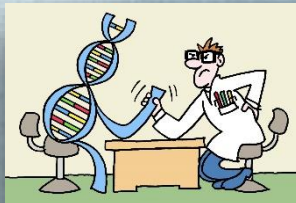


Exploiting Evolutionary Modeling to Prevail in Iterated Prisoner's Dilemma Tournaments

Marco Gaudesi, Elio Piccolo
Alberto Tonda, Giovanni Squillero





Iterated Prisoner's Dilemma

		Player B	
		Defection	Cooperation
Player A	Defection	(P: 1 , P: 1)	(T: 5 , S: 0)
	Cooperation	(S: 0 , T: 5)	(R: 3 , R: 3)



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[A Sparks](#), [T Burleigh](#), [P Barclay](#) - Evolution and Human Behavior, 2016 - Elsevier

Abstract Humans form impressions and make social judgments about others based on information that is quickly and easily available, such as facial and vocal traits. The evolutionary function of impression formation and social judgment mechanisms have ...

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Abstract Reciprocity is an important factor in human-human interaction, so it can be expected that it should also play a major role in human-robot interaction (HRI). Participants in our study played the Repeated **Prisoner's Dilemma** Game (RPDG) and the mini ...

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[JE Bone](#), [B Wallace](#), [R Bshary](#), [NJ Raihani](#) - PloS one, 2016 - journals.plos.org

Abstract In many two-player games, players that punish receive lower payoffs than those who abstain from punishing. However, punishment at promoting cooperation, especially in the context of ...

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When is the risk of cooperation worth the cost?

“A problem of indisputable difficulty in its field”

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Play profiles: The effect of infinite-length games on evolution in the iterated Prisoner's Dilemma

Lee-Ann Barlow; Jeffrey Tsang

2015 IEEE Conference on Computational Intelligence and Games (CIG)

Year: 2015

Pages: 368 - 375, DOI: 10.1109/CIG.2015.7317950

IEEE Conference Publications

▶ Abstract ((.html)) PDF (5527 Kb) ©

Evolutionary Prisoner's Dilemma in damp power system oscillations

V. S. Vakula; A. Padmaja; K. Rama S

IET Generation, Transmission & Distr

Year: 2015, Volume: 9, Issue: 5

Pages: 445 - 456, DOI: 10.1049/iet-g

IET Journals & Magazines

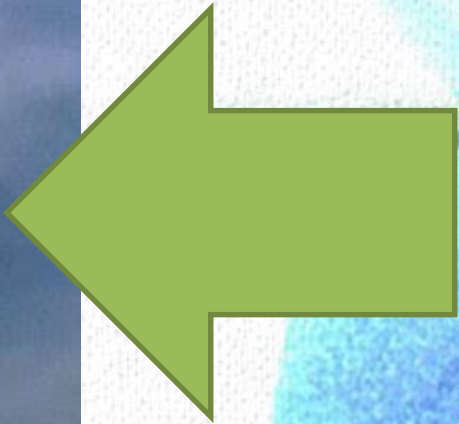
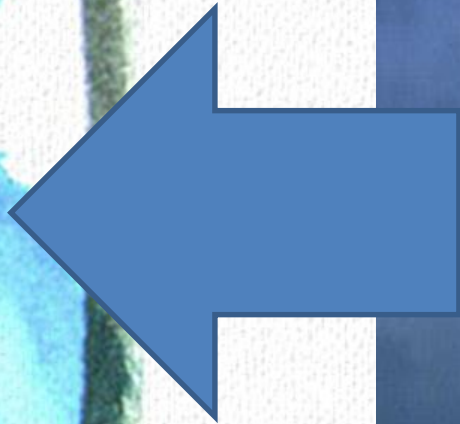
“A problem of indisputable difficulty in its field”

