

CS492: Probabilistic Programming

Basics of Clojure and

tiny bit of Anglican

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Does anyone use Clojure, Scheme, or Lisp?

Does anyone use Clojure, Scheme, or Lisp?

What are the cons and pros of such a lang.?

Clojure

- Re-design of Scheme for Java virtual machine, with concurrency in mind.
- Untyped.
- Highly expressive.
- Cousin language for Anglican, the probabilistic programming language used in this course.

Learning outcome

- Can write simple Clojure programs with recursion, loop, sequence, and map.
- Can write simple Anglican programs with no conditioning, and perform inference.
- All by copy-past-modify programming.

Clojure in a nutshell

1. Prefix instead of infix notation:

`(+ 3 3)`, not `3+3`

2. Use `let` to bind variables to values.

```
(let [x (* 3 3) y (* 4 4)] (+ x y))
```

3. Anonymous function using `fn`:

```
(let [f (fn [x] (* x x))] (+ (f 3) (f 4)))
```

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[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

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```
(let [f (fn [x] (* x x))]
```

```
  (+ (f 1)
```

```
    (f 2)
```

```
    (f 3)
```

```
    (f 4)
```

```
  (let [g (fn [x y] (+ x y))]
    (g (f 5) (f 5))))
```

3. Anonymous function using fn:

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2. Use

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```
  (+ x y))
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[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

Clojure in a nutshell

4. Separate function definition:

```
(defn f [n] ...)
```

E.g.

```
(defn f [n]
  (if (= n 0)
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      (+ n (f (- n 1)))))

(println (f 10))
```

[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

Closure in a nutshell

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Recursion
allowed



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Closure in a nutshell

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```

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allowed



[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

Chaining in a nutshell

The screenshot shows a Clojure REPL window with the following code:

```
(ns lecture2)

(defn sq [x] (* x x))

(defn g [n]
  (if (= n 0)
      0
      (+ (sq n) (g (- n 1)))))

~
~
~
~
~
```

At the bottom of the window, the text "1,8" and "All" are visible, along with a scrollbar.

tion
ed

[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

NB: I installed leiningen. Then, I ran "lein repl".

The screenshot shows a Leiningen REPL window titled "Lecture2 — java • lein repl — 48x14". The window contains the following code and output:

```
(ns lecture2/g)
[user=> (load-file "sum.clj")]
[lecture2/g]
[def (lecture2/g 100) 338350]
[def (lecture2/g 1000) 333833500]
[def (lecture2/g 10000)]
[StackOverflowError clojure.lang.Numbers.equal
 (Numbers.java:216)]
[user=>]
[user=>]
```

At the bottom of the window, there is a status bar with the text "1,8" and "All".

[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

Clojure in a nutshell

5. Tail recursion using loop and recur.

```
(defn f [n]
  (if (= n 0)
      0
      (+ n
         (f (- n 1))))))
```

```
(defn f [n]
  (loop [n0 n r0 0]
    (if (= n0 0)
        r0
        (recur (- n0 1)
                 (+ n0 r0))))))
```

[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

Clojure in a nutshell

No further work
after recursive call.

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Not tail recursive

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(defn f [n]
  (loop [n0 n r0 0]
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```

[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

```
(defn f [n r]
  (if (= n 0)
      r
      (f (- n 1)
          (+ n r))))
```

Tail recursive

in a nutshell

No further work
after recursive call.

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(defn f [n]
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        r0
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```

[Q] Write a program that computes $1^2 + 2^2 + \dots + \sqrt{5^2}$.

```
(defn f [n r]
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      (f (- n 1)
          (+ n r)))))
```

• **Ask Clojure to do tail-call optimisation**



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(defn f [n]
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(defn f [n]
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(defn f [n]
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in a nutshell

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(defn f [n]
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    (if (= n0 0)
        r0
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                 (+ n0 r0)))))
```



[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.


```
Lecture2 — vi sum_loop.clj — 45x13
...es/Lecture2 — -bash  java • lein repl  vi sum_loop.clj
(ns lecture2b)

(defn sq [x] (* x x))

(defn g [n]
  (loop [n0 n r0 0]
    (if (= n0 0)
        r0
        (recur (- n0 1) (+ (sq n0) r0)))))

11,0-1  All
```

[Q] Write a program that computes $1^2 + 2^2 + \dots + 5^2$.

NB: I installed leiningen. Then, I ran "lein repl".

