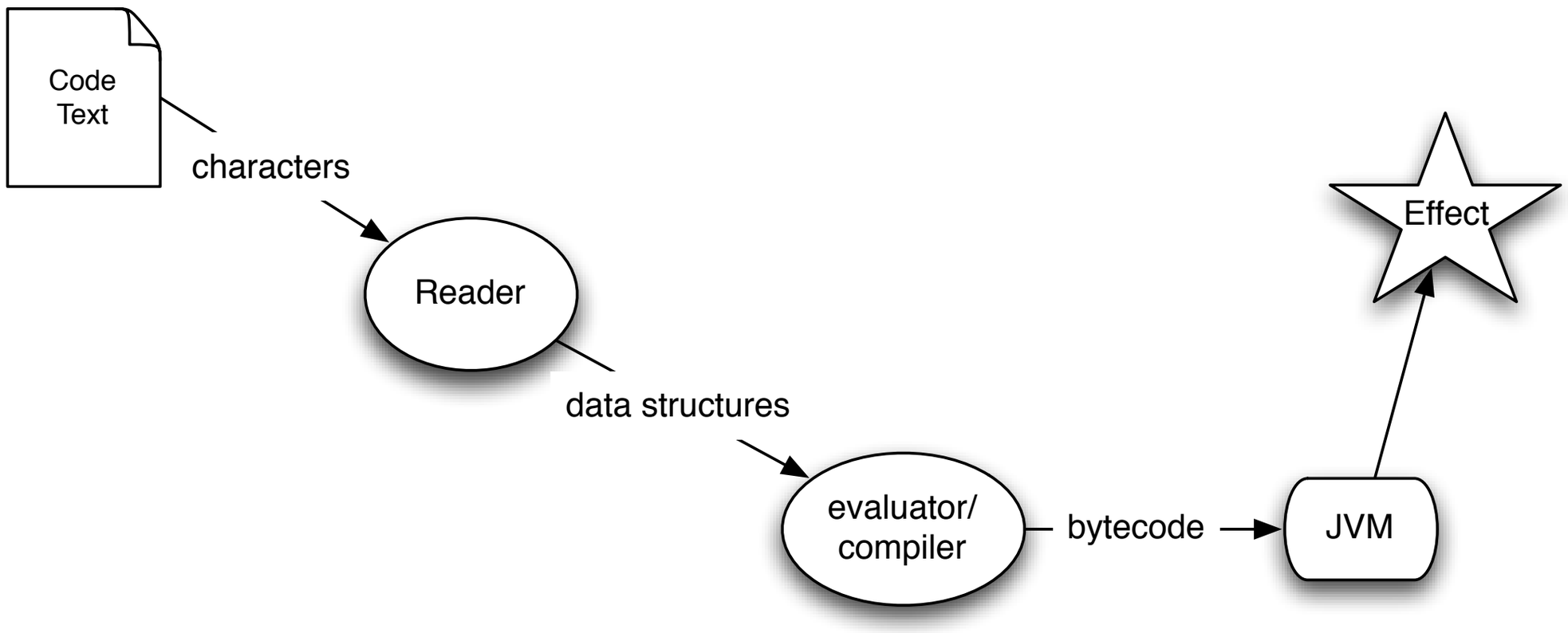


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(let [expr (read-string "(+ 1 2)")]
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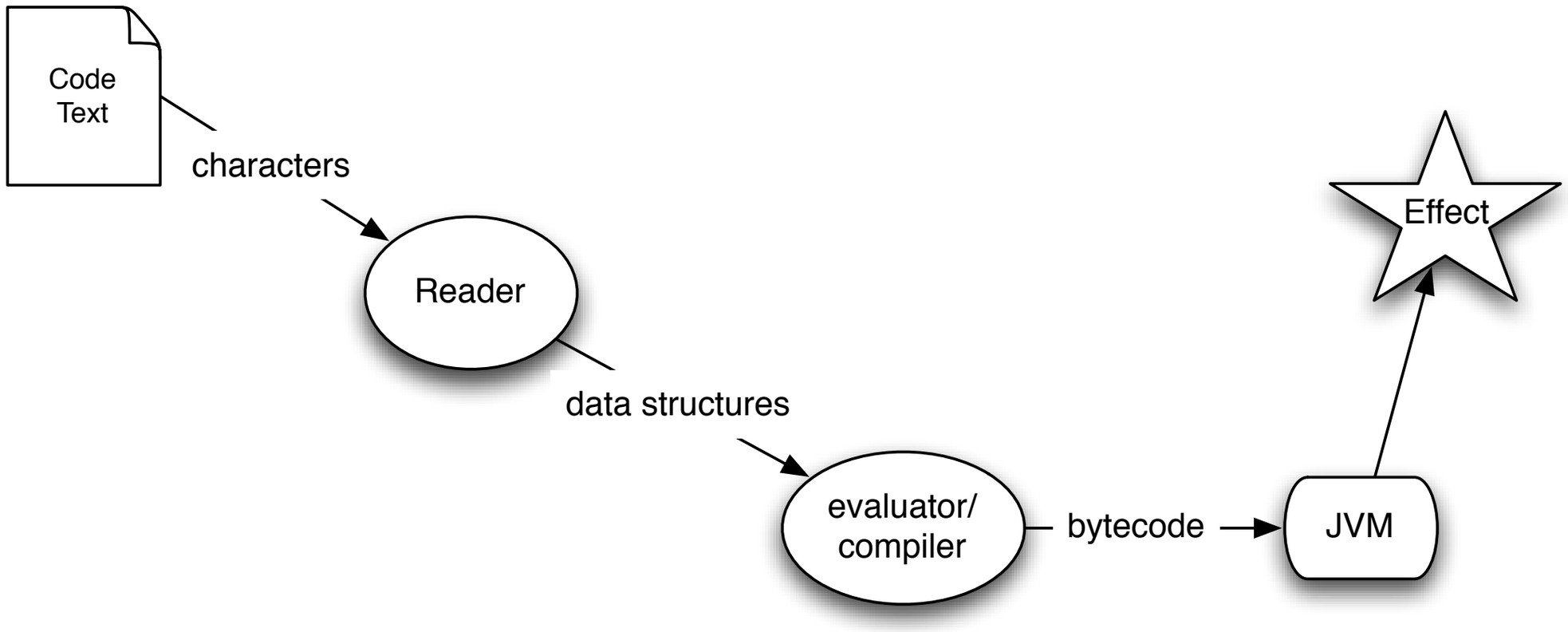
(image credit: Rich Hickey)