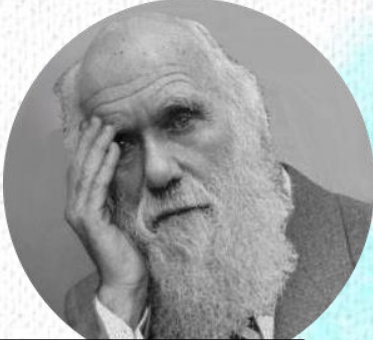
Proposed Approach



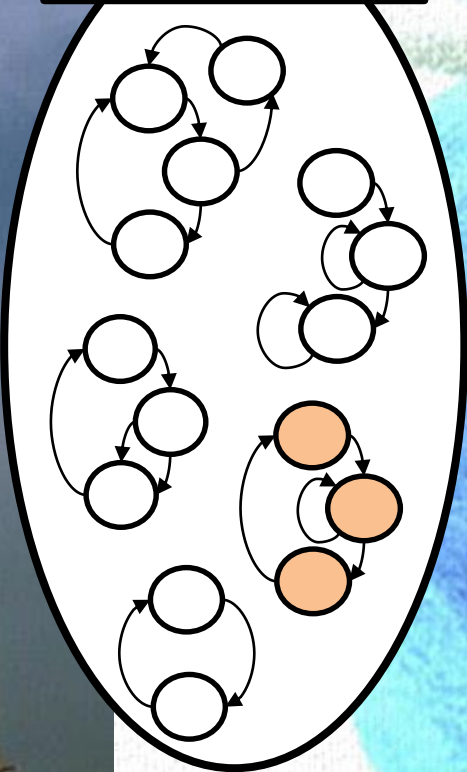
Proposed Approach

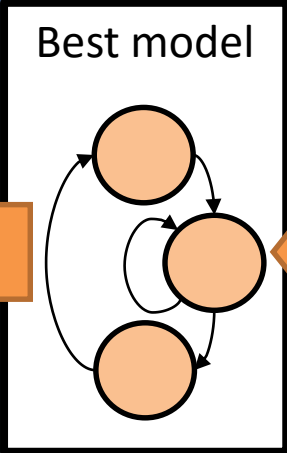
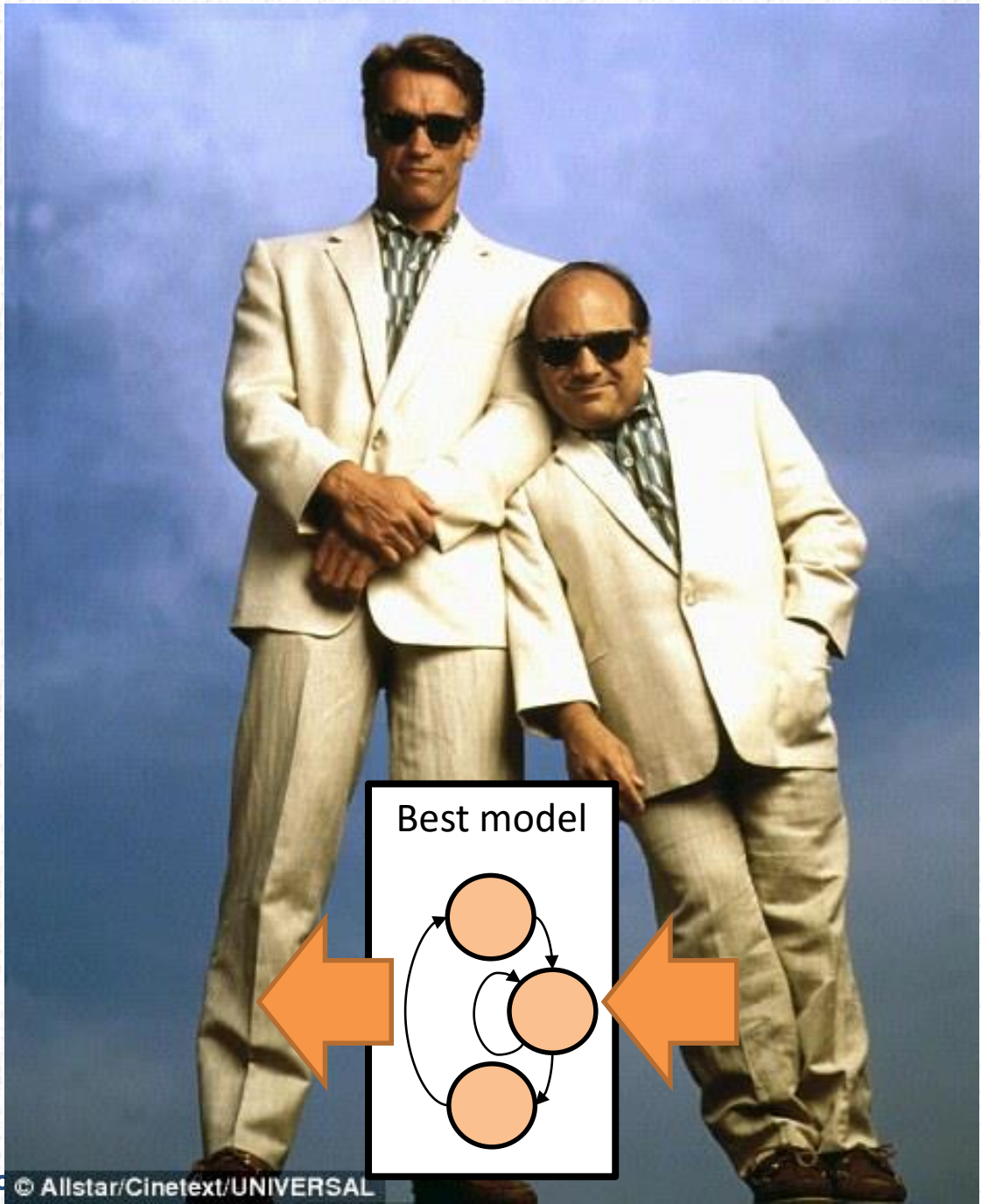






Evolutionary
Algorithm







Brute force approach
(try all possibilities)



