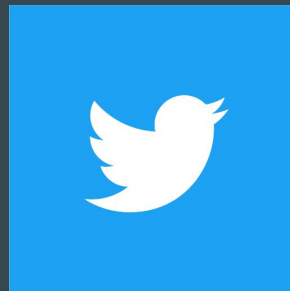
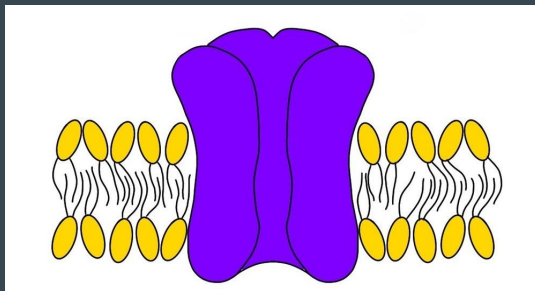


Baseball's Unprecedented Half-innings and Other Insights from Markov Chains

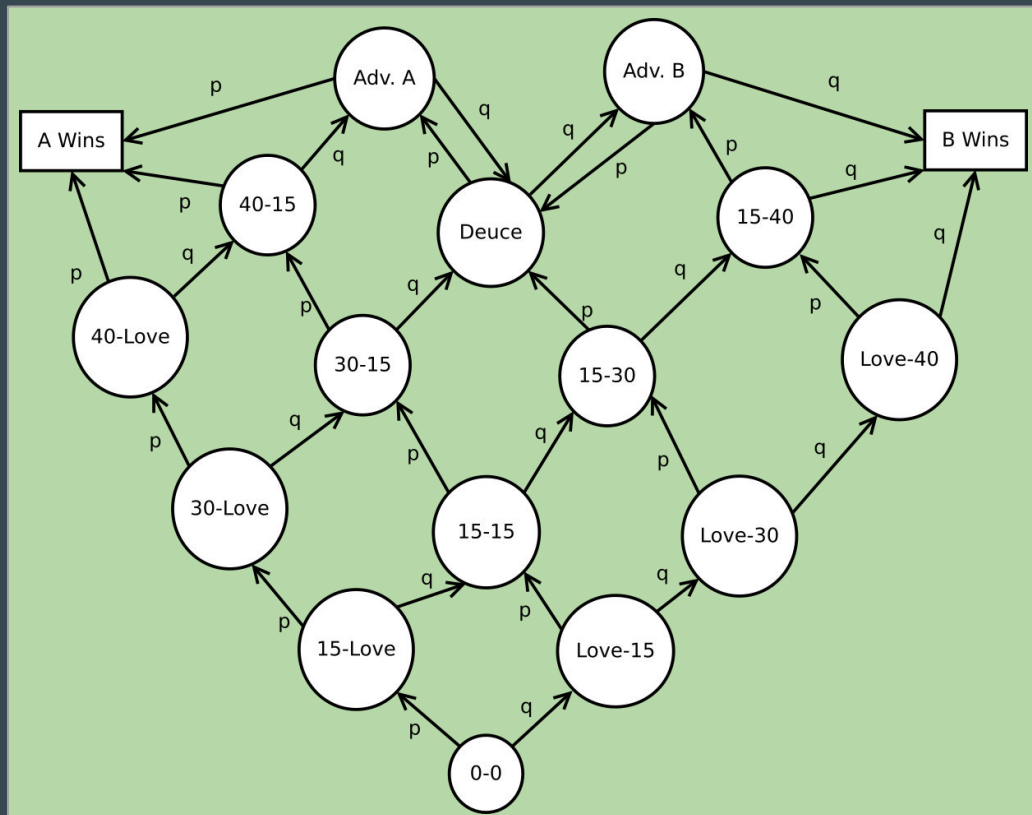
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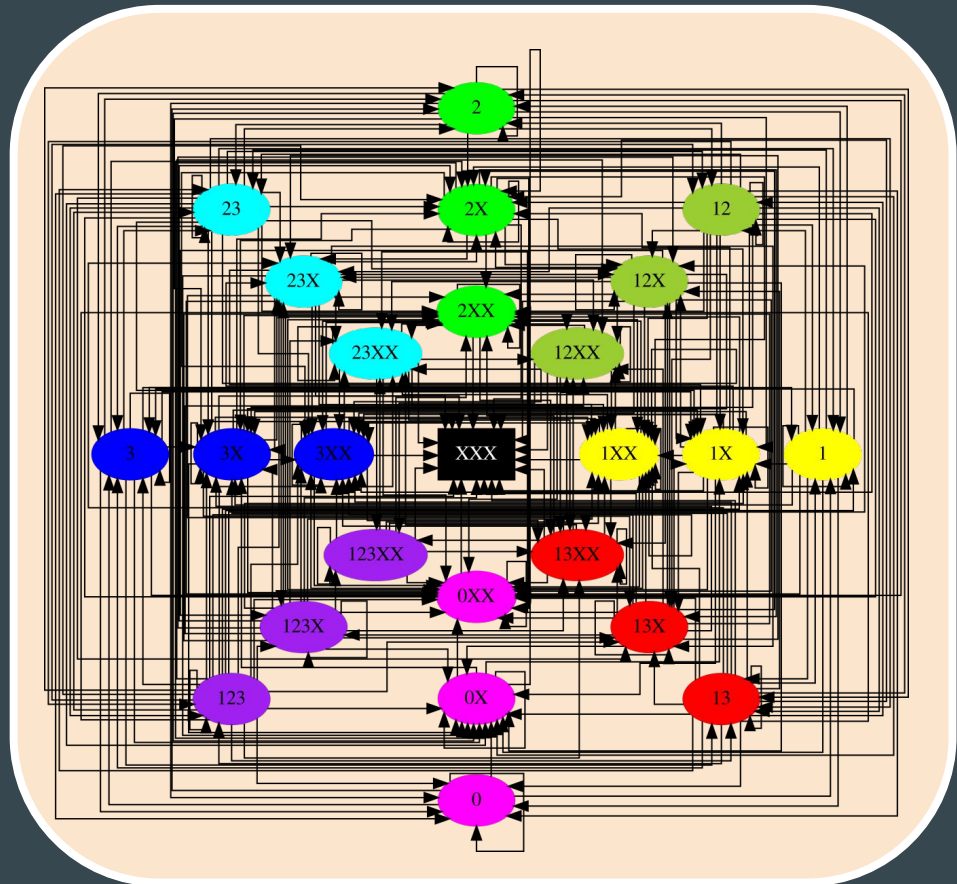
Sean G. Carver, Ph.D.

