Event-Strategy Analytics

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IIIS has about 40 professors and 70 PhD students across ICT, Eng, Sci and Biz and has expertise in AI, Computer Vision, Robotic, Data Analytics, Cybersecurity, Formal Verification & Analysis

Early Work on Formal Analysis

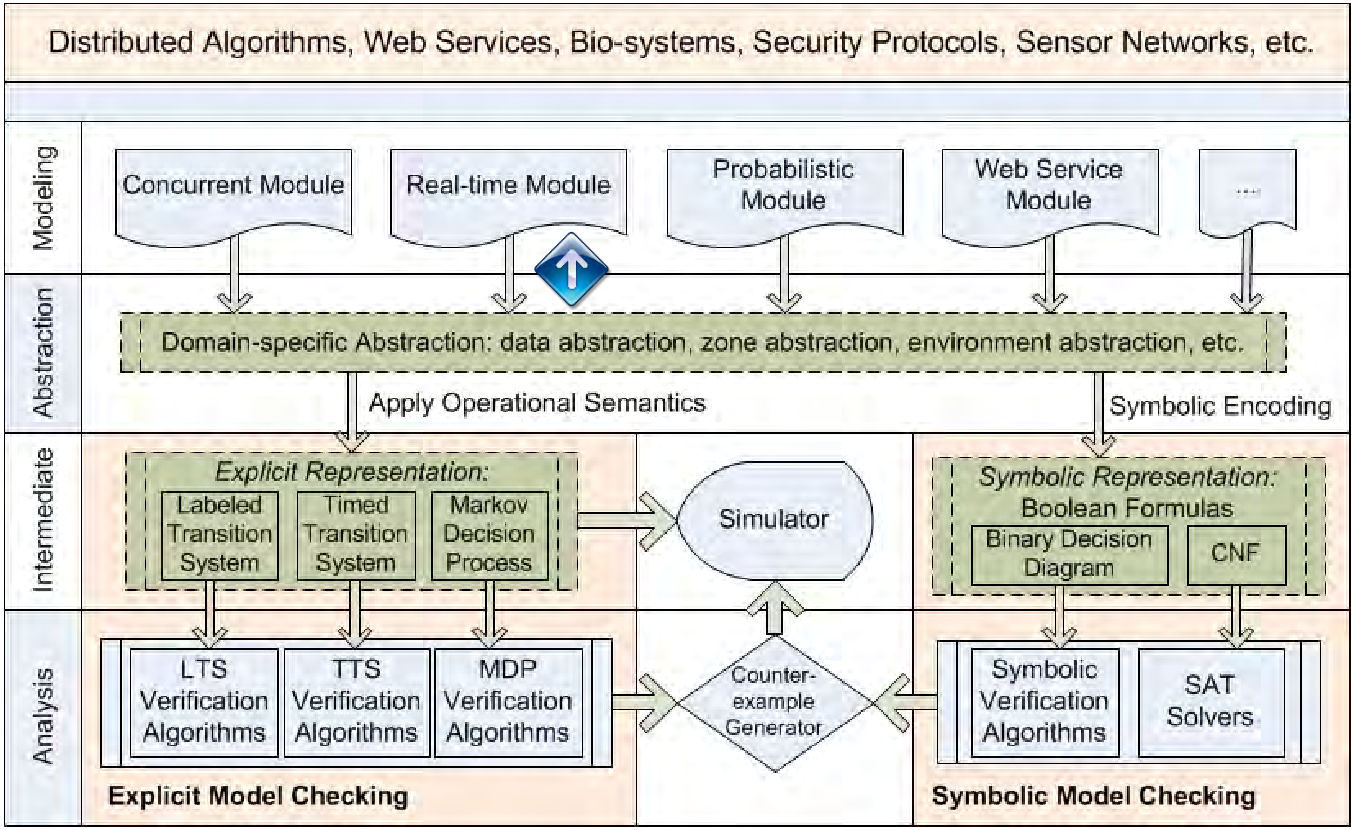
- 1949 Alan Turing: “Checking Large Routine”

- 1978 C. A. R. Hoare (1980 Turing Winner). Communicating Sequential Processes: event based calculus for modelling concurrency and communication.

- 2007 three researchers won ACM Turing Award for inventing model checking, one of them E. Clarke (CMU) has also won Franklin Institute 2014 Bower Award.
    - successfully applied in industries, e.g.,

Past 10 years work on Process Analysis Toolkit (PAT)

(CAV '09'11'13'15, ICSE'08'13,15'16, FM'09'11'12'15, TSE'08'13'15, TOSEM'10'13)



Distributed Algorithms, Web Services, Bio-systems, Security Protocols, Sensor Networks, etc.
Modeling
Concurrent Module
Real-time Module
Probabilistic Module
Web Service Module
....
Abstraction
Domain-specific Abstraction: data abstraction, zone abstraction, environment abstraction, etc.
Apply Operational Semantics
Symbolic Encoding
Intermediate
Explicit Representation:
Labeled Transition System
Timed Transition System
Markov Decision Process
Simulator
Symbolic Representation: Boolean Formulas
Binary Decision Diagram
CNF
Analysis
LTS Verification Algorithms
TTS Verification Algorithms
MDP Verification Algorithms
Counter-example Generator
Symbolic Verification Algorithms
SAT Solvers
Explicit Model Checking
Symbolic Model Checking

J.Sun, SUTD

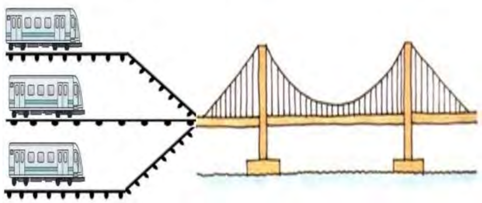
Y.Liu, NTU

J.S.Dong, NUS

- 1Million lines of C# code, 15 verification systems, 200+ build in examples, 10 PhDs, 100+ publications

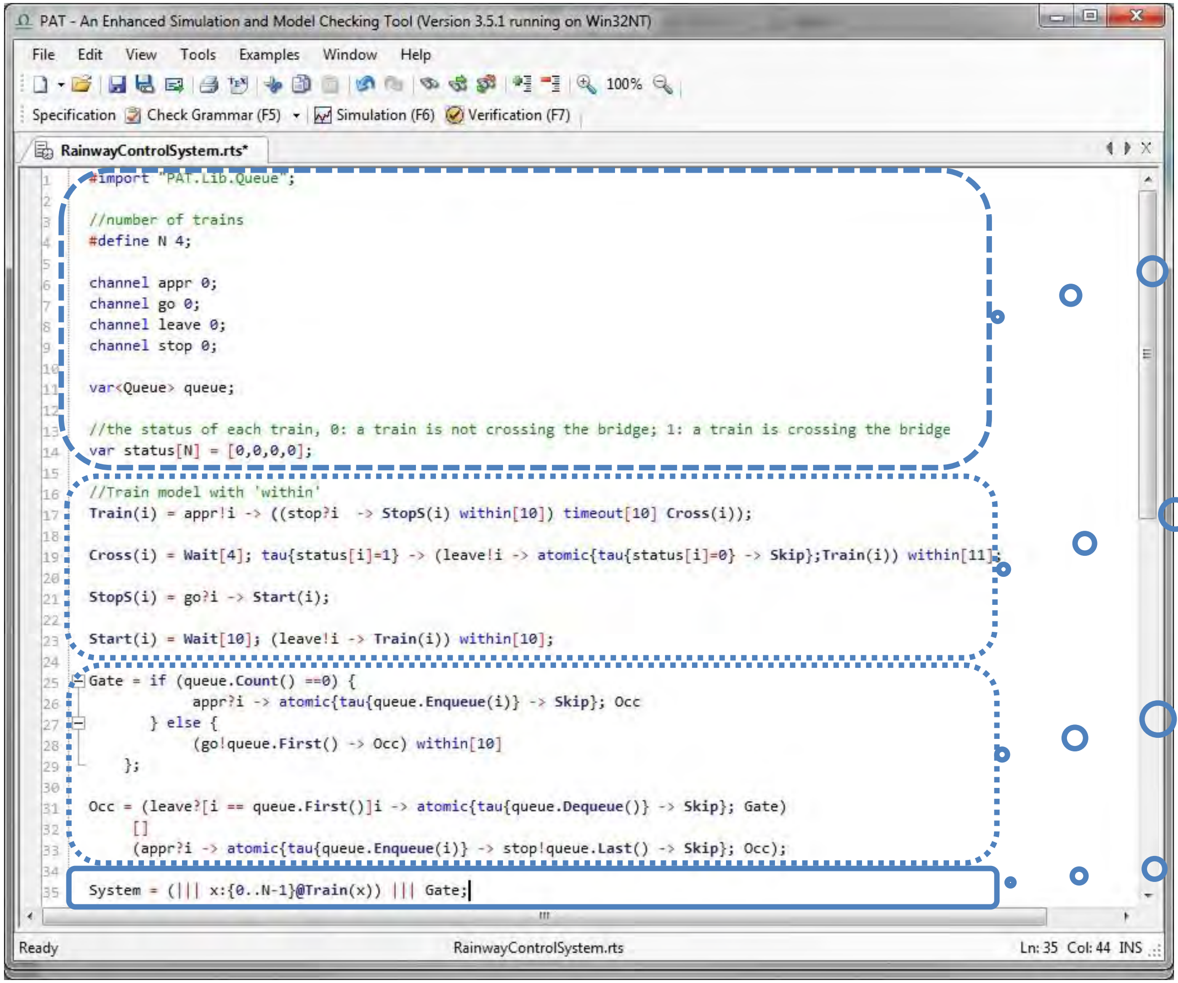
- 3700+ registered users from 900+ organizations in 89 countries, e.g. Microsoft, HP, Sony, Mitsubishi, NTT, Toyota, JAXA … Commercialised in Japan and thanks to CATS, NII and others

Example: Train Control System



- Problem: to model a railway control system to automatically control trains passing a critical point such as a bridge
  - to use a computer to guide trains from several tracks crossing a single bridge instead of building many bridges
- Safety Property
  - Avoid the situation where more than one train are crossing the bridge at the same time
- How to verify the correctness of such system?
  - Model checking approach and PAT

System Modeling



```
#import "PAT.Lib.Queue";

//number of trains
#define N 4;

channel appr 0;
channel go 0;
channel leave 0;
channel stop 0;

var<Queue> queue;

//the status of each train, 0: a train is not crossing the bridge; 1: a train is crossing the bridge
var status[N] = [0,0,0,0];

//Train model with 'within'
Train(i) = appr!i -> ((stop?i  -> StopS(i) within[10]) timeout[10] Cross(i));

Cross(i) = Wait[4]; tau{status[i]=1} -> (leave!i -> atomic{tau{status[i]=0} -> Skip};Train(i)) within[11];

StopS(i) = go?i -> Start(i);

Start(i) = Wait[10]; (leave!i -> Train(i)) within[10];

Gate = if (queue.Count() ==0) {
            appr?i -> atomic{tau{queue.Enqueue(i)} -> Skip}; Occ
        } else {
            (go!queue.First() -> Occ) within[10]
    };

Occ = (leave?[i == queue.First()]i -> atomic{tau{queue.Dequeue()} -> Skip}; Gate)
     []
     (appr?i -> atomic{tau{queue.Enqueue(i)} -> stop!queue.Last() -> Skip}; Occ);

System = (||| x:{0..N-1}@Train(x)) ||| Gate;
```

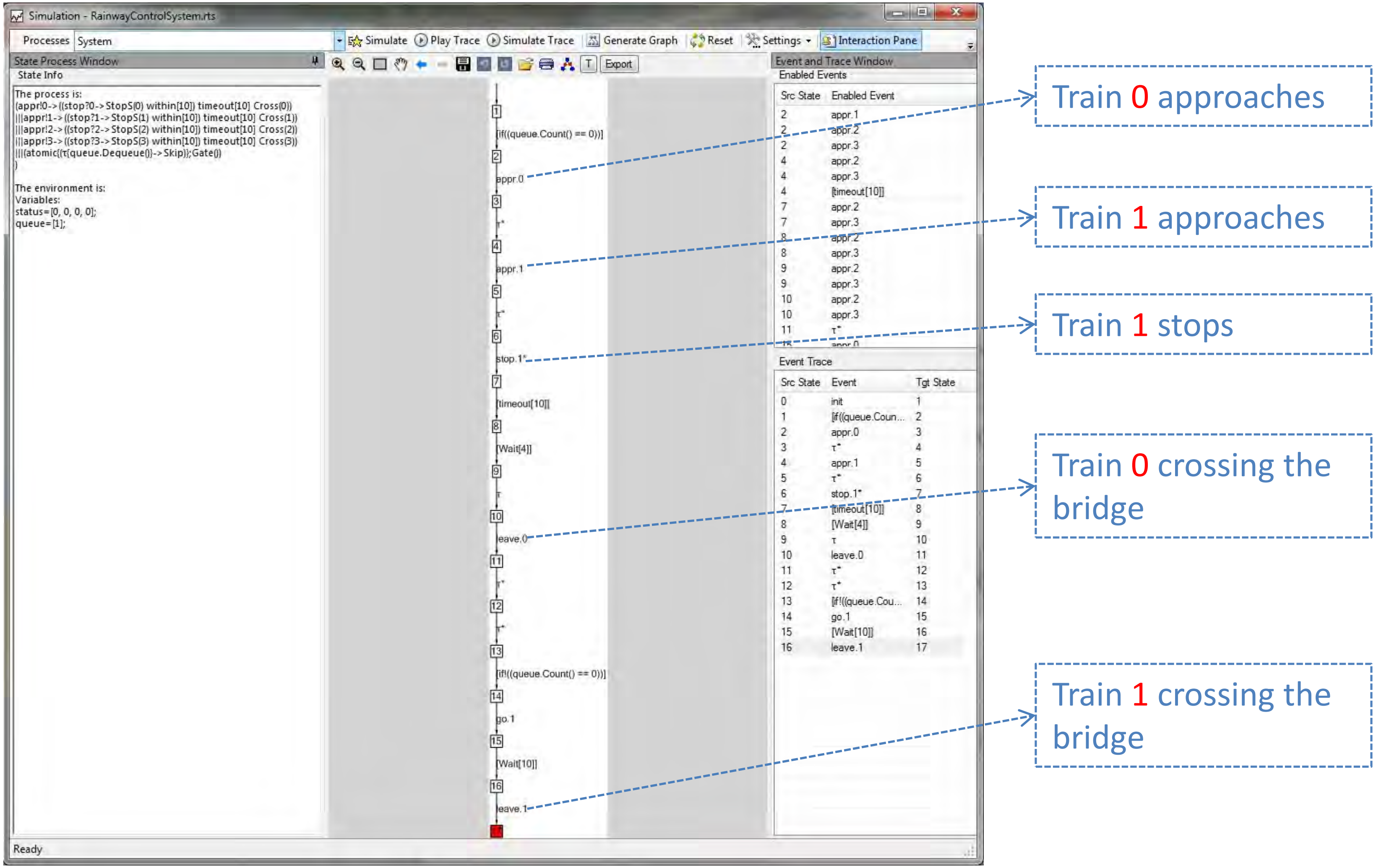
Declaration

Processes for Train model

Processes for Controller model

Whole system

Simulation



```
The process is:
(appr!0->((stop?0->StopS(0) within[10]) timeout[10] Cross(0))
|||appr!1->((stop?1->StopS(1) within[10]) timeout[10] Cross(1))
|||appr!2->((stop?2->StopS(2) within[10]) timeout[10] Cross(2))
|||appr!3->((stop?3->StopS(3) within[10]) timeout[10] Cross(3))
|||(atomic{(τ{queue.Dequeue()}->Skip)};Gate())
)

The environment is:
Variables:
status=[0, 0, 0, 0];
queue=[1];
```

Enabled Events

Src State	Enabled Event
2	appr.1
2	appr.2
2	appr.3
4	appr.2
4	appr.3
4	[timeout[10]]
7	appr.2
7	appr.3
8	appr.2
8	appr.3
9	appr.2
9	appr.3
10	appr.2
10	appr.3
11	τ*
15	appr.0

Event Trace

Src State	Event	Tgt State
0	init	1
1	[if((queue.Coun...	2
2	appr.0	3
3	τ*	4
4	appr.1	5
5	τ*	6
6	stop.1*	7
7	[timeout[10]]	8
8	[Wait[4]]	9
9	τ	10
10	leave.0	11
11	τ*	12
12	τ*	13
13	[if!((queue.Cou...	14
14	go.1	15
15	[Wait[10]]	16
16	leave.1	17

Train 0 approaches

Train 1 approaches

Train 1 stops

Train 0 crossing the bridge

Train 1 crossing the bridge

Verification

- Safety Property: there can never be more than one train crossing the bridge at the same time

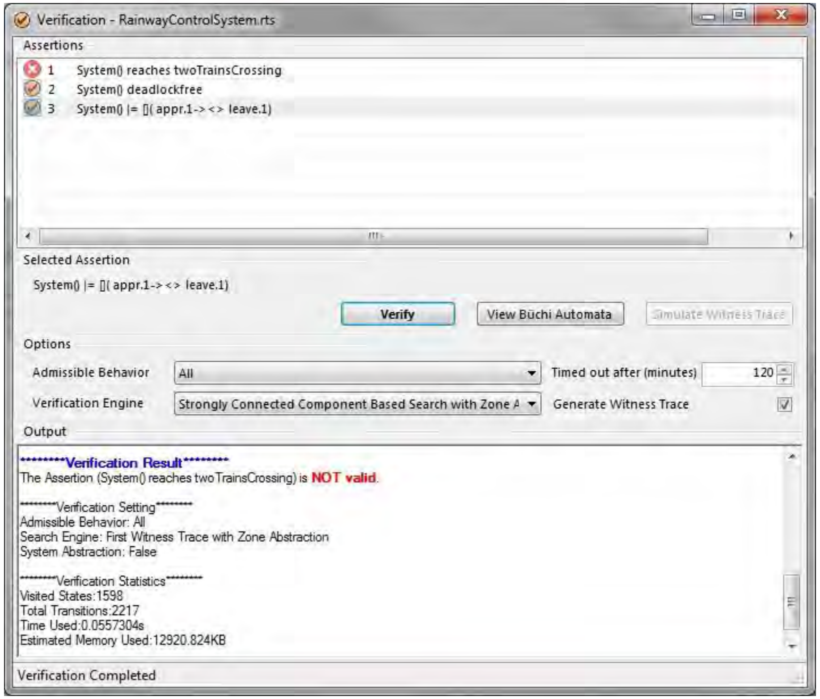
```
#define twoTrainsCrossing ((status[0]==1 && status[1]==1) || (status[0]==1 && status[2]==1)
                       || (status[0]==1 && status[3]==1) || (status[1]==1 && status[2]==1)
                       || (status[0]==1 && status[3]==1) || (status[2]==1 && status[3]==1));
#assert System reaches twoTrainsCrossing;
```

- Other Properties
  - Deadlock free

```
#assert System deadlockfree;
```

  - Whenever a train approaches the

```
#assert System |= [](appr.1 -> <>leave.1);
```



```
1    System() reaches twoTrainsCrossing
2    System() deadlockfree
3    System() |= []( appr.1-> <> leave.1)
```

Selected Assertion

System() |= [](appr.1-> <> leave.1)

Options

Admissible Behavior: All

Timed out after (minutes): 120

Verification Engine: Strongly Connected Component Based Search with Zone A

Generate Witness Trace ☑

Output

```
*********Verification Result*********
The Assertion (System() reaches twoTrainsCrossing) is NOT valid.

*********Verification Setting*********
Admissible Behavior: All
Search Engine: First Witness Trace with Zone Abstraction
System Abstraction: False

*********Verification Statistics*********
Visited States:1598
Total Transitions:2217
Time Used:0.0557304s
Estimated Memory Used:12920.824KB
```

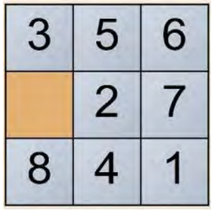
Verification Completed

Model Checking for Planning

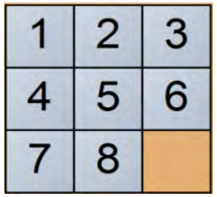
- *Model Checking as Services for Event Planning, Scheduling, Predication, Decision-Making* [FMSD'14]

Model checking as planning/problem-solving

```
//@@Sliding Game@@
//The following models the sliding game with the extra 'costs' complexity

var board[9]:{0..8} = [3,5,6,  // 0,1,2 :index
                       0,2,7,  // 3 4 5 :index
                       8,4,1]; // 6,7,8 :index
hvar empty:{0..8} = 3; //empty position is a secondary variable, no need to put it in the state space

var c = 0; // cost utility, e.g. costs 1 for left and right move, 2 for up, 0 for down

Game() = Left() [] Right() [] Up() [] Down();

Left() = [empty!=2 && empty!=5 && empty!=8] left                         // c=c+1
         {board[empty]=board[empty+1]; board[empty+1]=0; empty=empty+1; c++} -> Game();

Right() = [empty!=0 && empty!=3 && empty!=6] right
          {board[empty]=board[empty-1]; board[empty-1]=0; empty=empty-1; c++} -> Game();

Up() = [empty!=6&&empty!=7&&empty!=8] up
       {board[empty]=board[empty+3]; board[empty+3]=0; empty=empty+3; c=c+2} -> Game();

Down() = [empty!=0&&empty!=1&&empty!=2] down
         {board[empty]=board[empty-3]; board[empty-3]=0; empty=empty-3} -> Game();


#define goal board[0] == 1 && board[1] == 2 && board[2] == 3 &&
             board[3] == 4 && board[4] == 5 && board[5] == 6 &&
             board[6] == 7 && board[7] == 8 && board[8] == 0;

#assert Game() reaches goal with min(c);
```



3	5	6
	2	7
8	4	1



1	2	3
4	5	6
7	8	

The sliding game problem cont'd

8	7	6
0	4	1
2	5	3

(a) Hard1

8	0	6
5	4	7
2	3	1

(b) Hard2

8	5	6
7	2	3
4	1	0

(c) Most1

8	5	4
7	6	3
2	1	0

(d) Most2

8	2	1
3	6	4
0	5	7

(e) Rand1

4	1	7
8	0	3
5	6	2

(f) Rand2

Figure: Initial configurations of *the sliding game problem* instances

Experimental Results

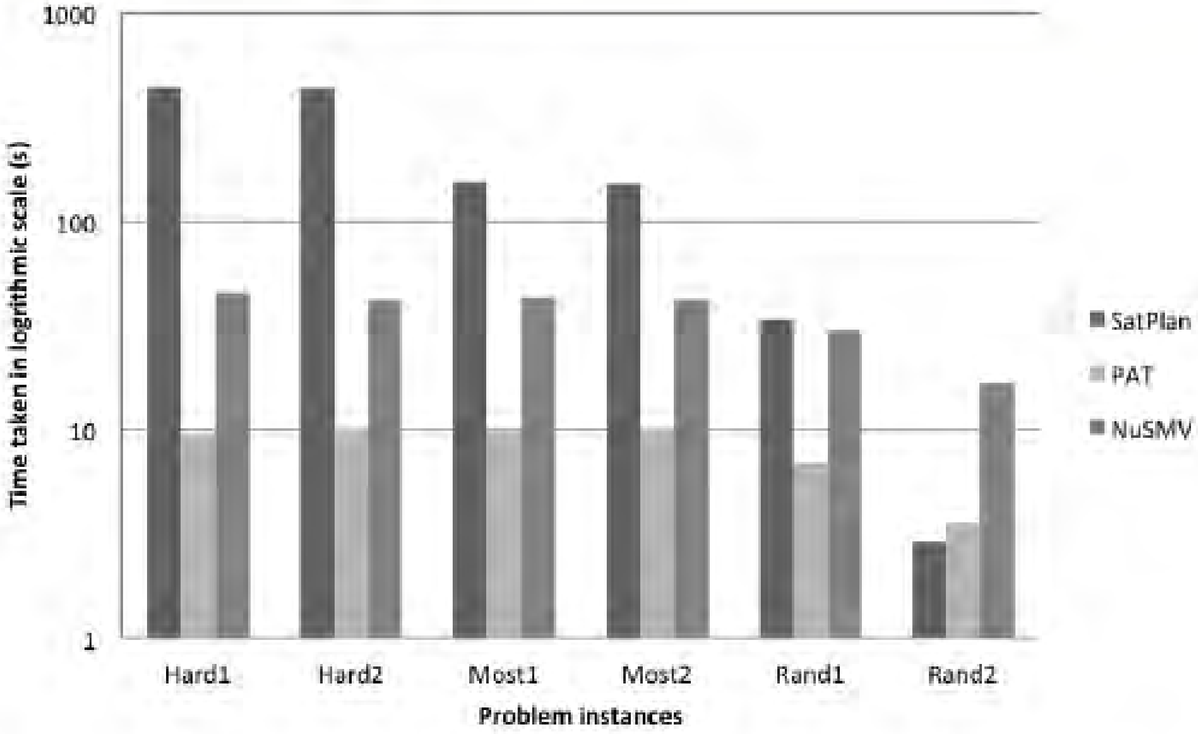


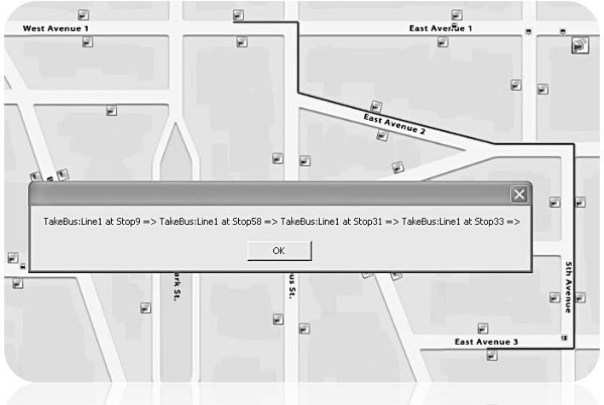
Figure: Execution time comparison of PAT, NuSMV and SatPlan on *the sliding game problem*, shown on a logarithm scale

