Understanding responses to environments for the Prisoner's Dilemma: A meta analysis, multidimensional optimisation and machine learning approach

Nikoleta E. Glynatsi

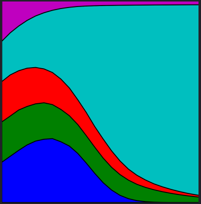
Dr Vincent Knight & Dr Jonathan Gillard

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

soapbox science

siam UKIE

Software Sustainability Institute



$$\begin{bmatrix} (3,3) & (0,5) \\ (5,0) & (1,1) \end{bmatrix}$$

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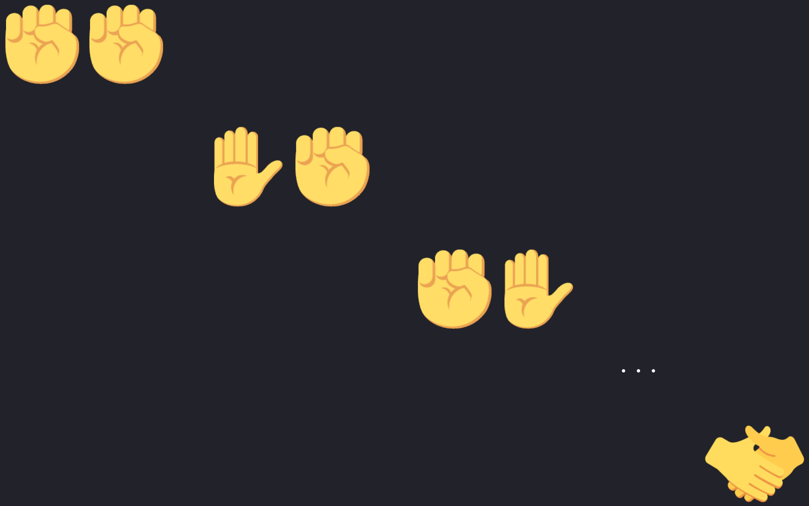
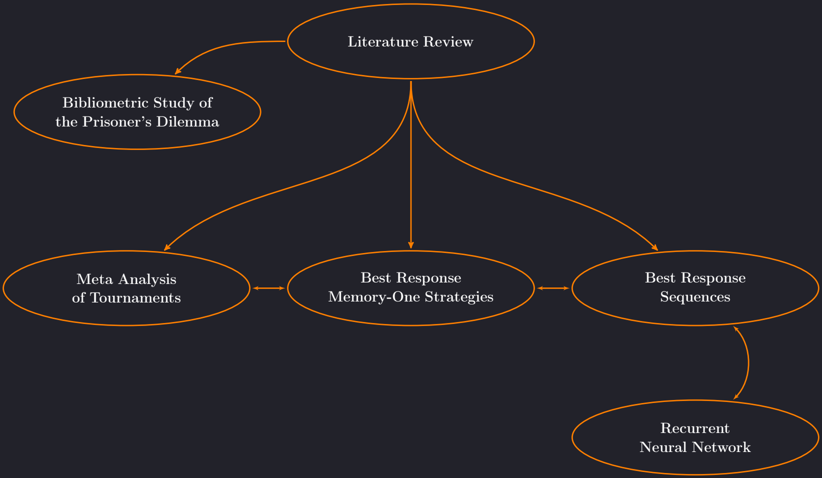
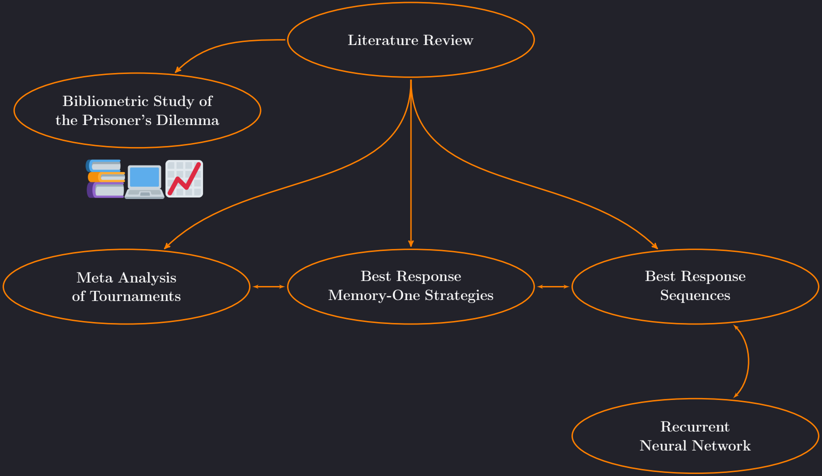



