Combining Normative Ethics Principles for Prosociality in Norm-Learning Agents

Supplement 6541

The supplement is organised in the following way. Section A lists details of experimental setups including computer infrastructure and parameter selection. Section B discusses additional scenarios and results. Section C describes norm emergence and presents results for emerged norms. Section D presents results for different principle aggregation methods.

A Details of Experimental Setups

A.1 Computing Infrastructure

We conducted the simulation experiments on a workstation with Intel Xeon Processor W-2245 (8C 3.9 GHz), 256GB RAM, and Nvidia RTA A6000 48GB GPU.

A.2 Hyperparameter Selection

Table A1 lists the interaction module parameters and range of values tried per parameter. We select these parameters empirically, with reference to literature (Bengio, 2012).

A.3 Simulation Parameters Selection

Table A2 lists the simulation parameters and range of values tried per parameter. We select these parameters empirically.

Rewards To encourage agents to learn to survive, agents are positively rewarded for reaching the end of an episode and negatively rewarded for dying. Agents are rewarded for throwing to provide incentive for egoistic agents that do not implement ethics sanctioning to learn cooperative behaviours. Providing environmental rewards for cooperative behaviours allows for fair comparison between agent types, rather than giving agents that implement ethical principles additional rewards. Rewards are also normalised between egoistic agents and agents implementing ethical principles to avoid obvious results by giving additional rewards. Table A3 lists complete rewards received by agents.

B Additional Results

Here, we present and discuss results from capabilities and allotment harvest scenarios. We then present a summary of results across all three scenarios.

Table A1: DQN Parameters.

Description	Parameter	Range Tried	Final Value	Criterion
Batch size	B	{32, 64, 128}	64	Training time
Iteration for updating weights of target network	C	{1000, 100, 50}	50	Test performance
Probability of exploration	ϵ	0.9–0.0	0.0	Test performance
Learning rate	α	{0.01, 0.001, 0.0001}	0.0001	Test performance
Number of hidden units	Hn	{32, 64, 128}	128	Test performance
Number of hidden layers	Hl	1–3	2	Test performance

B.1 Colours Harvest

Table A4 summarises the results comparing PriENE with individual principles. PriENE societies have lowest inequality, highest minimum experience, highest social welfare, and highest robustness.

B.2 Capabilities Harvest

Table A5 summarises results from the capabilities harvest. PriENE societies have lowest inequality, highest social welfare, and highest robustness.

M_1 (inequality) PriENE and maximin societies have lowest inequality. PriENE societies have lowest median for ag_{days} and ag_{berries} and maximin societies have lowest mean for ag_{days}. Utilitarian societies have next lowest inequality.

Table A2: Simulation Parameters.

Description	Parameter	Range Tried	Final Value
Grid size	$o_{\text{basic}} \times p_{\text{basic}}$	$\{4 \times 4, 8 \times 4\}$	8×8
Number of agents	k	$\{2, 4\}$	4.0
Initial number of berries	b_{initial}	$\{8, 12, 16\}$	12.0
Initial health of agent	h_{initial}	$\{5.0, 10.0\}$	5.0
Health decay	h_{decay}	$\{–0.01, –0.1\}$	-0.01
Health gain from eating berry	h_{gain}	$\{0.1, 1.0\}$	0.1
Minimum health to throw	h_{throw}	$\{0.5, 0.6, 1.0\}$	0.6
Number of episodes	e	$\{500, 1000\}$	1000.0
Maximum steps in episode	$t_{\max}$	$\{50, 200\}$	200.0

Table A3: Rewards received by an agent. Rewards are normalised between egoistic and other agents to avoid obvious results by giving agents implementing other principles more rewards.

Action	Egoistic	Principles
Survive episode	1.00	1.00
Eat berry	1.00	0.80
Forage berry	1.00	0.80
Throw berry	0.50	0.50
Try to eat without berries	-0.20	-0.10
Try to throw without berries	-0.20	-0.10
Try to throw without sufficient health	-0.20	-0.10
Try to throw without recipient	-0.20	-0.10
Die	-1.00	-1.00
Positive ethics sanction	0.00	0.40
Negative ethics sanction	0.00	-0.40

Egoistic societies have highest inequality. Figure A1 displays results for inequality.

M_2 (minimum experience) Minimum individual experience is highest for utilitarian societies, followed by egalitarian, maximin, egoistic, and then PriENE. Figure A2 displays results for minimum experience.

M_3 (maximum experience) Maximum individual experience is highest for ag_{days} in egalitarian societies, which also have second highest ag_{berries}. Egoistic societies have highest ag_{berries} and second highest ag_{days}. PriENE societies come third for maximum ag_{days} and ag_{berries}. Maximin societies have fourth highest maximum ag_{days} and ag_{berries}. Utilitarian societies have lowest maximum experience. Figure A3 dis-

Table A4: Comparing PriENE with individual principles ag_{days} and ag_{berries} mean $\bar{x}$, median M, and standard deviation σ. for colours harvest