Model Checking as Planning/Scheduling/Service:

Transport4You, an intelligent public transportation manager

ICSE 2011 SCORE Competition Project (PAT won FM Award)

- PAT model checker is used not only as a verification tool for the system design but also as a service that computes an optimal travel plan.



```
TakeBus:Line1 at Stop9 => TakeBus:Line1 at Stop58 => TakeBus:Line1 at Stop31 => TakeBus:Line1 at Stop33 =>
```

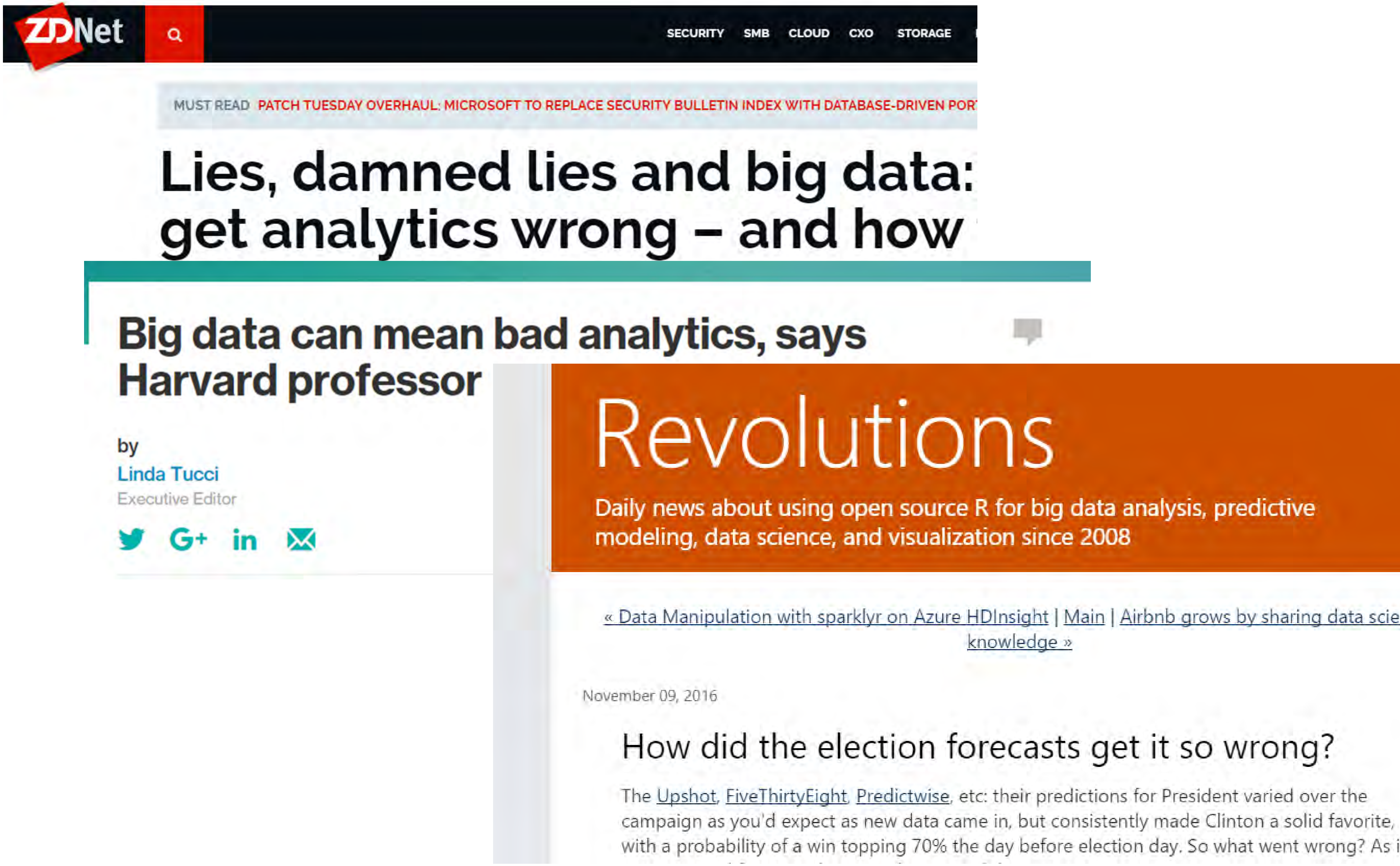
- 94 teams from 48 universities in 22 countries started the competition; Two winners (Formal Methods Award and Overall Award) were selected during the conference.

  PAT student team won Formal Method Award

Event-Strategy Analytics

- *Proabilistic Model Checking for Predication, Decision-Making*
- *Different from black-box ML based Data Analytics*

Data Analytics is a major IT industry but can lead to wrong decisions/predications



MUST READ PATCH TUESDAY OVERHAUL: MICROSOFT TO REPLACE SECURITY BULLETIN INDEX WITH DATABASE-DRIVEN POR

Lies, damned lies and big data: get analytics wrong – and how

Big data can mean bad analytics, says Harvard professor

by
Linda Tucci
Executive Editor

Revolutions

Daily news about using open source R for big data analysis, predictive modeling, data science, and visualization since 2008

« Data Manipulation with sparklyr on Azure HDInsight | Main | Airbnb grows by sharing data scie knowledge »

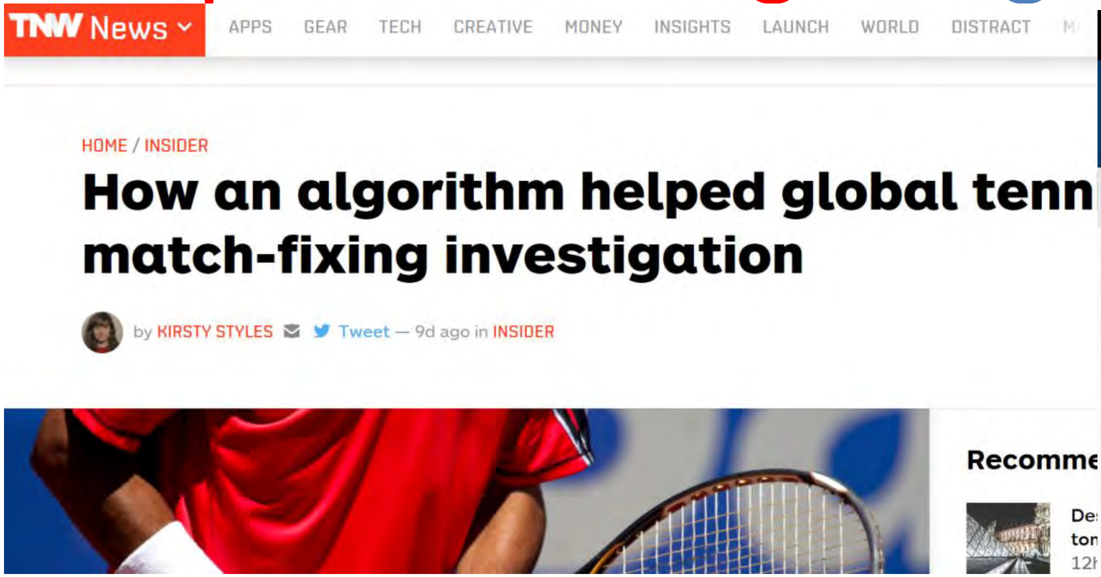
November 09, 2016

How did the election forecasts get it so wrong?

The Upshot, FiveThirtyEight, Predictwise, etc: their predictions for President varied over the campaign as you'd expect as new data came in, but consistently made Clinton a solid favorite, with a probability of a win topping 70% the day before election day. So what went wrong? As i

2016 news on tennis match-fixing

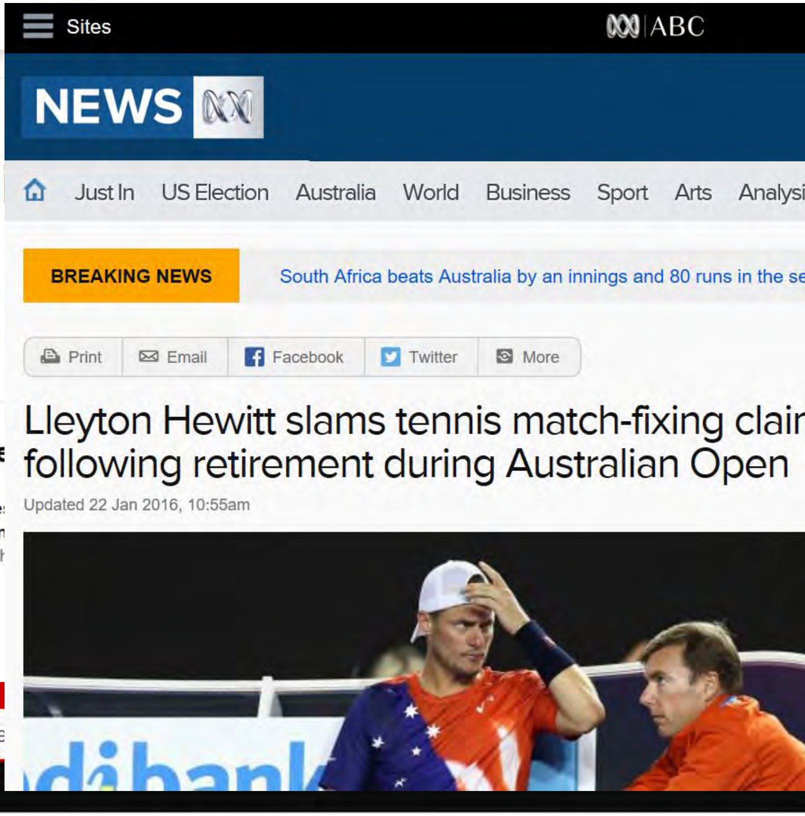
is proved wrong using formal methods



HOME / INSIDER

How an algorithm helped global tenn
match-fixing investigation

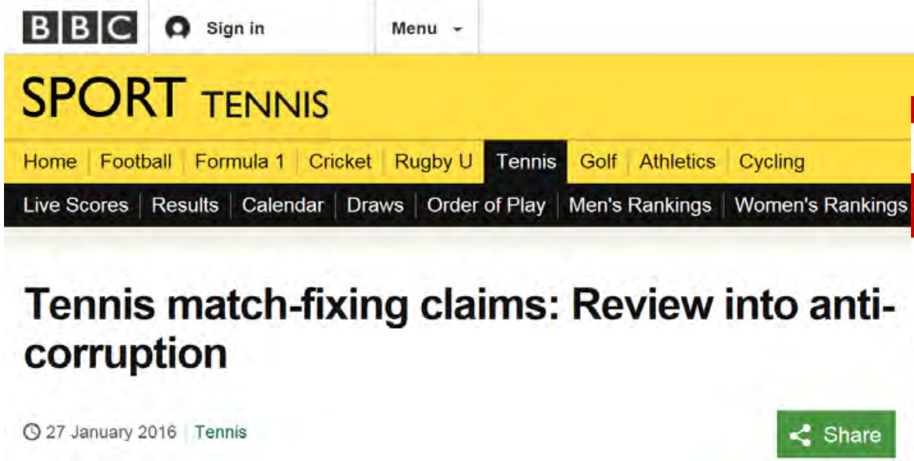
by KIRSTY STYLES Tweet — 9d ago in INSIDER



BREAKING NEWS South Africa beats Australia by an innings and 80 runs in the se

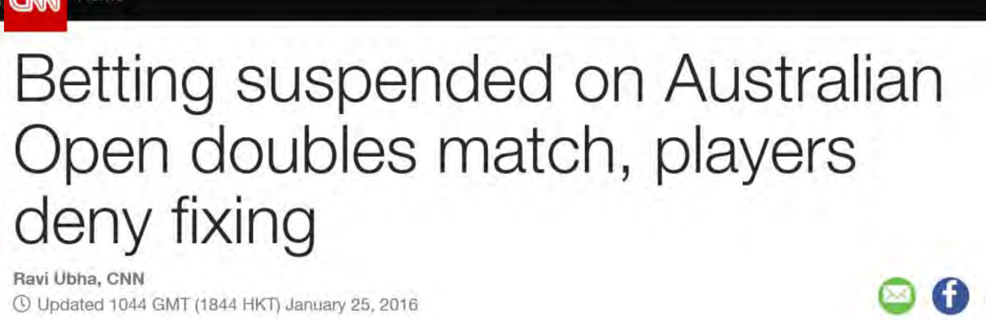
Lleyton Hewitt slams tennis match-fixing clair
following retirement during Australian Open

Updated 22 Jan 2016, 10:55am



Tennis match-fixing claims: Review into anti-corruption

27 January 2016 Tennis



BREAKING NEWS

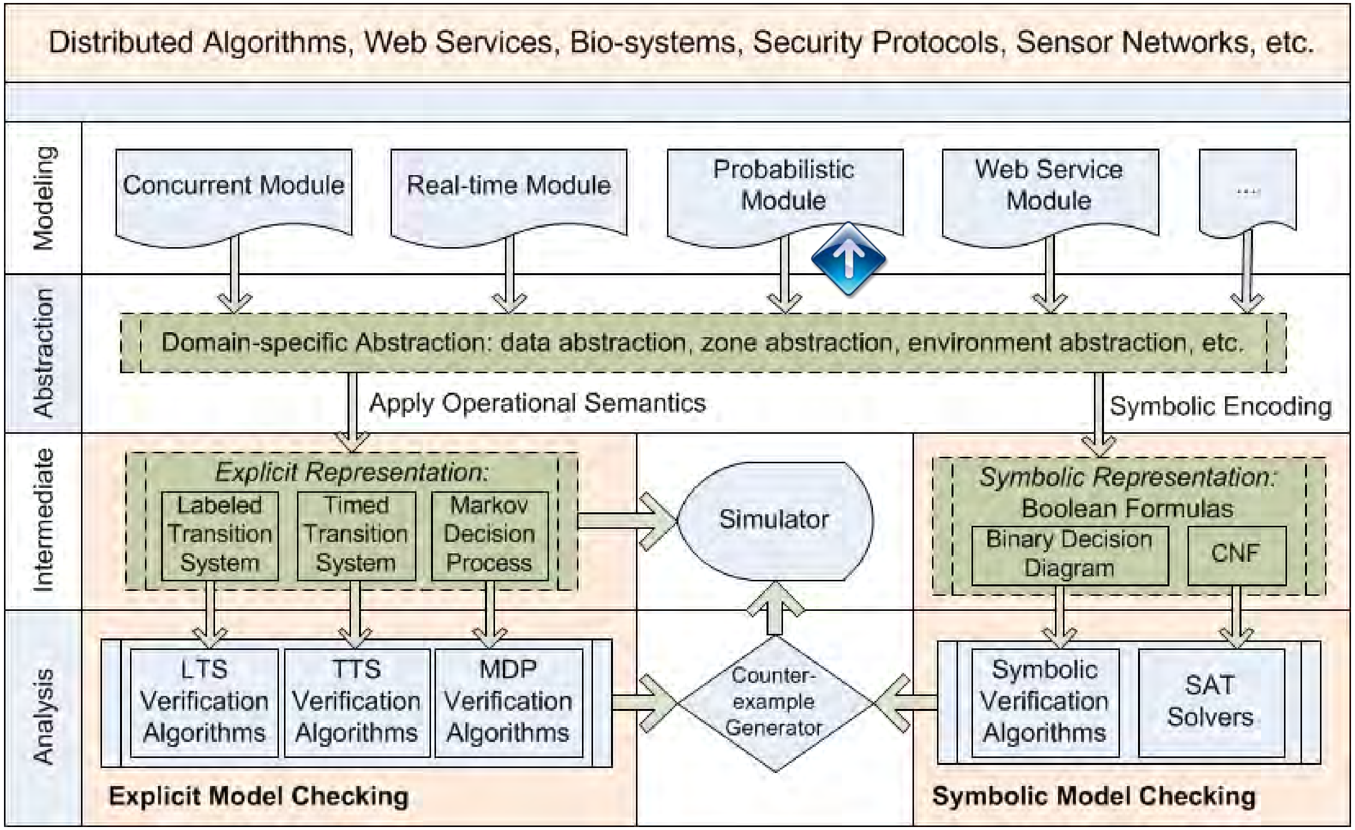
Police swoop on le

Betting suspended on Australian Open doubles match, players deny fixing

Ravi Ubha, CNN

Updated 1044 GMT (1844 HKT) January 25, 2016

Past 10 years work on Process Analysis Toolkit (PAT)


Distributed Algorithms, Web Services, Bio-systems, Security Protocols, Sensor Networks, etc.
Modeling
Abstraction
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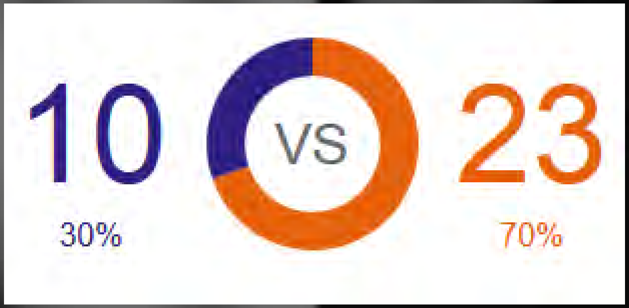
Probabilistic Model Checking [CAV’12]

- Syntax
  - Hierarchical concurrent systems with probabilistic choices
- Semantics
  - Markov decision processes
- Given a property, probabilistic model checking returns, instead of true or false
  - the maximum and minimum probability of satisfying the property.

Roger Federer

Rafael Nadal



- 17 Grand Slam
- 302 weeks at #1
- 6 ATP Year End Titles

- 14 Grand Slam
- 141 weeks at #1
- 0 ATP Year End Titles

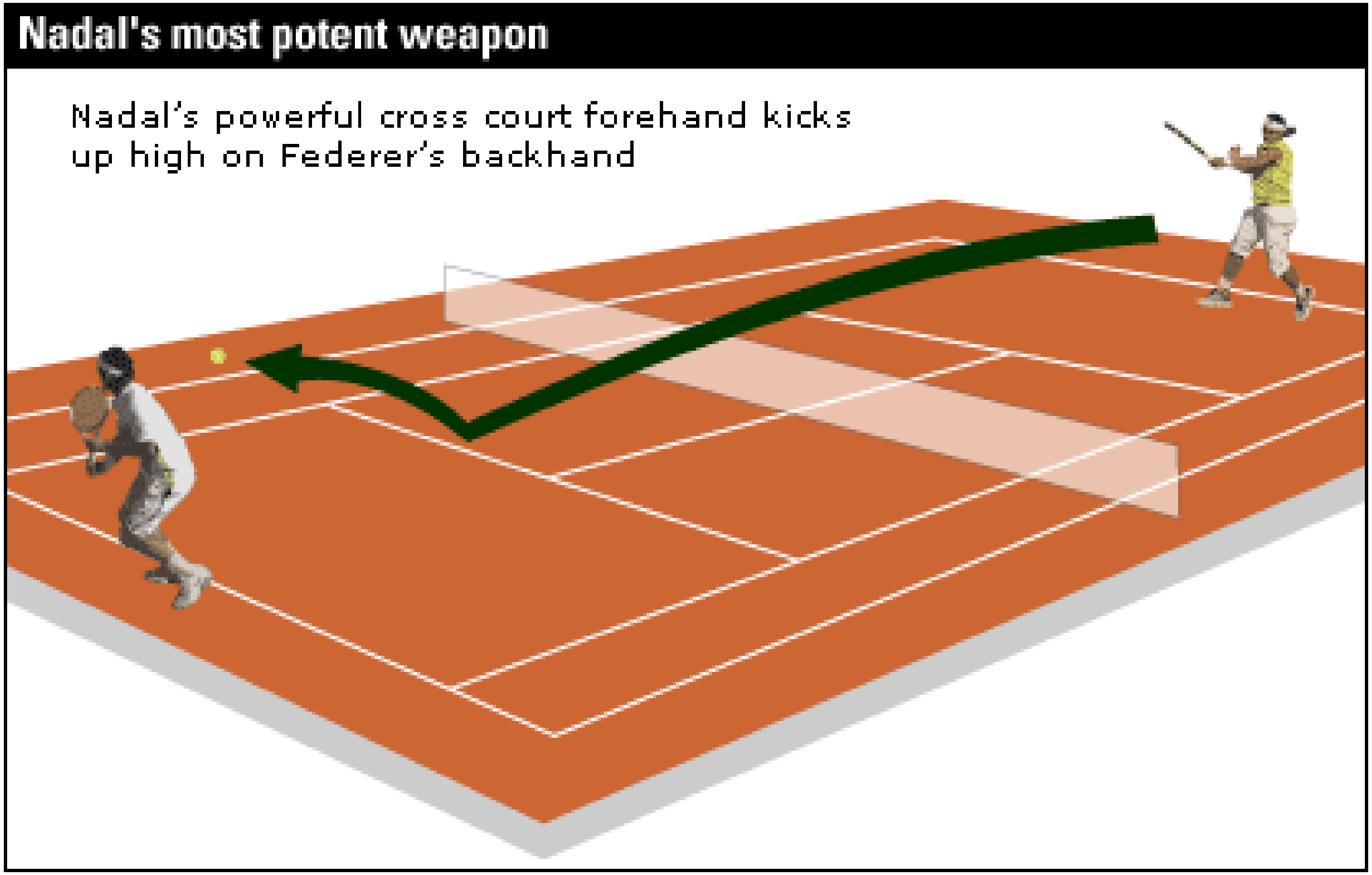
Before 2017

Roger Federer

Rafael Nadal

Strategy Analytics

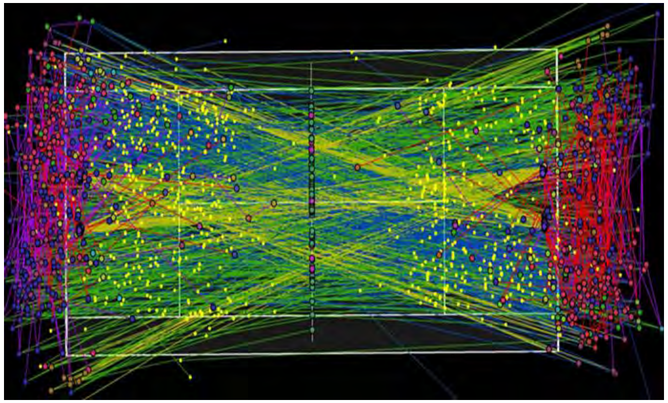
Nadal’s strategy

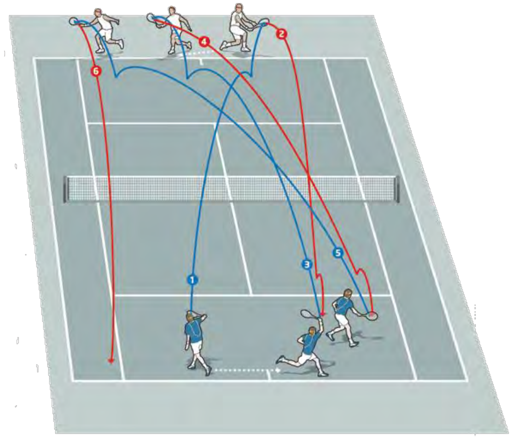


Nadal's most potent weapon

Nadal’s powerful cross court forehand kicks up high on Federer’s backhand

Model Description





```
//       *****
//      Player1: Right Handed
// de_ct  ad_ct
// -----+-----
// |    |    |
// | 1  |  2 |
// |    |    |
// |=========|
// |    |    |
// | 3  |  4 |
// |    |    |
// -----+----+
// ad_ct  de_ct
//      Player2: Right Handed
//       *****
```