Literature Review
Bibliometric Study of the Prisoner's Dilemma
Meta Analysis of Tournaments
Best Response Memory-One Strategies
Best Response Sequences
Recurrent Neural Network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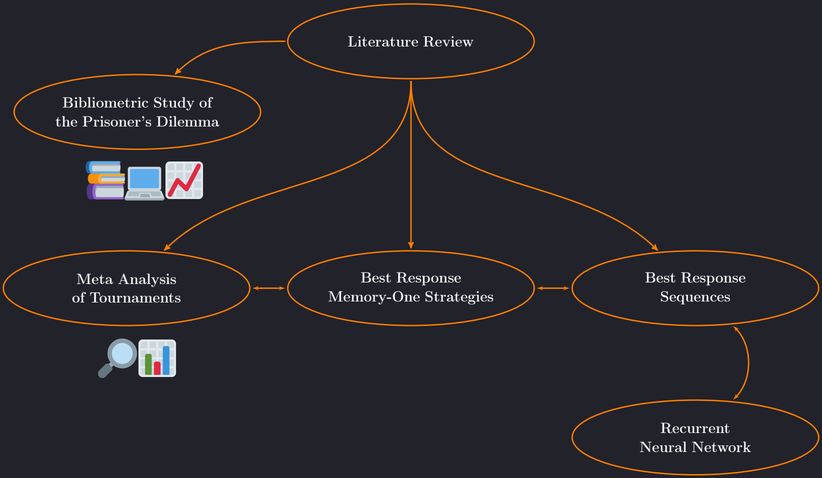
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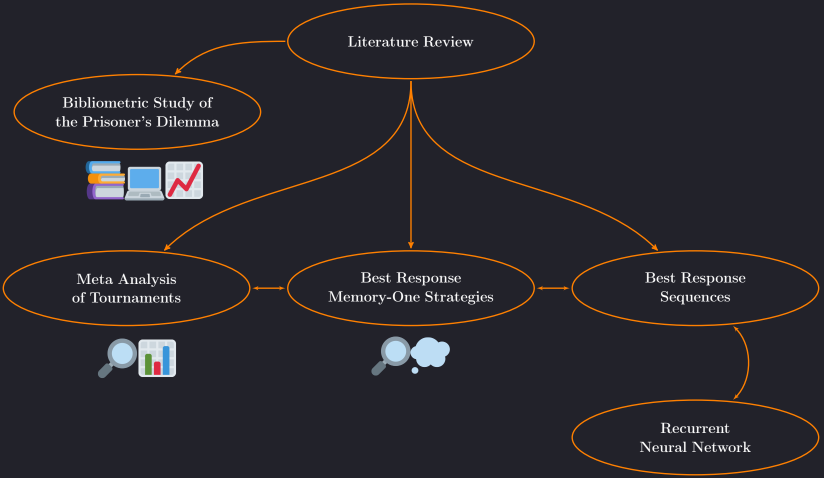

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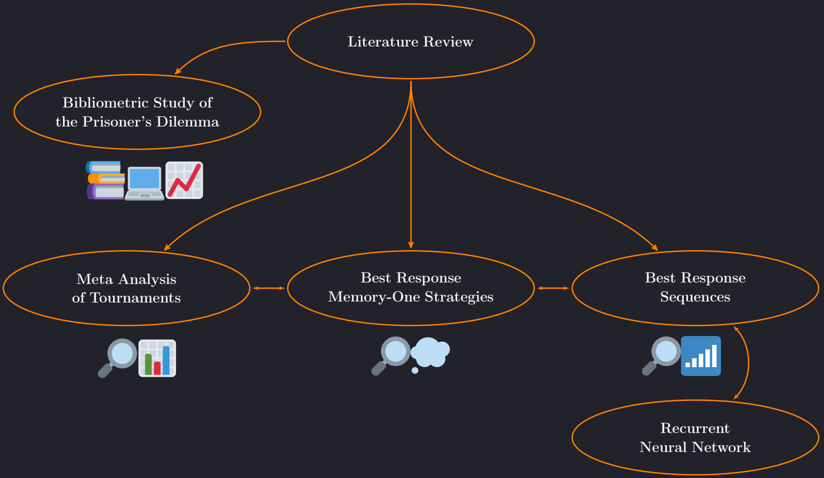