Metric	Variable	Egoistic			Utilitarian			Maximin			Egalitarian			PriENE		
		$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ
M_1	ag_{days}	0.38	0.39	0.13	0.41	0.41	0.1	0.37	0.38	0.11	0.33	0.34	0.13	**0.31**	**0.31**	0.11
	ag_{berries}	0.43	0.44	0.14	0.48	0.47	0.11	0.42	0.43	0.12	0.38	0.38	0.14	**0.37**	**0.38**	0.11
M_2	ag_{days}	16.93	9.0	13.78	18.95	15.0	12.57	18.67	15.0	13.1	**25.41**	15.0	27.9	23.29	**21.0**	16.07
	ag_{berries}	2.06	1.0	2.43	1.96	1.0	2.15	2.09	1.0	2.14	**3.23**	**2.0**	4.69	2.81	**2.0**	2.59
M_3	ag_{days}	179.18	**200.0**	49.07	**196.92**	**200.0**	21.77	185.97	**200.0**	41.78	161.03	**200.0**	55.4	174.16	**200.0**	54.93
	ag_{berries}	35.48	39.0	11.66	**42.9**	**44.0**	5.72	37.95	41.0	9.5	29.28	35.0	12.05	35.0	40.0	11.47
M_4	ag_{days}	380.34	370.5	166.58	402.19	430.0	111.43	424.79	447.0	142.87	379.3	335.0	195.37	**427.38**	**460.0**	172.05
	ag_{berries}	69.12	64.5	34.08	77.14	83.0	21.9	**79.51**	86.0	29.06	65.82	56.0	39.13	78.64	**87.5**	34.19
M_5		95.08	51.0	83.91	100.55	57.0	83.75	106.2	68.0	85.38	94.83	57.0	79.48	**106.85**	**69.0**	82.12

Table A5: Comparing PriENE with individual principles ag_{days} and ag_{berries} mean $\bar{x}$, median M, and standard deviation σ for capabilities harvest.

Metric	Variable	Egoistic			Utilitarian			Maximin			Egalitarian			PriENE		
		$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ
M_1	ag_{days}	0.39	0.4	0.14	0.32	0.33	0.13	**0.31**	0.3	0.11	0.33	0.33	0.11	0.32	**0.28**	0.12
	ag_{berries}	0.46	0.47	0.15	**0.37**	0.38	0.14	**0.37**	0.38	0.12	0.4	0.4	0.12	**0.37**	**0.34**	0.13
M_2	ag_{days}	19.82	15.0	13.72	**29.16**	**21.0**	26.24	21.56	15.0	15.16	22.57	15.0	17.15	18.56	9.0	17.92
	ag_{berries}	2.34	**2.0**	2.31	**3.77**	**2.0**	4.47	2.48	**2.0**	2.55	2.55	**2.0**	2.91	2.18	1.0	2.97
M_3	ag_{days}	199.04	**200.0**	12.48	187.62	**200.0**	33.38	193.23	**200.0**	31.39	**199.54**	**200.0**	8.34	195.75	**200.0**	24.28
	ag_{berries}	**48.81**	**49.0**	5.57	40.02	43.0	9.96	43.51	45.0	8.14	47.22	47.0	4.76	43.68	45.0	7.24
M_4	ag_{days}	432.62	442.0	145.52	464.5	466.0	163.24	501.14	490.0	135.94	499.73	490.0	107.44	**503.53**	**525.0**	135.62
	ag_{berries}	91.99	95.0	29.28	91.07	98.0	35.66	103.17	103.0	29.14	**103.5**	103.0	21.64	102.06	**108.0**	28.66
M_5		108.16	69.0	87.19	116.13	116.0	82.25	125.29	**200.0**	86.16	124.93	**200.0**	84.25	**125.88**	**200.0**	86.85

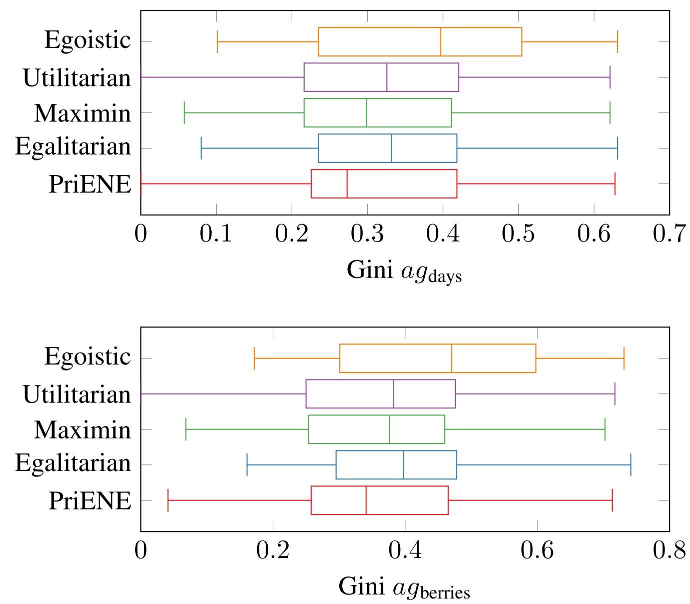

Figure A1: capabilities harvest comparing M_1 (inequality) for PriENE and societies with agents implementing individual principles. Results show that PriENE societies have lowest Gini index indicating lowest inequality.