Building a PAT Location based MDP model

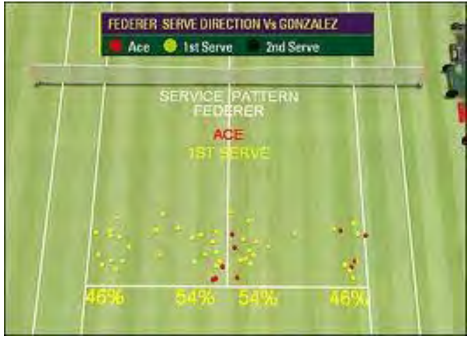
```
   Federer
 de_ct    ad_ct
 ------+------  baseline
 |  1  |  2  |
 |-----|-----|  service line
 |  3  |  4  |
 |===========|  net
 |  5  |  6  |
 |-----|-----|  service line
 |  7  |  8  |
 ------+------  baseline
 ad_ct    de_ct
    Nadal
```

```
"9" represents net error or
hit outside
```

```
enum{f_ad_ct, n_ad_ct, f_de_ct, n_de_ct};
//serve position: ad court or deuce court

enum{federer, nadal, na};

var turn = na; //serve turn;
var fscore = 0;
var nscore = 0;
var won = na;
var ball = 9;

WhoServe1st = []i:{f_de_ct,n_de_ct}@
       TossCoin{turn = i} -> Skip;

TieBreakGame = WhoServe1st;
       (FedererServe [] NadalServe);
```

Probability distribution on Federer Serve

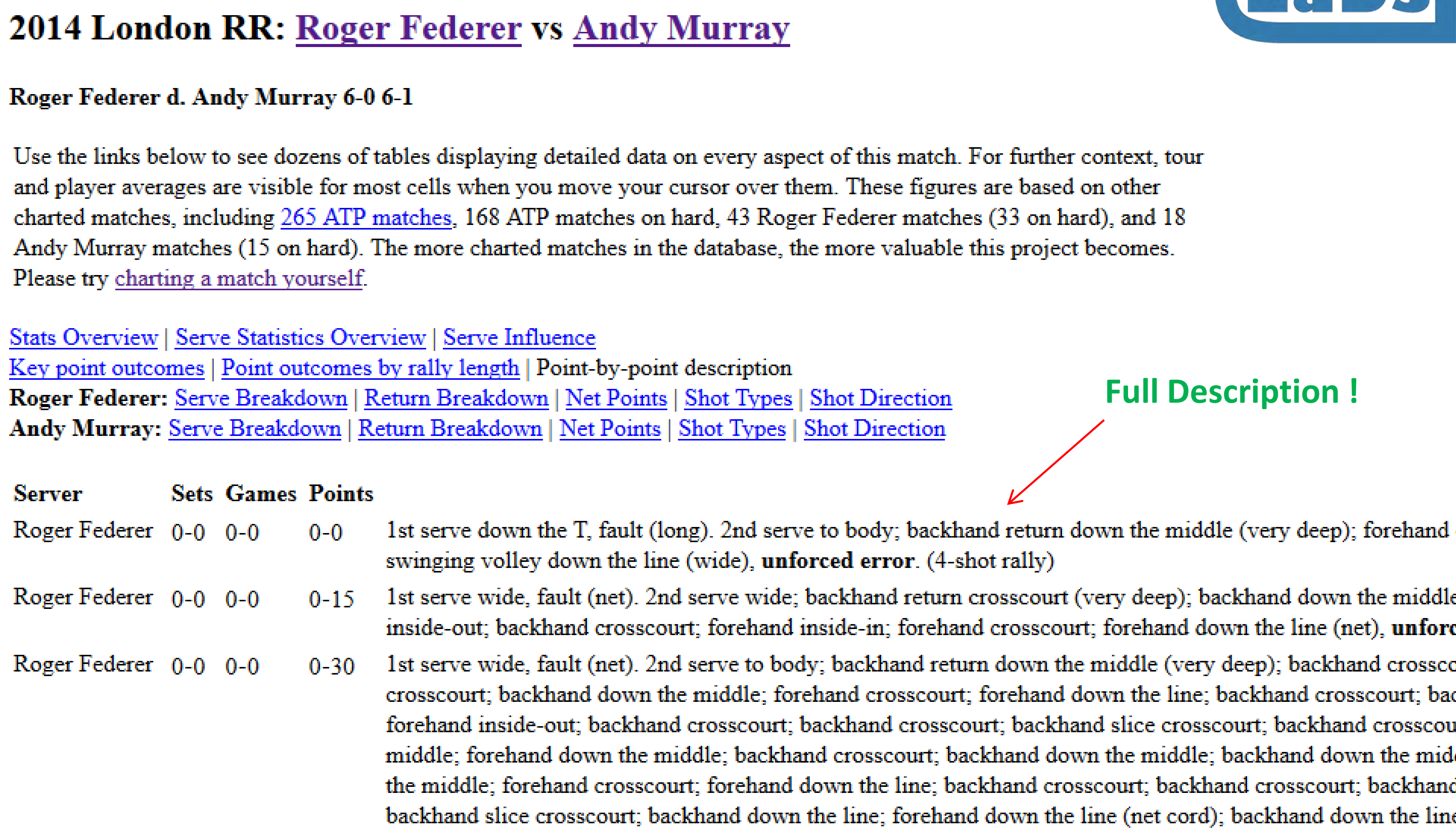
(parameters are based on the last 4 years online data)



```
De_Fed1stServe = pcase {
        23: ServeT_in{ball= 6} -> NadForehandR
        15: ServeT_err{ball=9} -> De_Fed2ndServe
        30: ServeWide_in{ball =6} -> NadBackhandR
        11: ServeWide_err{ball=9} -> De_Fed2ndServe
        14: ServeBody_in{ball=6} -> (NadBackhandR [] NadForehandR)
         7: ServeBody_err{ball=9} -> De_Fed2ndServe};

De_Fed2ndServe = pcase {
        15: ServeT_in{ball= 6} -> NadForehandR
         3: ServeT_err{ball=9} ->
             Fdoublefault{nscore++; if (nscore == 7) {won = nadal}
                                    else {if (turn == f_ad_ct){turn = f_de_ct}
        …                                 else {turn = n_ad_ct}}} -> NextPt
        33: ServeWide_in{ball =6} -> NadBackhandR
         2: ServeWide_err{ball=9} -> …
        …
NextPt = FedererServe [] NadalServe [] ([won != na] GameOver -> Skip);
```

```
   Federer
de_ct    ad_ct
------+------
|  1  |  2  |
|-----|-----|
|  3  |  4  |
|===========|
|  5  |  6  |
|-----|-----|
|  7  |  8  |
------+------
ad_ct    de_ct
    Nadal
```

"9" represents hit outside



2014 London RR: Roger Federer vs Andy Murray

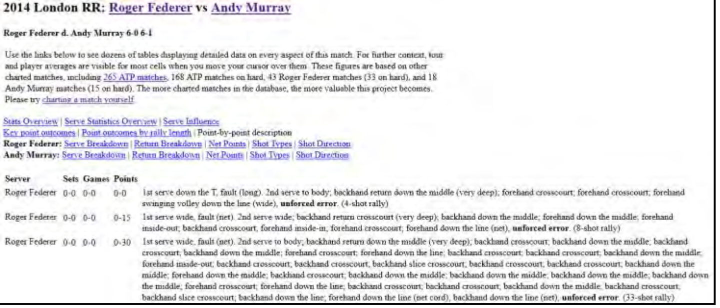
Roger Federer d. Andy Murray 6-0 6-1

Use the links below to see dozens of tables displaying detailed data on every aspect of this match. For further context, tour and player averages are visible for most cells when you move your cursor over them. These figures are based on other charted matches, including 265 ATP matches, 168 ATP matches on hard, 43 Roger Federer matches (33 on hard), and 18 Andy Murray matches (15 on hard). The more charted matches in the database, the more valuable this project becomes. Please try charting a match yourself.

Stats Overview | Serve Statistics Overview | Serve Influence
Key point outcomes | Point outcomes by rally length | Point-by-point description
Roger Federer: Serve Breakdown | Return Breakdown | Net Points | Shot Types | Shot Direction
Andy Murray: Serve Breakdown | Return Breakdown | Net Points | Shot Types | Shot Direction

Full Description !

Server	Sets	Games	Points	
Roger Federer	0-0	0-0	0-0	1st serve down the T, fault (long). 2nd serve to body; backhand return down the middle (very deep); forehand swinging volley down the line (wide), **unforced error**. (4-shot rally)
Roger Federer	0-0	0-0	0-15	1st serve wide, fault (net). 2nd serve wide; backhand return crosscourt (very deep); backhand down the middle inside-out; backhand crosscourt; forehand inside-in; forehand crosscourt; forehand down the line (net), **unforc**
Roger Federer	0-0	0-0	0-30	1st serve wide, fault (net). 2nd serve to body; backhand return down the middle (very deep); backhand crossco crosscourt; backhand down the middle; forehand crosscourt; forehand down the line; backhand crosscourt; bac forehand inside-out; backhand crosscourt; backhand crosscourt; backhand slice crosscourt; backhand crosscou middle; forehand down the middle; backhand crosscourt; backhand down the middle; backhand down the mid the middle; forehand crosscourt; forehand down the line; backhand crosscourt; backhand crosscourt; backhand backhand slice crosscourt; backhand down the line; forehand down the line (net cord); backhand down the line



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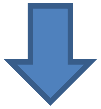
Roger Federer	0-0	0-0	0-15	1st serve wide, fault (net). 2nd serve wide; backhand return crosscourt (very deep); backhand down the middle; forehand down the middle; forehand inside-out; backhand crosscourt, forehand inside-in; forehand crosscourt; forehand down the line (net), **unforced error**. (8-shot rally)
Roger Federer	0-0	0-0	0-30	1st serve wide, fault (net). 2nd serve to body; backhand return down the middle (very deep); backhand crosscourt; backhand down the middle; backhand crosscourt; backhand down the middle; forehand crosscourt; forehand down the line; backhand crosscourt; backhand crosscourt; backhand down the middle; forehand inside-out; backhand crosscourt; backhand crosscourt; backhand slice crosscourt; backhand crosscourt; backhand crosscourt; backhand down the middle; forehand down the middle; backhand crosscourt; backhand down the middle; backhand down the middle; backhand down the middle; backhand down the middle; forehand crosscourt; forehand down the line; backhand crosscourt; backhand crosscourt; backhand down the middle; backhand crosscourt; backhand slice crosscourt; backhand down the line; forehand down the line (net cord), backhand down the line (net), **unforced error**. (33-shot rally)



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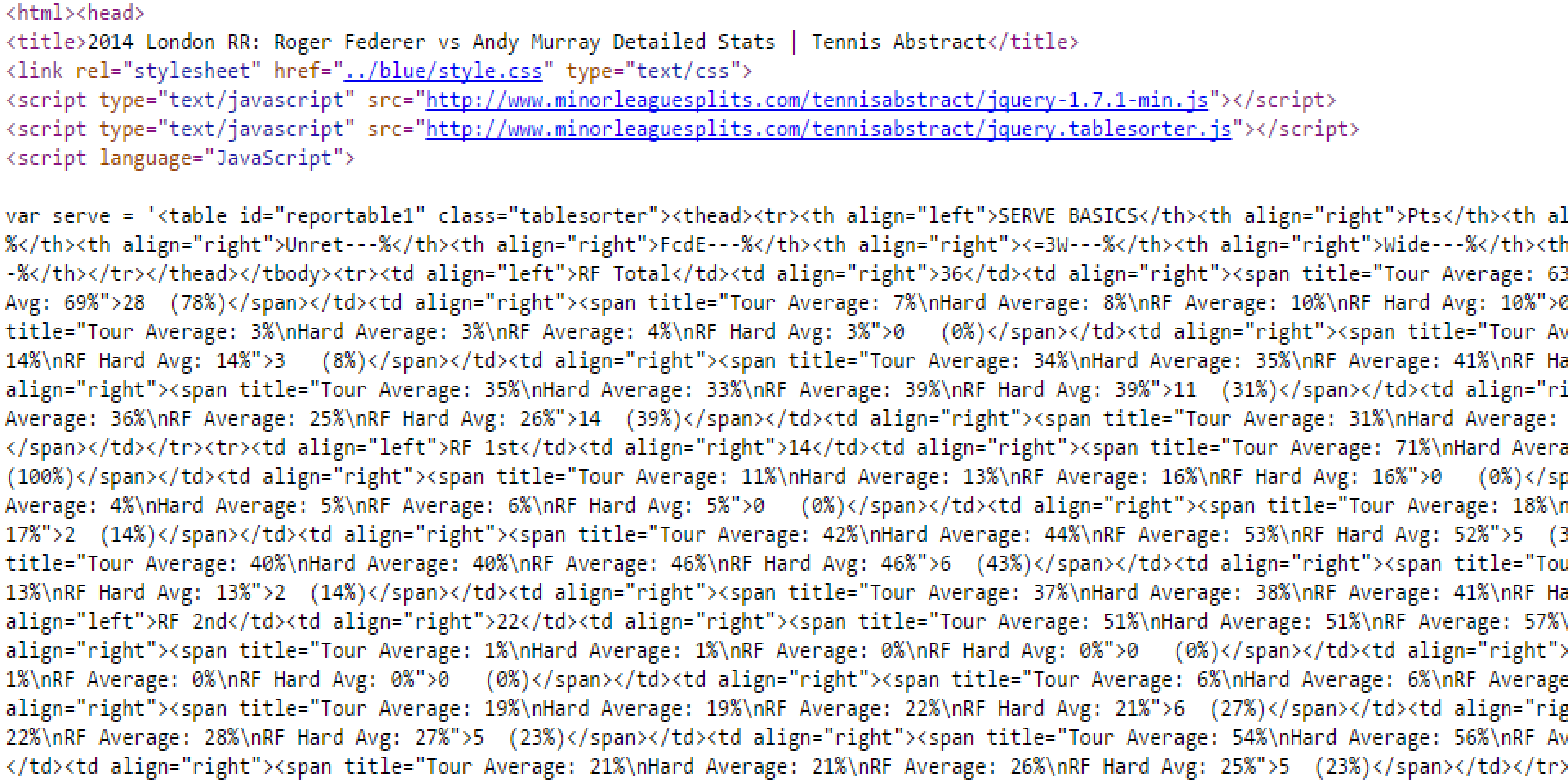

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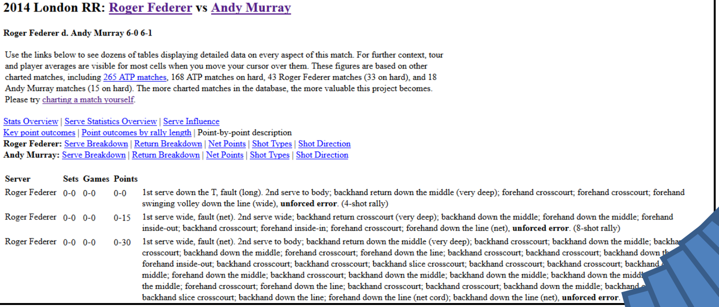

2014 London RR: Roger Federer vs Andy Murray

Roger Federer d. Andy Murray 6-0 6-1

Use the links below to see dozens of tables displaying detailed data on every aspect of this match. For further context, tour and player averages are visible for most cells when you move your cursor over them. These figures are based on other charted matches, including 265 ATP matches, 168 ATP matches on hard, 43 Roger Federer matches (33 on hard), and 18 Andy Murray matches (15 on hard). The more charted matches in the database, the more valuable this project becomes. Please try charting a match yourself.

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Roger Federer	0-0	0-0	0-15	1st serve wide, fault (net). 2nd serve wide; backhand return crosscourt (very deep); backhand down the middle; forehand down the middle; forehand inside-out; backhand crosscourt; forehand inside-in; forehand crosscourt; forehand down the line (net), **unforced error**. (8-shot rally)
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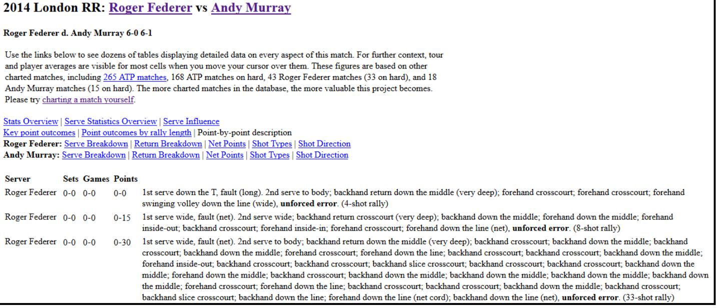

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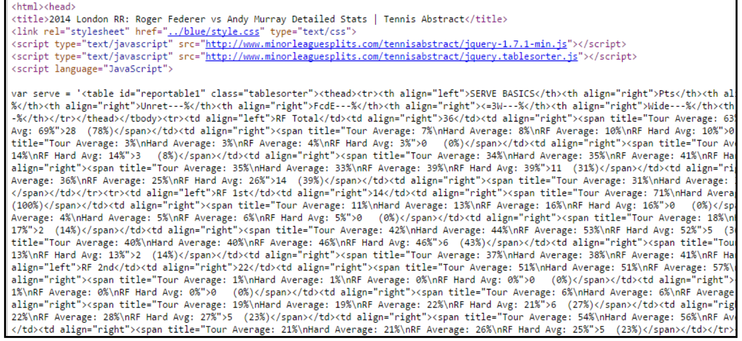

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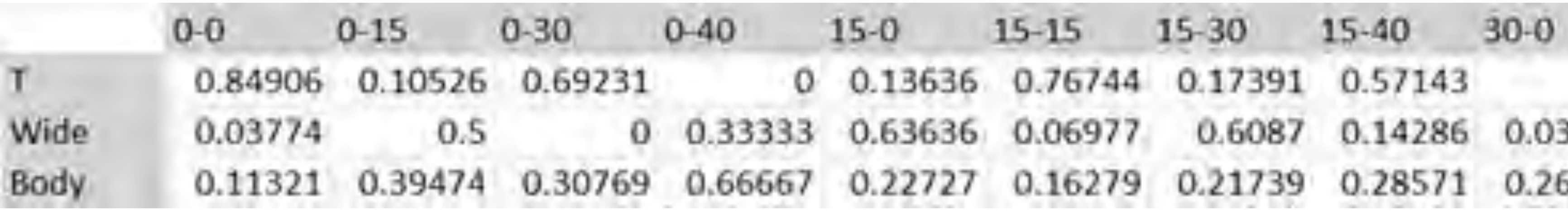
Extracting Information and Events Probability

Software to automate the process

Input data to model



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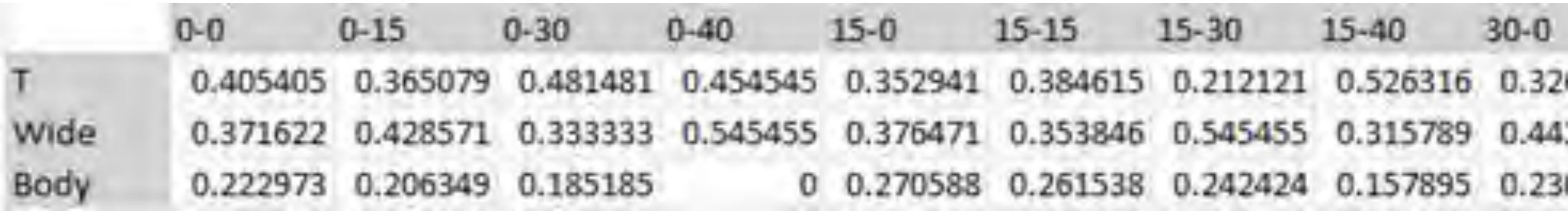
T	0.84906	0.10526	0.69231	0	0.13636	0.76744	0.17391	0.57143	
Wide	0.03774	0.5	0	0.33333	0.63636	0.06977	0.6087	0.14286	0.03
Body	0.11321	0.39474	0.30769	0.66667	0.22727	0.16279	0.21739	0.28571	0.26



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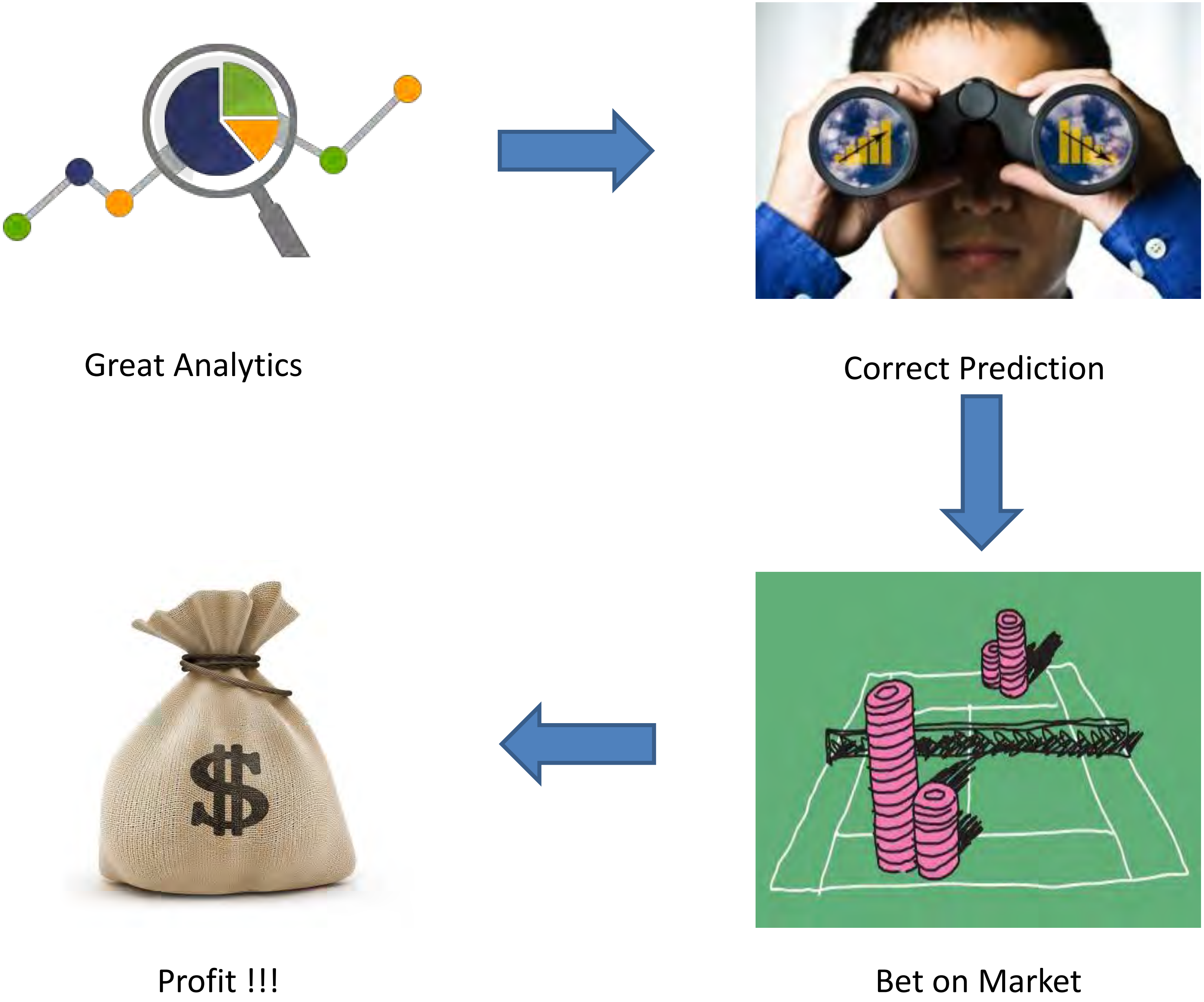
T	0.405405	0.365079	0.481481	0.454545	0.352941	0.384615	0.212121	0.526316	0.32
Wide	0.371622	0.428571	0.333333	0.545455	0.376471	0.353846	0.545455	0.315789	0.44
Body	0.222973	0.206349	0.185185	0	0.270588	0.261538	0.242424	0.157895	0.23