September 12, 2019

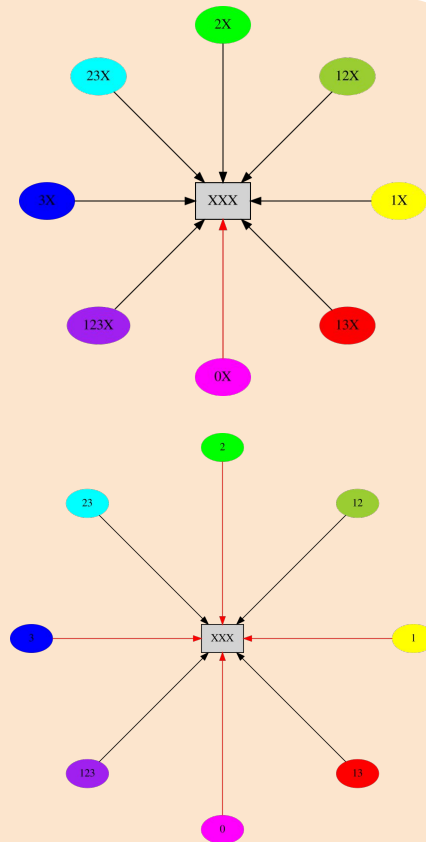
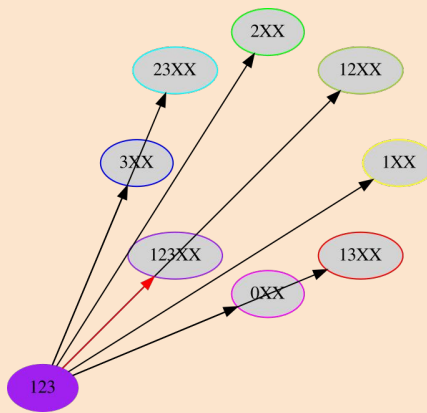
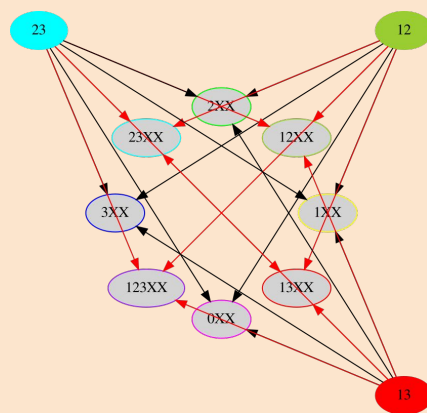
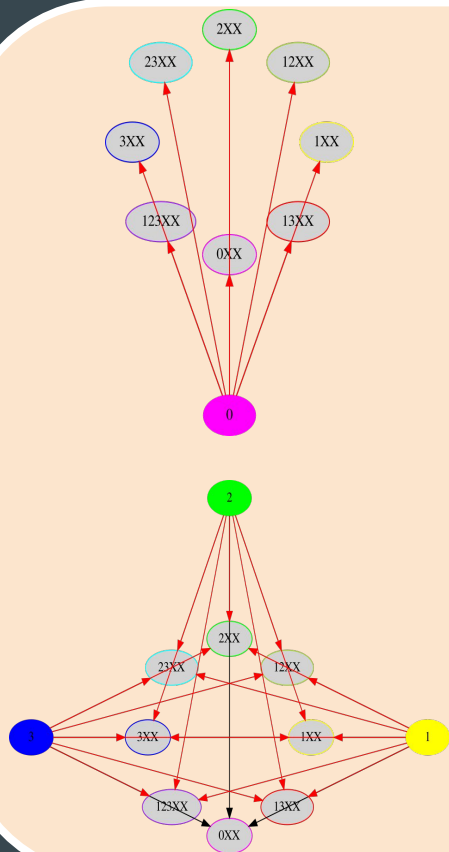


What is a Markov Chain?