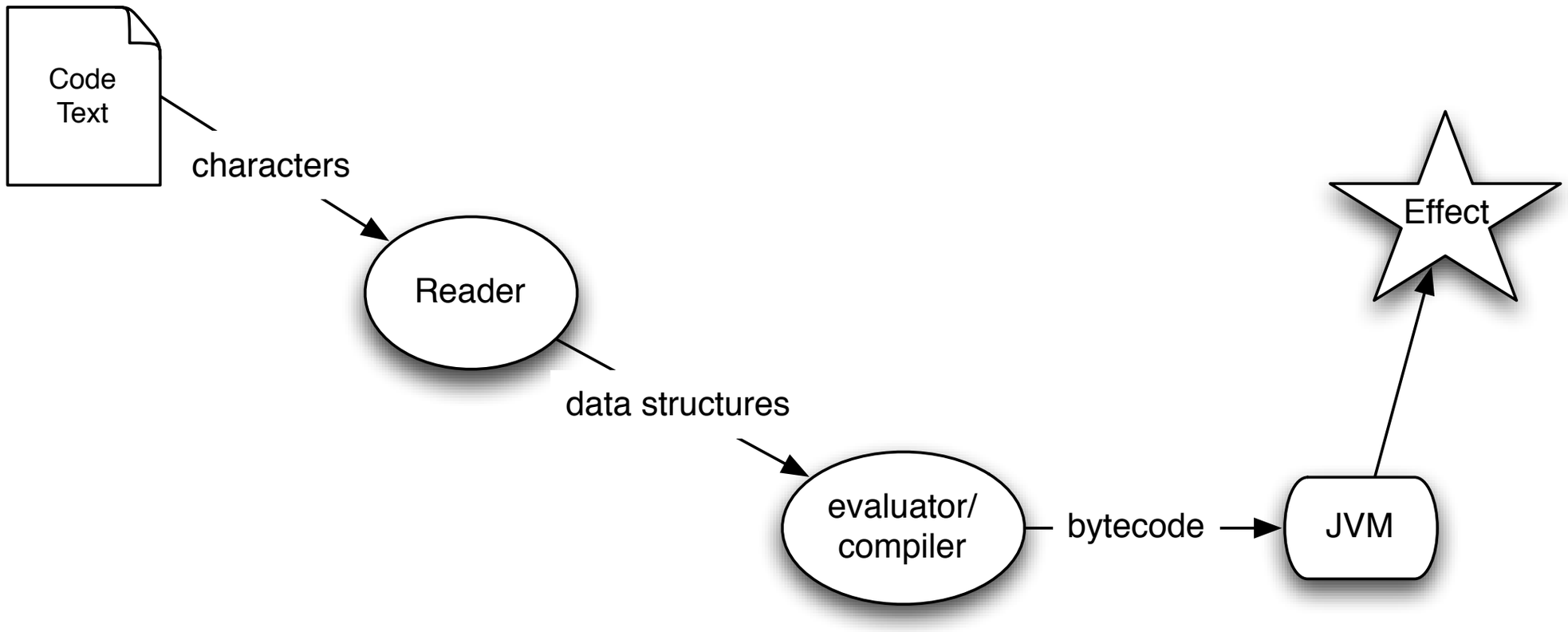
Evaluation in Clojure




```clojure
(let [expr (quote (+ 1 2))]
  (prn expr) ; => (+ 1 2)
  (prn (class expr)) ; => clojure.lang.Persistentlist
  (prn (class (first expr))) ; => clojure.lang.Symbol
  (eval expr)) ; => 6
```