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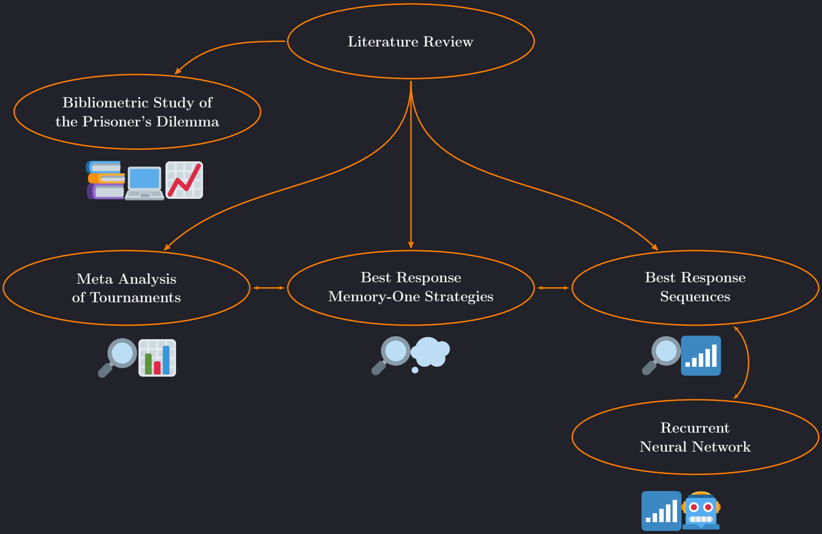
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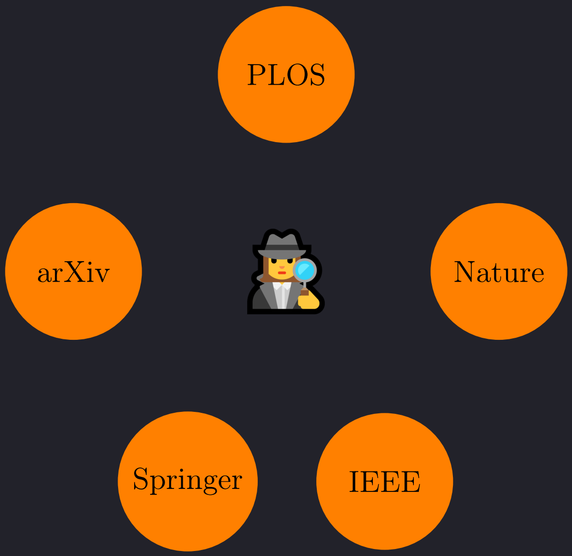
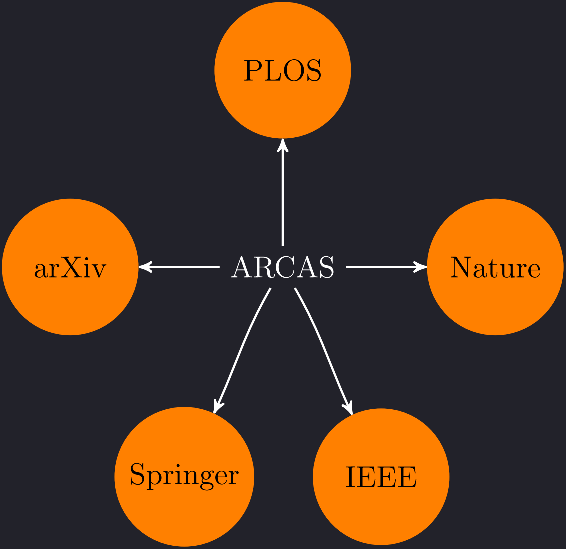
Bibliometric Study of the Prisoner's Dilemma


PLOS
arXiv
Nature
Springer
IEEE


PLOS
arXiv
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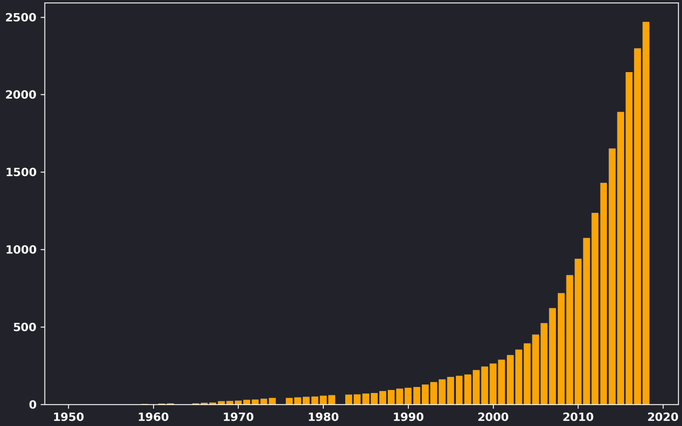
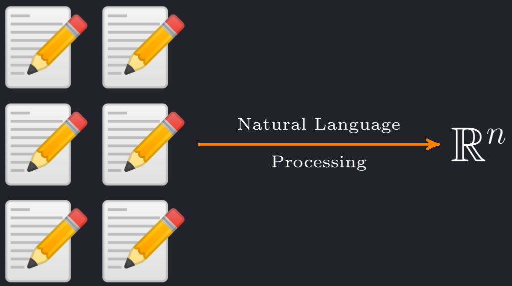
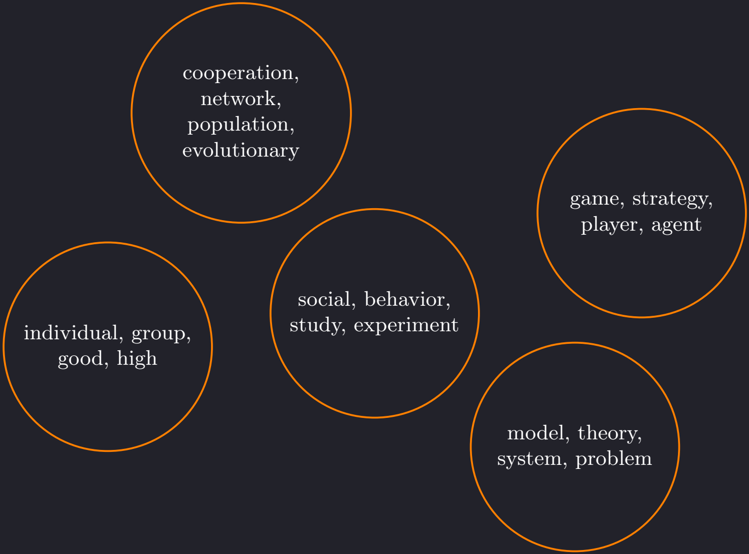
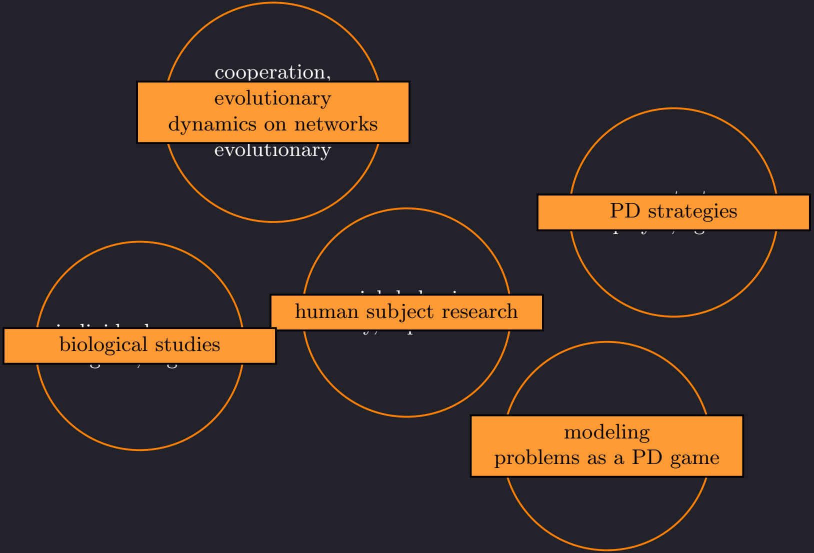
Nature
Springer
IEEE

