ISDA 609 - Mathematical Modeling Techniques for Data Analytics: Final Project #1

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Problem Definition

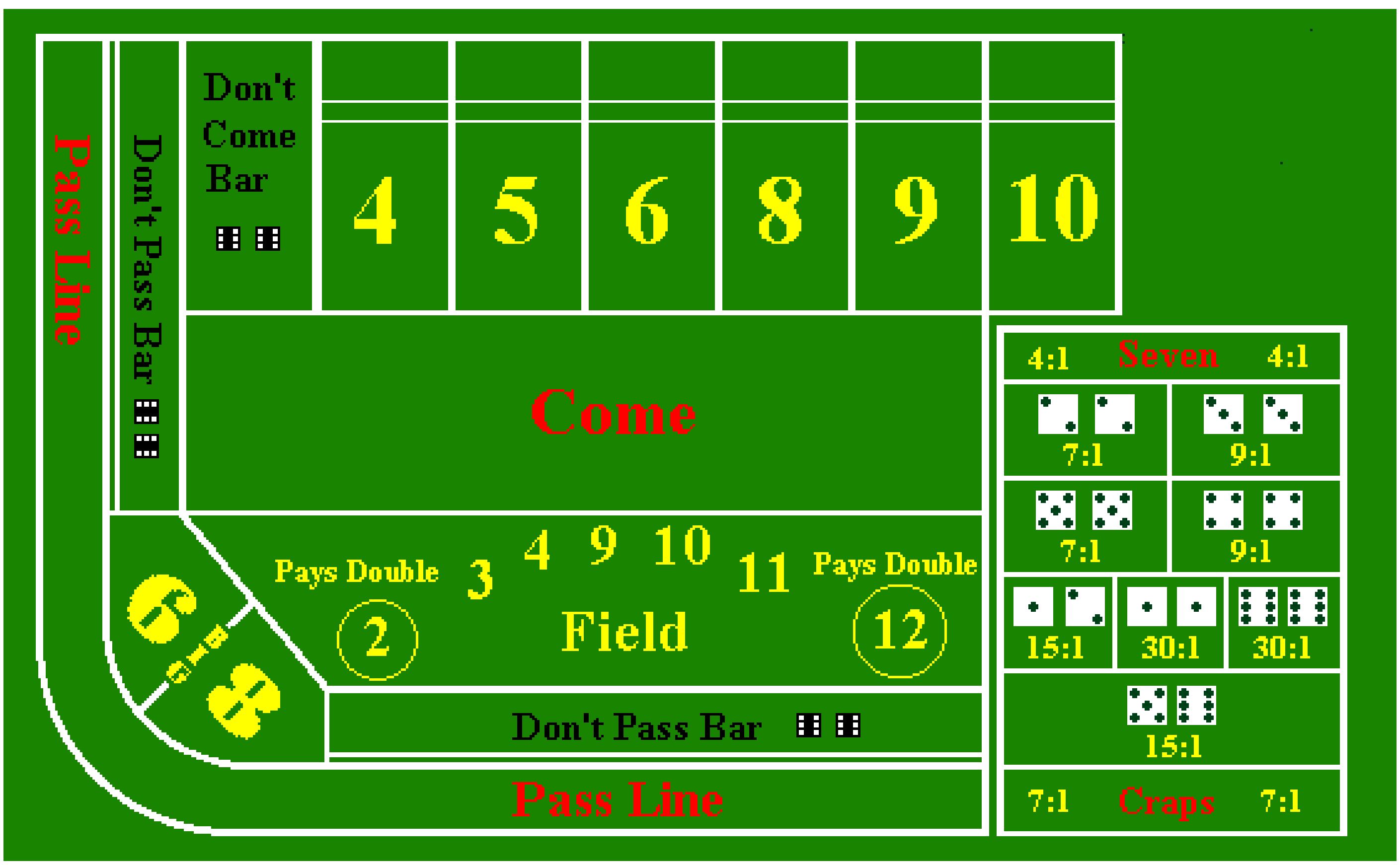
Project 5.3.3 (page 201): Craps Monte Carlo Simulation

