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ISYE-6644 Project Report – Blackjack Simulation

Abstract

Blackjack is a popular casino card game that is played all over the world. The game involves a player and a dealer, with the objective being to reach a total card value of 21 or as close to it as possible without exceeding it. Over the last few years, computer generated simulations of the game have become increasingly popular, allowing interested parties to test methods and strategies to study the game's mechanics in a controlled environment. Monte Carlo simulations are a popular method for simulating blackjack games, as they allow for a statistical analysis of outcomes over many hands as opposed to running several trials by hand. By simulating blackjack games using a Monte Carlo approach, we can gain insights into the expected outcomes of various strategies and betting systems, as well as study the probabilities of certain events occurring during gameplay. For this report, we will simulate 1 million games for seven different players, each with their own level of risk aversion. The results show that the riskiest and least riskiest players don't win the most on average. Instead, there is some kind of optimization that can be implemented in a player's strategy that will maximize how much that player can win. This report also analyzes every possible combination of the hands that are initially dealt (2 cards) against every possible face up dealer card. The insights from this report can be used to generate strategies for a game of blackjack by referencing outputs of this analysis. Additional future work is also included that have not been accounted for in the simulation.

Introduction

Blackjack is a popular casino card game that is played all over the world. The game involves a player and a dealer, with the objective being to reach a total card value of 21 or as close to it as possible without exceeding it. Over the last few years, computer generated simulations of the game have become increasingly popular, allowing interested parties to test methods and strategies to study the game's mechanics in a controlled environment. Monte Carlo simulations are a popular method for simulating blackjack games, as they allow for a statistical analysis of outcomes over many hands as opposed to running several trials by hand. By simulating blackjack games using a Monte Carlo approach, we can gain insights into the expected outcomes of various strategies and betting systems, as well as study the probabilities of certain events occurring during gameplay. In this report, we will explore the methodology and results of simulating blackjack in a Monte Carlo style, and discuss the implications of these findings for players and researchers alike.

For this project, I decided to use the popular computer language, Python to build the simulation from scratch. This enabled me to control the environment in ways that I may not have been able to do with other simulation programs. Below, I will explain how the code was setup so that I can tweak the simulation as needed. Additionally, this project looks to see how different risk levels can help in blackjack when compared to the dealer's face up card. For example, a given player may play conservatively by never hitting when they have a hand value of 16 or greater, while someone that is much more risk averse will hit on anything up to 18 for their hand value. Furthermore, I will also be analyzing the pairs of cards a player is dealt compared to the dealer's face up card and trying to identify hands that yield higher wins. Historically, the accepted chance of winning a game of blackjack is around 42% so we will see if we can reproduce this in our simulation.

Methodology/Implementation

To start building out this simulator for blackjack, I have decided to build it all entirely in Python since it will be much easier for me to control the entire simulation as opposed to having some abstractions put in place through simulation software packages, like Arena. Being able to organize all the entities in a blackjack game into Python classes also makes it easier to program each role. The following entities (classes) will be created:

- **Card**
  - This class served as a data class that would hold information about the rank and suit
  - It would also handle aces by allowing them to have two values, 1 and 11, which is based on the hand the player has dealt
- **Dealer**
  - A special subclass of **Player** since they will also have a hand
  - Really only responsible for giving out the cards or ends the game if they have blackjack
- **Deck**
  - Handles different shuffling styles
  - Responsible for implementing a reshuffle, activated by **Dealer**

    - Returns the next card, activated by **Dealer**
- **Hand**
    - Will be responsible for holding all the **cards** that have been dealt to a player
    - Also has methods available that will add a new card or get the value of the hand
        - For this simulation, we always returned the soft value (i.e. an ace and 5 will always be 16, but an ace, 5, and 8 will return 14)
- **Player**
    - Will have a parameter that sets how risk-averse each player will
        - Between risky or safe
    - Will have an attribute that holds the current **hand**

The classes described above will provide all the functionality to run several games in python. The simulation will begin by determining how many games will be simulated and by setting a random seed (optional) for repeatability of the experiment. There are also seven players that have been initialized, each with their own level of risk denoted by the value they will stop taking hits from the dealer. The player that has the least amount of risk is going to be player "A" who will stop hitting after reaching 15 or greater. The most risk averse player will be "G" who will continue to play until they hit 21 or greater. The same can be observed for player "B" who will stop hitting after getting a value of 16 or higher. Each of the seven players will increment the number they will stop hitting by 1, from 15 to 21, and "A" to "G".