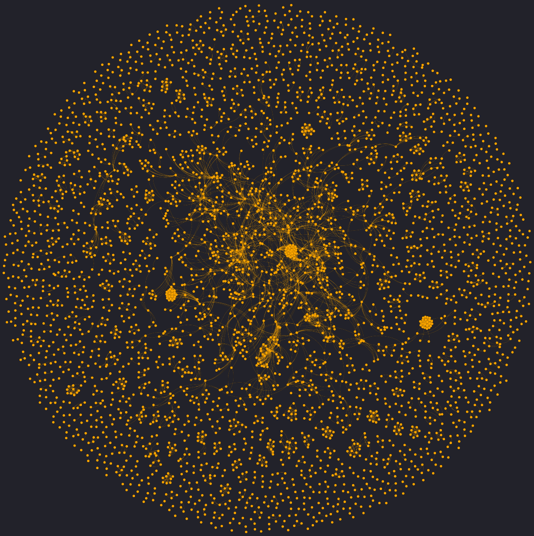

2500
2000
1500
1000
500
0
1950
1960
1970
1980
1990
2000
2010
2020


Natural Language
Processing
$\mathbb{R}^n$

Natural Language
Processing
$\mathbb{R}^n$
Topics


cooperation, network, population, evolutionary
game, strategy, player, agent
social, behavior, study, experiment
individual, group, good, high
model, theory, system, problem


cooperation,
evolutionary
dynamics on networks
evolutionary
PD strategies
human subject research
biological studies
modeling
problems as a PD game



“A bibliometric study of research topics, collaboration and influence in the field of the Iterated Prisoner’s Dilemma”