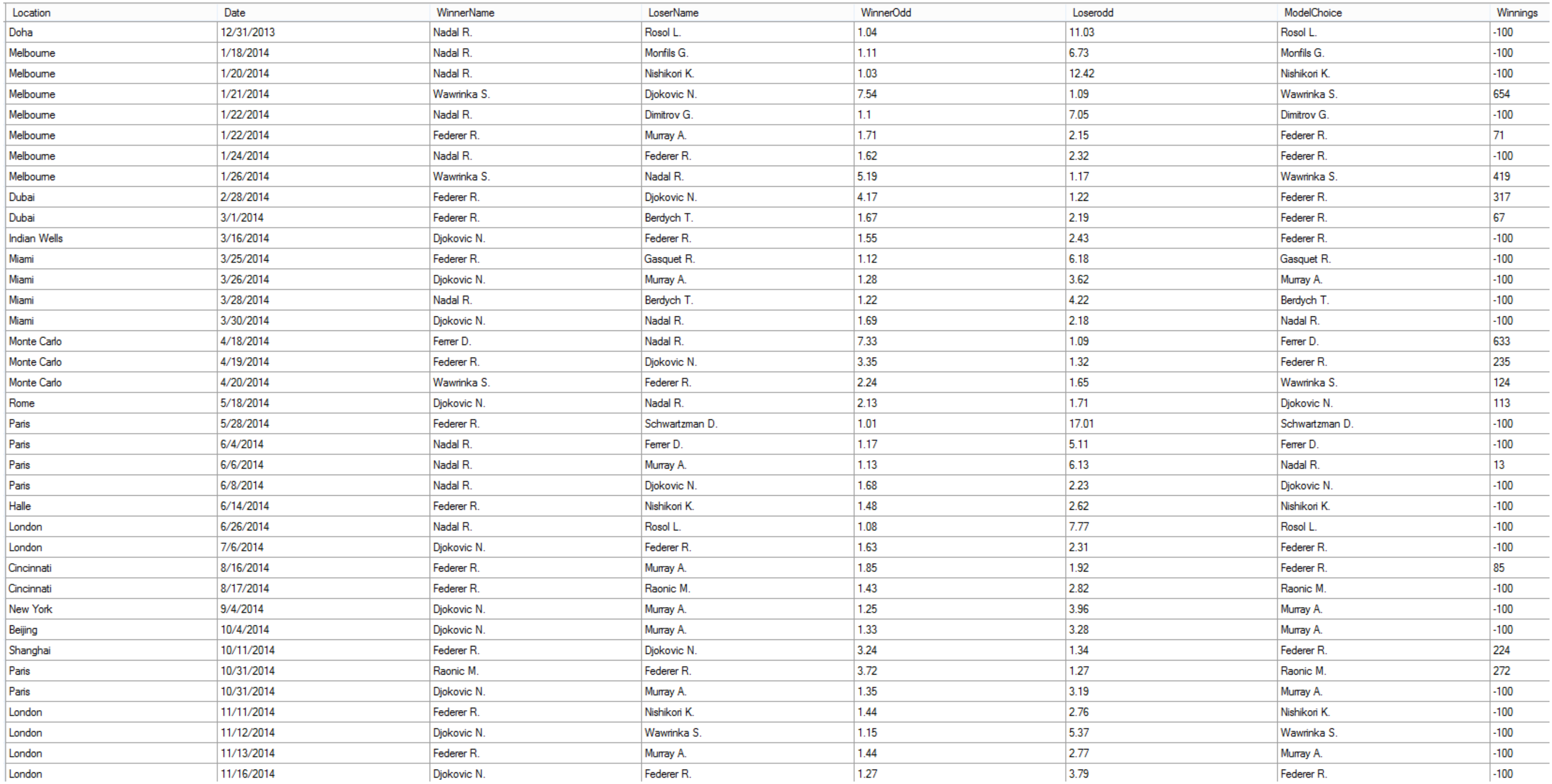


Great Analytics

Correct Prediction

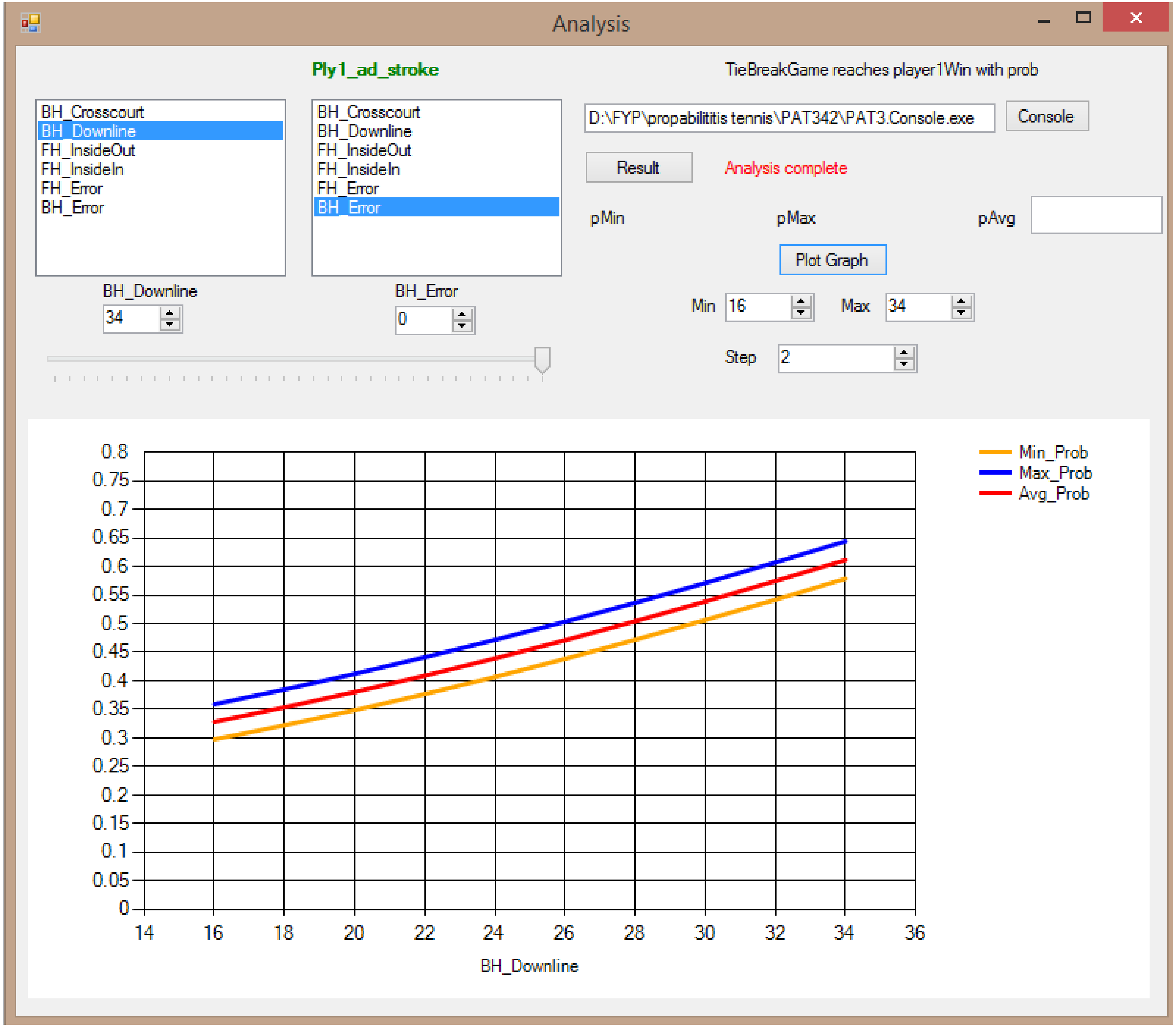
Bet on Market

Profit !!!



Location	Date	WinnerName	LoserName	WinnerOdd	Loserodd	ModelChoice	Winnings
Doha	12/31/2013	Nadal R.	Rosol L.	1.04	11.03	Rosol L.	-100
Melbourne	1/18/2014	Nadal R.	Monfils G.	1.11	6.73	Monfils G.	-100
Melbourne	1/20/2014	Nadal R.	Nishikori K.	1.03	12.42	Nishikori K.	-100
Melbourne	1/21/2014	Wawrinka S.	Djokovic N.	7.54	1.09	Wawrinka S.	654
Melbourne	1/22/2014	Nadal R.	Dimitrov G.	1.1	7.05	Dimitrov G.	-100
Melbourne	1/22/2014	Federer R.	Murray A.	1.71	2.15	Federer R.	71
Melbourne	1/24/2014	Nadal R.	Federer R.	1.62	2.32	Federer R.	-100
Melbourne	1/26/2014	Wawrinka S.	Nadal R.	5.19	1.17	Wawrinka S.	419
Dubai	2/28/2014	Federer R.	Djokovic N.	4.17	1.22	Federer R.	317
Dubai	3/1/2014	Federer R.	Berdych T.	1.67	2.19	Federer R.	67
Indian Wells	3/16/2014	Djokovic N.	Federer R.	1.55	2.43	Federer R.	-100
Miami	3/25/2014	Federer R.	Gasquet R.	1.12	6.18	Gasquet R.	-100
Miami	3/26/2014	Djokovic N.	Murray A.	1.28	3.62	Murray A.	-100
Miami	3/28/2014	Nadal R.	Berdych T.	1.22	4.22	Berdych T.	-100
Miami	3/30/2014	Djokovic N.	Nadal R.	1.69	2.18	Nadal R.	-100
Monte Carlo	4/18/2014	Ferrer D.	Nadal R.	7.33	1.09	Ferrer D.	633
Monte Carlo	4/19/2014	Federer R.	Djokovic N.	3.35	1.32	Federer R.	235
Monte Carlo	4/20/2014	Wawrinka S.	Federer R.	2.24	1.65	Wawrinka S.	124
Rome	5/18/2014	Djokovic N.	Nadal R.	2.13	1.71	Djokovic N.	113
Paris	5/28/2014	Federer R.	Schwartzman D.	1.01	17.01	Schwartzman D.	-100
Paris	6/4/2014	Nadal R.	Ferrer D.	1.17	5.11	Ferrer D.	-100
Paris	6/6/2014	Nadal R.	Murray A.	1.13	6.13	Nadal R.	13
Paris	6/8/2014	Nadal R.	Djokovic N.	1.68	2.23	Djokovic N.	-100
Halle	6/14/2014	Federer R.	Nishikori K.	1.48	2.62	Nishikori K.	-100
London	6/26/2014	Nadal R.	Rosol L.	1.08	7.77	Rosol L.	-100
London	7/6/2014	Djokovic N.	Federer R.	1.63	2.31	Federer R.	-100
Cincinnati	8/16/2014	Federer R.	Murray A.	1.85	1.92	Federer R.	85
Cincinnati	8/17/2014	Federer R.	Raonic M.	1.43	2.82	Raonic M.	-100
New York	9/4/2014	Djokovic N.	Murray A.	1.25	3.96	Murray A.	-100
Beijing	10/4/2014	Djokovic N.	Murray A.	1.33	3.28	Murray A.	-100
Shanghai	10/11/2014	Federer R.	Djokovic N.	3.24	1.34	Federer R.	224
Paris	10/31/2014	Raonic M.	Federer R.	3.72	1.27	Raonic M.	272
Paris	10/31/2014	Djokovic N.	Murray A.	1.35	3.19	Murray A.	-100
London	11/11/2014	Federer R.	Nishikori K.	1.44	2.76	Nishikori K.	-100
London	11/12/2014	Djokovic N.	Wawrinka S.	1.15	5.37	Wawrinka S.	-100
London	11/13/2014	Federer R.	Murray A.	1.44	2.77	Murray A.	-100
London	11/16/2014	Djokovic N.	Federer R.	1.27	3.79	Federer R.	-100

2014 betting simulation: 827/3700 = **22.35%**



Analysis

Ply1_ad_stroke

TieBreakGame reaches player1Win with prob

D:\FYP\propabilititis tennis\PAT342\PAT3.Console.exe

Analysis complete

BH_Downline 34

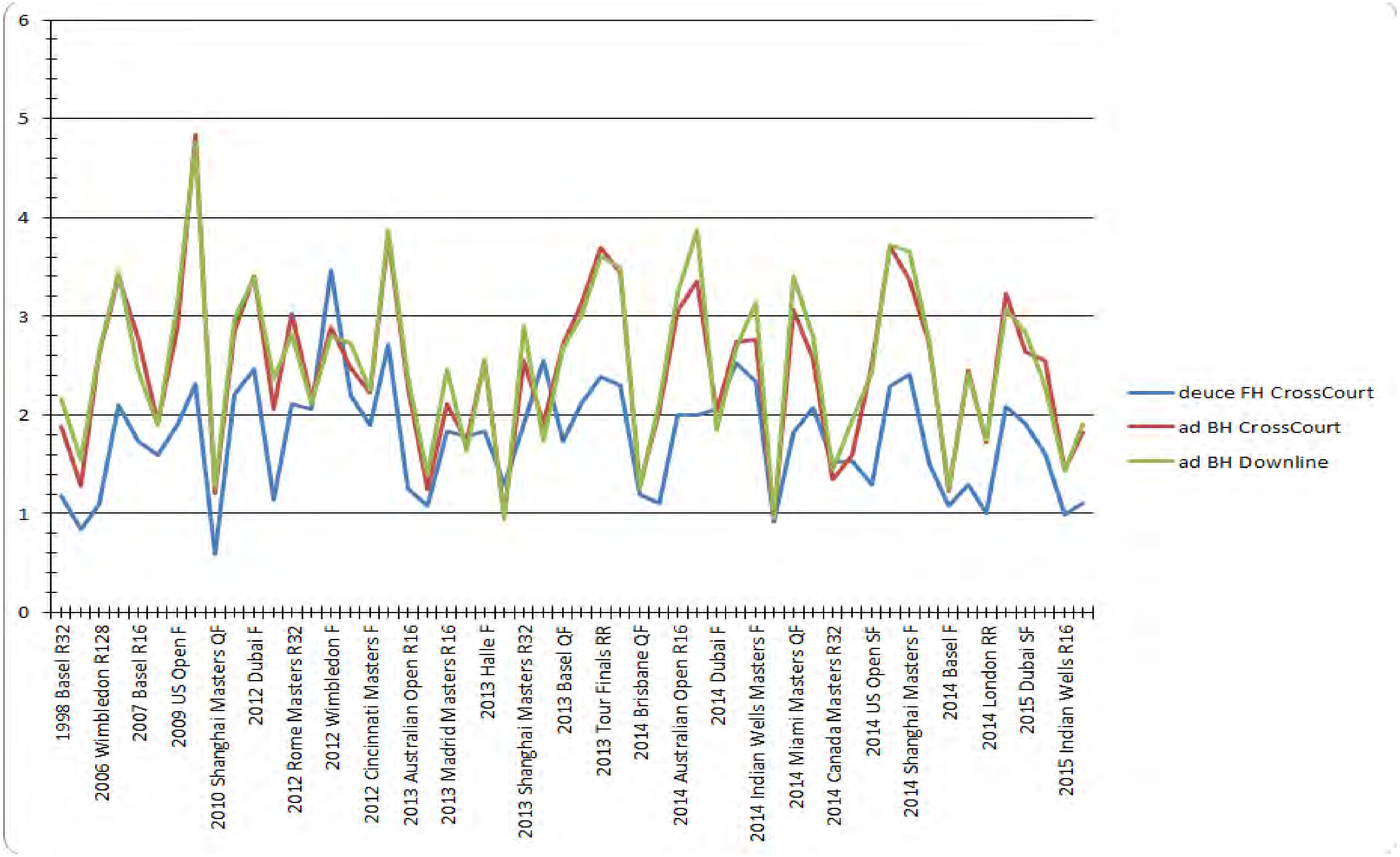
BH_Error 0

Min 16

Max 34

Step 2

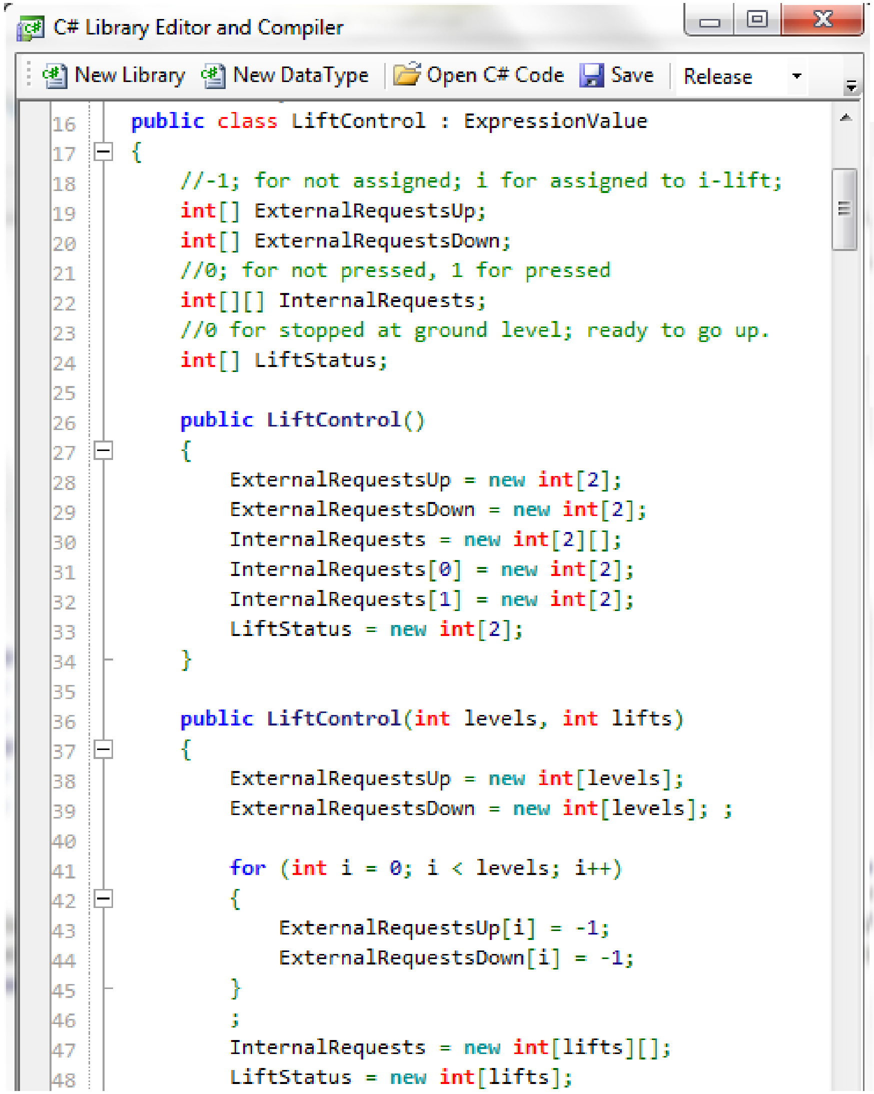
Finding the best action to improve: vs Right-handed players



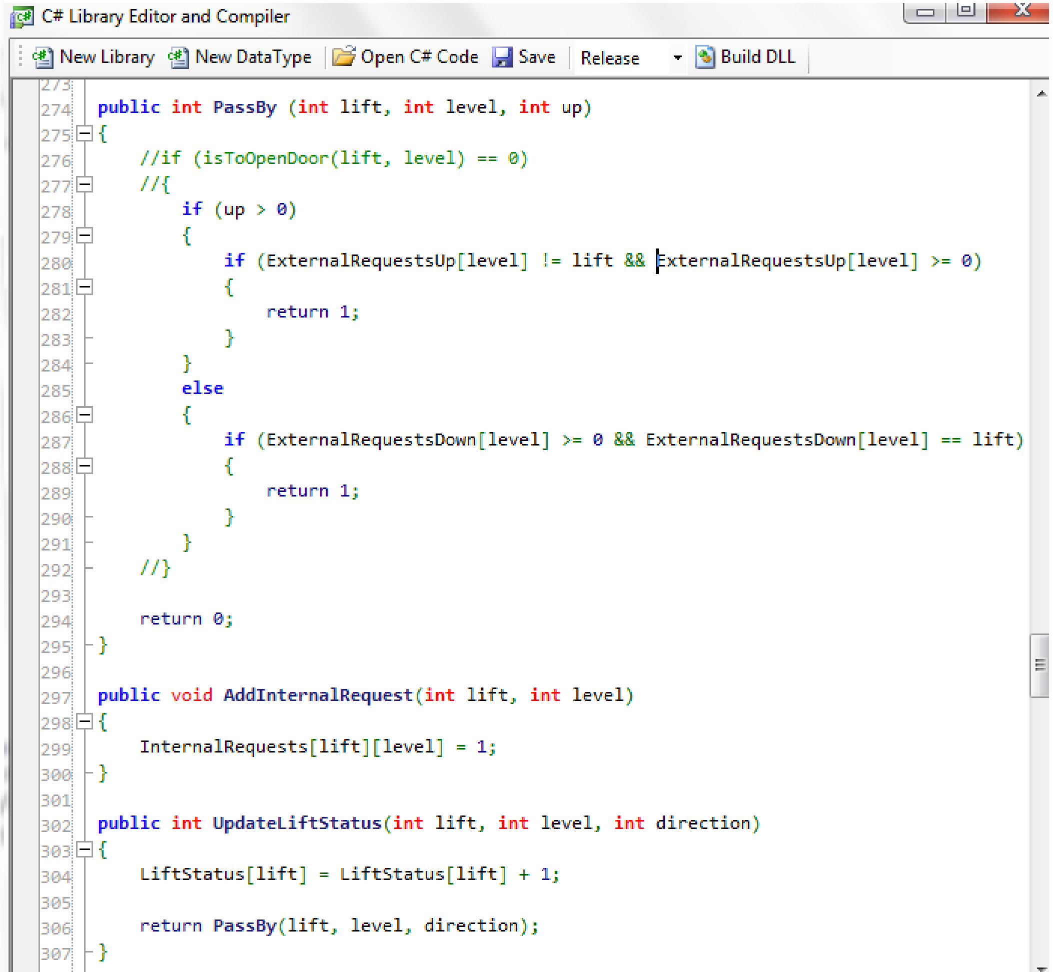
Combine Real-Time and Probability

Passing me without stopping!

