System ◊◯

Baseball for the skeptical and apathetic

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Problem

Baseball is poorly marketed to the average OPLSS attendee

Goals of this talk

Objective 1

Convince you that baseball is a rich, fascinating sport

Objective 2

Equip you to understand baseball games as a spectator

Outline

- Motivation
- Rules
- Discussion
- Future work

What's interesting about baseball?

Two months ago, I knew nothing about baseball and honestly thought it was pretty stupid.

- Not interested in sports, American patriotism
- Games have a reputation for being long and uneventful
- Seems to be: "which guy can smack the ball the hardest"

What else is there?

In a nutshell: entropy

Baseball is a sequence of **discrete probabilistic outcomes**

- Surprisingly bounded state space
- Individual plays are highly unpredictable
- Game structure causes nondeterminism to **compound**

Well-modeled by discrete-time Markov processes[1][2]

[1] Bukiet, B., Harold, E.R., Palacios, J.L. (1997) A Markov Chain Approach to Baseball. Operations Research 45(1):14-23.

[2] D'Angelo, J.P. (2010) Baseball and Markov Chains: Power Hitting and Power Series. Notices of the AMS 57(4), April 2010.

Variance

Extremely **high variance** compared to other professional sports

- 162 games/season
- Each matchup is a **series** of 3 games, over consecutive days

Transitivity often violated

- *Dodgers* $>$ ... $>$ *Rockies* in overall standings
- *Rockies* $>^3$ *Marlins* $>^3$ *Giants* in series sweeps

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- *Giants* vs. *Dodgers* individual games:
  1. *Giants*, 6-2
  2. *Dodgers*, 5-11
  3. *Dodgers*, 4-5

Variance: Home game win probability

When the best team plays at home in the NBA, it is always favored to win at least 60% of the time [. . .] ranging from a 68% probability to an 84% probability. Meanwhile, even with a home advantage, it is ***rare that the best MLB team is ever given a 70% probability of winning*** *[. . .] ranging from* ***57% to 63%****.*[3]

[3] Lopez, M.J., Matthews, G.J., Baumer, B.S., "How often does the best team win? A unified approach to understanding randomness in North American sport," Ann. Appl. Stat. 12(4), (December 2018).

Variance: Baseball has high n, but not enough

Sport	League	Games/season
Baseball	**MLB**	**162**
Hockey	NHL	82
Basketball	NBA	82
Football	Brasileirão	68.7
Football	Premier League	46.9
American football	NFL	17

[4] Ben-Naim, E., Hengartner, N.W., Redner, S. et al. "Randomness in Competitions." J Stat Phys 151 (2013).

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Would need to play *256 games* to ensure the best team wins[4]

[4] Ben-Naim, E., Hengartner, N.W., Redner, S. et al. "Randomness in Competitions." J Stat Phys 151 (2013).

Regression to the mean

- Yet somehow, statistics work
- **Sabermetrics**: many hobbyists; teams employ multiple PhDs for their analytics teams
- *Example*: Batters perform better the **third time** they face a pitcher in a game
  - Use a backup pitcher for the first inning, then send in your main starting pitcher
  - On average, starter can get ~1 more inning

Other interesting bits

- **Signals**: pitching strategy and on-field coordination
  - Teams obfuscate their systems
  - Feasible because of limited state machine
- Home runs are **not standardized**: "HR in $n/30$ ballparks"
  - Defined as "going out-of-bounds into the outfield"
  - But stadium dimensions vary
- MLB team names
  - Canadian team (Toronto Blue Jays)
  - Most are cities, except: Texas, Minnesota, Colorado, Arizona
  - Some cities have two teams (Los Angeles, Chicago)
- **Hand dominance** matters a lot
  - Only 10% of general population is left-handed, but 25-33% of MLB players

Hand dominance: First order effects

- Infield positions strongly favor **throwing right-handed**, due to direction of play
  - Exception: 1B, and maybe catcher
- **Batting left-handed** is slightly closer to first base, easier to hit into gaps

Hand dominance: Second order effects

- **Same-handed matchups** favor the pitcher; easier to hit balls from the opposite side
- Effect is **asymmetric**: hitting LH-on-LH is harder than hitting RH-on-RH
- **Switch-hitters** learn to hit from both their non-dominant side
  - Much easier than switch-pitching

