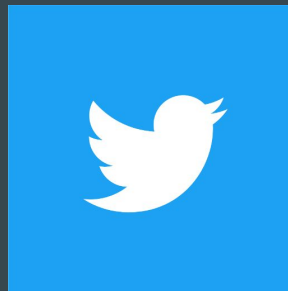
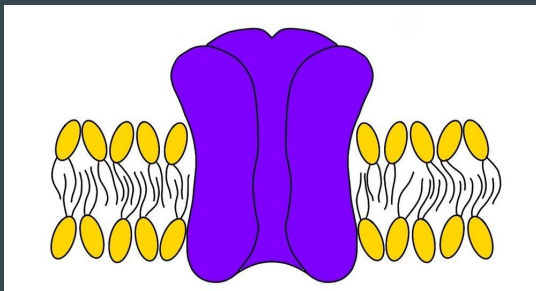


Baseball's Unprecedented Half-innings and Other Insights from Markov Chains

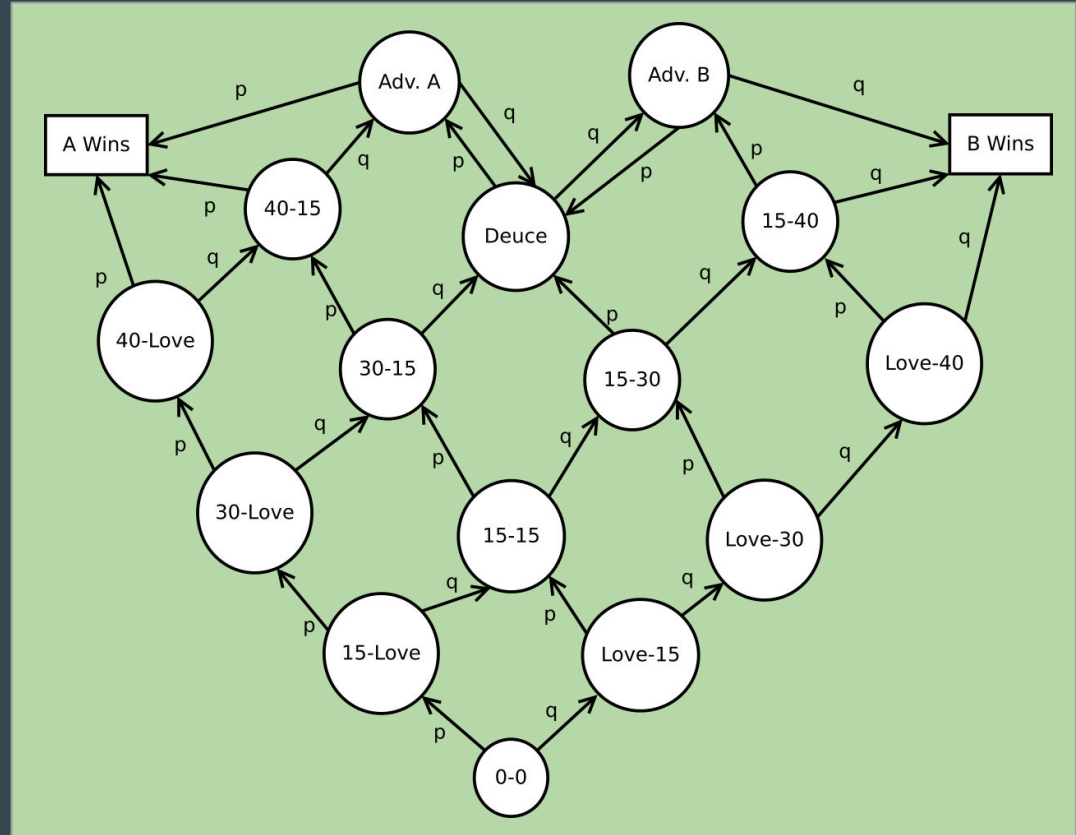
...

Sean G. Carver, Ph.D.