Etruscan Mythology

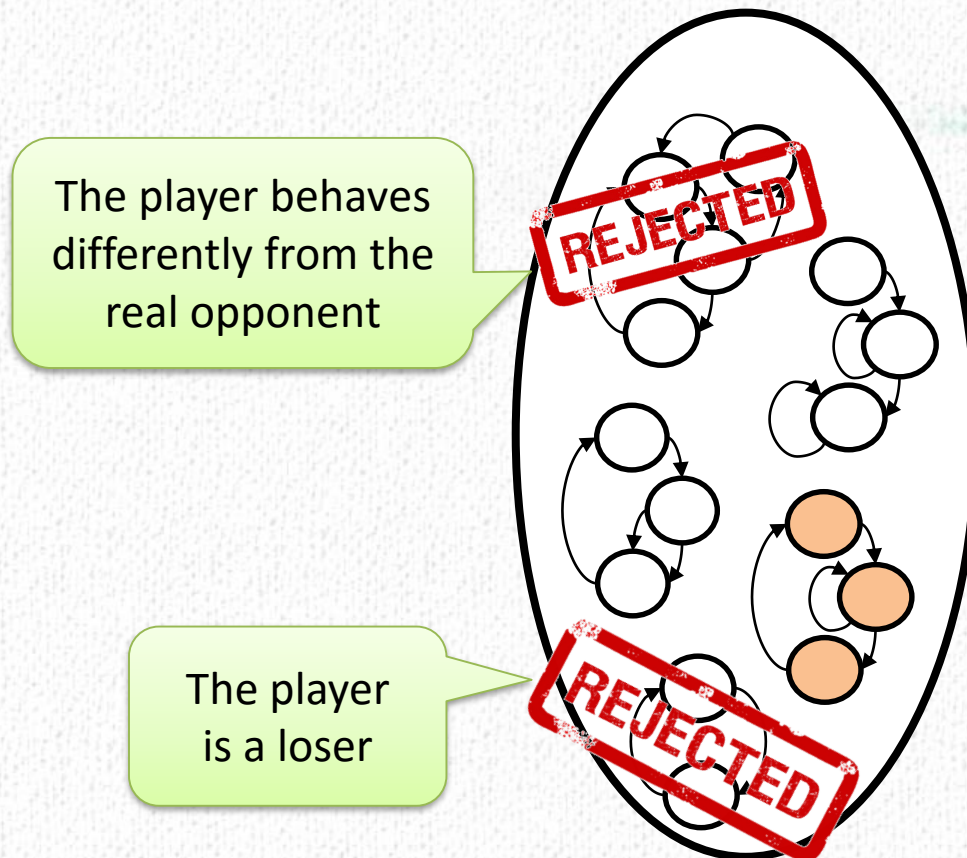
- Laran (2011)
 - First prototype based on FSM
- Turan (2014)
 - First prototype based on ND-FSM
- Tages (2016)

What if the
opponent is
not an FSM?



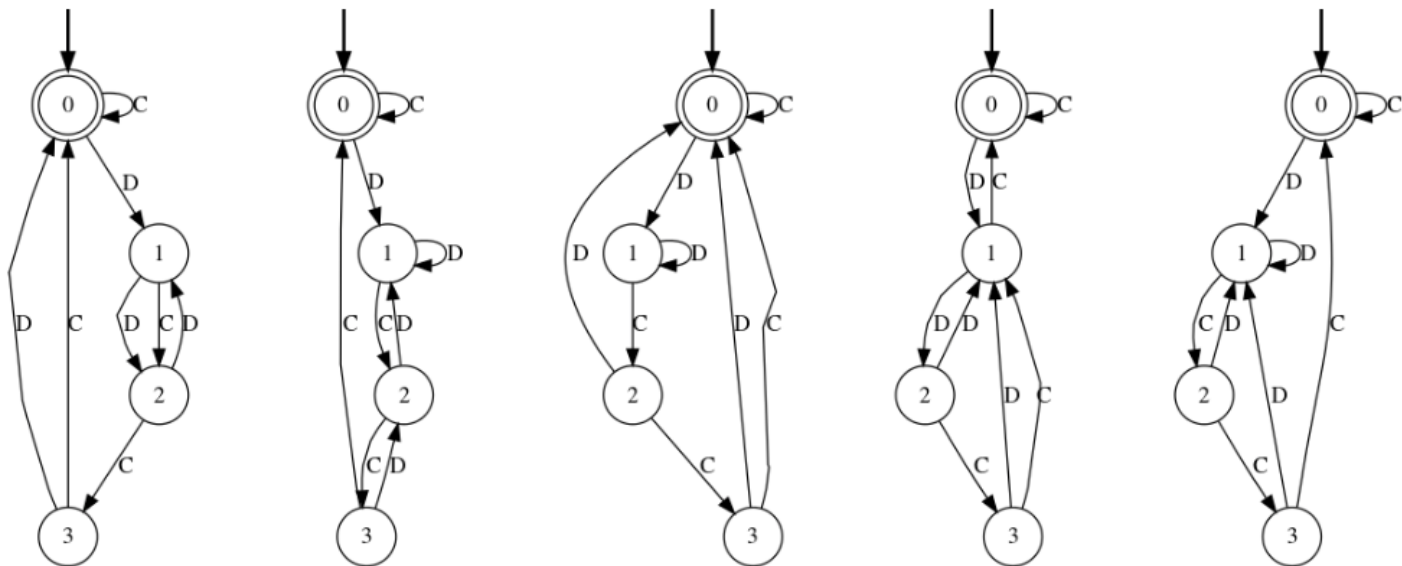
Etruscan Mythology

- **Turan:** Only strong players can be good models



Etruscan Mythology

- **Turan:** Only strong players can be good models
- **Laran:** Models don't need to be exact to be useful