Left-handed players are heavily overrepresented

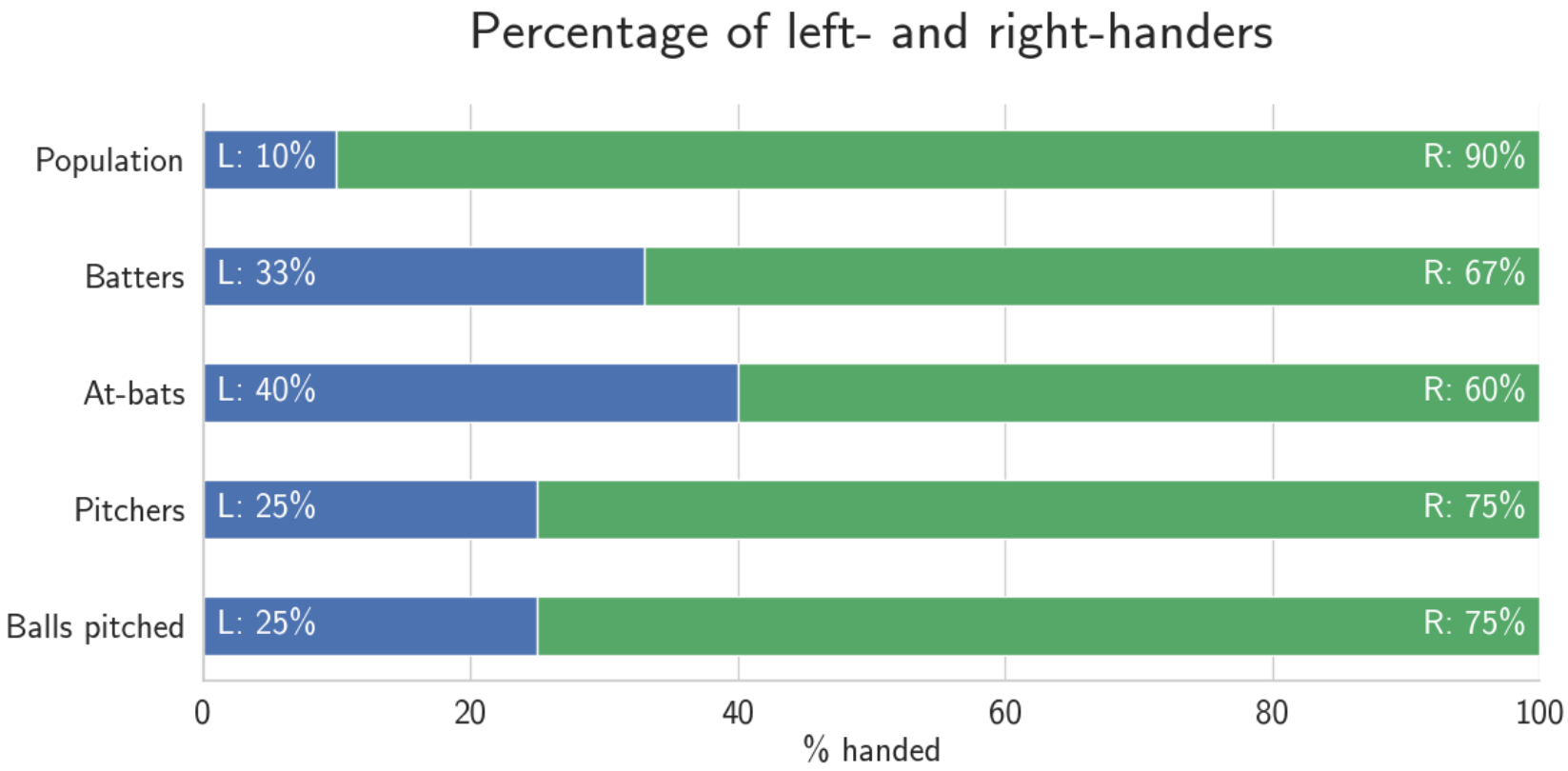

Figure 1: Dominant hand, by position

Gameplay: High-level intuition

- Hit the ball to get on base
- Sprint through all the bases to score a **run**
- Winner = team with most runs after 9 innings

This leaves a lot of gaps

- What happens for the other 95% of the game?
- Are the pitcher and batter on the same team, opposing teams, or are the pitchers a separate third faction?
  - What is the point of the pitcher, anyway?
- What is a “ball”?
- What is Minor League Baseball and why do all of the teams have such fundamentally unserious names?
  - Akron RubberDucks, Pensacola Blue Wahoos, Rocket City Trash Pandas, Albuquerque Isotopes