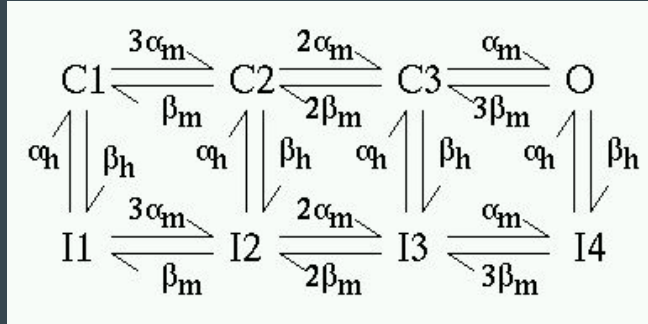
September 12, 2019



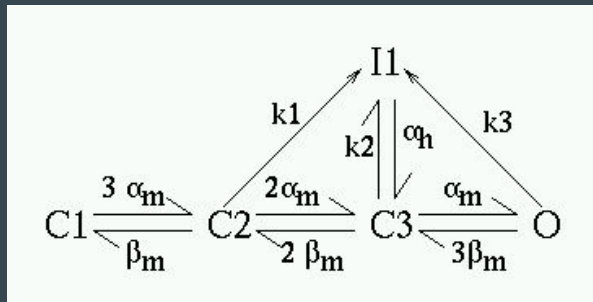
What is a Markov Chain?