Etruscan Mythology

- **Turan:** Only strong players can be good models
- **Laran:** Models don't need to be exact to be useful
- **Laran:** Lose a match, win the tournament

Opponent name	Tages		Opponent		Model	
	\bar{P}	P_σ	\bar{P}	P_σ	\bar{E}	E_σ
2TFT	2.89	0.04	2.98	0.02	0.97	0.01
ATFT	3.10	0.29	2.34	0.23	0.88	0.07
CTFT	3.00	0.00	2.77	0.18	0.99	0.00
GTFT $\epsilon = 0.05$	2.94	0.04	2.92	0.07	0.97	0.02
GTFT $\epsilon = 0.1$	2.89	0.20	2.83	0.27	0.92	0.14
GTFT $\epsilon = 0.33$	2.89	0.11	2.41	0.55	0.70	0.33
HTF2T	3.77	0.06	1.61	0.03	0.97	0.00
HTFT2	2.88	0.04	2.97	0.02	0.97	0.01
HTFT3	2.84	0.07	3.00	0.03	0.96	0.01
NP	2.48	0.13	2.85	0.12	0.82	0.13
NPM	2.94	0.05	2.94	0.06	0.97	0.03
OTFT	1.89	1.04	2.29	0.65	0.96	0.02
RP $\epsilon = 0.01$	2.91	0.07	2.94	0.07	0.97	0.01
RP $\epsilon = 0.1$	2.44	0.12	2.63	0.19	0.67	0.18
RTFT	4.92	0.04	0.04	0.03	0.98	0.00
STFT	2.94	0.03	2.96	0.03	0.99	0.00
TF2T	3.88	0.04	1.56	0.02	0.97	0.00
TFT	2.96	0.01	2.96	0.01	0.98	0.00

Game 2	Game 3			\bar{P}^T	P_σ^T				
	\bar{P}^O	P_σ^O	\bar{P}^T						
60	8.2	1080	2.2	906	7.7	921	1.8	1835	10.1
678	25.5	411	21.0	319	5.2	331	19.5	629	4.1
658	357.2	739	198.6	370	90.5	633	198.9	673	100.1
96	140.8	711	57.5	853	331.4	620	83.9	1721	691.1
177	0.0	1056	10.2	918	0.3	898	9.1	1866	0.6
333	57.8	723	117.5	413	47.2	521	71.7	808	55.5
177	0.0	1056	9.7	918	0.0	907	11.6	1866	0.6
159	11.9	1056	11.4	906	7.3	894	9.1	1850	5.4
146	12.4	1034	18.6	892	16.0	883	14.3	1827	23.2
117	46.2	1068	12.8	888	35.7	911	10.2	1734	116.7
91	165.4	531	153.7	393	114.7	412	105.5	759	105.0
168	10.7	1066	14.1	913	4.9	912	4.7		
157	29.3	1043	44.1	883	48.4	863	73.6		
123	76.3	779	218.6	871	55.8	633	198.5		
986	509.7	646	206.7	785	418.6	498	111.0		
1416	14.0	580	6.5	1216	7.3	465	4.1		

Opponent name	Payoff			Model	
	\bar{P}	P_σ	P_{opt}	\bar{E}	E_σ
CD	2.91	0.04	3.00	0.99	0.00
CCD	3.57	0.02	3.67	0.97	0.01
DDC	2.19	0.02	2.33	0.97	0.01
DDC (AC)	4.98	0.01	5.00	1.00	0.00
$R_{1.0}$	4.54	0.18	4.60	0.46	0.22
$R_{0.9}$	3.97	0.26	4.20	0.33	0.18
$R_{0.8}$	3.43	0.44	3.80	0.12	0.06
$R_{0.7}$	2.92	0.14	3.40	0.14	0.08
$R_{0.6}$	2.68	0.24	3.00	0.11	0.10
$R_{0.5}$ (RND)	2.14	0.17	2.60	0.16	0.04
$R_{0.4}$	1.83	0.12	2.20	0.14	0.08
$R_{0.3}$	1.51	0.11	1.80	0.25	0.06
$R_{0.2}$	1.01	0.15	1.40	0.56	0.05
$R_{0.1}$	0.86	0.03	1.00	1.00	0.00
$R_{0.0}$ (AD)					

Strategy	Tages		Opponent		Model	
	\bar{P}	P_σ	\bar{P}	P_σ	\bar{E}	E_σ
ADP	0.97	0.03	1.49	0.12	0.98	0.00
APAV	1.89	0.78	2.41	0.50	0.79	0.20
ATFT	3.26	0.21	2.28	0.31	0.92	0.05
CTFT	3.00	0.00	2.83	0.13	0.99	0.00
FBF	3.00	0.00	2.83	0.11	0.99	0.00
GRD	2.82	0.14	2.96	0.06	0.93	0.04
HM	2.72	1.18	1.85	0.47	0.97	0.04
OTFT	1.85	1.07	2.24	0.70	0.96	0.02
PAV	4.97	0.02	0.04	0.02	0.99	0.00
SG	2.91	0.04	2.97	0.02	0.97	0.01
SM	3.59	0.20	1.80	0.16	0.95	0.03