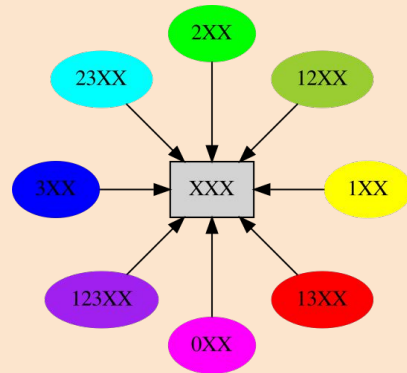
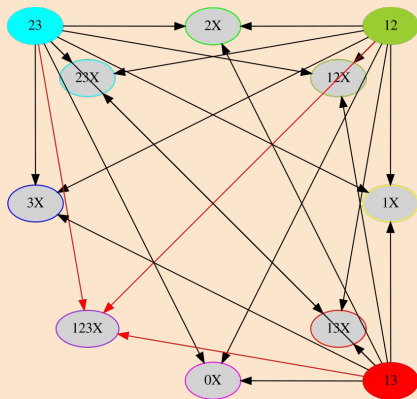
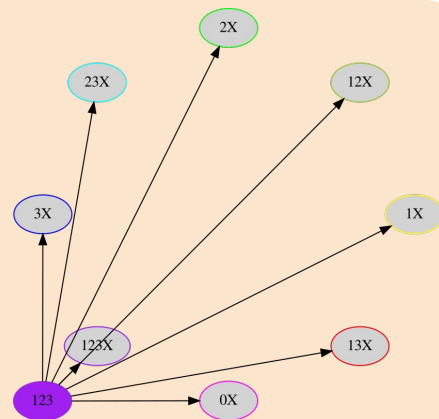
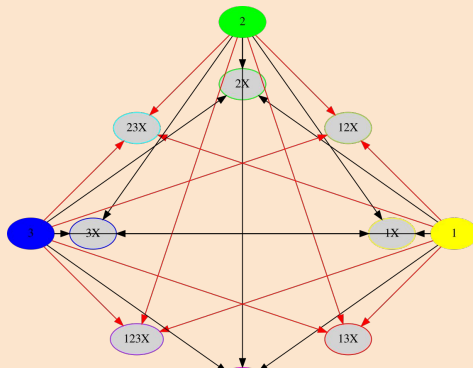
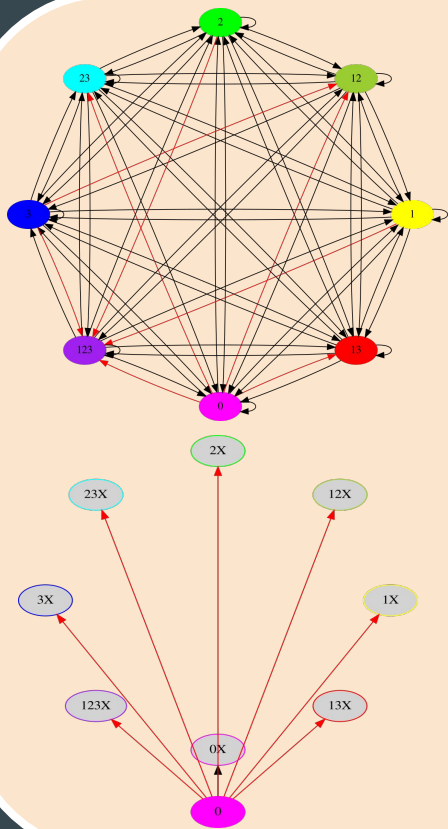