Field layout

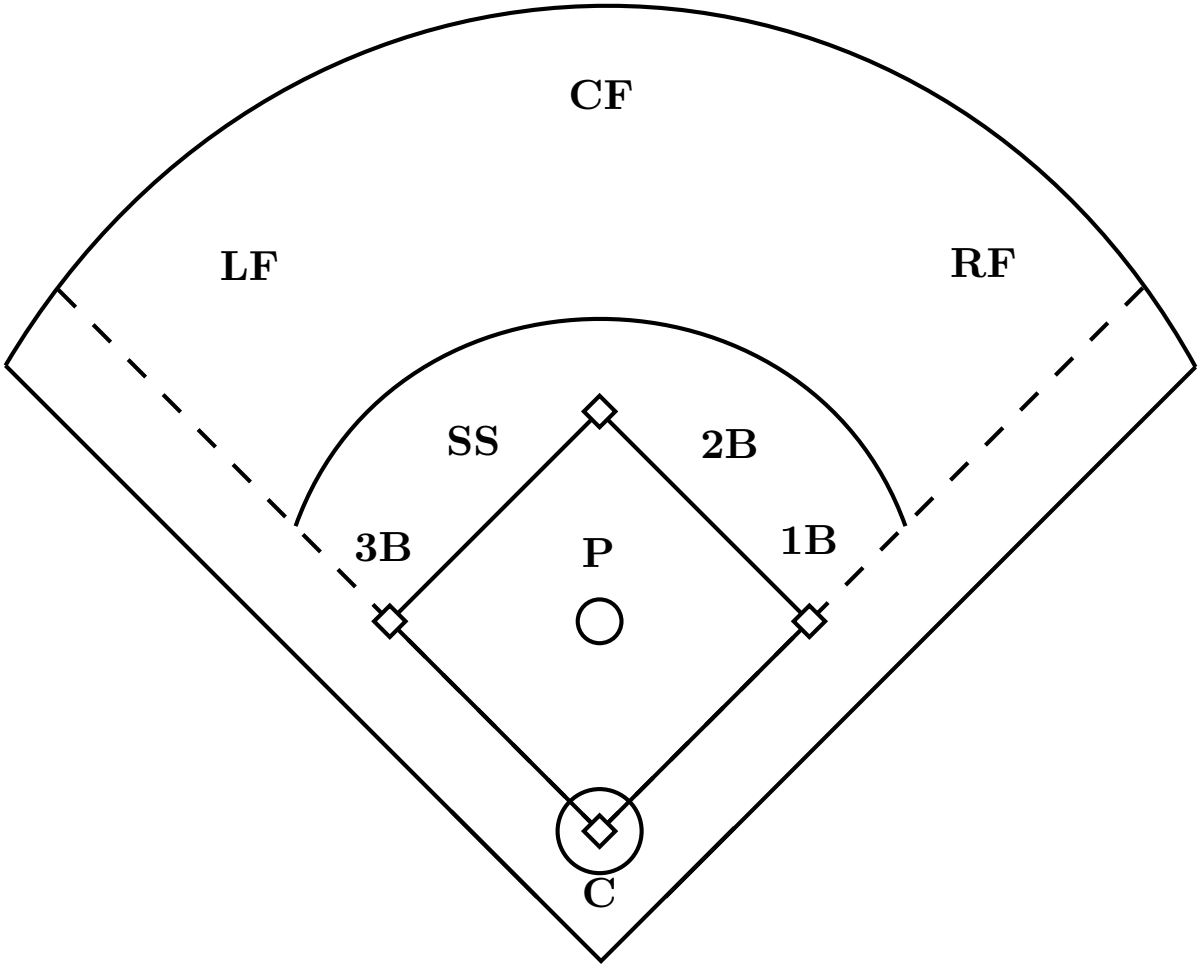

Fig. 1: Defensive positions

Field layout: Infield

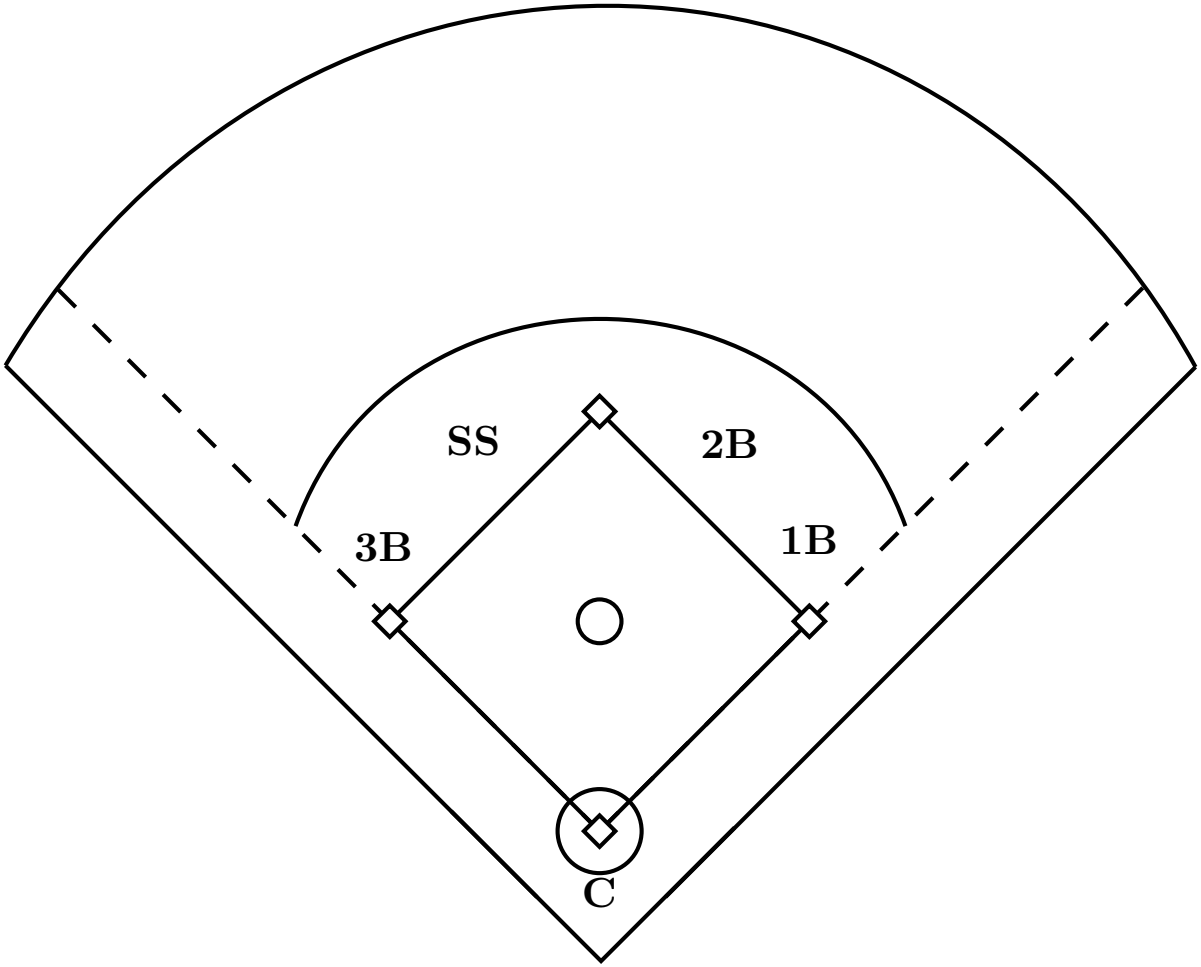

Fig. 2: Defensive positions, infield

Field layout: Outfield

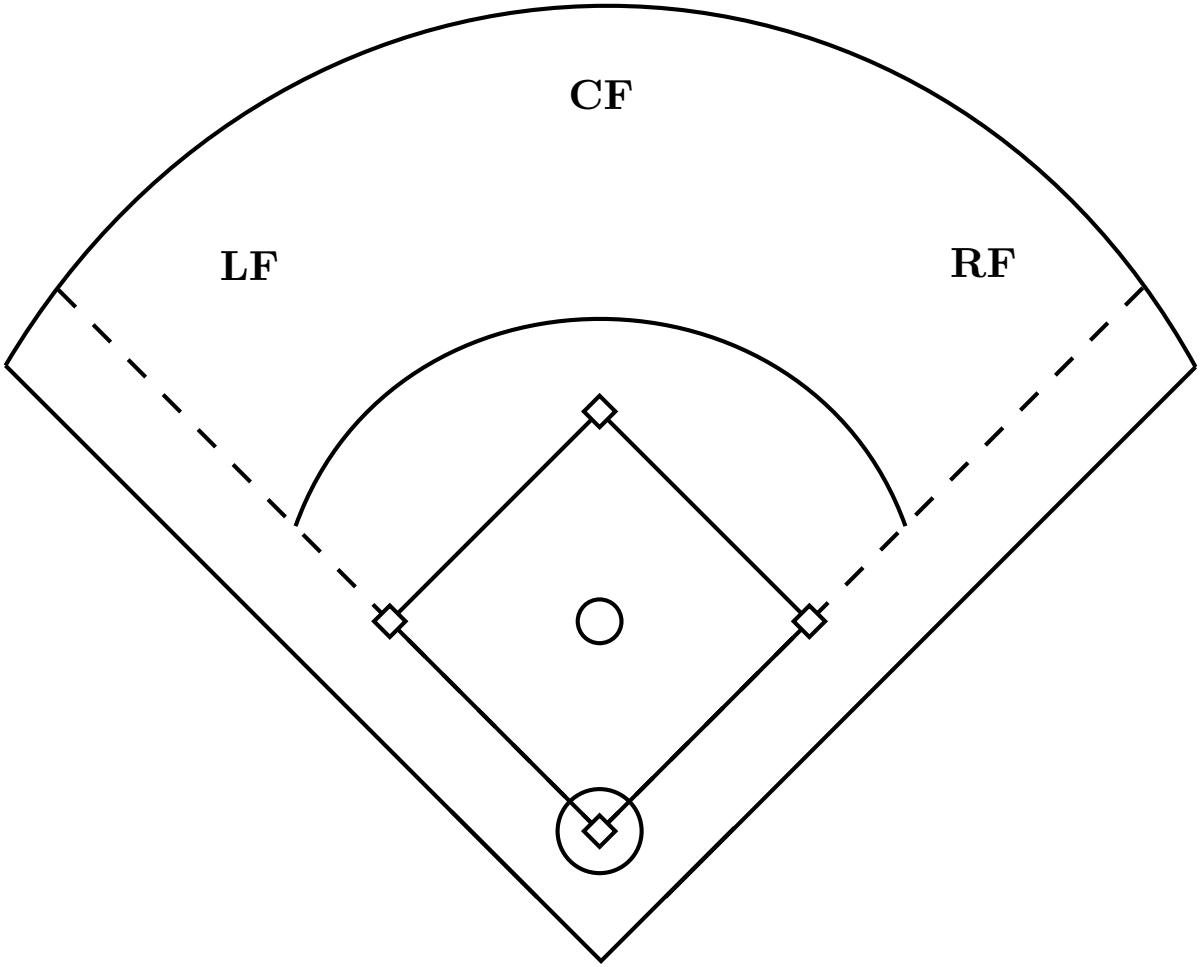

Fig. 3: Defensive positions, outfield

Pitchers vs. position players

Roster divided in ~half

- **Pitchers** are the defensive anchor of the team
- **Position players** switch between offense and defense
- Disjoint skillsets; most players can only do one
  - **Two-way players** (Shohei Ohtani) rare, highly valuable

