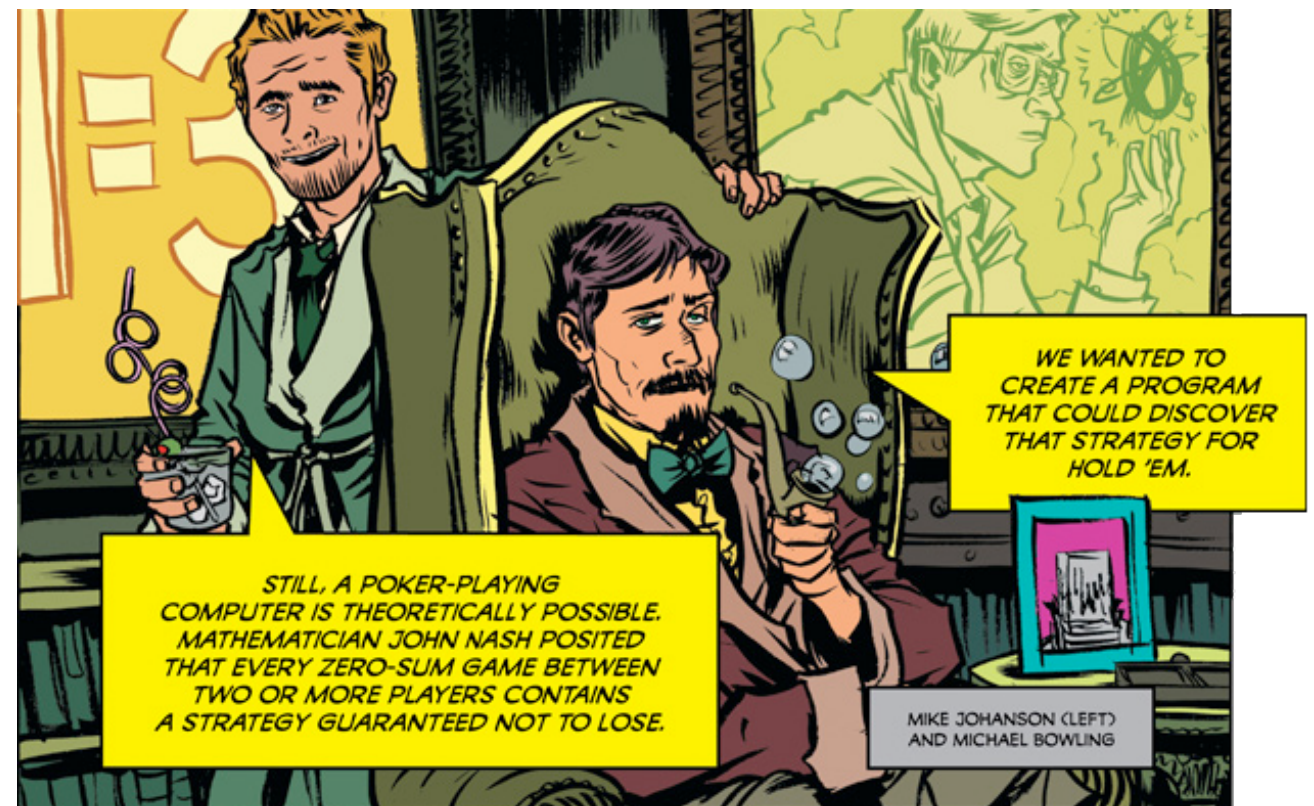


# The Polaris Computer Poker Program

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Dr. Michael Bowling  
University of Alberta

*Wired*, December 2008

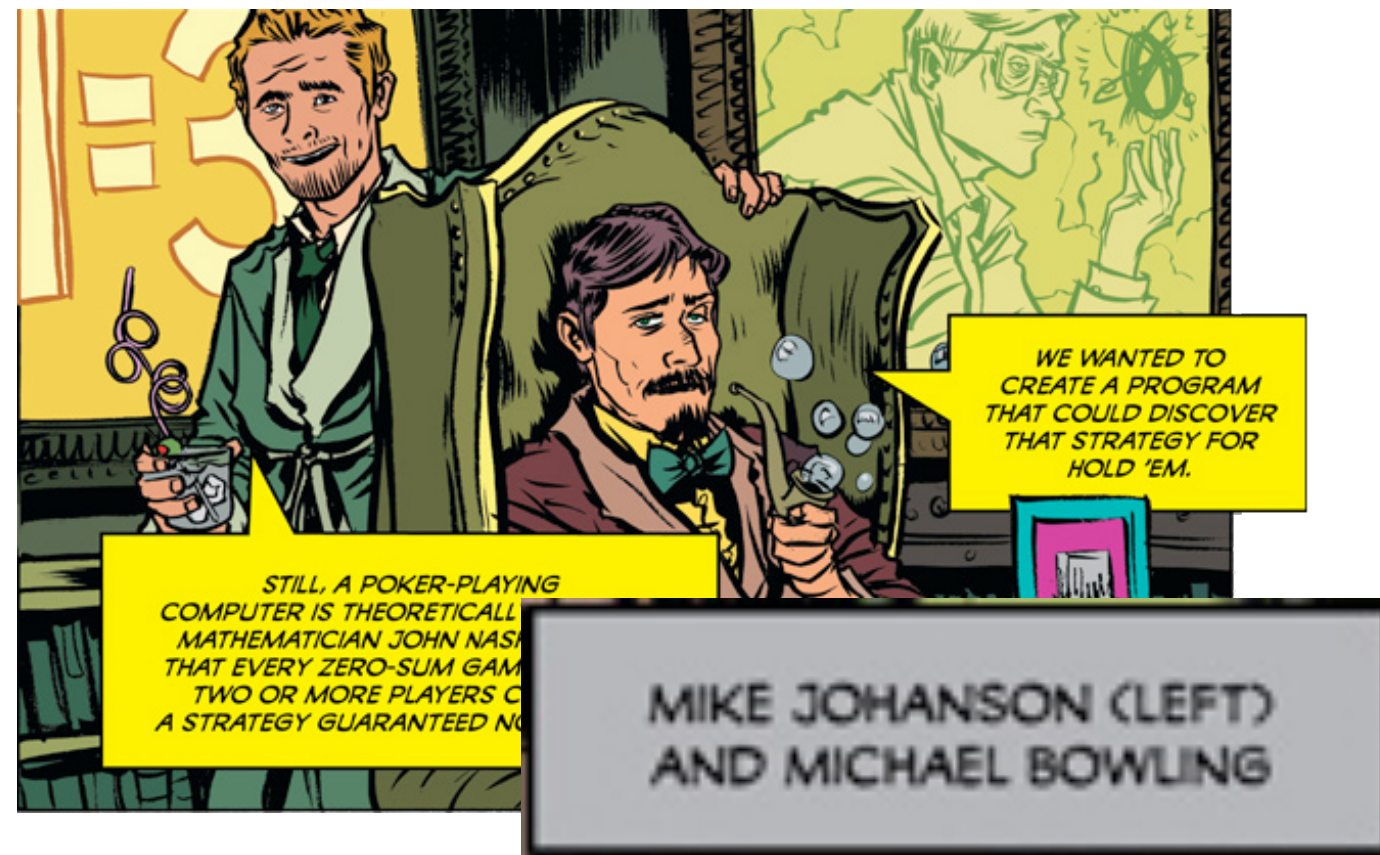


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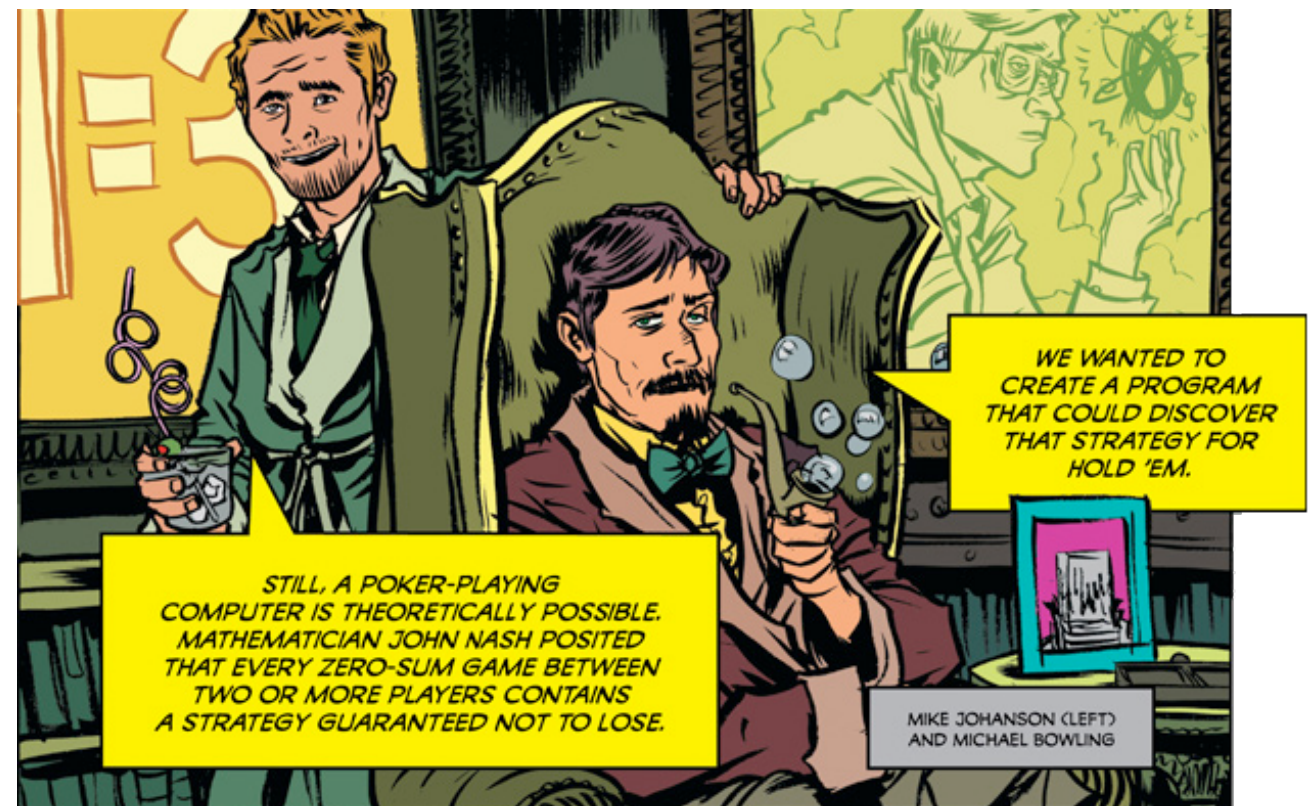


# The Polaris Computer Poker Program

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Dr. Michael Bowling  
University of Alberta

*Wired*, December 2008



# Why am I here?

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- I am not a sociologist, economist, or political scientist
- I am a computer scientist
- I study artificial intelligence: how do we make computers make intelligent decisions?
- I have a passion for games
- My five year obsession: computers beating humans at **poker**

# The Computer Poker Research Group

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- Started in 1997 (by J. Schaeffer and D. Szafron)
- Poker research at Alberta started in 1992 with Darse Billings (M.Sc. student)
- 9 M.Sc. and 1 Ph.D. dissertations later...
  - 4 Faculty
  - 6 Students
  - 2 Programmers
  - 2 Consultants

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# The Game

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# The Game

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# Why Poker?

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“The real world is much more like a poker game...”  
David Moschella in Computerworld, 1999

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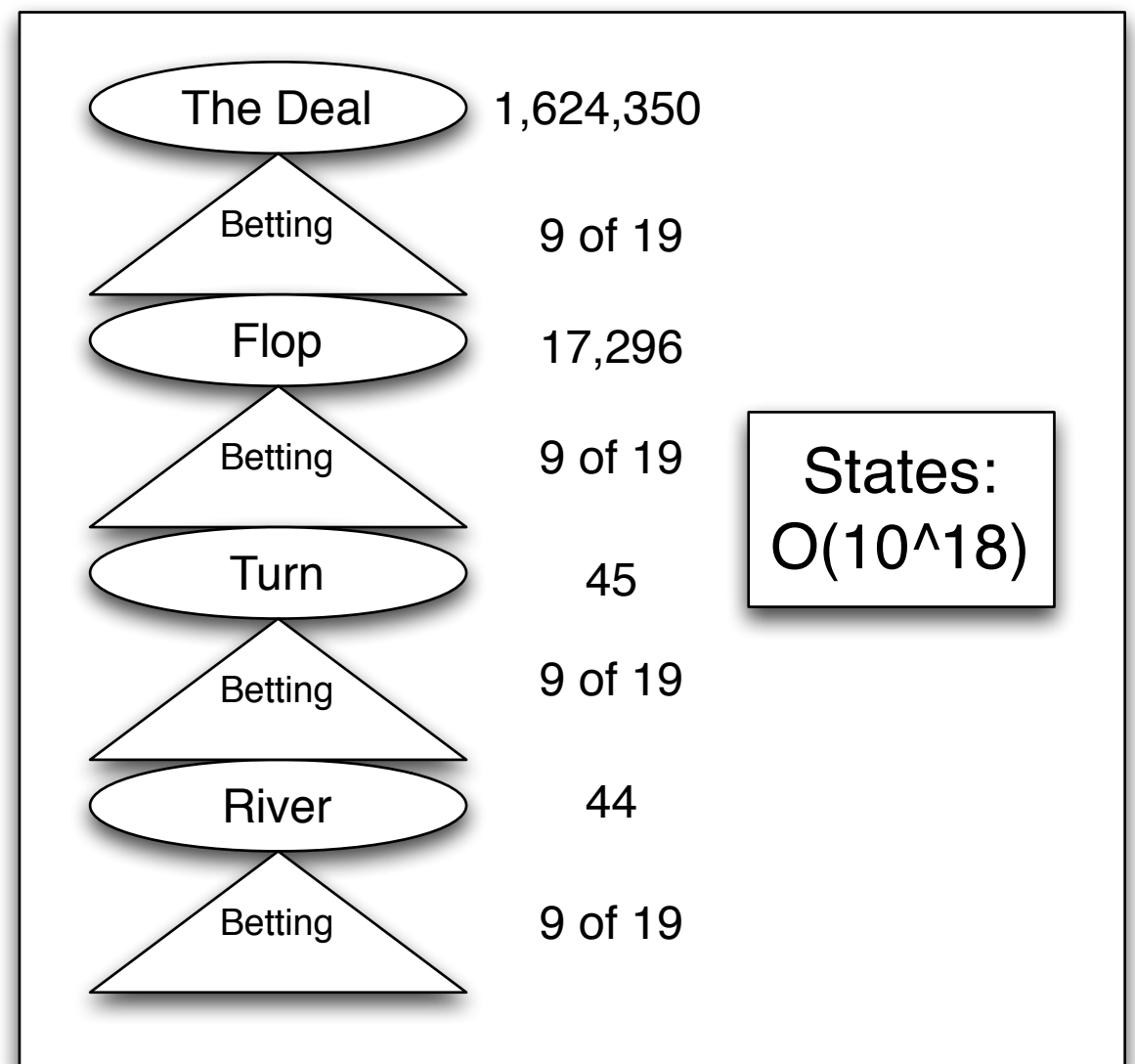
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# Why Poker?

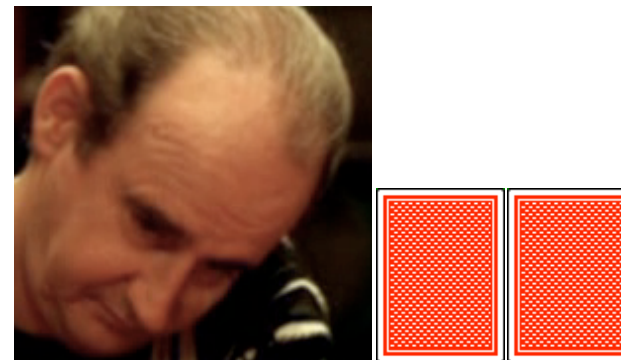
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“The real world is much more like a poker game...”  
David Moschella in Computerworld, 1999

- Imperfect information
- Large game tree
- Variable number of players (2-10, or more)
- Stochastic element
- Amount of winnings matters

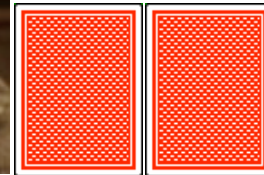
# The Challenges

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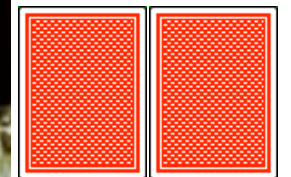
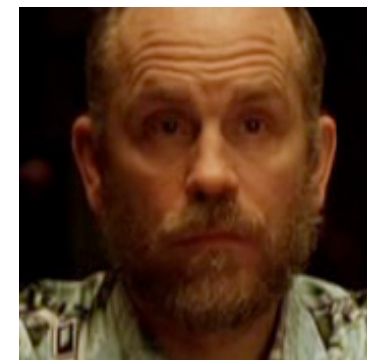
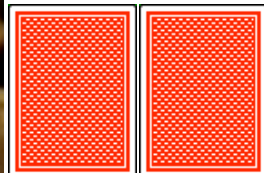


# The Challenges

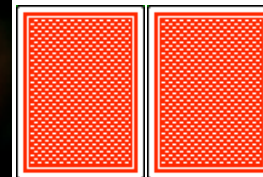
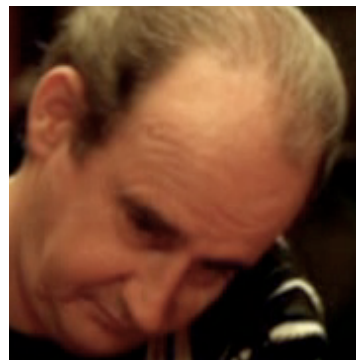
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Small Blind

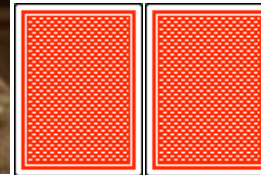


Big Blind

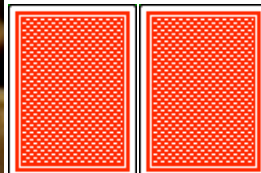


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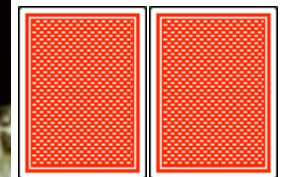
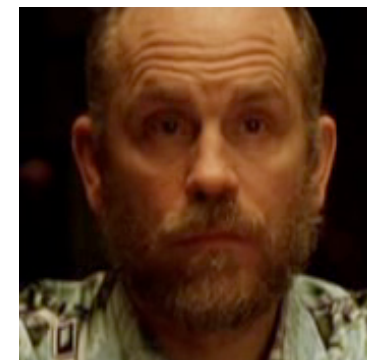
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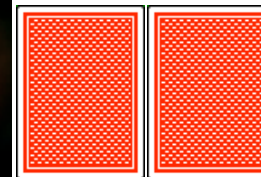
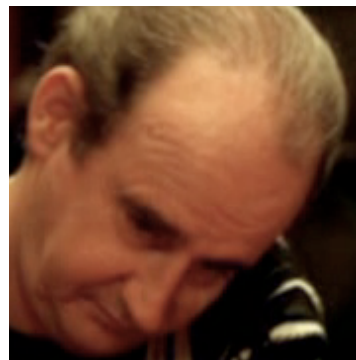
Small Blind



Call

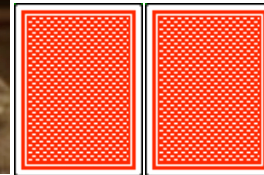


Big Blind

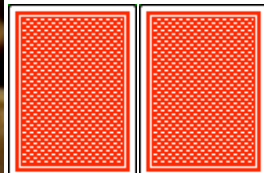


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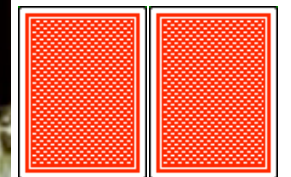
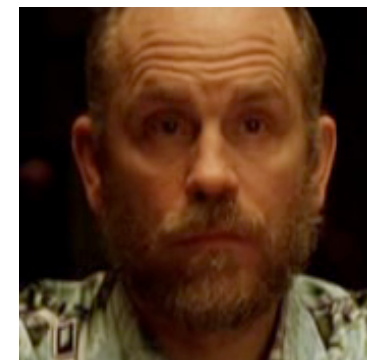


Small Blind

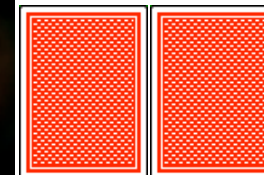
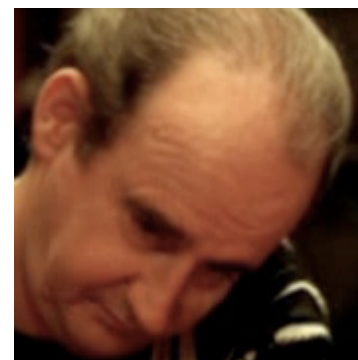


Raise

Call

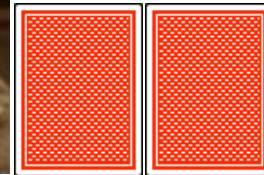


Big Blind

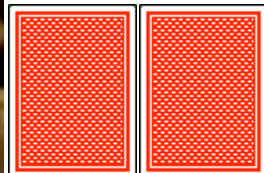


# The Challenges

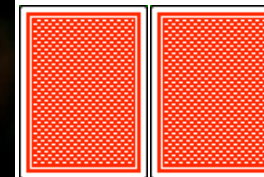
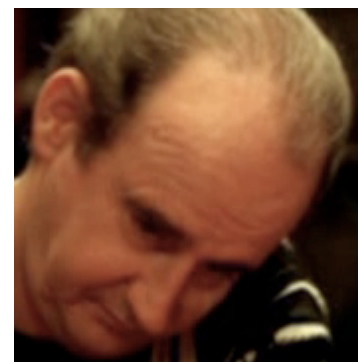
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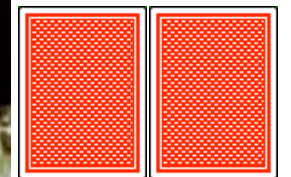
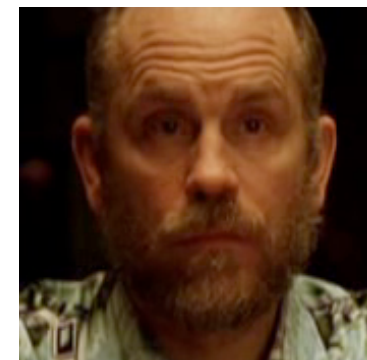
Small Blind  
Fold



Raise



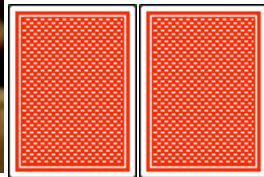
Call



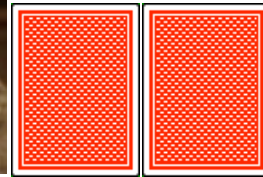
Big Blind

# The Challenges

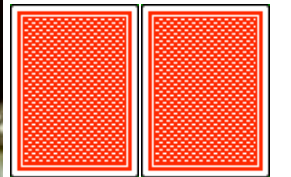
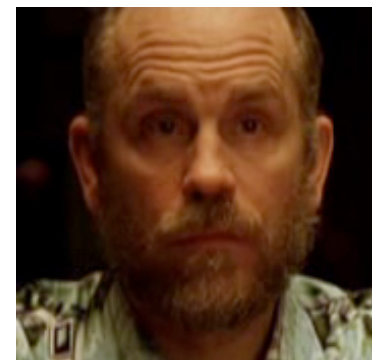
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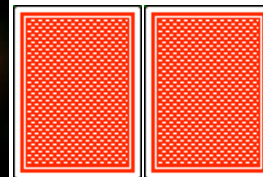
Raise



Small Blind  
Fold



Big Blind  
Call



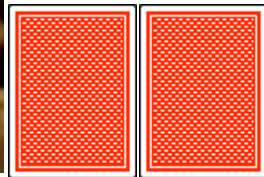
Call

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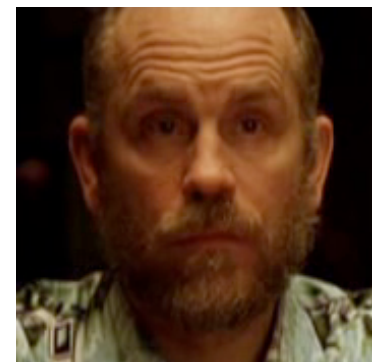
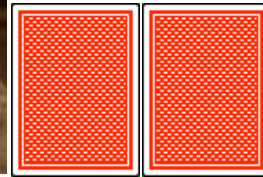
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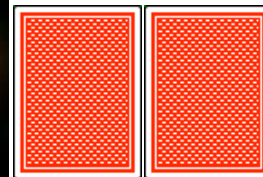
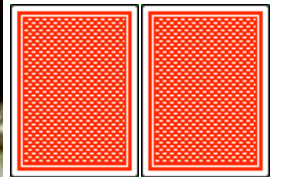
Raise



Small Blind  
Fold



Big Blind  
Call

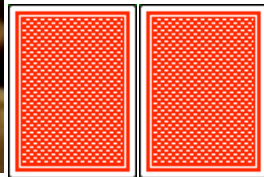


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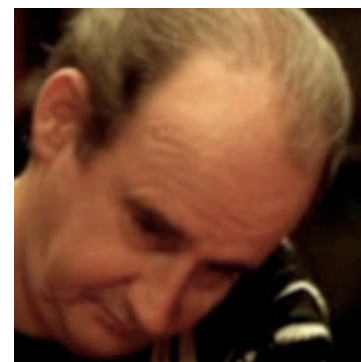
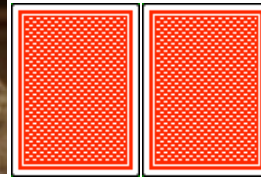
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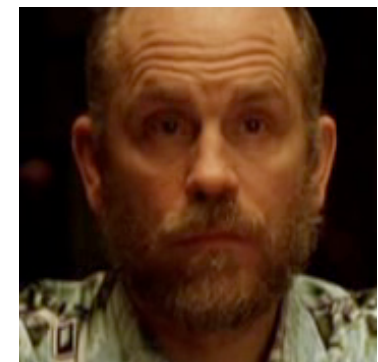
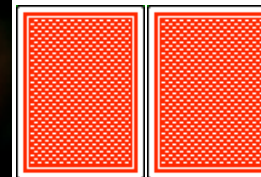
Raise



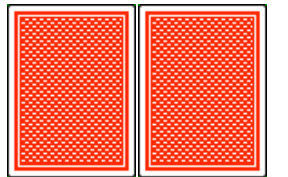
Small Blind  
Fold



Call  
Fold



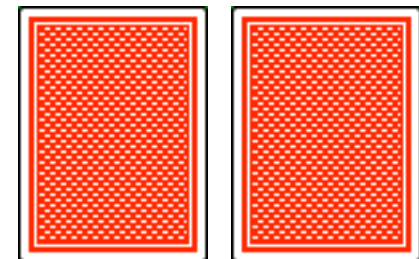
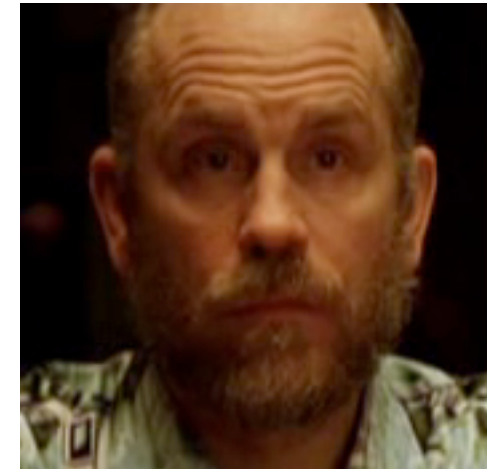
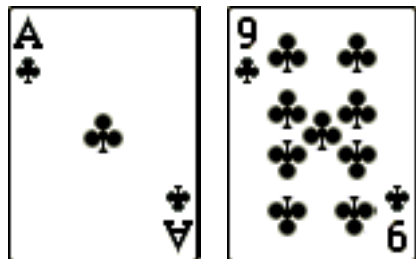
Big Blind  
Call



“It’s a position raise.” (> 2 player)

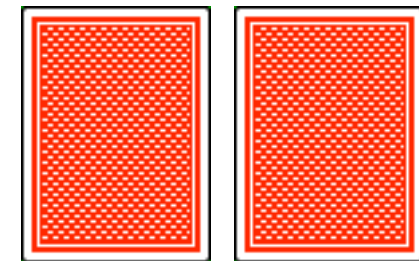
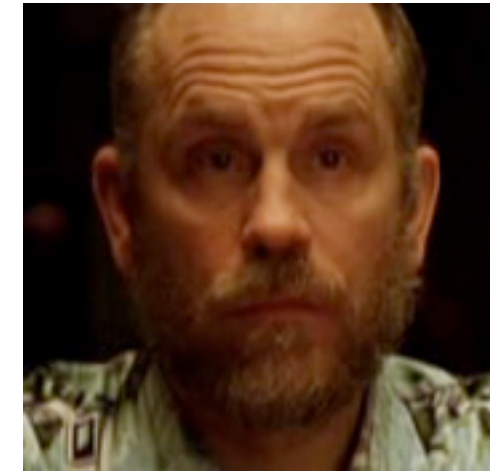
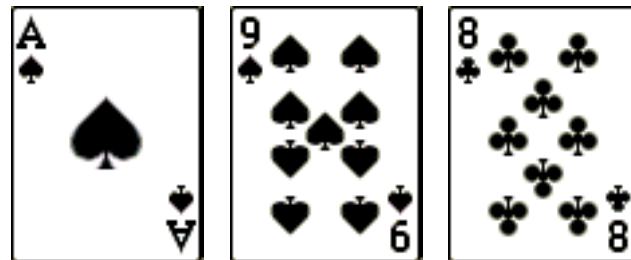
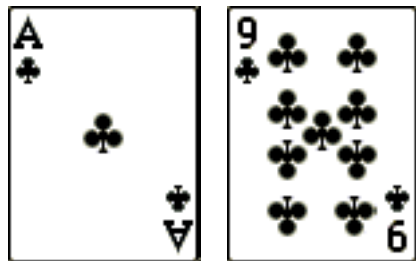
# The Game of Poker

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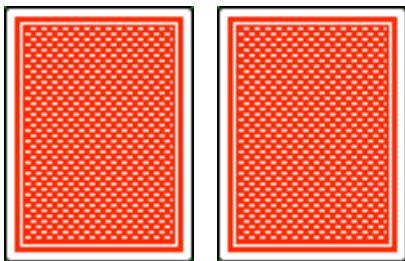
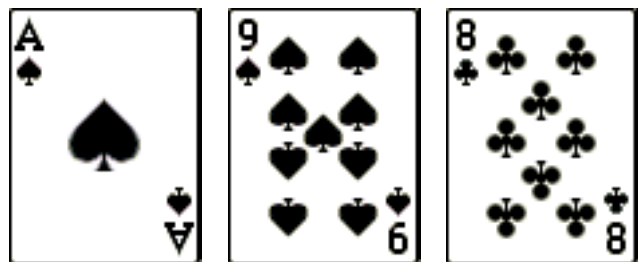
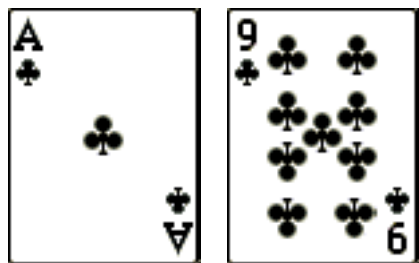
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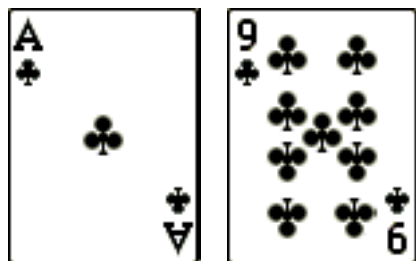
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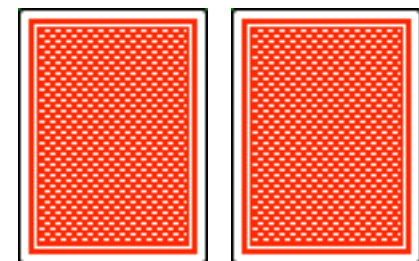
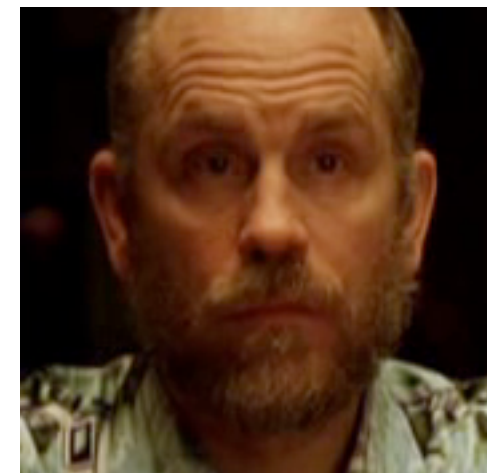
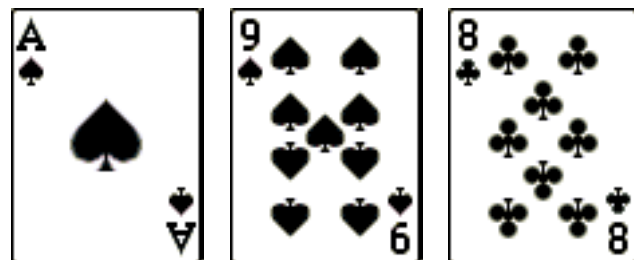
Check

# The Game of Poker

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Raise

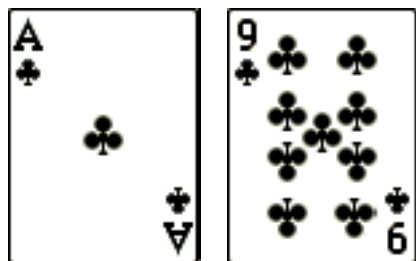


Check

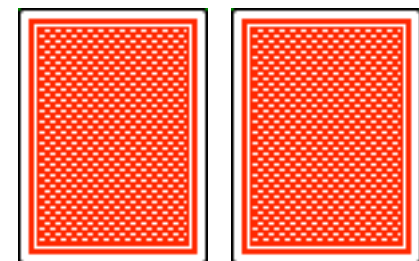
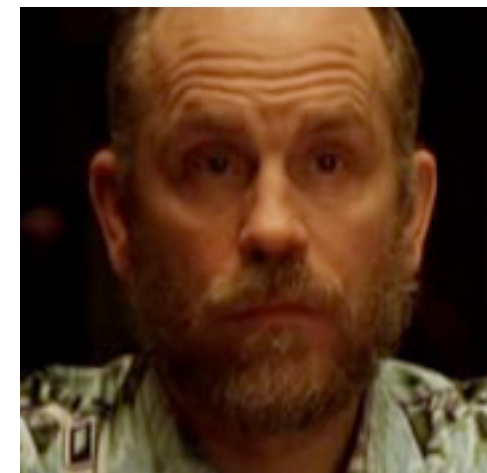
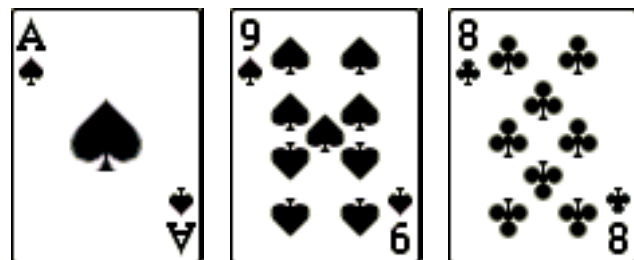
“Overbet to fake weakness” (winnings matter)

# The Game of Poker

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Raise



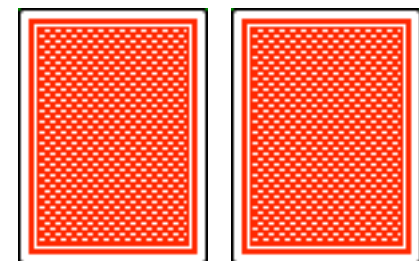
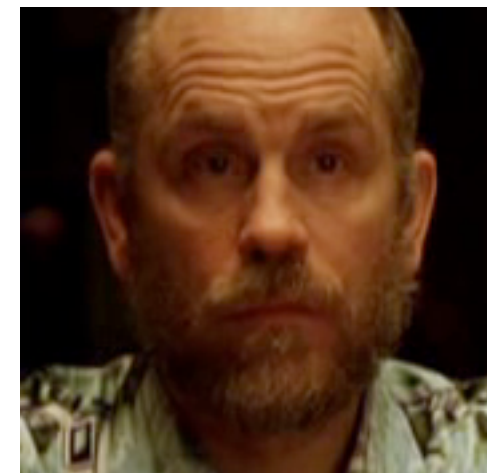
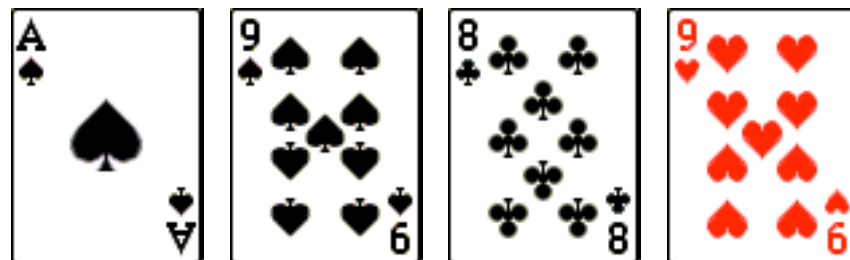
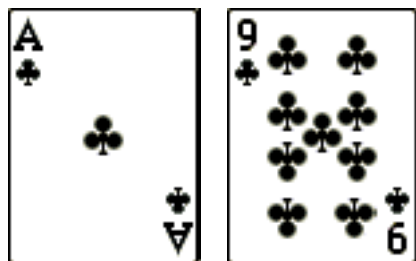
Check  
Call

“Overbet to fake weakness” (winnings matter)

“Teddy has a flush draw” (imperfect information)

# The Game of Poker

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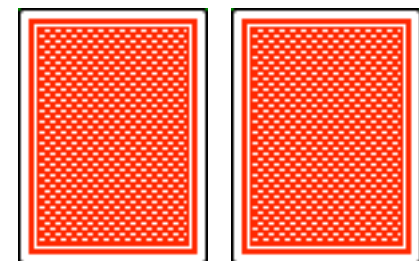
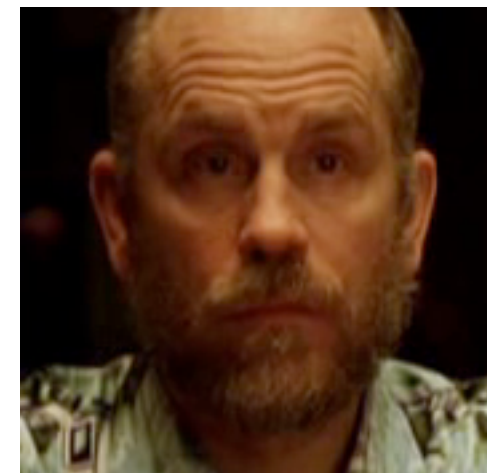
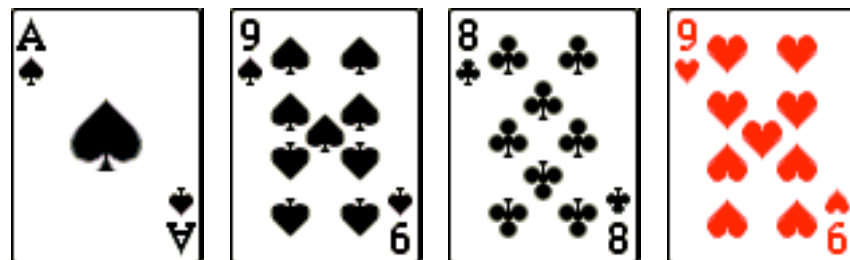
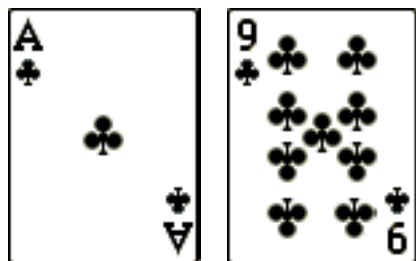


“Overbet to fake weakness” (winnings matter)

“Teddy has a flush draw” (imperfect information)

# The Game of Poker

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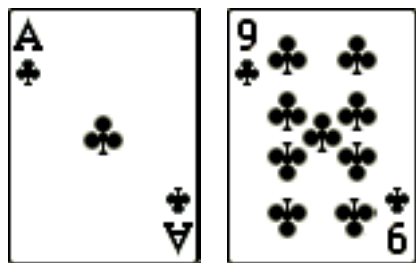
Check

“Overbet to fake weakness” (winnings matter)