Nikoleta E. Glynatsi, Vincent A. Knight

Palgrave Communications

arxiv.org/abs/1911.06128

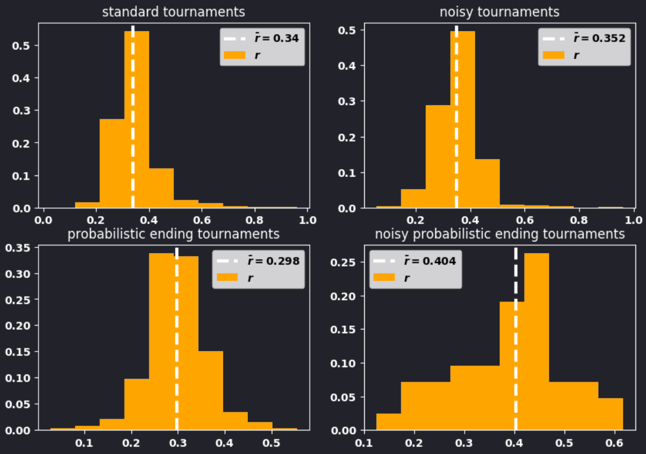
Meta Analysis of Tournaments

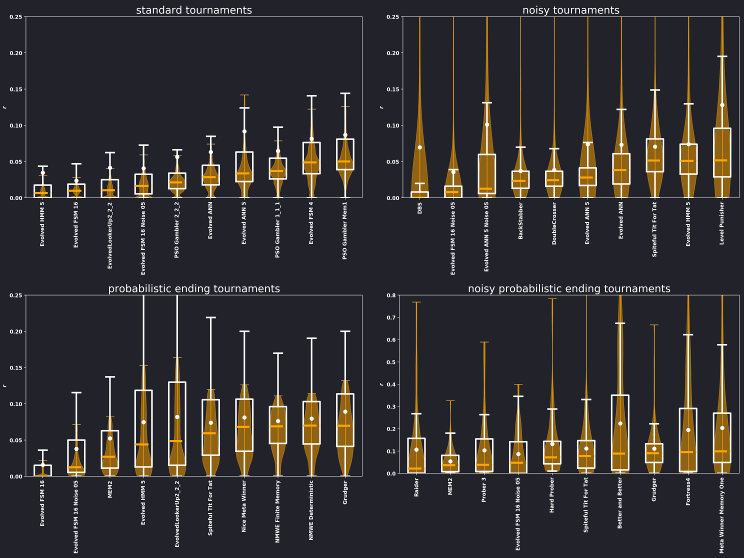
🔍📊

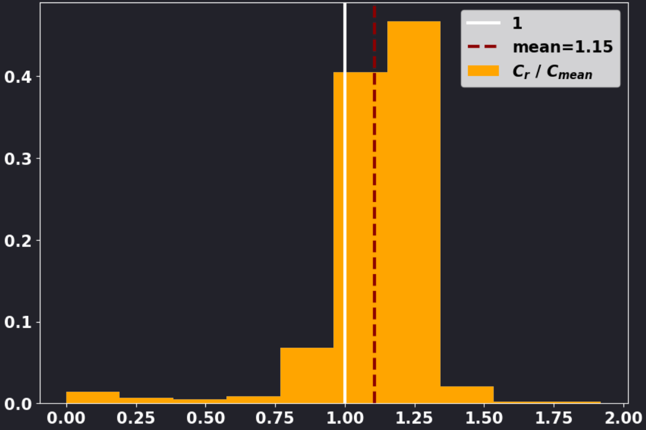
Axelrod-Python

195 strategies in **45686** tournaments

Tit For Tat Normalised Rank




standard tournaments
noisy tournaments
probabilistic ending tournaments
noisy probabilistic ending tournaments
r
Evolved HMM 5
Evolved FSM 16
EvolvedLookerUp2_2_2
Evolved FSM 16 Noise 05
PSO Gambler 2_2_2
Evolved ANN
Evolved ANN 5
PSO Gambler 1_1_1
Evolved FSM 4
PSO Gambler Mem1
DBS
Evolved FSM 16 Noise 05
Evolved ANN 5 Noise 05
BackStabber
DoubleCrosser
Evolved ANN 5
Evolved ANN
Spiteful Tit For Tat
Evolved HMM 5
Level Punisher
Evolved FSM 16
Evolved FSM 16 Noise 05
MEM2
Evolved HMM 5
EvolvedLookerUp2_2_2
Spiteful Tit For Tat
Nice Meta Winner
NMWE Finite Memory
NMWE Deterministic
Grudger
Raider
MEM2
Prober 3
Evolved FSM 16 Noise 05
Hard Prober
Spiteful Tit For Tat
Better and Better
Grudger
Fortress4
Meta Winner Memory One



1
mean=1.15
C_r / C_{mean}
0.0
0.1
0.2
0.3
0.4
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

“Properties of Winning Iterated Prisoner’s Dilemma Strategies”

Nikoleta E. Glynatsi, Vincent A. Knight, Marc Harper

arXiv:2001.05911

data: DOI:10.5281/zenodo.3516652

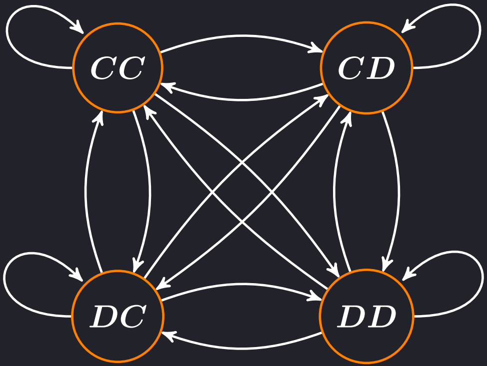
Best Response Memory One Strategies


CC
CD
DC
DD

$$p = (p_1, p_2, p_3, p_4)$$

$$p = (p_1, p_2, p_3, p_4)$$

$$q = (q_1, q_2, q_3, q_4)$$



$$p = (p_1, p_2, p_3, p_4)$$

$$q = (q_1, q_2, q_3, q_4)$$

$$u_q(p) = v \cdot (3, 0, 5, 1)$$

$$u_q(p) = v \cdot (3, 0, 5, 1)$$

$$\downarrow$$

$$u_q(p) = \frac{\frac{1}{2} p Q p^T + c p + a}{\frac{1}{2} p \bar{Q} p^T + \bar{c} p + \bar{a}}$$

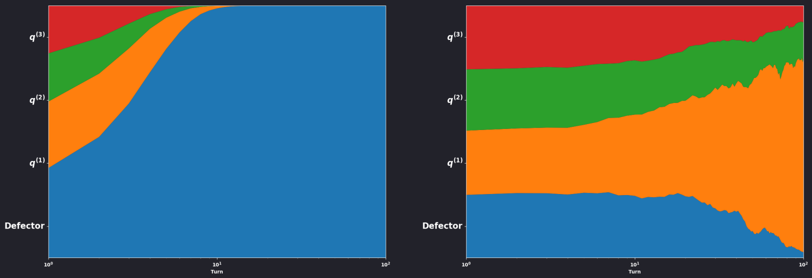
$$u_q(p) = v \cdot (3, 0, 5, 1)$$

$$u_q(p) = \frac{\frac{1}{2}pQp^T + cp + a}{\frac{1}{2}p\bar{Q}p^T + \bar{c}p + \bar{a}}$$

$$\frac{1}{N}\sum_{i=1}^{N} {u_q}^{(i)}(p)$$

$$\sum_{i=1}^{N}(c^{(i)T}\bar{a}^{(i)} - \bar{c}^{(i)T}a^{(i)}) \leq 0 \;\Rightarrow \text{Defection}$$

$$\sum_{i=1}^{N}(c^{(i)T}\bar{a}^{(i)} - \bar{c}^{(i)T}a^{(i)}) \leq 0 \ \Rightarrow \text{Defection}$$