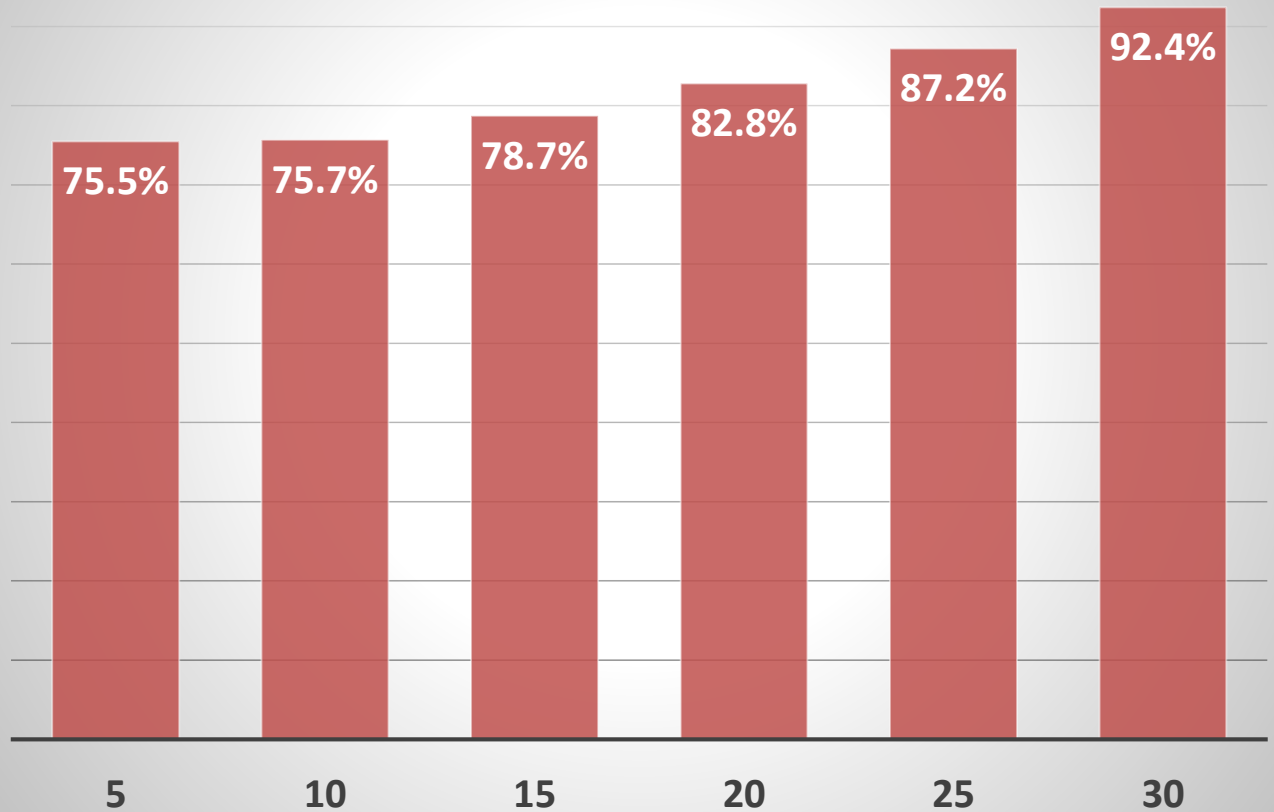
Opponent name	Payoff			Model	
	\bar{P}	P_σ	P_{opt}	\bar{E}	E_σ
2TFT	2.89	0.04	2.98	0.97	0.01
AC	28.1	10.4	2.8	0.5	0.0
AD	19.3	1.1	0.0	0.0	0.0
ADP	33.0	17.1	7.7	2.4	0.3
APAV	19.5	5.0	1.2	0.1	0.0
ATFT	29.4	10.3	3.5	0.7	0.1
CTFT	20.3	6.7	2.2	0.6	0.1
EXT2	1.6	0.0	0.0	0.0	0.0
FBF	19.7	6.7	2.2	0.6	0.1
FRT3	12.1	1.5	0.1	0.0	0.0
FRT4	15.1	2.2	0.2	0.0	0.0
GRD	26.5	14.3	6.8	2.4	0.5
GRM	19.5	7.7	1.6	0.1	0.0
GTFT $\epsilon = 0.05$	32.5	25.4	18.9	12.4	6.4
GTFT $\epsilon = 0.1$	36.3	33.1	29.4	23.1	16.7
GTFT $\epsilon = 0.33$	40.0	36.0	31.4	25.0	18.1
HM	2.0	0.0	0.0	0.0	0.0
HTF2T	26.4	9.2	2.4	0.4	0.0
HTFT2	13.2	1.3	0.1	0.0	0.0
HTFT3	17.9	3.1	0.5	0.0	0.0
NP	2.7	0.0	0.0	0.0	0.0
OTFT	36.2	30.3	27.3	22.9	15.6
PAV	29.4	11.5	3.6	0.7	0.1
PRO	1.1	0.0	0.0	0.0	0.0
RND	6.1	0.1	0.0	0.0	0.0
RP $\epsilon = 0.01$	6.5	0.2	0.0	0.0	0.0
RP $\epsilon = 0.1$	5.1	0.1	0.0	0.0	0.0
RTFT	11.0	1.2	0.0	0.0	0.0
SG	25.2	12.7	6.3	2.7	0.8
SM	36.5	20.9	11.8	5.6	1.8
STF2T	31.3	12.0	3.5	0.8	0.1
STFT	3.0	0.1	0.0	0.0	0.0
Tages	75.5	75.7	78.7	82.8	87.2
TFT	18.6	5.0	1.5	0.3	0.0
ZDE	2.1	0.0	0.0	0.0	0.0
ZDF	2.8	0.0	0.0	0.0	0.0
ZDG	22.4	8.9	2.9	0.6	0.1