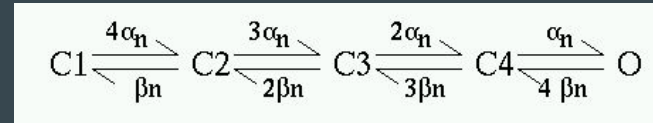
Markov Chains Beyond Sports



Hodgkin-Huxley Sodium Channel



Modern Model of Sodium Channel



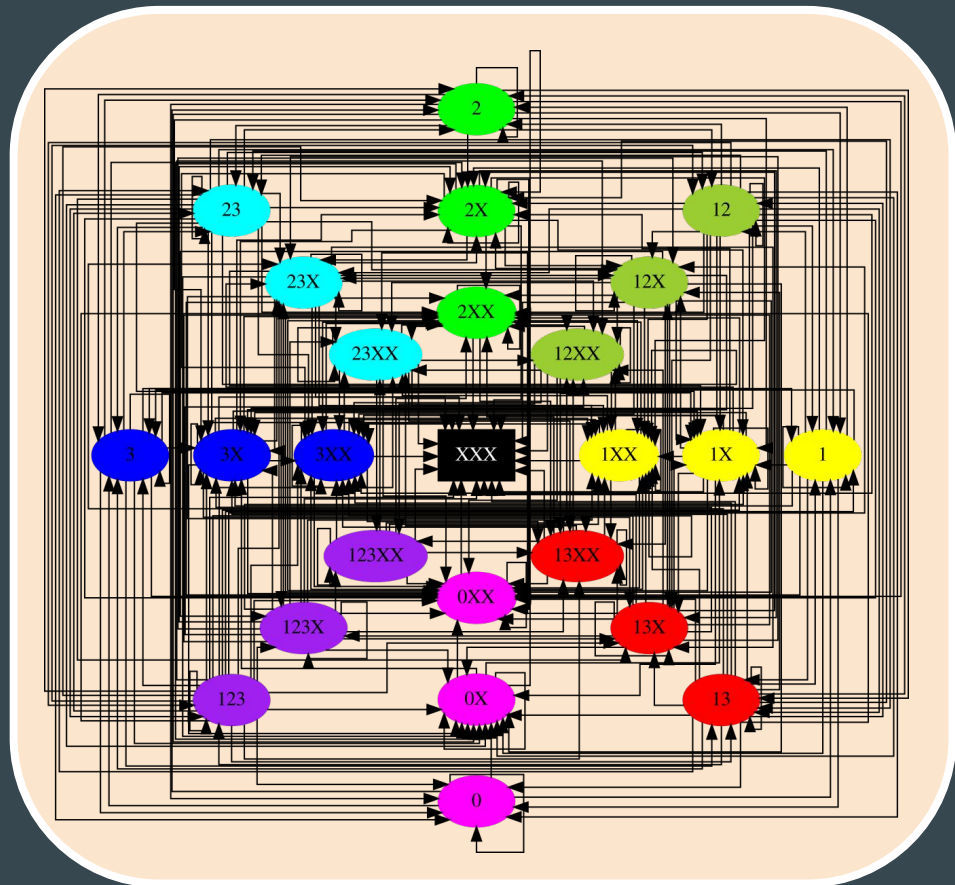
Potassium Channel



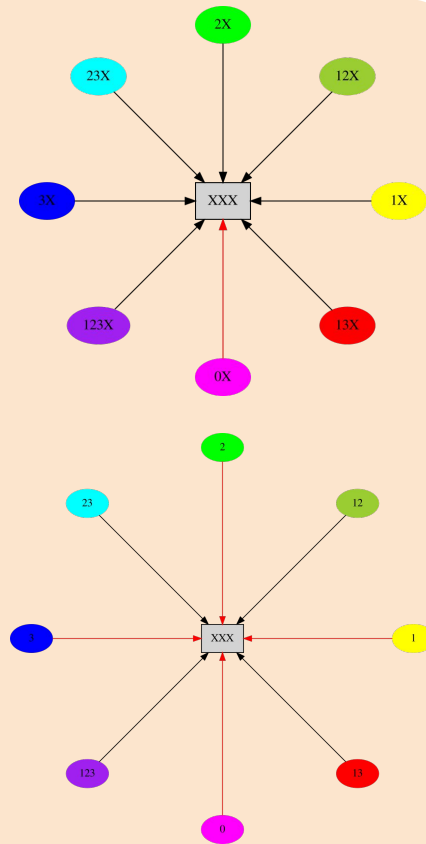
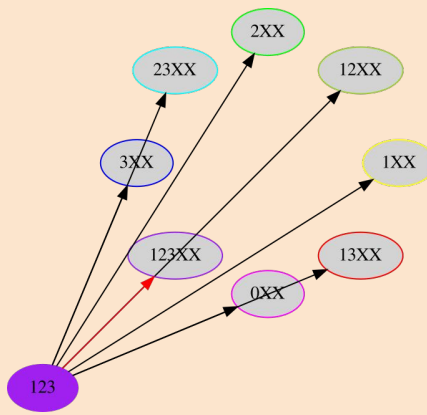
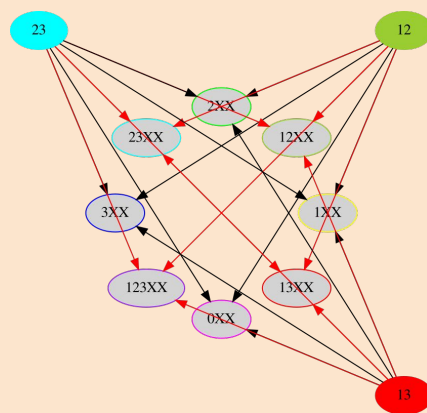
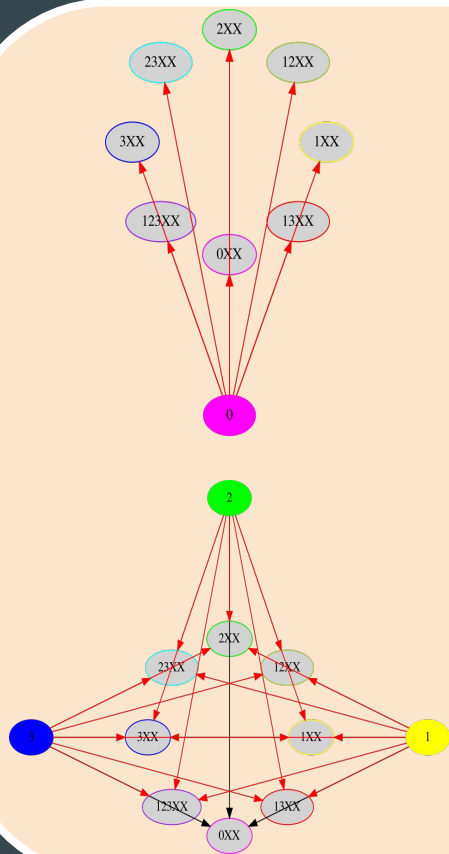
Exposure
Incubation
Transmission
Immunity

Detect statistically significant changes to users' or communities' interactions with Twitter