(image credit: Rich Hickey)

Evaluation in Clojure




```clojure
(let [expr '(+ 1 2)]
  (prn expr) ; => (+ 1 2)
  (prn (class expr)) ; => clojure.lang.Persistentlist
  (prn (class (first expr))) ; => clojure.lang.Symbol
  (eval expr)) ; => 6
```

(image credit: Rich Hickey)

Macros

```clojure
(defmacro unless
  "Inverted 'if"
  [pred then else]
  (list 'if pred else then))
```

```clojure
(def flavor :tasty)

(unless (= flavor :tasty)
  :yuk
  :yum)

; ~> (macro-expansion)

(if (= flavor :tasty)
  :yum
  :yuk)

; => (evaluation)

:yum
```

Macros

```clojure
(defmacro dbg
  "Prints an expression and
  its value for debugging."
  [expr]
  `(let [value# ~expr]
     (println "[dbg]"
              '~expr
              value#)
     value#))
```

```clojure
(dbg (+ 1 2))
; => [dbg] (+ 1 2) 3
; => 3

(macroexpand '(dbg (+ 1 2))
; => (let* [value__23707__auto__
;                (+ 1 2)]
;    (clojure.core/println
;      "[dbg]"
;      (quote (+ 1 2))
;      value__23707__auto__)
;    value__23707__auto__)
```

Method Dispatch

Collections

```
(count (list 1 2 3))
; => 3
(count [1 2 3 4 5]))
; => 5
(count {:a 1, :b 2})
; => 2

(conj (list 1 2 3) 0)
; => (0 1 2 3)
(conj [1 2 3] 4)
; => [1 2 3 4]
(conj {:a 1, :b 2} [:c 3])
; => {:a 1 :b 2 :c 3}
```

Sequences

```
(seq [1 2 3])
; => (1 2 3)
(seq {:a 1, :b 2})
; => ([:a 1] [:b 2])
(seq (list))
; => nil

(first [1 2 3])
; => 1
(rest [1 2 3])
; => (2 3)
(cons 0 [1 2 3])
; => (0 1 2 3)
```

Method Dispatch

Associative

(*vectors*, *maps*)

```
(get {:a 1 :b 2} :a)
; => 1
(get ["a" "b"] 0)
; => "a"
```

```
(assoc {:a 1 :b 2} :c 3)
;=>  {:a 1 :b 2 :c 3}
(assoc ["a" "b"] 2 "c")
; => ["a" "b" "c"]
```

