The Gin Rummy AI Challenge

Todd W. Neller
Gin Rummy Rules

• 2 players, 52 cards, Aces low
• **Object**: to be the first player to score 100 points or more.
• **Meld**: a set of 3 or more cards of the (1) same rank (e.g. 7♣, 7♦, 7♥) or (2) same suit in sequence (e.g. A♠, 2♠, 3♠, 4♠)
• **Deadwood**: cards not in melds
• **Card points**: 10 for face cards, A=1, number value for number ranks
• **Deadwood points**: sum of card points for all cards not in disjoint melds. (Melds must not share cards.)
Gin Rummy Play

- The dealer alternates. The dealer deals 10 cards to each player and turns the top card of the remaining draw pile face up to form a discard pile.
- Each turn, player may draw the top face-up card from the discard pile or the top face-down card of the draw pile.
  - First turn exception: If the dealer declines the top face-up card, the opponent may begin the deal play by drawing that card, or may also decline. If the opponent declines, the dealer begins by drawing from the draw pile.
- After drawing, the player must discard.
- A player who would have less than or equal to 10 deadwood points after discard may end the deal’s play by knocking, sometimes signalled by discarding face-down.
Gin Rummy Scoring

• After a player knocks,
  – The knocking player lays down melds face-up and reveals deadwood cards.
  – The opponent lays down any melds.
  – If the knocking player has any deadwood, the opponent may then “lay off” opponent deadwood cards to knocking player melds. Any remaining opponent deadwood is revealed.

• If the knocking player has no deadwood, they are said to have “gin”. That player scores 25 points + opponent deadwood points.

• If the knocking player has deadwood that is...
  – ... less than opponent deadwood, the knocking player scores the deadwood point difference.
  – ... greater than or equal to the opponent deadwood, the opponent “undercuts” and scores 25 points + the deadwood point difference.
Let’s Play

• Decks for local play
• Android: Gin Rummy Free by AI Factory Limited
• Web: https://www.gin-rummy-online.com/
• iOS: Gin Rummy Plus by Zynga
Research Topics Overview

• Opponent Hand Estimation
  – Given:
    • Your knowledge of which cards are discarded and unavailable, in your hand, and in the opponents hand
    • Your observations of which face-up cards were refused by the opponent, or discarded by the opponent
  – Estimate: the probability / relative likelihood of the opponent holding a particular card

• Optimal Play
  – Given: above game state knowledge and opponent hand estimation
  – Choose: a draw/discard action that maximizes the probability of winning
Opponent Hand Estimation

• Some basic opponent hand estimation is described by Jeff Rollason (AI Factory) at https://www.aifactory.co.uk/newsletter/2007_02_imperfect_info.htm
  – An opponent *drawing* a face-up card or *discarding* a card respectively *increases* or *decreases* the probability of having same rank or adjacent suit cards.
Example Estimation

• What can we learn if we observe a player:
  – Draw a face-down card with 4H face-up?
  – Discard 6D?
  – Draw a face-down card with 6H face-up?
  – Discard 7C?
  – Draw a face-up QD?

Image source: https://www.aifactory.co.uk/newsletter/2007_02_imperfect_info.htm
Bayes’ Theorem

\[ P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)} \]

where \( A \) and \( B \) are events and \( P(B) \neq 0 \).

- \( P(A \mid B) \) is a conditional probability: the likelihood of event \( A \) occurring given that \( B \) is true.
- \( P(B \mid A) \) is also a conditional probability: the likelihood of event \( B \) occurring given that \( A \) is true.
- \( P(A) \) and \( P(B) \) are the probabilities of observing \( A \) and \( B \) independently of each other; this is known as the marginal probability.

Source: https://en.wikipedia.org/wiki/Bayes%27_theorem
Bayes’ Theorem

Let: A = holding card C in hand
B = observing draw/discard of card D

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Bayes’ Theorem

Let:
- A = holding card C in hand
- B = observing draw/discard of card D

Observe:
- P(B) doesn’t change for different A, so we can focus on the fact that
  \[ P(A | B) \propto P(B | A)P(A) \]
- For a given player strategy, we can simulate a lot of play, collect a lot of frequency data for P(B | A) and P(A), and estimate the relative P(A | B) for different possibly held cards when we make a draw/discard observation.
Experimental Simple Gin Rummy Player

• Poor, simple strategy:
  – Ignore opponent actions and cards no longer in play.
  – Draw face up card only if it becomes part of a meld. Draw face down card otherwise.
  – Discard a highest ranking unmelded card from among the deadwood of melds that minimize deadwood points (without regard to breaking up pairs, etc.)
  – Knock as early as possible.
Simple Hand Estimation Experiment