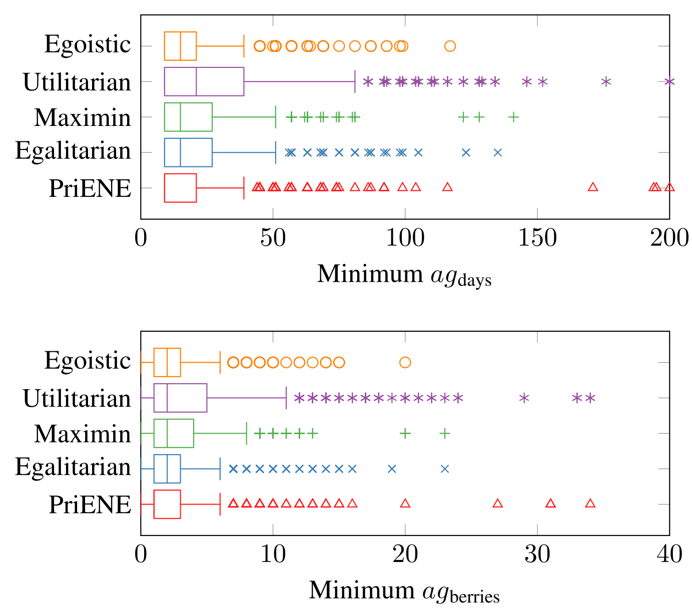

Figure A2: Capabilities harvest comparing M_2 (minimum experience) for PriENE and societies with agents implementing individual principles. Results show that egalitarian societies have highest minimum ag_{days} and ag_{berries} closely followed by PriENE. Egoist societies have lowest minimum experience.

plays the results for maximum experience.

M_4 (social welfare) PriENE societies have highest social welfare for ag_{days} and ag_{berries} median. Egalitarian societies

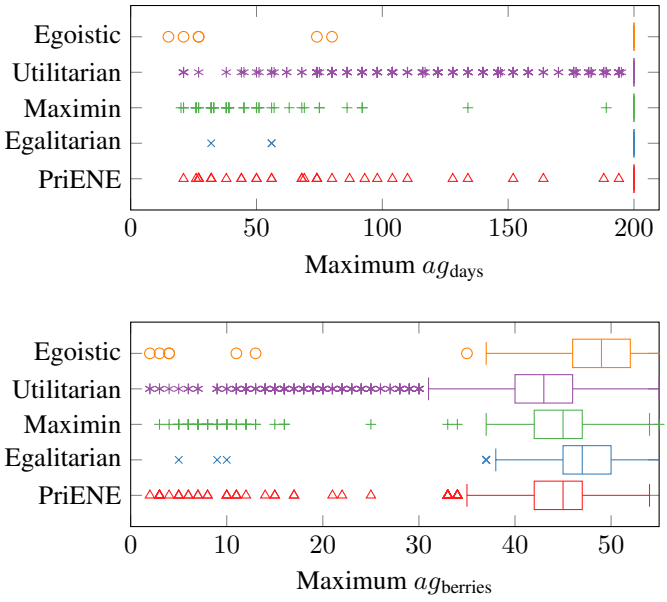

Figure A3: Capabilities harvest comparing M_3 (maximum experience) for PriENE and societies with agents implementing individual principles. Results show that utilitarian societies have highest ag_{days} mean and maximin societies have highest ag_{berries} mean.

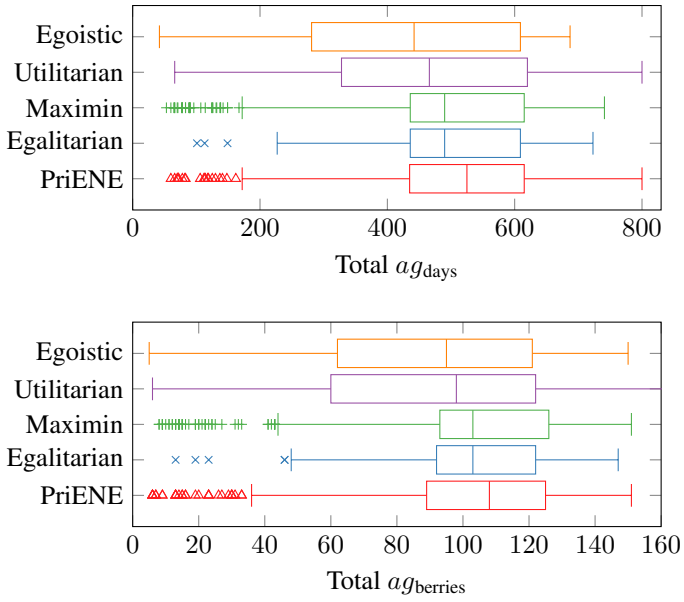

Figure A4: Capabilities harvest comparing M_4 (social welfare) for PriENE and societies with agents implementing individual principles. Results show that PriENE societies have highest total for both ag_{days} and ag_{berries}.

have highest ag_{berries} mean. Maximin and egalitarian societies have joint second highest median for ag_{berries} and ag_{days}. Maximin societies have second highest mean for ag_{berries} and ag_{days}. PriENE societies have third highest ag_{berries} mean. Utilitarian societies have fourth highest mean and median for ag_{days} and ag_{berries} median. Egoistic societies have lowest social welfare except for ag_{berries} mean, which is second lowest. Figure A4 displays the results for social welfare.

M_5 (robustness) Societies of PriENE agents survive longest, followed by maximin, egalitarian, utilitarian, and then egoistic. Figure A5 displays the results for robustness.