Half-inning

1. Next batter goes up for plate appearance
   - **Walk** (pitcher fail): batter gets on-base for free
   - **Strikeout** (batter fail): +1 out, next batter
   - Ball **in play**
2. During play:
   - Offense runs bases, balancing risk/reward
   - Defense tries to catch the ball, pass around to tag runners out
3. Repeat until **three outs**

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Outs

- **Three strikes** in one plate appearance
- **Ball caught** before touching ground
- **Runner tagged** before safely reaching base

Understanding the at-bat

Where a lot of the action happens!

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How I used to think it worked

1. Pitcher throws
2. Batter tries to hit
   1. If they hit, try to run to first base
   2. If they miss, strike $\rightarrow$ bad for batter
   3. If ???, ball $\rightarrow$ bad for pitcher
3. 3 strikes = out (batter fail)

Understanding the at-bat

How it actually works (approx.)

1. Pitcher throws **aiming for invisible rectangle** ("strike zone")
2. Batter **predicts trajectory and decides** to hit
   1. If they hit, try to run to first base $\rightarrow$ good for batter
   2. If they miss, strike $\rightarrow$ bad for batter
   3. If they don't swing, and **ball misses strike zone**, ball $\rightarrow$ bad for pitcher
3. 3 strikes $=$ out (batter fail)
4. **4 balls = walk** (pitcher fail, batter gets free pass to first base)