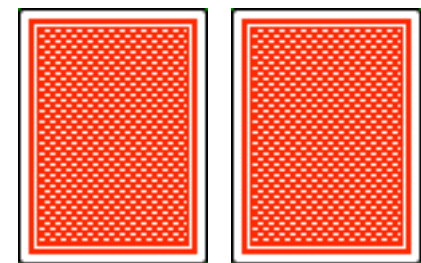
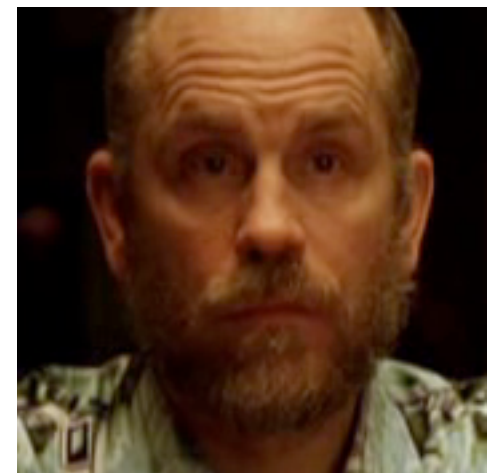
“Teddy has a flush draw” (imperfect information)

# The Game of Poker

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Check



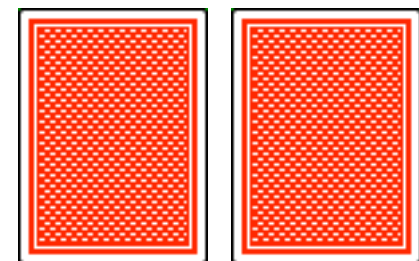
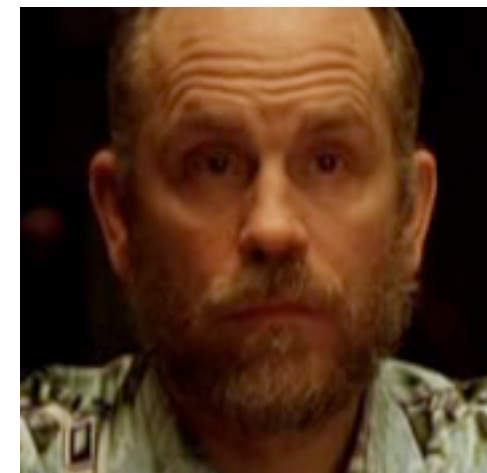
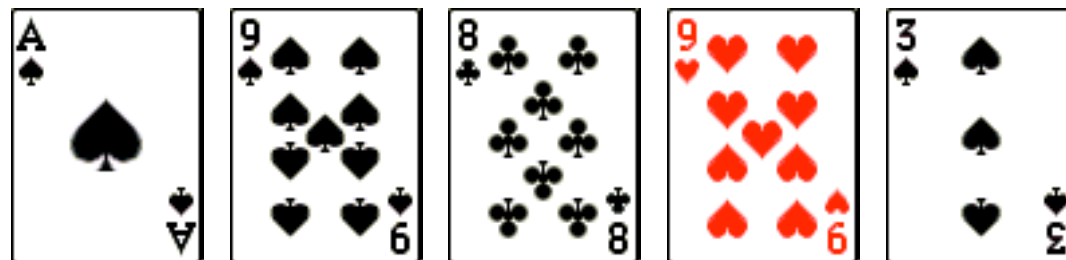
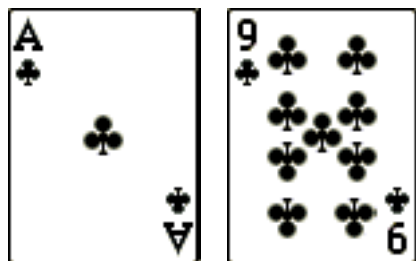
Check

“Overbet to fake weakness” (winnings matter)

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# The Game of Poker

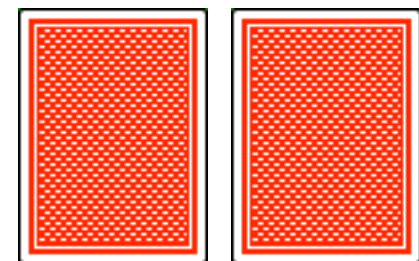
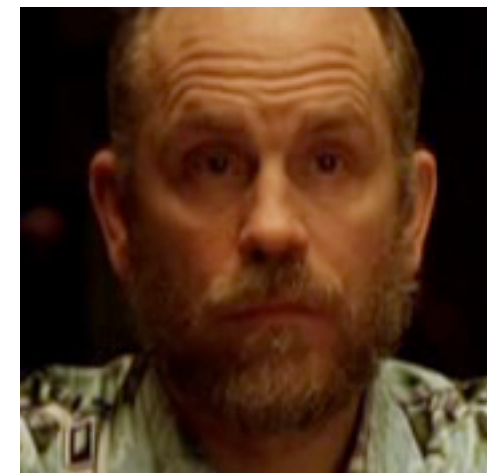
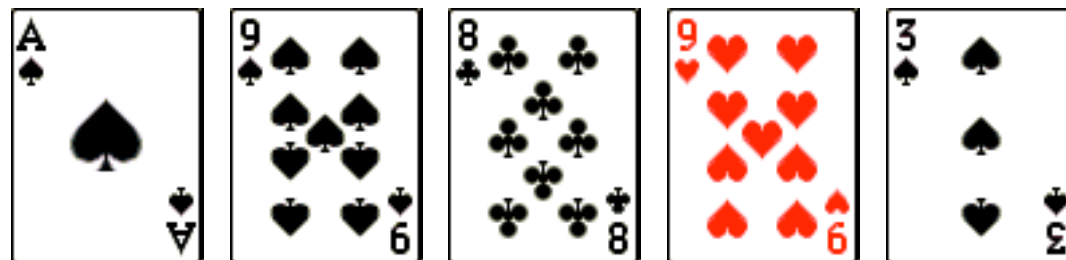
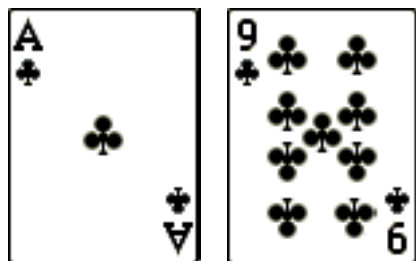
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“Overbet to fake weakness” (winnings matter)  
“Teddy has a flush draw” (imperfect information)

# The Game of Poker

---



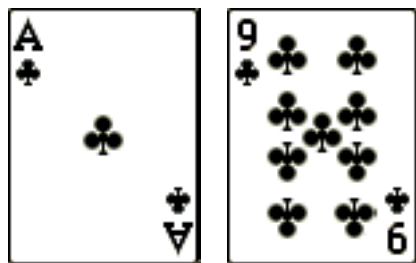
Raise

“Overbet to fake weakness” (winnings matter)

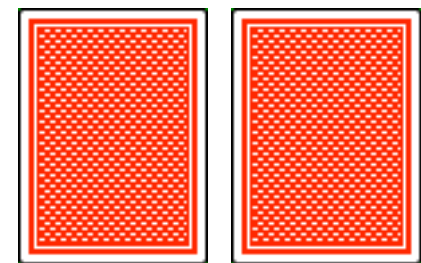
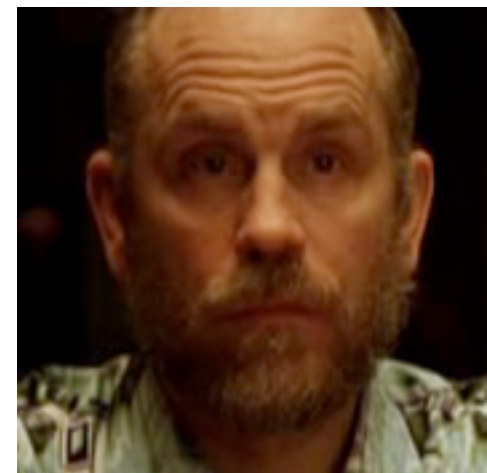
“Teddy has a flush draw” (imperfect information)

# The Game of Poker

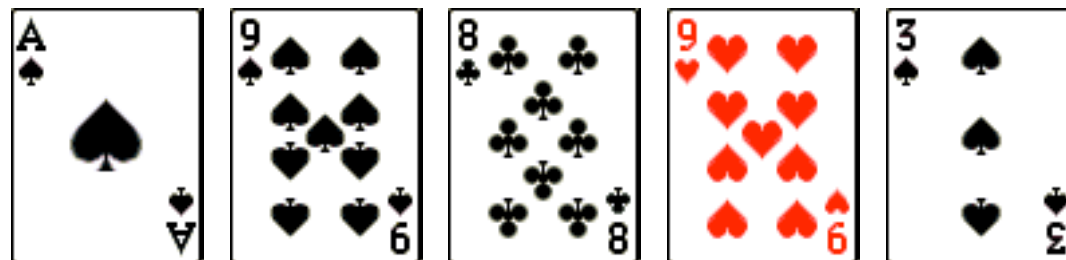
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All-In



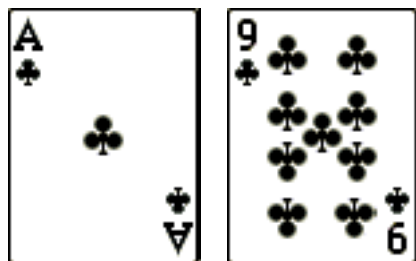
Raise



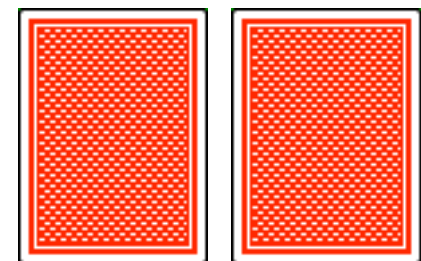
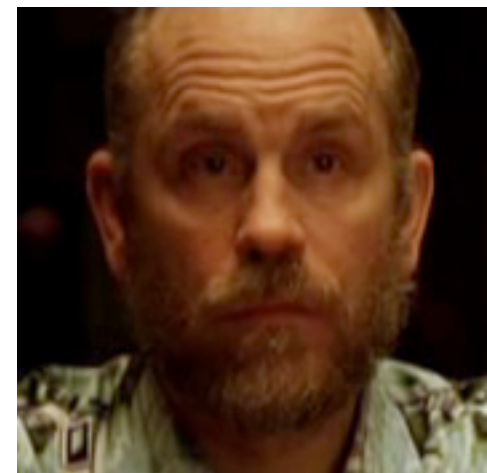
- “Overbet to fake weakness” (winnings matter)
- “Teddy has a flush draw” (imperfect information)
- “Got’em... All-In” (opponent modelling)

# The Game of Poker

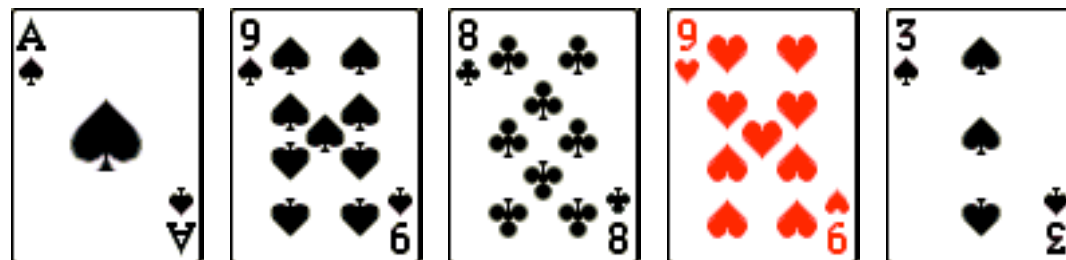
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All-In



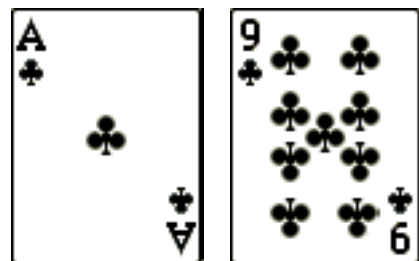
Raise  
Call



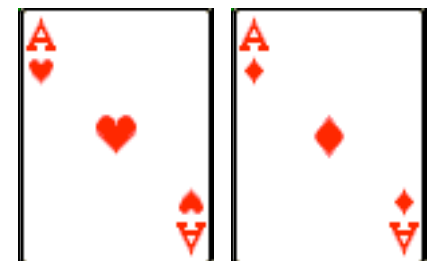
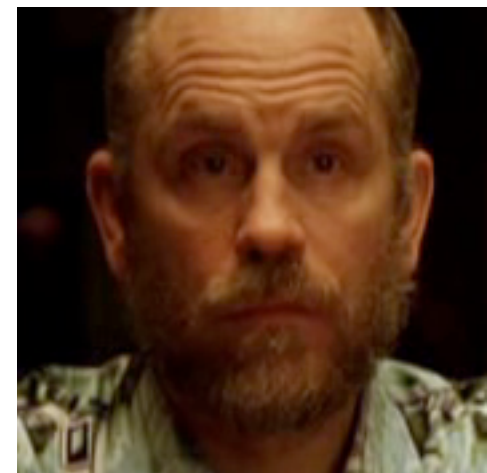
- “Overbet to fake weakness” (winnings matter)
- “Teddy has a flush draw” (imperfect information)
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# The Game of Poker

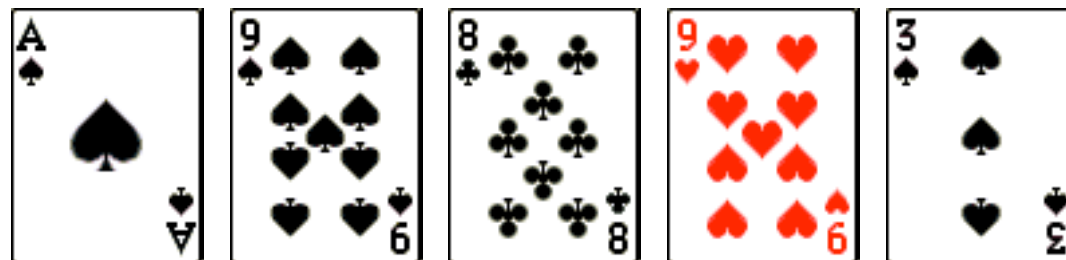
---



All-In



Raise  
Call



- “Overbet to fake weakness” (winnings matter)
- “Teddy has a flush draw” (imperfect information)
- “Got’em... All-In” (opponent modelling)
- “Ouch!” (stochastic element)

# The Challenges

---

“The real world is much more like a poker game...”  
David Moschella in Computerworld, 1999

- Imperfect information
- Large game tree
- Variable number of players (2-10, or more)
- Stochastic element
- Amount of winnings matters

# The Challenges

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# The Challenges

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- Imperfect information 
- Large game tree 
- Variable number of players (2-10, or more)
- Stochastic element 
- Amount of winnings matters 

# Four Years of Research (2003-2007)... One Slide

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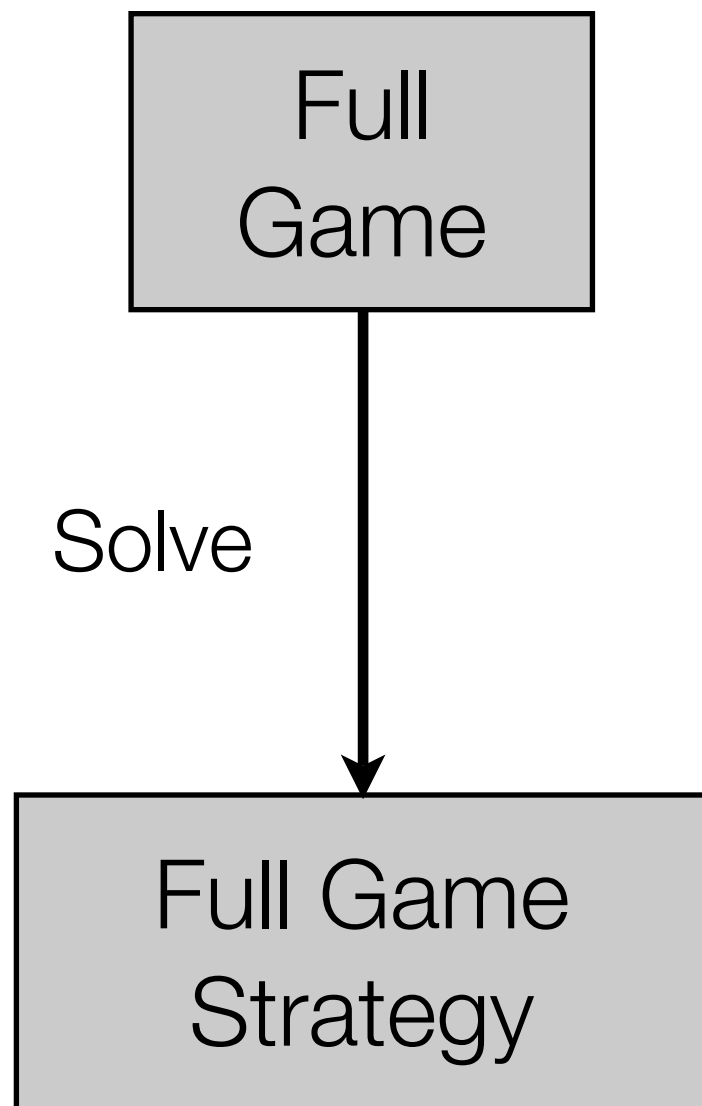
# Four Years of Research (2003-2007)... One Slide

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- Game theoretic optimal strategies!
  - Static strategies, but may employ randomness
  - Guaranteed not to lose money in the long run

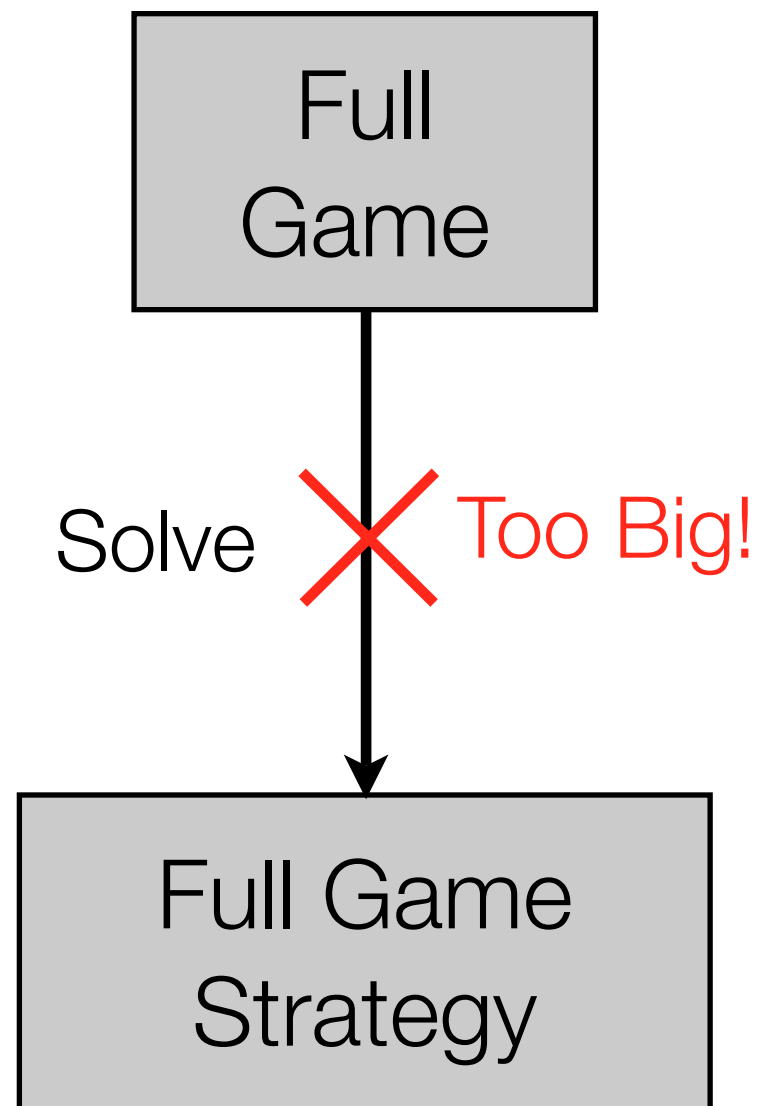
# Four Years of Research (2003-2007)... One Slide

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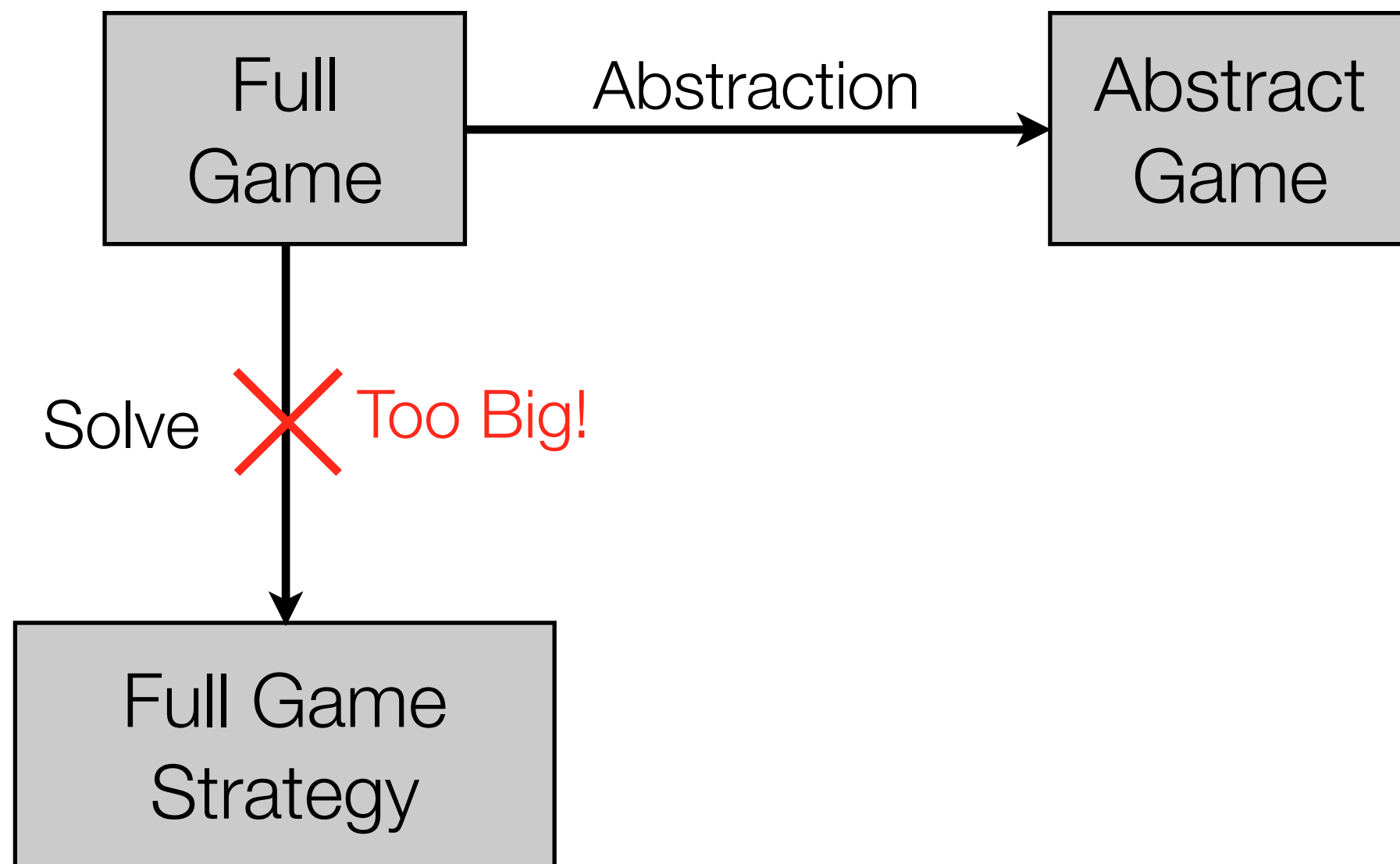
# Four Years of Research (2003-2007)... One Slide

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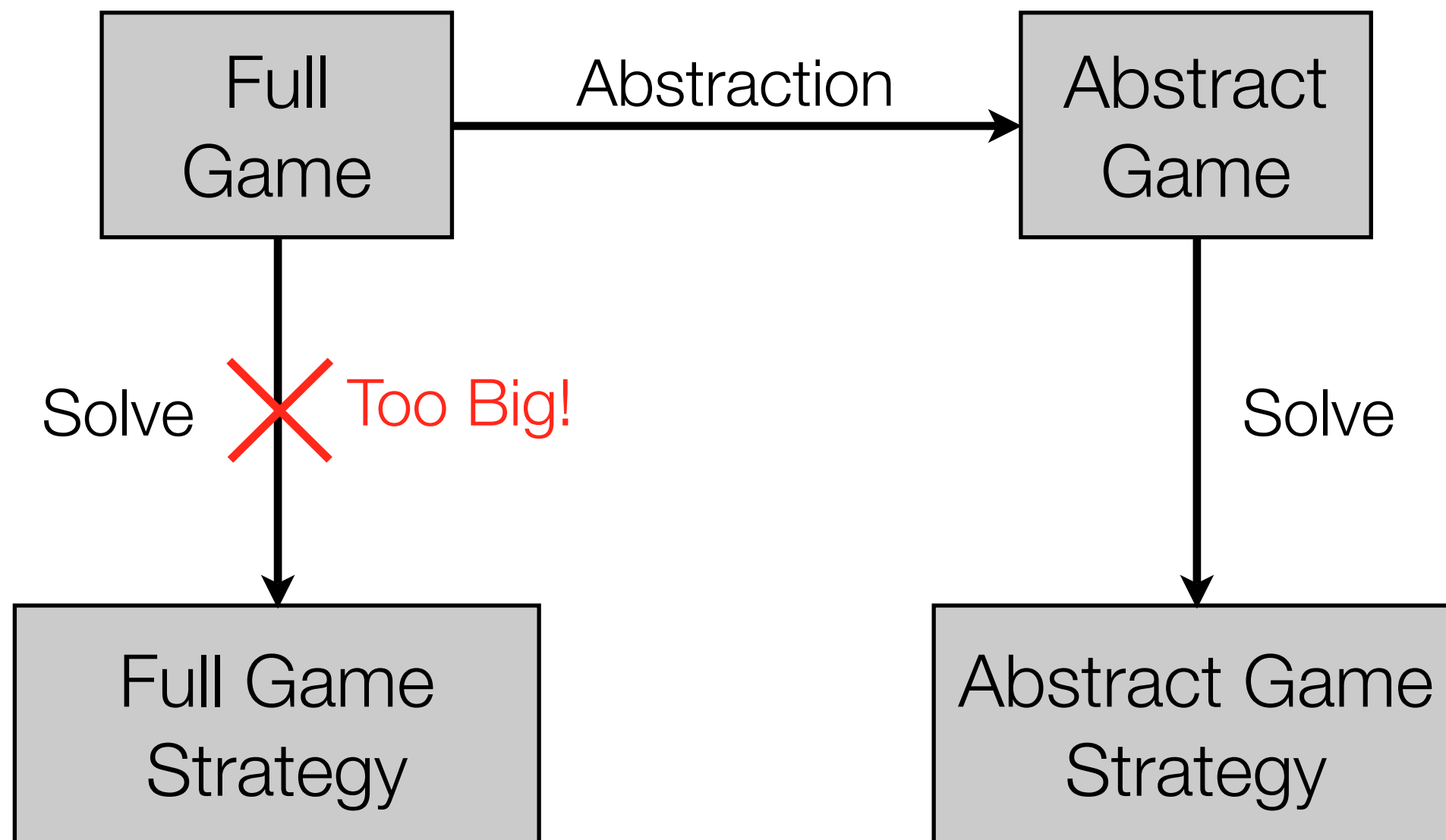
# Four Years of Research (2003-2007)... One Slide

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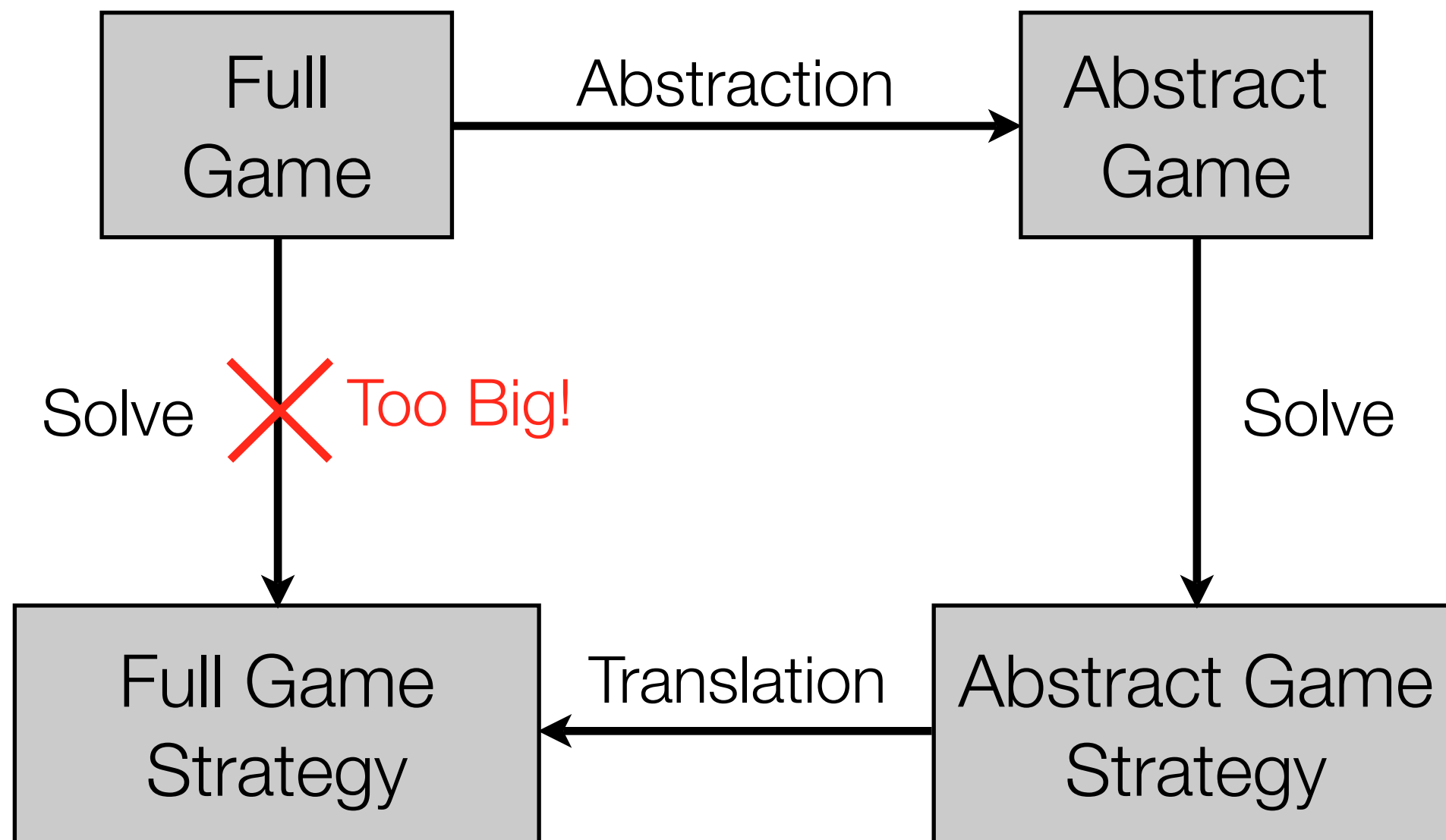
# Four Years of Research (2003-2007)... One Slide

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# Four Years of Research (2003-2007)... One Slide

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# First Man-Machine Poker Championship

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- AAI, Vancouver 2007



Ali Eslami

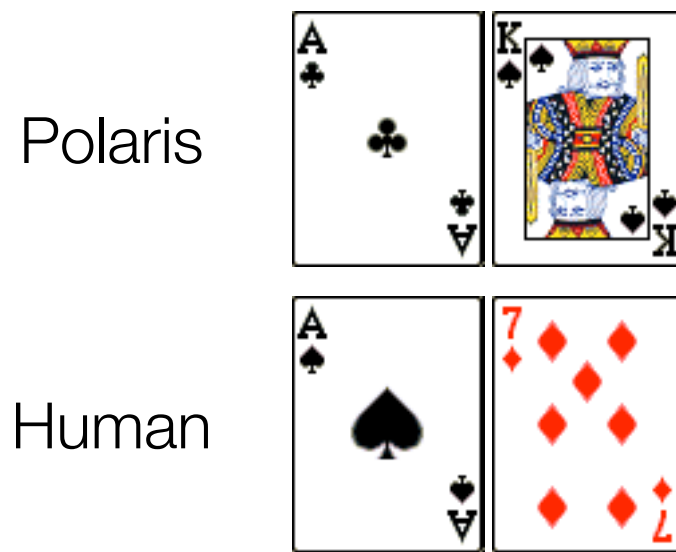


Phil Laak  
“The Unabomber”

# First Man-Machine Poker Championship

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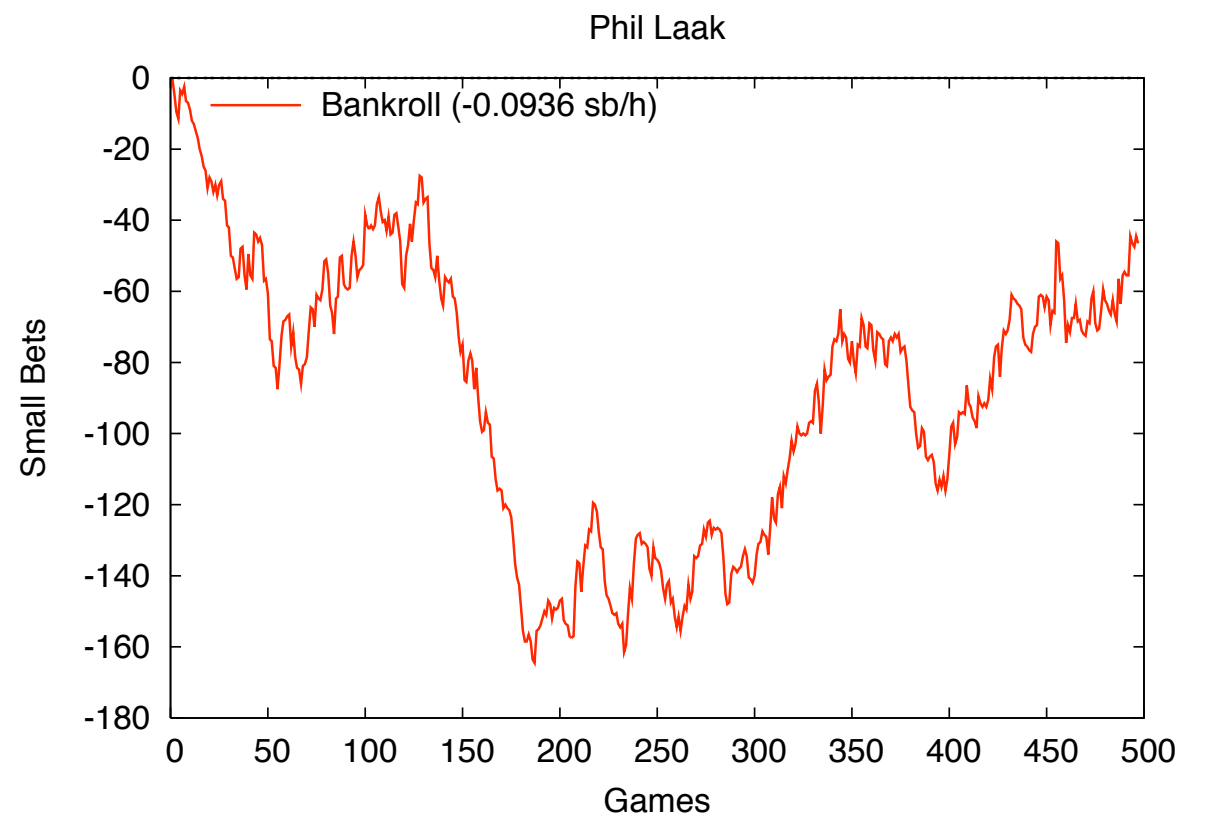
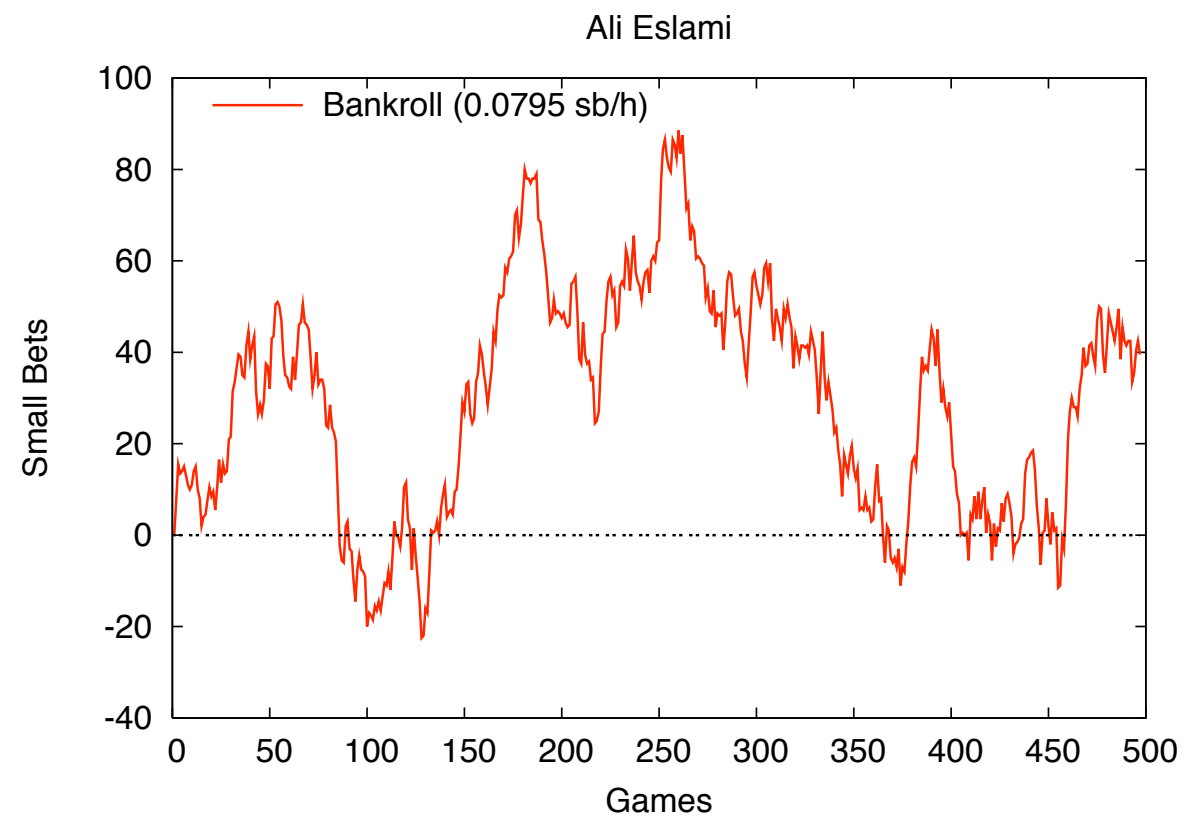
- 500 hand duplicate matches



- One match played in public
- Other played simultaneously in private
- Team's total winnings must exceed 25sb to win