Discussion

Overall in the capabilities harvest, societies of PriENE agents have lowest inequality, highest social welfare, highest robustness, third highest maximum experience, and lowest minimum experience. The combination of highest social welfare and robustness suggests that norms emerging in societies of PriENE agents lead to higher sustainability than norms emerging in societies of agents implementing individual principles. However, although PriENE societies have the lowest inequality, minimum experience is also lowest. Together, these results suggest that norms emerging in societies of PriENE agents promote sustainability and mitigate inequality.

Societies of egoistic agents are last for every metric aside from maximum individual experience, suggesting that norms emerging in egoistic societies lead to selfish behaviour that advances the well-being of some agents whilst diminishing the sustainability of the society as a whole.

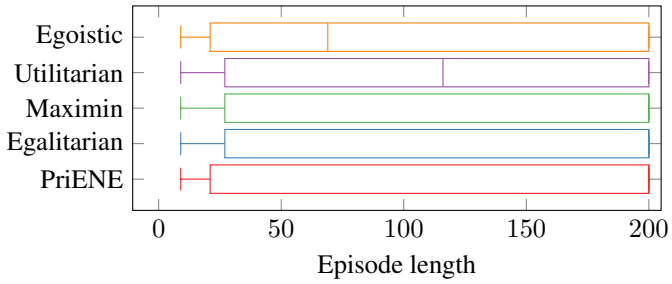

Figure A5: Capabilities harvest comparing M_5 (robustness) for PriENE and societies with agents implementing individual principles. Results show that PriENE societies have longest episode lengths indicating higher robustness.

B.3 Allotment Harvest

Table A6 summarises results from the allotment harvest. PriENE societies have lowest inequality, highest social welfare, and highest robustness.

M_1 (inequality) Societies of PriENE agents have lowest median for ag_{days} and ag_{berries}, and joint lowest ag_{berries} mean with utilitarian. Utilitarian societies have lowest ag_{days} mean. Maximin societies come second apart from ag_{berries} median which is lower in egalitarian societies. Egoistic societies have highest inequality. Figure A6 displays results for inequality.

M_2 (minimum experience) Minimum experience is highest in utilitarian societies, followed by maximin for ag_{days} and ag_{berries}, except for ag_{berries} mean which is higher in egalitarian societies. Egoistic societies have next highest minimum, followed by PriENE societies. Figure A7 displays results for

Table A6: Comparing PriENE with individual principles ag_{days} and ag_{berries} mean $\bar{x}$, median M, and standard deviation σ for allotment harvest.

Metric	Variable	Egoistic			Utilitarian			Maximin			Egalitarian			PriENE		
		$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ
M_1	ag_{days}	0.38	0.39	0.14	**0.31**	0.3	0.13	0.32	0.33	0.11	0.33	0.32	0.11	0.32	**0.24**	0.12
	ag_{berries}	0.46	0.46	0.15	**0.37**	0.36	0.14	**0.37**	0.4	0.12	0.4	0.39	0.12	**0.37**	**0.31**	0.13
M_2	ag_{days}	19.53	15.0	12.3	**30.72**	**21.0**	28.6	21.19	15.0	15.0	21.7	15.0	16.86	18.18	15.0	15.21
	ag_{berries}	2.19	1.0	2.26	**4.0**	**2.0**	4.85	2.41	**2.0**	2.49	2.45	**2.0**	2.87	2.12	1.0	2.5
M_3	ag_{days}	199.46	**200.0**	9.49	190.54	**200.0**	29.37	194.13	**200.0**	29.89	**199.64**	**200.0**	8.01	196.79	**200.0**	21.59
	ag_{berries}	**48.7**	**49.0**	5.21	40.92	44.0	9.05	43.82	45.0	7.64	47.3	47.0	4.64	44.0	45.0	6.64
M_4	ag_{days}	438.19	442.0	143.82	478.33	483.0	159.47	496.08	478.0	133.17	504.78	496.0	110.98	**508.94**	**555.0**	132.19
	ag_{berries}	92.94	95.0	28.87	94.02	100.0	34.69	102.5	101.0	28.49	**104.56**	104.5	21.83	104.28	**112.0**	28.04
M_5		109.55	81.0	87.06	119.58	140.0	81.96	124.02	**200.0**	86.49	126.2	**200.0**	84.55	**127.25**	**200.0**	86.62

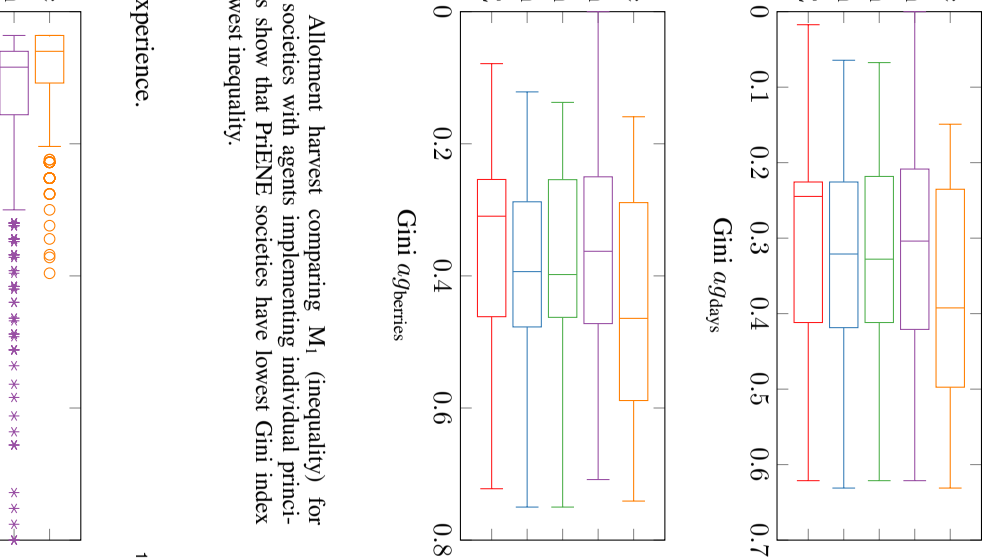

Figure A6: Allotment harvest comparing M_1 (inequality) for PriENE and societies with agents implementing individual principles. Results show that PriENE societies have lowest Gini index indicating lowest inequality.