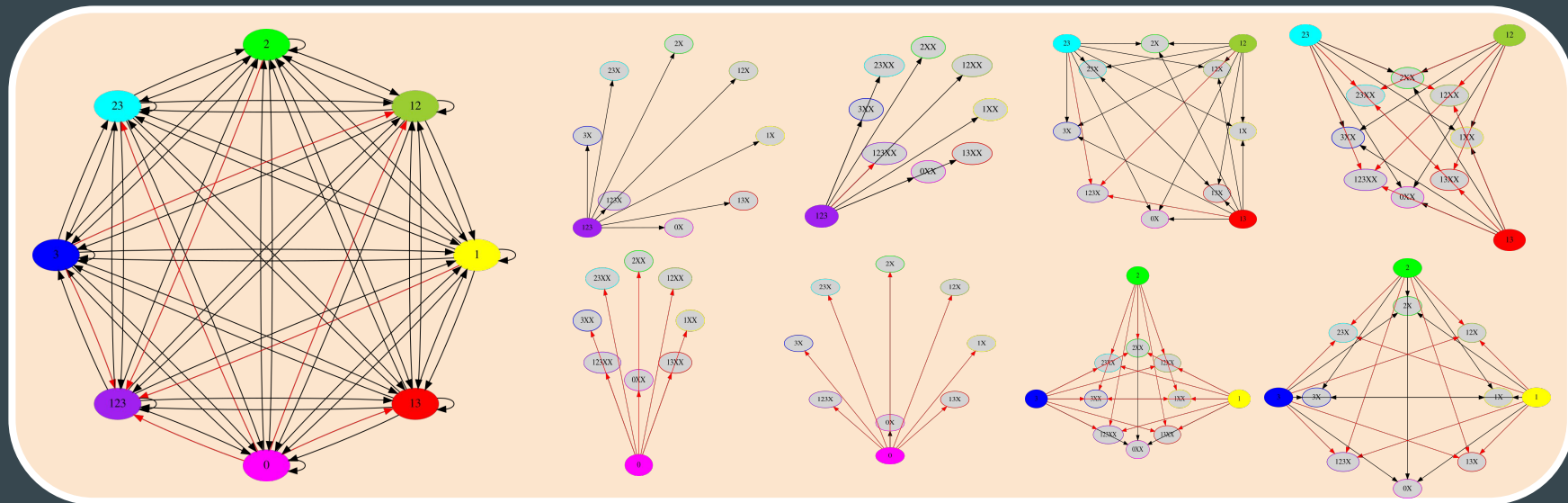
Visualizing Baseball's Graph (Double and Triple Plays)



Visualizing Baseball's Graph (Clean and Single Plays)



Symmetry and Asymmetry in Baseball's Graph



Rules of symmetric & real baseball: $\Delta \text{ Outs} \geq 0$ AND $0 \leq \text{Runners-on-base} \leq 3$
 $\Delta \text{ Runners-on-base} = 1 - \Delta \text{ Outs} - \Delta \text{ Score}$
 $\Delta \text{ Score} \geq 0$

Additional asymmetries in real baseball: Three outs and it's over!
 3:12 (3X:12X, ...) impossible---runners cannot retreat!