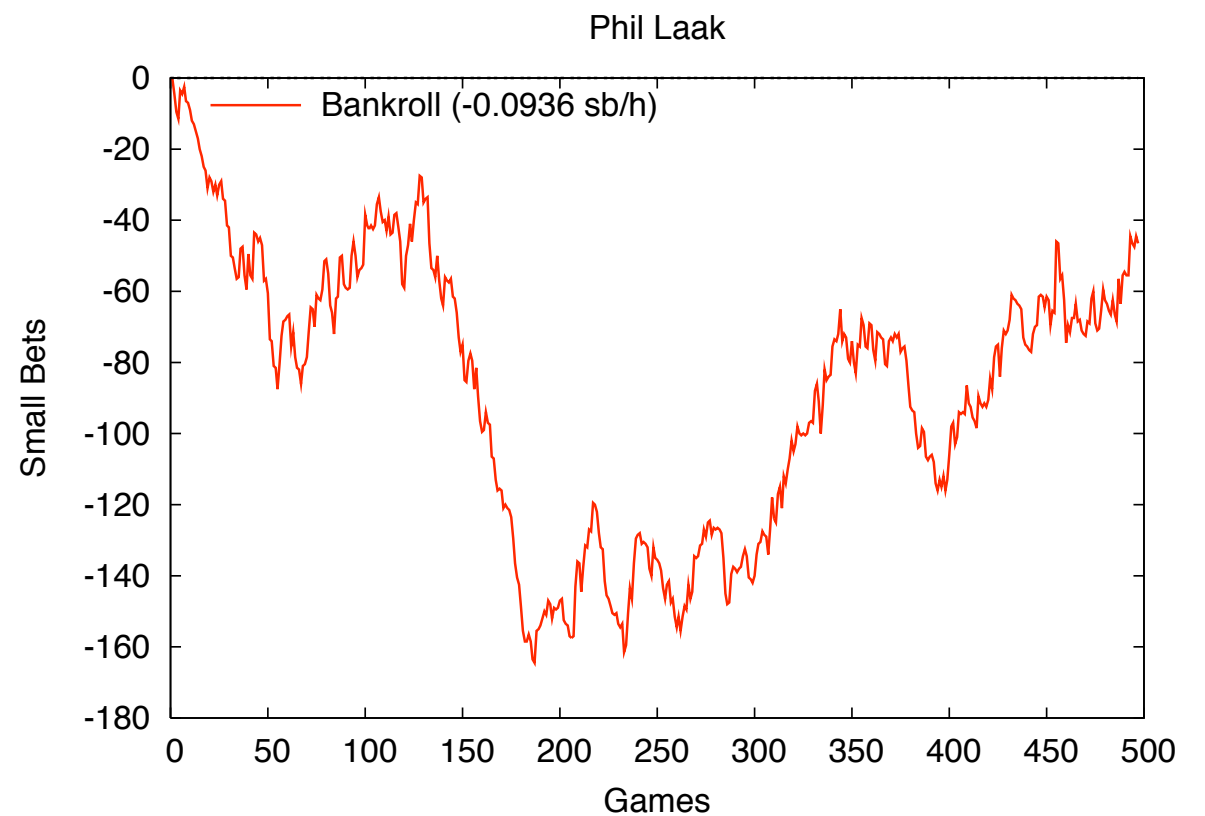
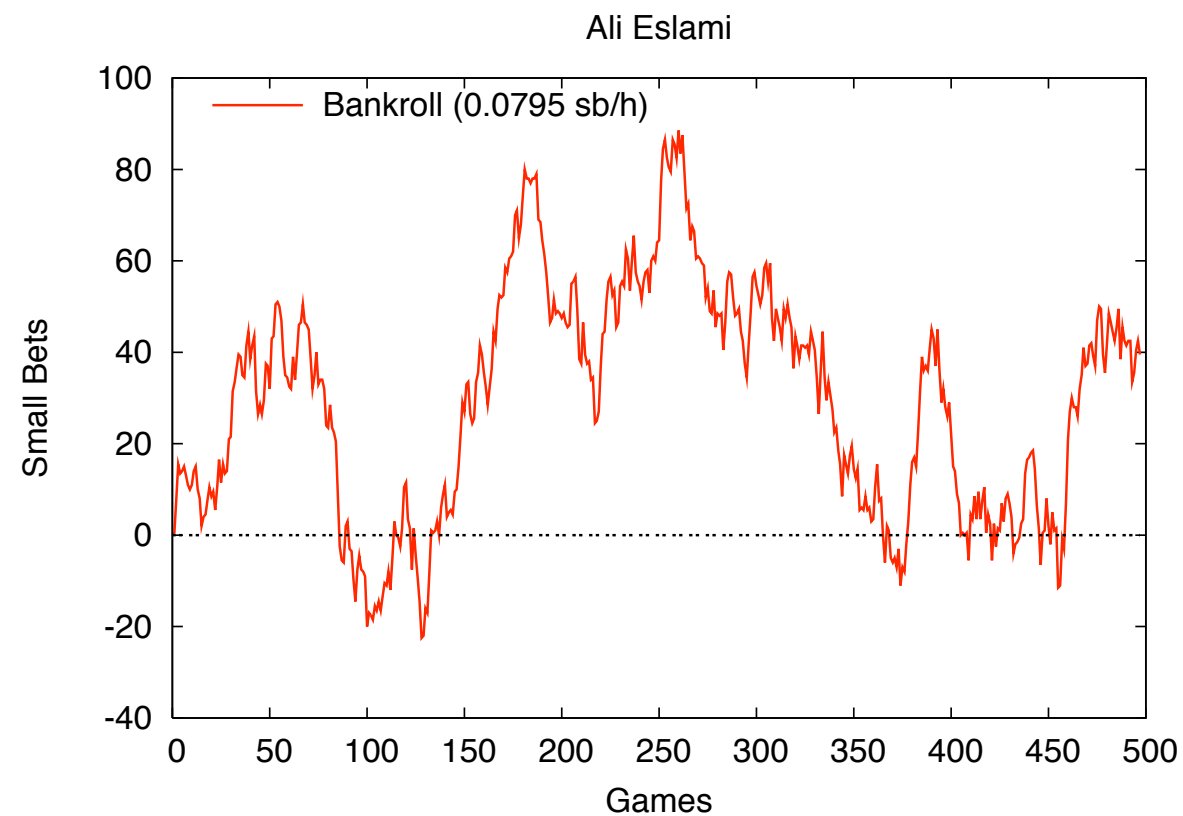
# The Results

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# The Results

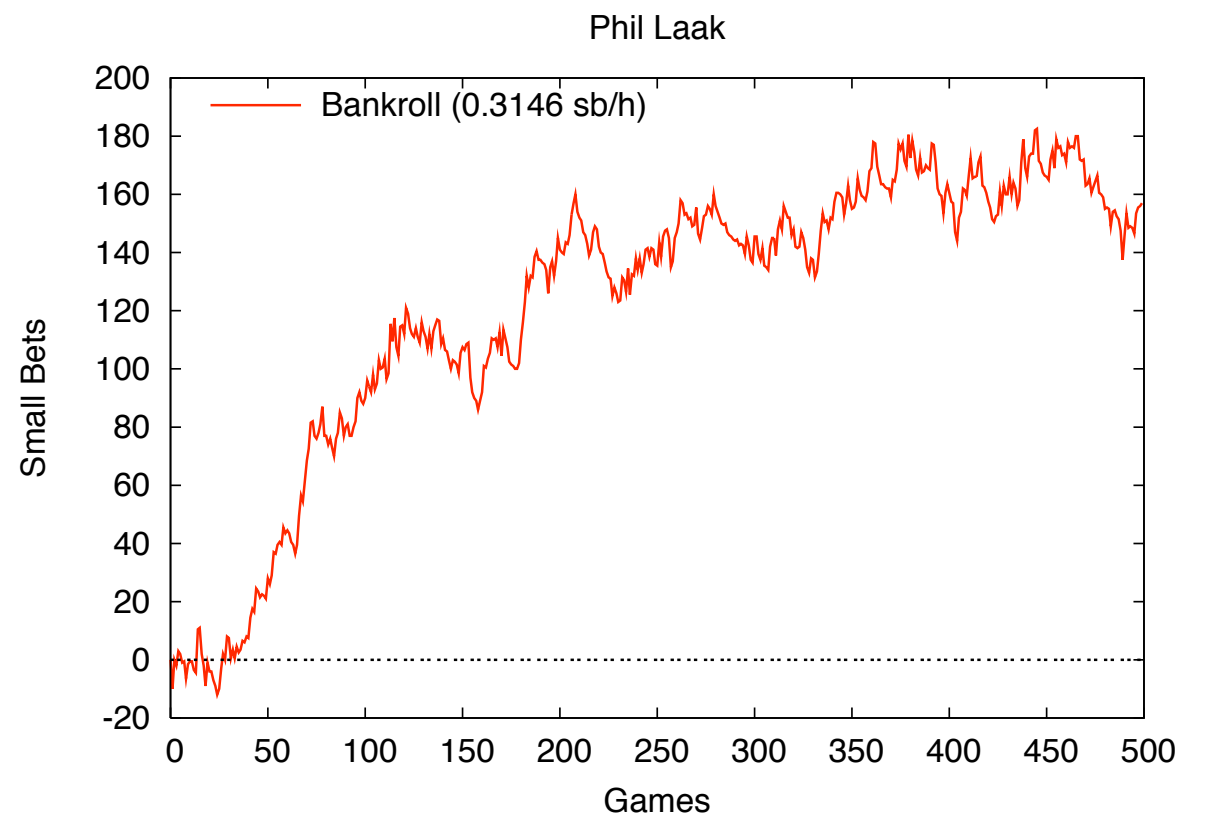
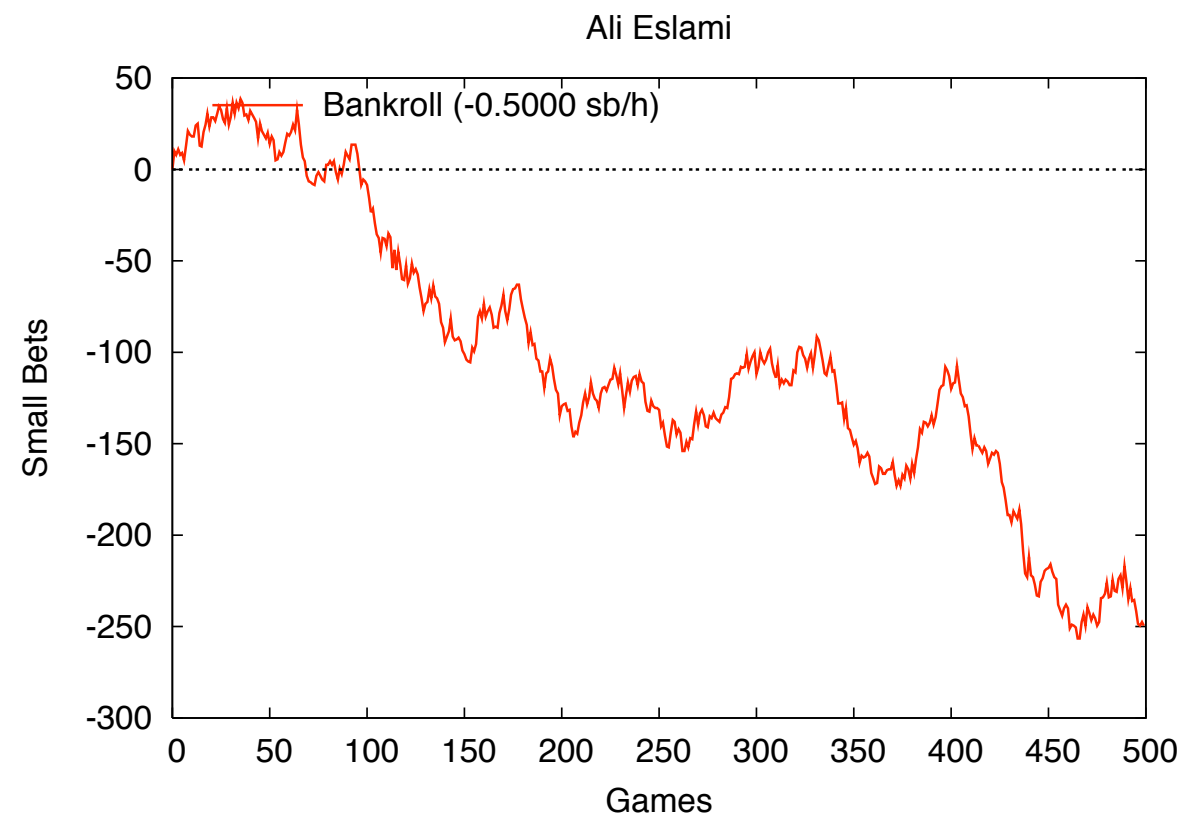
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- Match 1: Polaris up by 7 bets – Draw

# The Results

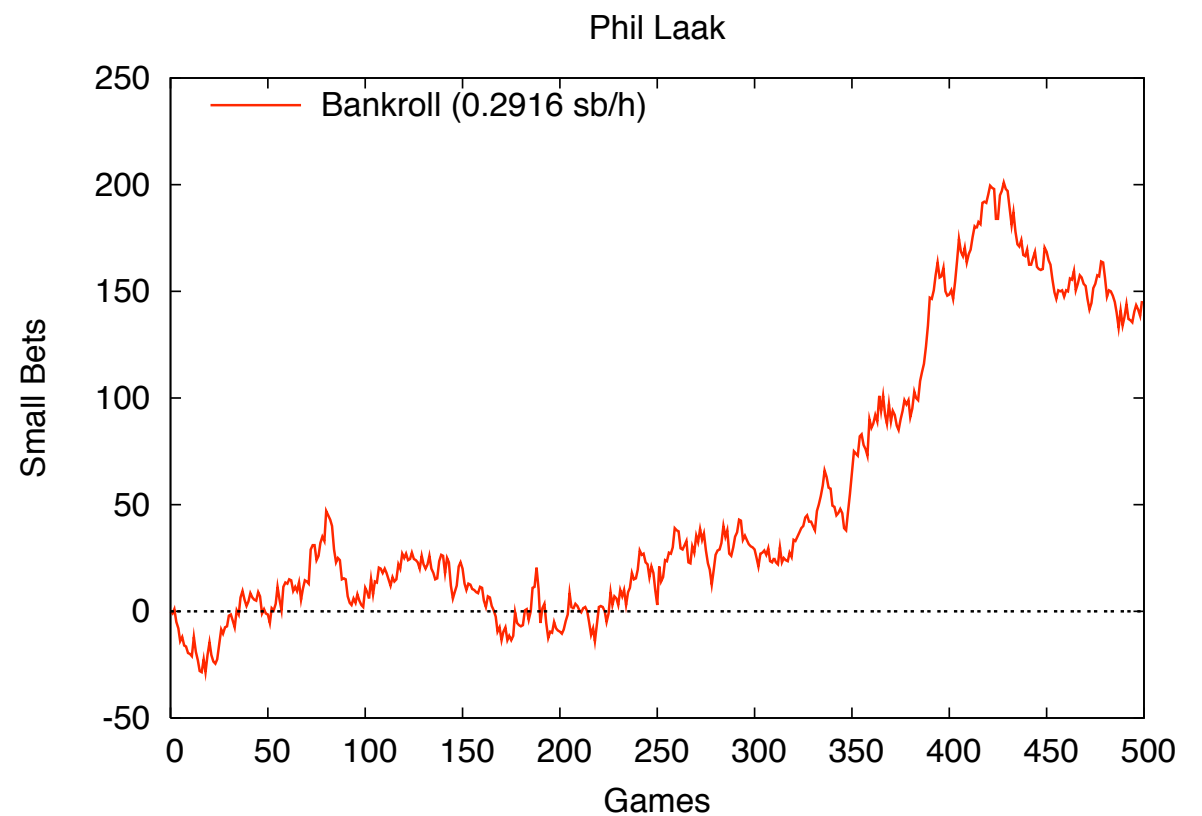
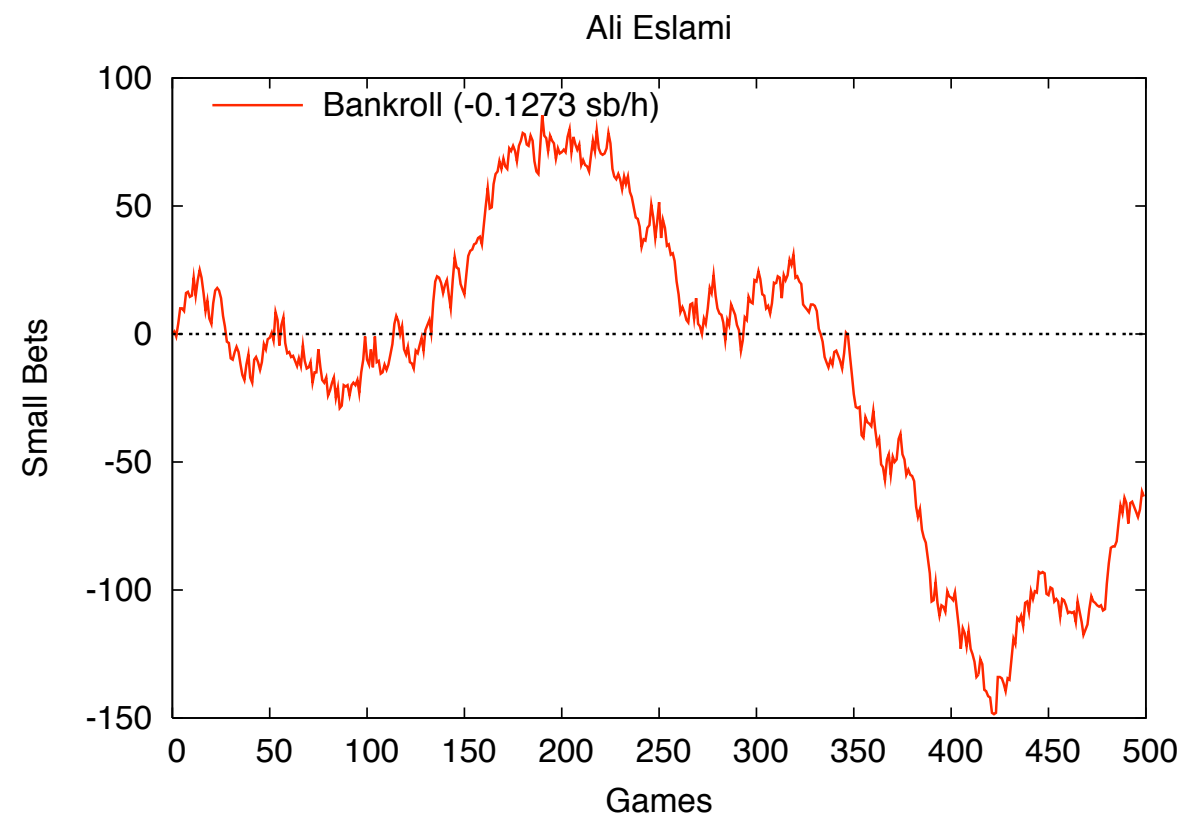
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- Match 1: Polaris up by 7 bets – Draw
- Match 2: Polaris up by 93 bets – Win

# The Results

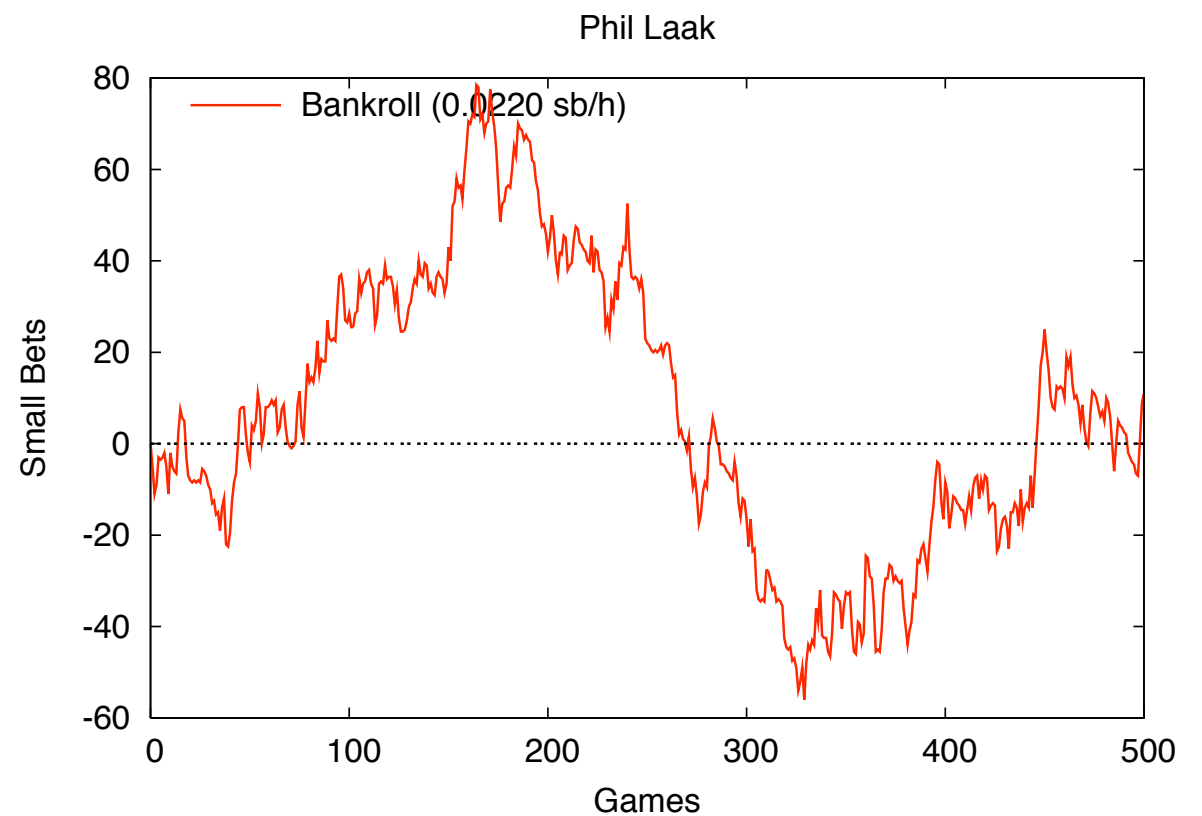
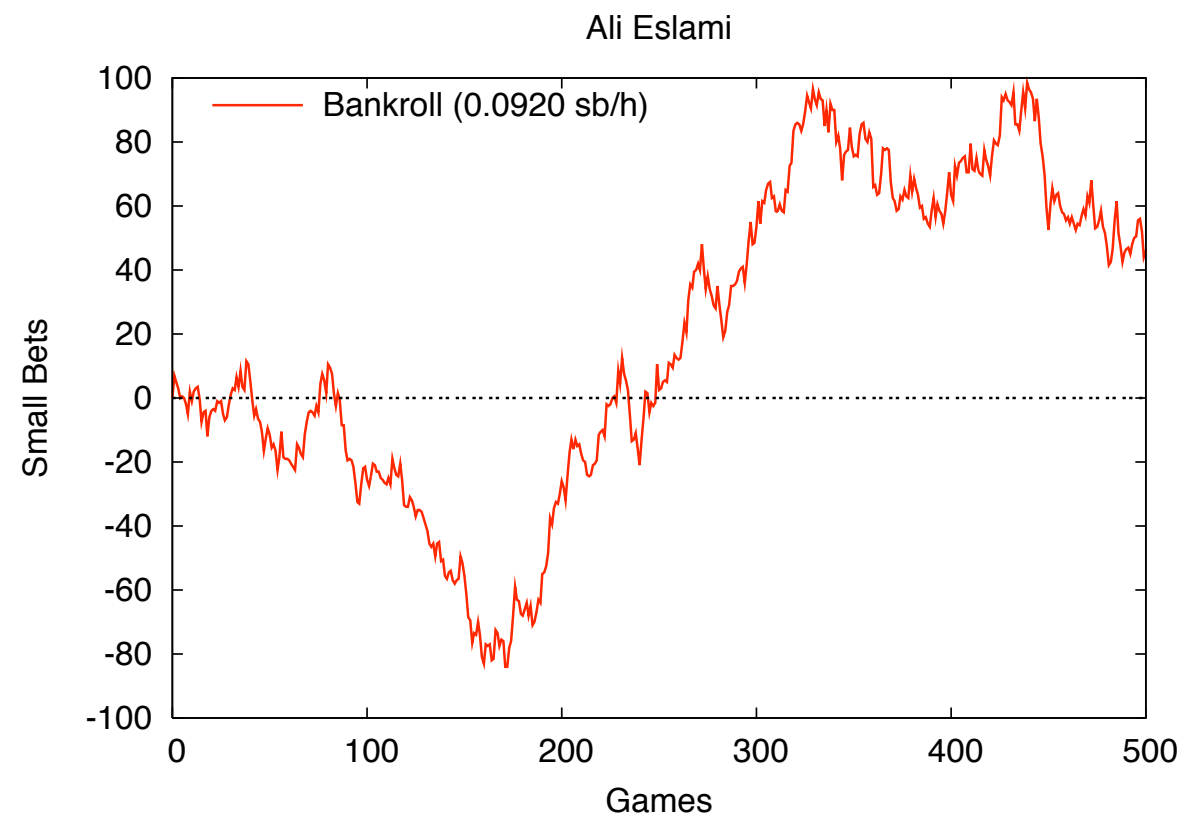
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- Match 1: Polaris up by 7 bets – Draw
- Match 2: Polaris up by 93 bets – Win
- Match 3: Polaris down by 82 bets – Loss

# The Results

---



- Match 1: Polaris up by 7 bets – Draw
- Match 2: Polaris up by 93 bets – Win
- Match 3: Polaris down by 82 bets – Loss
- Match 4: Polaris down by 57 bets – Loss

# The Results

---

- 1 Win, 2 Losses, 1 Draw
- First Law of Poker

# The Results

---

- 1 Win, 2 Losses, 1 Draw
- First Law of Poker

*All players emphasize the skill in poker when they win and the luck when they lose.*

# The Results

---

- 1 Win, 2 Losses, 1 Draw
- First Law of Poker

*All players emphasize the skill in poker when they win and the luck when they lose.*

- The humans got lucky!

# The Results

---

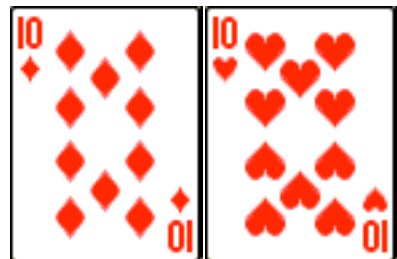
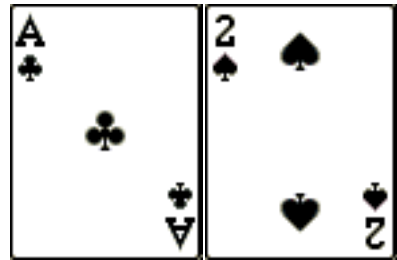
- 1 Win, 2 Losses, 1 Draw
- First Law of Poker

*All players emphasize the skill in poker when they win and the luck when they lose.*

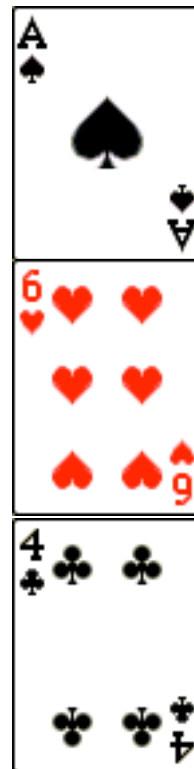
- The humans got lucky!
  - None of the match results were statistically significant
  - Need 20K hands without duplicate!
  - Need 2K pairs of hands with duplicate!

# Removing More Luck: DIVAT

---



check  
bet  
raise  
call



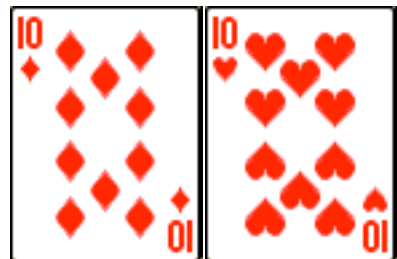
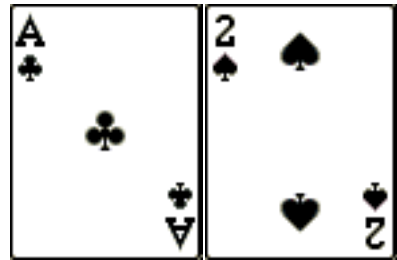
bet  
call



bet  
fold

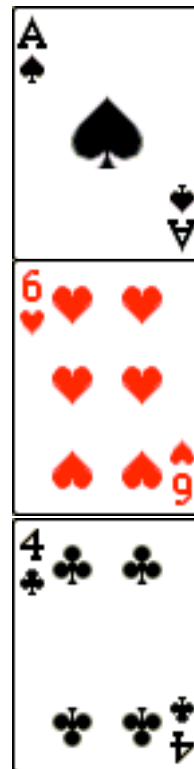
# Removing More Luck: DIVAT

---



+3 sb

check  
bet  
raise  
call



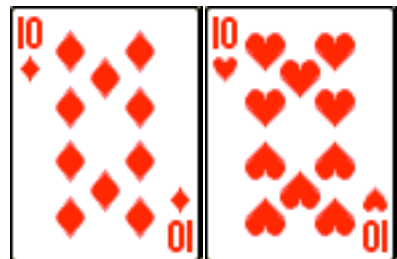
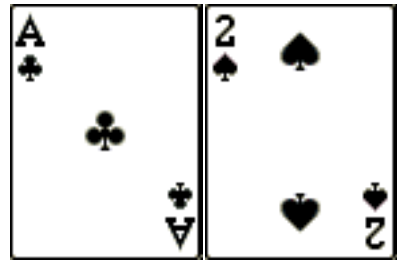
bet  
call



bet  
fold

# Removing More Luck: DIVAT

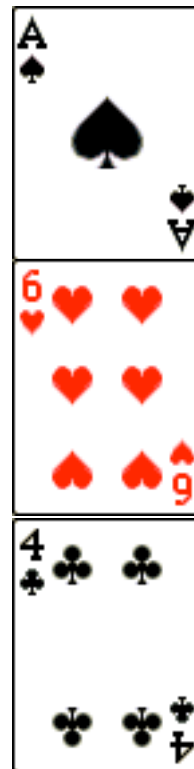
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+3 sb

check  
bet  
raise  
call

+4 sb



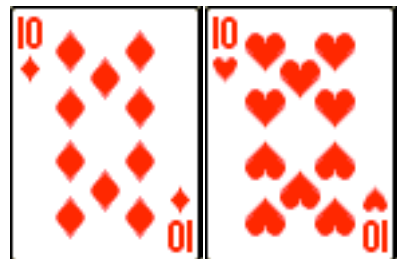
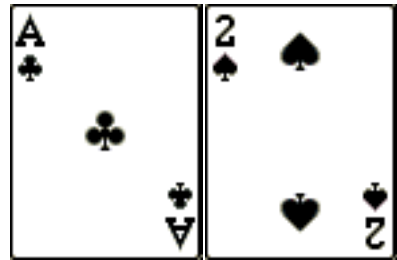
bet  
call



bet  
fold

# Removing More Luck: DIVAT

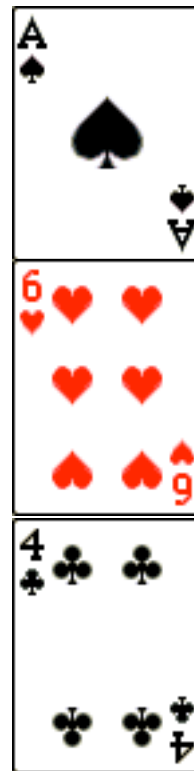
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+3 sb

check  
bet  
raise  
call

+4 sb



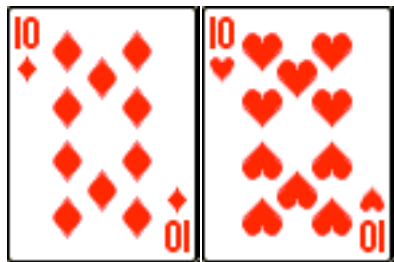
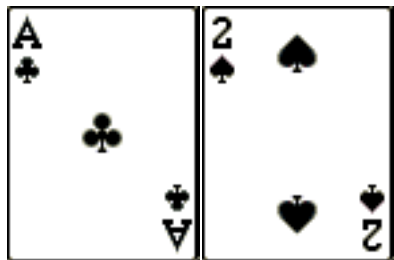
-8 sb

bet  
call



bet  
fold

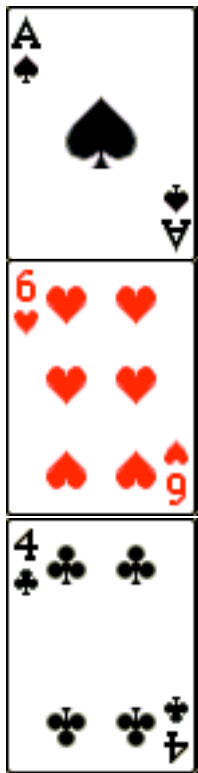
# Removing More Luck: DIVAT



+3 sb

check  
bet  
raise  
call

+4 sb



-8 sb

bet  
call

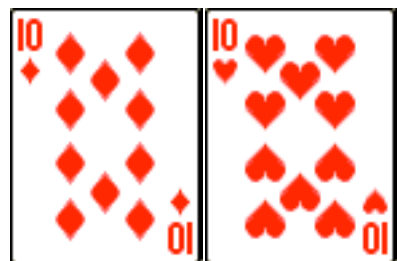
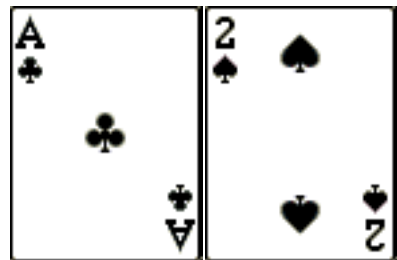
-7 sb



bet  
fold

# Removing More Luck: DIVAT

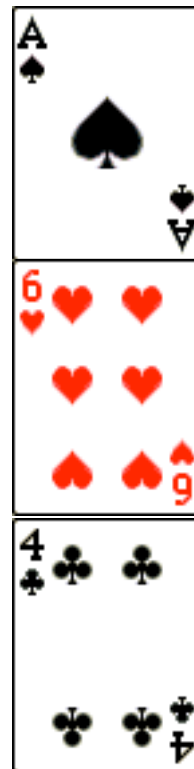
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+3 sb

check  
bet  
raise  
call

+4 sb



-8 sb

bet  
call

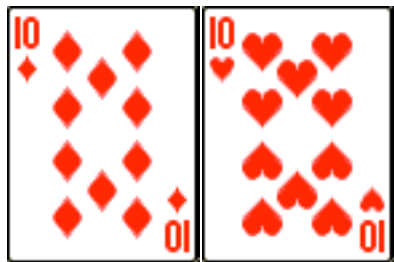
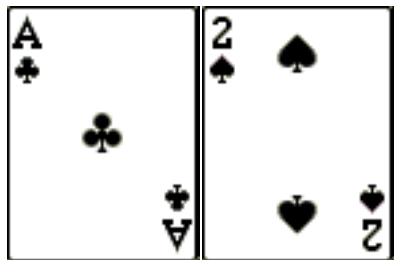
-7 sb



-6 sb

bet  
fold

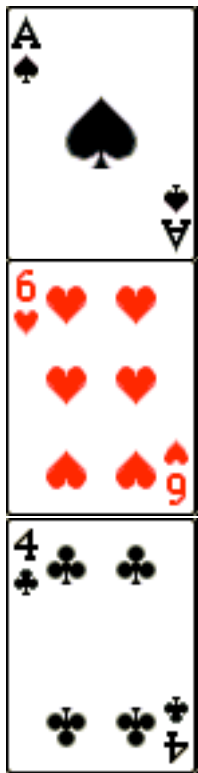
# Removing More Luck: DIVAT



+3 sb

check  
bet  
raise  
call

+4 sb



-8 sb

bet  
call

-7 sb

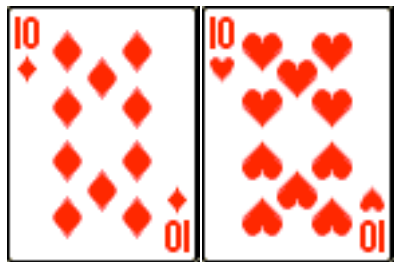
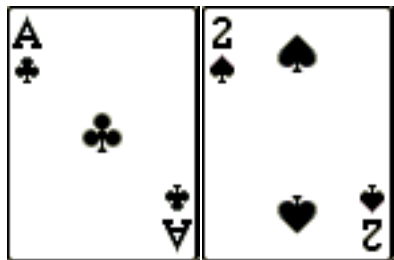


-6 sb

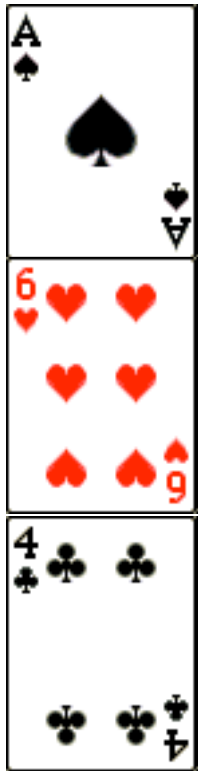
bet  
fold

-4 sb

# Removing More Luck: DIVAT



check  
bet  
raise  
call



bet  
call



bet  
fold

+3 sb

+4 sb

-8 sb

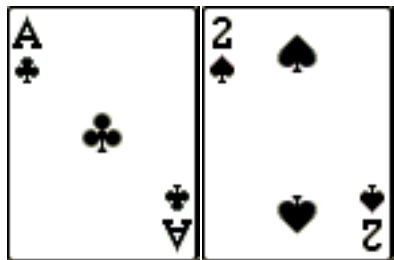
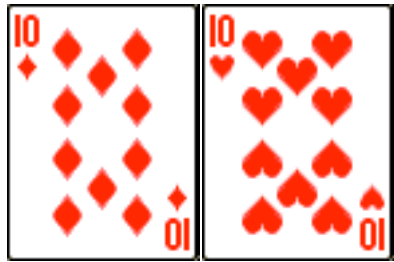
-7 sb

-6 sb

-4 sb

LUCK

# Removing More Luck: DIVAT

|                                                                                    |                               |                                                                                      |             |                                                                                      |             |
|------------------------------------------------------------------------------------|-------------------------------|--------------------------------------------------------------------------------------|-------------|--------------------------------------------------------------------------------------|-------------|
|   | check<br>bet<br>raise<br>call |  | bet<br>call |  | bet<br>fold |
|  |                               |                                                                                      |             |                                                                                      |             |
| <div>+3 sb      +4 sb</div>                                                        |                               | <div>-8 sb    -7 sb</div>                                                            |             | <div>-6 sb    -4 sb</div>                                                            |             |

SKILL

# Evaluating Poker Players

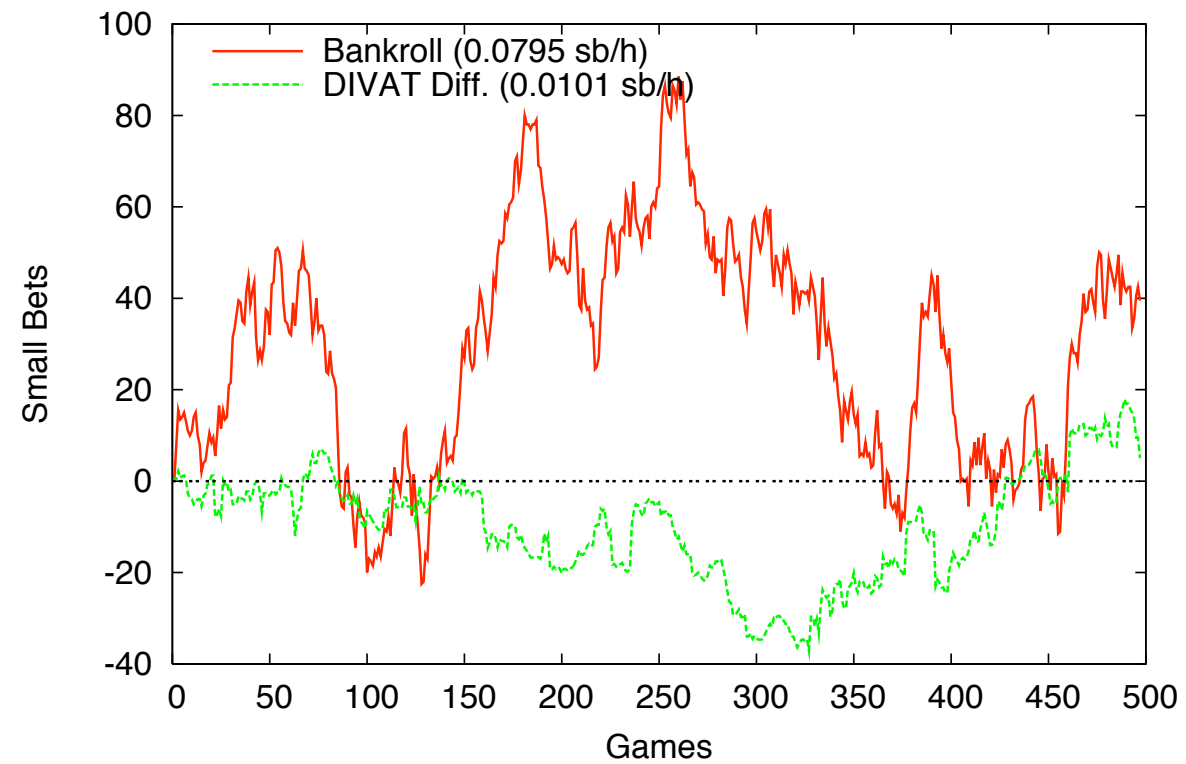
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- Money is a terrible estimator!
  - ~20K hands needed for statistical significance
- Duplicate helps
  - ~2000 pairs of hands
- DIVAT+Duplicate is almost enough
  - ~1200 pairs of hands