The screenshot shows a Leiningen REPL window titled "Lecture2 — java ◀ lein repl — 45x13". The window has three tabs: "...es/Lecture2 — -bash", "java ◀ lein repl", and "vi sum_loop.clj". The REPL prompt is "user=>". The code entered is as follows:

```
(ns lecture2b)

(defn sum-loop [n]
  (loop [acc 0]
    (if (= 0 n)
        acc
        (recur (dec n) (+ acc n))))

(defn lecture2b/g [n]
  (loop [acc 0]
    (if (= 0 n)
        acc
        (recur (dec n) (+ acc n))))

(user=> (load-file "sum_loop.clj"))
(user=> (lecture2b/g 10000))
(:3333833335000
user=> (lecture2b/g 100000))
333338333350000
user=> (lecture2b/g 1000000))
333333833333500000
user=>
```

The bottom of the window shows a status bar with "11, 0-1" and "All".

[Q] Write a program that computes $1^2 + 2^2 + \dots + n^2$.

Exercise 1:

Fibonacci sequence

[Q] Write a Clojure function that takes $n \geq 2$ and computes the n -th Fibonacci number F_n :

$$F_1 = 1, \quad F_2 = 1, \quad F_{n+2} = F_n + F_{n+1}$$

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[Hint]

```
(defn fib [n]
  (loop [n0 . . . . ]
    (if (= n0 n)
      .
      (recur (+ n0 1)
              . . . .
              . . . . )))))
```

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[Hint]

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(defn fib [n]
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    (if (= n0 n)
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                 (+ r0 r1)))))
```

Exercise 2: Random Fibonacci sequence R_n

$$R_1 = 1, \quad R_2 = 1,$$

$$R_{n+2} = R_n + R_{n+1} \text{ or } R_{n+1} - R_n, \text{ each with prob. } 1/2$$

[Q] What does the distribution of R_n look like?

Anglican in a nutshell

- I. Define a Anglican query using defquery.

```
(defquery baby-rfib [n]
  (let [b (sample (flip 0.5))
        new-n (if b n (+ n 1))]
    (loop [n0 2 r0 1 r1 1]
      (if (= n0 new-n)
          r1
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```


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query name

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query body

Anglican in a nutshell

Creating and sampling
from distribution object

ry using defquery.

query name

arguments

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[Q] Write an Anglican query for generating R_n for given n .

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        ...
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Anglican in a nutshell

I. Define a Anglican query using defquery.

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(defquery rfib [n]
  (loop [n0 2 r0 1 r1 1]
    (if (= n0 n)
      r1
      (let [b (sample (flip 0.5))
            r2 (if b (+ r1 r0) (- r1 r0))]
        (recur (+ n0 1)
              r1
              r2))))))
```

[Q] Write an Anglican query for generating R_n for given n .

Anglican in a nutshell

2. Perform inference using doquery.

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Clojure keyword.

Chooses an inference algorithm.

Anglican in a nutshell

2. Perform inference using doquery.

```
(doquery :importance rfib [20])
```



Clojure keyword.

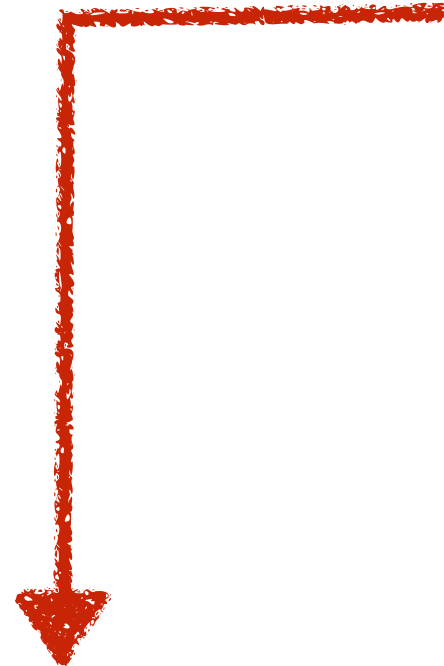
Chooses an inference algorithm.

**query name,
arguments**



Anglican in a nutshell

2. Perform inference using doquery. query name,
arguments

 (doquery :importance rfib [20])


Clojure keyword.
Chooses an inference algorithm.

Returns a lazy infinite
sequence of samples.
Only a finite prefix used.

Anglican in a nutshell

2. Perform inference using doquery.