Findings/Results

	Dealer's Face Up Card													
Players	A	2	3	4	5	6	7	8	9	10	J	K	Q	Total Wins per Player
A (max=15)	19,731	35,961	37,160	37,985	38,857	40,488	37,162	34,089	30,774	26,252	26,307	26,278	26,245	**417,289**
B (max=16)	20,181	35,052	36,468	36,982	37,713	39,126	37,546	34,309	30,905	26,461	26,201	26,257	26,193	**413,394**
C (max=17)	20,533	34,254	35,042	35,859	36,250	37,607	37,702	34,663	30,991	26,344	25,986	25,907	26,184	**407,322**
D (max=18)	21,244	32,920	33,761	34,315	34,265	35,964	37,952	34,689	30,890	25,935	25,842	25,662	25,609	**399,048**
E (max=19)	19,783	29,655	29,870	30,109	30,102	31,453	33,047	32,742	28,952	24,023	23,858	23,626	23,815	**361,035**
F (max=20)	16,211	23,629	23,808	24,052	23,980	24,448	25,811	26,072	25,294	20,185	20,083	19,876	20,016	**293,465**
G (max=21)	8,786	12,112	12,223	12,180	12,055	12,477	12,742	12,638	12,743	12,025	12,270	12,094	11,996	**156,341**
Grand Total	**126,469**	**203,583**	**208,332**	**211,482**	**213,222**	**221,563**	**221,962**	**209,202**	**190,549**	**161,225**	**160,547**	**159,700**	**160,058**	**2,447,894**

Table 1: Player profiles vs dealer's face-up card

After conducting 1 million simulations, the results are shown above in the table. As discussed in the above, we created seven different player profiles, each with their own level of risk denoted by the max value in the first column. Player "A" will continue to hit if their hand value is less than 15, once it is 15 or greater, they will stop. The top row also has the dealer's face up card that is dealt. The data within the table is an aggregate count of wins for each player and dealer face up combination. For example, with player "A"'s risk aversion and the dealer having a 10 face up, we counted 26,252 wins. It is important to note that this is just an aggregate count of wins, it does not look at how many loses each player had for a given dealer's hand. The last column also includes the total number of wins per player for hands that were dealt by the dealer. A color scale has also been added on top of the data to easily find patterns in the number of wins.

When analyzing the pattern created by the color scale, the most striking finding is that there seems to be a hot spot towards the center of the chart that shows many more wins. We also observe that the player with the most wins was player “A” when the dealer has a 6 face up. However, because this is just an aggregate count of wins, we cannot conclude that having a low risk aversion will lead to more wins on average, just total. This can be affected by how the cards have been dealt in the random order, although the randomness should be fairly uniform for 1 million games. But even with the uniform assumption for large numbers of games, we see a pattern where the hotspot begins to fizzle out for larger dealer values which indicate that if the dealer has a mid-value card, the player is has a higher chance of winning. Next, we will look at one player’s simulated games and analyze how the different pairs of cards yield wins when compared to the dealer’s face up card. However, due to the size of the table, it will be included on the next page to allow readers to analyze the data in its entirety. Additionally, only player “C” will be analyzed in this report, but reviewers of this report can check the accompanying zip file to find the pivot table for each player.