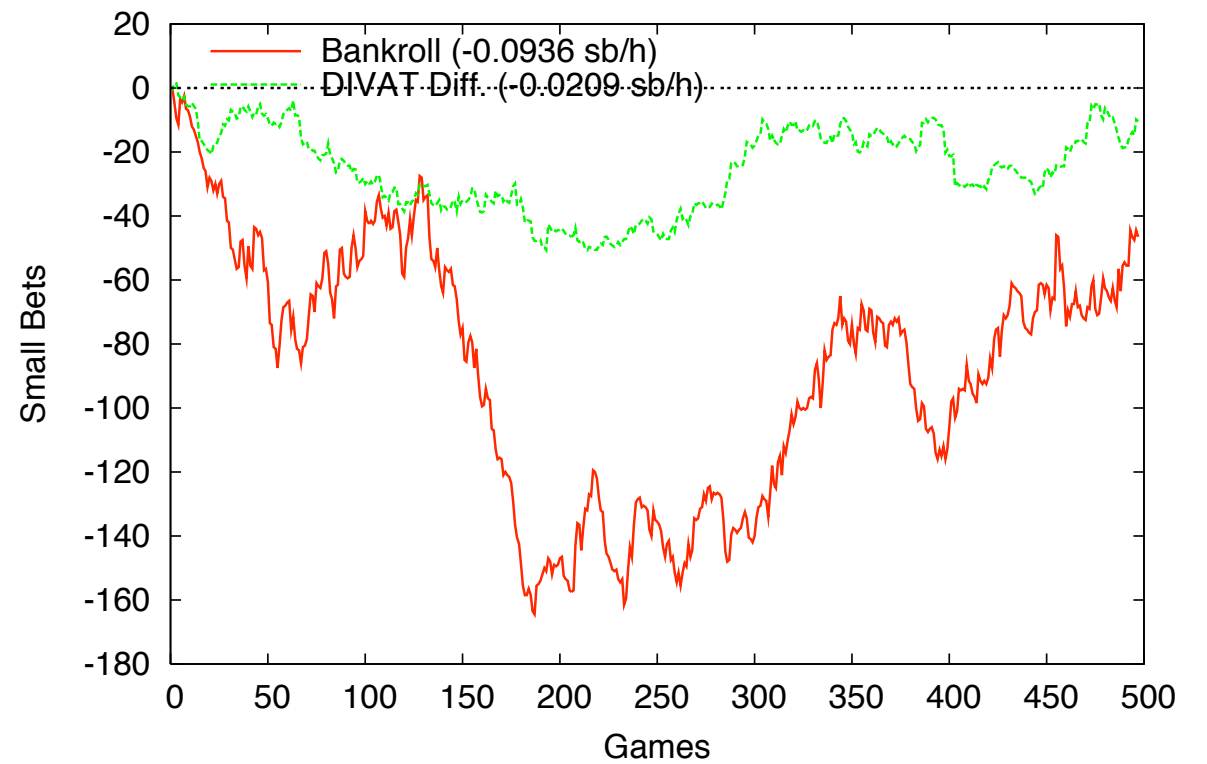
# The Results

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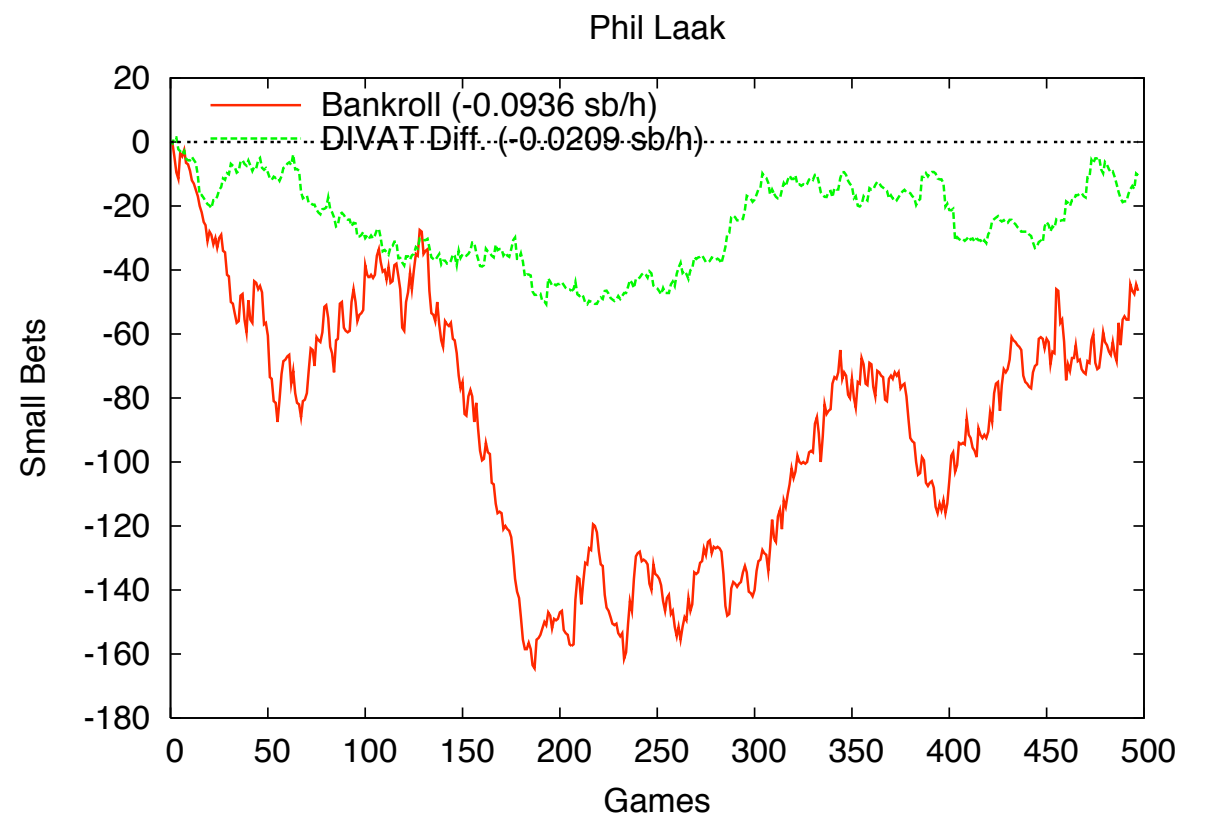
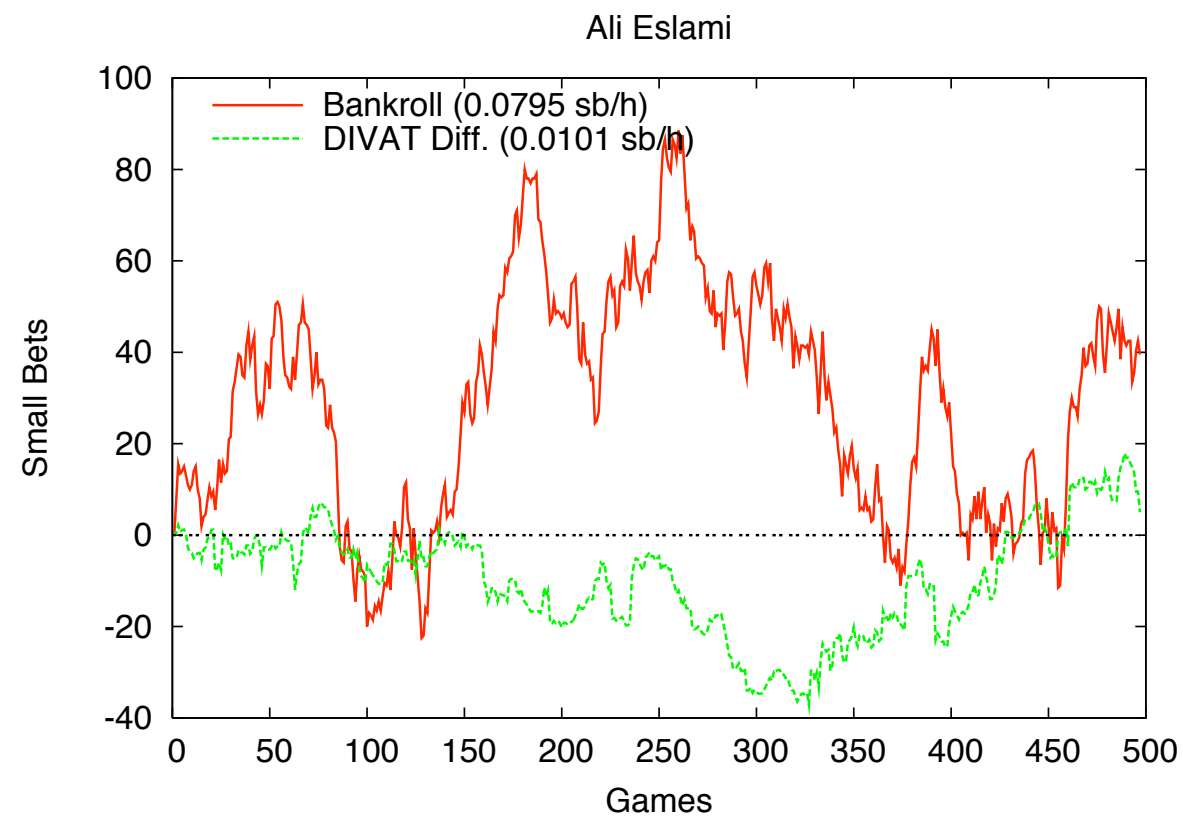
Ali Eslami



Phil Laak

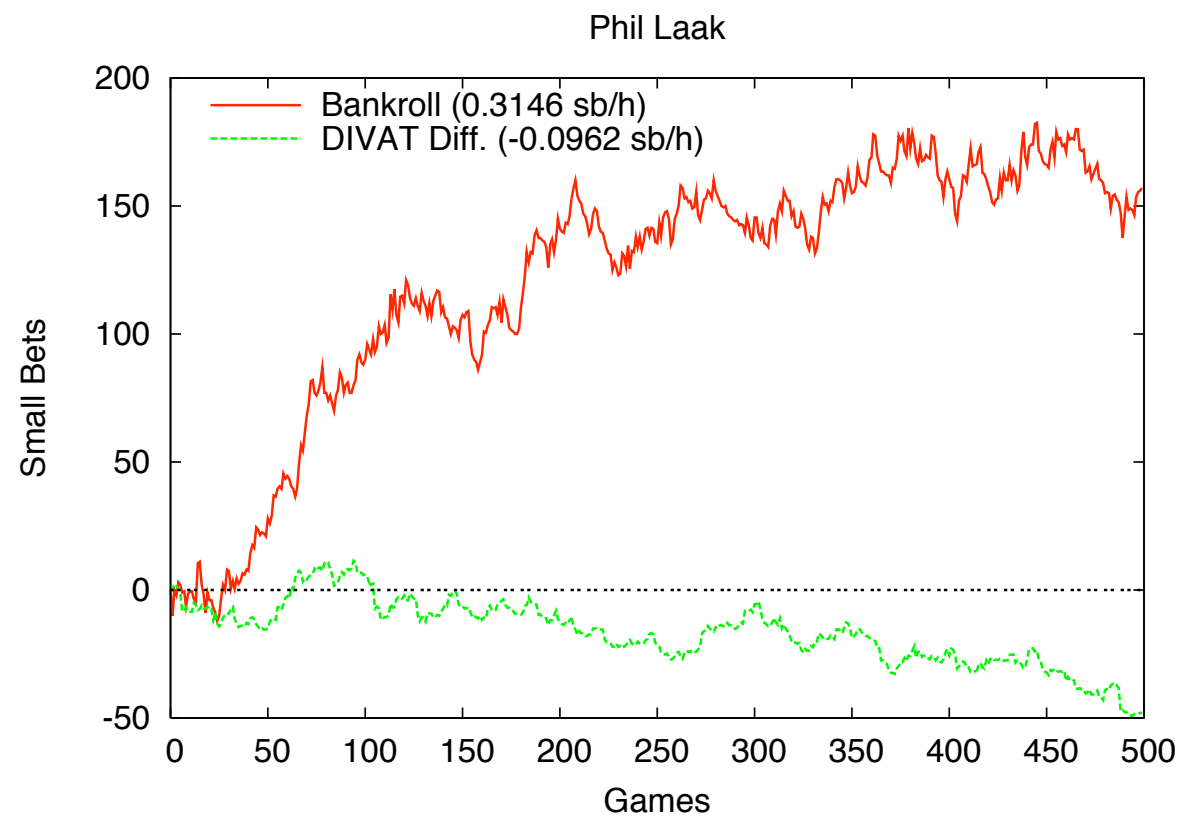
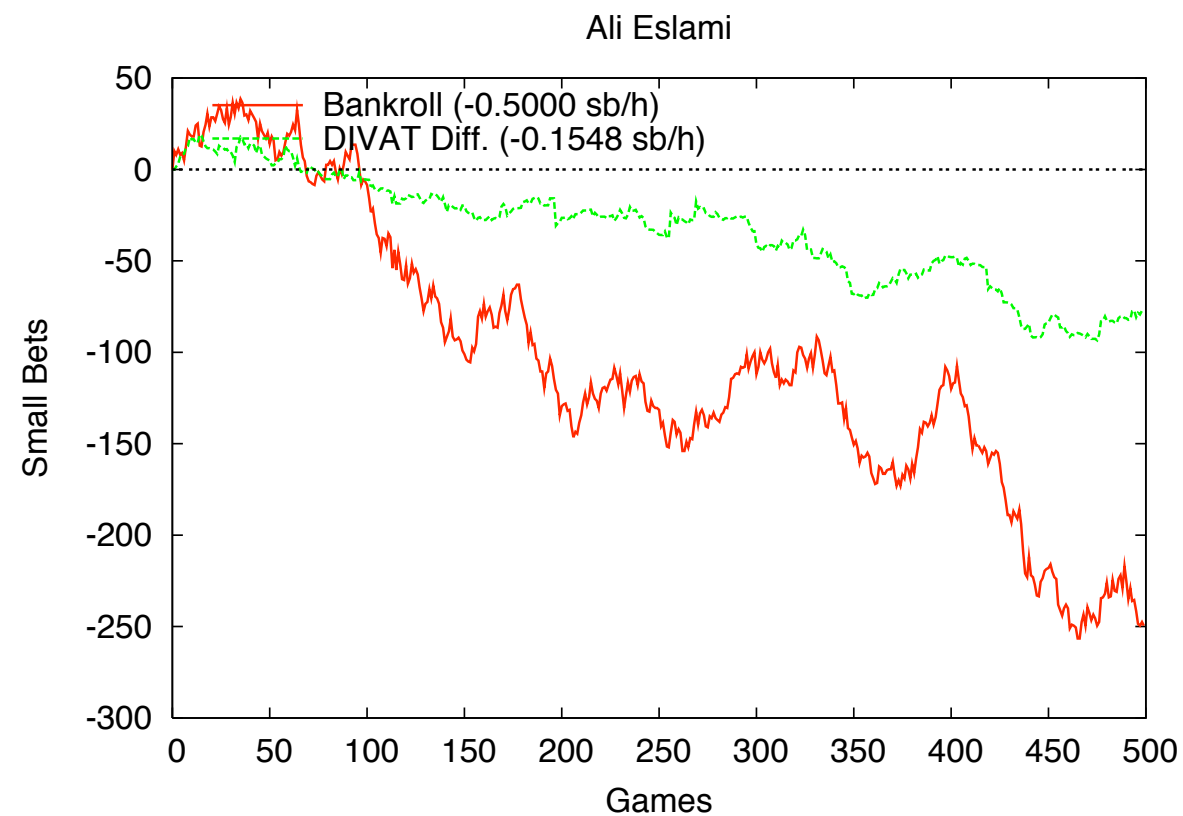


# The Results



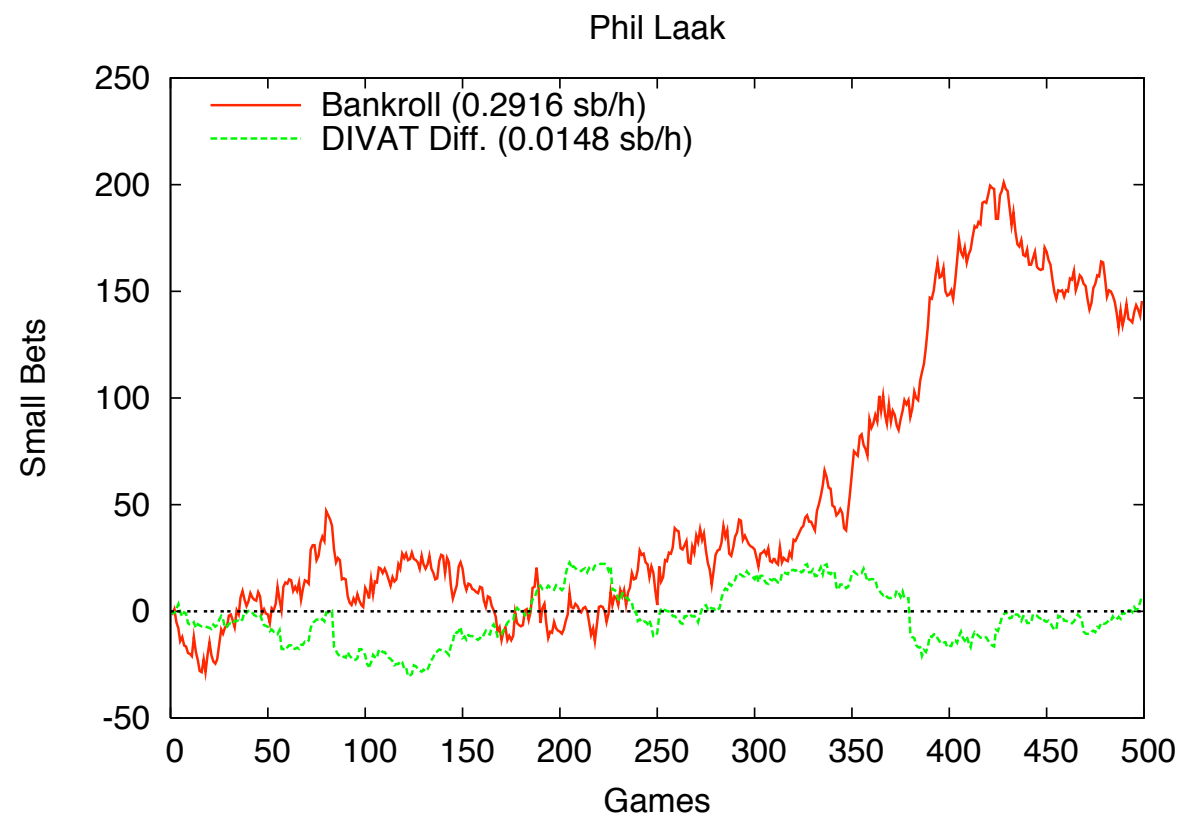
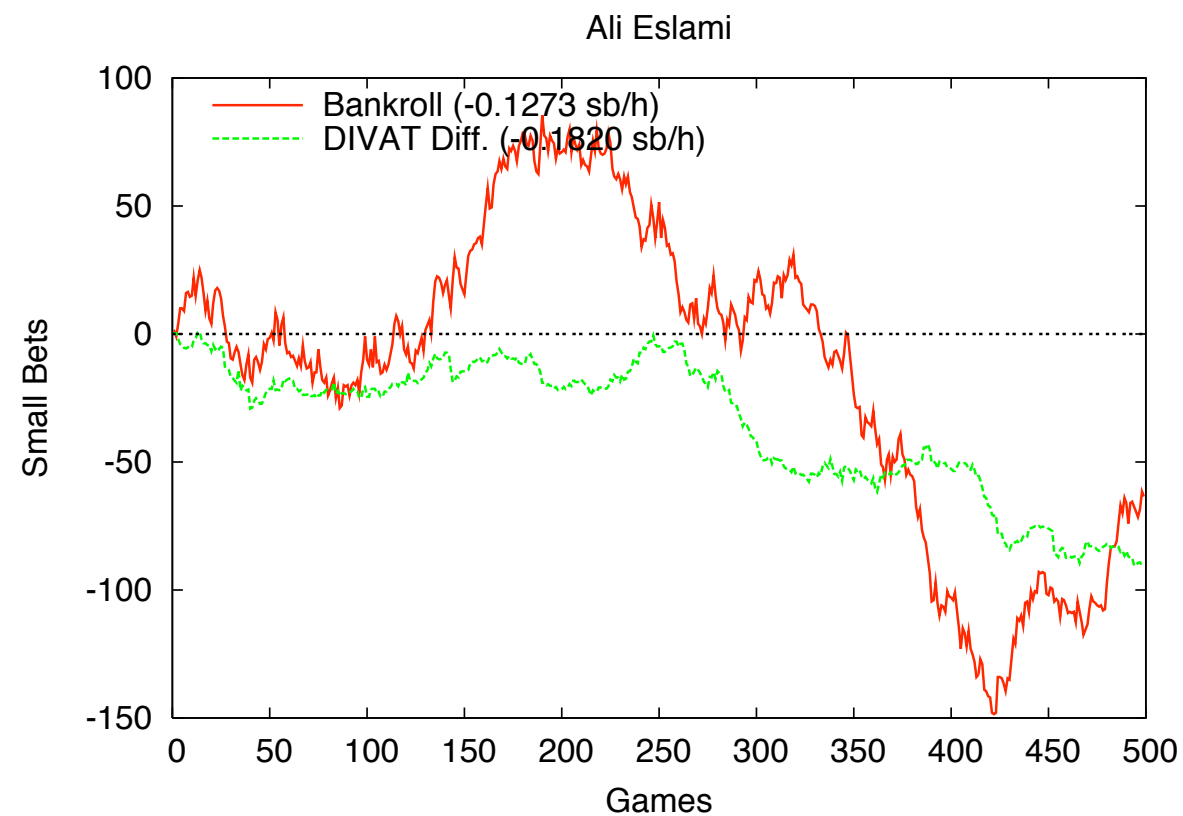
- Match 1: Polaris “up” by 6 bets

# The Results



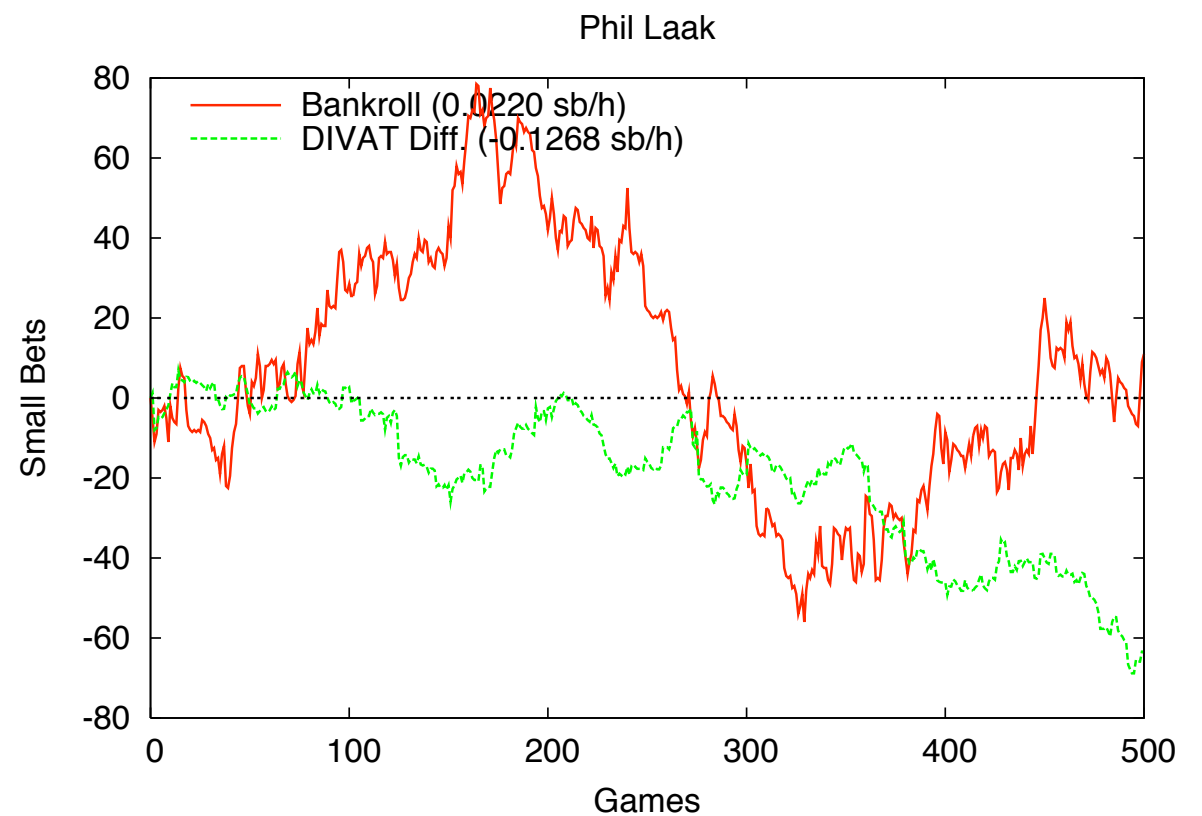
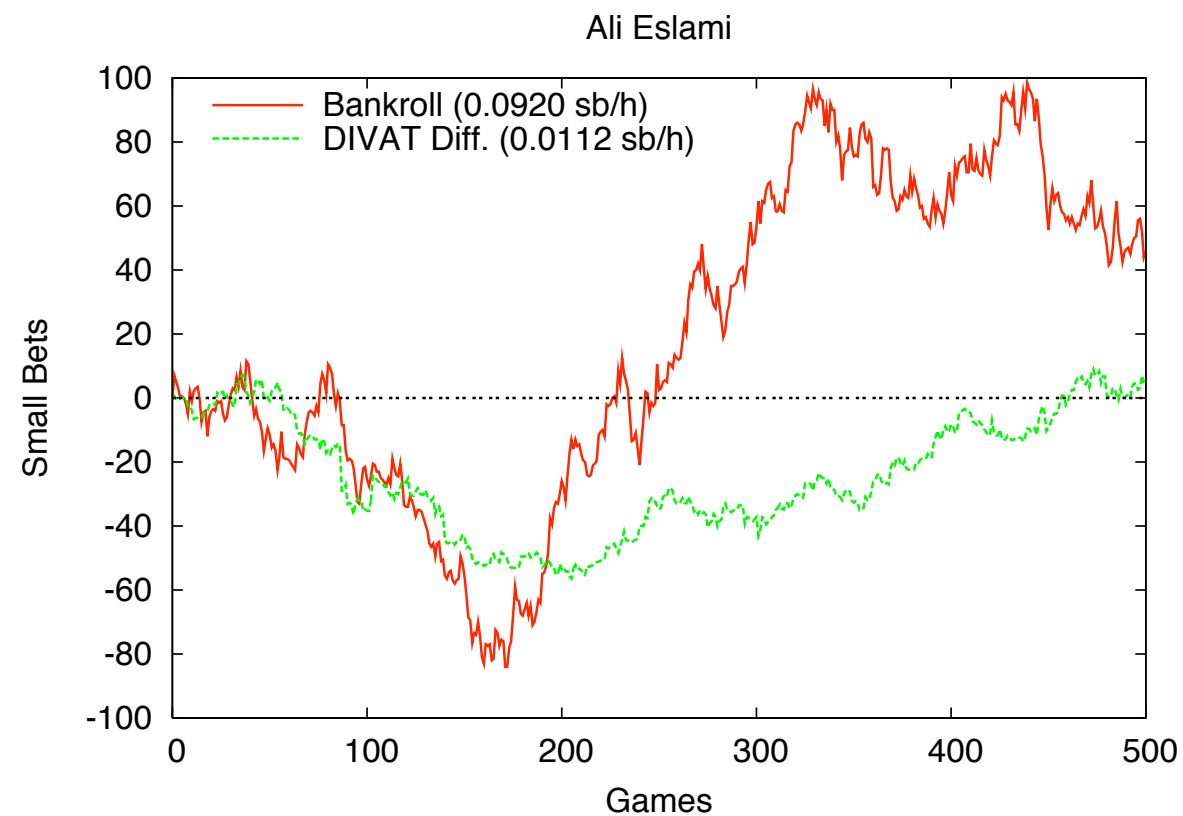
- Match 1: Polaris “up” by 6 bets
- Match 2: Polaris “up” by 126 bets — p-value of 0.0018

# The Results



- Match 1: Polaris “up” by 6 bets
- Match 2: Polaris “up” by 126 bets — p-value of 0.0018
- Match 3: Polaris “up” by 84 bets — p-value of 0.07

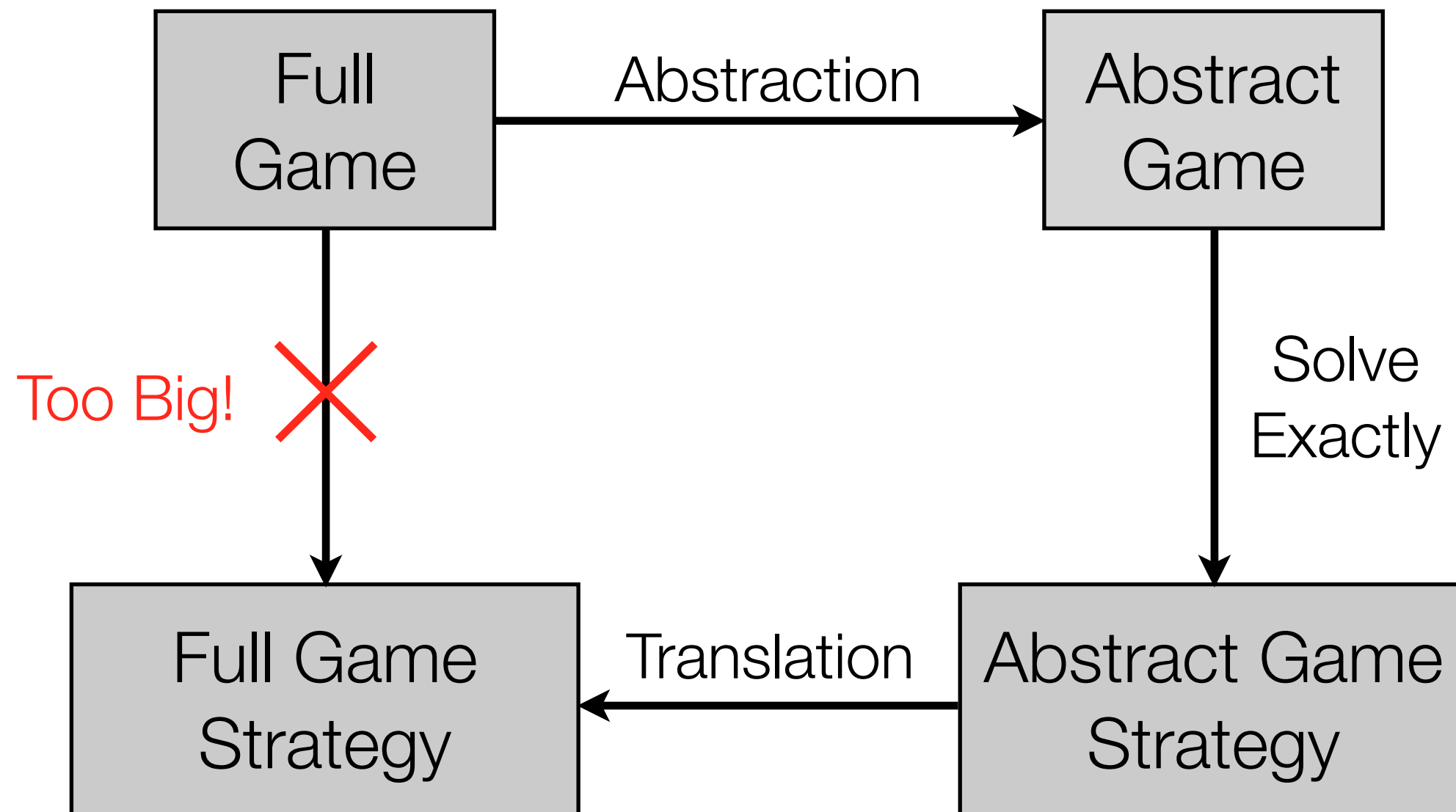
# The Results



- Match 1: Polaris “up” by 6 bets
- Match 2: Polaris “up” by 126 bets — p-value of 0.0018
- Match 3: Polaris “up” by 84 bets — p-value of 0.07
- Match 4: Polaris “up” by 58 bets — p-value of 0.14

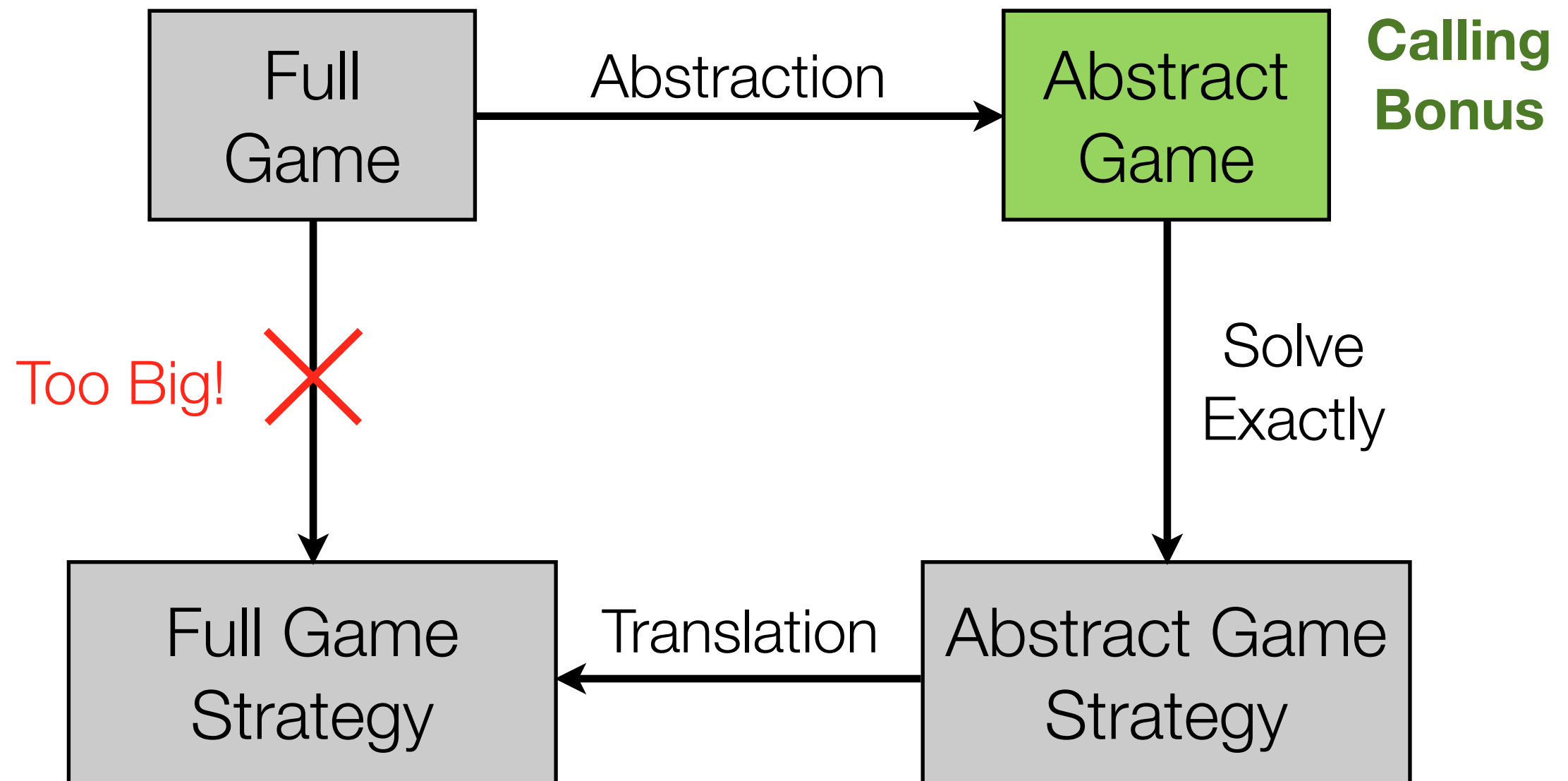
# One More Year of Research... In Two More Slides

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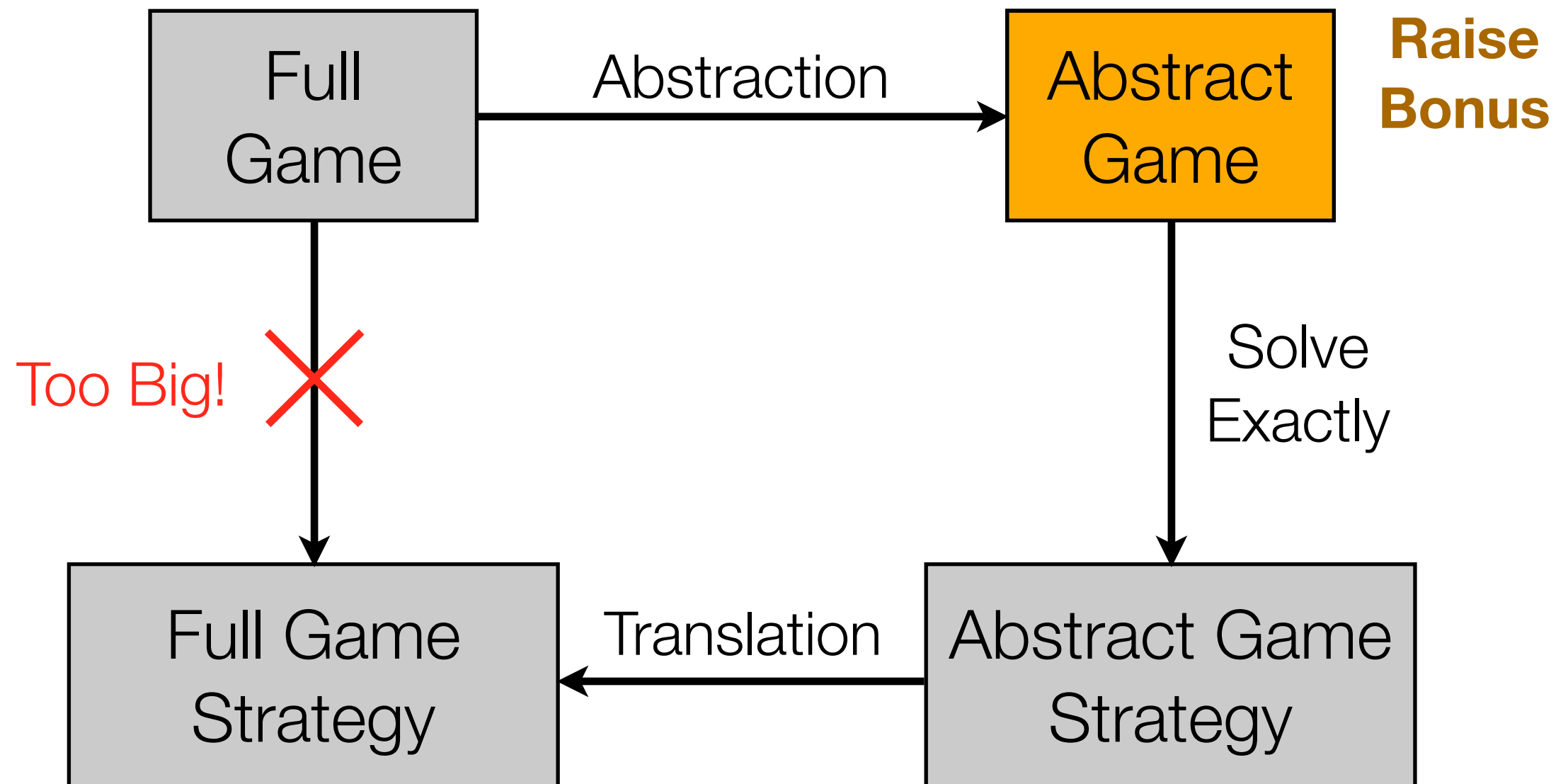
# One More Year of Research... In Two More Slides

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# One More Year of Research... In Two More Slides

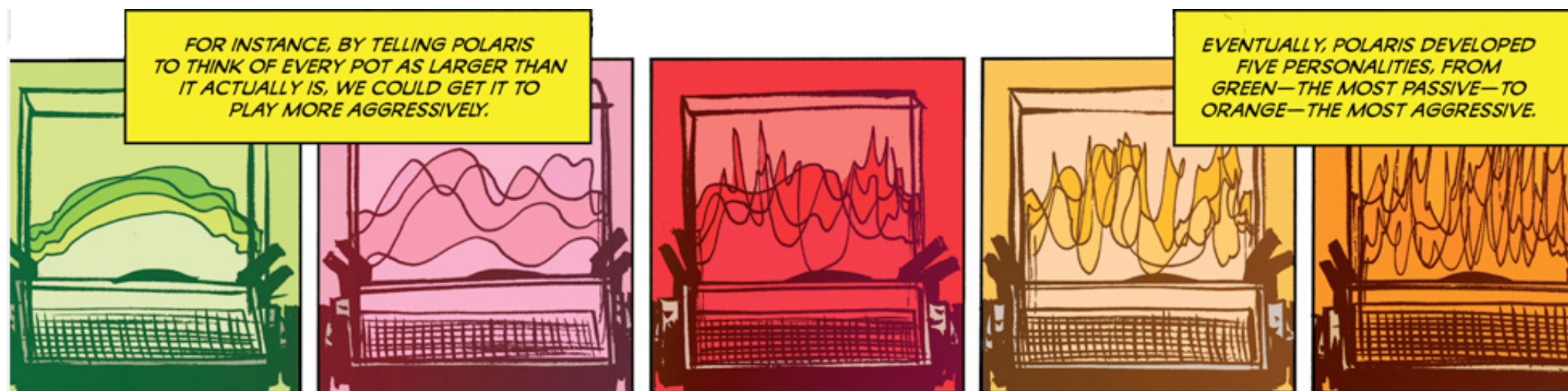
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# Polaris 2.0