Craps - Construct and perform a Monte Carlo simulation of the popular casino game of craps. The rules are as follows:

There are two basic bets in craps, pass and don't pass. In the pass bet, you wager that the shooter (the person throwing the dice) will win; in the don't pass bet, you wager that the shooter will lose. We will play by the rule that on an initial roll of 12 ("boxcars"), both pass and don't pass bets are losers. Both are even-money bets.

Conduct of the game:

- Roll a 7 or 11 on the first roll: Shooter wins (pass bets win and don't pass bets lose).
- Roll a 12 on the first roll: Shooter loses (boxcars; pass and don't pass bets lose).
- Roll a 2 or 3 on the first roll: Shooter loses (pass bets lose, don't pass bets win).
- Roll 4, 5, 6, 8, 9, 10 on the first roll: This becomes the point. The object then becomes to roll the point again before rolling a 7.
- The shooter continues to roll the dice until the point or a 7 appears. Pass bettors win if the shooter rolls the point again before rolling a 7. Don't pass bettors win if the shooter rolls a 7 before rolling the point again.



Write an algorithm and code it in the computer language of your choice. Run the simulation to estimate the probability of winning a pass bet and the probability of winning a don't pass bet. Which is the better bet? As the number of trials increases, to what do the probabilities converge?

Solution - Mathematical Approach

Craps involves the rolling of two dice. The assumption is that the dice are fair and the outcomes of the various rolls are independent.

Simple Mathematics

The possible totals obtained from rolling two dice are as below:

	1	2	3	4	5	6
1	2	3	4	5	6	7
2	3	4	5	6	7	8
3	4	5	6	7	8	9
4	5	6	7	8	9	10
5	6	7	8	9	10	11
6	7	8	9	10	11	12

Now let us examine the rules:

- Roll a 7 or 11 on the first roll ("natural"): Shooter wins
  Now the probability of getting 7 or 11 is $\frac{8}{36}$, or about 22.22%.
- Roll a 2 or 3 or 12 on the first roll ("craps"): Shooter loses
  The probability of getting 2 or 3 or 12 is $\frac{4}{36}$, or about 11.11%.
- Roll 4, 5, 6, 8, 9, 10 on the first roll: This becomes the point. The Shooter's goal then becomes to roll the point again before rolling a 7
  The probability of rolling 4 is $\frac{3}{36}$. Once Shooter has rolled the 4, the only cells that matter are the cells containing 4 and 7. All other cells can be ignored. There are 9 cells containing 4 or 7 of which only 3 cells are favorable to Shooter. Hence the probability of Shooter rolling another 4 before a 7 is $\frac{3}{9}$. Therefore, the probability of rolling a 4, and then rolling a 4 before a 7 is $\frac{3}{36} \times \frac{3}{9}$ or about 2.78%.
  Table below summarizes the winning probabilities of Shooter in craps:

Initial Roll	Probability of Winning	Probability in Decimal
4	$\frac{3}{36} \times \frac{3}{9}$	0.0278
5	$\frac{4}{36} \times \frac{4}{10}$	0.0444
6	$\frac{5}{36} \times \frac{5}{11}$	0.0631
7	$\frac{6}{36}$	0.1667
8	$\frac{5}{36} \times \frac{5}{11}$	0.0631
9	$\frac{4}{36} \times \frac{4}{10}$	0.0444
10	$\frac{3}{36} \times \frac{3}{9}$	0.0278
11	$\frac{2}{36}$	0.0556
	Total	**0.4929**

More Mathematical

Let $P(p = n)$ is the probability of rolling a total n. For rolls that are not naturals (7 or 11, say W) or craps (2 or 3 or 12, say L), the probability that the point $p = n$ will be rolled before 7 is found from