Given the C# Program of a lift algorithm

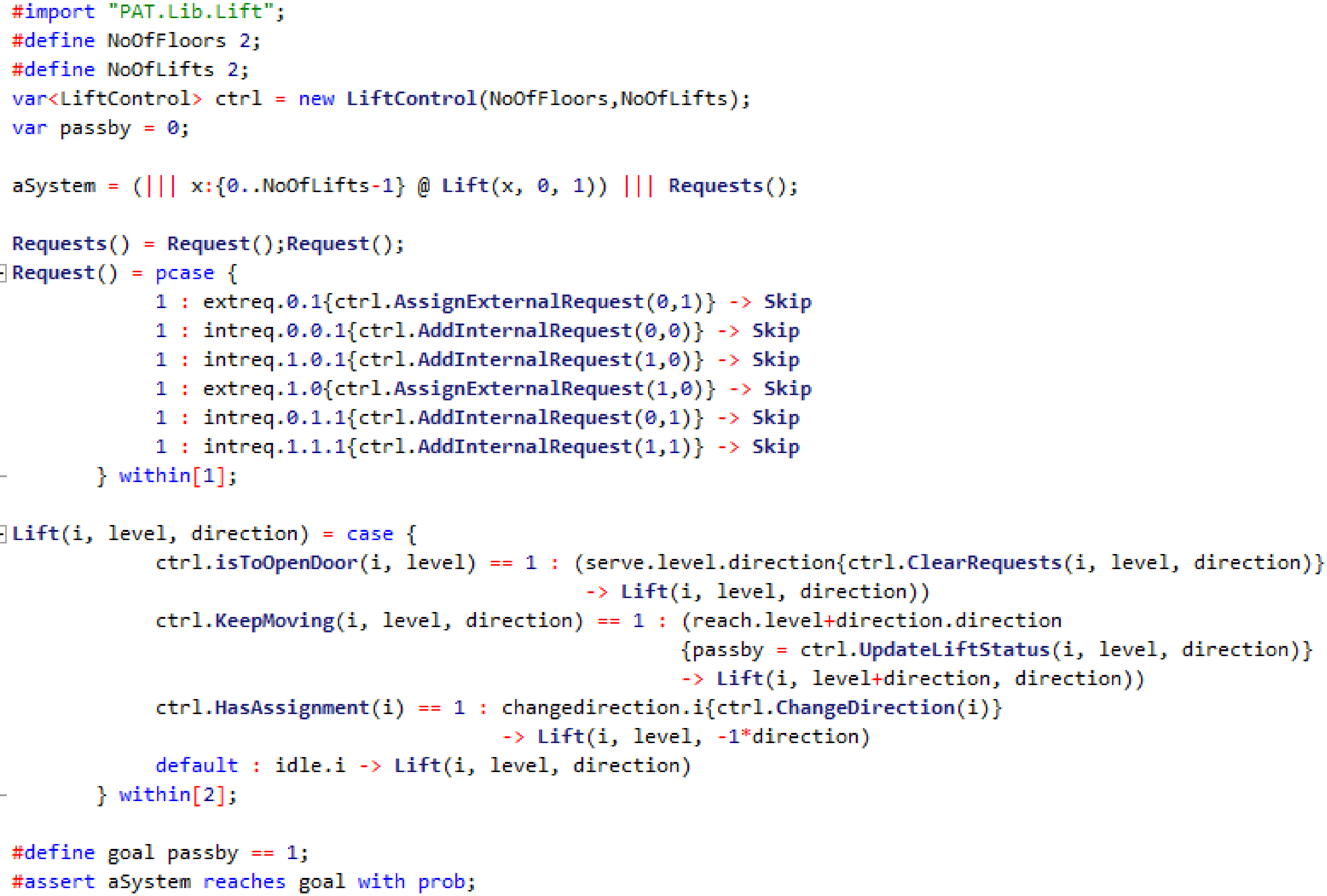


```
public class LiftControl : ExpressionValue
{
    //-1; for not assigned; i for assigned to i-lift;
    int[] ExternalRequestsUp;
    int[] ExternalRequestsDown;
    //0; for not pressed, 1 for pressed
    int[][] InternalRequests;
    //0 for stopped at ground level; ready to go up.
    int[] LiftStatus;

    public LiftControl()
    {
        ExternalRequestsUp = new int[2];
        ExternalRequestsDown = new int[2];
        InternalRequests = new int[2][];
        InternalRequests[0] = new int[2];
        InternalRequests[1] = new int[2];
        LiftStatus = new int[2];
    }

    public LiftControl(int levels, int lifts)
    {
        ExternalRequestsUp = new int[levels];
        ExternalRequestsDown = new int[levels]; ;

        for (int i = 0; i < levels; i++)
        {
            ExternalRequestsUp[i] = -1;
            ExternalRequestsDown[i] = -1;
        }
        ;
        InternalRequests = new int[lifts][];
        LiftStatus = new int[lifts];
```



```
public int PassBy (int lift, int level, int up)
{
    //if (isToOpenDoor(lift, level) == 0)
    //{
        if (up > 0)
        {
            if (ExternalRequestsUp[level] != lift && ExternalRequestsUp[level] >= 0)
            {
                return 1;
            }
        }
        else
        {
            if (ExternalRequestsDown[level] >= 0 && ExternalRequestsDown[level] == lift)
            {
                return 1;
            }
        }
    //}

    return 0;
}

public void AddInternalRequest(int lift, int level)
{
    InternalRequests[lift][level] = 1;
}

public int UpdateLiftStatus(int lift, int level, int direction)
{
    LiftStatus[lift] = LiftStatus[lift] + 1;

    return PassBy(lift, level, direction);
}
```

PAT checking the C# program with time+probability



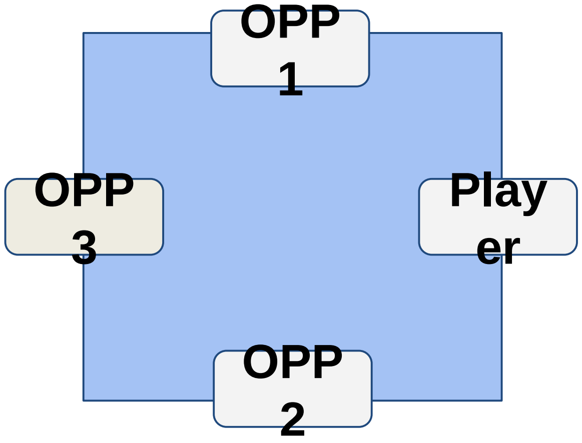
```
#import "PAT.Lib.Lift";
#define NoOfFloors 2;
#define NoOfLifts 2;
var<LiftControl> ctrl = new LiftControl(NoOfFloors,NoOfLifts);
var passby = 0;

aSystem = (||| x:{0..NoOfLifts-1} @ Lift(x, 0, 1)) ||| Requests();

Requests() = Request();Request();
Request() = pcase {
            1 : extreq.0.1{ctrl.AssignExternalRequest(0,1)} -> Skip
            1 : intreq.0.0.1{ctrl.AddInternalRequest(0,0)} -> Skip
            1 : intreq.1.0.1{ctrl.AddInternalRequest(1,0)} -> Skip
            1 : extreq.1.0{ctrl.AssignExternalRequest(1,0)} -> Skip
            1 : intreq.0.1.1{ctrl.AddInternalRequest(0,1)} -> Skip
            1 : intreq.1.1.1{ctrl.AddInternalRequest(1,1)} -> Skip
       } within[1];

Lift(i, level, direction) = case {
            ctrl.isToOpenDoor(i, level) == 1 : (serve.level.direction{ctrl.ClearRequests(i, level, direction)}
                                                -> Lift(i, level, direction))
            ctrl.KeepMoving(i, level, direction) == 1 : (reach.level+direction.direction
                                                        {passby = ctrl.UpdateLiftStatus(i, level, direction)}
                                                        -> Lift(i, level+direction, direction))
            ctrl.HasAssignment(i) == 1 : changedirection.i{ctrl.ChangeDirection(i)}
                                         -> Lift(i, level, -1*direction)
            default : idle.i -> Lift(i, level, direction)
       } within[2];

#define goal passby == 1;
#assert aSystem reaches goal with prob;
```

Probabilistic Model Checking + Learning
4-Player Kuhn Poker

- Simplified Poker Game
- Probabilistic in Nature
- Requires Opponent Learning

4-Player Kuhn Poker: Rules

- 4 Players
- 5 Cards
  - TEN (lowest value) to ACE (highest value)

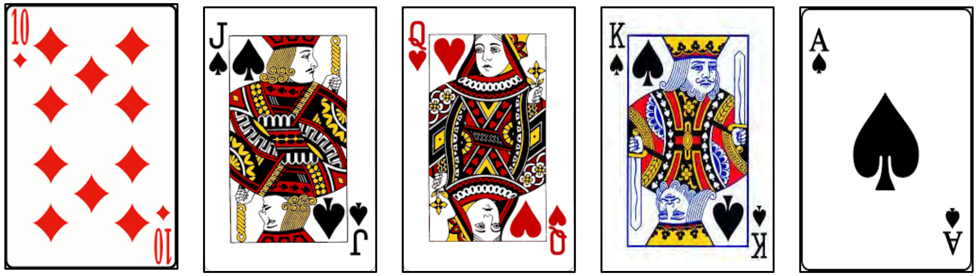


OPP 1

OPP 3

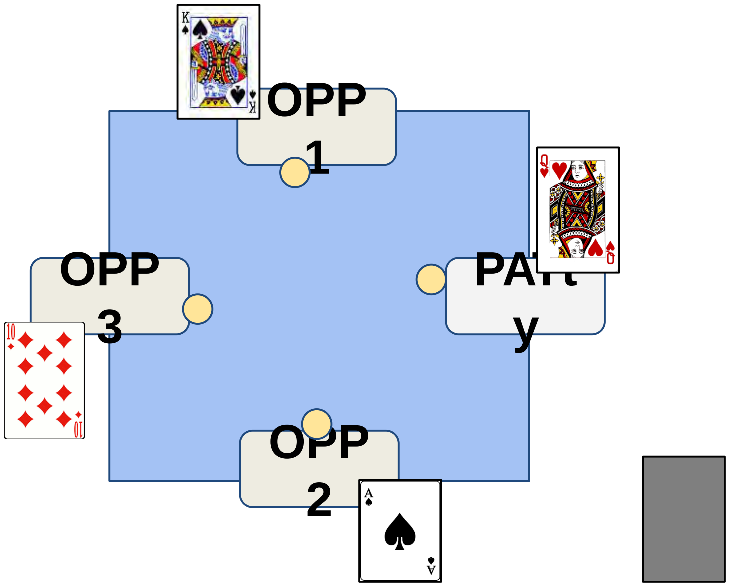
Player

OPP 2



4-Player Kuhn Poker: Rules

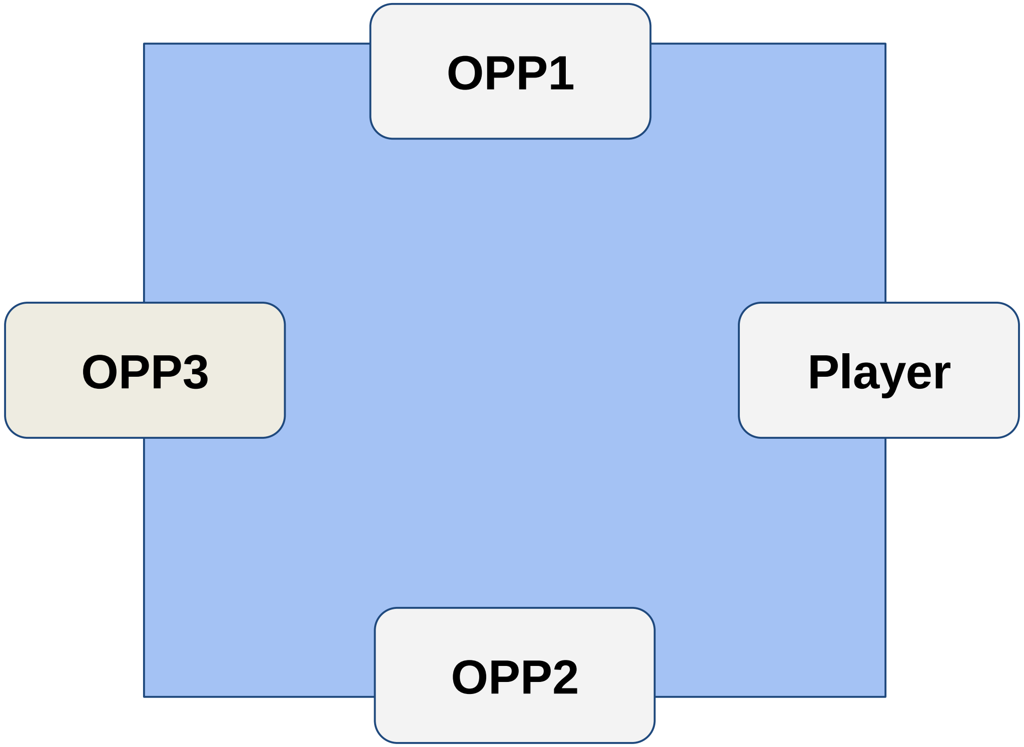
- Each hand
  - every player puts a chip down
  - each player is dealt a card
  - each player can choose to bet or not bet during their turn



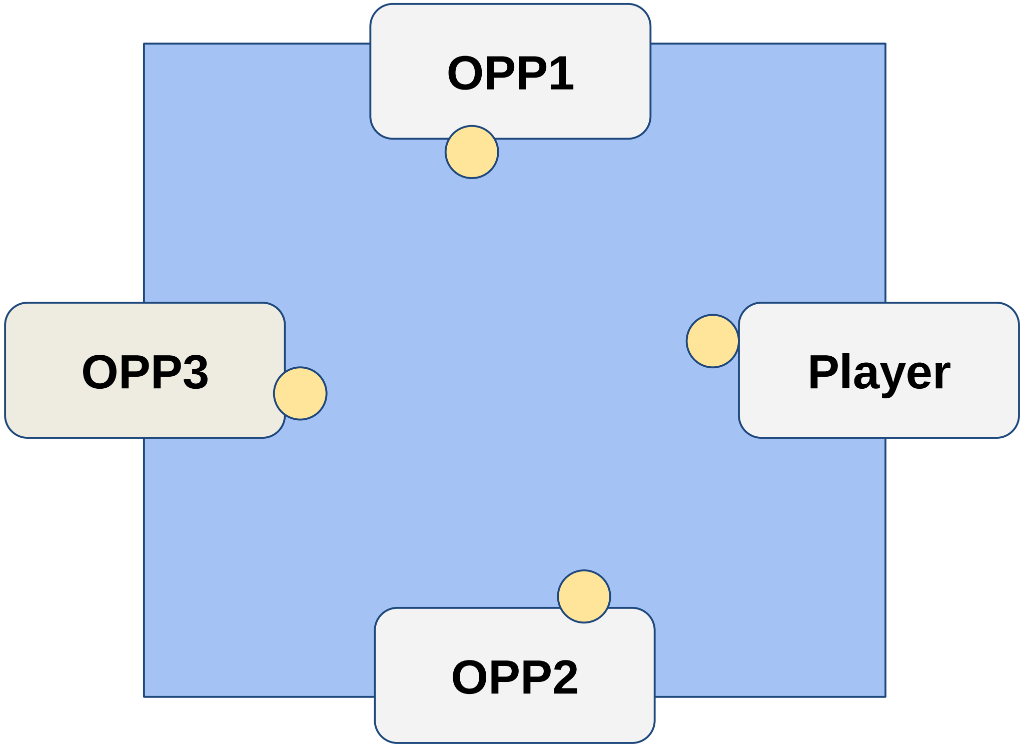
4-Player Kuhn Poker: Rules

- Game ends when:
  - All players don’t Bet
  - Some player has Bet, and all players have responded to the Bet
- Player who bets with highest card wins