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- 5 personalities: varying degrees of aggression



- Each personality is a solution to a game with  $10^{12}$  states
- Adapts online to the personality most effective against its opponent's style

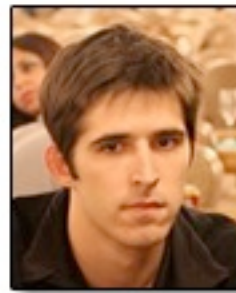
# The Second Man-Machine Poker Championship

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- Las Vegas, July 2008



**GRUDZIEN**



**HAWRILENKO**



**PALANSKY**



**PARADIS**



**HENDON**

**VS**

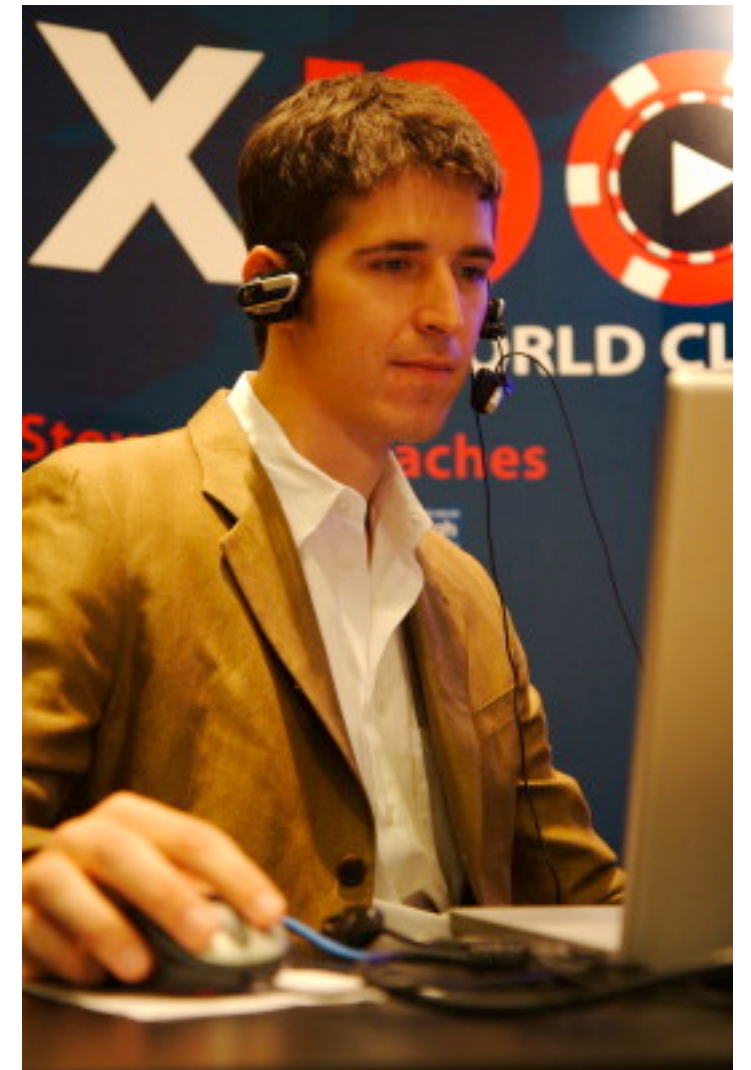


**POLARIS**

# The Competitors

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- 7 Professionals: Hawrilenko, Grudzien, Palanski, Hendon, Newhouse, McRoberts, Acosta
- Coaches with Stoxpoker.com
- Matt “Hoss\_TBF” Hawrilenko
  - World’s best current heads-up, limit player
  - Plays at \$1K/\$2K games online



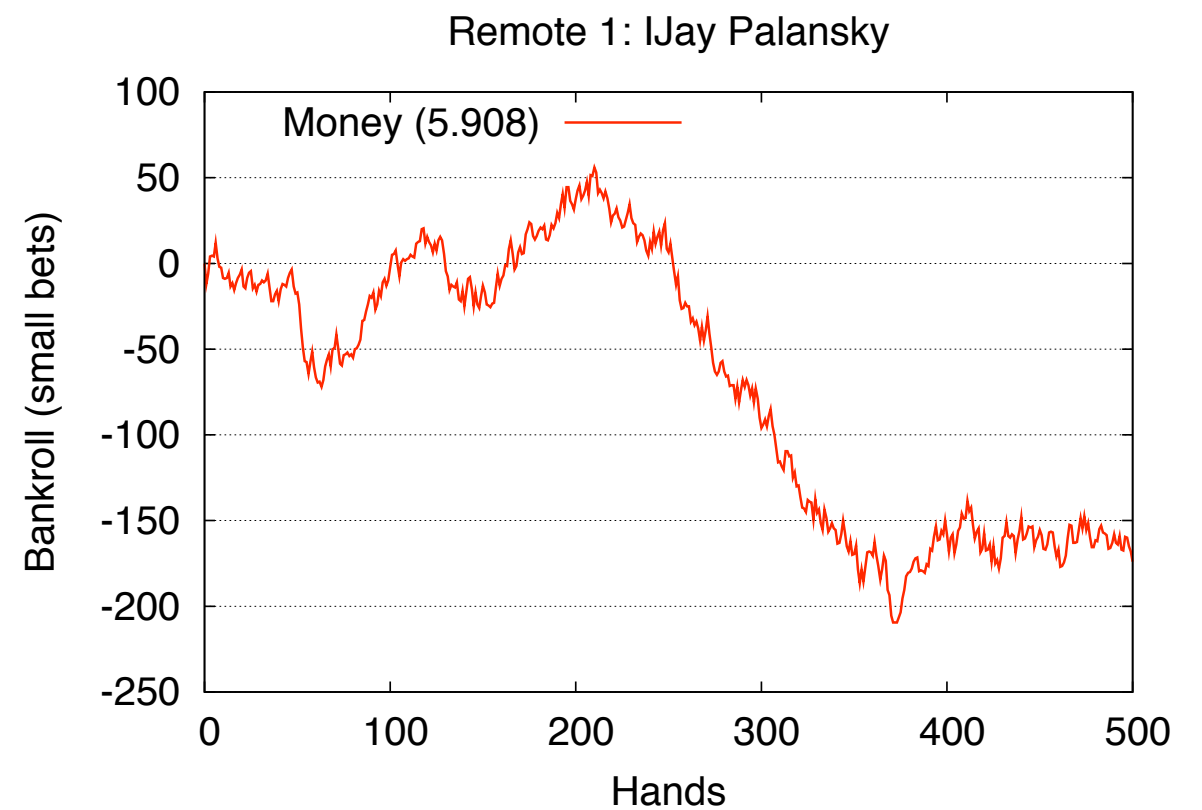
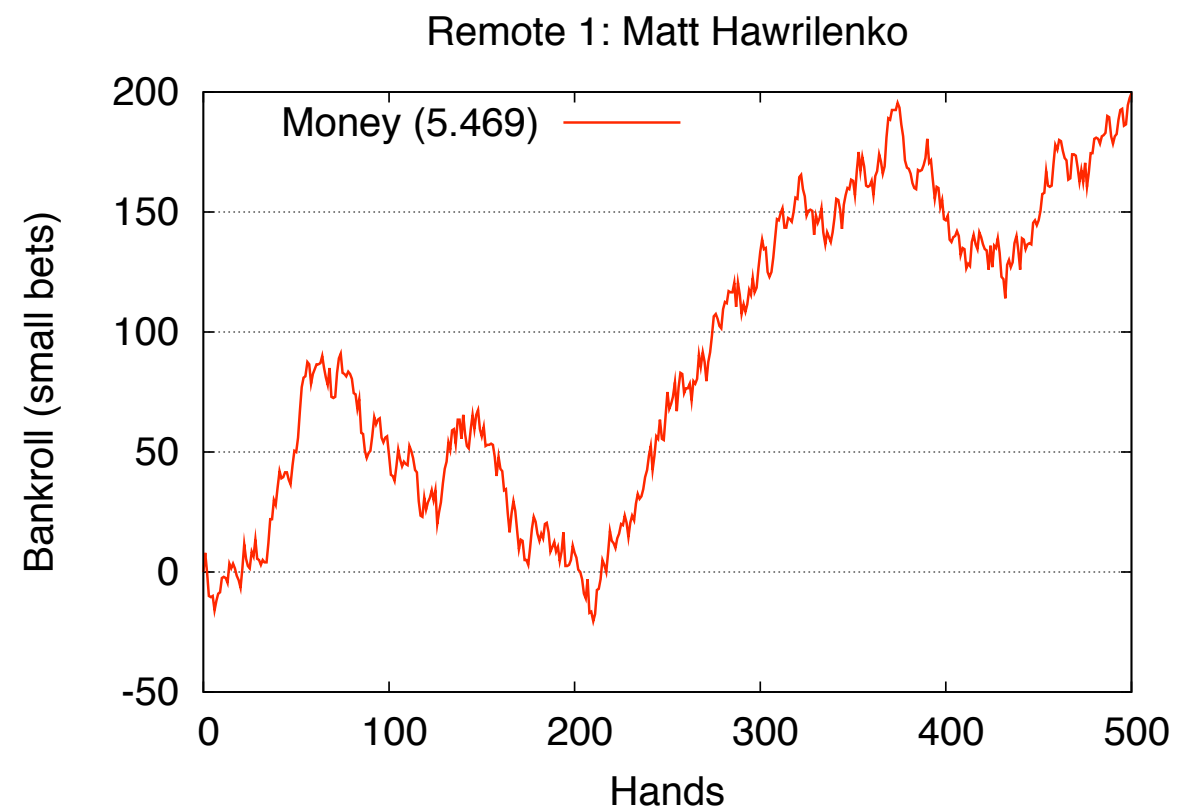
# The Rules

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- 500 hand duplicate matches
- 2 remote, 4 live (1 each day)
- Must win by \$25K (\$1K/\$2K Limits) to win the match

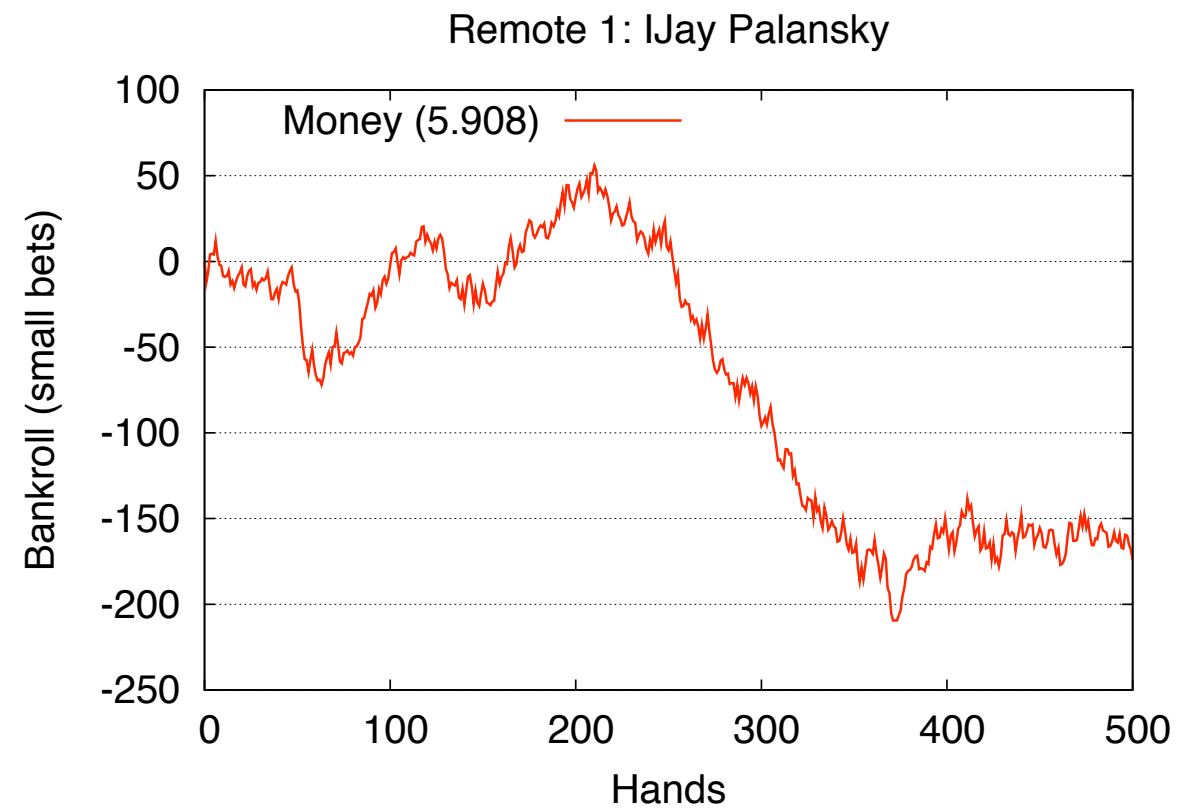
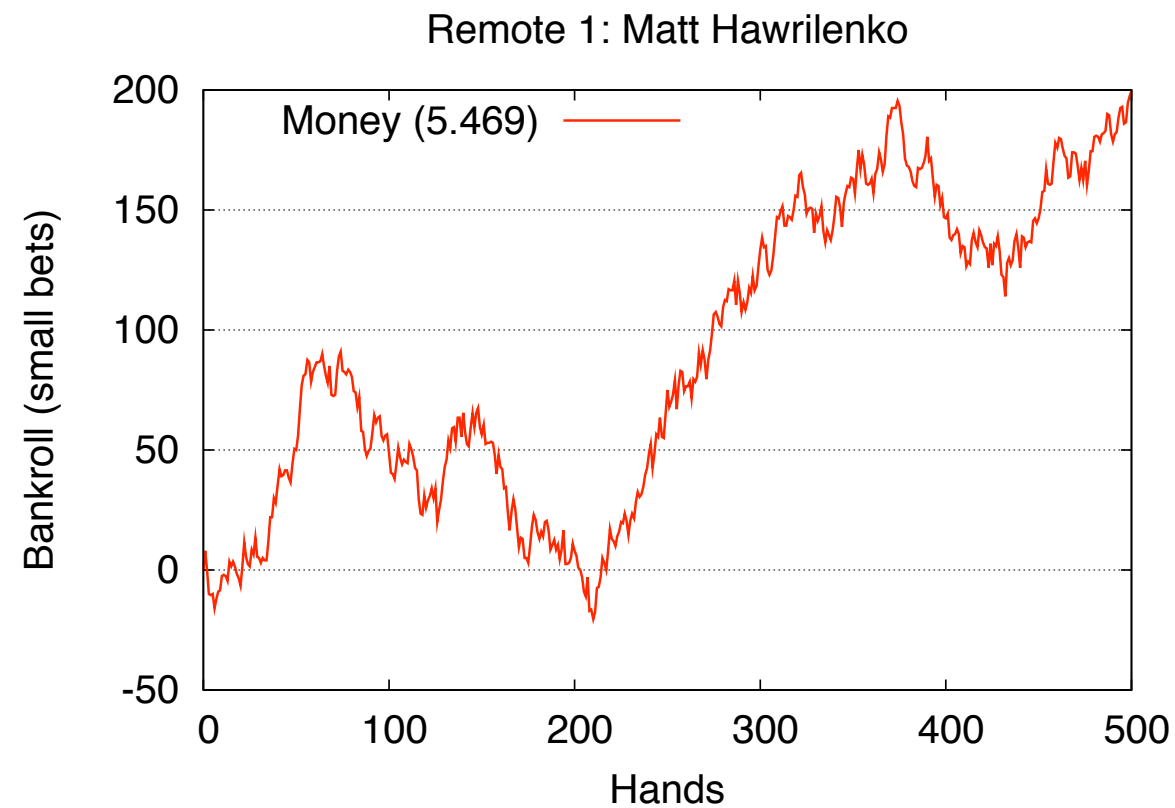
# Remote Match 1: Hoss-IJay

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# Remote Match 1: Hoss-IJay

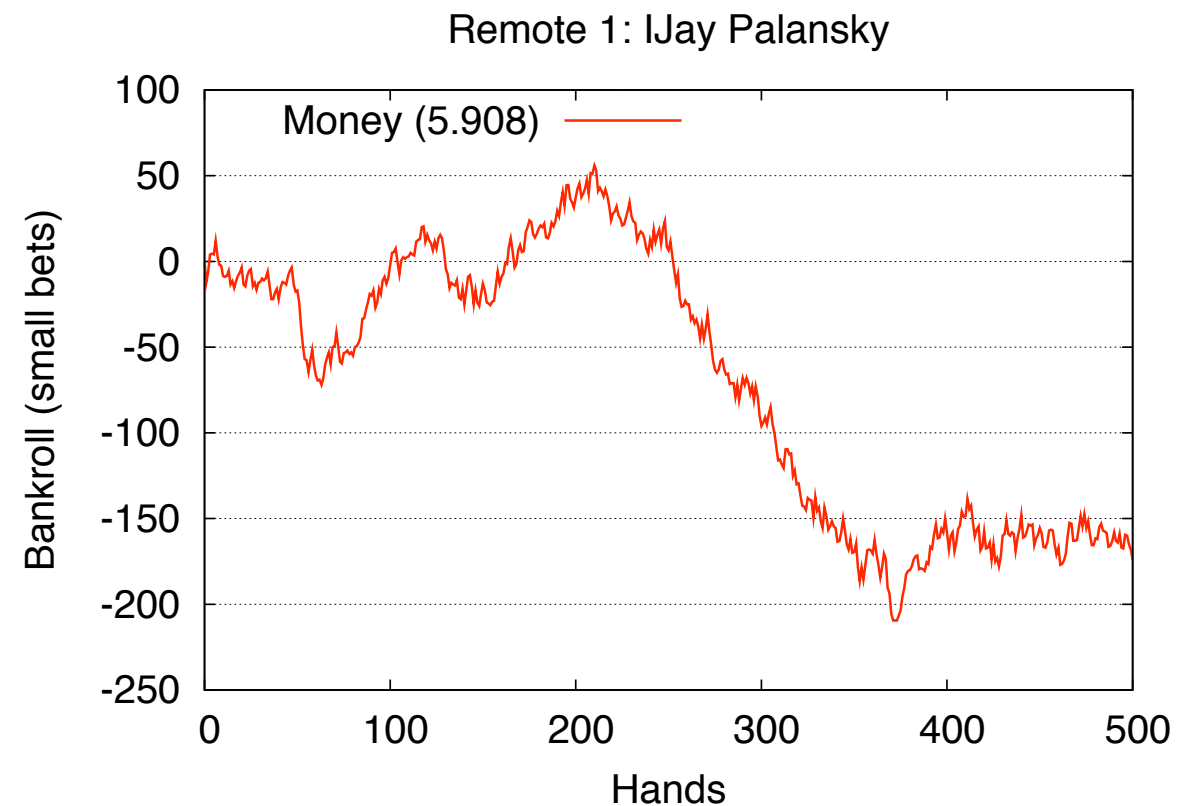
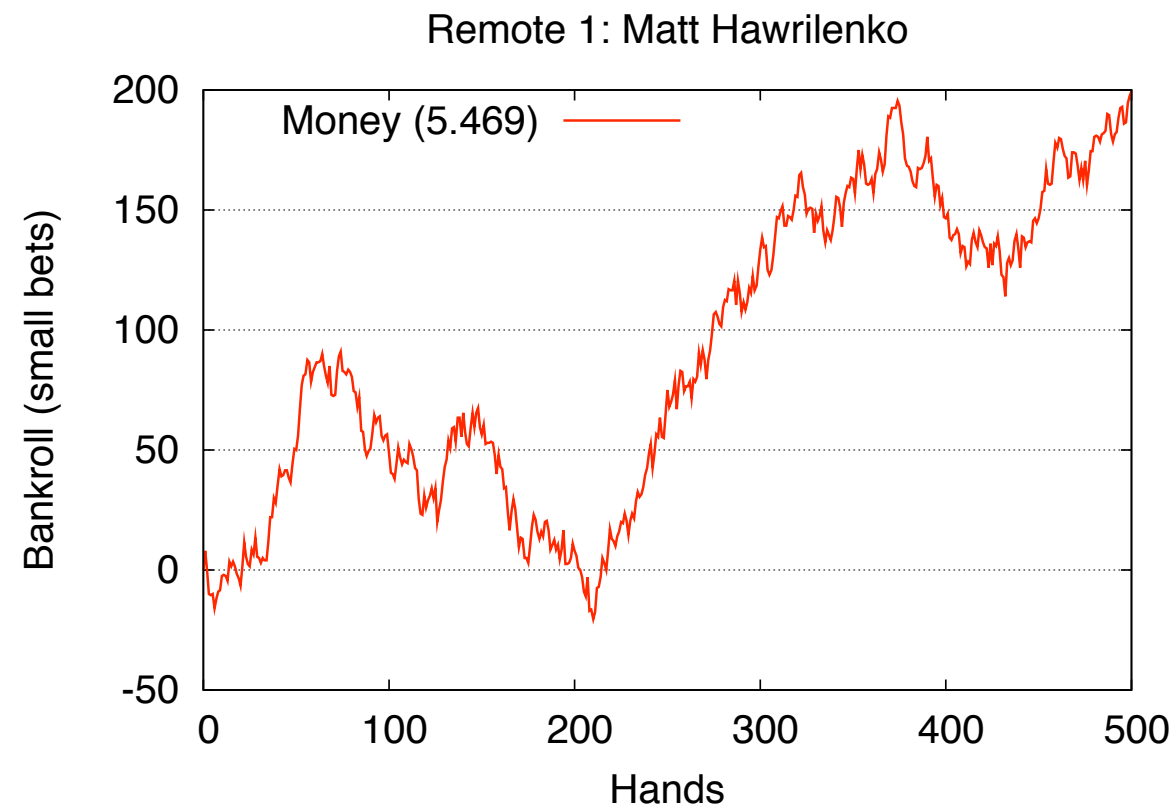
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- Humans up by 25.5 bets — Polaris loses!

# Remote Match 1: Hoss-IJay

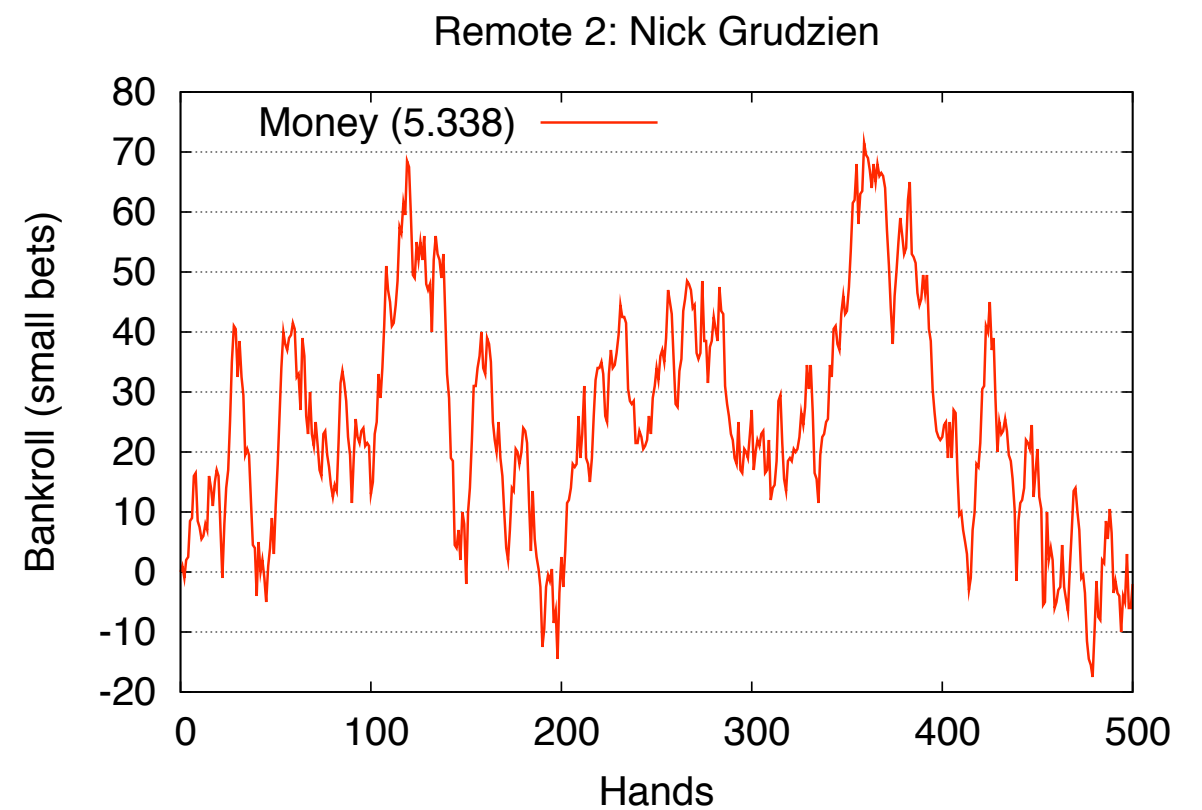
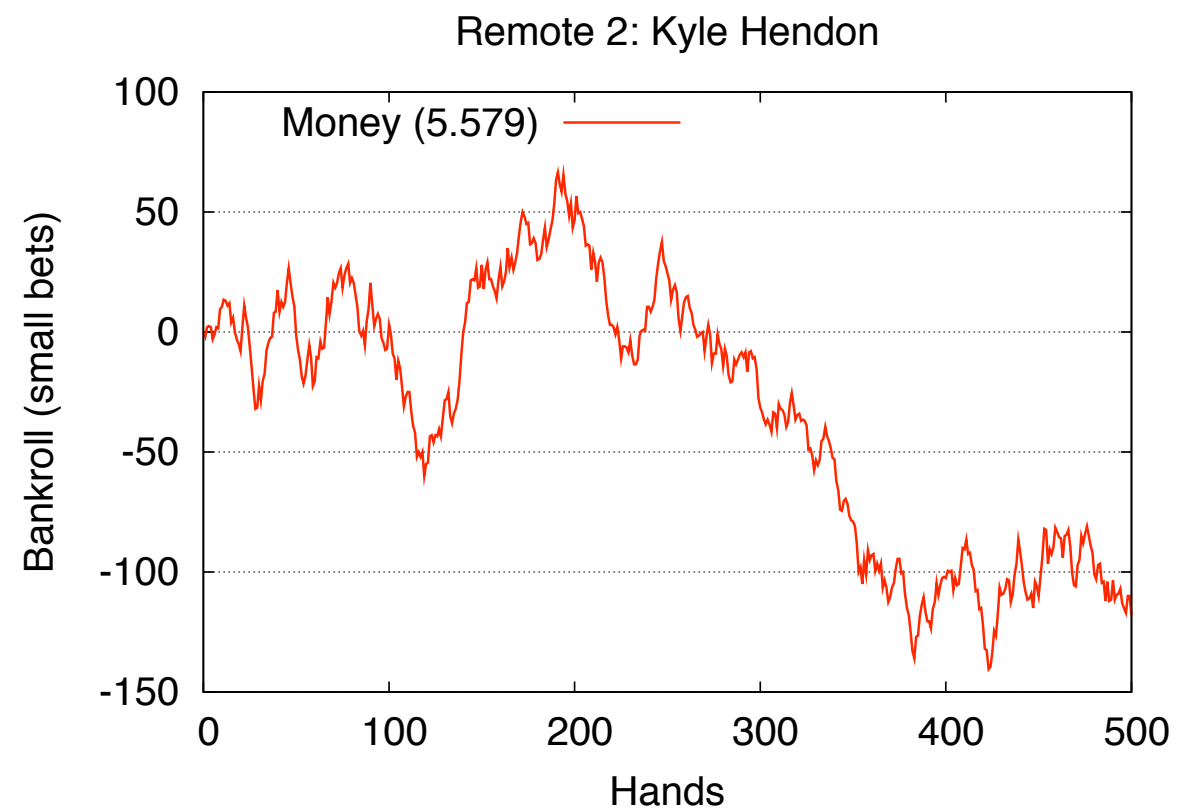
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- Humans up by 25.5 bets — Polaris loses!
- The smallest possible margin of victory!

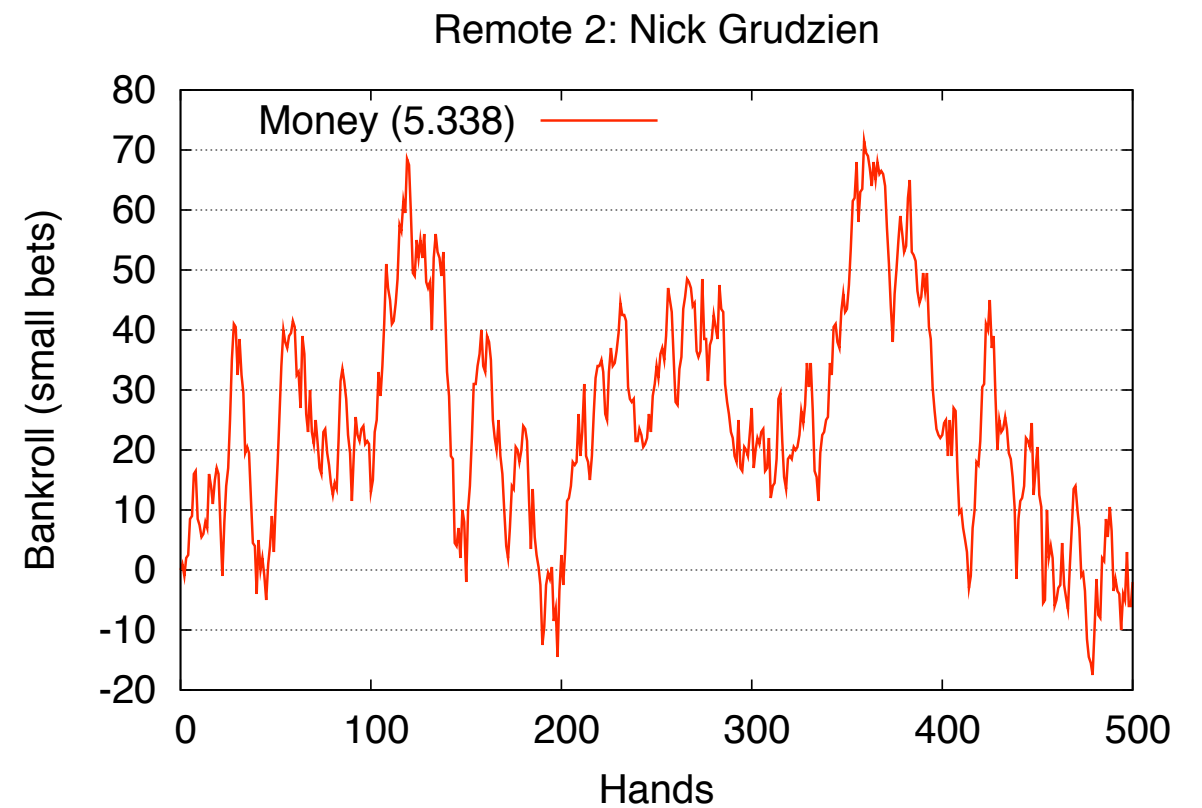
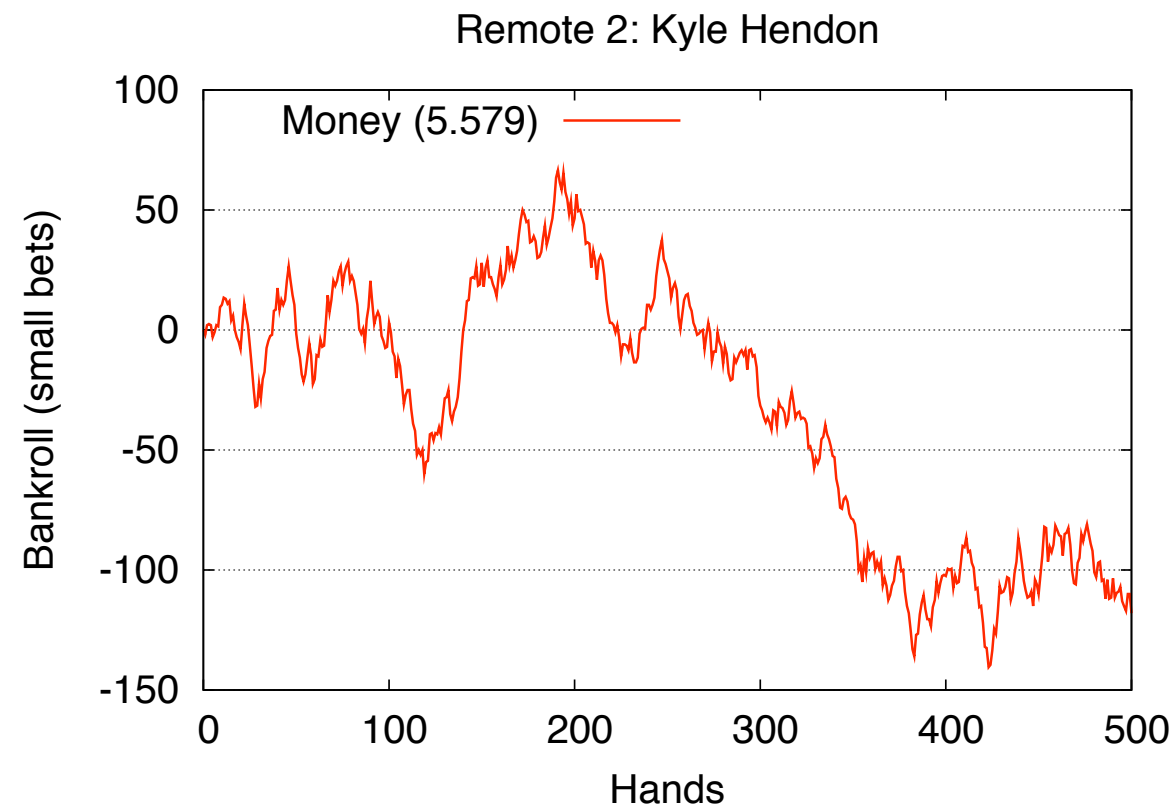
# Remote Match 2: Kyle-Nick

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# Remote Match 2: Kyle-Nick

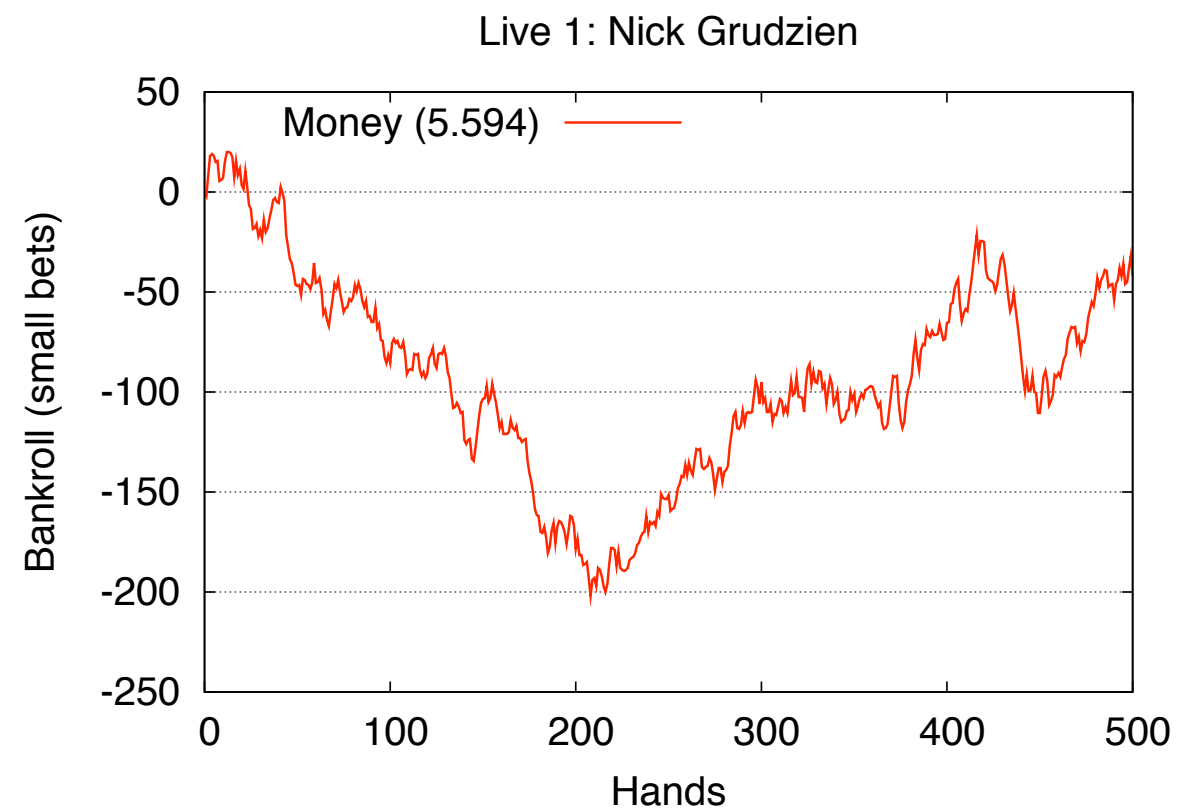
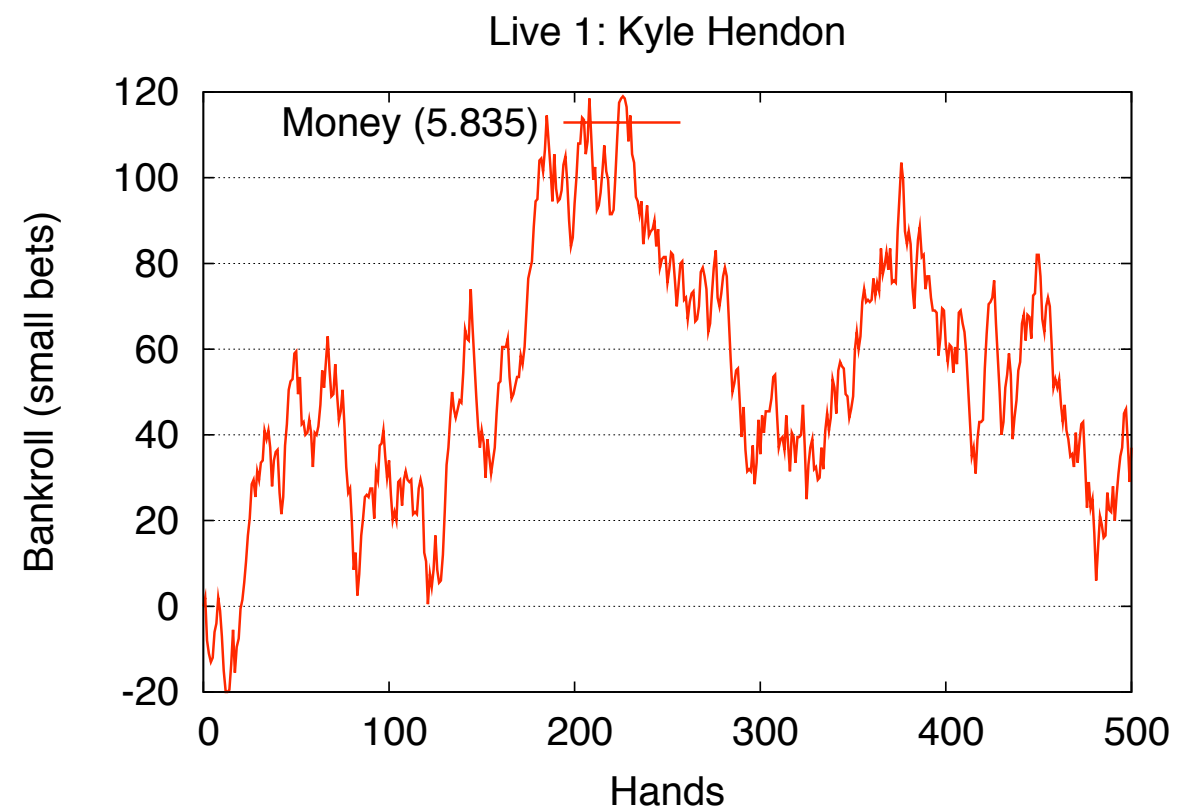
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- Polaris up by 120 bets — Polaris wins!