$P(win \mid p = n) = \frac{P(p=n)}{P(p=7)+P(p=n))} = \frac{P(p=n)}{\frac{1}{6}+P(p=n)}$

Applying the above, we get the same result as above:

Initial Roll (n)	$P(p = n)$	$P(win \mid p = n)$	$P(win) = P(p = n)P(win \mid p = n)$	Probability in Decimal
2	$\frac{1}{36}$	0	0	0
3	$\frac{2}{36}$	0	0	0
4	$\frac{3}{36}$	$\frac{3}{9}$	$\frac{3}{36} \times \frac{3}{9}$	0.0278
5	$\frac{4}{36}$	$\frac{4}{10}$	$\frac{4}{36} \times \frac{4}{10}$	0.0444
6	$\frac{5}{36}$	$\frac{5}{11}$	$\frac{5}{36} \times \frac{5}{11}$	0.0631
7	$\frac{6}{36}$	1	$\frac{6}{36}$	0.1667
8	$\frac{5}{36}$	$\frac{5}{11}$	$\frac{5}{36} \times \frac{5}{11}$	0.0631
9	$\frac{4}{36}$	$\frac{4}{10}$	$\frac{4}{36} \times \frac{4}{10}$	0.0444
10	$\frac{3}{36}$	$\frac{3}{9}$	$\frac{3}{36} \times \frac{3}{9}$	0.0278
11	$\frac{2}{36}$	1	$\frac{2}{36}$	0.0556
12	$\frac{1}{36}$	0	0	0

Hence, $P(win) = \sum_{n=2}^{12} P(p = n)P(win \mid p = n) = 0.4929$. Meaning the probability of the Shooter wins = 49.29% which implies the probability that the Shooter loses = 50.71%

Note: *We will see the same results in our decision tree model while solve this Craps game.*

Back to Craps Problem

Here we have 2 types of bets - Pass and Don't Pass. In the Pass bet, the gambler wins only when Shooter wins and in Don't Pass bet the gambler wins only when Shooters loses except the Boxcars (Roll a 12 on the first roll).

Hence, for the ***Pass bet gambler***, the winning probability is: 49.29%. And for the **Casino** (or house), the winning probability is: 50.71%. Thus, *the house has an advantage of about 1.4% on any Pass bet.*

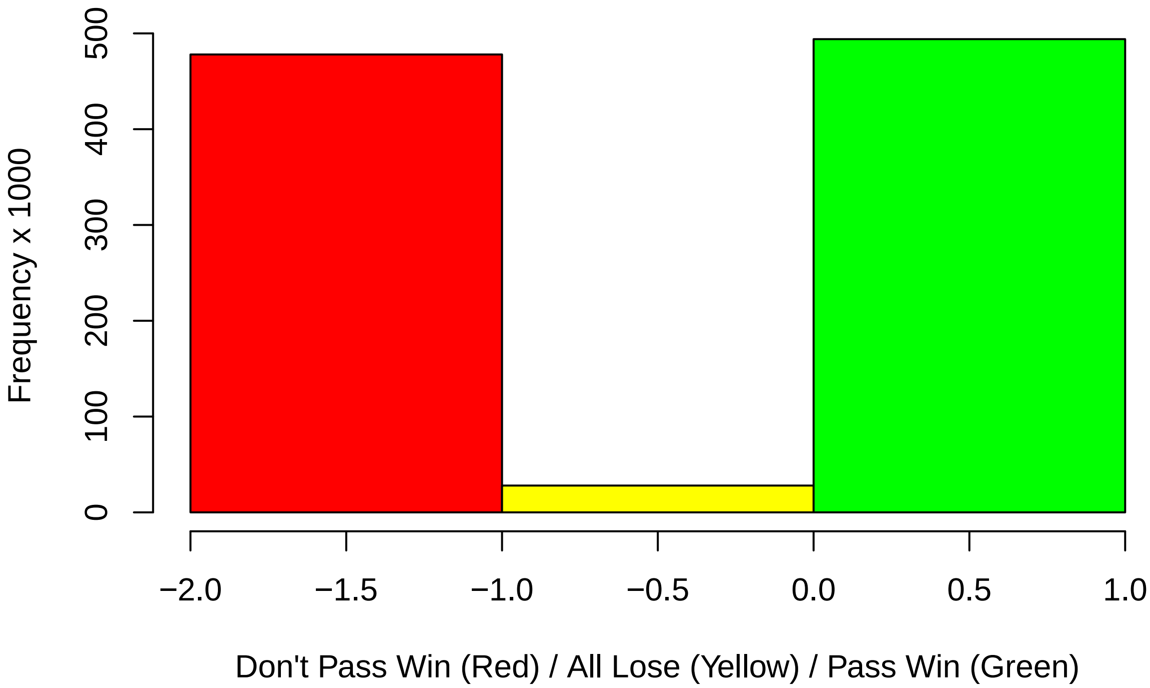
Now the probability of Boxcars = $\frac{1}{36}$ = 2.78%