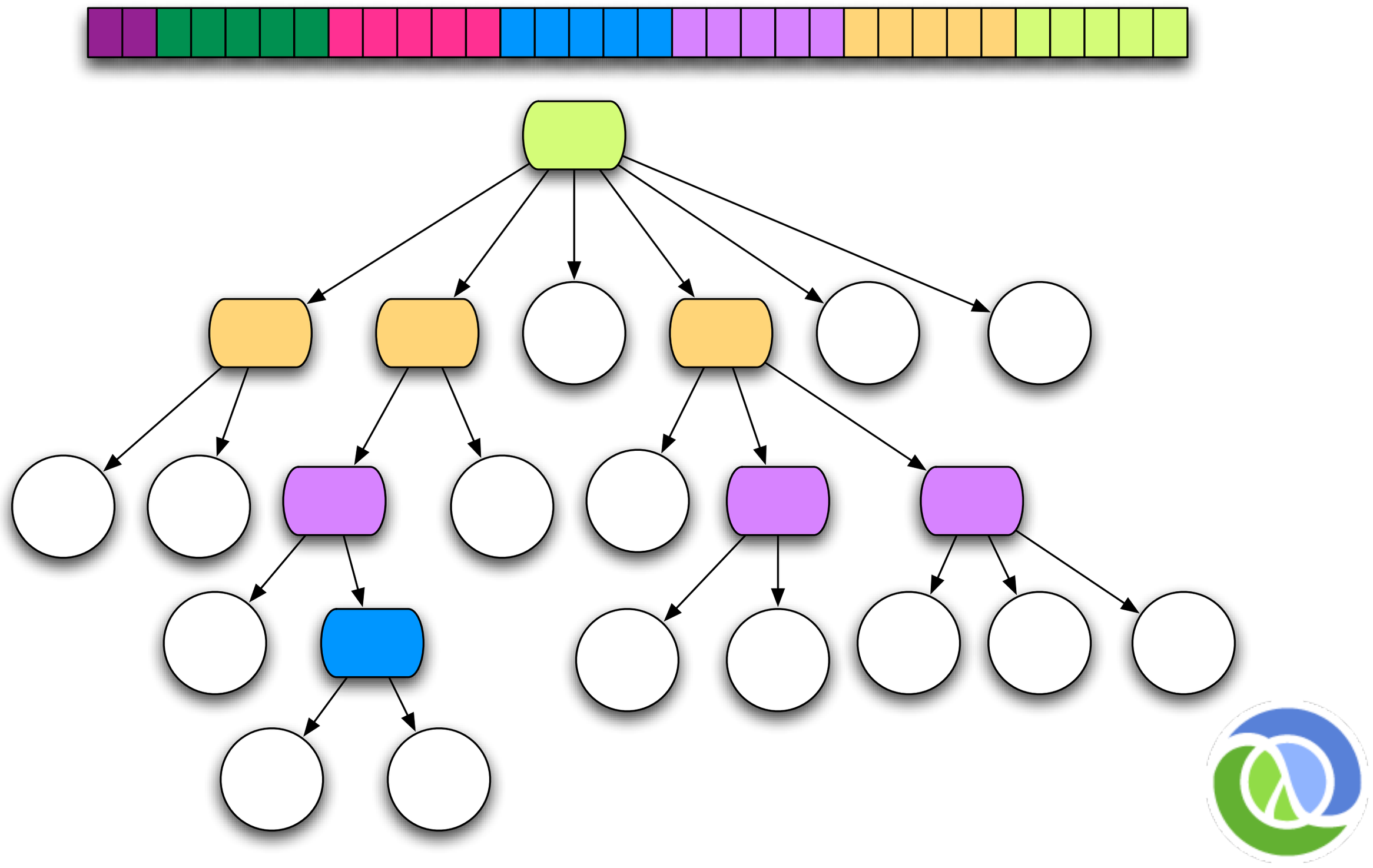
Stacks

(*lists*, *vectors*)

```
(peek (list 1 2 3))
; => 1
(peek [1 2 3])
; => 3
```

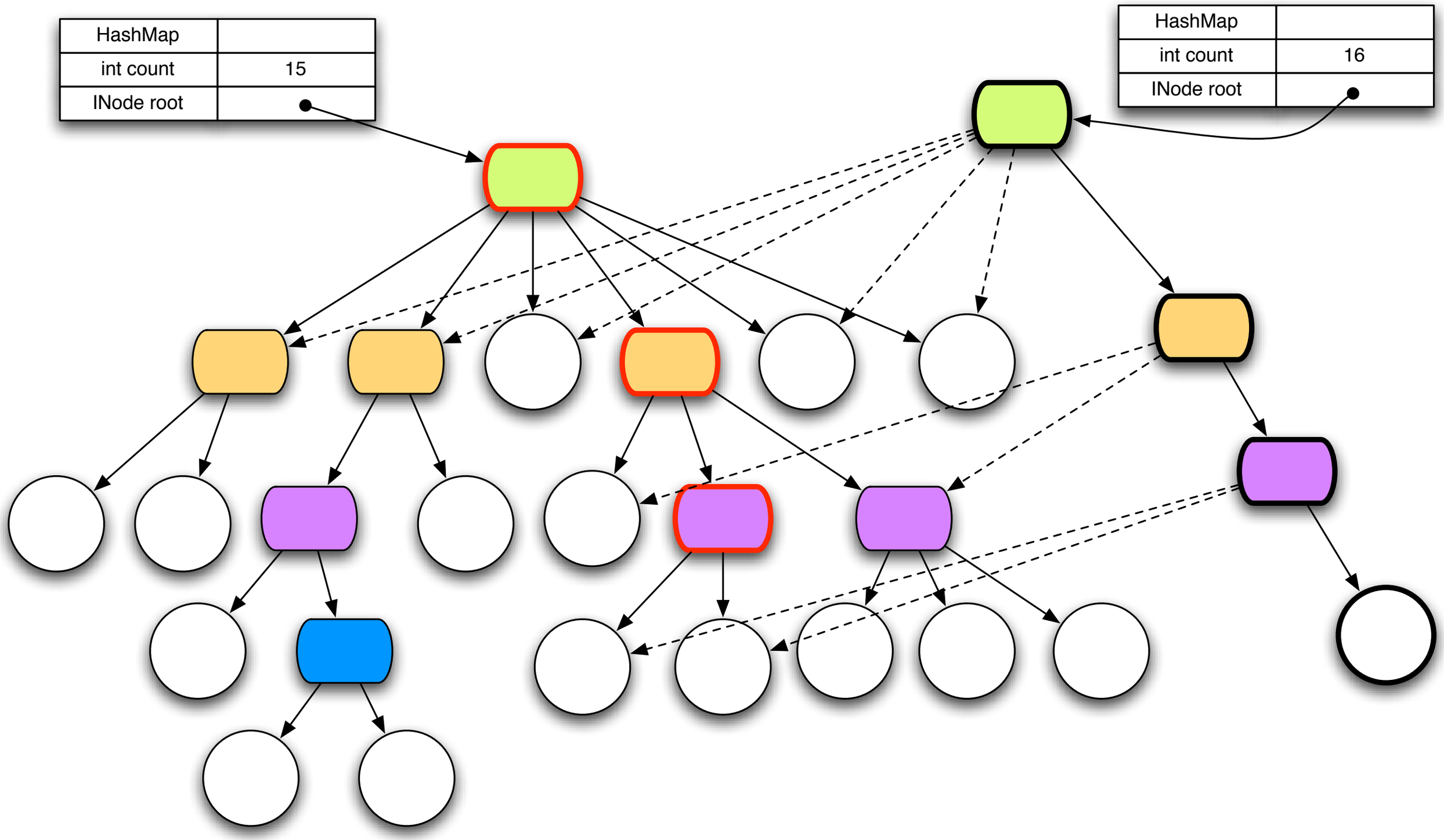
```
(pop (list 1 2 3))
; => (list 2 3)
(pop [1 2 3])
; => [1 2]
```

Bit-partitioned Hash Tries



(image credit: Rich Hickey)

Path Copying



(image credit: Rich Hickey)

Looping

```
(defn factorial
  "computes n * (n-1) * ... * 1"
  [n]
  (if (= n 1)
    1
    (* n (factorial (- n 1)))))
```

Looping

```clojure
(defn factorial
  "computes n * (n-1) * ... * 1"
  [n]
  (if (= n 1)
    1
    (* n (factorial (- n 1)))))
```

```clojure
(factorial 21)
; => ArithmeticException integer overflow
;    clojure.lang.Numbers.throwIntOverflow (Numbers.java:1501)
```

Looping

```clojure
(defn factorial
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    1N
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Looping

```clojure
(defn factorial
  "computes n * (n-1) * ... * 1"
  [n]
  (if (= n 1)
    1
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```

```clojure
(factorial 10000)
; => StackOverflowError
     clojure.lang.Numbers.equal (Numbers.java:216)
```

Looping

```clojure
(defn factorial
  "computes n * (n-1) * ... * 1"
  [n]
  (if (= n 1)
    1
    (*' n (factorial (- n 1)))))
```

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    if n == 1:
        return 1
    else:
        return n * factorial(n - 1)
```

Looping

```clojure
(defn factorial
  "computes n * (n-1) * ... * 1"
  [n]
  (if (= n 1)
    1
    (*' n (factorial (- n 1)))))
```

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    result = 1
    for i in range(2, n + 1):
        result *= i
    return result
```