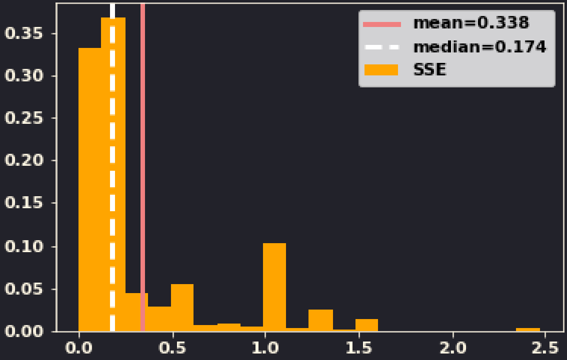


$$\sum_{i=1}^{N} {u_q}^{(i)}(p)$$

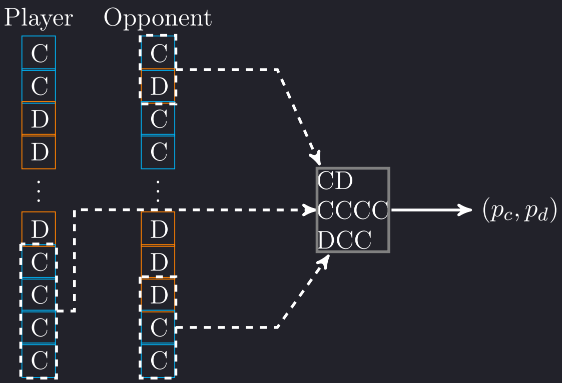
$$\sum_{i=1}^{N} u_q{}^{(i)}(p) \longrightarrow \max_p : \sum_{i=1}^{N} u_q{}^{(i)}(p)$$

$$\sum_{i=1}^{N} u_q{}^{(i)}(p) \longrightarrow \max_p : \sum_{i=1}^{N} u_q{}^{(i)}(p)$$

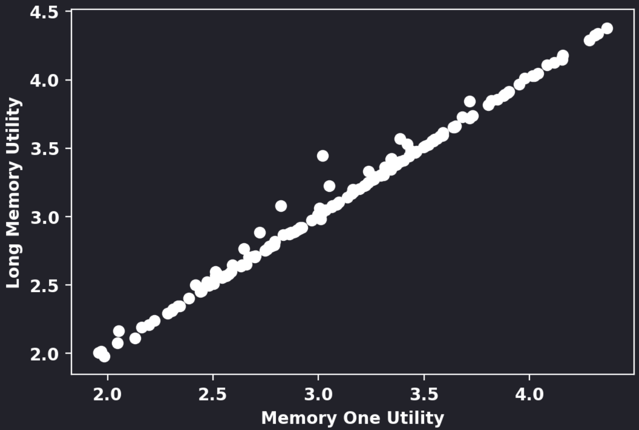
$$\sum_{i=1}^{N} u_q{}^{(i)}(p) + K u_p(p) \longrightarrow \max_p : \sum_{i=1}^{N} u_q{}^{(i)}(p) + K u_p(p)$$



Recognising and evaluating the effectiveness of extortion in the Iterated Prisoner's Dilemma.
Vincent Knight, Marc Harper, **Nikoleta E. Glynatsi**, Jonathan Gillard - Preprint
arXiv:1904.00973



Player
Opponent
C
C
D
D
D
C
C
C
C
C
D
C
C
D
D
D
C
C
CD
CCCC
DCC
(p_c, p_d)



Long Memory Utility
Memory One Utility
4.5
4.0
3.5
3.0
2.5
2.0
2.0
2.5
3.0
3.5
4.0

“Using a theory of mind to find best responses to memory-one strategies”