Hence, for ***Don't Pass bet gambler***,

Event	Probability
TIE on Don't Pass bet	$\frac{1}{36}$ = 0.0278 = 2.78%
WIN on Don't Pass bet	0.5071 - $\frac{1}{36}$ = 0.4793 = 47.93%
LOSE on Don't Pass bet	1 - $\frac{1}{36}$ - 0.4793 = 0.4929 = 49.29%

Hence, mathematically we can say that for a particularly game, the winning probability of

- Pass bets: 49.29%
- Don't Pass bets: 47.93%
- Boxcars (both Pass and Don't Pass bets lose): 2.78%



Mathematical Conclusion

The casino has only a slight edge in craps. But, in the long run, the game is a money-maker for the casino since the casino plays on indefinitely. While in Pass bet scenario house is always in advantage, we need to analyze Don't Pass bet bit more.

Since on the tie or Boxcars nobody wins, let us ignore that situation. If we reduce this to a win or lose situation, the probability that a Don't Pass Bet wins is $\frac{0.479293}{(0.479293+0.492929)} = 0.492987$ and the probability that a Don't Pass Bet loses is 1 - 0.492987 = 0.507013. Thus the casino maintains a 1.4% advantage over the player even in Don't Pass bet.

Simulation to verify Mathematical Approach

Monte Carlo Simulation in R

```
## Number of simulations = 10000
```

Data Definition

- fx = Outcome of Dice-1 in first roll
- fy = Outcome of Dice-2 in first roll

- lx = Outcome of Dice-1 in last roll (if subsequent rolls are needed)
- ly = Outcome of Dice-2 in last roll (if subsequent rolls are needed)
- n = number of rolls
- flag:
  - 1 = Pass win
  - 0 = Boxcars (no one wins)
  - -1 = Don't Pass win