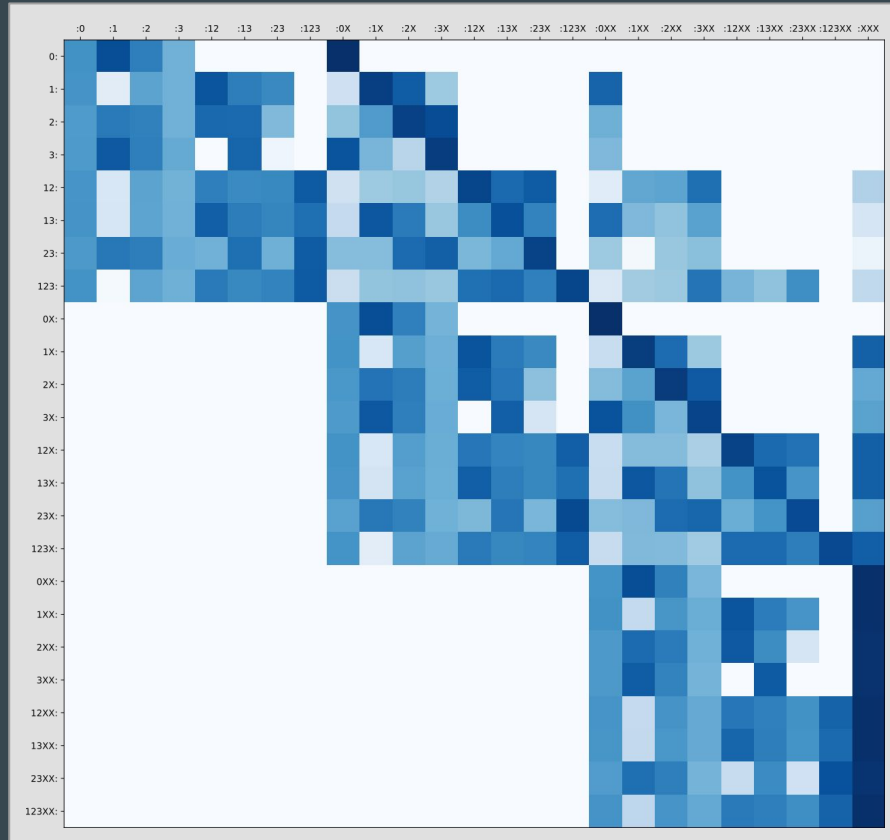
Transition Probability Matrix -- Clean Plays, No Outs

	:0	:1	:2	:3	:12	:13	:23	:123
0:	0.02461	0.25336	0.04649	0.00708	0	0	0	0
1:	0.022	0.00027	0.01252	0.00713	0.19619	0.04865	0.03269	0
2:	0.01757	0.05453	0.04364	0.00725	0.1006	0.09487	0.00528	0
3:	0.01819	0.16967	0.04674	0.00963	0	0.11433	0.00015	0
12:	0.02192	0.00039	0.01232	0.00702	0.04658	0.03199	0.03381	0.16033
13:	0.02273	0.00042	0.01208	0.00726	0.13831	0.04993	0.03784	0.07977
23:	0.01894	0.05878	0.04808	0.00878	0.00721	0.07985	0.00758	0.15326
123:	0.02439	0.00011	0.01215	0.0077	0.05556	0.03441	0.04034	0.16284

$$\text{Prob.} = \frac{\# (\text{From} \rightarrow \text{To})}{\# \text{ From}}$$

Computed with respect to a
population of transitions

Full Transition Probability Matrix



Relative Transition Probabilities

-log10(probability)