Figure A7: Allotment harvest comparing M_2 (minimum experience) for PriENE and societies with agents implementing individual principles. Results show that egalitarian societies have highest minimum ag_{days} and ag_{berries} closely followed by PriENE. Egoist societies have lowest minimum experience.

M_3 (maximum experience) Maximum ag_{days} is highest in egalitarian societies and ag_{berries} is highest in egoistic societies. PriENE societies have next highest maximum experience, followed by maximin, and then utilitarian. Figure A8 displays the results for maximum experience.

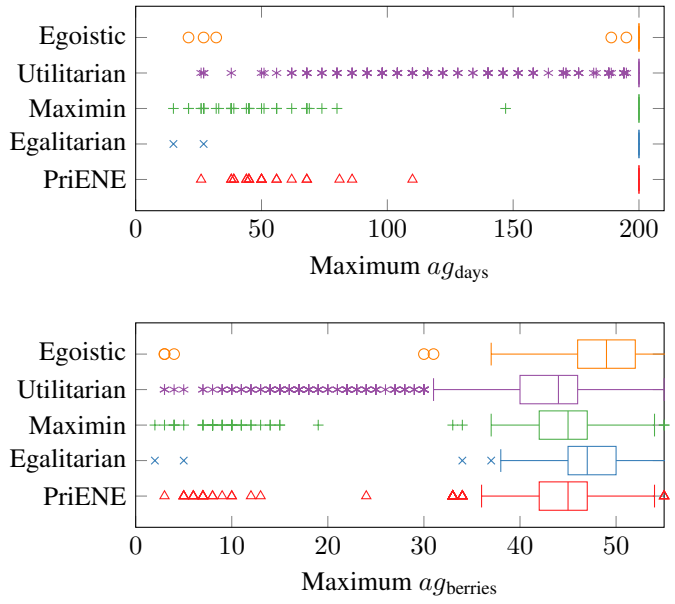

Figure A8: Allotment harvest comparing M_3 (maximum experience) for PriENE and societies with agents implementing individual principles. Results show that utilitarian societies have highest ag_{days} mean and maximin societies have highest ag_{berries} mean.

M_4 (social welfare) PriENE societies have highest social welfare for ag_{days} and highest ag_{berries} median. Egalitarian societies come second, followed by maximin, utilitarian, and egoistic societies are last. Figure A9 displays results for social welfare.

M_5 (robustness) Societies of PriENE agents survive for longest, followed by egalitarian, maximin, utilitarian, and then egoistic. Figure A10 displays the results for robustness.

Discussion

In the allotment harvest societies of PriENE agents have lowest inequality, highest social welfare, highest robustness, third highest maximum experience, and lowest minimum experience. Results suggest that norms emerging in societies of PriENE agents lead to better sustainability and lower inequality than norms emerging in societies of agents implementing individual principles. Egoistic societies do worst for inequality, social welfare and robustness, and second worst for minimum experience, suggesting that norms emerging in egoistic societies do not support fairness or sustainability.

A Note on Egoism

Egoistic agents are a baseline that prioritise individual interests. It is interesting to note that in all scenarios, prioritising egoism leads to lower total social welfare than all principles

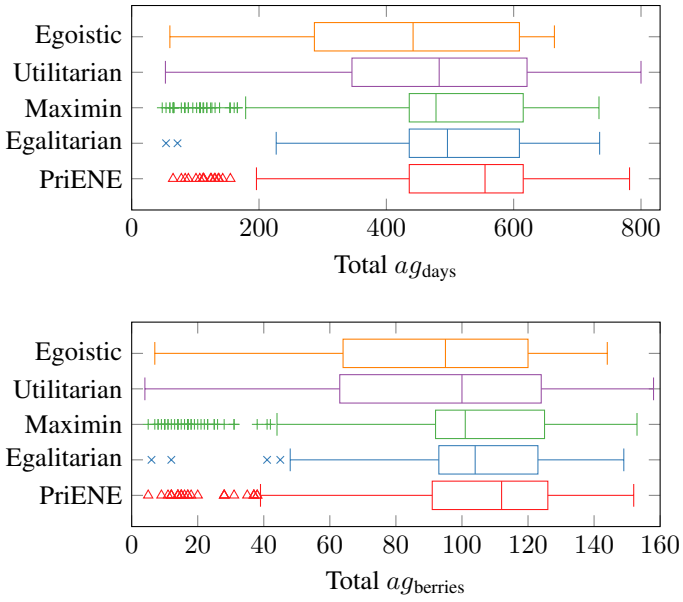

Figure A9: Allotment harvest comparing M_4 (social welfare) for PriENE and societies with agents implementing individual principles. Results show that PriENE societies have highest total for both ag_{days} and ag_{berries}.