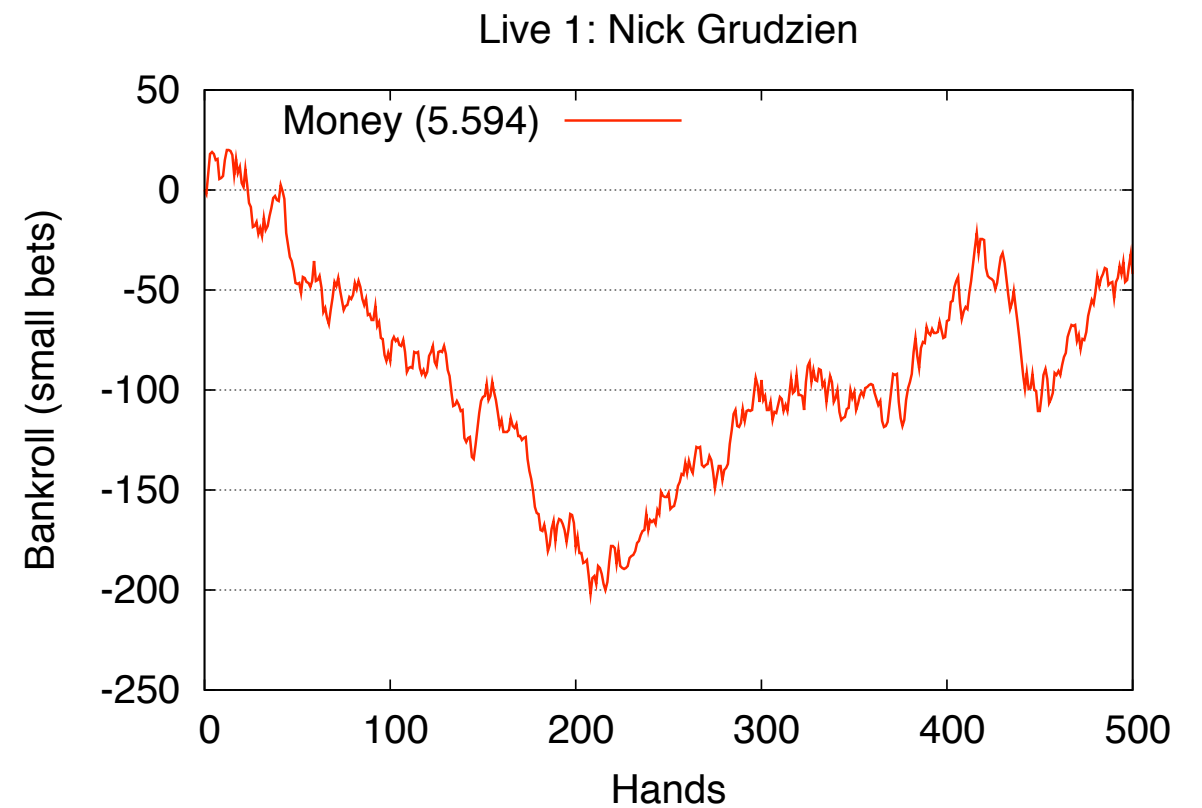
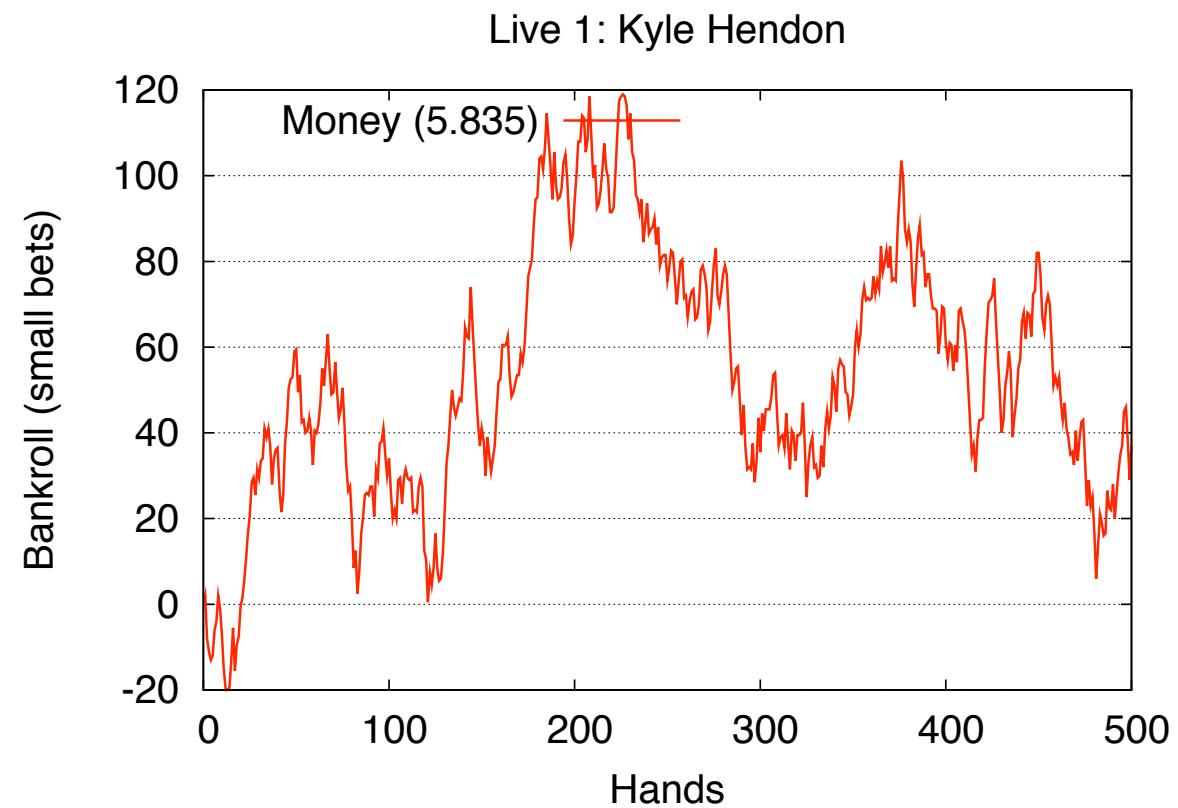
# Live Match 1: Kyle-Nick

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# Live Match 1: Kyle-Nick

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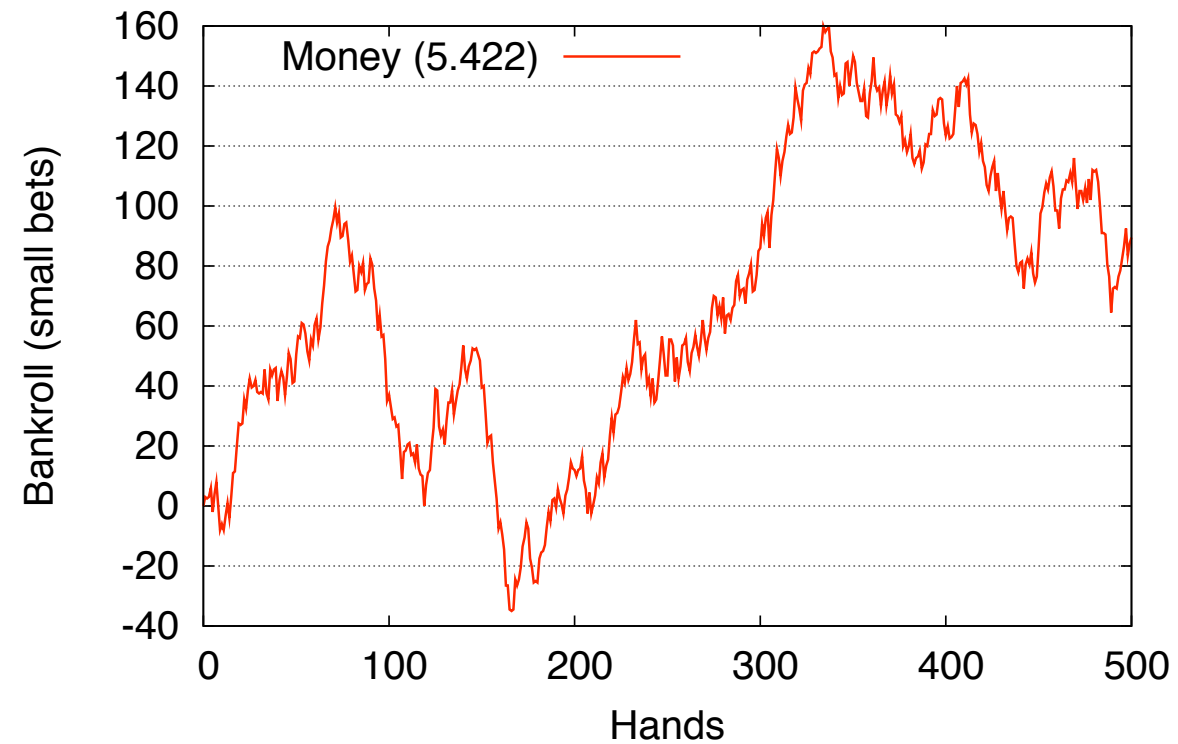


- Polaris up by 5 bets — Draw

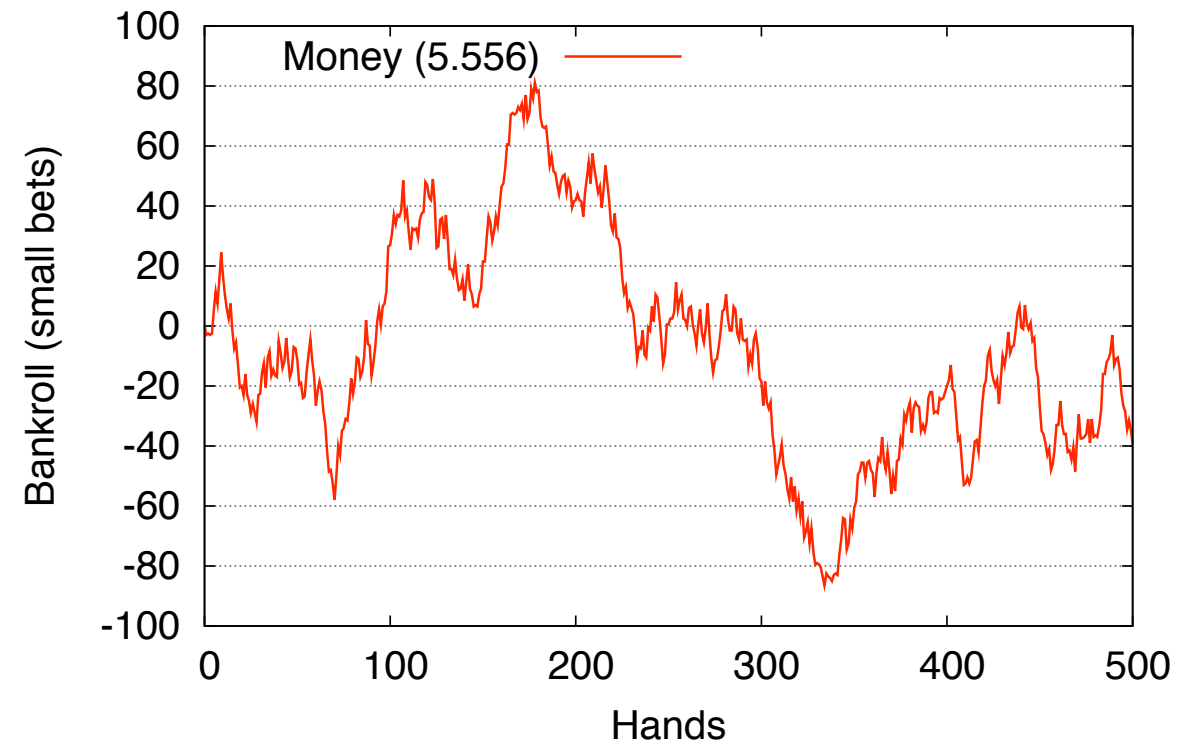
# Live Match 2: Rich-Victor

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Live 2: Rich McRoberts

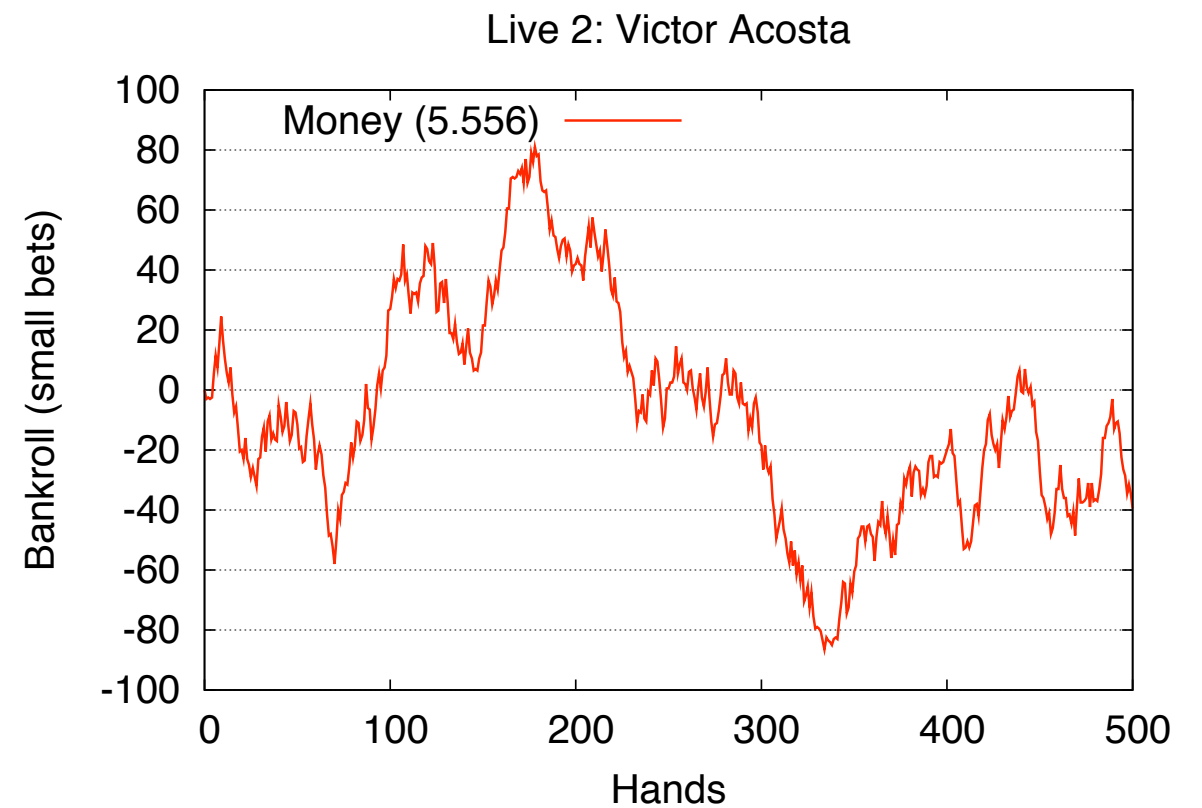
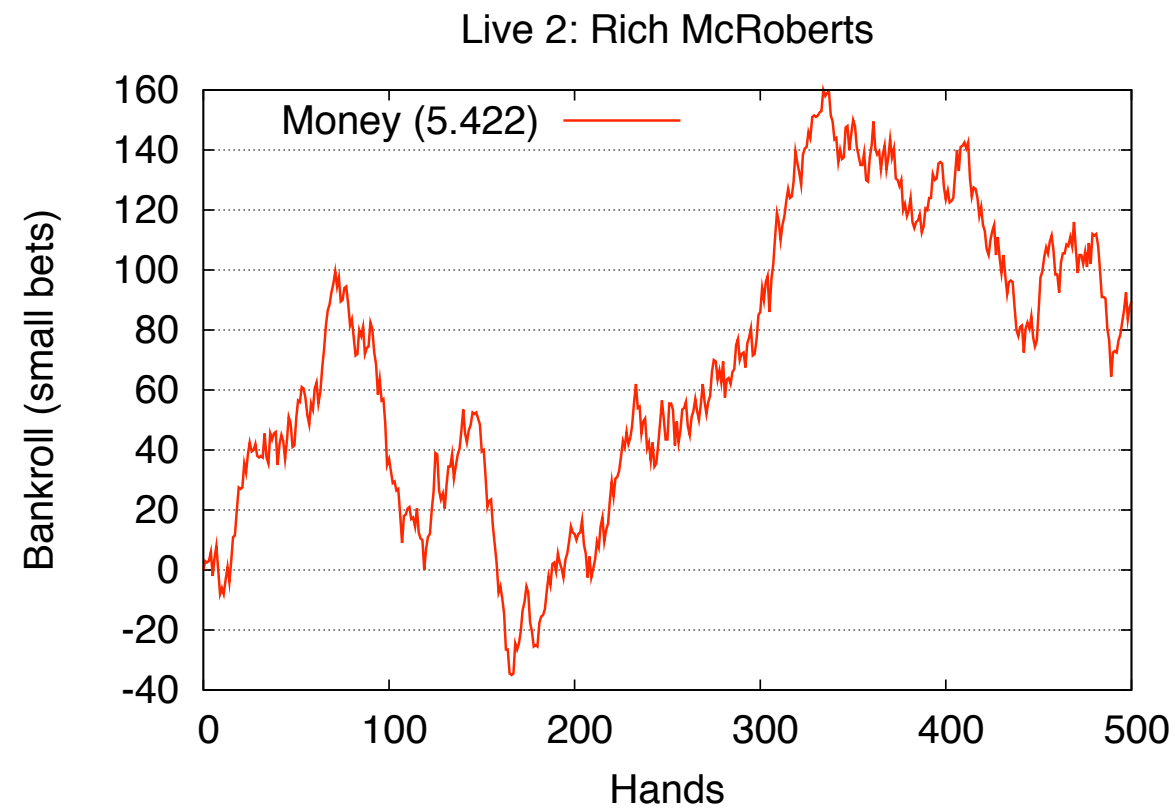


Live 2: Victor Acosta



# Live Match 2: Rich-Victor

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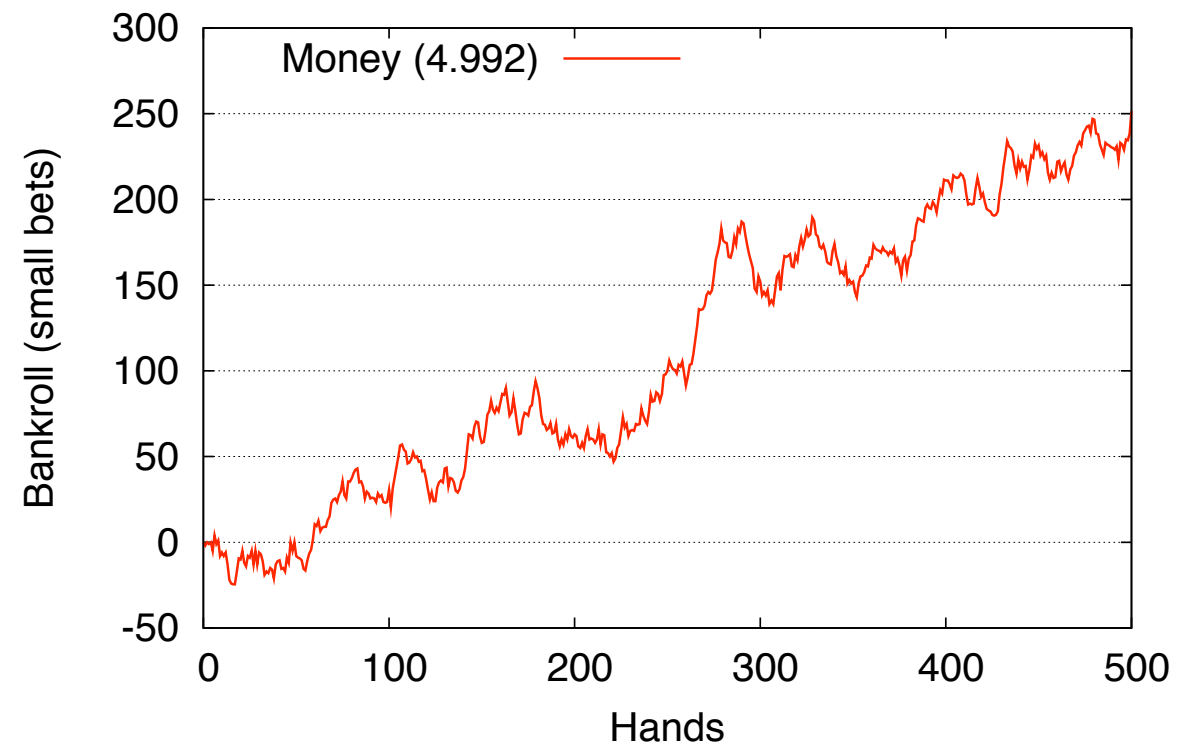


- Humans up by 50 bets — Polaris loses!

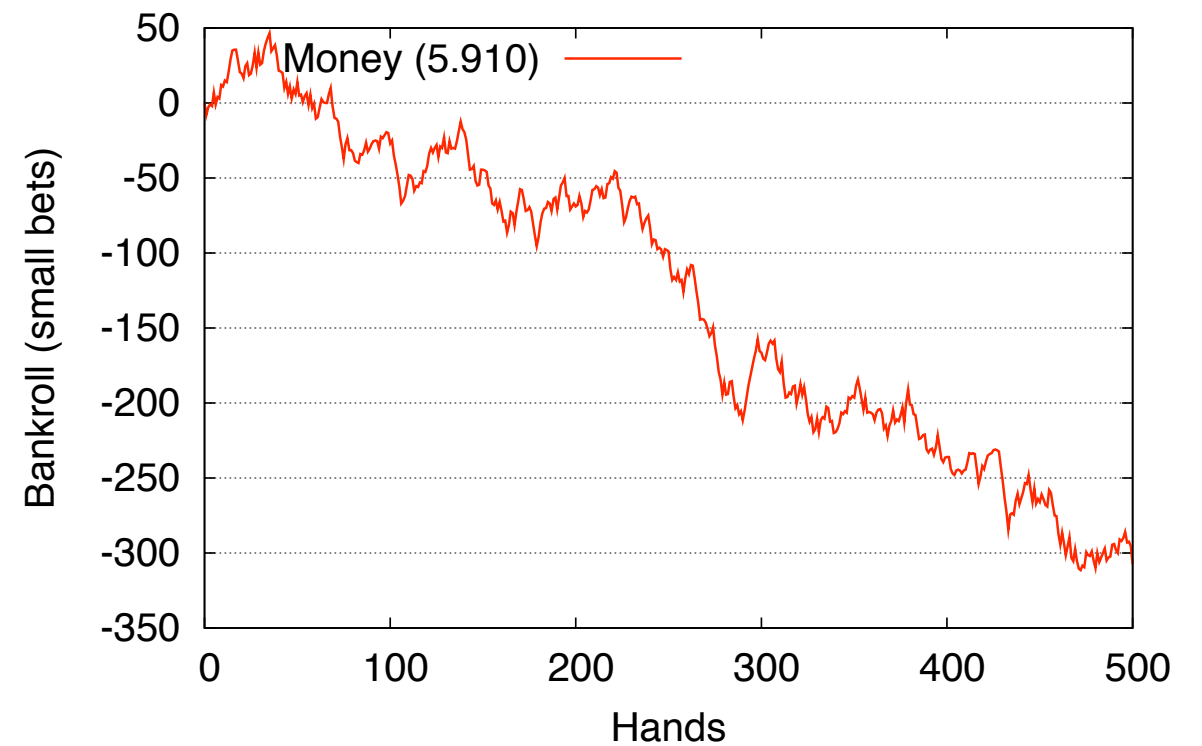
# Live Match 3: Mark-IJay

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Live 3: Mark Newhouse

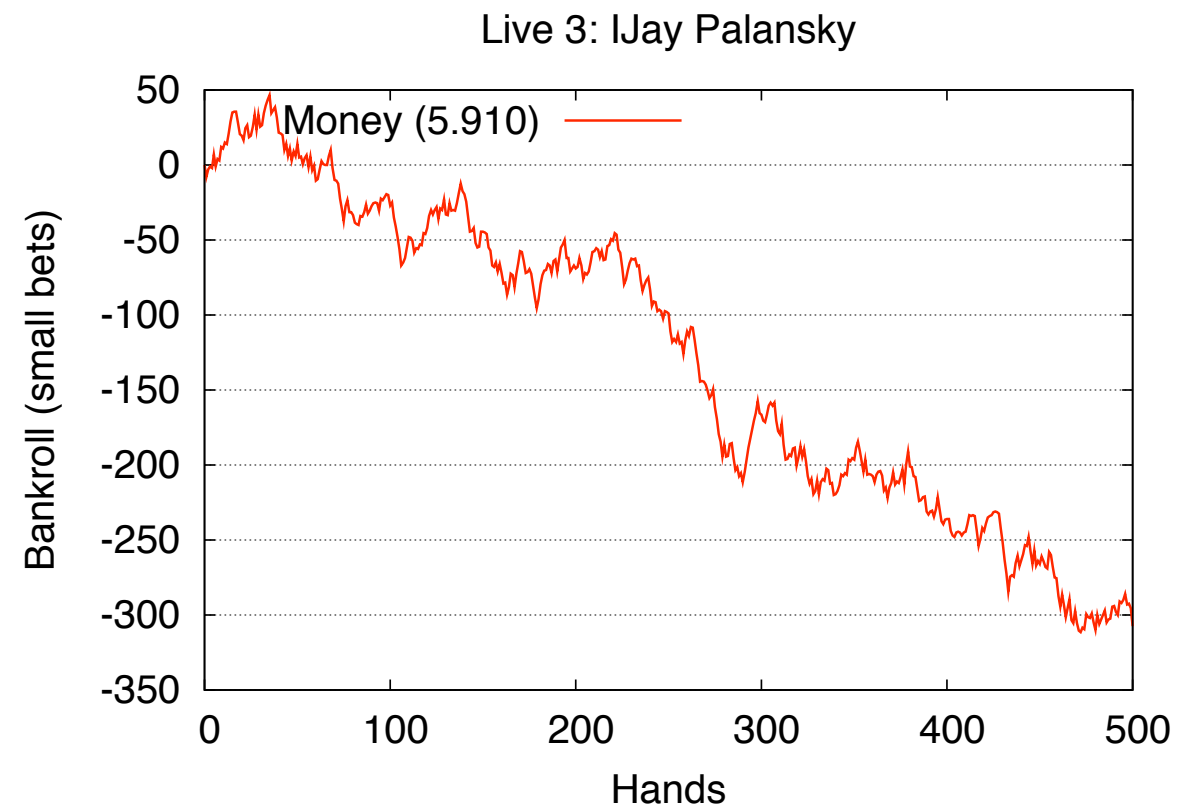
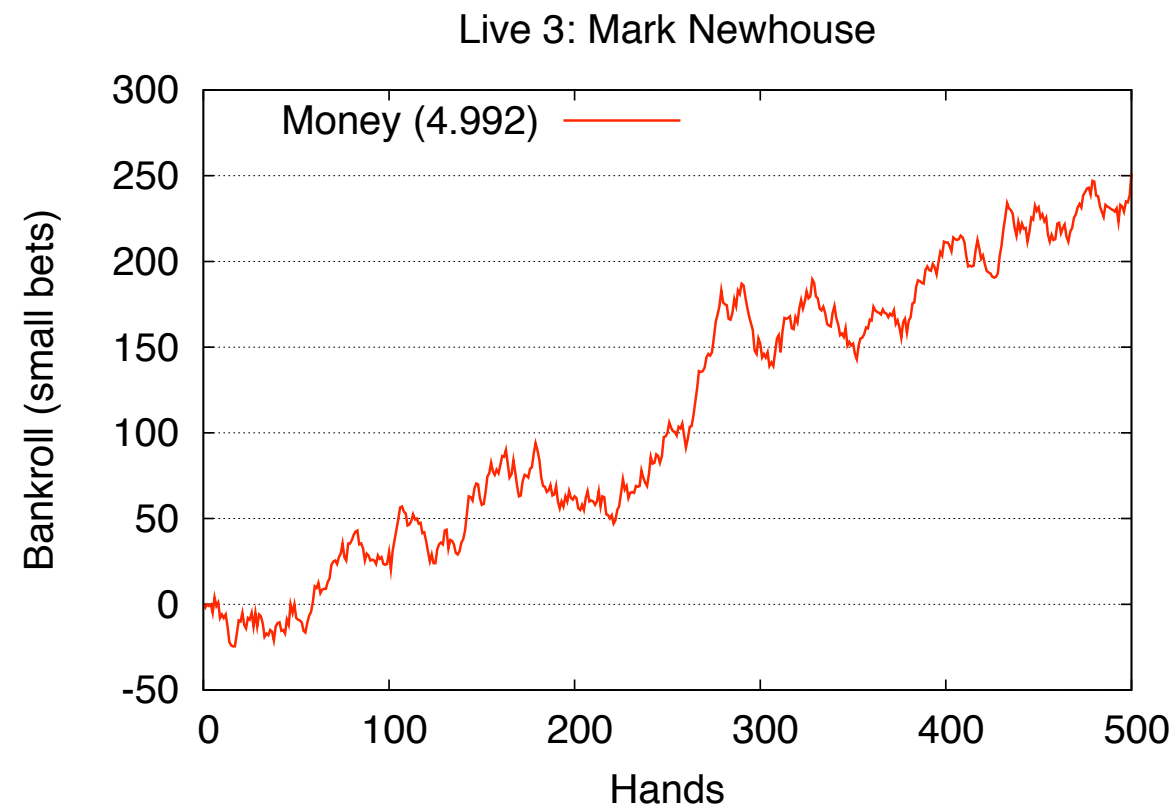


Live 3: IJay Palansky



# Live Match 3: Mark-IJay

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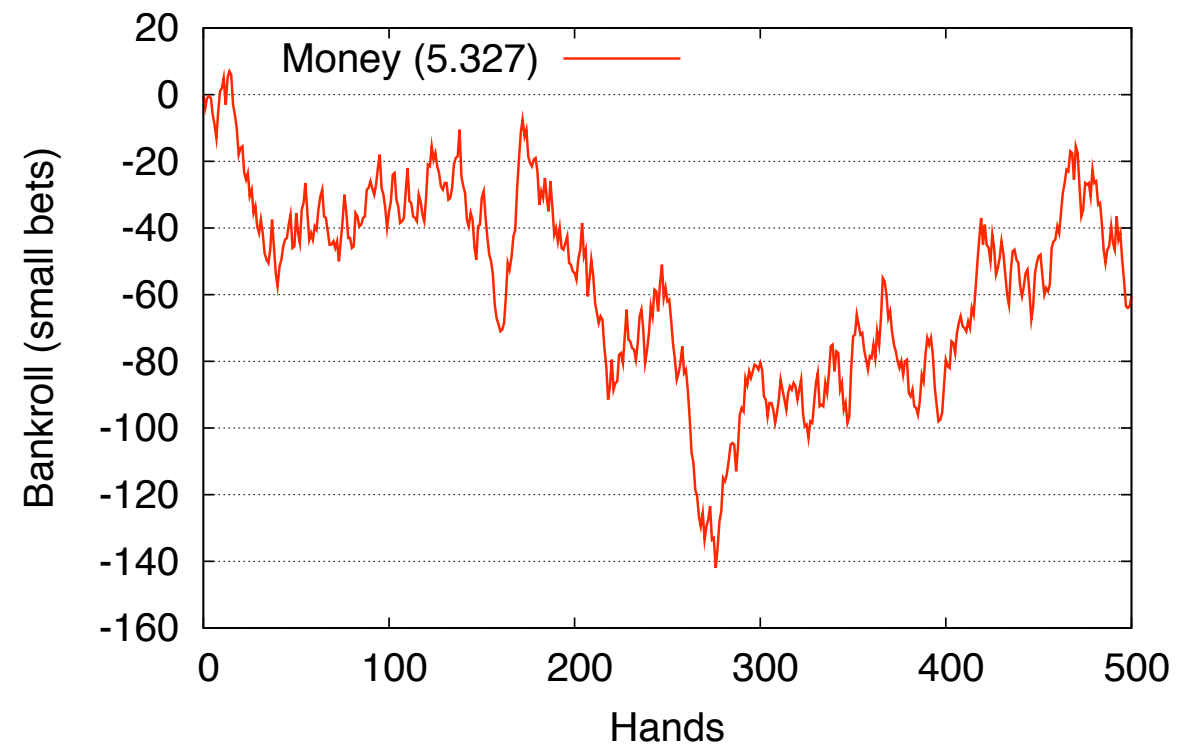


- Polaris up by 56 bets — Polaris wins!

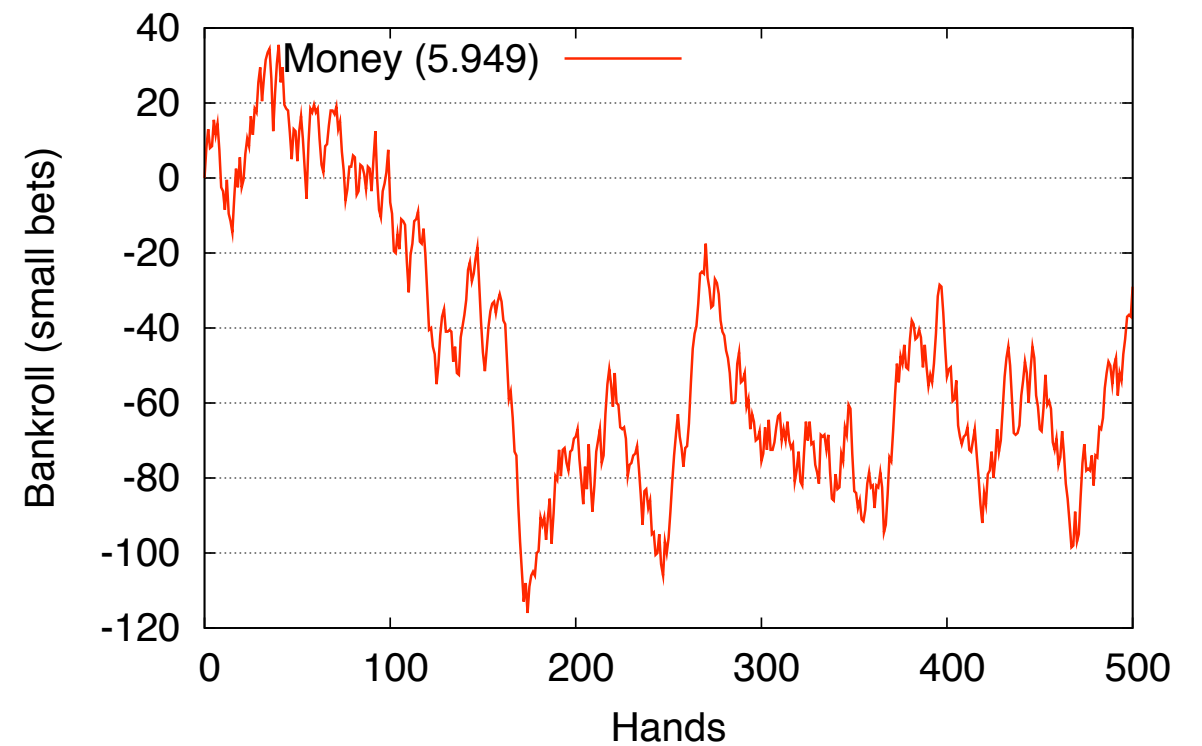
# Live Match 4: Hoss-IJay

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Live 4: Matt Hawrilenko

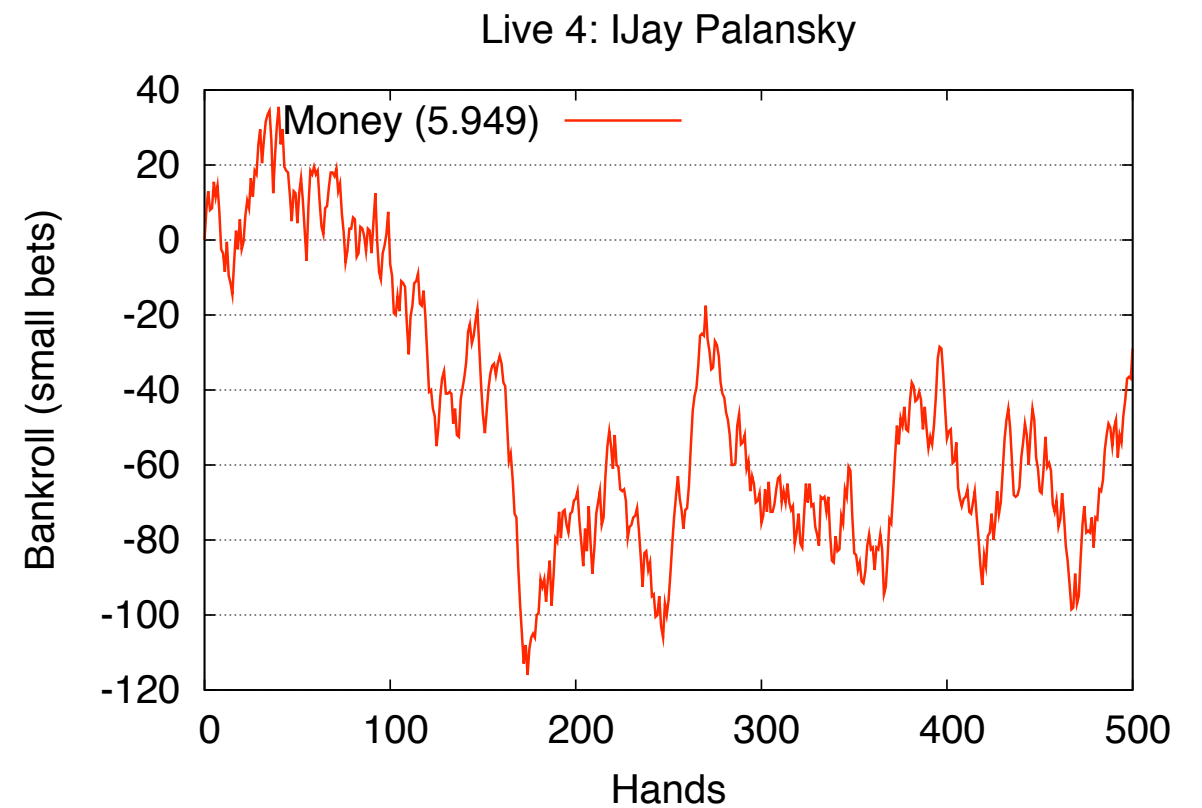
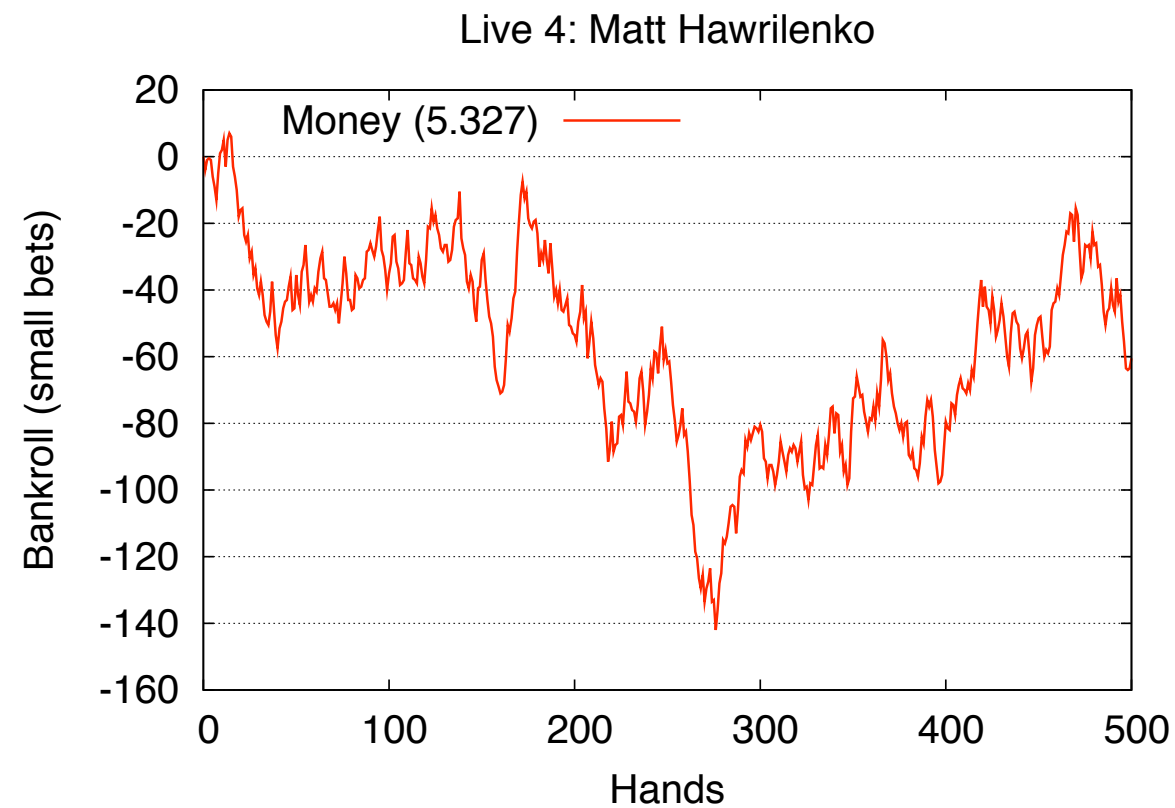


Live 4: IJay Palansky



# Live Match 4: Hoss-IJay

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- Polaris up by 89.5 bets — Polaris wins!