4

3

2

1

0

123:1
23:1XX
3:23
23:XXX

1:1

12:0XX

123X:1X

1X:1X

2XX:23XX

12X:1X

12:1

13X:1X

3X:23X

123:0XX

1:0X

1X:0XX

12X:0XX

12:0X

13X:0XX

23XX:23XX

13:1
13:XXX

1XX:1XX

12XX:1XX

13XX:1XX

23XX:12XX

23X:0XX

13:0X

123:XXX

3:2X

1X:3XX

1:3X

12:3X
12:XXX

12:1X
12:2X

13X:3XX

123X:3XX

123:1XX

123:2XX

23:0XX
23:2XX

2X:23X

2X:0XX

12X:2XX

2:0X

2:23

2:0X

3XX:3XX

12:3

13X:3X

3X:2XX

23XX:3XX

23X:3X

13:1XX

123:12XX

23:12X

3:0XX
3:1X

0:3

0X:3X

0XX:3XX

1X:3X

1XX:3XX

1:3

2XX:3XX

2X:3X

12X:3X

2:3

3XX:3XX

12:3

13X:3X

3X:3X

23XX:3XX

23X:3X

13:3

123:12XX

23:12

23:23

23:3

3:3

1X:2X

1:2

2X:1XX

12X:2X

2:1X

2:0

3XX:0XX

12:1XX

13X:2X

3X:XXX

123X:2X

23X:0X

23X:XXX

13:2

13:3XX

123:2

23:13X

23:0

3:0

0:0

0X:0X

0XX:0XX

1X:0X

1XX:0XX

1:0

2XX:0XX

2X:0X

12X:0X

13XX:0XX

13XX:23XX

12:0

13X:0X

3X:0X

23XX:0XX

123X:0X

23X:13XX

13:0

123:0

123:23XX

1X:23X

1:23

2XX:13XX

12X:23X

12X:13X

2:2

3XX:2XX

13XX:13XX

12:12

13X:13X

123XX:13XX

13X:2XX

23XX:2XX

123X:23XX

13:23