```
(let [s (doquery :importance rfib [20])]  
  (take 2 s))
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Anglican in a nutshell

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```
( { :log-weight 0.0,  
    :result 1,  
    :predict []}  
  
  { :log-weight 0.0,  
    :result -17,  
    :predict []} )
```

Anglican in a nutshell

2. Perform inference using doquery.

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(let [s (doquery :importance rfib [20])]  
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( { :log-weight 0.0,  
    :result 1,  
    :predict []}  
  
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    :predict []} )
```

Sequence

Anglican in a nutshell

2. Perform inference using doquery.

```
(let [s (doquery :importance rfib [20])]  
  (take 2 s))
```

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( { :log-weight 0.0,  
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```

Sequence
of maps

Anglican in a nutshell

2. Perform inference using doquery.

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(let [s (doquery :importance rfib [20])]  
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```

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    :predict []} )
```

Sequence
of maps
with three keys

Anglican in a nutshell

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(let [s (doquery :importance rfib [20])]  
  (take 2 s))
```

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( { :log-weight 0.0,  
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  { :log-weight 0.0,  
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Sequence
of maps
with three keys

- To move on, we need to understand map and sequence datatypes of Clojure.

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- Two key questions:
 1. How to construct a datatype?
 2. How to destruct (or decompose) it?

Map in Clojure

1. Constructed using `{..}` or `assoc` typically.

```
{:a 0, :b 1, :c 10},
```

```
(assoc {:a 0, :b 1} :c 10)
```

2. Accessed (or destructured) by `get` & keyword.

```
(get {:a 0, :b 1, :c 10} 3)
```

```
(get {:a 0, :b 1, :c 10} :a)
```

```
(:a {:a 0, :b 1, :c 10})
```

Sequence in Clojure

1. Created using `list` and `conj` typically.

`(list 1 2 3)`, `(conj (list 2 3) 1)`

2. Destructured by `first`, `rest` and `reduce`.

`(first (list 1 2 3))`,

`(rest (list 1 2 3))`,

`(reduce + (list 1 2 3))`

Sequence in Clojure

3. Changed using map and filter.

```
(map inc (list 1 2 3)),  
(filter (fn [x] (>= x 2)) (list 1 2 3))
```

Anglican in a nutshell

1. Define a Anglican query using `defquery`.
2. Perform inference using `doquery`.

```
(let [s (doquery :importance rfib [20])]
  (take 2 s))
```

```
( { :log-weight 0.0,
    :result 1,
    :predict [] }
  { :log-weight 0.0,
    :result -17,
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```

Sequence
of maps
with three keys

Anglican in a nutshell

3. Pick :result entries and analyse them.

```
(doquery :importance rfib [20])
```

Anglican in a nutshell

3. Pick `:result entries` and analyse them.