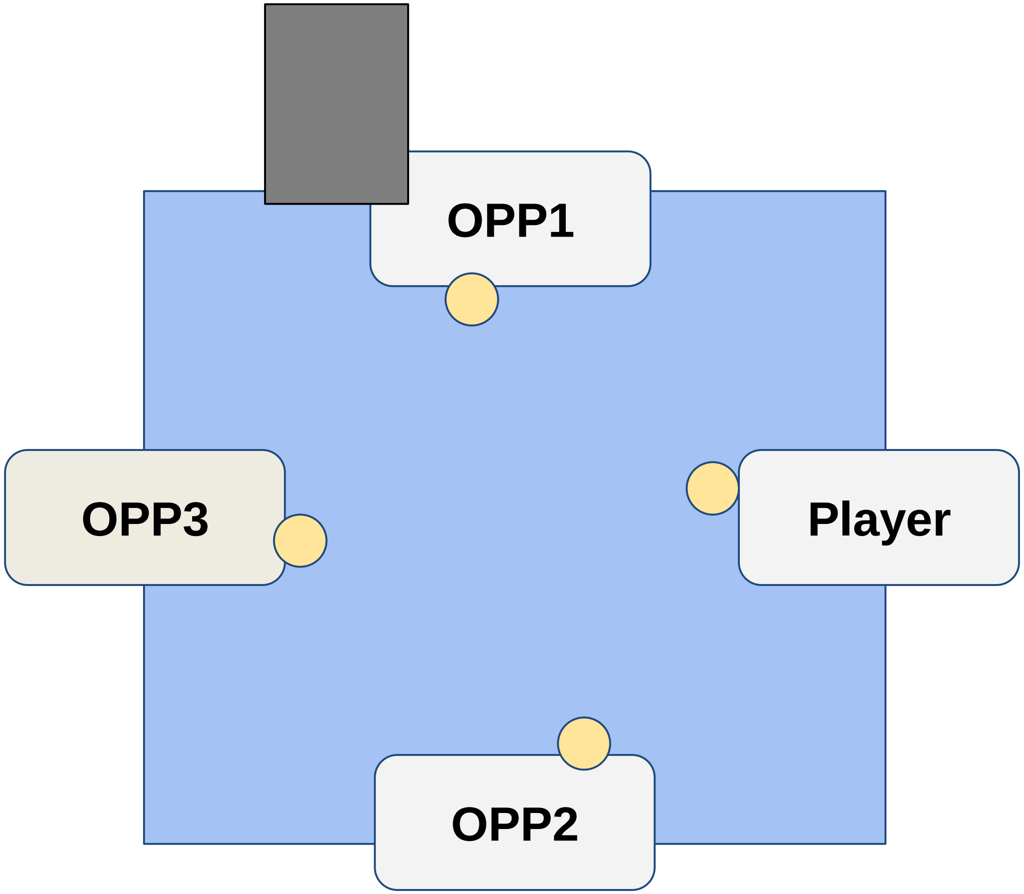
4-Player Kuhn Poker: Example



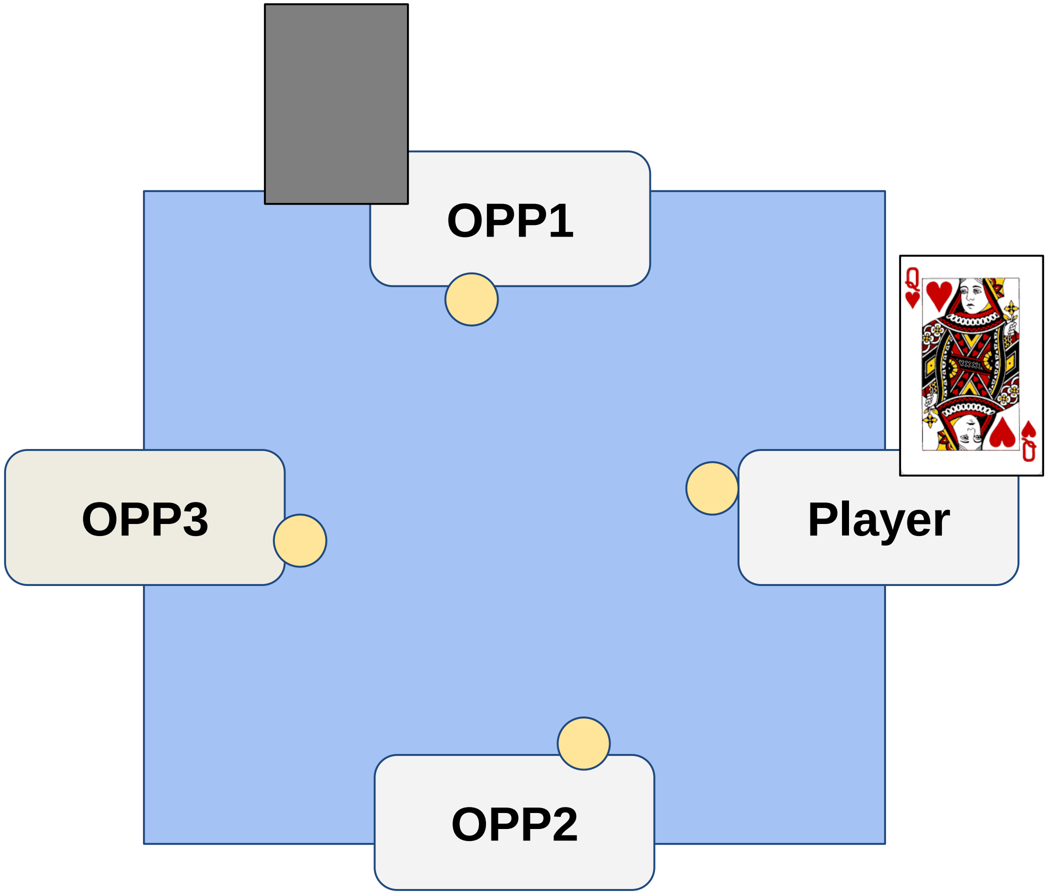
4-Player Kuhn Poker: Example



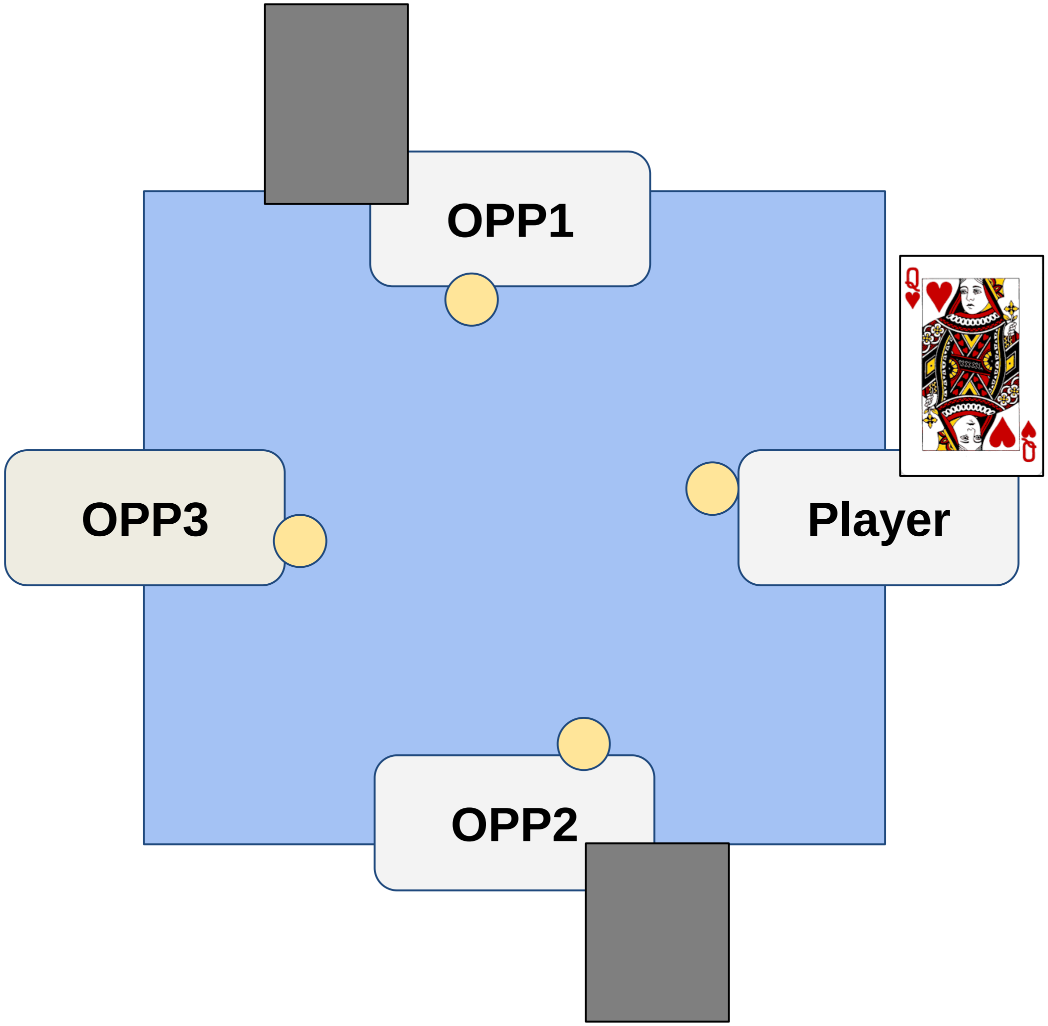
4-Player Kuhn Poker: Example



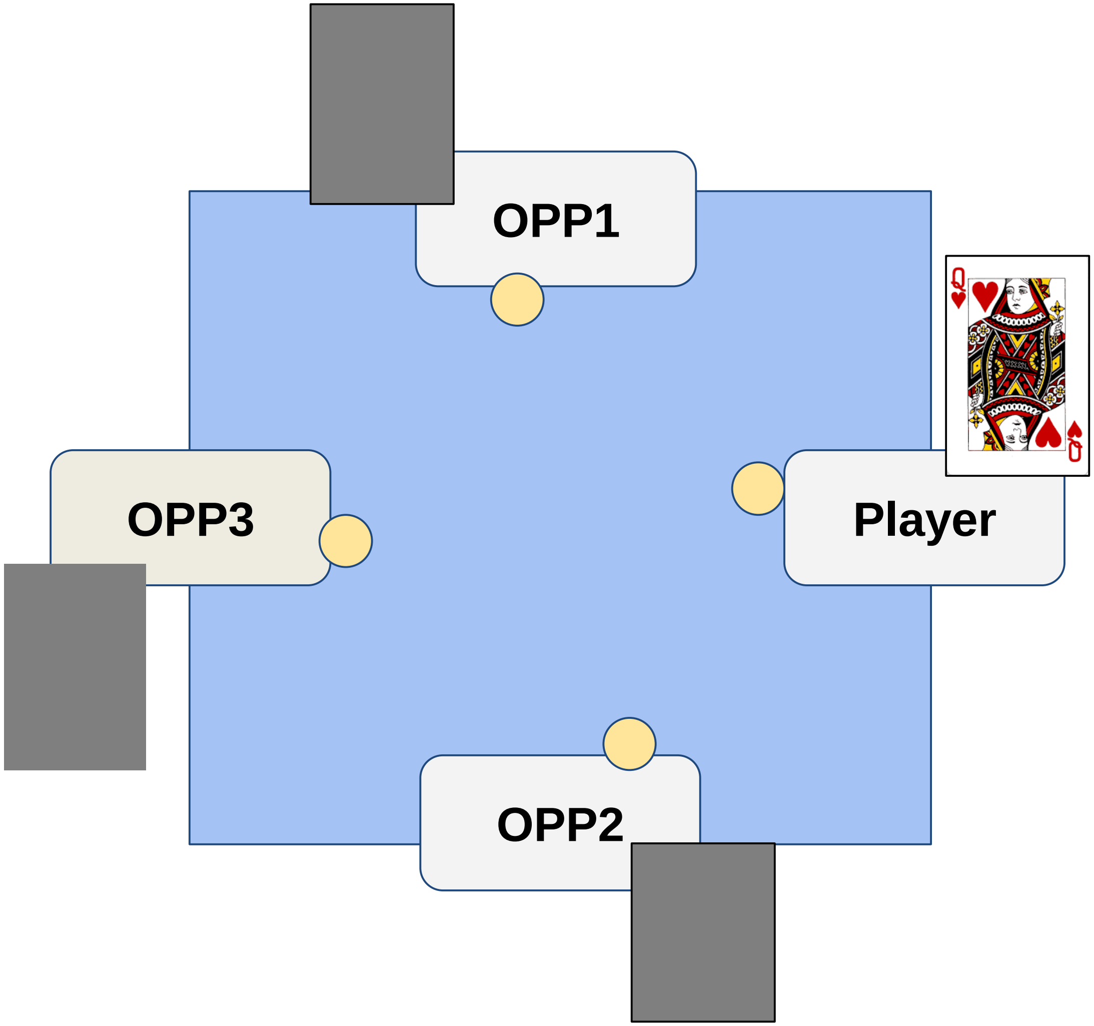
4-Player Kuhn Poker: Example



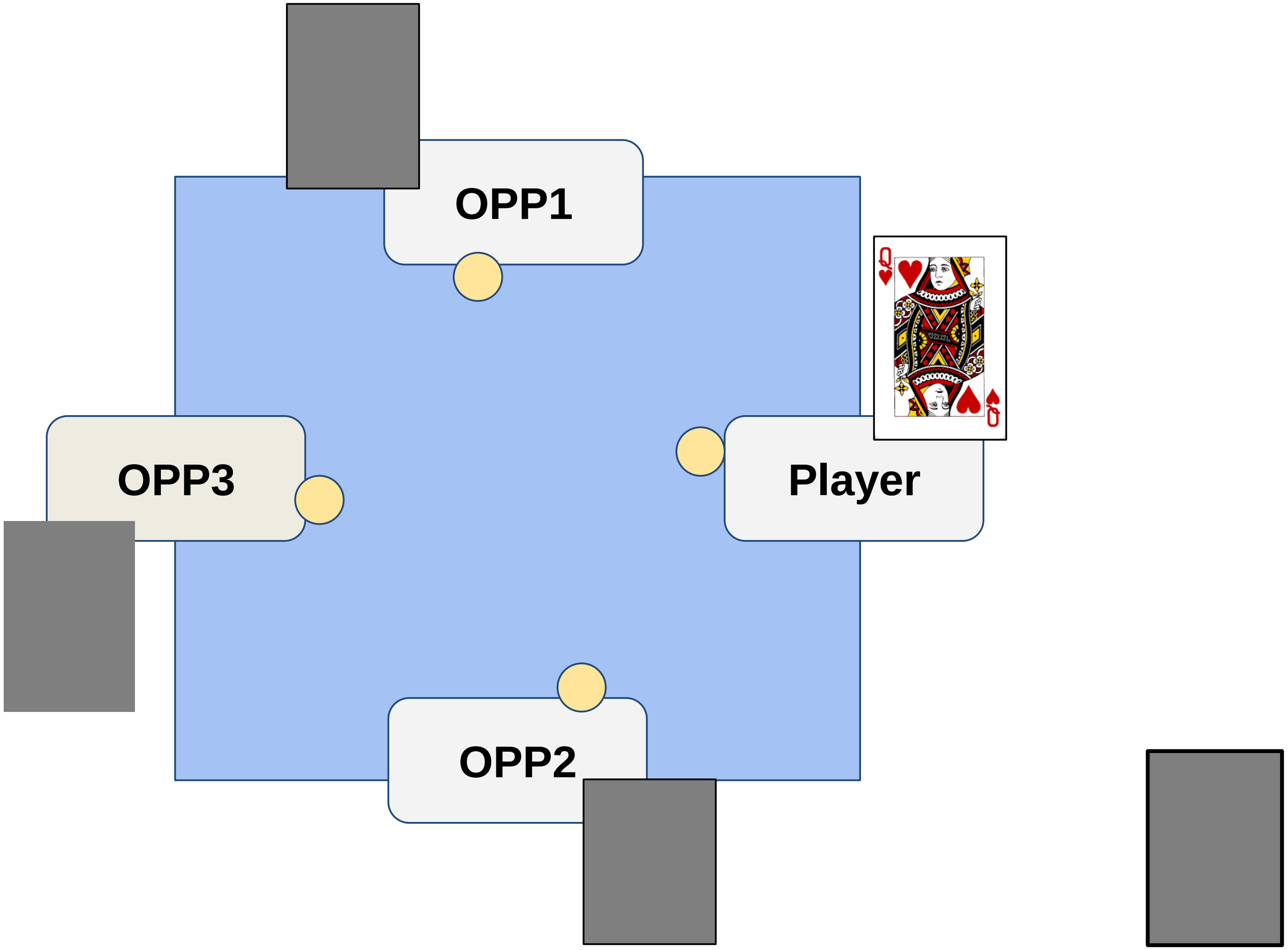
4-Player Kuhn Poker: Example



4-Player Kuhn Poker: Example



4-Player Kuhn Poker: Example



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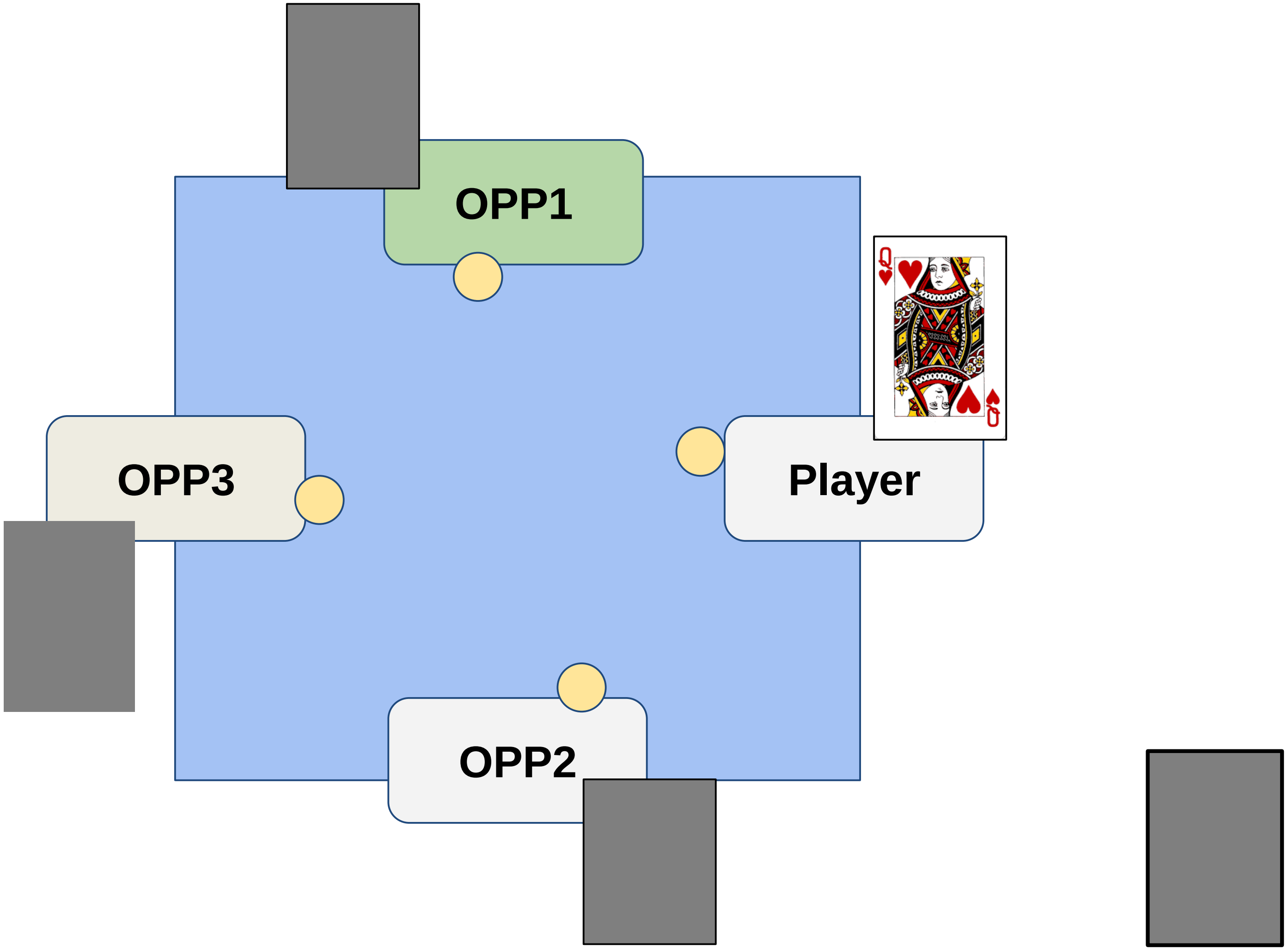

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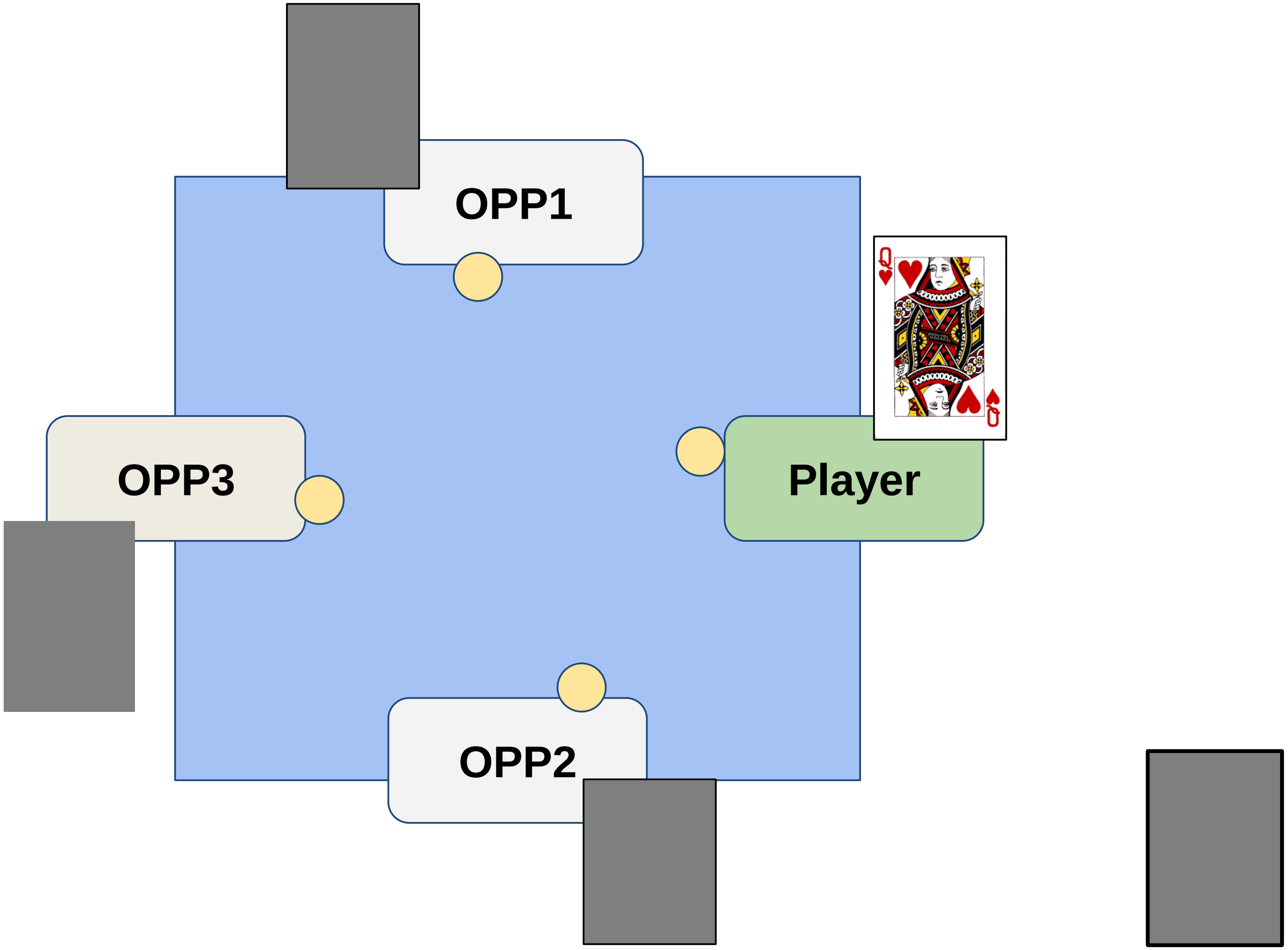

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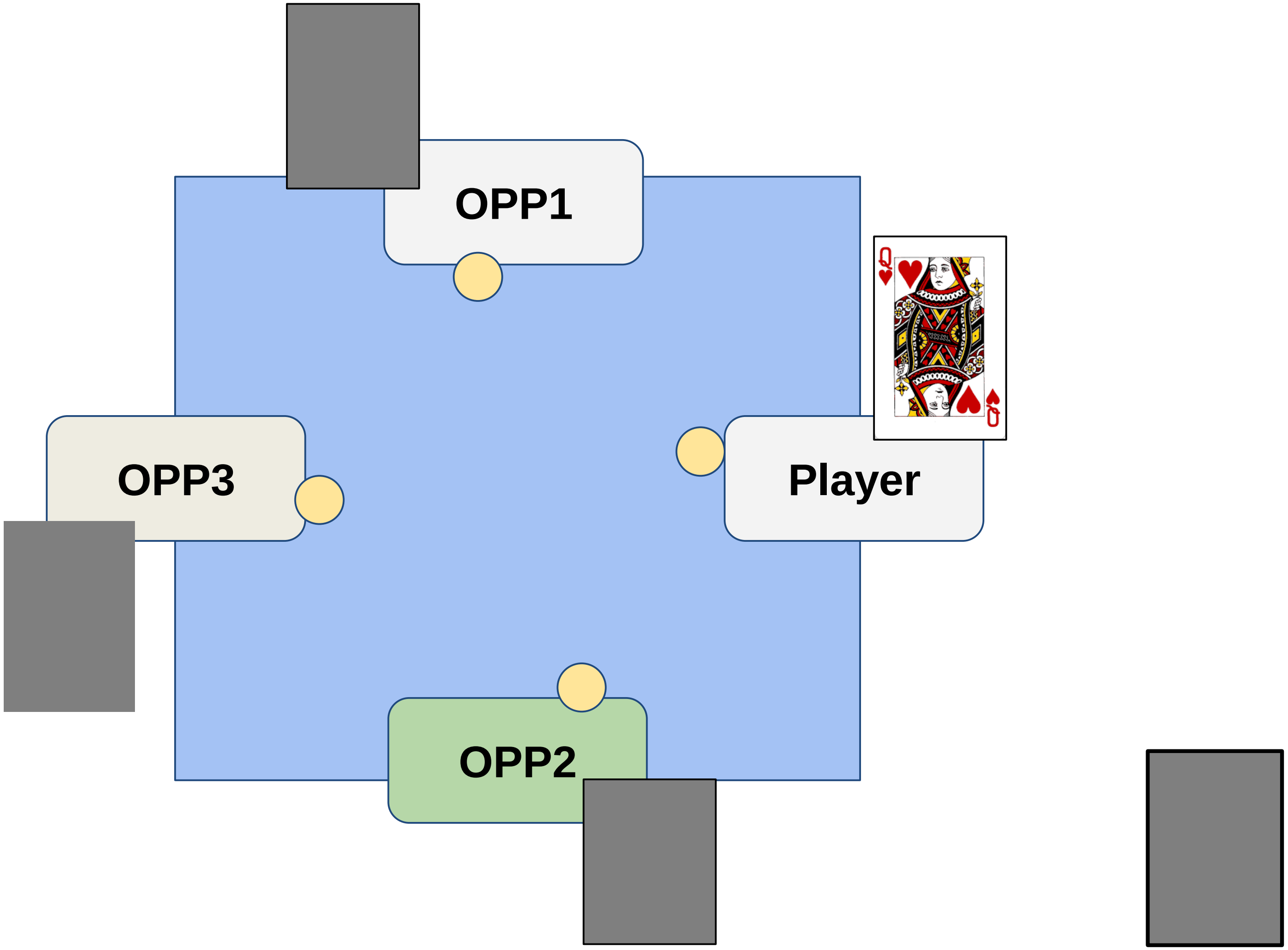

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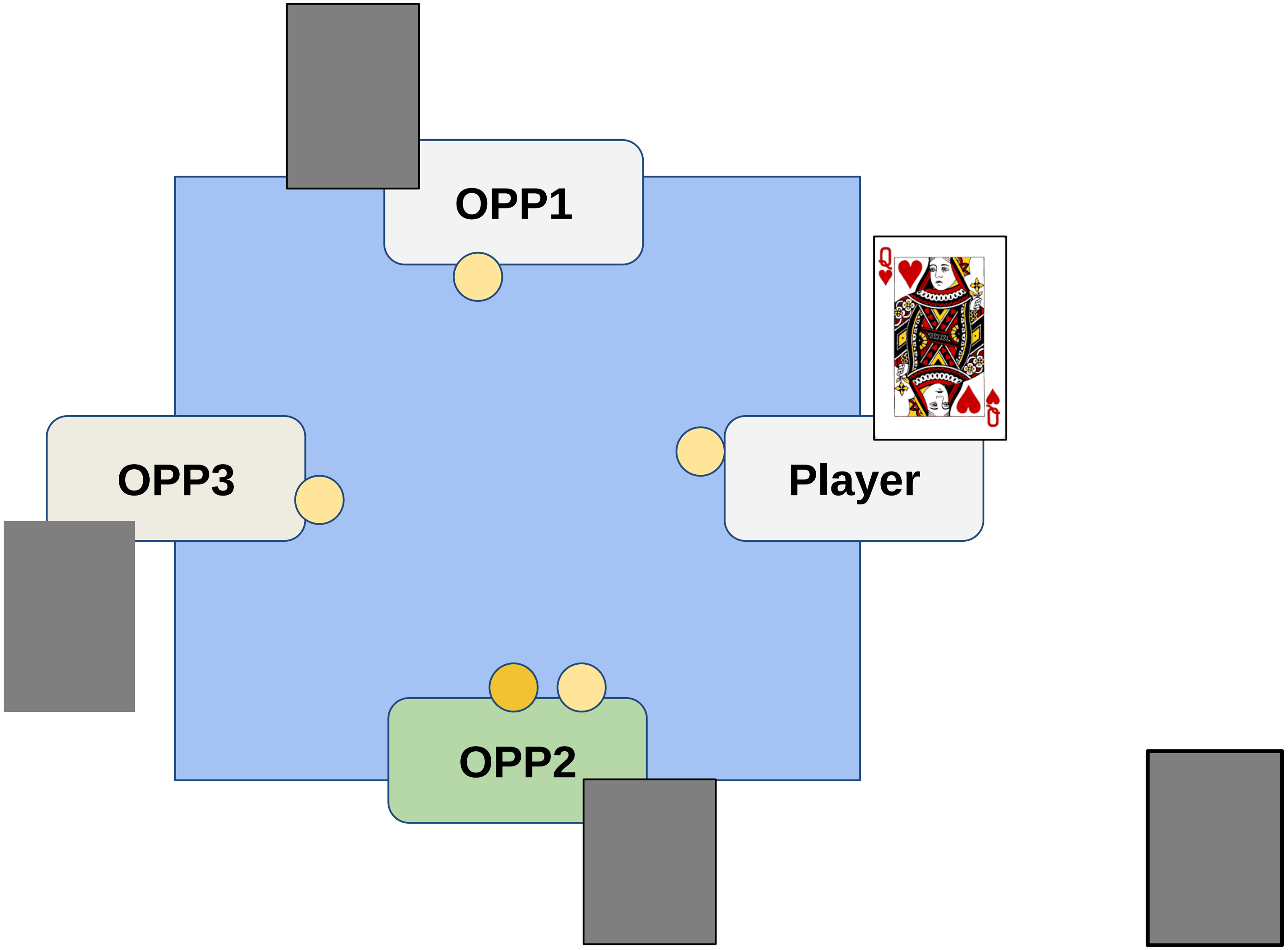

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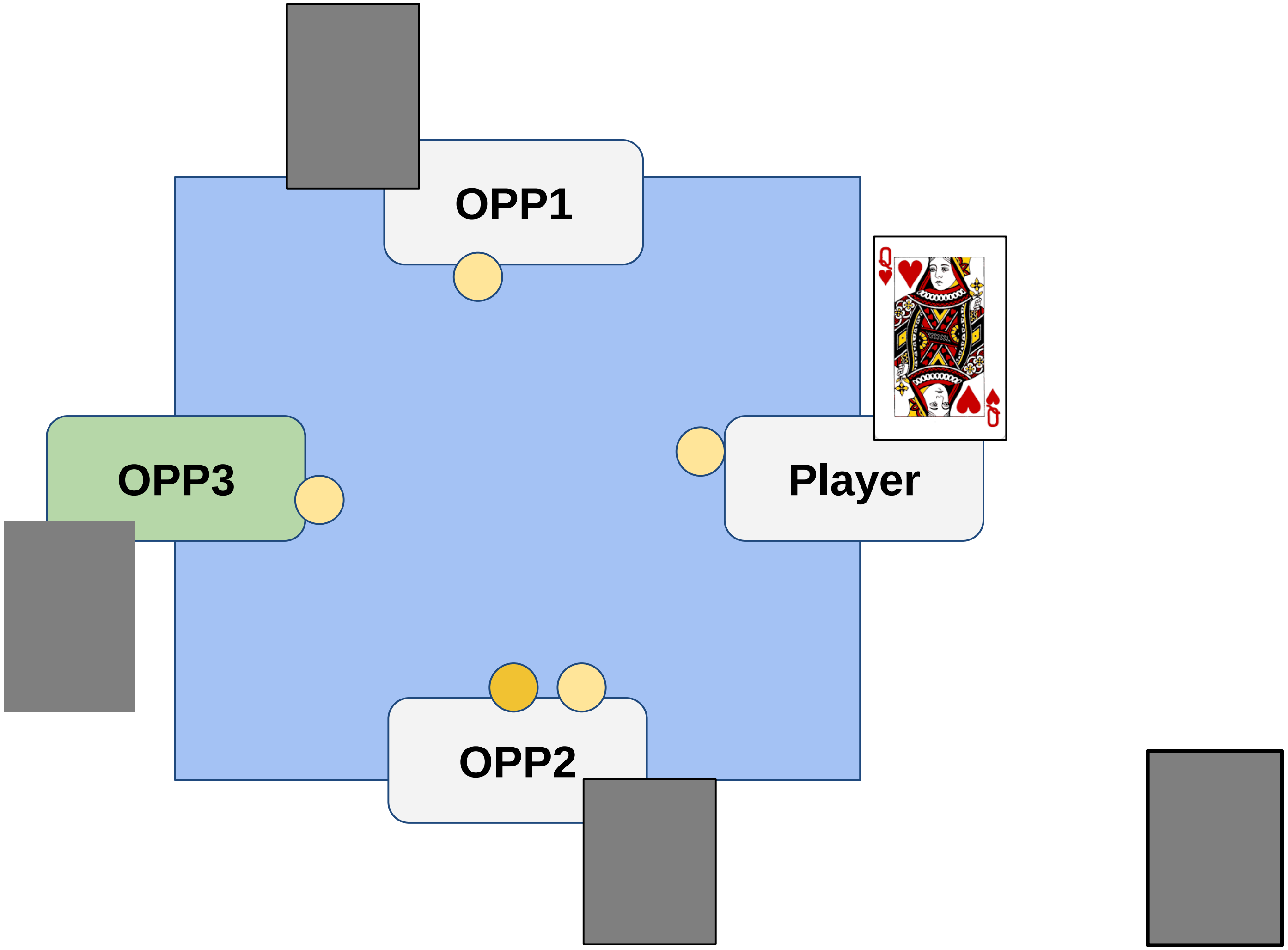