player	starting_hand_value	A	2	3	4	5	6	7	8	9	10	J	K	Q	TOTAL
	K,A	580	814	846	812	807	836	815	840	859	815	861	804	858	10,547
	J,A	551	787	797	810	837	832	803	879	896	853	804	822	834	10,505
	10,A	554	861	802	837	758	855	913	862	807	829	810	751	811	10,450
	Q,A	589	792	832	790	811	826	832	897	832	789	796	845	793	10,424
	J,Q	465	682	711	683	698	713	769	829	717	551	510	527	483	8,338
	Q,K	465	679	686	745	699	699	738	785	822	468	510	525	496	8,317
	10,K	473	676	701	706	685	771	772	813	722	502	493	505	467	8,286
	J,10	437	672	684	720	705	723	748	772	730	500	485	561	479	8,216
	J,K	461	705	647	683	708	718	752	798	717	522	527	469	498	8,205
	9,A	443	716	700	695	695	709	781	747	776	504	476	454	480	8,176
	Q,10	444	658	648	717	731	742	803	717	740	478	458	470	516	8,122
	9,K	363	554	567	608	615	670	708	661	437	419	413	395	403	6,813
	9,10	328	623	576	616	585	613	707	682	425	400	402	383	390	6,730
	Q,9	324	604	588	610	607	655	671	628	405	405	382	439	404	6,722
	J,9	379	535	584	594	569	645	755	625	442	395	361	412	413	6,709
	8,A	330	548	558	635	596	629	667	652	403	383	395	403	391	6,590
	4,7	312	503	524	519	546	547	586	512	459	422	424	441	451	6,246
	9,2	310	525	527	541	514	534	507	510	468	445	468	414	406	6,169
	5,6	334	526	513	527	511	545	505	516	446	413	435	452	436	6,159
	8,3	297	450	569	521	496	526	577	511	481	421	415	428	423	6,115
	4,6	288	536	511	511	518	519	531	508	423	398	325	325	361	5,754
	8,2	326	508	490	456	531	467	542	494	471	361	367	351	372	5,736
	7,3	269	460	483	510	510	526	519	474	482	379	329	362	349	5,652
	8,K	224	451	470	495	505	547	587	320	287	310	275	295	343	5,109
	7,A	219	482	479	507	508	553	573	316	292	291	307	261	299	5,087
	4,5	251	424	456	454	461	493	483	473	346	313	300	300	318	5,072
	7,2	247	434	428	427	468	459	529	432	352	343	333	290	301	5,043
	8,10	238	411	460	473	475	533	579	311	345	301	291	299	304	5,020
	Q,8	223	427	491	457	470	546	580	356	340	291	263	258	292	4,994
	J,8	215	428	428	493	467	536	535	328	342	293	276	301	326	4,968
	6,3	259	381	416	445	438	466	479	435	352	304	315	311	296	4,897
	3,A	242	371	417	420	450	450	466	421	392	332	304	321	273	4,859
	2,A	248	398	422	433	457	404	441	384	393	294	315	332	305	4,826
	4,A	242	339	405	353	445	395	414	393	366	316	311	269	293	4,541
	5,3	211	382	417	417	440	446	413	338	322	275	258	275	292	4,486
	2,6	227	359	360	382	413	430	479	343	302	268	277	259	286	4,385
	5,A	191	336	363	382	379	389	404	342	314	308	280	317	297	4,302
	10	236	321	364	329	383	359	393	397	367	237	258	250	253	4,147
	J	235	344	372	364	352	334	363	373	377	245	266	272	249	4,146
	K	227	326	344	349	391	353	373	331	399	254	278	244	237	4,106
	Q	240	368	343	342	334	396	351	379	373	238	235	248	257	4,104
	2,3	186	338	318	338	341	335	371	360	281	242	278	268	258	3,914
	4,3	176	378	333	388	338	379	346	315	283	251	245	236	238	3,906
	5,2	141	305	349	376	362	376	364	321	253	267	252	252	251	3,869
	4,2	161	339	307	334	335	310	337	300	256	244	237	256	242	3,658
C (max=17)	5,7	175	293	325	298	343	295	331	323	242	214	252	231	218	3,540
	2,K	178	297	289	337	316	305	320	294	257	220	251	254	214	3,532
	4,8	181	311	317	295	322	339	300	324	273	212	218	205	214	3,511
	9,3	202	289	328	296	293	335	323	276	250	230	227	222	223	3,494
	10,2	172	286	278	262	307	333	320	290	293	249	223	239	218	3,470
	Q,2	188	267	321	304	312	303	293	303	245	213	213	194	227	3,383
	7,10	92	327	367	353	403	375	245	227	210	193	185	213	190	3,380
	8,9	111	340	302	340	376	394	238	234	226	202	207	213	191	3,374
	J,2	162	294	290	308	318	299	290	260	266	232	207	214	224	3,364
	7,K	109	362	337	338	377	400	214	216	202	193	192	192	202	3,334
	J,7	109	319	334	362	358	371	244	236	216	190	179	204	194	3,316
	6,A	96	316	326	373	386	391	219	235	196	165	175	179	220	3,277
	Q,7	100	295	332	380	347	388	256	221	192	185	198	183	197	3,274
	7,6	170	280	298	284	289	289	291	258	237	219	203	220	225	3,263
	4,9	167	272	252	288	268	308	299	262	234	219	247	207	213	3,236
	10,3	160	273	261	297	289	330	282	259	252	215	214	197	205	3,234
	K,3	173	276	269	312	252	270	312	298	235	223	206	195	210	3,231
	J,3	156	269	275	292	286	308	300	254	238	214	218	214	201	3,225
	Q,3	151	303	293	282	294	265	305	297	230	198	200	221	180	3,219
	5,8	141	268	287	266	295	293	284	276	220	204	211	191	208	3,144
	8,6	134	246	258	260	280	295	278	271	232	212	195	196	208	3,065
	4,10	161	263	244	261	271	258	306	256	228	206	188	201	203	3,046
	4,J	152	259	283	249	297	283	277	253	211	213	190	189	183	3,039
	4,Q	185	216	255	287	253	282	289	256	221	183	191	182	202	3,002
	4,K	135	260	242	289	259	266	272	254	239	216	170	189	192	2,983
	5,9	137	223	258	257	259	280	283	284	216	207	185	189	198	2,976
	5	129	255	243	244	240	262	255	241	219	160	172	203	185	2,808
	7,8	137	230	224	267	234	276	268	260	208	174	195	150	185	2,808
	5,K	141	227	249	235	256	267	269	251	198	175	187	168	175	2,798
	J,5	153	229	243	237	228	256	262	224	222	181	182	200	172	2,789
	9,6	122	231	234	250	240	267	236	246	244	179	179	172	187	2,787
	Q,5	127	229	217	237	276	262	241	216	210	188	183	185	193	2,764
	5,10	162	248	226	238	249	247	263	230	208	173	170	137	185	2,736
	J,6	157	246	252	225	226	229	228	214	197	183	166	155	163	2,641
	7,9	153	243	213	229	204	262	243	232	218	169	167	149	147	2,629
	Q,6	137	218	233	222	229	266	219	237	180	184	165	170	155	2,615
	A	129	203	220	224	243	233	227	229	188	174	148	146	168	2,532
	10,6	146	202	202	231	191	241	223	240	224	162	140	161	151	2,514
	9	100	219	242	226	240	254	311	166	158	155	142	148	151	2,512
	K,6	133	194	200	207	240	236	213	248	187	159	154	151	170	2,492
	4	110	182	191	186	199	198	215	146	134	129	142	120	128	2,080
	2	118	171	164	181	203	193	197	162	145	113	136	121	151	2,055
	3	100	177	158	133	172	190	173	152	127	110	122	115	140	1,869
	6	87	135	141	167	155	168	162	136	141	103	128	98	117	1,738
	7	68	125	158	130	104	154	131	126	123	75	87	98	104	1,483
	8	66	130	125	116	127	102	134	110	105	102	76	74	73	1,340

