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In this appendix we will describe the model for punts in more detail. Suppose we are the kicking team, and let the variable y denote distance in yards from our own goal line. So, for example, the opponent's 10 yard line is the line $y = 90$. Let x denote distance in yards from the centerline of the field to the sidelines. Thus, the points with $x = 0$ are those that are equidistant from the sidelines. We adopt the convention that $x > 0$ denotes points to our right, and $x < 0$ denotes points to out left. Note that the points within the field of play (excluding the end zones) satisfy $-26.67 \leq x \leq 26.67$ and $0 \leq y \leq 100$. The hash marks are the lines with $x = \pm 3.083$.

Denote by (x_0, y_0) the spot on the field at which the punter's foot strikes the ball. The ball is kicked in the direction θ, and travels in the air a distance d. We adopt the convention that $\theta = 0$ is straight ahead (parallel to the centerline), $\theta > 0$ is toward the right, and $\theta < 0$ is toward the left.

Let $\bar{d}$ and $\bar{\theta}$ denote the punter's *intended* distance and direction. The *actual* distance d is assumed to be lognormal with mean $\bar{d}$. The actual direction θ, measured in radians, is assumed normal with mean $\bar{\theta}$, and independent of d.

The ball comes down at the point with coordinates

$$x = x_0 + d \sin\theta$$

$$y = y_0 + d \cos\theta$$

and it is easy to determine whether the ball has landed out of bounds or in the end zone, and if so, where it should be spotted. For example, if

$$\theta \geq \tan^{-1}\left[\frac{26.67 - x_0}{100 - y_0}\right]$$

and $x \geq 26.67$, then the ball flew out of bounds on the right prior to reaching the end zone, and by rule 7-5-1 the opponents take over at the

$$y_0 + (26.67 - x_0)/\tan\theta$$

yard line. If the ball didn't fly out of bounds before reaching the end zone, but does have $y \geq 100$, then it is a touchback.

If the ball comes down inbounds and short of the end zone, there may be a fair catch. We assume that if the ball comes down short of a specified yard line y_f, then there is a fair catch and the opponents take over at y_f. Otherwise the ball bounces. We assume that after bouncing, the ball moves in a straight line. The bounce is therefore characterized by a distance d_b and a direction θ_b. We assume that given θ, the change in direction $\theta_b - \theta$ has the distribution of $\gamma \mathbf{z}$ conditional on $|\gamma \mathbf{z}| < \pi$, where $\mathbf{z}$ is standard normal and γ is a scale parameter.

Conditional on the bounce direction, the bounce distance d_b is assumed lognormal with mean

$$\alpha \cos(\lambda(\theta_b - \theta)),$$

where α and λ are parameters with $\lambda < 0.5$. Thus, we assume that on average the ball bounces farther when it bounces forward than when it bounces backward.

Left untouched, the bouncing ball would come to rest at coordinates

$$x_b = x + d_b \sin \theta_b$$

$$y_b = y + d_b \cos \theta_b.$$

As before, it is easy to determine whether the bouncing ball goes out of bounds, or into the end zone, or stays in play. If it stays in play, the spot where it comes to rest is where the opponents take over. If it goes out of bounds, simple trigonometry again allows us to determine where the ball is spotted.

However, if the bouncing ball, were it to be untouched, would go into the end zone, then the kicking team has an opportunity to down the ball before it gets there. We assume that the probability that the kicking team downs the ball before it reaches the end zone is $(100 - y)/(y_b - y)$.