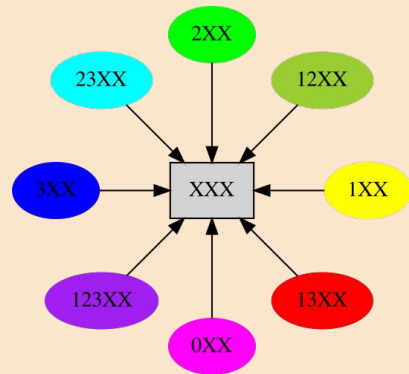
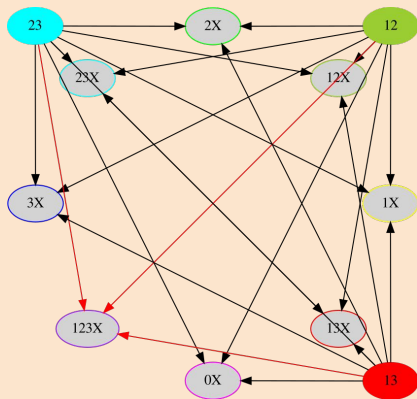
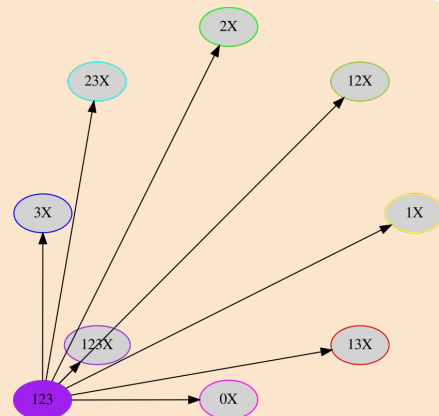
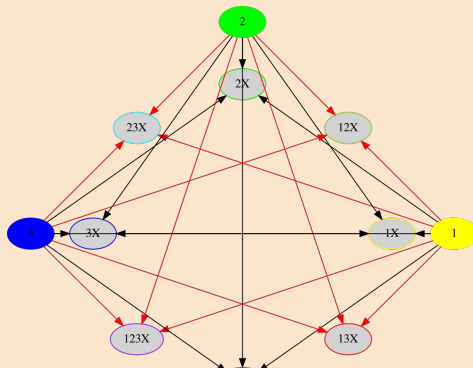
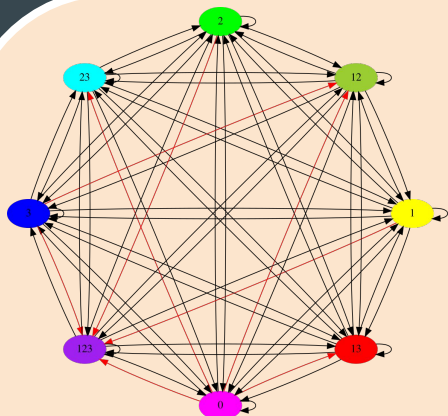
Baseball as a Markov Chain



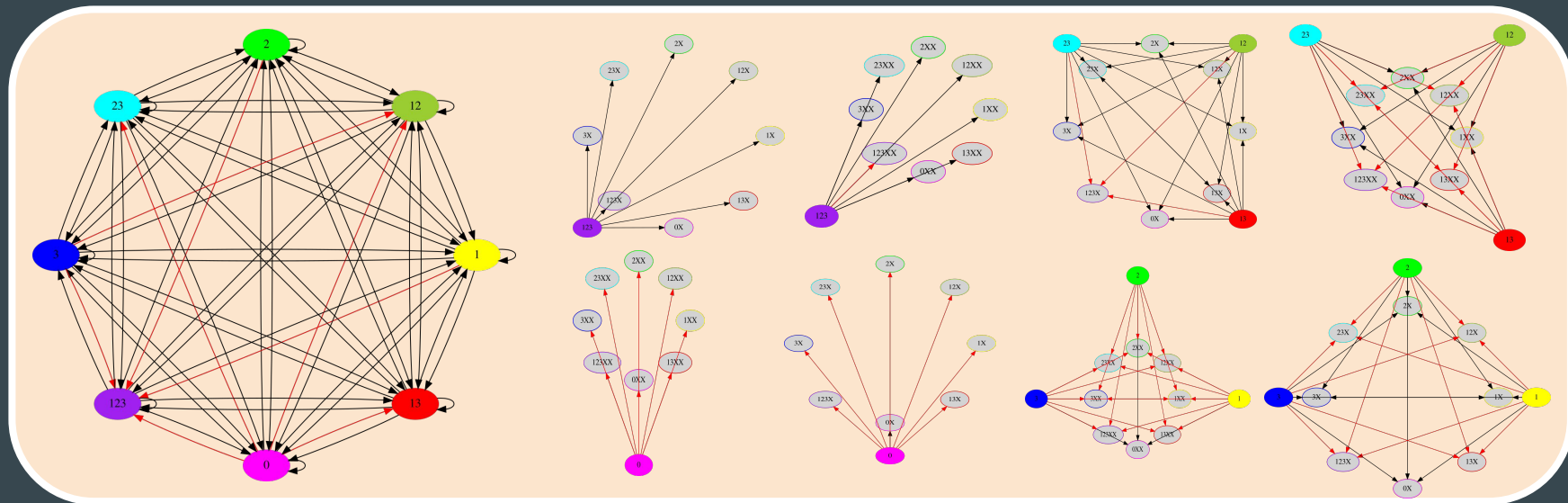
Visualizing Baseball's Graph (Double and Triple Plays)