```
(let [s (doquery :importance rfib [20])  
      r (map :result (take 1000 s))]
```

)

Anglican in a nutshell

3. Pick :result entries and **analyse them**.

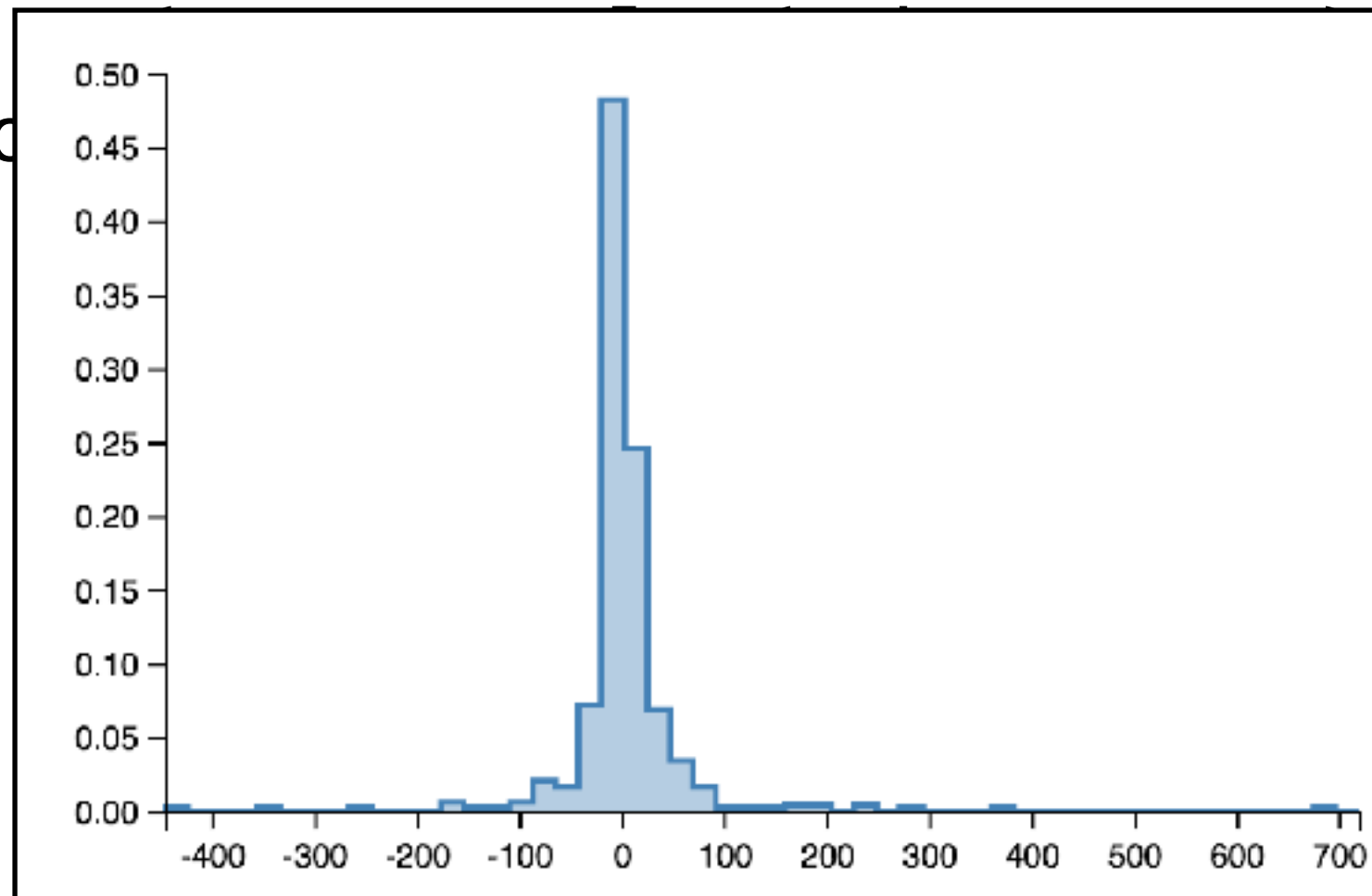
```
(let [s (doquery :importance rfib [20])  
      r (map :result (take 1000 s))]  
  (plot/histogram r  
                  :bins 50  
                  :normalize :probability))
```

Anglican in a nutshell

3. Pick :result entries and analyse them.

```
(let [s (doquery :importance rfib [20])
```

```
(plot
```



```
ability))
```


Anglican in a nutshell

3. Pick `:result` entries and analyse them.

```
(let [s (doquery :importance rfib [20])
      r (map :result (take 1000 s))]
  (plot/histogram r
                  :bins 50
                  :normalize :probability))
```

[Q1] Compute the average of generated R_{20} using 1000 samples. This is called empirical mean.

Anglican in a nutshell

3. Pick :result entries and analyse them.

```
(let [s (doquery :importance rfib [20])  
      r (map :result (take 1000 s))]  
  (/ (reduce + r) 1000))
```

[Q1] Compute the average of generated R_{20} using 1000 samples. This is called empirical mean.

Anglican in a nutshell

3. Pick `:result` entries and analyse them.

```
(let [s (doquery :importance rfib [20])  
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  (/ (reduce + r) 1000))
```

[Q1] Compute the average of generated R_{20} using 1000 samples. This is called empirical mean.

[Q2] Compute the variance of generated R_{20} .

Anglican in a nutshell

3. Pick :result entries and analyse them.

```
(let [s (doquery :importance rfib [20])  
      r (map :result (take 1000 s))  
      m (/ (reduce + r) 1000)  
      f (fn [x] (Math/pow (- x m) 2))]  
  (/ (reduce + (map f r)) 1000))
```

[Q1] Compute the average of generated R_{20} using 1000 samples. This is called empirical mean.

[Q2] Compute the variance of generated R_{20} .

Topics covered

- Functions, recursion, loop, sequence, and map in Clojure.
- `defquery`, and `doquery` in Anglican.

Announcement

1. Homework 0 in the course webpage.
 - It will teach you how to use Gorilla and to try examples in the web browser.
2. No lectures on 4 & 6 September 2017.
3. Form a group and tell us by the midnight of September 11 2017 (Monday).