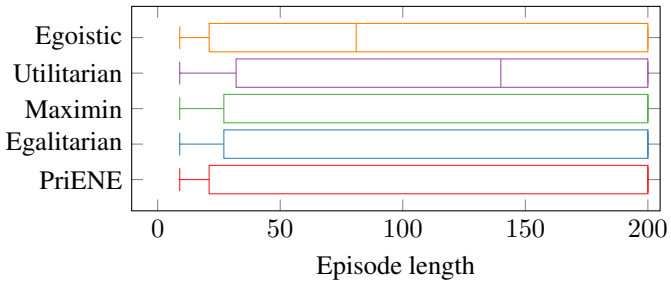

Figure A10: Allotment harvest comparing M_5 (robustness) for PriENE and societies with agents implementing individual principles. Results show that PriENE societies have longest episode lengths indicating higher robustness.

in the capabilities and allotment harvest, and all principles other than egalitarianism in the colours harvest. This supports the claim of Dong et al. (2024) that excessive emphasis on egoism can diminish social welfare, and direct egalitarianism incurs a loss of social welfare. In the colours harvest, egoistic societies do not do better than other principles on any metric, even maximum individual experience. That utilitarianism and maximin have the highest maximum experience indicates that in the colours harvest, prioritising societal utility raises the maximum experience more than prioritising solely an agent's own utility. In the capabilities and allotment harvests, egoistic societies have higher maximum experience yet do badly along other metrics. These results suggest that in the capabilities and allotment harvest, it is possible for individual agents to do well by prioritising their own interests but society as a whole suffers.

No cooperative norms emerge in any scenario in egoistic societies, suggesting that agents are not behaving in ways that promote prosocial norms despite receiving environmental rewards for cooperative actions. These results suggest that environmental rewards for cooperative actions are not sufficient for agents to learn behaviour that supports prosocial norm emergence.

C Emerged Norms

To track emerged norms, an agent stores behaviours in a behaviour base and norms in a norm base. For each behaviour, the norms module of the agent computes and stores the numerosity of the behaviour num, obtained from the number of times the norm is used, and the reward r'_{t+1} received after using the behaviour. For each behaviour, the norms module calculates its fitness τ from $\mathrm{num} \cdot r'_{t+1}$ decayed over time. Where η is the age of the behaviour and λ is the decay rate,

$$\tau(\zeta) = \mathrm{num} \cdot r'_{t+1} \cdot \lambda^{\eta} \quad (1)$$

When a behaviour is adopted by $> 90\%$ of agents in the society, it is deemed to have emerged as a norm and it is stored in a norm base shared by society. To evaluate the system of emerged norms over e episodes, we examine the numerosity num and fitness τ of cooperative norms. In the scenarios we evaluate, cooperative norms are understood as those that entail throwing berries to other agents. Table A7 lists results for total number of distinct emerged norms and total number of distinct emerged cooperative norms in each scenario.

In the colours harvest, more cooperative norms emerge in societies of PriENE agents. Table A8 displays the results for fitness and numerosity of emerged cooperative norms in colours harvest. The full list of emerged norms are in the code base under `data/results/200_days/4_agents/colours/norms`.

In the capabilities harvest, more cooperative norms emerge in societies of PriENE agents. Table A9 displays the results for fitness and numerosity of emerged cooperative norms in capabilities harvest. The full list of emerged norms are in the code base under `data/results/200_days/4_agents/capabilities/norms`.

In the allotment harvest, societies of PriENE agents, utilitarian agents, and maximin agents have joint highest number of emerged cooperative norms. Table A10 displays results for fitness and numerosity of emerged cooperative norms in allotment harvest. The full list of emerged norms are in the code base under `data/results/200_days/4_agents/allotment/norms`.

D Comparing Principle Aggregations

Depending on the scenario, various aggregation methods are appropriate. We demonstrate this by applying each aggregation method to each scenario and selecting the aggregation most successful in that scenario. In the colours harvest, societies with average aggregation have lowest inequality, highest minimum experience, highest social welfare, and highest robustness. Veto societies have highest maximum experience. In the capabilities and allotment harvests, societies with optimist aggregation have lowest inequality, highest social welfare, and highest robustness. Table A11 summarises results comparing principle aggregation methods in all scenarios.

The colours harvest explores individual resource assignment across a grid shared amongst the whole population. The capabilities harvest explores group resource assignment across a grid shared amongst the whole population. The allotment harvest explores group resource assignment where groups are restricted to limited portions of the grid. In the colours harvest, berries are assigned to individual agents; in the capabilities and allotment harvests, berries are assigned to groups. Whilst the total amount of berries is the same in all scenarios, berries are divided into fewer portions in the capabilities and allotment harvests. As there are fewer portions in the capabilities and allotment harvests, there are more berries in each portion and agents can take more risks. Optimist aggregation is not risk averse as it positively sanctions an action if any principle positively sanctions the action. Average aggregation is more risk averse by balancing the recommendations of all principles. Optimist aggregation is thus more appropriate in capabilities and allotment harvests as it is less cautious than average aggregation. For colours harvest, we use average aggregation PriENE; for capabilities and allotment harvest, we use optimist aggregation in PriENE.