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!

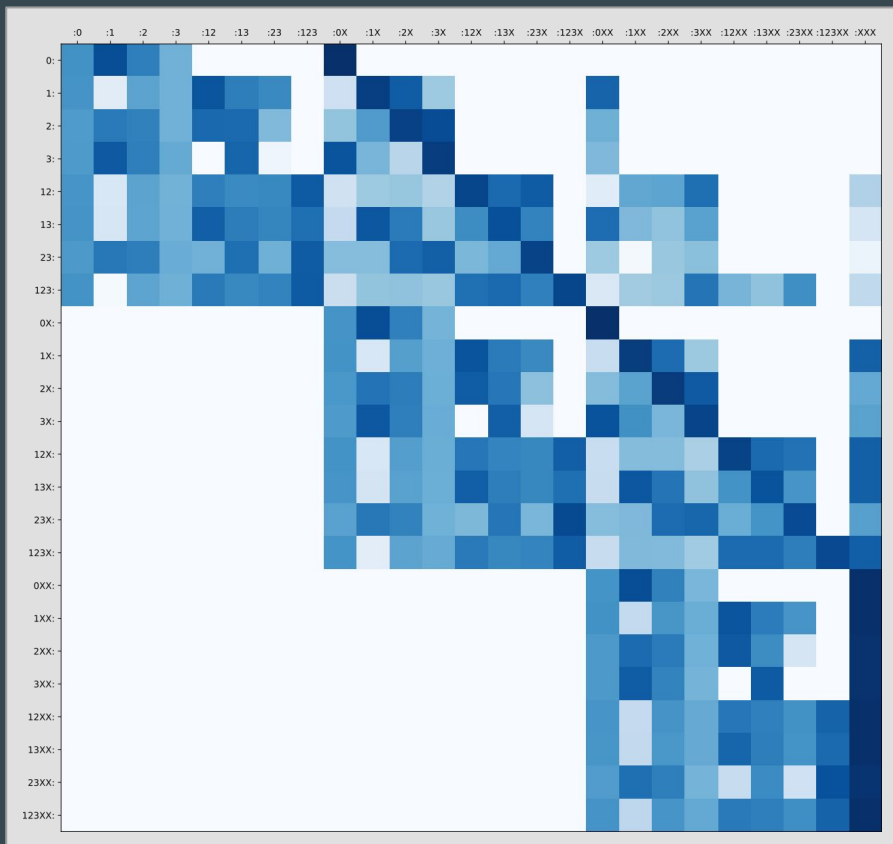
Transition Probability Matrix -- Clean Plays, No Outs

	: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



Population:
All MLB teams, 1930-2018,
Regular season

Many More Probabilities Are Zero for Subpopulations



Washington Nationals, batting at home, 2018

Relative Transition Probabilities (1930-2018)