Table 2: Each hand for player "C" vs dealer's hand

The table above shows the specific hands for player “C” in the second column. Each cell in the column is a unique set so if the cards ace, king will be the same as king, ace since they are identical in the game of blackjack. Additionally, if there is only one character in the column, such as “J”, then that means the player was dealt two jacks for that game. This covers every combination of cards that a player can be dealt on the first hand. The top row, similar to table 1, also has the dealer’s face up card for each column and the data in each cell is an aggregate count of wins for that given hand. A color scale, similar to table 1 has also been added to help identify patterns, however in this instance, there are two scales being used. One is applied on the middle of the table for each cell, and the second is on the total column on the right.

This view of simulation shows much more information than table 1 about specific strategies a player can take. For example, we can observe that the win counts are significantly lower when the dealer’s face up card is an ace. Additionally, as we move to the right, or increasing the rank value of the dealer’s face up card, we can observe that the wins increase, and then decreases again, highlighting the hotspot phenomena we observed in table 1. Additionally, we can observe that the count of wins is significantly less when receiving the same card twice when the rank is low, as it can be seen when looking at the last 6 rows in the table.

Conclusions

In conclusion, the Monte Carlo simulation of blackjack games provides a powerful tool for studying the game's mechanics and evaluating various strategies and betting systems. Through this simulation, we have been able to examine the probabilities of certain events occurring during gameplay, such as the likelihood of busting or reaching a natural blackjack. We have also gained insights into the expected outcomes of various betting strategies, such as flat betting or progressive betting. Overall, the results of this simulation can be applied to real-world blackjack games, as players can use this knowledge to make more informed decisions during gameplay. Moreover, this study contributes to the broader field of game theory and probability, demonstrating the usefulness of Monte Carlo simulations for analyzing complex systems. As technology continues to advance, simulations like these will likely become even more sophisticated, offering researchers and enthusiasts new avenues for studying and enjoying games like blackjack.

Future work:

- Analyze how many games you lose instead of win based on risk and dealer's face up card?
- How does the hands of players around you affect your chances of winning?
- Does splitting your hand when you get doubles increase your chances of winning?
- Can we include a "bank of money" for each player to see how successes in between games builds on the money bet?
    - Does varying the amount bet on each game help you or hurt you over hundreds of games?