D.1 Colours Harvest Principle Aggregations

In the colours harvest, societies with average aggregation have lowest inequality, highest median minimum experience, highest social welfare, and highest robustness. Societies with veto aggregation have highest maximum individual experience, followed by optimist, majoritarian, and then average. Majoritarian and veto have highest inequality. Societies with majoritarian aggregation have lowest social welfare and robustness. Table A12 displays results for principle aggregations in colours harvest.

As average aggregation has lowest inequality and highest minimum experience median, results support average as the most fair aggregation method for colours harvest. Societies with average aggregation have highest total experience for both ag_{days} and ag_{berries} and highest robustness. These results suggest that agents learn more successful behaviour strategies to survive in the scenario. Societies with average aggregation have third highest maximum experience. We argue this is sufficient when combined with higher fairness and total cumulative experience. Overall, societies with average aggregation do best for fairness and sustainability. We thus use average aggregation to combine principles in PriENE for colours harvest.

D.2 Capabilities Harvest Principle Aggregations

In the capabilities harvest, optimist societies do best for inequality, social welfare, and robustness. Minimum individual experience is highest in veto societies, followed by majoritarian, optimist, and then average societies. Veto societies do best for maximum individual experience. Robustness is highest in optimist societies, followed by veto, then average and majoritarian. Table A13 list results for principle aggregations in the capabilities harvest.

Table A7: Comparing total number of distinct emerged norms and total number of distinct emerged cooperative norms over $e = 1000$ episodes for $t_{\max} = 200$ steps in PriENE with individual principles for colours, capabilities, and allotment harvests. Bold highlight indicates best results.

Principle	Colours		Capabilities		Allotment	
	Norms	Cooperative	Norms	Cooperative	Norms	Cooperative
Egoistic	113	0	143	0	155	0
Utilitarian	13	0	16	2	20	**2**
Maximin	18	1	16	2	13	**2**
Egalitarian	20	0	23	2	25	1
PriENE	21	**3**	28	**4**	29	**2**

Table A8: Comparing fitness and numerosity of emerged cooperative norms in PriENE with individual principles for colours harvest. Bold highlight indicates best results.

Society	Numerosity			Fitness		
	$\bar{x}$	M	σ	$\bar{x}$	M	σ
Egoistic	0.0	0.0	0.0	0.0	0.0	0.0
Utilitarian	0.0	0.0	0.0	0.0	0.0	0.0
Maximin	**28.33**	**26.0**	5.86	**439.4**	**183.6**	496.47
Egalitarian	0.0	0.0	0.0	0.0	0.0	0.0
PriENE	9.62	9.0	3.93	119.08	91.2	111.91

Table A9: Comparing fitness and numerosity of emerged cooperative norms in PriENE with individual principles for capabilities harvest. Bold highlight indicates best results.

Society	Numerosity			Fitness		
	$\bar{x}$	M	σ	$\bar{x}$	M	σ
Egoistic	0.0	0.0	0.0	0.0	0.0	0.0
Utilitarian	**28.67**	**27.0**	12.94	**427.63**	**219.3**	317.1
Maximin	14.34	11.0	9.79	144.79	108.0	132.09
Egalitarian	8.5	8.5	6.36	103.35	103.35	119.0
PriENE	17.89	13.0	12.7	186.6	93.6	235.07

Table A10: Comparing fitness and numerosity of emerged cooperative norms in PriENE with individual principles for allotment harvest. Bold highlight indicates best results.

Society	Numerosity			Fitness		
	$\bar{x}$	M	σ	$\bar{x}$	M	σ
Egoistic	0.0	0.0	0.0	0.0	0.0	0.0
Utilitarian	**28.86**	**27.0**	18.79	693.64	345.6	831.66
Maximin	14.37	12.0	8.87	202.53	184.8	151.39
Egalitarian	26.0	26.0	0.0	**763.8**	**763.8**	0.0
PriENE	14.0	16.0	5.29	143.9	171.0	113.6

The combination of best social welfare and robustness suggests that norms emerging in optimist societies promote higher sustainability than societies implementing veto, majoritarian, or average. Inequality is lowest in optimist societies. We argue that this is satisfactory as perfect fairness is challenging to achieve (Dignum, 2021). Although veto societies do better for minimum and maximum experience, we argue that the combination of highest sustainability and lowest inequality denotes that optimist aggregation is the most appropriate aggregation method for capabilities harvest.

D.3 Allotment Harvest Principle Aggregations

In the allotment harvest, societies of optimist agents do best for inequality, social welfare, and robustness. Veto societies have highest minimum experience, closely followed by majoritarian societies. Veto societies have highest maximum experience. Majoritarian societies have second highest maximum experience, closely followed by optimist societies. Average societies have lowest maximum experience. Majoritarian societies have second highest minimum experience, followed by average, then optimist. Social welfare and robustness is second highest in veto societies, whilst majoritarian and average societies are similar. Table A14 list results for principle aggregations in the allotment harvest.

Highest social welfare and robustness in optimist societies suggests that norms emerging improve sustainability more than norms emerging in veto, majoritarian, or average societies. Optimist societies have lowest inequality, indicating low disparity. Despite low minimum experience, high sustainability and low disparity in optimist societies supports optimist aggregation as the most appropriate aggregation for the allotment harvest.

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Table A11: Comparing principle aggregation methods ag_{days} mean $\bar{x}$ and median M for colours, capabilities, and allotment harvests.