Plate appearance

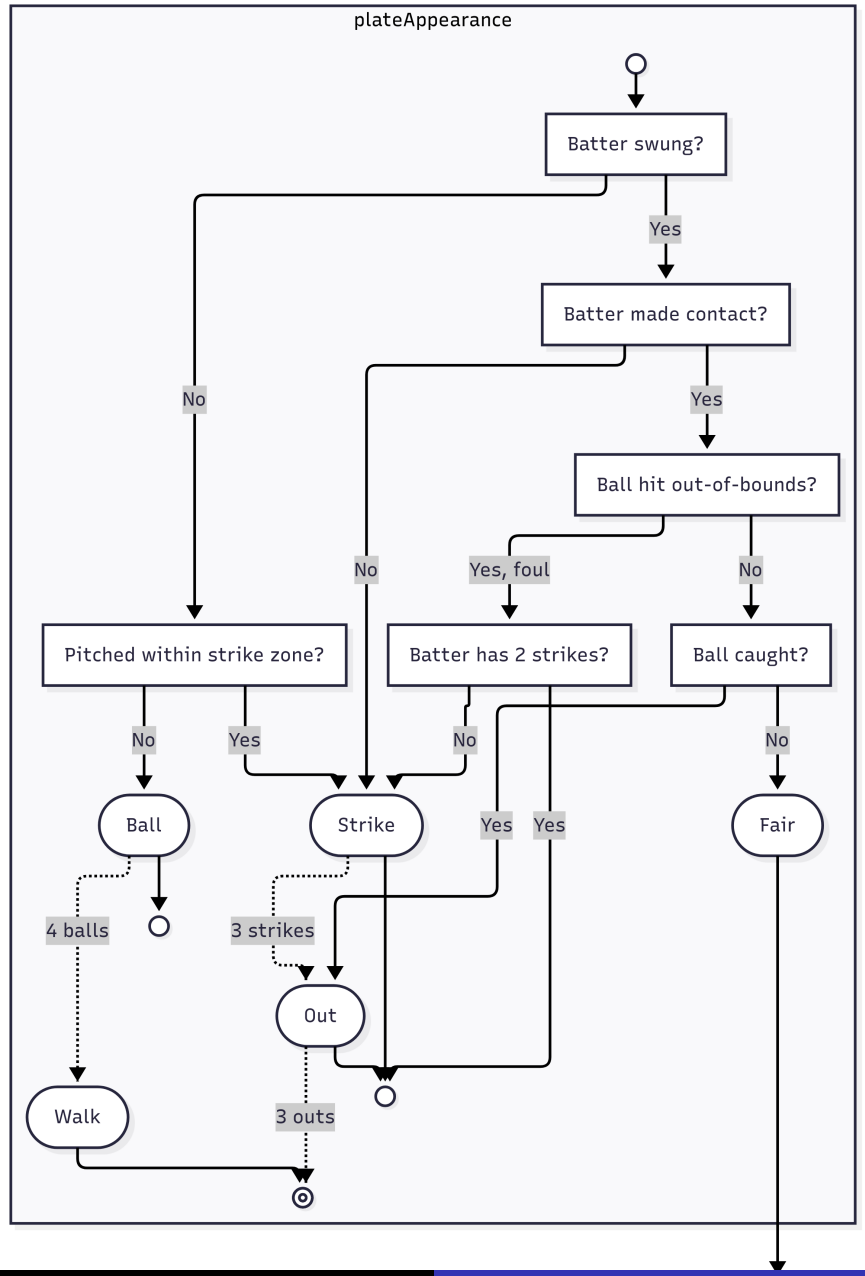


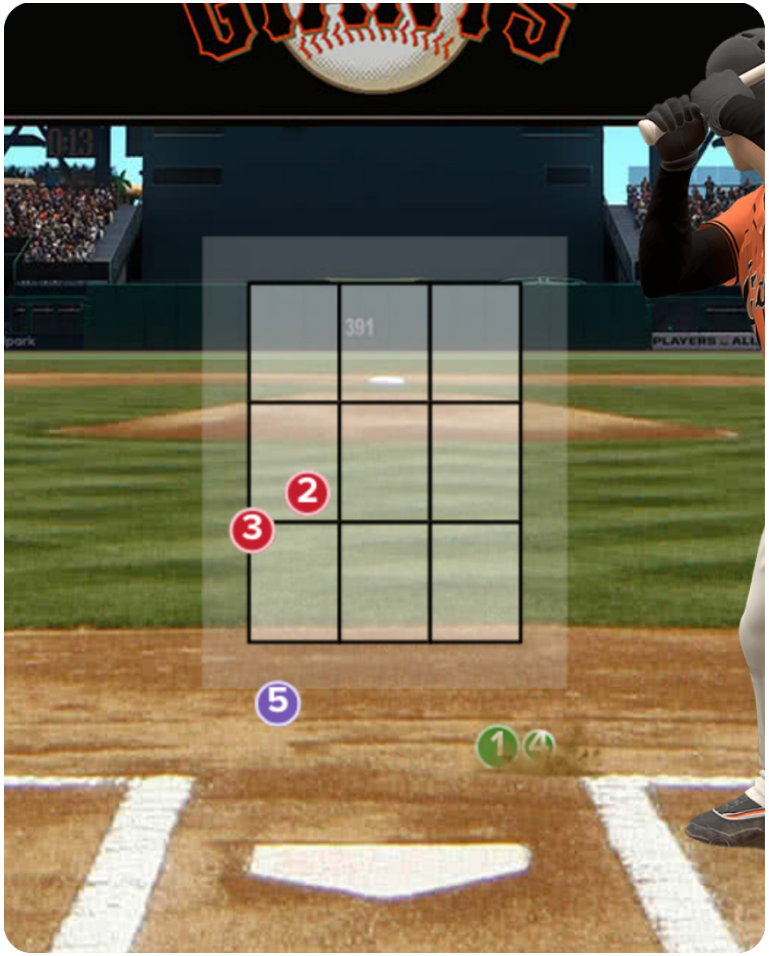
Plate appearance

Checklist

- Did the pitcher throw to strike zone?
- Did batter make contact?
- Did ball go out of bounds?
- Did ball get caught?

Volume increases with each successive level

Strike zone



1 **Ball In Dirt** **1 - 0**
78.3 mph Curveball

2 **Called Strike** **1 - 1**
94.9 mph Four-Seam Fastball

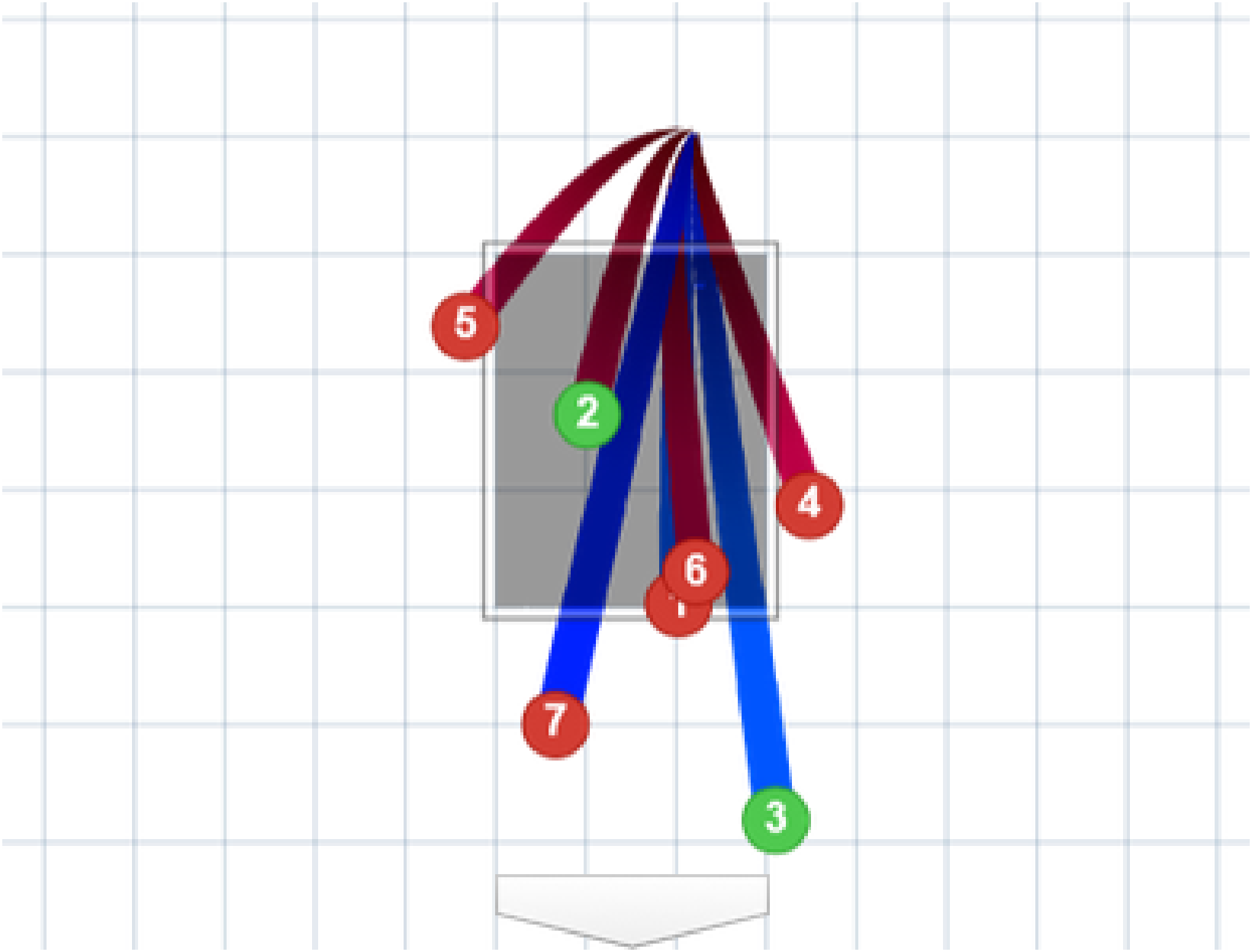
3 **Called Strike** **1 - 2**
85 mph Slider

4 **Ball In Dirt** **2 - 2**
79.6 mph Curveball

5 **In play, out(s)**
86.1 mph Slider

Figure 3: You can't see it in the game, and nothing makes sense without it

Umpires are fallible



Pitching strategy

- **Faster** is better: 100mph fastballs are normal
  - Four-seam, cutter, sinker
- Outwitting the batter with different pitch types
  - **Breaking ball**: curveball, slider
  - **Weird speeds**: changeup, splitter
- **Location**: strikeouts, batter hot zones
  - e.g. some batters can't hit "outside" pitches
- Catcher's job is to **trick the umpire** by moving glove

First pitch strikes

"Getting ahead in the count"

Count	BA	OBP	SLG	K%	BB%	HR%
1-0	.267	.384	.474	18.9%	15.4%	3.9%
0-1	.220	.266	.364	31.3%	5.0%	2.9%

Pitcher's count (0-2, 1-2)

- Nearly half of plate appearances that start 0-2 end in a strikeout
- Can throw a "waste pitch" far from the zone