Nikoleta E. Glynatsi, Vincent A. Knight

Scientific Reports

arXiv:1911.12112

Best Response Sequences

🔍📶

	1	2	3	4	5	U
Tit For Tat						
S						

	1	2	3	4	5	U
Tit For Tat						
S	D	D	D	D	D	

	1	2	3	4	5	U
Tit For Tat	C	D	D	D	D	
S	D	D	D	D	D	

	1	**2**	**3**	**4**	**5**	U
Tit For Tat	C	D	D	D	D	**0.8**
S	D	D	D	D	D	**1.8**

	1	2	3	4	5	U
Tit For Tat	C	D	D	D	D	0.8
S	D	D	D	D	D	1.8

	1	**2**	**3**	**4**	**5**	U
Tit For Tat						
S						

	1	**2**	**3**	**4**	**5**	U
Tit For Tat	C	C	C	C	C	
S						

	1	**2**	**3**	**4**	**5**	U
Tit For Tat	C	C	C	C	C	
S	C	C	C	C	D	

	1	2	3	4	5	U
Tit For Tat	C	C	C	C	C	**2.5**
S	C	C	C	C	D	**3.3**

Tit For Tat

Alternator

AntiTitForTat

Random

Cooperator

Defector

SuspiciousTitForTat

WinShiftLoseStay

⋮

Evolved FSM 16

197

Tit For Tat

Alternator

AntiTitForTat

Random

Cooperator

Defector

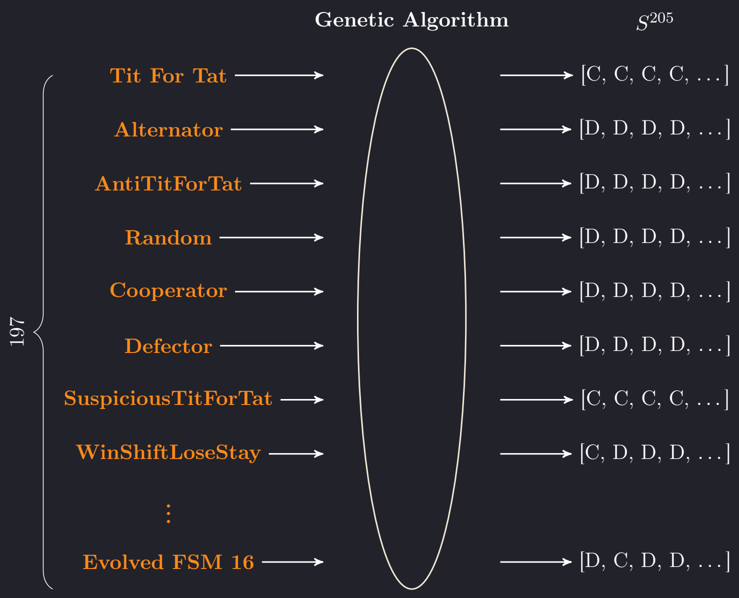
SuspiciousTitForTat

WinShiftLoseStay

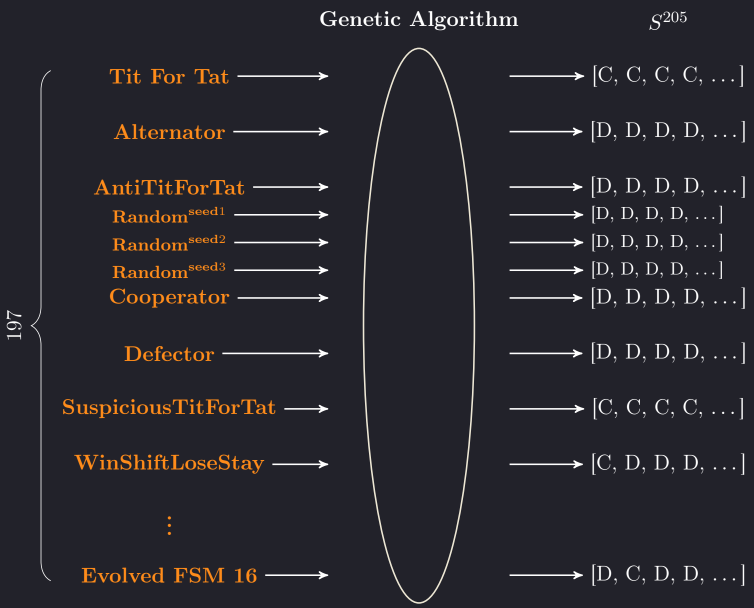
⋮

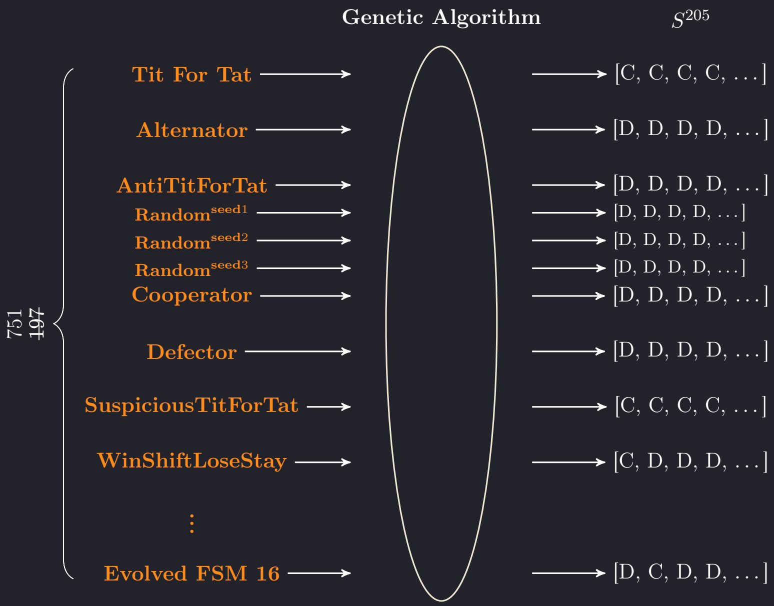
Evolved FSM 16


Genetic Algorithm
197
Tit For Tat
Alternator
AntiTitForTat
Random
Cooperator
Defector
SuspiciousTitForTat
WinShiftLoseStay
⋮
Evolved FSM 16



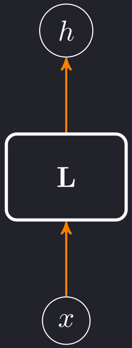
Genetic Algorithm
S^{205}
197
Tit For Tat
Alternator
AntiTitForTat
Random
Cooperator
Defector
SuspiciousTitForTat
WinShiftLoseStay
Evolved FSM 16
[C, C, C, C, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[C, C, C, C, ...]
[C, D, D, D, ...]
[D, C, D, D, ...]