-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

13:1

13:XXX

1:0X

1X:0XX

1XX:1XX

12XX:1XX

12X:0XX

12:0X

13X:0XX

23XX:23XX

23XX:12XX

23X:0XX

123:0X

13:0X

123:XXX

3:2X

12:3X

12:XXX

12X:3XX

1X:3XX

1:3X

123X:3XX

123:1XX

123:2XX

23:2XX

13:3X

13:2XX

123:1X

123:2X

23:3XX

23:0X

2X:23X

2X:0XX

12X:2XX

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23X:3XX

3:0XX

3:1X

3:2

3:3

3:13

3:23

3:33

3:123

3:213

3:313

3:123

3:213

3:313

3:123

3:213

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3:123

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1XX:3XX

1:3

2XX:3XX

2X:3X

12X:3X

2:3

3XX:3XX

12:3

13X:3X

3X:3X

23XX:3XX

23X:3X

123X:3X

23X:12XX

23X:13XX

23X:23XX

23X:3XX

23X:12XX

23X:13XX

0:0

0X:0X

0XX:0XX

1X:0X

1XX:0XX

1:0

2XX:0XX

2X:0X

12X:0X

2:0

3XX:0XX

12:0

13X:0X

3X:0X

23XX:0XX

23X:0X

123X:0X

23X:0X

23X:0X

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23X:0X

23X:0X

23X:0X

0:2

0X:2X

0XX:2XX

1X:2X

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123X:2X

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12X:1X

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2X:0X

12X:0X

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3XX:0XX

12:0

13X:0X

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123X:0X

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23X:0X

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2X:1X

12X:1X

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3XX:1XX