Substitution principle

Recall the **platoon advantage** (same-handed matchups favor pitcher)

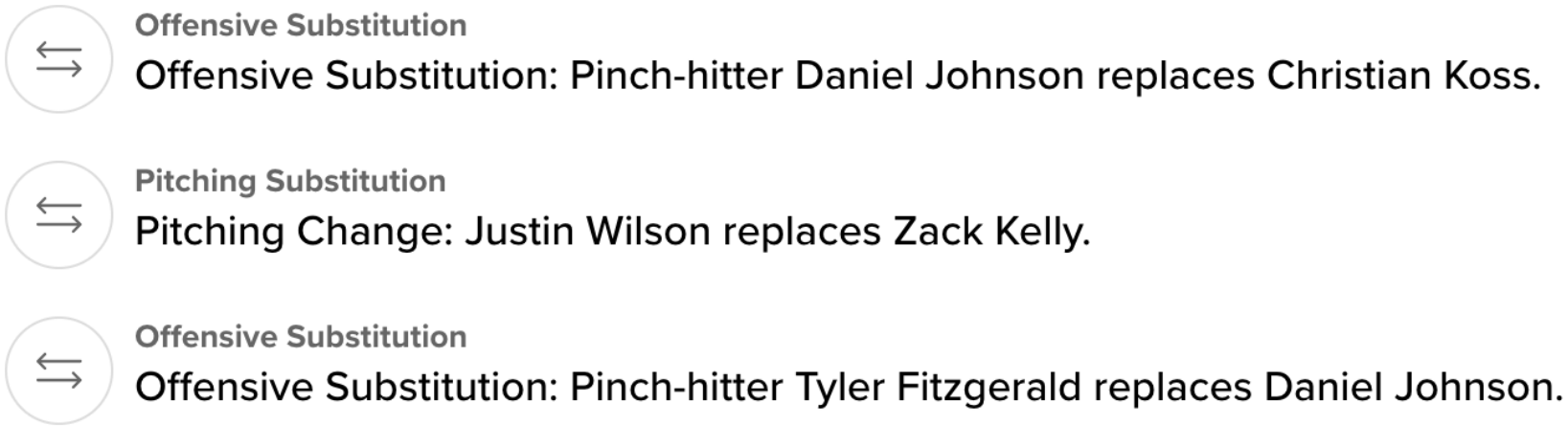


Figure 5: Back-to-back player changes

Substitution principle

$$\boxed{M[x \mapsto N]}$$

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$$\begin{aligned} M' = M[&\text{Koss}_R \mapsto \text{Johnson}_L] \\ &[\text{Wilson}_{LP} \mapsto \text{Kelly}_{RP}] \\ &[\text{Johnson}_L \mapsto \text{Fitzgerald}_R] \end{aligned}$$

Batter	Pitcher
Koss (R)	Kelly (R)
Johnson (L)	Kelly (R)
Johnson (L)	**Wilson (L)**
Fitzgerald (R)	Wilson (L)

Substitution principle

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Batter	Pitcher
Koss (R)	Kelly (R)
Johnson (L)	Kelly (R)
Johnson (L)	**Wilson (L)**
Fitzgerald (R)	Wilson (L)

Substitution is *not free*: once a player exits the game, they cannot go back in

Pitching lineup

- **Starting pitchers**: 5
  - Rotate pitching every 5 days to recover
  - Usually pitch for 5-7 innings
- **Bullpen**: ~6-7 relief pitchers
  - Take over for 1-2 innings after the starter gets tired
- **Closer:** specializes in endgame pitching
  - Usually does not pitch in blow-out situations

Pitcher statistics

- **Earned Run Average** (ERA): how much would the other team score if you pitched a whole game
  - ≤ 2 is elite, 3-4 is great to good
- **Strikeouts** (K%): can you hit the perimeter of the rectangle
- **Walks** (BB): can you hit the rectangle at all
- **Innings pitched** (IP): endurance

Hitting strategy

- Example: "taking" pitches with a $(3, 0)$ count
  - Pitcher has one last chance; hitter has three
  - **89.2%** of the time, if batter doesn't swing, it's called a ball
  - But slugging .847 when they do swing
- "Hit it where they ain't"
- Reading the ball: better than 20/20 vision

Types of batted balls

- **Line drive**: usually best, straight w/ not much arc
- **Ground ball**: not much distance, hard to insta-catch
- **Fly ball**: high parabolic trajectory, easy to catch unless far
- **Pop-up**: fly ball that doesn't travel, often leads to outs
- **Bunt**: doink

Situational hitting

Depends on the count, base configuration, and number of outs

- Example: sacrifice bunt

$$\langle \underbrace{(3,2)}_{\text{count}}, 1 \text{ out}, \blacklozenge\blacklozenge\blacklozenge \mid \underbrace{(\!|3,4|\!)}_{\text{score}}, \overbrace{8^{\perp}}^{\text{frame}} \rangle$$

Hitting statistics

- **Batting average** (BA): % of time you record a hit
  - No fouls, no outs
  - Elite hitters are close to .300
- **Slugging** (SLG): harder-hit balls count for more
  - For top hitters, often ∼twice their average
- **On-base plus slugging** (OPS): slugging + batting + walks

“Three True Outcomes”

Previous style: pitchers want to pitch hard-to-hit balls; batters want to get on base

Now, trend toward all-or-nothing gameplay

- Strikeout
- Walk
- Home run

Counterexample: Ichiro

Exercises

Consider two players, B and K:[5]

- B hits only **singles** with probability p, striking out otherwise
- K hits only **home runs** with probability q, striking out otherwise

Let $B(p)$ and $K(q)$ denote the expected number of runs scored per half-inning (until 3 outs are reached), assuming only player B or K is batting in each case.

Assume 3 singles score 1 run, and all at-bats are i.i.d.

[5] Adapted from D'Angelo, J.P. (2010) Baseball and Markov Chains: Power Hitting and Power Series. Notices of the AMS 57(4), April 2010.

Exercises

1. Set $q = p/4$. For what values of p is $B(p) \geq K(p/4)$?
2. Set $q = 2p/5$. For what values of p is $B(p) = K(2p/5)$?
3. Prove that

$$K(q) = \frac{3q}{1-q}$$

$$B(p) = \frac{p^3(3p^2 - 10p + 10)}{1-p}$$

and sketch their respective graphs for $0 \leq p \leq 1$.