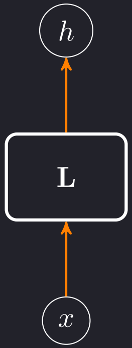

Genetic Algorithm
S^{205}
197
Tit For Tat
Alternator
AntiTitForTat
Random^{seed1}
Random^{seed2}
Random^{seed3}
Cooperator
Defector
SuspiciousTitForTat
WinShiftLoseStay
⋮
Evolved FSM 16
[C, C, C, C, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[C, C, C, C, ...]
[C, D, D, D, ...]
[D, C, D, D, ...]


Genetic Algorithm
S^{205}
Tit For Tat
Alternator
AntiTitForTat
Random seed1
Random seed2
Random seed3
Cooperator
Defector
SuspiciousTitForTat
WinShiftLoseStay
Evolved FSM 16
[C, C, C, C, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[D, D, D, D, ...]
[C, C, C, C, ...]
[C, D, D, D, ...]
[D, C, D, D, ...]

“Training Recurrent Neural Network strategies for Iterated Prisoner’s Dilemma”

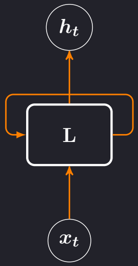
data: DOI:10.5281/zenodo.3685251

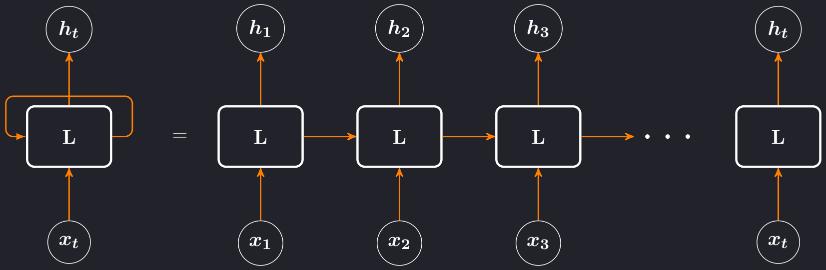

h
L
x



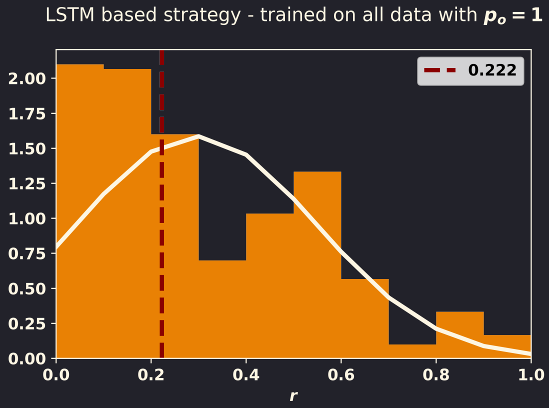
Reinforcement learning produces dominant strategies for the Iterated Prisoner's Dilemma: doi.org/10.1371/journal.pone.0188046

Evolution Reinforces Cooperation with the Emergence of Self-Recognition Mechanisms: doi.org/10.1371/journal.pone.0204981


h_t
L
x_t



h_t
L
x_t
=
h_1
L
x_1
h_2
L
x_2
h_3
L
x_3
h_t
L
x_t


LSTM based strategy - trained on all data with $p_o = 1$
0.222
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.2
0.4
0.6
0.8
1.0
r

Be nice & Open with cooperation

Be nice & Open with cooperation

Be a little envious & Be complex

Be nice & Open with cooperation

Be a little envious & Be complex

Adapt to the environment & Longer memory

Published

1. Using a theory of mind to find best responses to memory-one strategies. **Nikoleta E. Glynatsi** and Vincent A. Knight - Scientific Reports - Preprint arXiv:1911.12112
2. Reinforcement learning produces dominant strategies for the Iterated Prisoner's Dilemma. Marc Harper, Vincent Knight, Martin Jones, Georgios Koutsovoulos, **Nikoleta E. Glynatsi**, Owen Campbell - PLOS One - Preprint arXiv:1707.06307
3. An evolutionary game theoretic model of rhino horn devaluation. **Nikoleta E. Glynatsi**, Vincent Knight, Tamsin Lee. Ecological Modelling - Preprint arXiv:1712.07640
4. Evolution reinforces cooperation with the emergence of self-recognition mechanisms: an empirical study of the Moran process for the Iterated Prisoner's dilemma. Vincent Knight, Marc Harper, **Nikoleta E. Glynatsi**, Owen Campbell - PLOS ONE - Preprint arXiv:1707.06920
5. An open framework for the reproducible study of the Iterated prisoner's dilemma. Vincent Knight, Owen Campbell, Marc Harper et al - Journal of Open Research Software

Under review

1. A bibliometric study of research topics, collaboration and influence in the field of the Iterated Prisoner's Dilemma. **Nikoleta E. Glynatsi** and Vincent A. Knight - Palgrave Communications - Preprint arXiv:1911.06128
2. Game Theory and Python: An educational tutorial to game theory and repeated games using Python **Nikoleta E. Glynatsi** and Vincent A. Knight - Journal of Open Source Education Nikoleta-v3/Game-Theory-and-Python

In preparation

1. Properties of Winning Iterated Prisoner's Dilemma Strategies. **Nikoleta E. Glynatsi**, Vincent A. Knight and Marc Harper - Preprint arXiv:2001.05911
2. Recognising and evaluating the effectiveness of extortion in the Iterated Prisoner's Dilemma. Vincent Knight, Marc Harper, **Nikoleta E. Glynatsi**, Jonathan Gillard - Preprint arXiv:1904.00973