# The Results

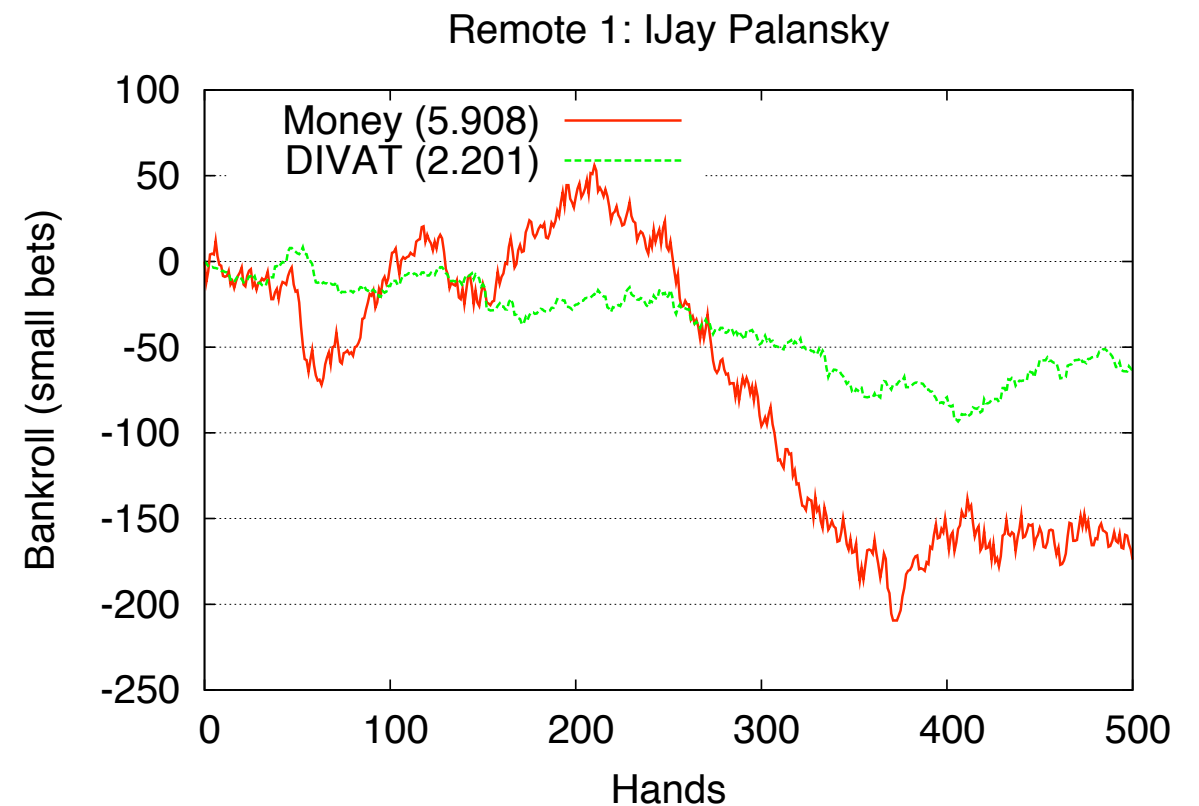
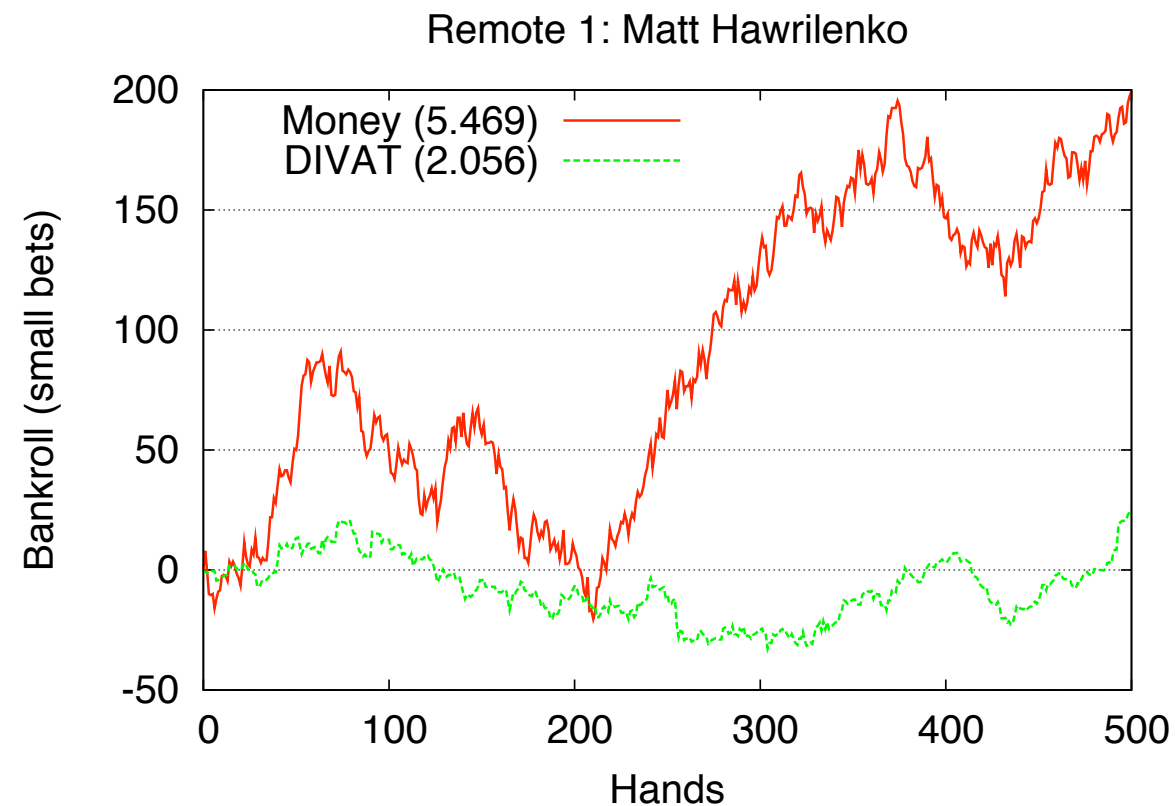
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- Final Result: 3 Wins, 2 Losses, 1 Draw
- First time a computer has beaten professionals in a meaningful poker competition!

# First Law of Poker?

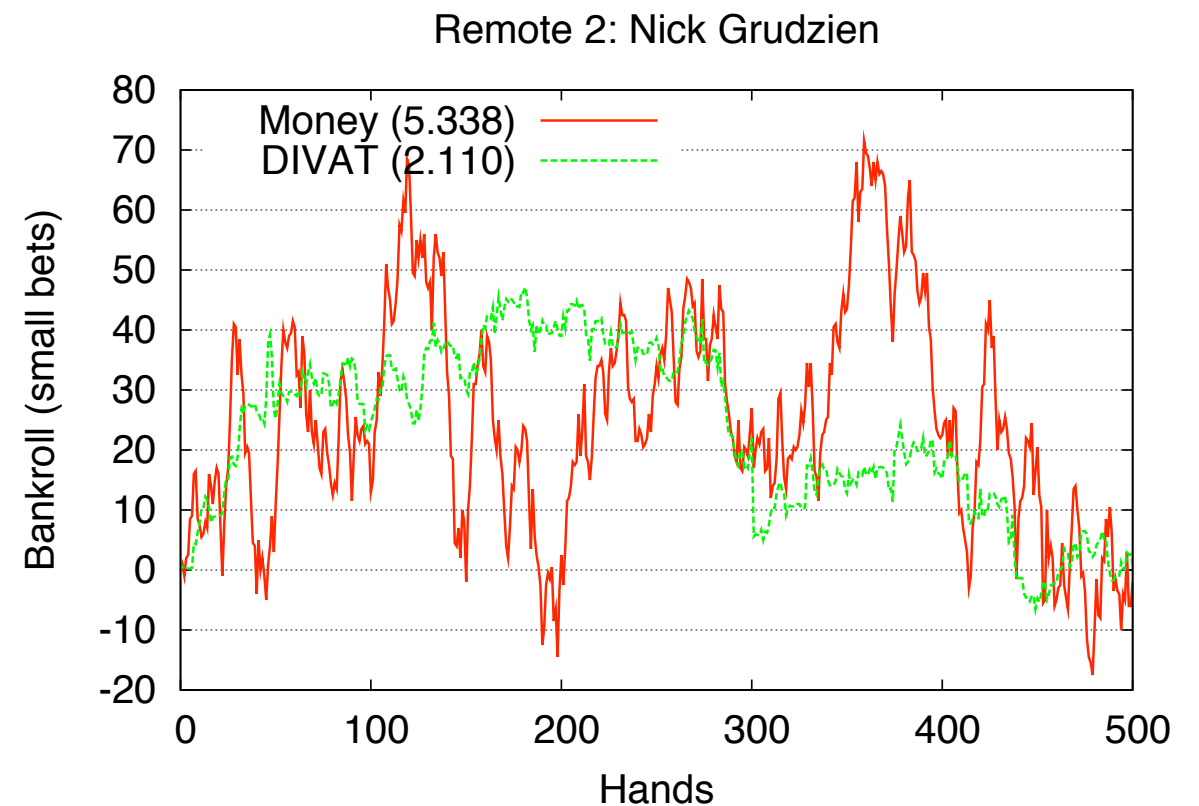
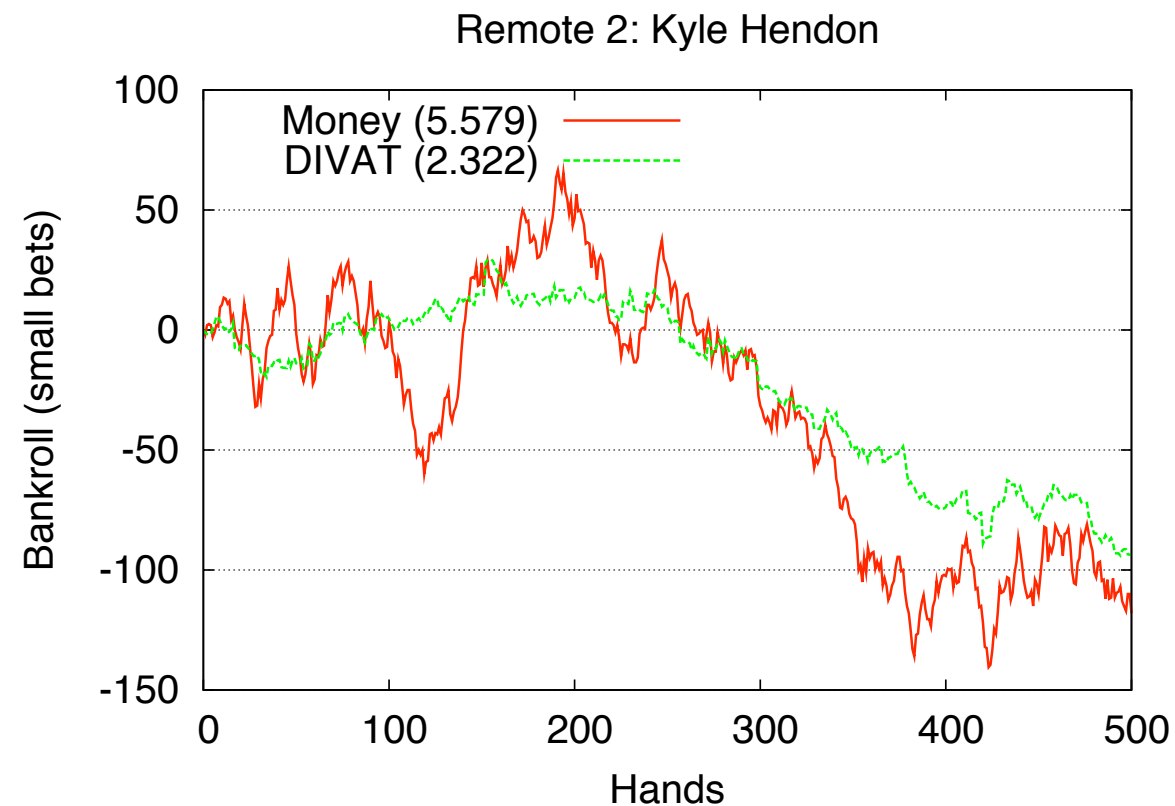
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# Remote Match 1: Hoss-IJay



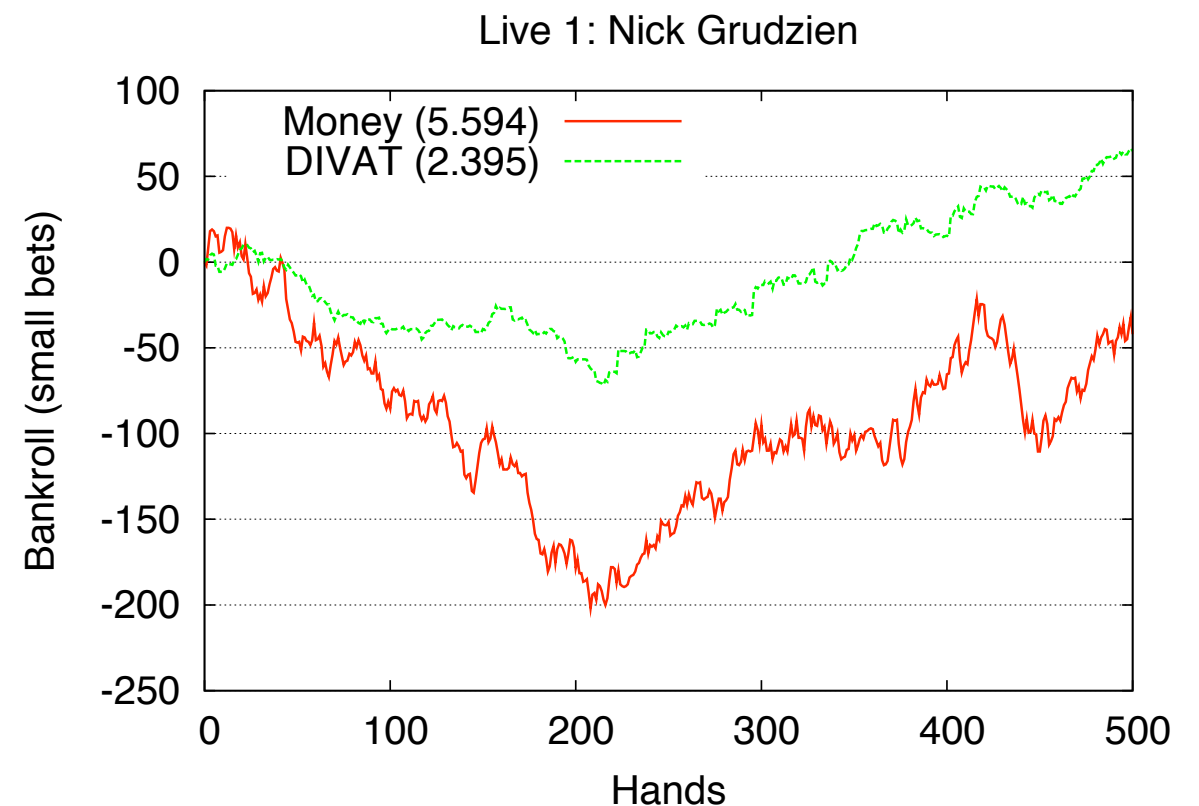
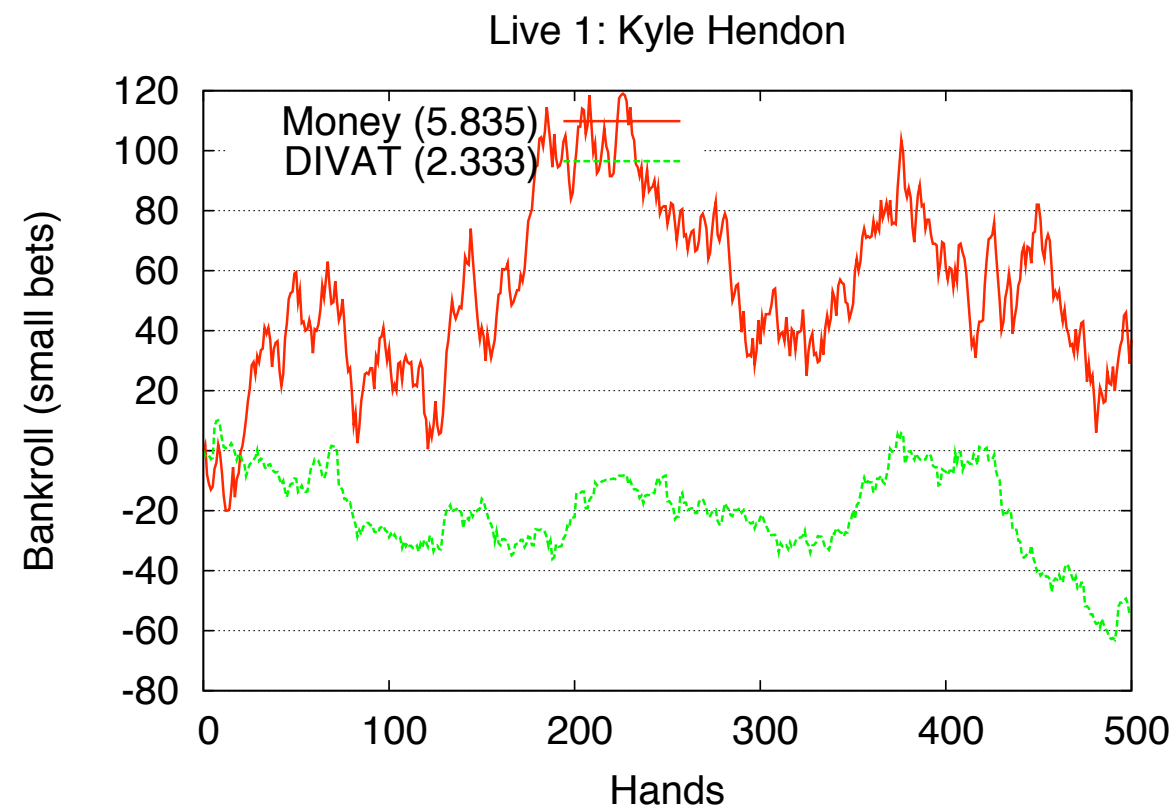
- Humans up by 25.5 bets — Polaris loses!
  - Not statistically significant, p-value = 0.38
- DIVAT showed Polaris up by 41 bets
  - Not statistically significant, p-value = 0.26

# Remote Match 2: Kyle-Nick



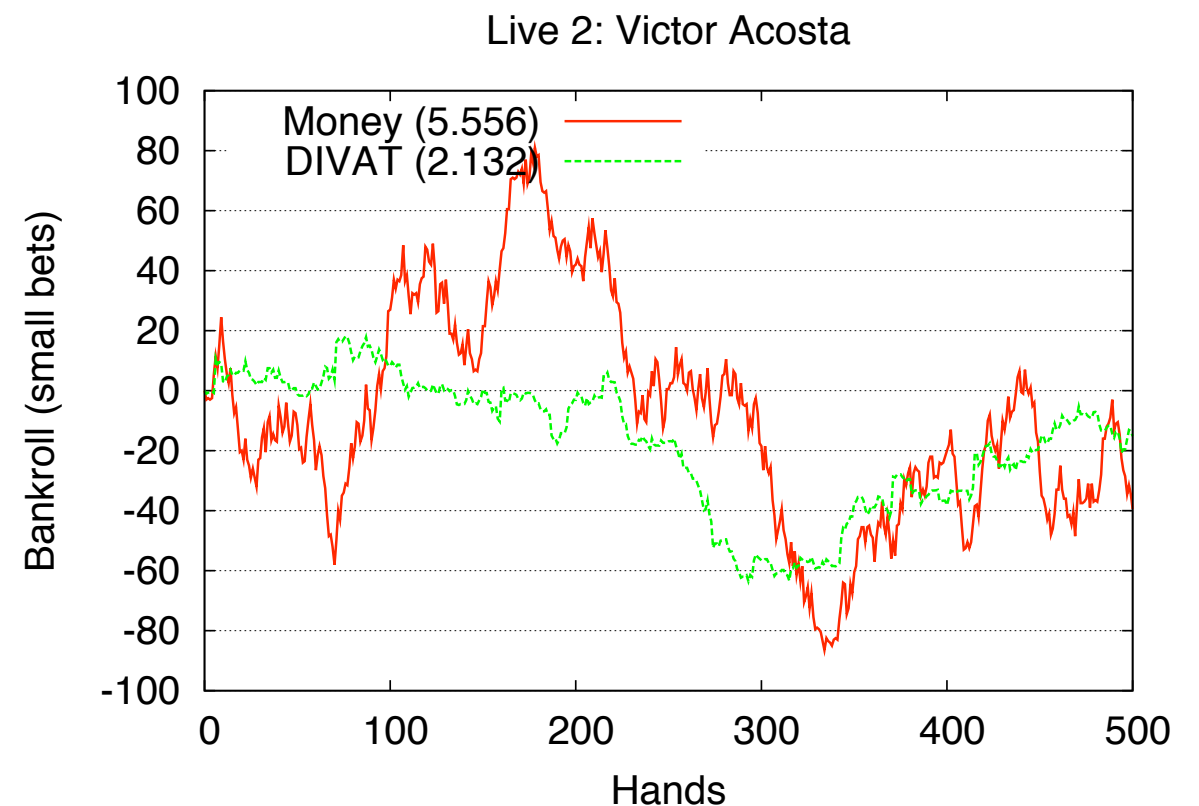
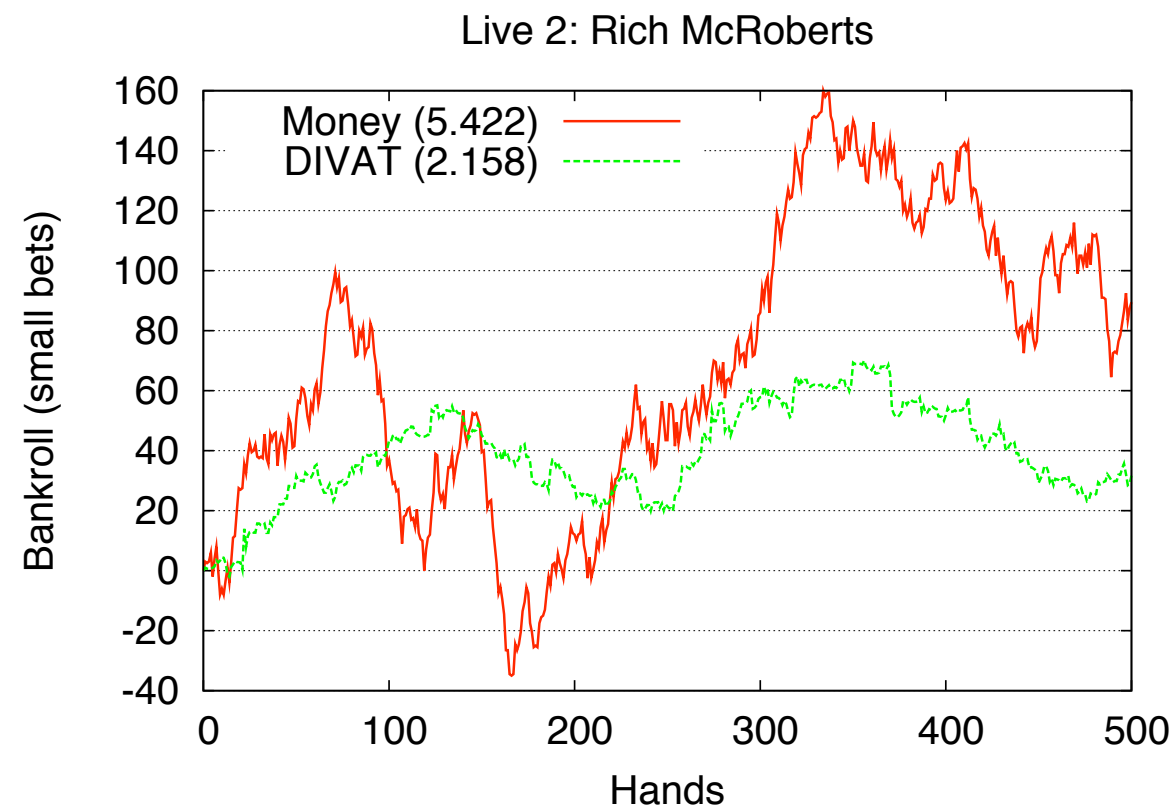
- Polaris up by 120 bets — Polaris wins!
  - Not statistically significant, p-value = 0.09
- DIVAT showed Polaris up by 92 bets
  - Not statistically significant, p-value = 0.07

# Live Match 1: Kyle-Nick



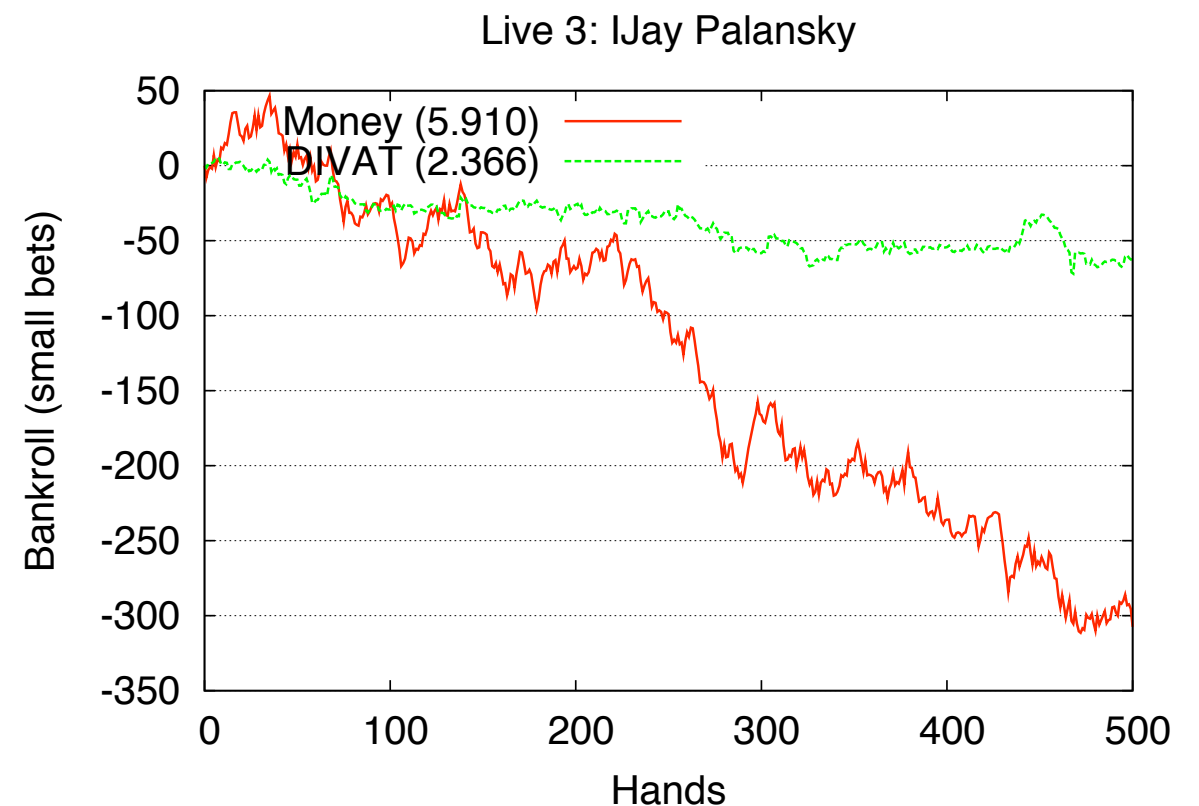
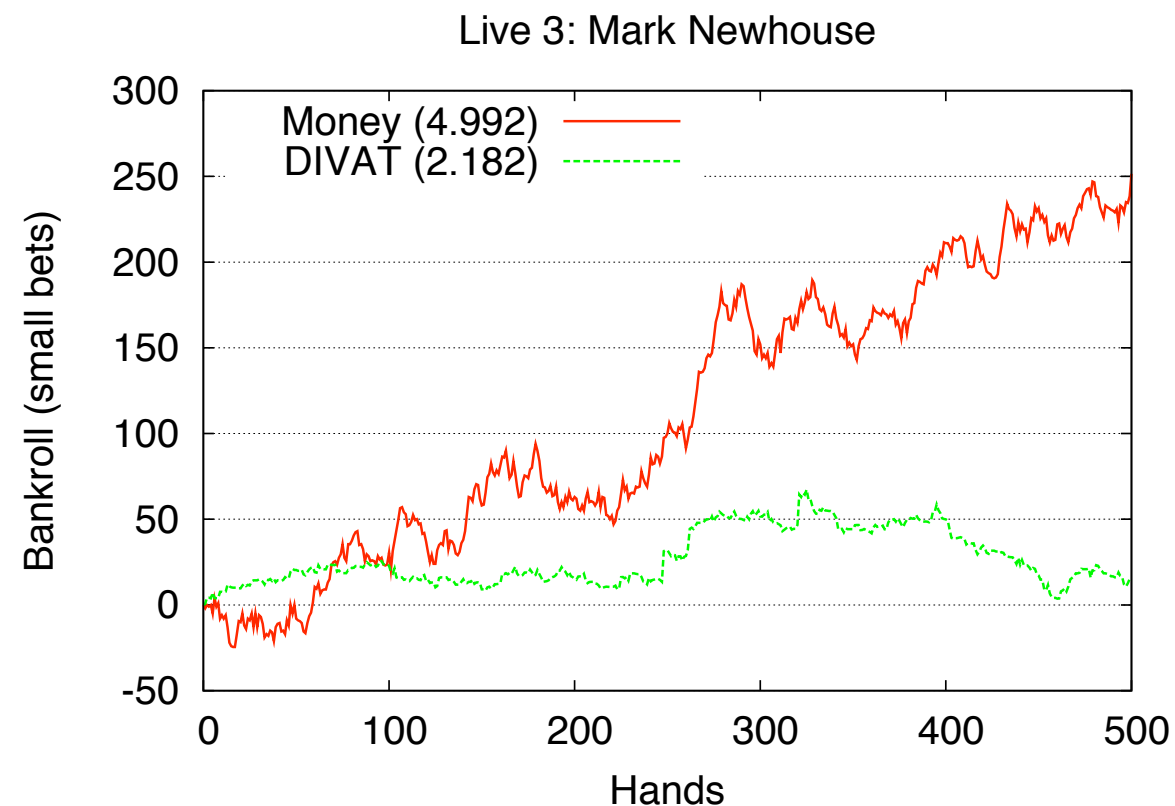
- Polaris up by 5 bets — Draw
  - Not statistically significant, p-value = 0.48
- DIVAT showed Humans up by 10 bets
  - Not statistically significant, p-value = 0.44

# Live Match 2: Rich-Victor



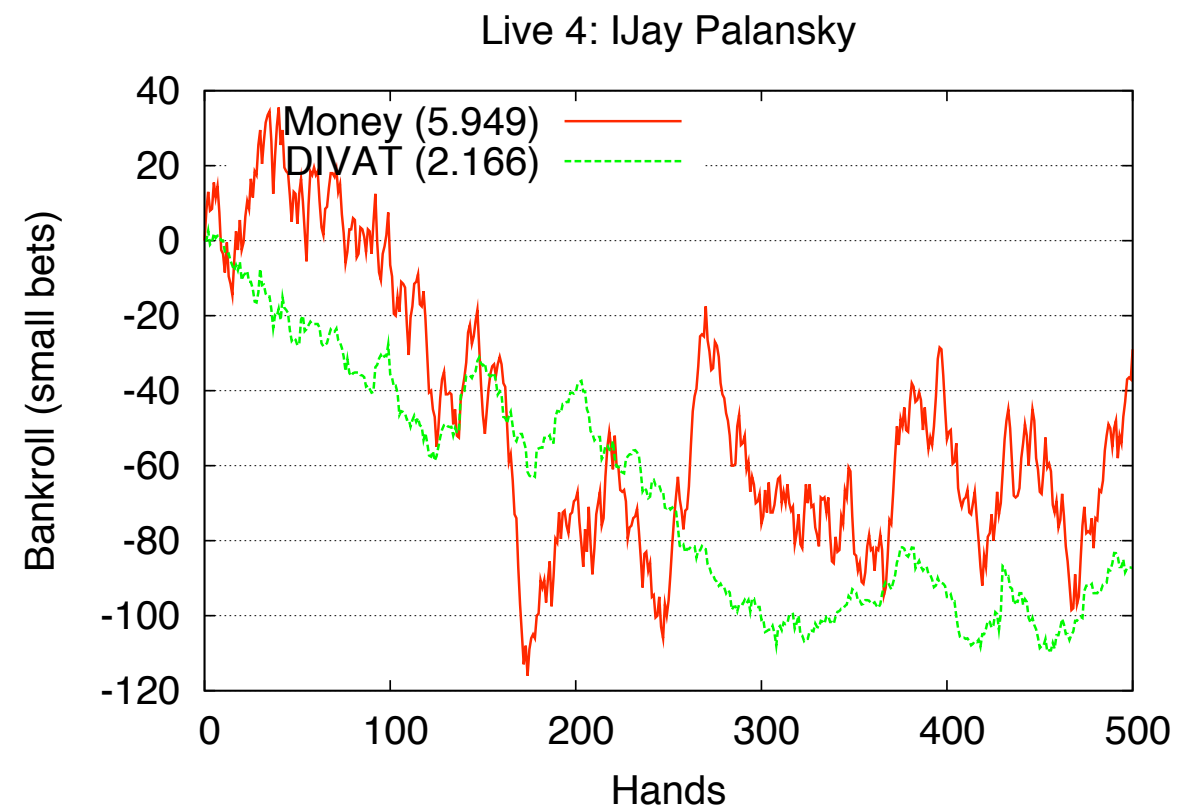
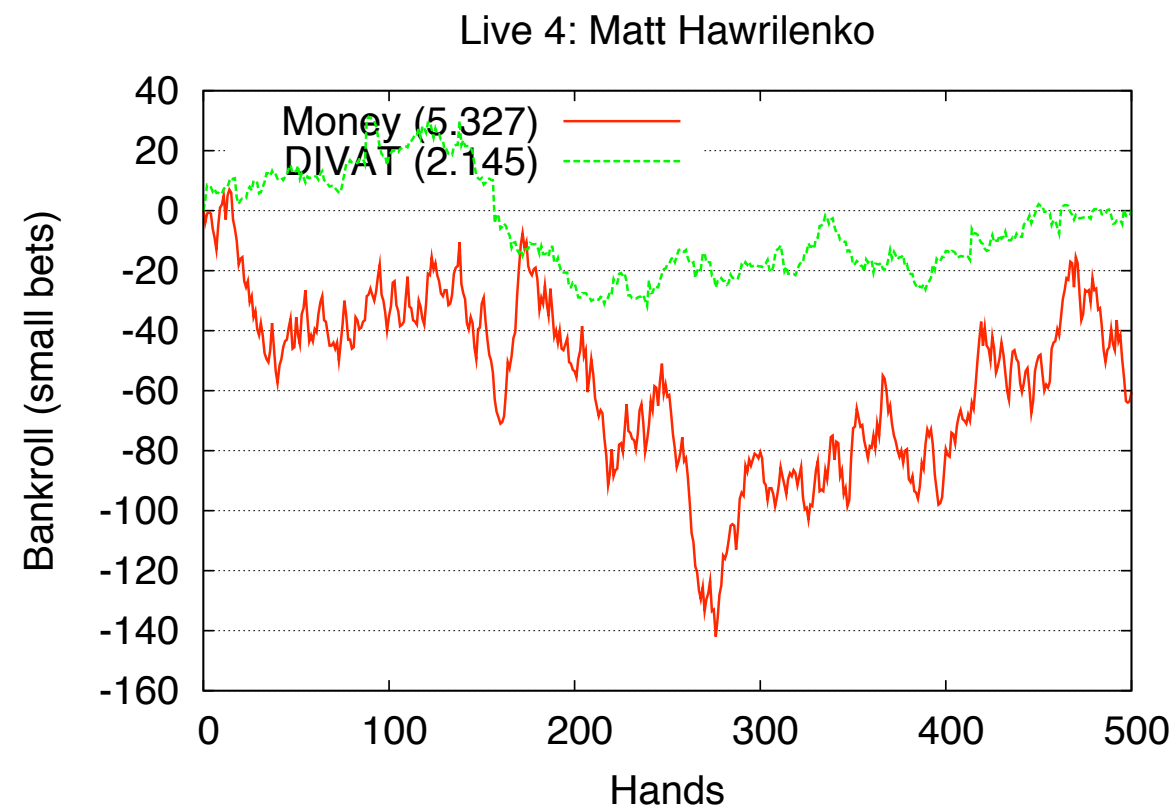
- Humans up by 50 bets — Polaris loses!
  - Not statistically significant, p-value = 0.27
- DIVAT showed Humans up by 16 bets
  - Not statistically significant, p-value = 0.40

# Live Match 3: Mark-IJay



- Polaris up by 56 bets — Polaris wins!
  - Not statistically significant, p-value = 0.26
- DIVAT showed Polaris up by 47 bets
  - Not statistically significant, p-value = 0.23

# Live Match 4: Hoss-IJay



- Polaris up by 89.5 bets — Polaris wins!
  - Not statistically significant, p-value = 0.17
- DIVAT showed Polaris up by 87 bets
  - Not statistically significant, p-value = 0.08

# The Results

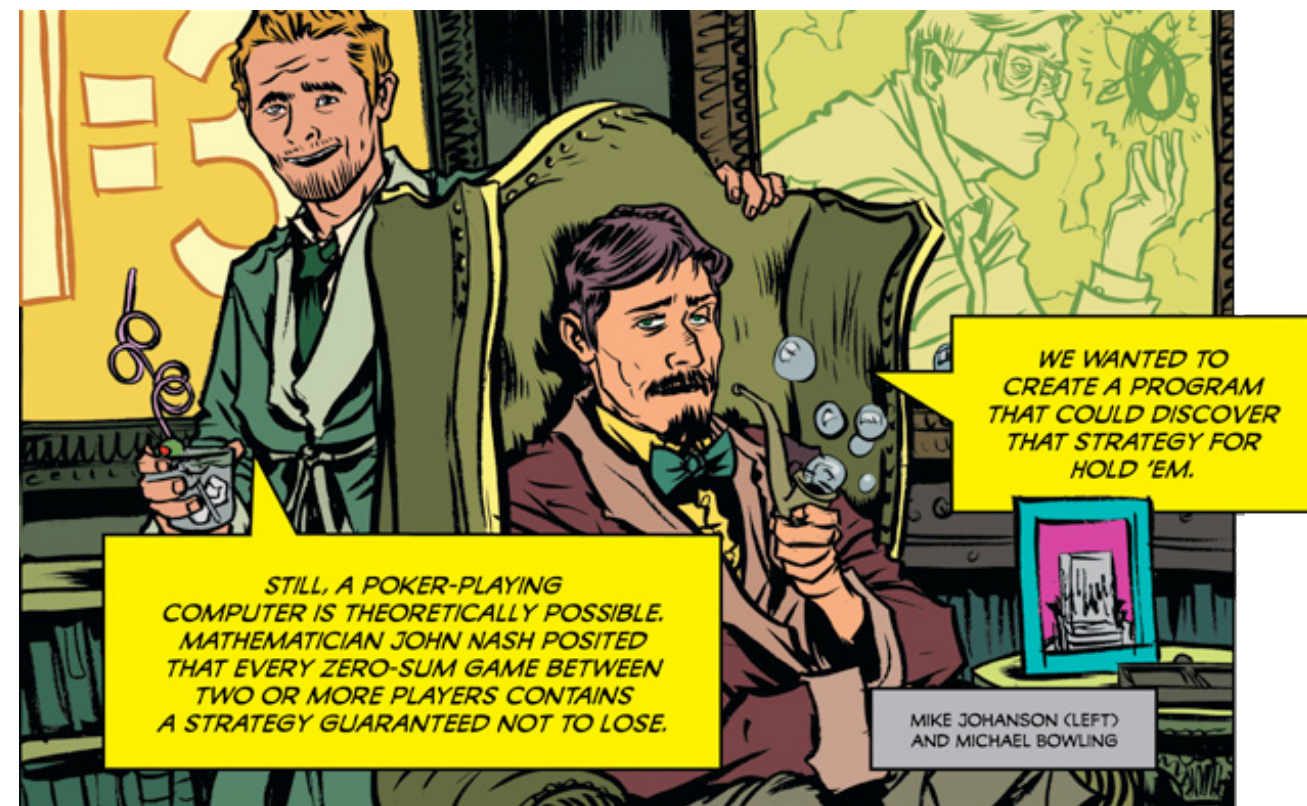
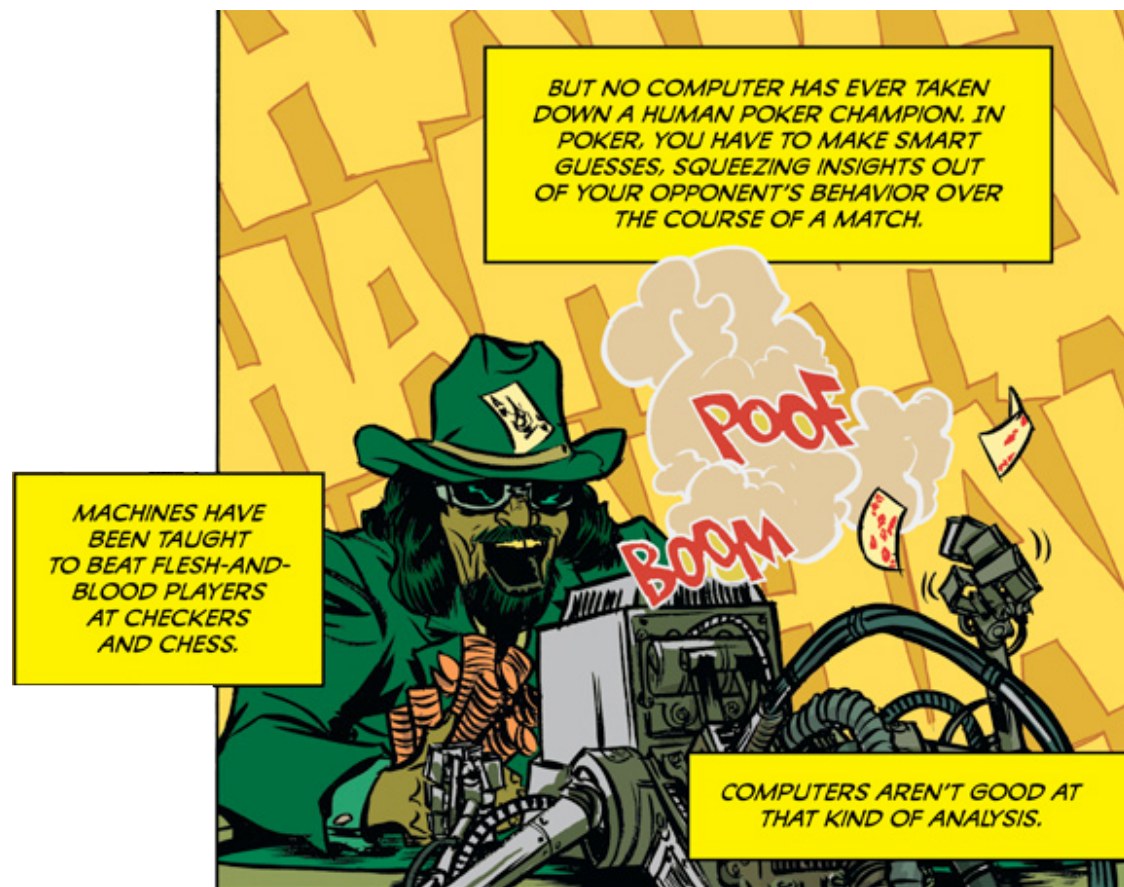
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- Final Result: 3 Wins, 2 Losses, 1 Draw
- Not one match was statistically significant, even with DIVAT

# The Results

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- Final Result: 3 Wins, 2 Losses, 1 Draw
- Not one match was statistically significant, even with DIVAT
- Is this the end of the story for the heroic scientists?