13:23X

123:23X

0:2

0X:2X

0XX:2XX

1X:13X

1XX:13XX

1:13

2XX:2XX

12XX:12XX

12X:12X

2:1

13XX:13XX

12:12

13X:13X

123XX:12XX

13X:2XX

23XX:1XX

123X:1XX

23X:1X

13:13

123:12X

23:12

23:1

1X:2XX

2XX:1XX

12X:13XX

2:13

13XX:123XX

12:13X

13XX:12XX

123XX:123XX

3X:13X

123X:XXX

123X:123X

13:12

123:123

23:3X

3:13

1X:XXX

1:0XX

12XX:123XX

12X:XXX

12X:123X

3XX:1XX

3XX:13XX

12:123

13X:1XX

3X:1X

123X:XXX

123X:123X

13:12

123:123

23:3X

3:13

1X:12X

1XX:12XX

1:12

2XX:12XX

2X:3XX

12X:123X

2:3X

13XX:123XX

12:12X

13X:13XX

3X:0XX

23XX:123XX

123X:123XX

13:13X

123:123X

23:23X

3:3X

0:1

0X:1X

0XX:1XX

1X:1XX

1:1X

12X:12XX

2:2X

12:12X

3X:3XX

123X:123XX

123:123X

23:23X

0:0X

0X:0XX

0XX:XXX

1XX:XXX

2XX:XXX

12XX:XXX

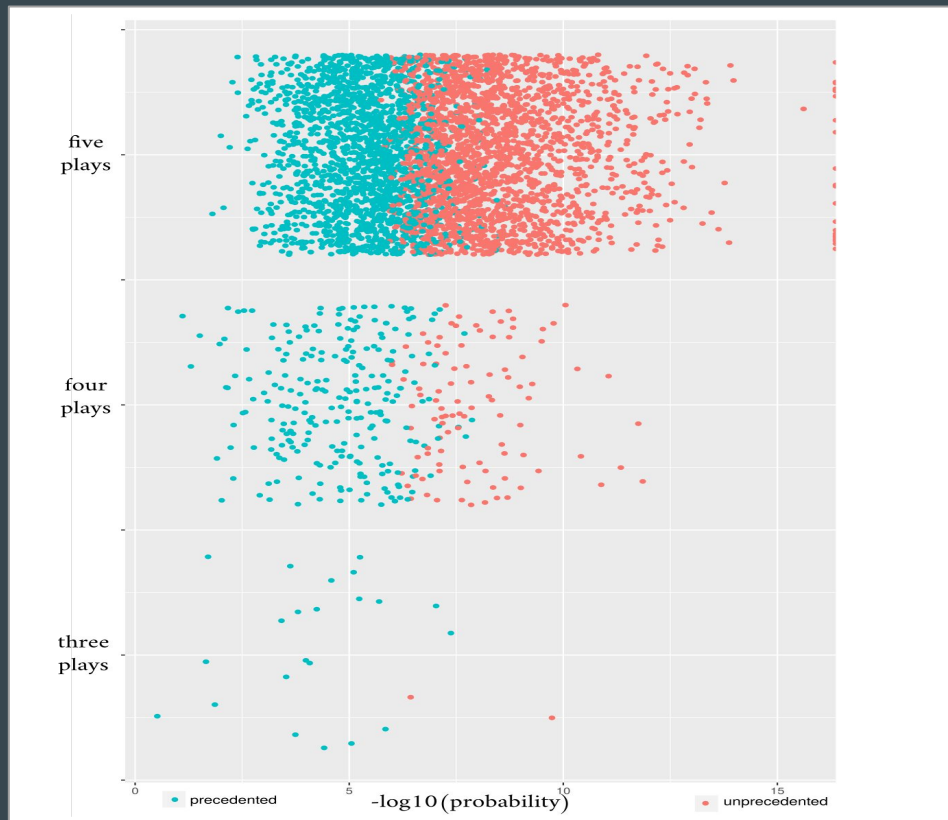
3XX:XXX

13XX:XXX

123XX:XXX

23XX:XXX

Baseball's Unprecedented Half-innings

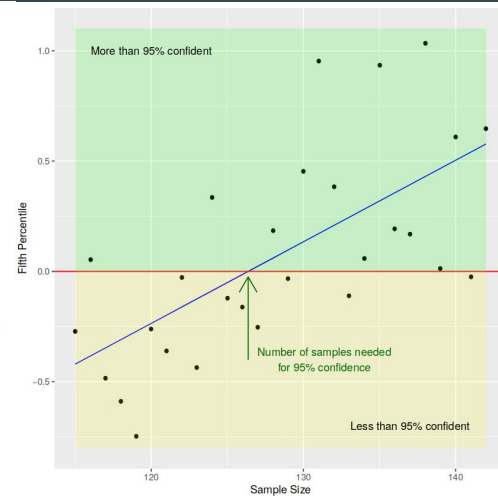
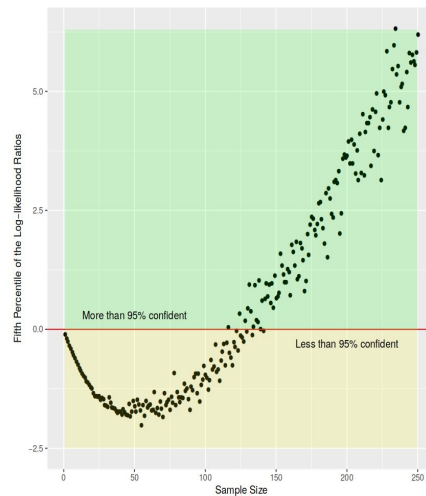
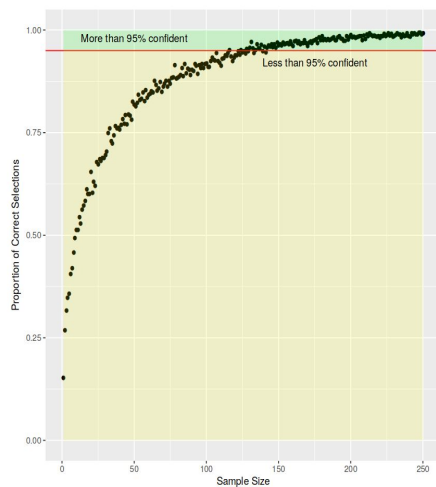
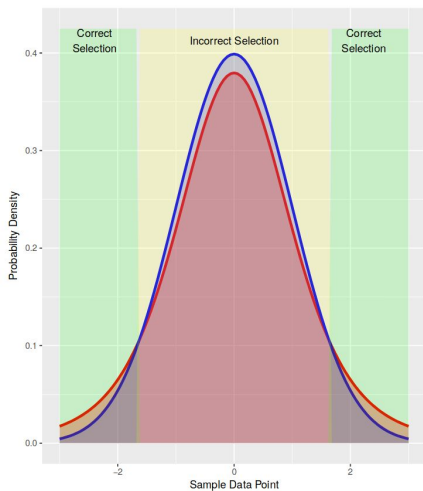