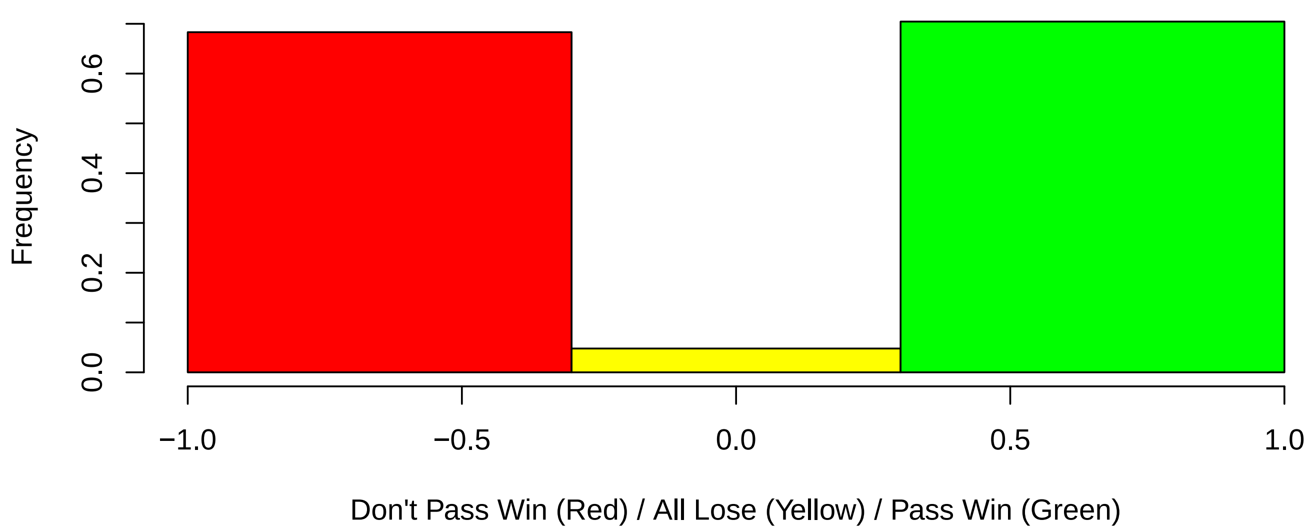
Top 10 simulated Craps data:

```
##   fx fy lx ly n flag
##    6  5        1    1
##    4  6  1  6 2   -1
##    1  3  2  2 2    1
##    1  2        1   -1
##    4  2  2  5 2   -1
##    5  5  2  5 2   -1
##    1  2        1   -1
##    2  3  4  1 5    1
##    3  4        1    1
##    2  5        1    1
```

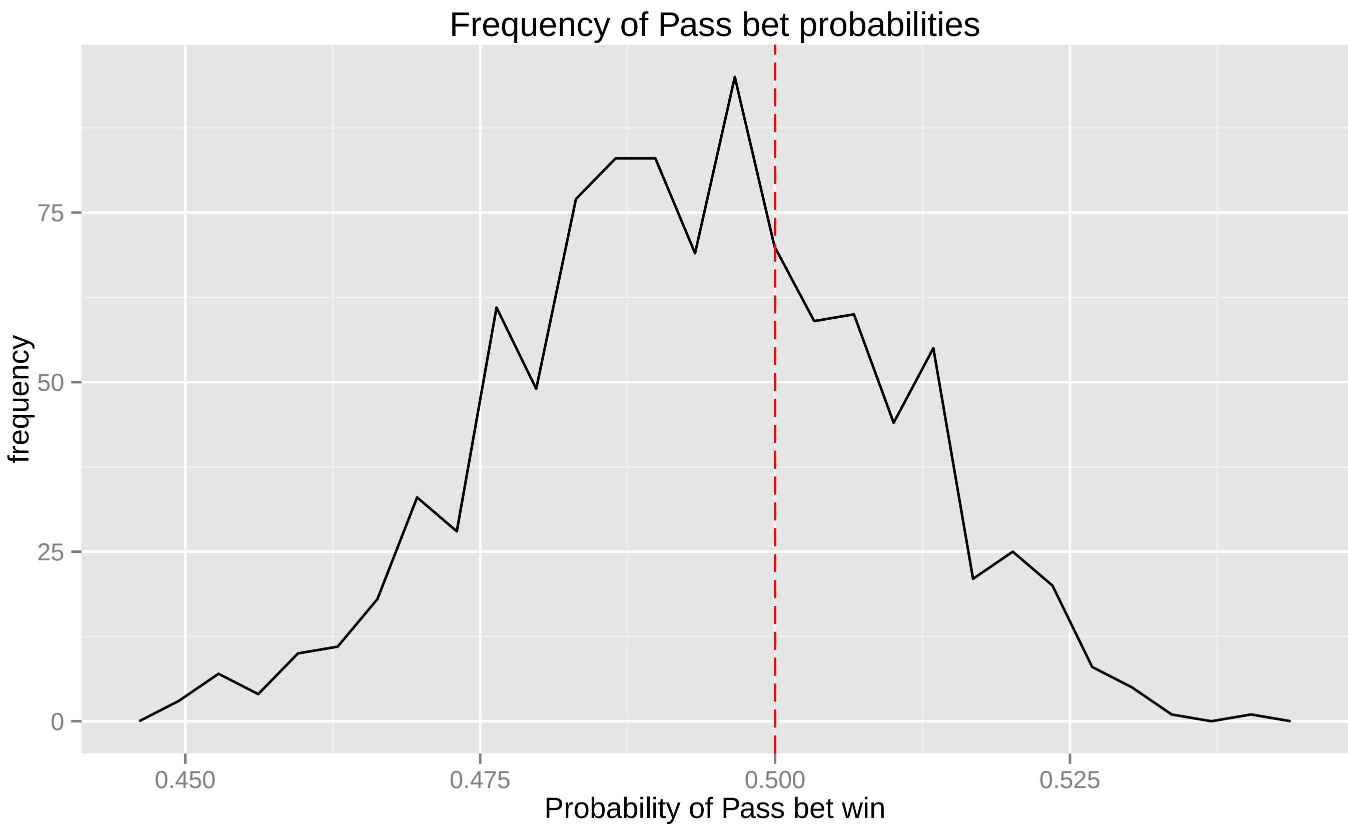
Pass wins: 4931 or 49.31%
Don't Pass wins: 4782 or 47.82%
No one wins: 287 or 2.87%