Parameters	Tages		Opponent		Model	
	\mathcal{G}	μ	\bar{P}	P_σ	\bar{P}	P_σ
300	100	1.41	0.12	1.37	0.11	0.23
30	100	1.30	0.14	1.32	0.12	0.08
300	10	1.49	0.15	1.38	0.15	0.12
30	10	1.62	0.11	2.06	0.13	0.32

average over 100,000 random tournaments for each tournament size

40 opponents (all the usual suspects + others)

Tages victories in tournaments of different sizes



Opponent name	Payoff			Model	
	\bar{P}	P_σ	P_{opt}	\bar{E}	E_σ
CD	2.91	0.04	3.00	0.99	0.00
CCD	3.57	0.02	3.67	0.97	0.01
DDC	2.19	0.02	2.33	0.97	0.01
DDC	4.98	0.01	5.00	1.00	0.00
$\mathcal{R}_{1.0}$ (AC)	4.54	0.18	4.60	0.46	0.22
$\mathcal{R}_{0.9}$	3.97	0.26	4.20	0.33	0.18
$\mathcal{R}_{0.8}$	3.43	0.44	3.80	0.12	0.06
$\mathcal{R}_{0.7}$	2.92	0.14	3.40	0.14	0.08
$\mathcal{R}_{0.6}$				0.11	0.10

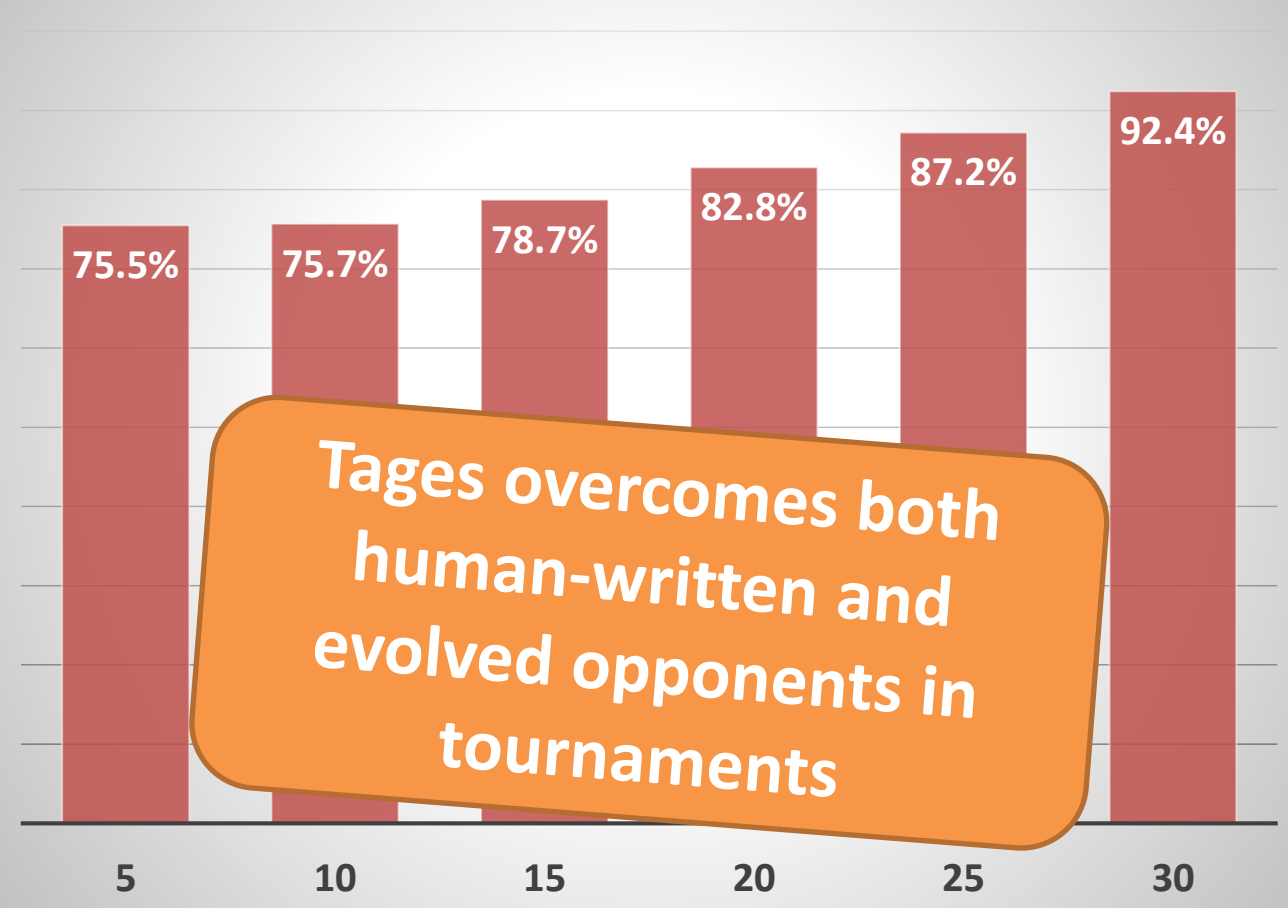
Opponent name	Tages		Opponent	
	\bar{P}	P_σ	\bar{P}	P_σ
NPM	2.48	0.13	2.85	0.12
NPM	2.94	0.05	2.94	0.06
NPM	1.89	1.04	2.29	0.65
ADP	0.97	0.78	2.44	0.31
APAV	1.89	0.21	2.28	0.31
ATFT	3.26	0.00	2.83	0.13
CTFT	3.00	0.00	2.83	0.11
FBF	3.00	0.00	2.96	0.06
GRD	2.82	0.14	2.96	0.06
HM	2.72	1.18	1.85	0.47
OTFT	1.85	1.07	2.24	0.70
PAV	4.97	0.02	0.04	0.02
PAV	4.97	0.02	2.97	0.02
SG	2.91	0.04	2.97	0.02
SM	3.59	0.20	1.80	0.16