The most unlikely unprecedented half-innings:

sequence	$-\log_{10}(\text{probability})$
Three Plays	
0:3:13:XXX	6.43509767499117
0:3:23:XXX	9.73543779430501
Four Plays	
0:2:3:23:XXX	11.0579993507313
0:0:3:23:XXX	11.3442887847059
0:3:3:23:XXX	11.7519898723546
0:3:23:23:XXX	11.855734799529
Five Plays	
0:3:23:3:23:XXX	15.6122744428876
3XX:23XX	Infinity

$$\log_{10}(\text{number of half-innings played}) = 6.45$$

Quantifying the Similarity Between Model Baseball Teams

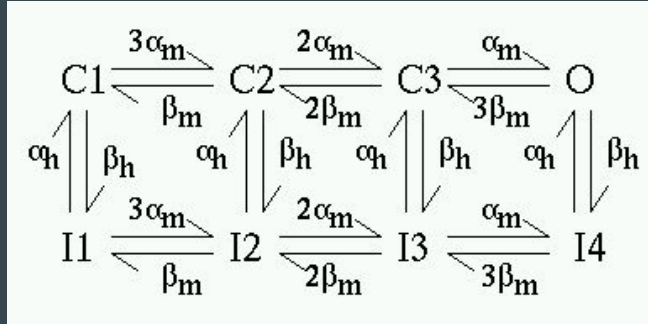


Result: it takes 30 ± 1 half-innings, simulated from the 2011 Baltimore Orioles model, to reject, with 95% confidence, the statement that these half-innings were sampled from the 2011 New York Yankees model.

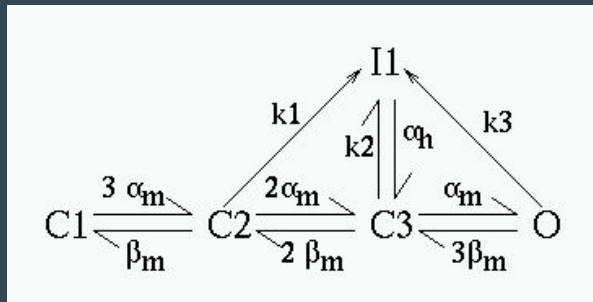
Making Half-inning History and Markov Transition Probabilities Easily Accessible to All



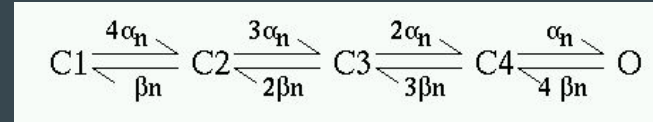
Beyond Sports



Hodgkin-Huxley Sodium Channel



Modern Model of Sodium Channel



Potassium Channel



Exposure
Incubation
Transmission
Immunity

Collaborators on Related Projects



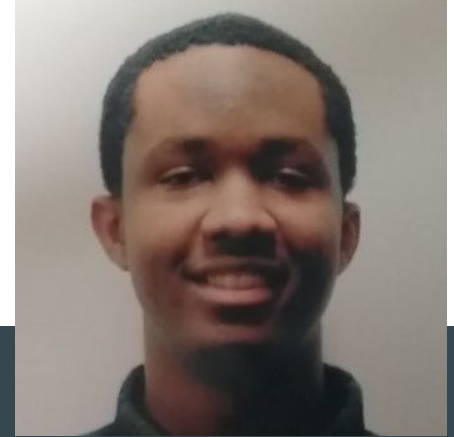
Jacob Ward

Formerly Professorial
Lecturer, American
University



Jake Berberian

Class of 2022, American
University



Kingsley Iyawe

Masters Student, American
University, expected
graduation: May 2020