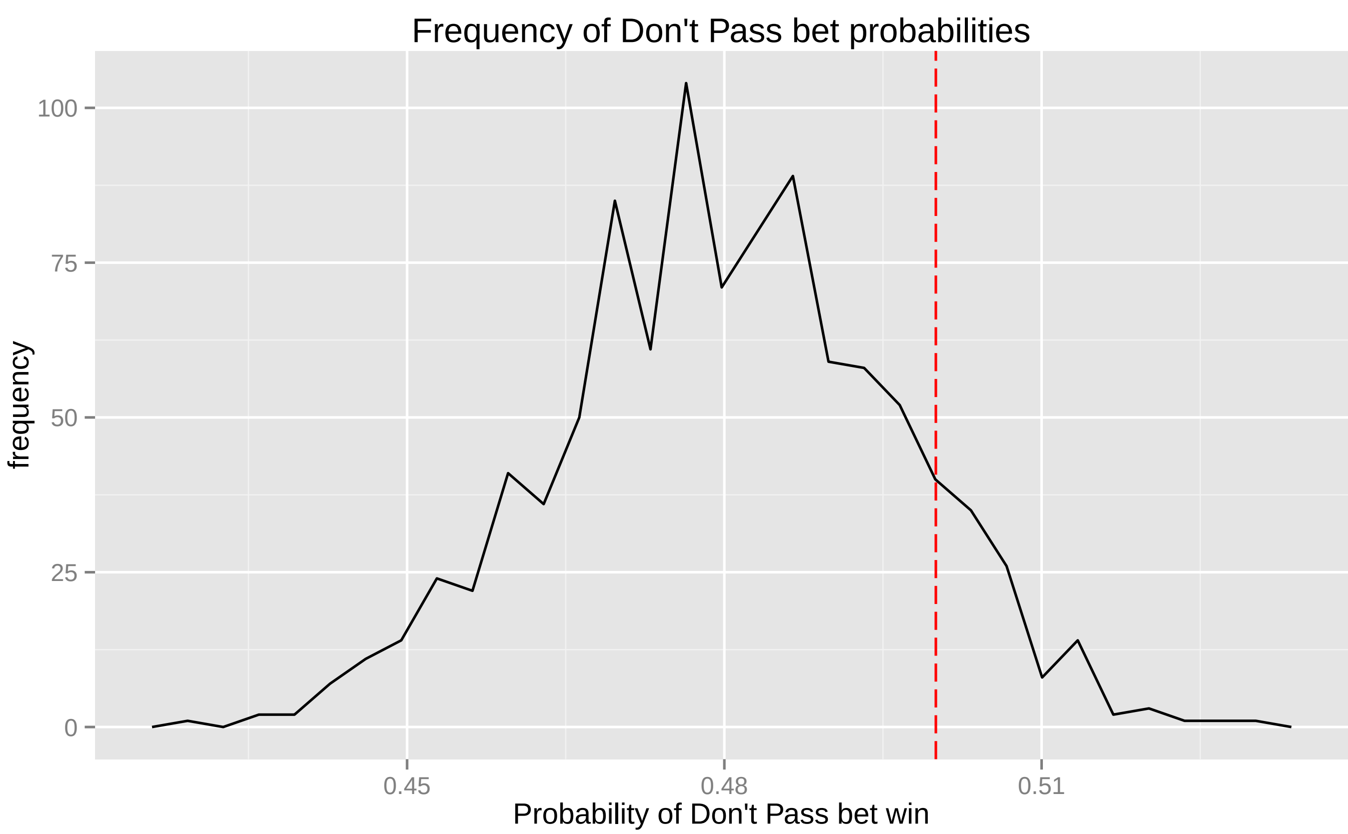
Mean: 0.0149
SD: 0.9855

The results obtained by simulation are very close to probabilities calculated Mathematically above.