12:1

13X:1X

3X:1X

23XX:1XX

23X:1X

123X:1X

23X:1X

23X:1X

23X:1X

23X:1X

23X:1X

23X:1X

0:2

0X:2X

0XX:2XX

1X:2X

1XX:2XX

1:2

2XX:2XX

2X:2X

12X:2X

2:2

3XX:2XX

12:2

13X:2X

3X:2X

23XX:2XX

23X:2X

123X:2X

23X:2X

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23X:2X

23X:2X

23X:2X

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0X:3X

0XX:3XX

1X:3X

1XX:3XX

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23X:3X

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23X:3X

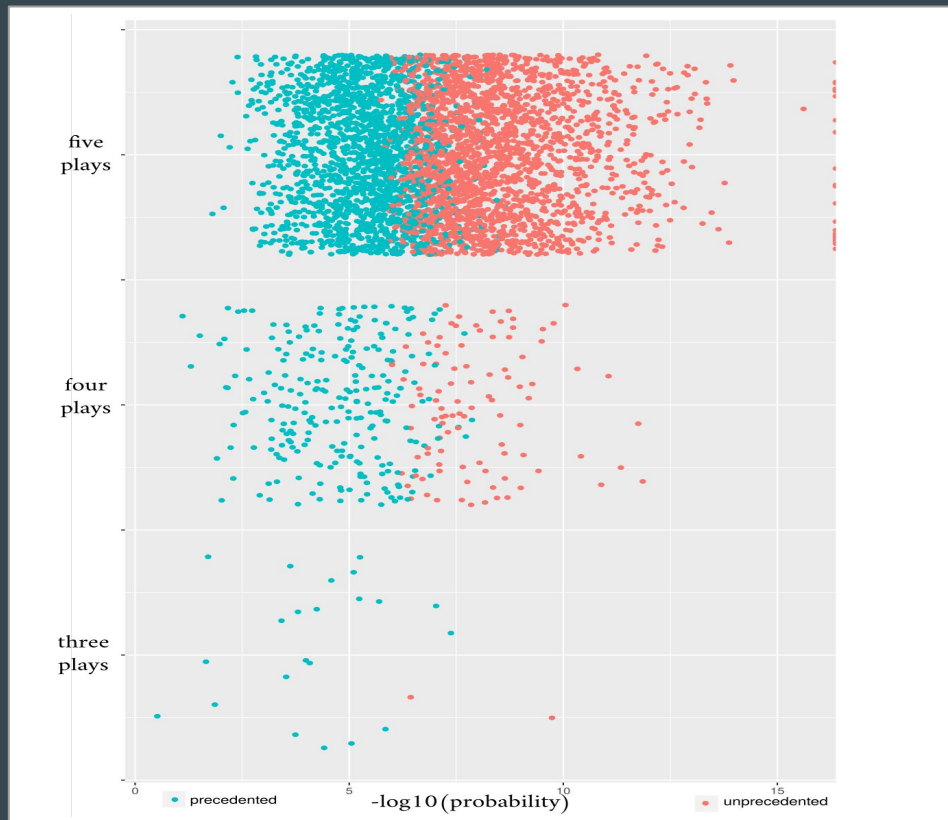
23X:3X

0:0

0X:0X

0XX:0XX

Baseball's Unprecedented Half-innings

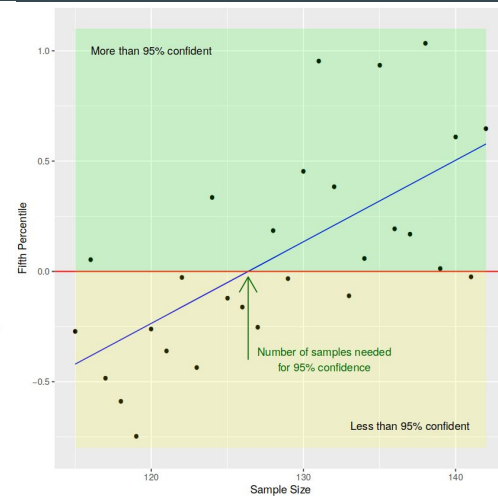
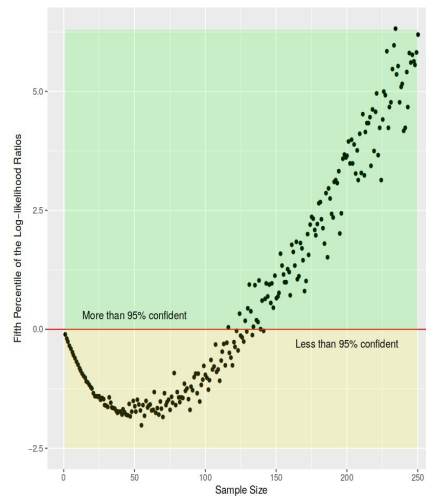
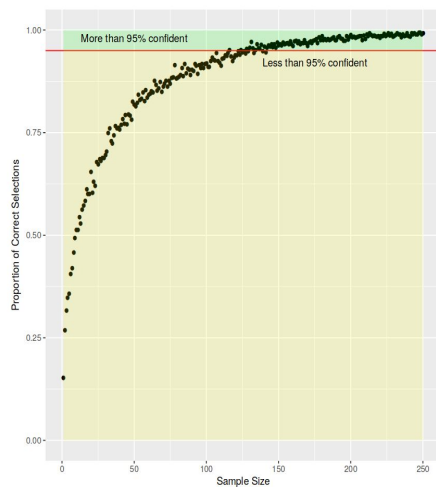
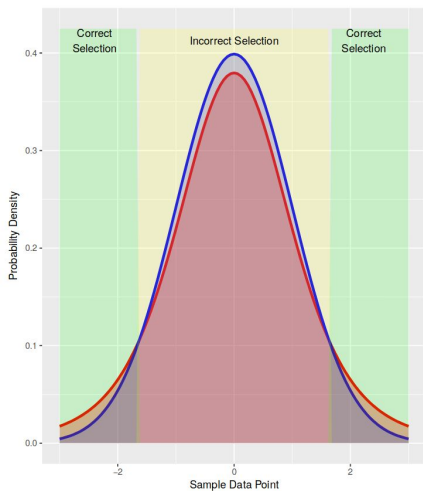


The most unlikely unprecedented half-innings:

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**



Future work: Applying Markov Chains to Win Games

The Markov model can be used to detect statistically significant changes, including...

- Changes to a team's play,
- Changes to the whole league's play.

Once a change has been detected, insight into why can be pursued.

This insight can be leveraged to win games.



Collaborators on Related Projects



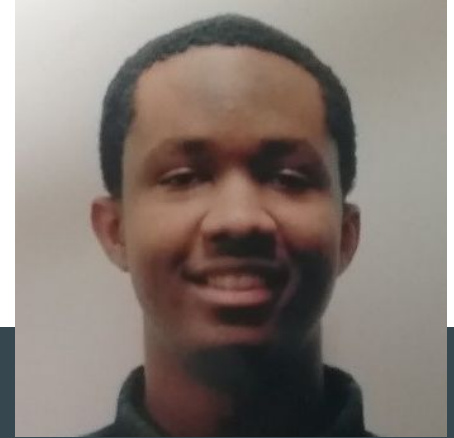
Jacob Ward

Formerly Professorial
Lecturer, American
University



Jake Berberian

Class of 2022, American
University



Kingsley Iyawe

Masters Student, American
University, expected
graduation: May 2020