Possible outcomes

```
-- How far did the runner get?
data Base = First | Second | Third | Home

-- How was the ball hit?
data BattedBall = Fly | Pop | Line | Ground | Bunt

-- What was the outcome of the plate appearance?
data Outcome = Walk
     | Strikeout
     | Out BattedBall (Maybe Nat)
     | Hit Base BattedBall (Maybe Nat)
```

Game state $\sigma = \langle c, o, b \mid s, i \rangle$

$$\langle \underbrace{(2,2)}_{\text{count}}, 1 \text{ out}, \blacklozenge\!\!\diamondsuit\!\!\blacklozenge \mid \underbrace{(\!|6,4|\!)}_{\text{score}}, \overbrace{9^{\perp}}^{\text{frame}} \rangle$$

- $c \in \{0,1,2,3\} \times \{0,1,2\}$ is the **pitch count** (balls, strikes)
- $o \in \{0,1,2,3\}$ is the **number of outs**
- $b \in \{0,1\}^3$ is the state of the **bases**
  - $\blacklozenge\!\!\blacklozenge\!\!\blacklozenge$ = "bases loaded"
  - $\blacklozenge\!\!\diamondsuit\!\!\blacklozenge$ = "runner on first and third"
- $s \in \mathbb{N} \times \mathbb{N}$ is the **score** (home, away)
- $i \in \{1, \ldots, 9\} \times \{\top, \perp\}$ is the **inning/frame**
  - $9^{\perp}$ = "bottom of the 9th"

Possible outcomes: impact on σ

Outcome	Count	Outs	Bases	Score	Inning
Walk	✓	-	✓	(✓)	-
Strikeout	✓	✓	-	-	(✓)
Hit out	✓	✓	(✓)	(✓)	(✓)
Base hit	✓	(✓)	(✓)	(✓)	(✓)

Possible outcomes: big-step

- **Walk** $\sigma \mapsto \langle \vec{0}, o, b' \mid s', i \rangle$
  - Runner gets free pass to 1B, could drive in a run
- **Strikeout** $\sigma \mapsto \langle \vec{0}, o+1, b \mid s, i \rangle \xmapsto{o'=3} \langle \vec{0}, 0, \Diamond^{\Diamond}\Diamond \mid s, \mathrm{next}(i) \rangle$
  - Outs increment, possible inning change
  - Next batter comes up
- **Hit out** (type, position)

  $\sigma \mapsto \langle \vec{0}, o', b' \mid s', i \rangle \xmapsto{o'=3} \langle \vec{0}, 0, \Diamond^{\Diamond}\Diamond \mid s', \mathrm{next}(i) \rangle$
  - Possible base running, scoring by existing runners
  - Outs increment, possible inning change
- **Base hit** (n, type, position)

  $\sigma \mapsto \langle \vec{0}, o', b' \mid s', i \rangle \xmapsto{o'=3} \langle \vec{0}, 0, \Diamond^{\Diamond}\Diamond \mid s', \mathrm{next}(i) \rangle$
  - Bases change, possible scoring
  - Outs technically possible for inning change

Judgment

$$\boxed{\sigma \vdash A \text{ play} \dashv \sigma'}$$

Rules we didn't cover

- Double plays
- Force outs
- Infield fly rule
- Stealing bases
- Pickoff attempts
- Balks, wild pitches
- and more!

How to bring baseball into your life

Baseball is **constantly happening**: the Markov process runs every day!

- Not making progress on a key proof? $\rightarrow$ *"I wonder how the game is going"*
- Advisor micromanaging you? $\rightarrow$ *"How did my team do today?"*
- Department drama? $\rightarrow$ *"Let me read about the 2019 Houston Astros sign-stealing scandal instead"*

Advertisement

We are going to a Minor League baseball game **tomorrow, Wednesday June 2** at 6:30pm!

Tickets are **$12**. See `#baseball` on Slack for more info.

- Practice your new game-watching skills
- You could win a free car
- Learn how the Minor League system works, and how the MLB antitrust exemption allows for unfair labor practices

How to watch baseball the “official” “real” way

Streaming

- **MLB.TV** ($120/year) is the “official” “streaming” “service”
  - Many ways to get it for cheaper, but not needed
  - Note: Blackouts
- **Sportsurge.net** but *only* use this URL

How to follow baseball: Radio

Baseball is great on the radio!

- Action in short bursts, amenable to narration
- Pay attention when announcer's voice gets excited
- Use free online radio stations
- **MLB At Bat** ($20-30/year, included in MLB.TV)
  - Often better than TV announcers; can set audio source on MLB.TV