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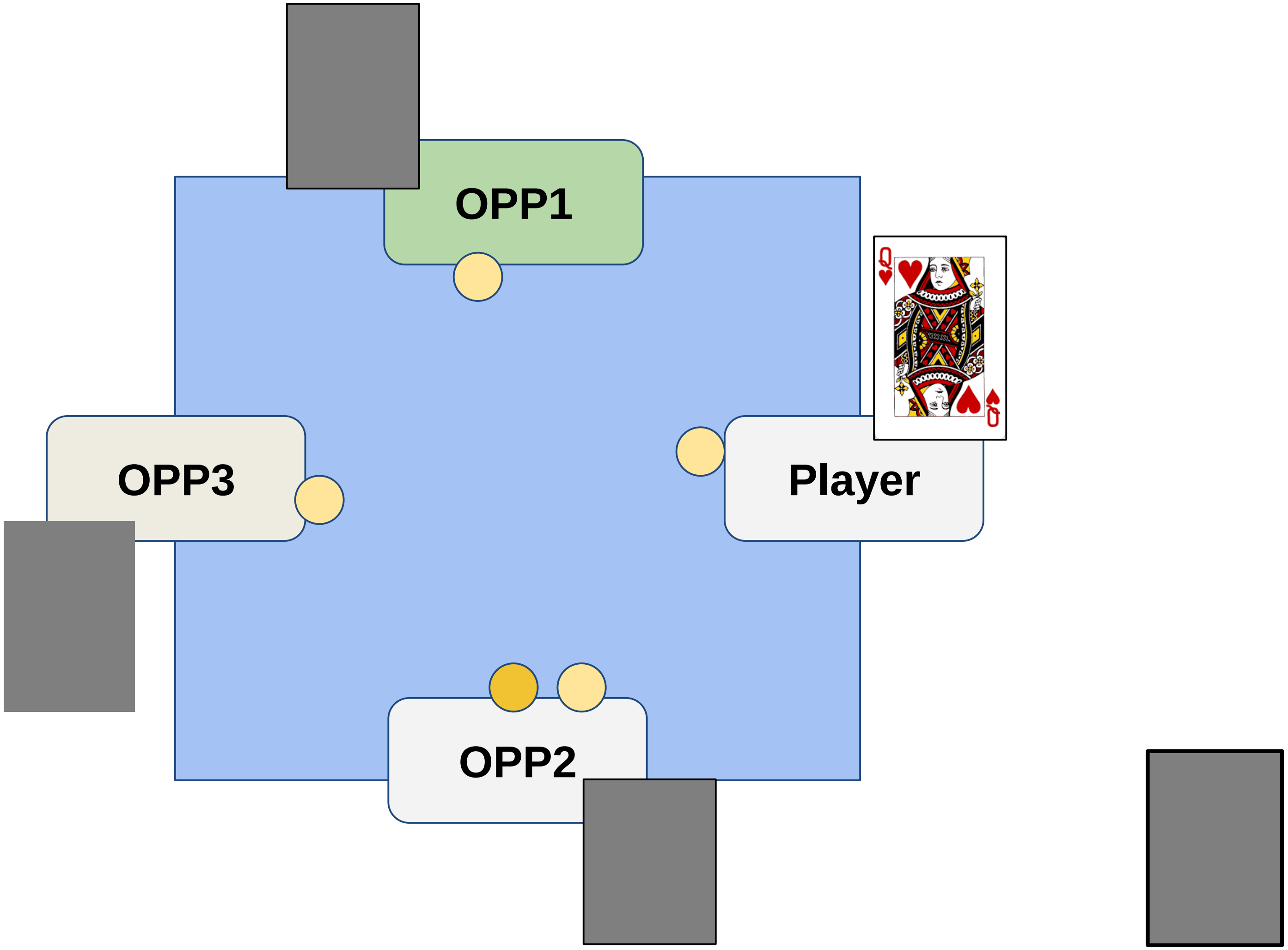

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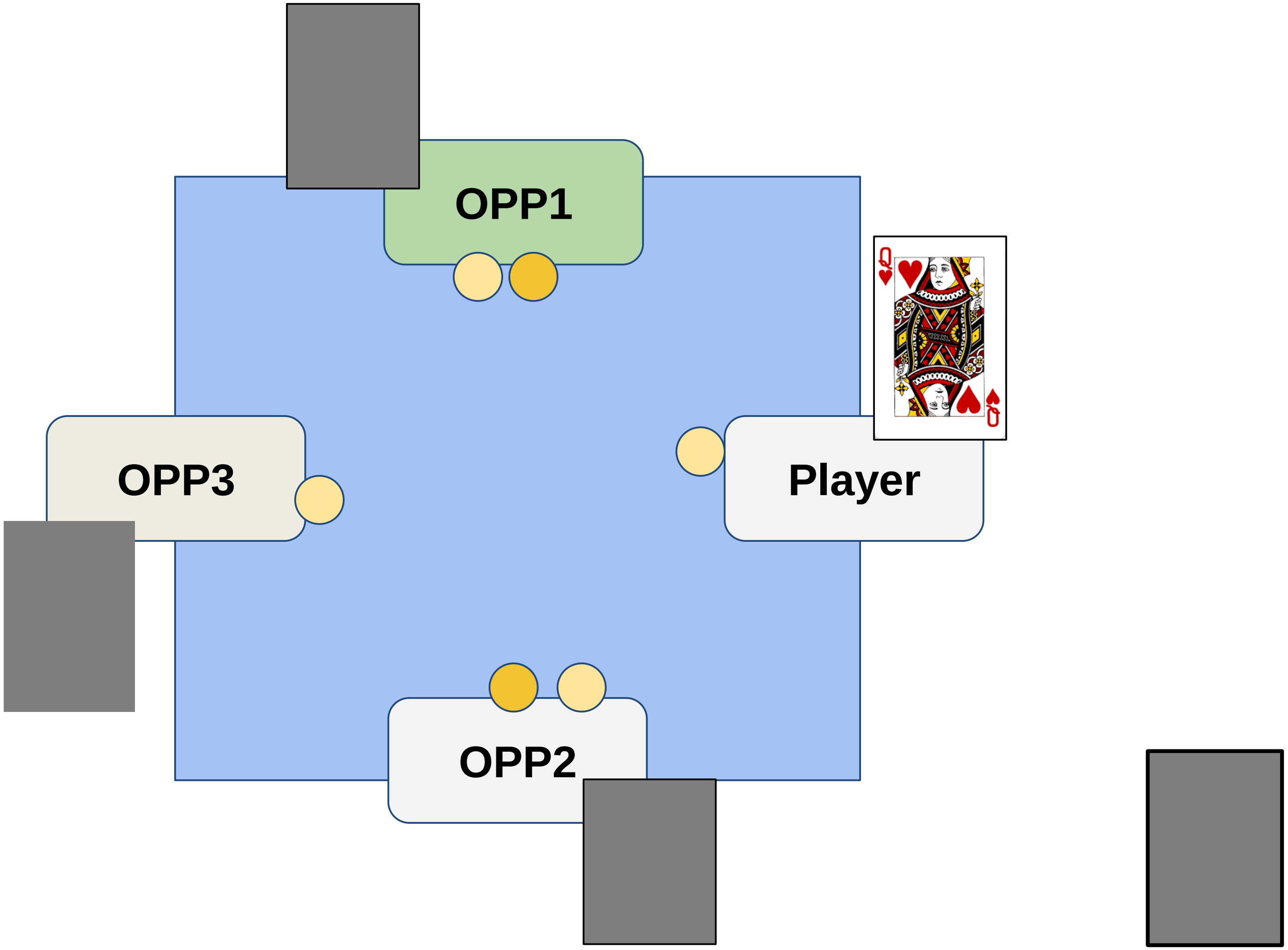

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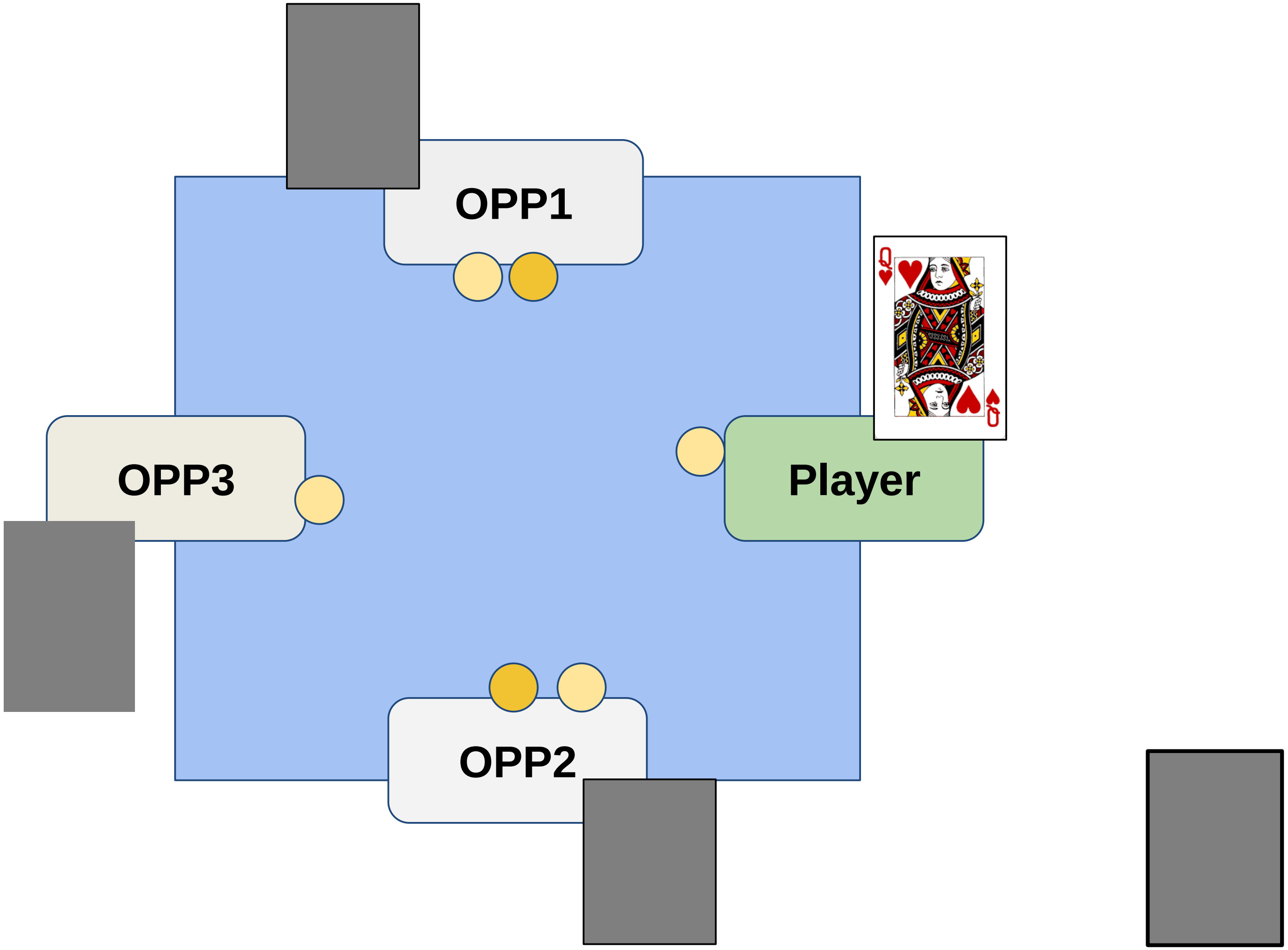

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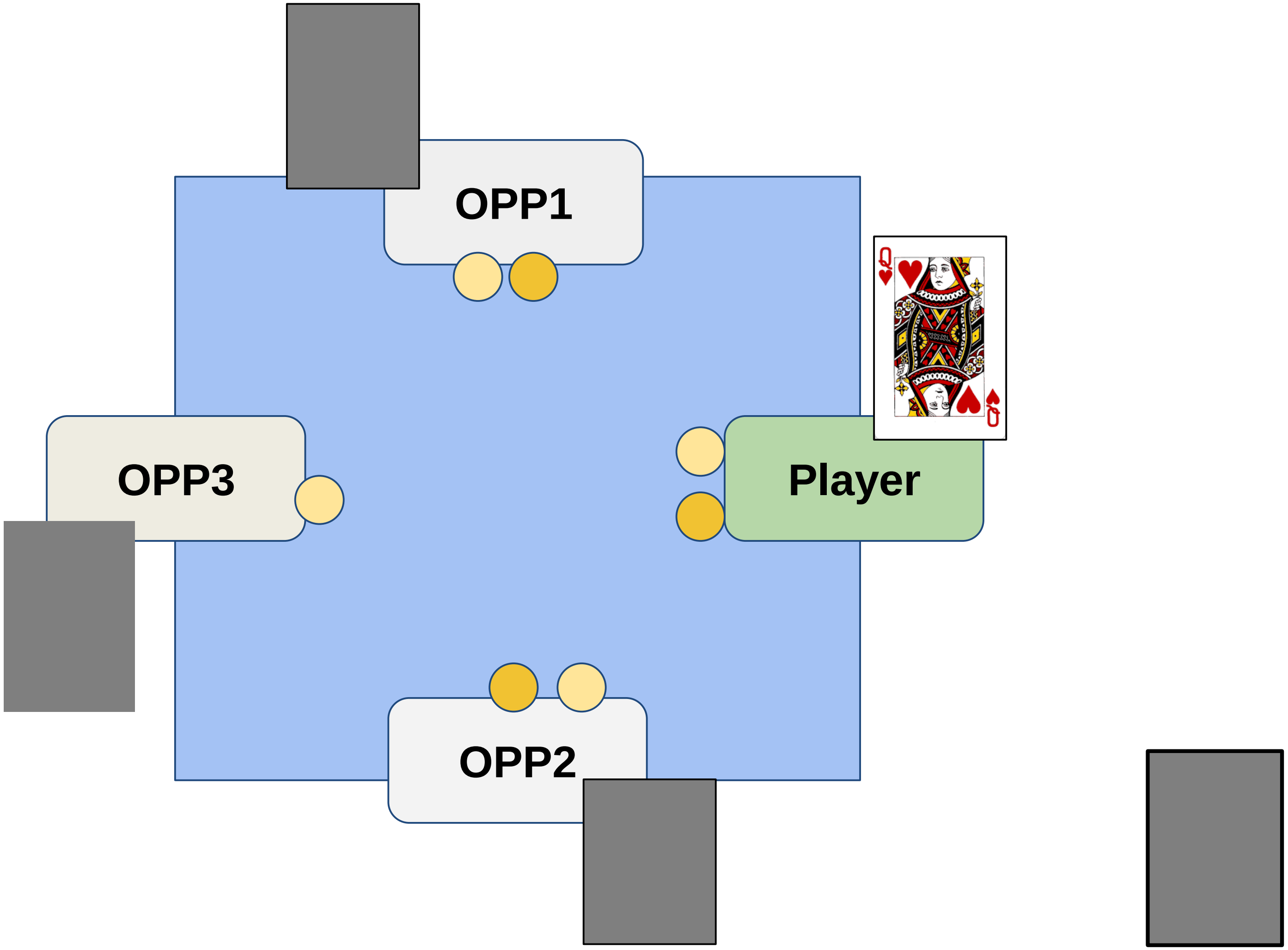

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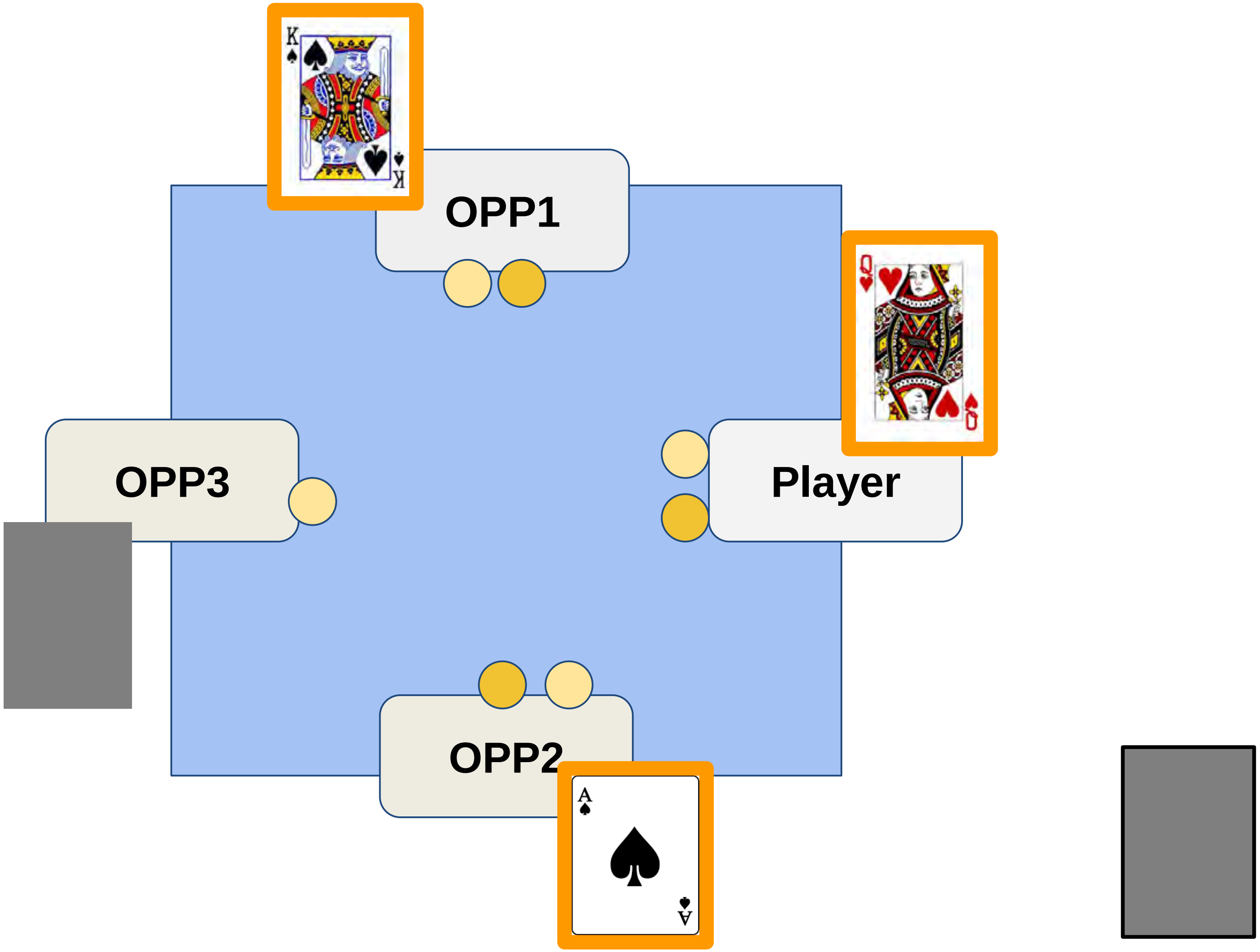