• Simulate 10,000 games.
• Collect frequency data on draw/discard events for each card with respect to:
  – Whether or not a card was drawn face-up
  – Rank of the face-up card
  – Rank of the card discarded
  – Whether the card was suited with the face-up card and/or discarded card
• Given such frequency data (with non-zero event probabilities), apply Bayes’ Theorem to adjust estimations of likelihoods of cards held.
• Demonstration: SimpleGinRummyPlayer2HETest
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<th>4</th>
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<th>Q</th>
<th>K</th>
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Player 1 discards 4H.
Player 1 has [[AC, 2C, 3C], [2S, 3S, 4S], [TC, TH, TD], [AH]] with 1 deadwood.
Player 1 melds [[AC, 2C, 3C], [2S, 3S, 4S], [TC, TH, TD]] with 1 deadwood from [AH].
Player 0 has 15 deadwood with [2H, 3H, 2D, 3D, 5D]
Player 0 melds [[4C, 5C, 6C, 7C, 8C]].
Player 1 scores the deadwood difference of 14.
Number of opponent cards known: 0
Number discarded: 12
Number of candidates: 30.0|

>>>> est. 5.801766427069696E-4 unif. 1.693508780843028E-5 ratio 34.258850575203866
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A Connect Four Example
Flat Monte Carlo

• Algorithm:
  – For each legal play action \( a \):
    • For \( n \) samples:
      – Make play action \( a \)
      – Simulate a random game to completion
      – Accumulate the result (win = +1, loss = -1, draw = 0)
    • Compute the average result for \( a \)
      – Choose to play \( a \) with the maximum average result.
• Lesson: Randomly sampled actions can inform play.
• Why is sampling important and necessary for complex games?

https://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.297.3086
DeepStack

• DeepStack and Libratus were the first two approaches to “solve” No-Limit Texas Hold'em Poker.

• Here, “solve” means that full-time play across a human lifetime could not find significant exploitable (suboptimal) play.

Structure of Poker Play

Image source: https://spencer-murray-zfht.squarespace.com/figures
Gin Rummy Game Tree Nodes

• Gin Rummy is also a game of imperfect information with choice and chance nodes.

• Types of choice nodes:
  – Take first up-card? (2 actions)
  – Draw face-up or face-down? (2)
  – Which card to discard? (11)
  – Whether or not to knock (when allowable)? (2)
  – (How to meld when knocking?) (≥1, often 1)

• Chance node:
  – Drawn face-down card (≤ 31)
DeepStack Operation

Image source: https://spencer-murray-zfht.squarespace.com/figures
DeepStack Operation

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Counterfactual Regret Minimization

• Predictability $\rightarrow$ exploitability
• Example: How often should one draw a face-up card that works towards meld(s)? Never? Always if low? Sometimes in some situations?
• Rock-Paper-Scissors (RPS)
  – 2 players, 3 possible simultaneous actions: rock (R), paper (P), scissors (S)
  – Win, tie, loss score +1, 0, -1, respectively
Regret

• Suppose you choose rock and your opponent chooses paper. Relative to your choice, how much do you regret not having chosen
  – paper?
  – scissors?

• Regret is the difference in utility between an action and your chosen action.
  – Initially no regrets, so picked from actions with equal probabilities.
  – New regrets: R→0 P→1 S→2
Regret Matching

• Choose an action with probability proportional to positive regrets.

• Regrets (0, 1, 2) normalized to probabilities: (0, 1/3, 2/3)

• Suppose we now choose S while our opponent chooses R.
  – Regrets: (1, 2, 0)
  – Cumulative regrets: (1, 3, 2)
  – Normalized cumulative regrets: (1/6, 3/6, 2/6)
Regret Minimization

• Regret Matching alone will not minimize regrets in the long run.
• However, the average strategy used over all iterations converges to a correlated equilibrium.
• In this example, average the strategies \((1/3, 1/3, 1/3)\), \((0, 1/3, 2/3)\), \((1/6, 3/6, 2/6)\), etc.
DeepStack Operation

A
Action history
Agent's range
Opponent counterfactual values
Current public state
Public tree
Agent's possible actions
Lookahead tree
Neural net [see B]
Subtree

B
Ranges
Values

C
Sampled poker situations

Image source: https://spencer-murray-zfht.squarespace.com/figures
Gin Rummy AI Research Topics

• Opponent Hand Estimation
  – Bayes’ Rule Estimation
  – Markov Chain Monte Carlo
  – Particle Filtering

• Learning Game Values
  – Neural Networks
  – Gradient Boosted Decision Trees

• Sampling Techniques
The Gin Rummy AI Challenge

• This coming summer of 2020, I hope to get X-SIG funds to mentor students in Gin Rummy AI research.

• We will build an AI bot to compete against AI bots developed by other students at other institution.

• Goal: Successful bot and published work presented at EAAI, collocated at AAAI, the main general AI conference of this hemisphere.

• Stay tuned!
Questions?