Why we deserve the prize?

average over 100,000 random tournaments for each tournament size

40 opponents (all the usual suspects + others)

Tages victories in tournaments of different sizes



Tages overcomes both human-written and evolved opponents in tournaments

Opponent name	Tages		Opponent		Model	
	\bar{P}	P_σ	\bar{P}	P_σ	\bar{E}	E_σ
2TFT	2.89	0.04	2.88	0.01		
ATFT	3.00	0.00	2.34	0.23	0.88	0.07
CTFT	3.00	0.00	2.77	0.18	0.98	0.00
GTFT $\epsilon = 0.05$	2.94	0.04	2.97	0.02	0.97	0.02
HTFT $\epsilon = 0.33$	2.89	0.11	2.41	0.55	0.92	0.14
HTFT2	3.47	0.00	2.97	0.02	0.97	0.00
HTFT3	2.88	0.04	2.97	0.02	0.97	0.01
NP	2.84	0.07	3.00	0.03	0.96	0.01
RP $\epsilon = 0.01$	2.48	0.13	2.85	0.12	0.82	0.13
RP $\epsilon = 0.1$	2.94	0.05	2.94	0.06	0.97	0.00
OTFT	1.89	1.04	2.29	0.65	0.9	0.04
APAV	2.91	0.07	2.94	0.07	0.9	0.08
GRD	2.44	0.12	2.63	0.19	0.6	0.06
RTFT	2.84	0.04	3.04	0.03	0.9	0.05
STFT	2.94	0.05	2.84	0.03	0.9	0.00
TF2T	3.88	0.04	1.56	0.02	0.9	0.00
TFT	2.86	0.04	2.96	0.01	0.9	0.00

Opponent name	Tages		Opponent		Model	
	\bar{P}	P_σ	\bar{P}	P_σ	\bar{E}	E_σ
ADP	0.97	0.03	1.49	0.72	0.98	0.79
APAV	1.89	0.78	2.41	0.50	0.92	0.99
ATFT	3.26	0.21	2.28	0.31	0.99	0.99
CTFT	3.00	0.00	2.83	0.13	0.99	0.93
FBF	3.00	0.00	2.83	0.11	0.99	0.93
GRD	2.82	0.14	2.96	0.06	0.93	0.97
HM	2.72	1.18	1.85	0.47	0.97	0.96
OTFT	1.85	1.07	2.24	0.70	0.96	0.99
PAV	4.97	0.02	0.04	0.02	0.97	0.97
SG	2.91	0.04	2.97	0.02	0.97	0.95
SM	3.59	0.20	1.80	0.16	0.95	0.95