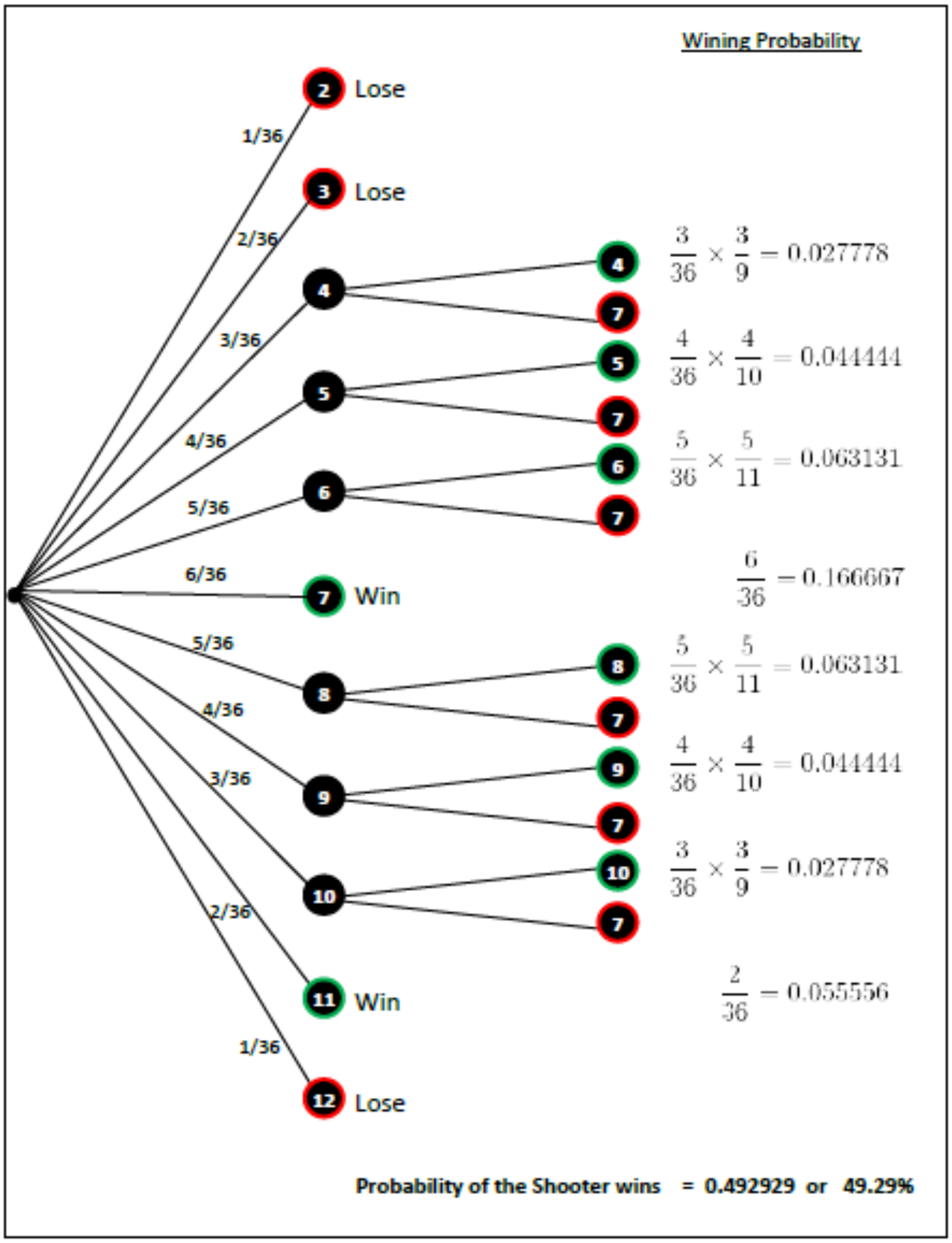
If we repeat this simulation for the Pass bet 1000 times and for the Don't Pass bet for 1000 times:





Note that no matter the choice, the odds are usually worse than a coin-flip

Decision tree with expected value of winning



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From the decision tree, we can see that the Probability of Shooter's wining = 49.29%

Conclusion

From the above mathematical analysis, simulation and decision tree, it is clear that the Craps game is close to a fair gamble where the chance for wining is close to 50%. However, as it is favorable to House and as the House will play longer, House will always come out ahead due to this slight imbalance.

Simulating a real life situation

[This is in addition to what this Project asked]

Let us simulate a board (game) with the following assumptions:

- Simulation period: 90 days
- Each day
  - 10 gamblers play on each day and no one will quit in betweeen a game
  - Each will play for $50 and bet anything between $0 (not playing that round) and $5 in each shoot/round
  - A player will quit the table only if (s)he loses $50 with which (s)he entered in Casino or game ends
  - Each player's choice on Pass bet or Don't Pass bet will be assigned randomly (though in reality each player plays with some strategy)
  - The game will end when less than 10% or only 1 gambler (whichever is greater) is at table
  - The game will also end in 3 hours even if all players are playing
  - Assume each shoot/dice throw takes 10 seconds and there is 2 minutes gap between 2 games

The objective of this simulation is to see how Cashino makes money (started with $0 balance) and whether it grows over time. We are no more focusing on percentages of Pass bet and Don't Pass bet in this real life simulation.

Below are the results of 1 day game, where

- Player: Player Number, Player 0 is Casino
- IniDolr: Initial Amount at the begining of the day
- WinDolr: Total Win Amount (negative means lose)
- BalDolr: Balance Amount at the end of the game

```
##    Player IniDolr WinDolr BalDolr
## 1       0       0     -19     -19
## 2       1      50       0      50
## 3       2      50     -10      40
## 4       3      50       2      52
## 5       4      50      10      60
## 6       5      50     -22      28
## 7       6      50      25      75
## 8       7      50      14      64
## 9       8      50       6      56
## 10      9      50      21      71
```

Total Wining Amount for all players including Casino = SUM(WinDolr) = $ 0, implies that this is a zero sum game.

While the amount earned by Casino after Day-1 is $ -19, total Amount made by Casino in 90 days = $ 2,765, implies longer the game, more profitable for Casino.