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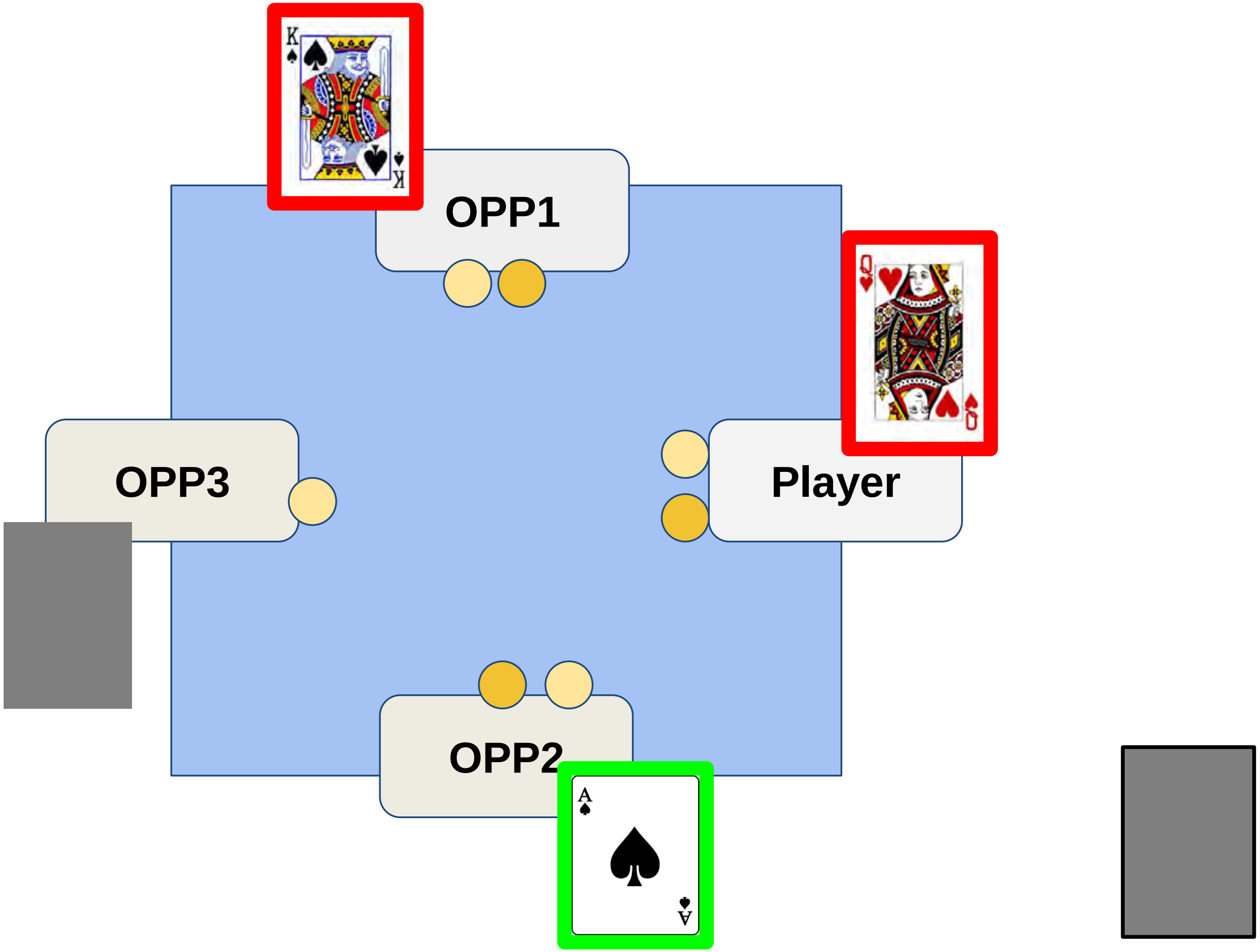
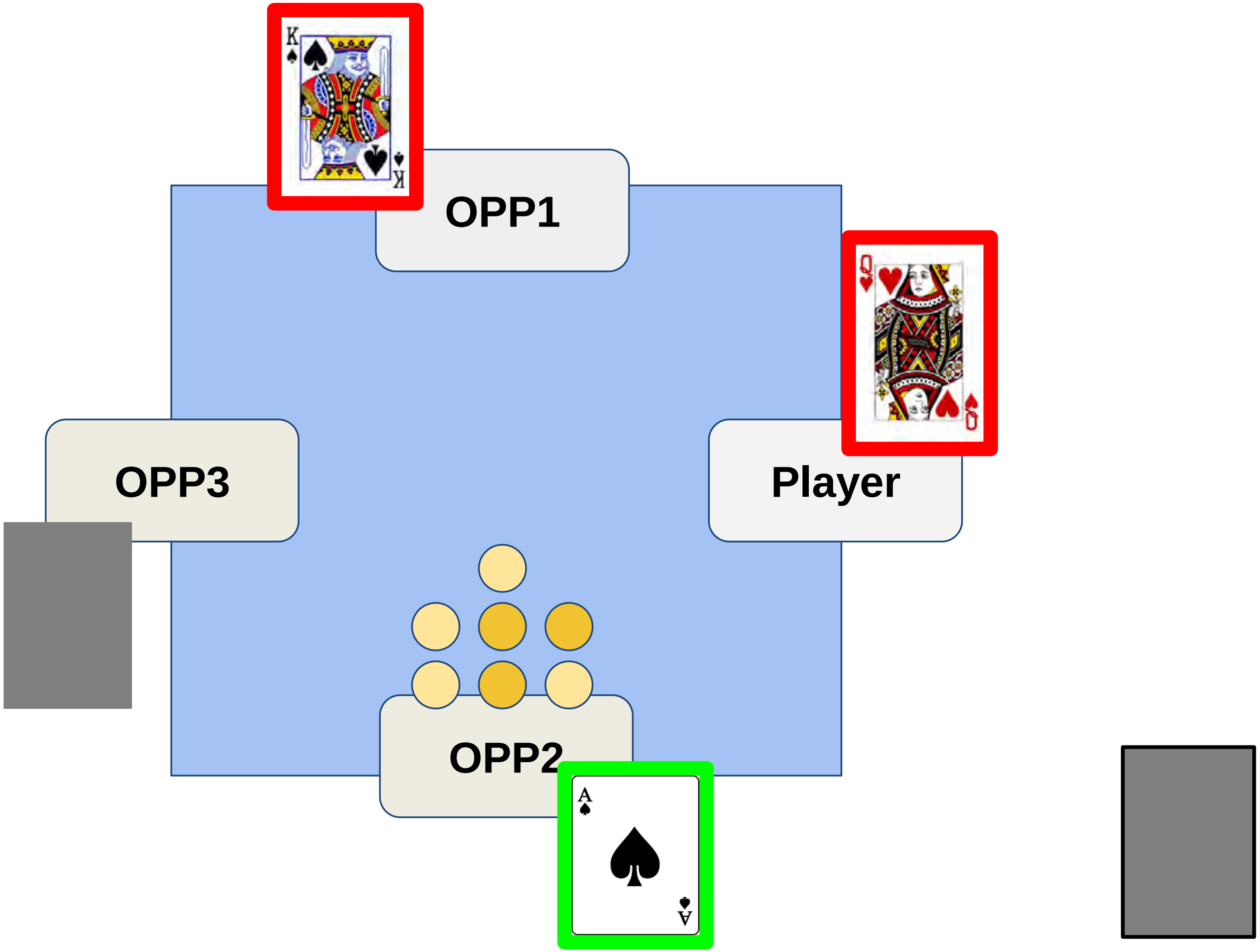
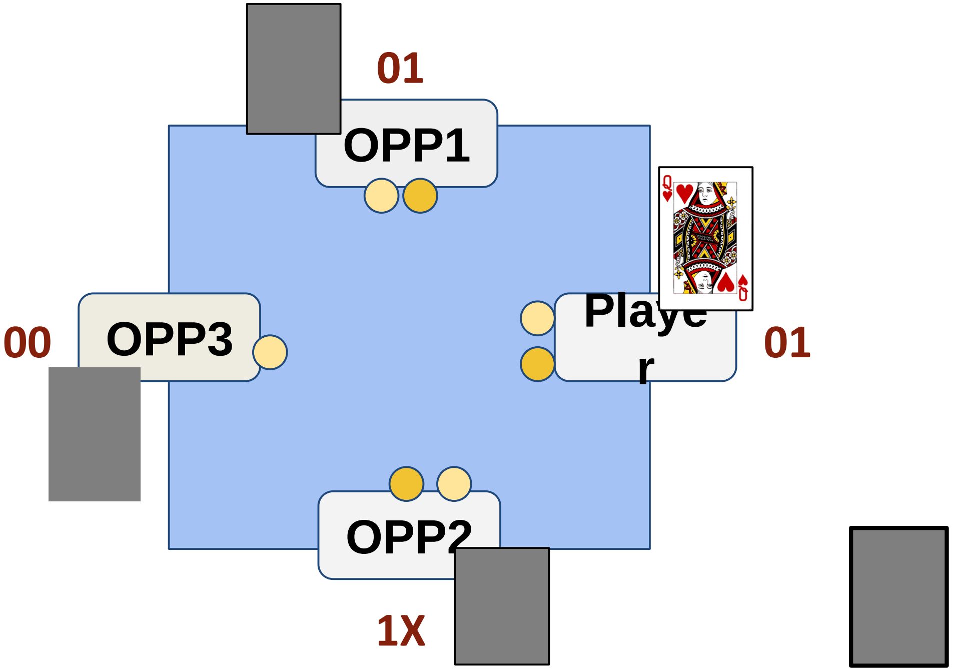


4-Player Kuhn Poker: Example

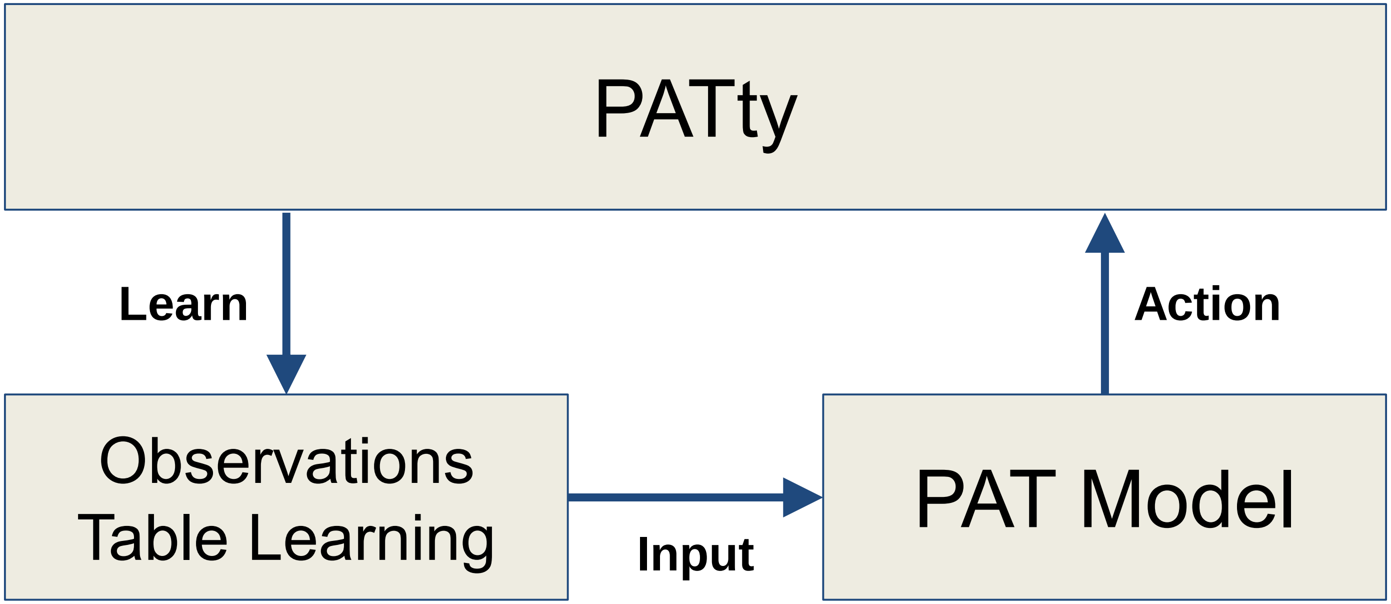


4-Player Kuhn Poker: Playing Method

- There are only 3 ways players play in
  - **00 -** Do not bet on both first and second turns
  - **01 -** Do not bet on first turn, but bet on second turn
  - **1X -** Bet on first turn, and will not have second turn



4-Player Kuhn Poker: Implementation



PATty

Learn

Action

Observations Table Learning

Input

PAT Model

4-Player Kuhn Poker: Experimentation

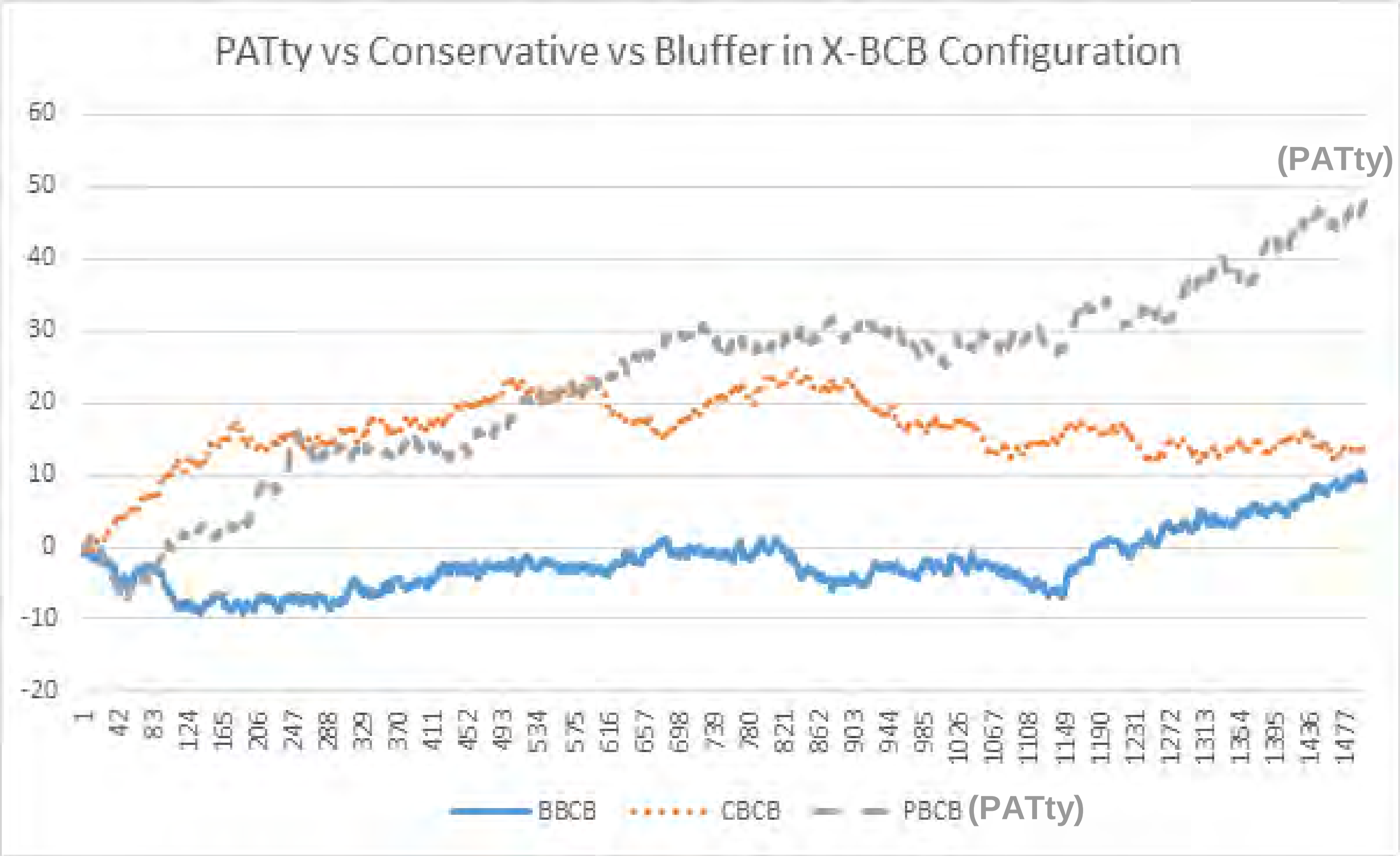
Different configurations

- X-Bluffer-Conservative-Bluffer (X-BCB)
- X-Conservative-Bluffer-Conservative (X-CBC)
- Where X can be either PATty, Bluffer or Conservative

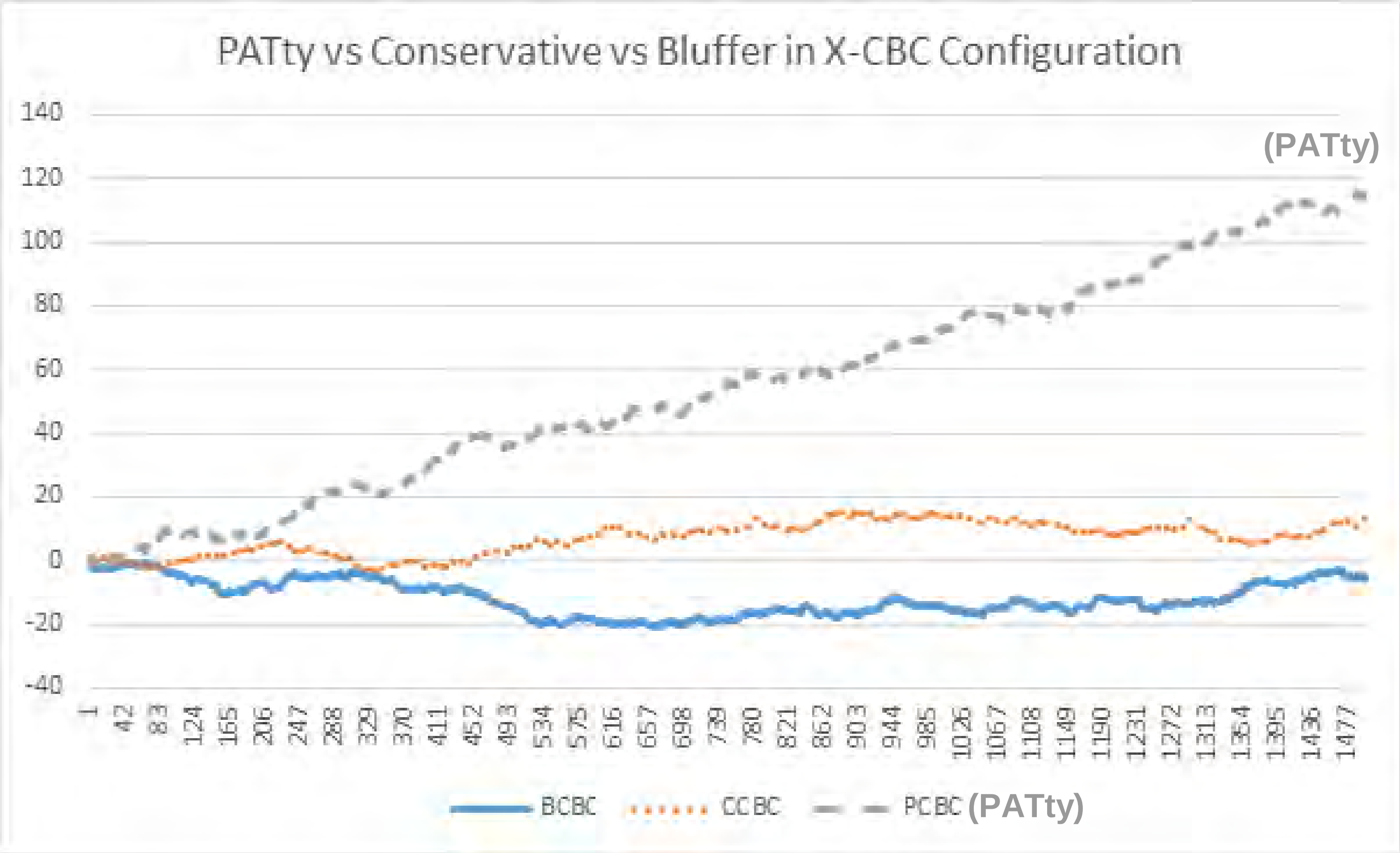
30 games each

1500 hands per game

4-Player Kuhn Poker: Findings



4-Player Kuhn Poker: Findings

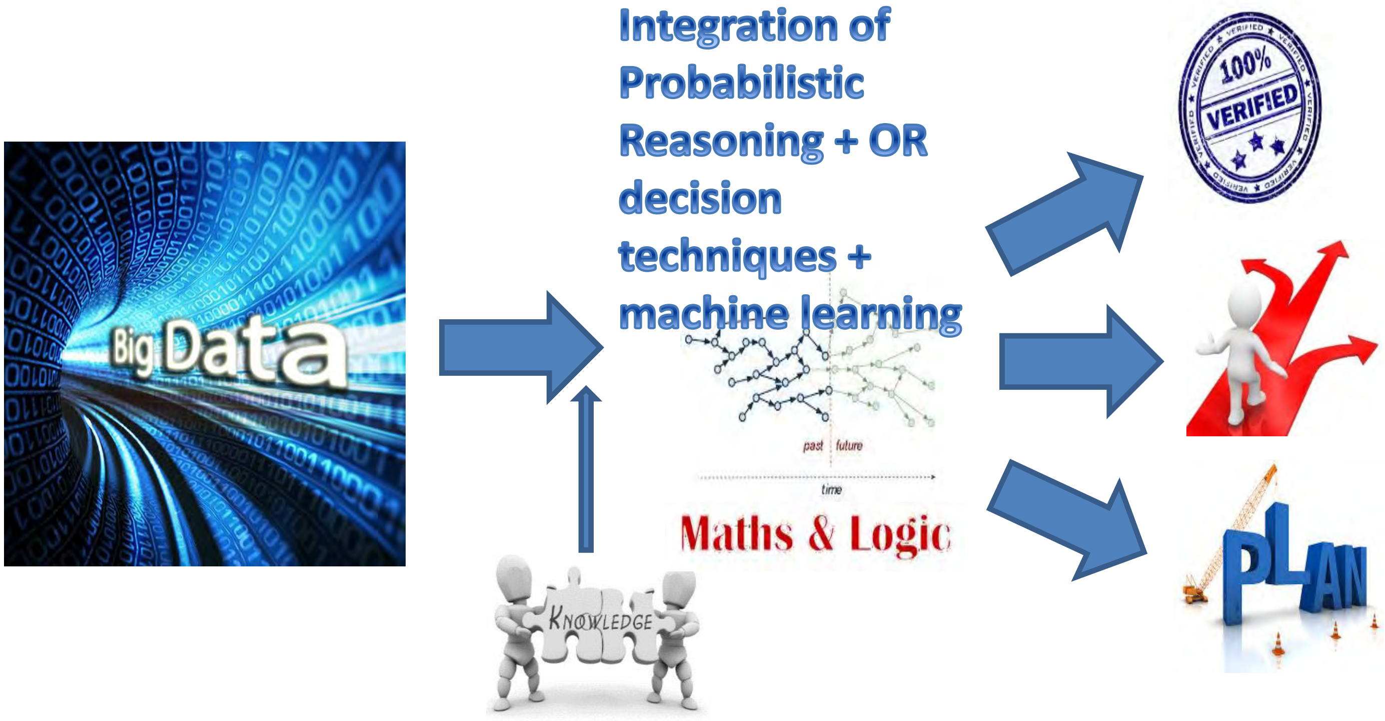


PATty vs Conservative vs Bluffer in X-CBC Configuration

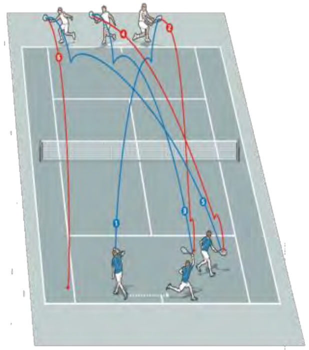
(PATty)

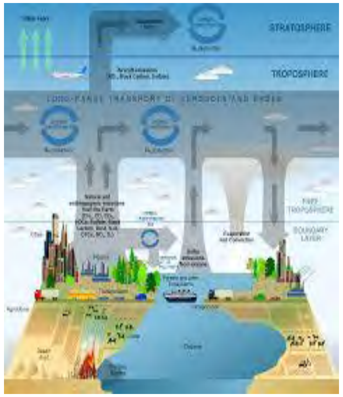
(PATty)

Event/Strategy Analytics



Integration of Probabilistic Reasoning + OR decision techniques + machine learning





Cyber Space
Physical Sensing
Actuation Information
Networks
Object Domain
Real Space

Event Analytics in current/new projects

- Singapore-UK joint cyber security project on smart grid security and privacy
  - With Andrew Martin (Oxford) and Bai Guangdong (SIT)
- Securify: A Compositional Approach of Building Security Verified System ($6M)
  - With Liu Yang (NTU), Sun Jun (SUTD), Chin Weingan (NUS) etc
- Trustworthy systems from untrusted Components ($6M)
  - With Abhik, Prateek (NUS) etc
- Singtel-NUS Cyber Security joint lab ($43M).
  - With David Rosenblum, Liang Zhenkai (NUS), etc
- Blockchain verification using timed and game-theory based reasoning
  - With Muthu (Griffith), Jun, Yang, Guangdong etc

We are hiring and looking for new collaborators

Thank You!

Some related and background papers

- J. S Dong, L. Shi, and L. V. Khanh, **Sports Analytics Using Probabilistic Reasoning**, ICECCS 2015.
- J. Sun, Y. Liu, J. S. Dong, E. Andre. **Modeling and Verifying Hierarchical Real-time Systems using Stateful Timed CSP**. The ACM Transactions on Software Engineering and Methodology (TOSEM). 2014
- Y. Liu, W. Chen, Y. A. Liu, J. Sun, S. Zhang and J. S. Dong. **Verifying Linearizability via Optimized Refinement Checking.** IEEE Transactions on Software Engineering (TSE), 2013
- Y. Liu, J. Sun and J. S. Dong. **PAT 3: An Extensible Architecture for Building Multi-domain Model Checkers**. The 22nd annual International Symposium on Software Reliability Engineering (ISSRE 2011), Hiroshima, Japan, Nov 29 - Dec 2, 2011.
- J. Sun, Y. Liu, S. Song and J. S. Dong. **PRTS: An Approach for Model Checking Probabilistic Real-time Hierarchical Systems**. ICFEM'11, pages 147-162, Durham, UK, October 25-28, 2011.
- S. Zhang, J. Sun, J. Pang, Y. Liu and J. S. Dong. **On Combining State Space Reductions with Global Fairness Assumptions**. FM'11, pages 432 - 447, Lero, Limerick, Ireland, June 20 - 24, 2011.
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- C. Chen, J. S. Dong, J. Sun and A. Martin. **A Verification System for Interval-based Specification Languages,** ACM Transactions on Software Engineering and Methodology, Volume 19(4), pages 1 - 36, ACM. 2010
- C. Chen, J. S. Dong and J. Sun. **A Formal Framework for Modeling and Validating Simulink Diagrams.** Formal Aspects of Computing. 21(5), pages 451-483, Springer. Oct, 2009.
- J. Sun, Y. Liu, J. S. Dong and J. Pang. **PAT: Towards Flexible Verification under Fairness.** CAV '09, Grenoble, France, June 2009.
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- C. Chen, J. S. Dong and J. Sun. **A Verification System for Timed Interval Calculus**, ICSE'08, 2008. .
- J. Sun and J. S. Dong, **Design Synthesis from Interaction and State-based Specifications.** IEEE Transactions on Software Engineering, Vol-32(6):349-364, 2006
- L. Yuan, J. S. Dong, J. Sun and H. A. Basit. **Generic Fault Tolerant Software Architecture Reasoning and Customization.** IEEE Transactions on Reliability. Vol-55(3):421-435, 2006
- J. Sun and J. S. Dong, **Synthesis of Distributed Processes from Scenario-based Specifications.** FM'05, pp 415-431, Newcastle, UK. 2005.
- S. C. Qin, J. S. Dong and W. N. Chin. **A Semantic Foundation of TCOZ in Unifying Theory of Programming.** FM'03. pages 321-340, 2003.
- B. Mahony and J.S. Dong. **Deep Semantic Links of TCSP and Object-Z: TCOZ Approach**. Formal Aspects of Computing journal, 13:142-160, Springer, 2002.
- B. Mahony and J.S. Dong. **Timed Communicating Object Z.** IEEE Transactions on Software Engineering, 26(2):150-177, Feb 2000.