How to follow baseball: Gameday website

`mlb.com/gameday/red-sox-vs-giants/2025/06/20/777425/`

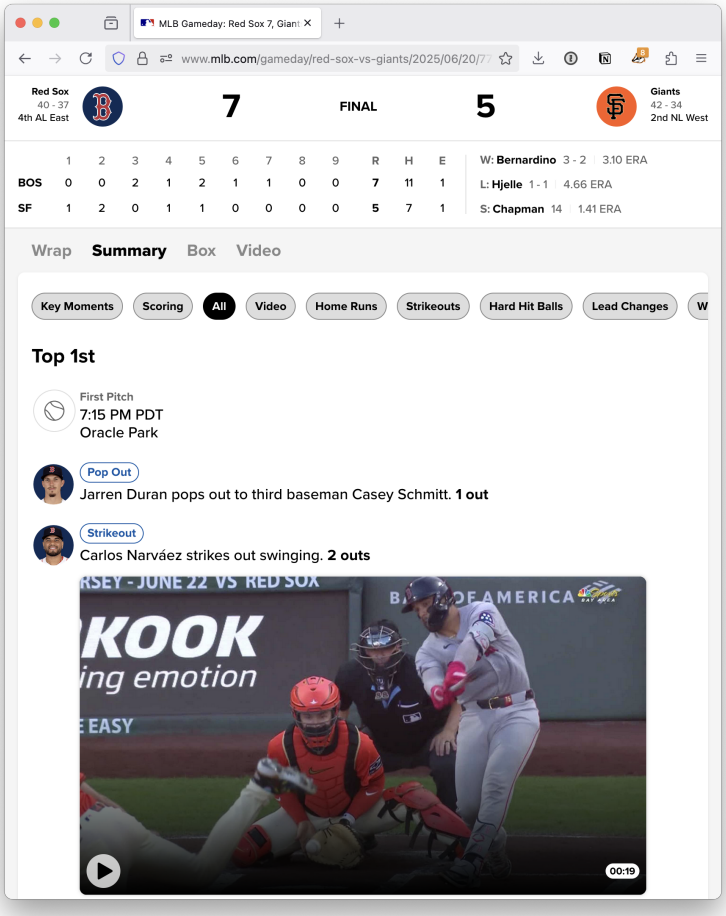

Figure 6: Gameday overview

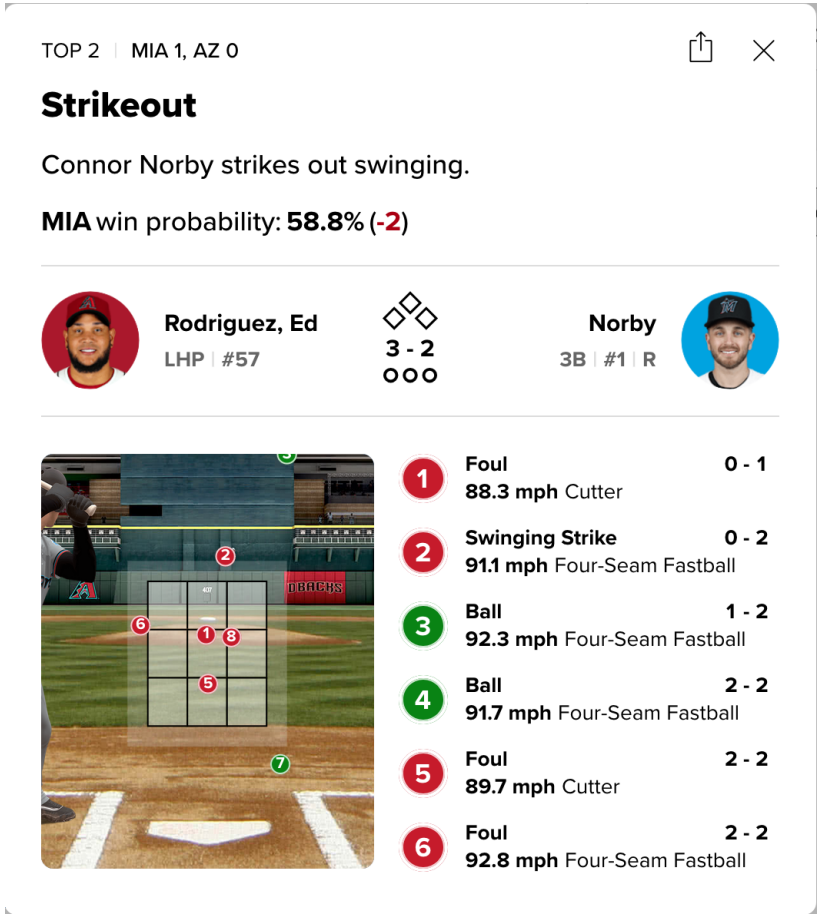

Figure 7: Pitch data

How to follow baseball: WebSocket API

wss://ws.statsapi.mlb.com/api/v1/game/push/subscribe/gameday/777425


```
{
  "timeStamp": "20250629_181140",
  "gamePk": "777313",
  "updateId": "dd076a14-20ec-49c2-9a45-b2c4f2e212b5",
  "wait": 10,
  "logicalEvents": [
    "countChange",
    "count01"
  ],
  "gameEvents": [
    "swinging_strike"
  ],
  "changeEvent": {
    "type": "new_entry"
  },
  "isDelay": true
}
```

How to follow baseball: mlbt

mlbt (`https://github.com/mlb-rs/mlbt`) Rust TUI

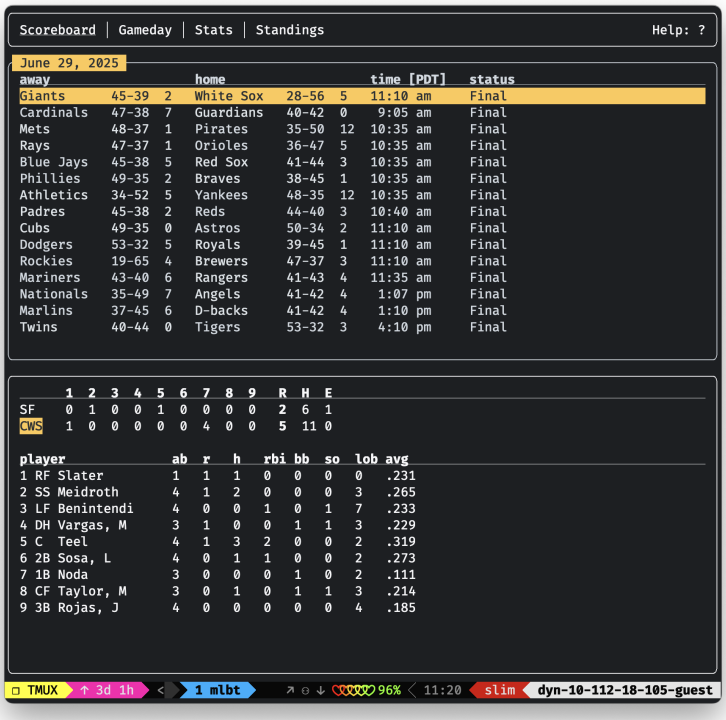

Figure 8: mlbt scoreboard

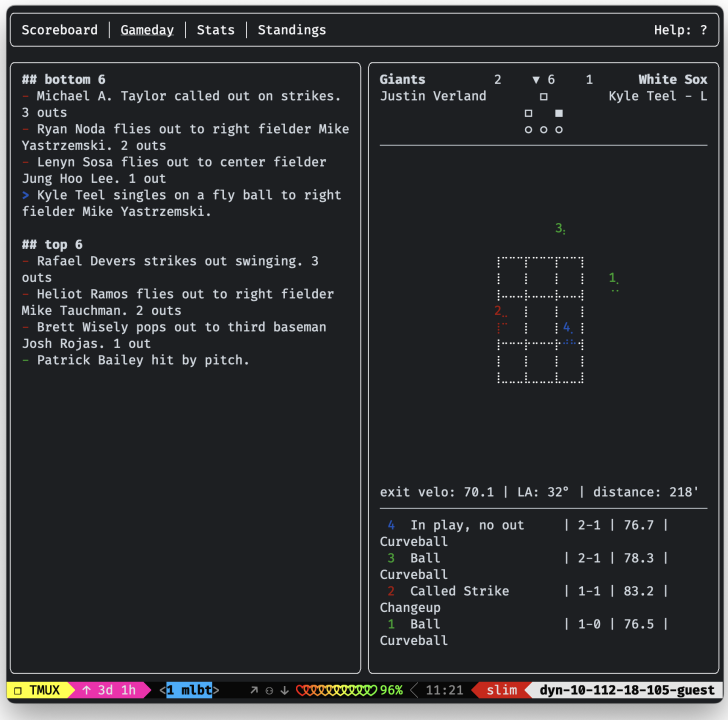

Figure 9: live game view

Acknowledgements

Thank you to Christopher Callahan and Connor O'Brien for patiently explaining baseball to me