Looping

```clojure
(defn factorial
  "computes n * (n-1) * ... * 1"
  [n]
  (if (= n 1)
    1
    (*' n (factorial (- n 1)))))
```

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    result = 1
    ivals = range(2, n + 1)
    while ivals:
        i = ivals.pop(0)
        result *= i
    return result
```

Looping

```clojure
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (loop [result 1
         ivals (range 2 (+ n 1))]
    (if (seq ivals)
      (recur (*' result (first ivals))
             (rest ivals))
      result)))
```

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    result = 1
    ivals = range(2, n + 1)
    while ivals:
        i = ivals.pop(0)
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(defn factorial [n]
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  (loop [result 1
         ivals (range 2 (+ n 1))]
    (if (seq ivals)
      (recur (*' result (first ivals))
             (rest ivals))
      result)))
```

Initial values

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    result = 1
    ivals = range(2, n + 1)
    while ivals:
        i = ivals.pop(0)
        result *= i
    return result
```

Looping

```clojure
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (loop [result 1
         ivals (range 2 (+ n 1))]
    (if (seq ivals)
      (recur (*' result (first ivals))
             (rest ivals))
      result)))
```

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    result = 1
    ivals = range(2, n + 1)
    while ivals:
        i = ivals.pop(0)
        result *= i
    return result
```

Any values
for `i` remaining?

Looping

```clojure
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (loop [result 1
         ivals (range 2 (+ n 1))]
    (if (seq ivals)
      (recur (*' result (first ivals))
             (rest ivals))
      result)))
```

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    result = 1
    ivals = range(2, n + 1)
    while ivals:
        i = ivals.pop(0)
        result *= i
    return result
```

Compute values for next iteration

Looping

```clojure
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (loop [result 1
         ivals (range 2 (+ n 1))]
    (if (seq ivals)
      (recur (*' result (first ivals))
             (rest ivals))
      result)))
```

Passed by value to next iteration

```python
def factorial(n):
    '''computes n * (n - 1) * ... * 1'''
    result = 1
    ivals = range(2, n + 1)
    while ivals:
        i = ivals.pop(0)
        result *= i
    return result
```

Mutated in place

Looping

```clojure
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (loop [result 1
         ivals (range 2 (+ n 1))]
    (if (seq ivals)
      (recur (*' result (first ivals))
             (rest ivals))
      result)))


(factorial 10000)
; => 402387260077093773543702433923003985719374864210714632543799910429938512398629020592044208486969404800479988610197196058631666872994808558901323829669944590997
;    ...
```

Looping

```clojure
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (loop [result 1
         ivals (range 2 (+ n 1))]
    (if (seq ivals)
      (recur (*' result (first ivals))
             (rest ivals))
      result)))
```

Can split into separate function

```clojure
(factorial 10000)
; => 402387260077093773543702433923003985719374864210714632543799910429938512398629020592044208486969404800479988610197196058631666872994808558901323829669944590997
;    ...
```

Looping

```
(defn floop
  "inner loop for factorial"
  [result ivals]
  (if (seq ivals)
    (floop (*' result (first ivals))
           (rest ivals))
    result))
```

```
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (floop 1
         (range 2 (+ n 1))))
```

Looping

```clojure
(defn floop
  "inner loop for factorial"
  [result ivals]
  (if (seq ivals)
    (floop (*' result (first ivals))
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; => StackOverflowError
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```
(defn floop
  "inner loop for factorial"
  [result ivals]
  (if (seq ivals)
    (floop (*' result (first ivals))
           (rest ivals))
    result))
```

Tail call

```
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (floop 1
         (range 2 (+ n 1))))
```

Looping

```
(defn floop
  "inner loop for factorial"
  [result ivals]
  (if (seq ivals)
    (recur (*' result (first ivals))
           (rest ivals))
    result))
```

`recur` allows tail call optimization

```
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (floop 1
         (range 2 (+ n 1))))
```

Looping

```clojure
(defn floop
  "inner loop for factorial"
  [result ivals]
  (if (seq ivals)
    (recur (*' result (first ivals))
           (rest ivals))
    result))
```

`recur` allows tail call optimization

```clojure
(defn factorial [n]
  "computes n * (n-1) * ... * 1"
  (floop 1
         (range 2 (+ n 1))))

(factorial 10000)
; => 40238726007709377354370243392300398571937486421071463
;    254379991042993851239862902059204420848696940480047999
;    886101971960586316668729948085589013238296699445909970
;    ...
```

Up Next: Exercises

```
$ lein gorilla
```