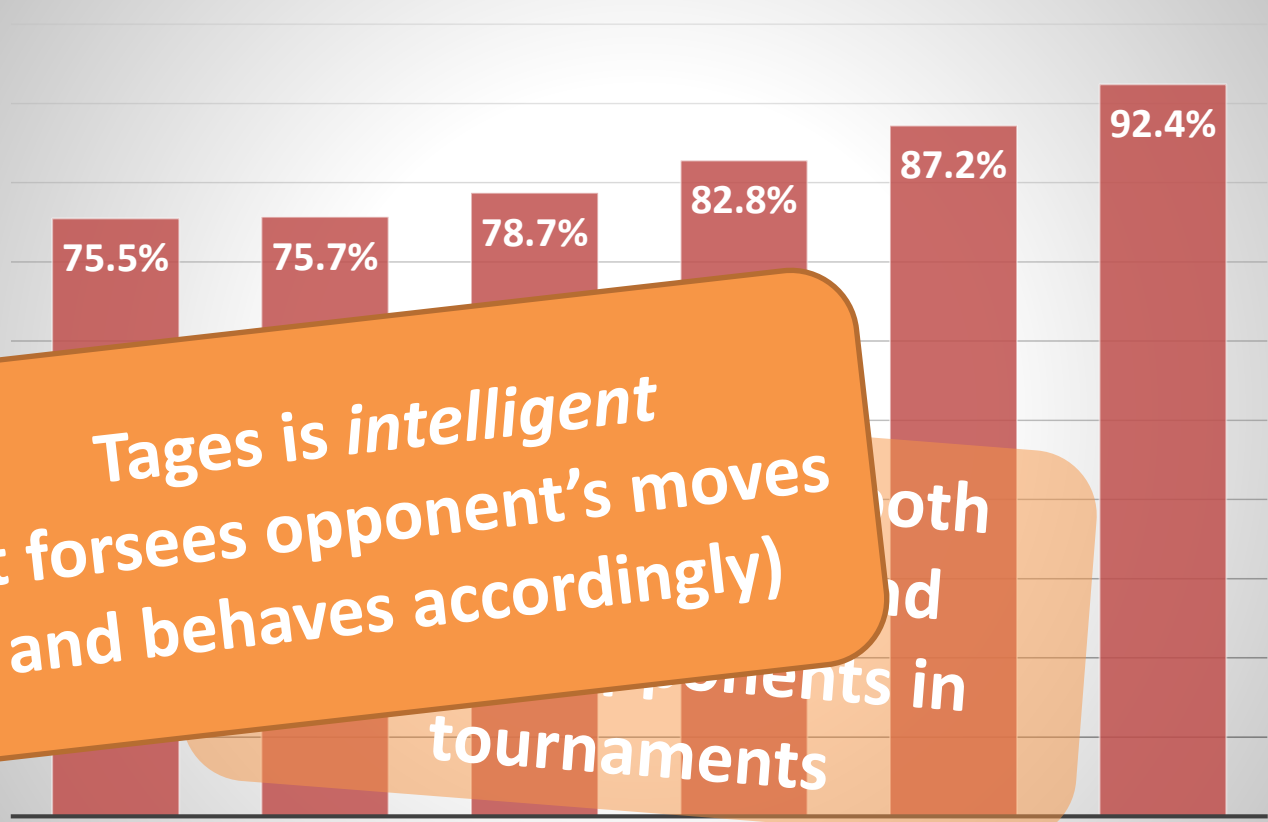
Parameters	Tages		Opponent	
\mathcal{G} μ	\bar{P}	P_σ	\bar{P}	P_σ
300 100	1.41	0.12	1.37	0.12
30 100	1.30	0.14	1.32	0.12
300 10	1.49	0.15	1.38	0.15

Why we deserve the prize?

average over 100,000 random tournaments for each tournament size

40 opponents (all the usual suspects + others)

Tages victories in tournaments of different sizes



Tages is intelligent (it forsee opponent's moves and behaves accordingly)

Opponent name	Tages		Opponent		Model	
	\bar{P}	P_σ	\bar{P}	P_σ	\bar{E}	E_σ
2TFT	2.89	0.04	2.88	0.01	0.01	0.01
ATFT	2.89	0.09	2.34	0.23	0.88	0.07
CTFT	3.00	0.00	2.77	0.18	0.98	0.00
GTFT $\epsilon = 0.05$	2.94	0.04	2.94	0.01	0.97	0.02
GTFT $\epsilon = 0.33$	2.89	0.11	2.41	0.55	0.92	0.14
HTFT2	3.47	0.00	2.97	0.02	0.97	0.00
HTFT2	2.88	0.04	2.97	0.02	0.97	0.01
HTFT3	2.84	0.07	3.00	0.03	0.96	0.01
NP	2.48	0.13	2.85	0.12	0.82	0.13
NPM	2.94	0.05	2.94	0.06	0.97	0.00
OTFT	1.89	1.04	2.29	0.65	0.91	0.00
RP $\epsilon = 0.01$	2.91	0.07	2.94	0.07	0.99	0.00
RP $\epsilon = 0.1$	2.44	0.12	2.63	0.19	0.6	0.00
RTFT	2.84	0.04	3.04	0.03	0.9	0.00
STFT	2.94	0.00	2.94	0.03	0.9	0.00
TF2T	3.88	0.04	1.56	0.02	0.9	0.00
TFT	2.86	0.00	2.96	0.01	0.9	0.00

Opponent name	Payoff			Model		
	\bar{P}	P_σ	P_{opt}	\bar{E}	E_σ	
				3.00	0.99	0.00
				3.67	0.97	0.01
				2.33	0.97	0.01
				5.00	1.00	0.00
				4.60	0.46	0.22
				4.20	0.33	0.18
				3.80	0.12	0.06
				3.40	0.14	0.08
				2.92	0.11	0.10

Thanks

- HPC@POLITO (computational resources)
- Andrea Mussano (Laran)
- Denny De Vito (presentation)
- Arnold Schwarzenegger (presentation)