# Evaluating Poker Players

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- Money is a terrible estimator!
  - ~20K hands needed for statistical significance
- Duplicate helps
  - ~2000 pairs of hands
- DIVAT+Duplicate is almost enough
  - ~1200 pairs of hands

# Removing More Luck: Imaginary Observations

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# Removing More Luck: Imaginary Observations

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- After every hand, imagine you saw many more hands

$$V = \sum_{h \in U} \text{MONEY}(h) \frac{P(h)}{\Pr(h \in U)}$$

$$= \sum_h I(h \in U) \text{MONEY}(h) \frac{P(h)}{\Pr(h \in U)}$$

$$E[V] = \sum_h \Pr(h \in U) \text{MONEY}(h) \frac{P(h)}{\Pr(h \in U)}$$

$$= \sum_h \text{MONEY}(h) P(h) = E[\text{MONEY}]$$

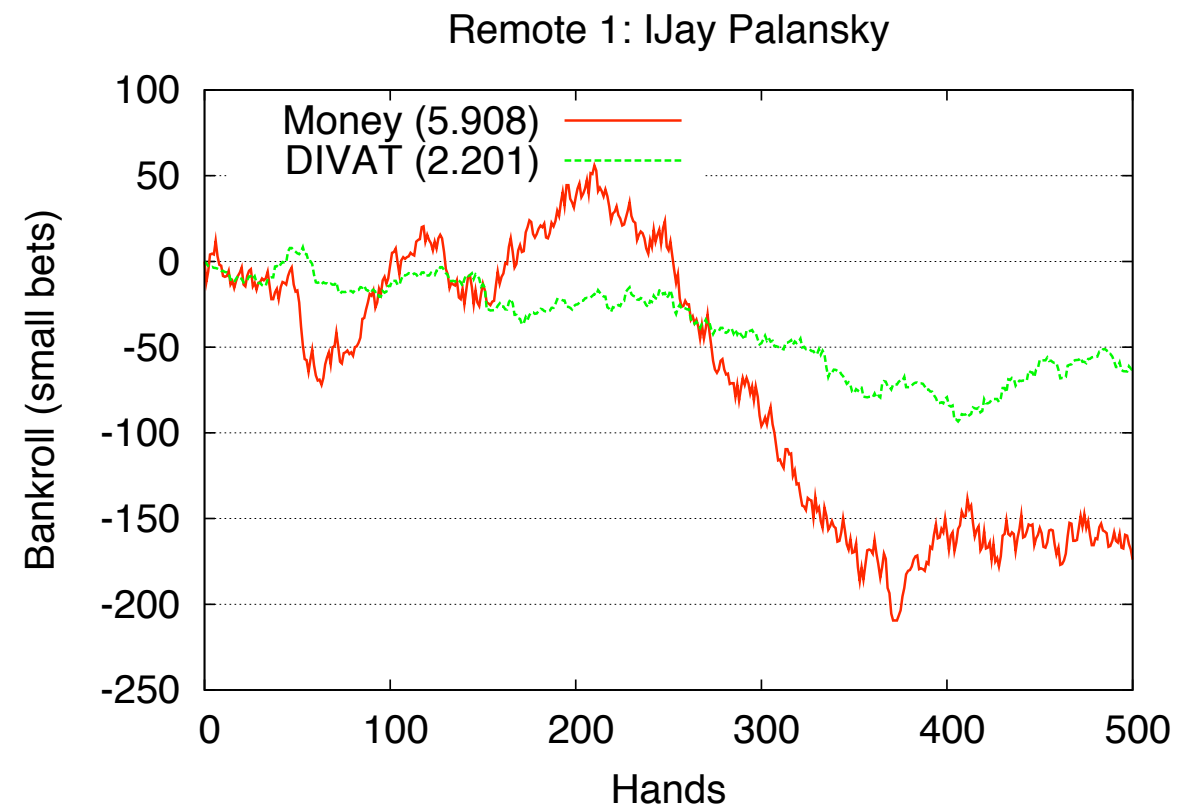
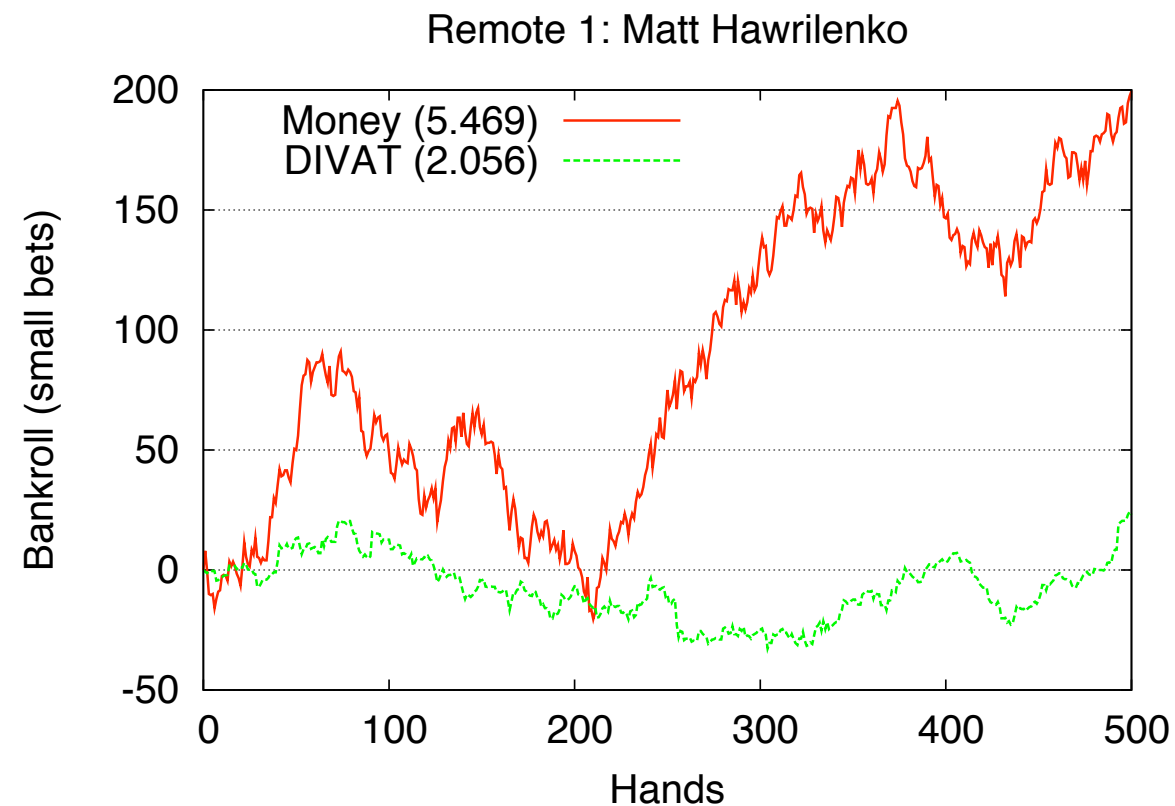
# Imaginary Observations

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- Imaginary Observations
  - ~10K hands needed for statistical significance
- Imaginary Observations + DIVAT
  - ~1800 pairs of hands
- Imaginary Observations + DIVAT + Duplicate
  - ~500 pairs of hands

# Remote Match 1: Hoss-IJay

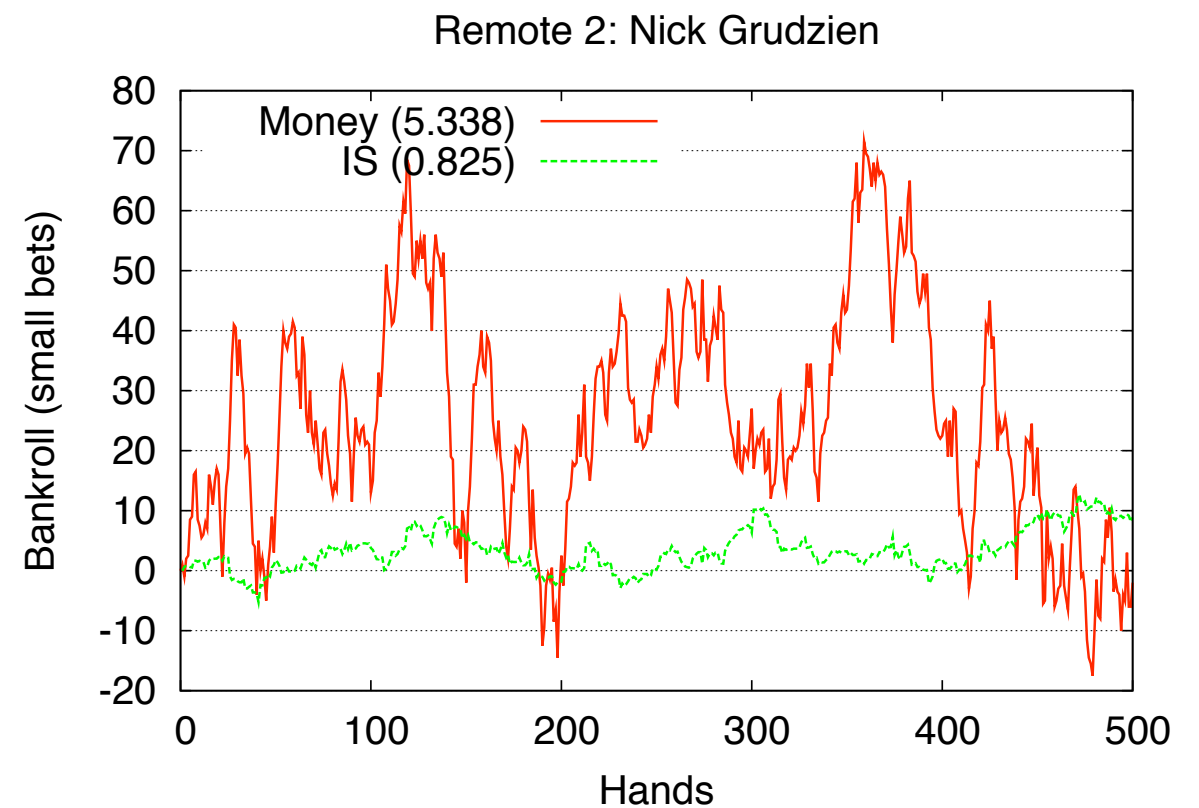
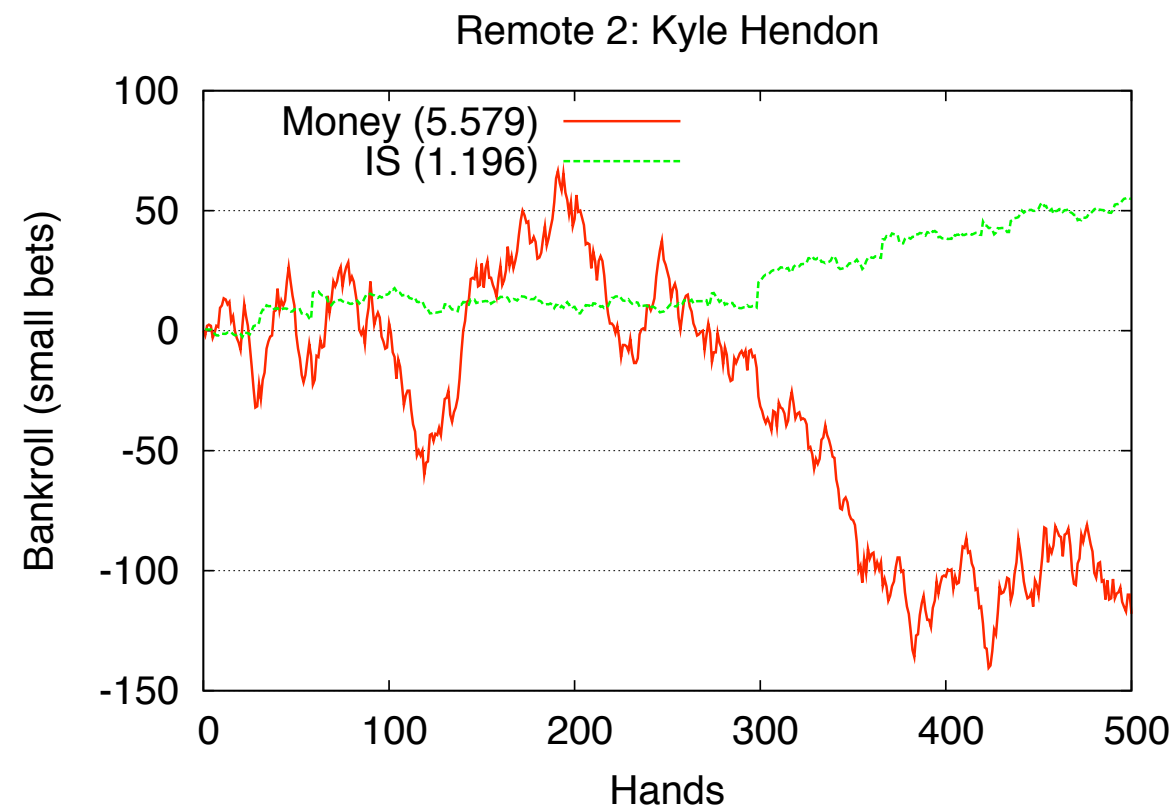
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- IO-DIVAT showed Polaris up by 41 bets
  - Not statistically significant, p-value = 0.26

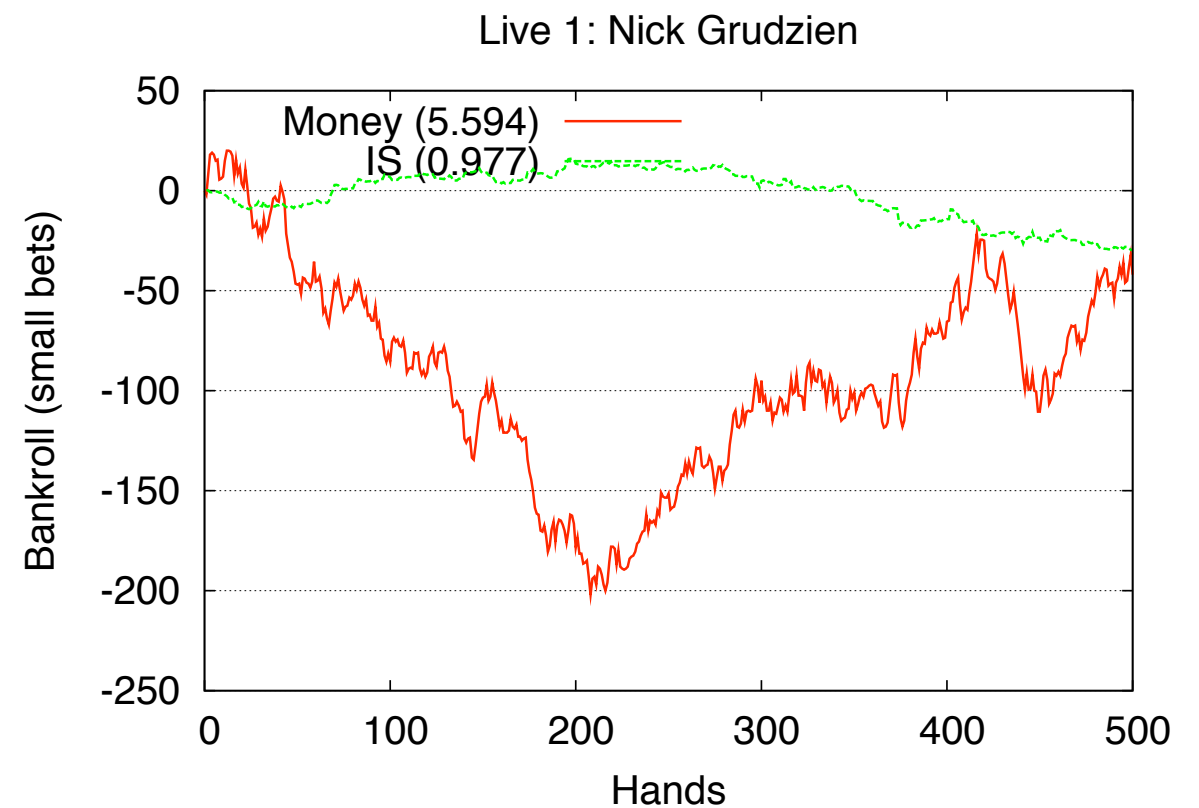
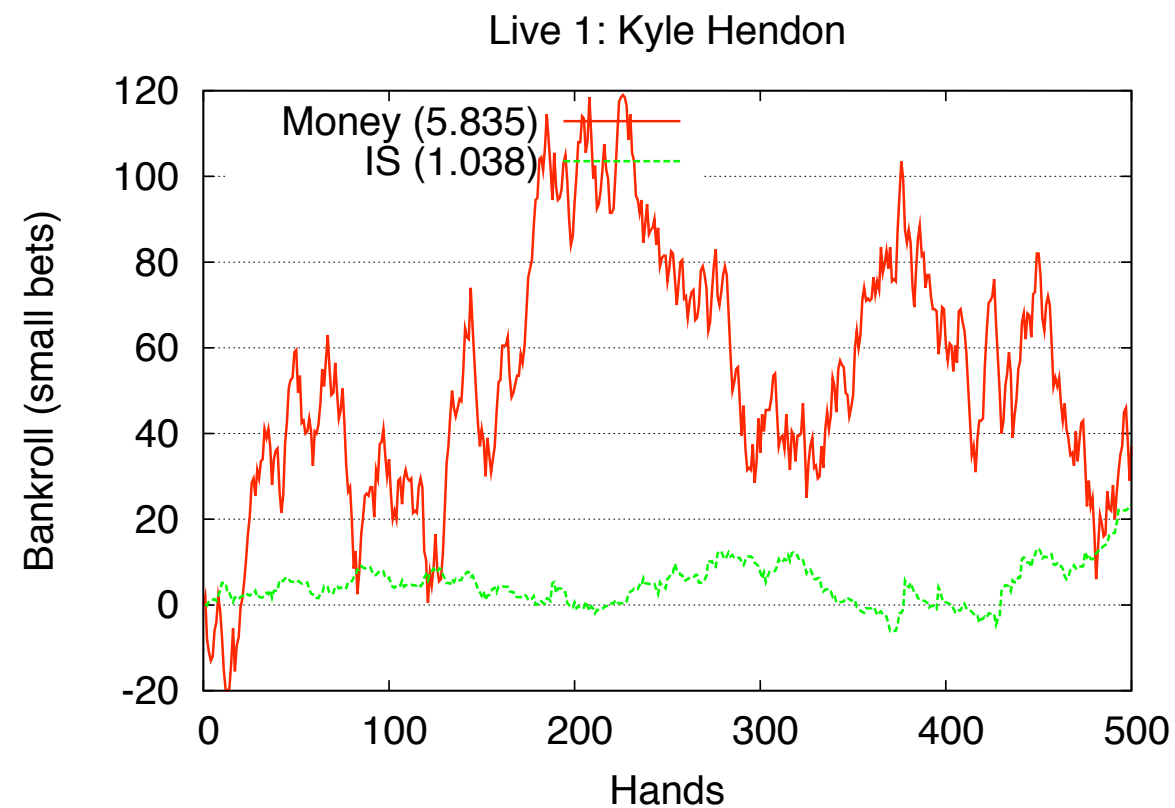
# Remote Match 2: Kyle-Nick

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- IO-DIVAT showed Polaris up by 32 bets
  - Statistically significant, p-value = 0.019

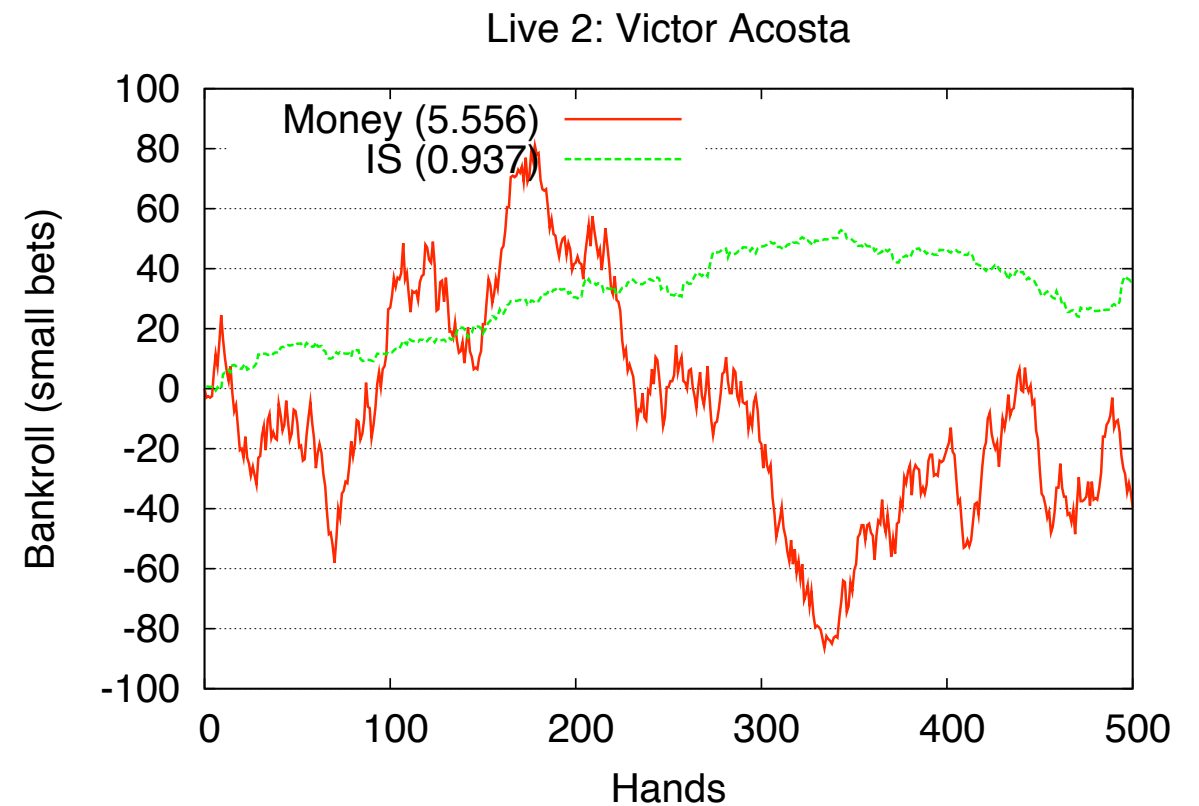
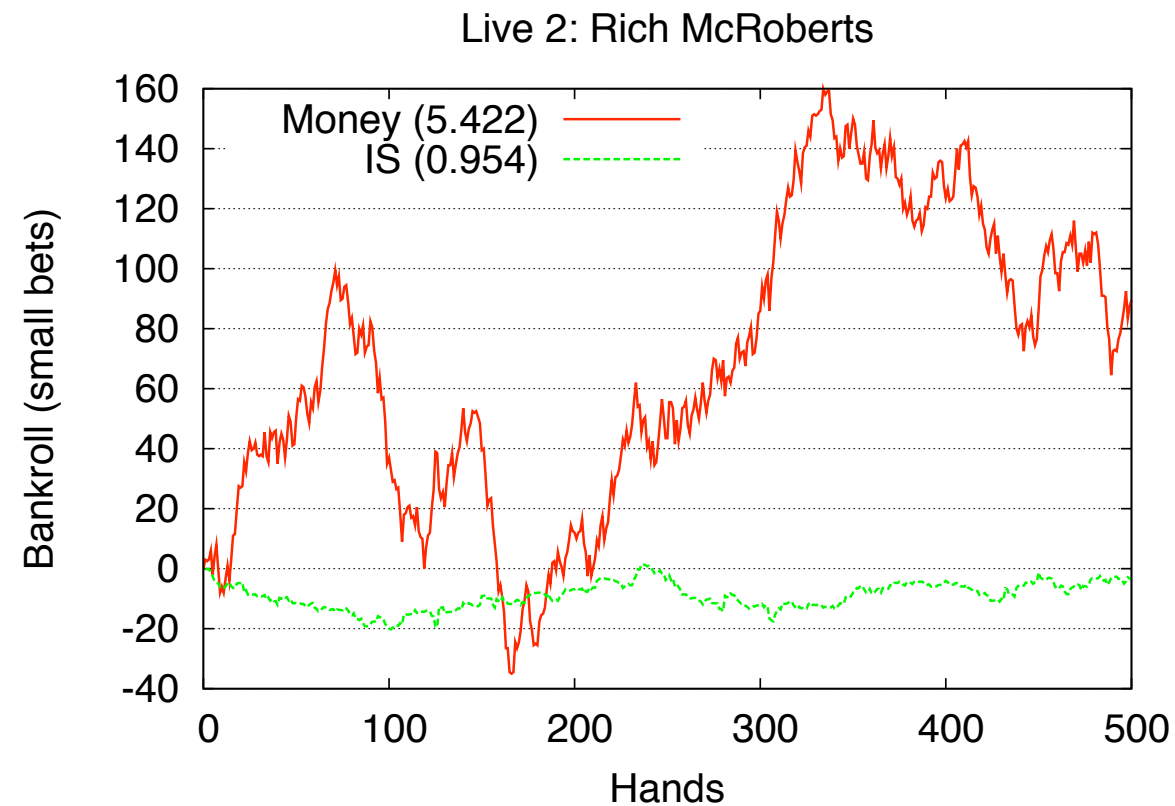
# Live Match 1: Kyle-Nick



- IO-DIVAT showed Humans up by 3 bets
  - Not statistically significant, p-value = 0.42

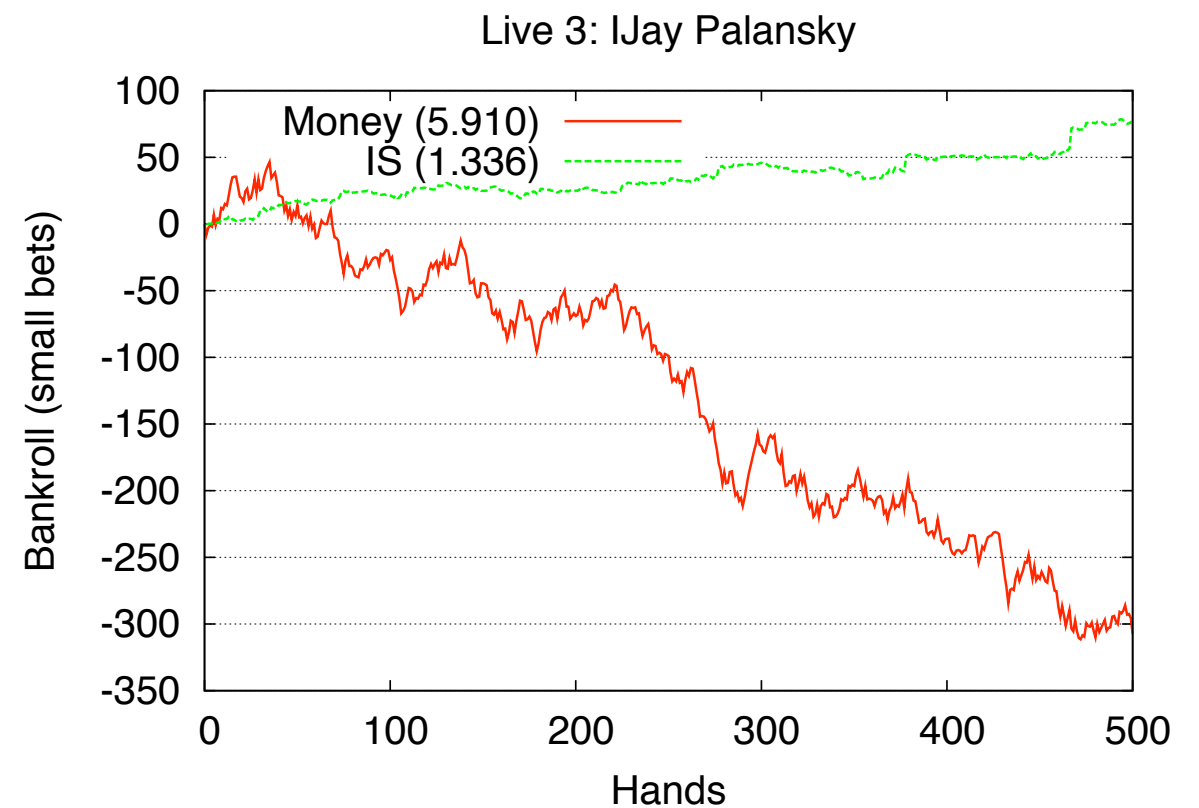
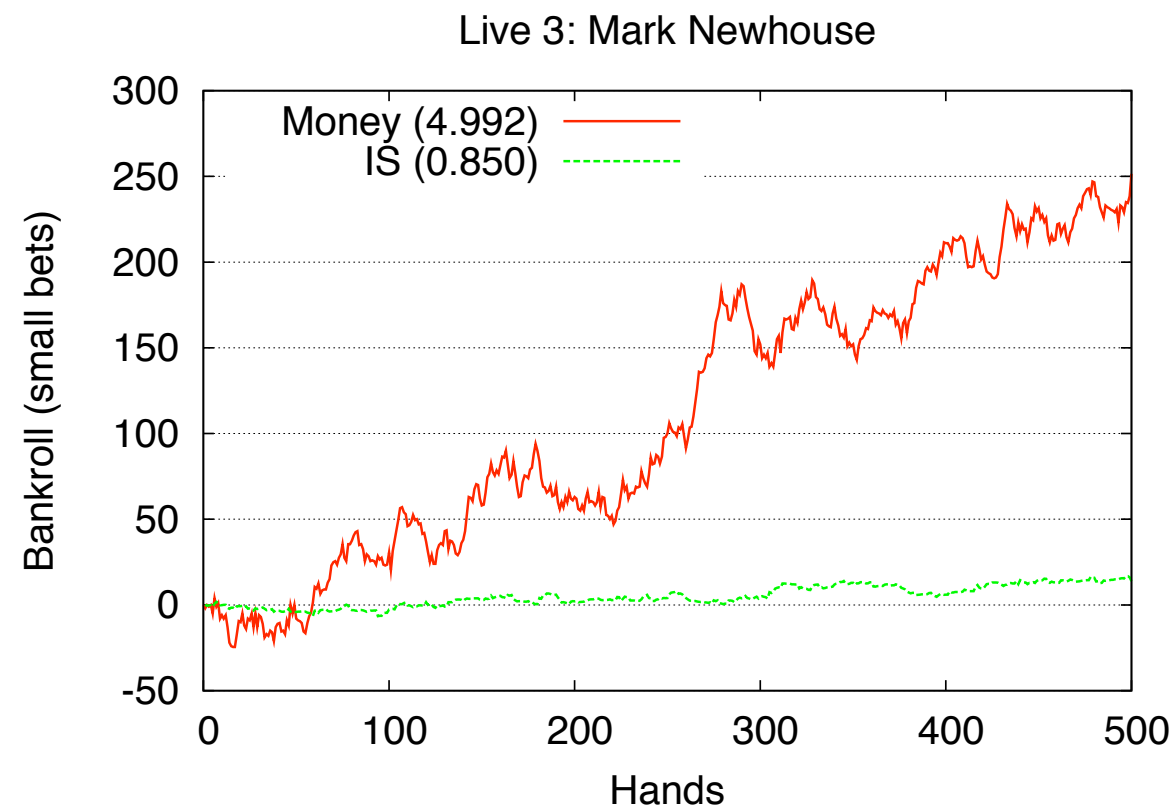
# Live Match 2: Rich-Victor

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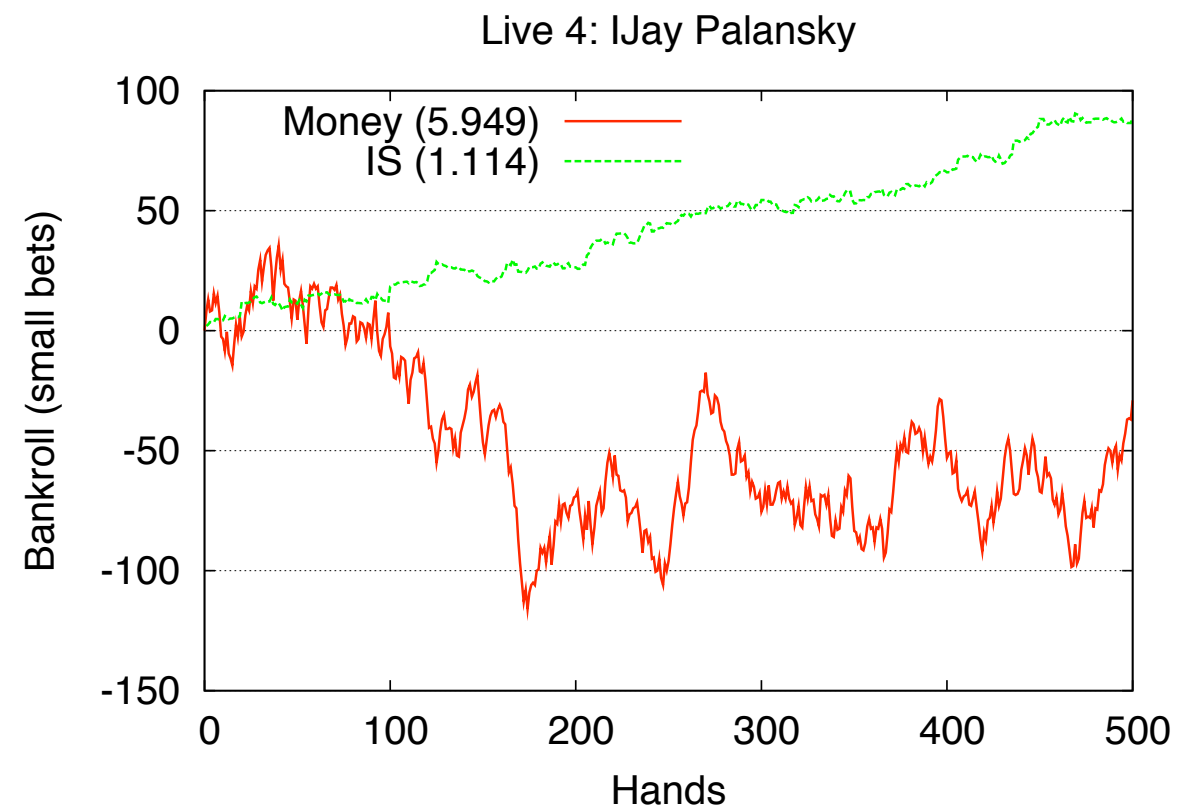
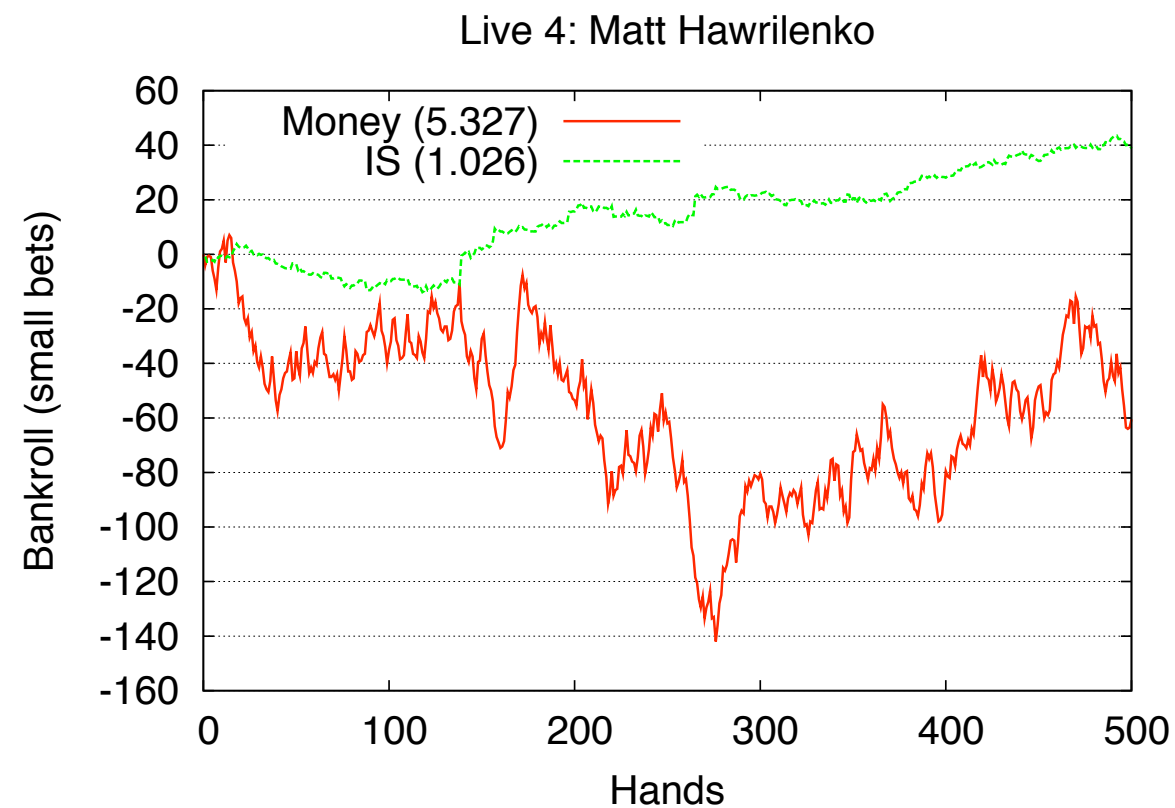
- IO-DIVAT showed Polaris up by 16.5 bets
  - Not statistically significant, p-value = 0.14

# Live Match 3: Mark-IJay



- IO-DIVAT showed Polaris up by 44.5 bets
  - Statistically significant, p-value = 0.002

# Live Match 4: Hoss-IJay



- IO-DIVAT showed Polaris up by 63.5 bets
  - Statistically significant,  $p\text{-value} = 0.00002$

# The Results

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# The Results

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- Final Result: 3 Statistically Significant Wins, 0 Losses, 3 Draws

# The Results

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- Final Result: 3 Statistically Significant Wins, 0 Losses, 3 Draws
- Winning rate of over 3 BB/100!

# The Results

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- Final Result: 3 Statistically Significant Wins, 0 Losses, 3 Draws
- Winning rate of over 3 BB/100!
- Against the best in the world

# Sweet Victory

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“I sat with the best in the world...  
and I won.”

Mike McDermott, *Rounders* (1998)

# Questions?

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