Aggregation	Scenario	M_1		M_2		M_3		M_4		M_5	
		$\bar{x}$	M	$\bar{x}$	M	$\bar{x}$	M	$\bar{x}$	M	$\bar{x}$	M
Optimist	Colours	0.38	0.41	**26.73**	15.0	189.47	200.0	412.0	400.0	103.0	**69.0**
	Capabilities	0.32	**0.28**	18.56	9.0	195.75	200.0	**503.53**	**525.0**	**125.88**	**200.0**
	Allotment	**0.32**	**0.24**	18.18	15.0	196.79	200.0	**508.94**	**555.0**	**127.25**	**200.0**
Veto	Colours	0.43	0.44	13.37	9.0	**190.17**	200.0	370.61	335.0	92.65	45.0
	Capabilities	0.33	0.33	**30.31**	**21.0**	198.26	200.0	485.36	488.0	121.34	164.0
	Allotment	0.33	0.32	**30.87**	**21.0**	**199.49**	200.0	488.77	495.0	122.19	176.0
Majoritarian	Colours	0.42	0.45	18.2	9.0	174.73	200.0	333.49	281.0	83.37	33.0
	Capabilities	0.37	0.37	30.03	15.0	**199.22**	200.0	442.9	424.5	110.73	110.0
	Allotment	0.36	0.38	30.66	15.0	198.62	200.0	439.8	424.0	109.95	104.0
Average	Colours	**0.31**	**0.31**	23.29	**21.0**	174.16	200.0	**427.38**	**460.0**	**106.85**	**69.0**
	Capabilities	**0.31**	0.31	28.27	**21.0**	181.99	200.0	454.69	471.0	113.67	92.0
	Allotment	**0.32**	0.33	28.35	**21.0**	180.83	200.0	444.87	465.0	111.22	86.0

Table A12: Comparing ag_{days} and ag_{berries} mean $\bar{x}$, median M, and standard deviation σ for different principle aggregations for colours harvest.

Metric	Variable	Optimist			Veto			Majoritarian			Average		
		$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ
M_1	ag_{days}	0.38	0.41	0.16	0.43	0.44	0.13	0.42	0.45	0.14	**0.31**	**0.31**	0.11
	ag_{berries}	0.43	0.46	0.17	0.49	0.51	0.13	0.47	0.5	0.16	**0.37**	**0.38**	0.11
M_2	ag_{days}	**26.73**	15.0	36.28	13.37	9.0	10.35	18.2	9.0	27.23	23.29	**21.0**	16.07
	ag_{berries}	**3.5**	1.0	6.27	1.47	1.0	1.69	2.28	1.0	4.82	2.81	**2.0**	2.59
M_3	ag_{days}	189.47	**200.0**	35.68	**190.17**	**200.0**	35.32	174.73	200.0	51.89	174.16	**200.0**	54.93
	ag_{berries}	**38.17**	40.0	8.77	**40.37**	**43**	9.37	33.49	38.0	11.87	35.0	40.0	11.47
M_4	ag_{days}	412.0	400.0	169.33	370.61	335.0	141.57	333.49	281.0	169.80	**427.38**	**460.0**	172.05
	ag_{berries}	75.7	74.0	32.17	70.13	64.5	28.78	59.14	50.0	33.73	**78.64**	**87.5**	34.2
M_5		103.0	**69.0**	84.64	92.65	45.0	84.1	83.37	33.0	82.67	**106.85**	**69.0**	81.12

Table A13: Comparing ag_{days} and ag_{berries} mean $\bar{x}$, median M, and standard deviation σ for different principle aggregations for capabilities harvest.

Metric	Variable	Optimist			Veto			Majoritarian			Average		
		$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ
M_1	ag_{days}	0.32	**0.28**	0.12	0.33	0.33	1.23	0.37	0.37	0.16	**0.31**	0.31	0.11
	ag_{berries}	**0.37**	**0.34**	0.13	0.4	0.4	0.12	0.43	0.44	0.17	0.38	0.4	0.13
M_2	ag_{days}	18.56	9.0	17.92	**30.31**	**21.0**	26.78	30.03	15.0	41.66	28.27	**21.0**	21.49
	ag_{berries}	2.18	1.0	2.97	3.89	**2.0**	4.48	**4.18**	**2.0**	7.45	3.5	**2.0**	3.56
M_3	ag_{days}	195.75	**200.0**	24.29	198.26	**200.0**	14.71	**199.22**	**200.0**	11.02	181.99	**200.0**	45.12
	ag_{berries}	43.68	45.0	7.24	**46.69**	**48.0**	6.95	44.29	44.5	4.49	39.47	41.0	9.17
M_4	ag_{days}	**503.53**	**525.0**	135.62	485.36	488.0	130.35	442.9	424.5	164.61	454.69	471.0	161.3
	ag_{berries}	**102.86**	**108.0**	28.66	97.91	101.0	28.19	88.68	90.5	34.67	87.12	95.0	30.58
M_5		**125.88**	**200.0**	86.85	121.34	164.0	82.15	110.73	110.0	84.67	113.67	92.0	81.6

Table A14: Comparing ag_{days} and ag_{berries} mean $\bar{x}$, median M, and standard deviation σ for different principle aggregations for allotment harvest.

Metric	Variable	Optimist			Veto			Majoritarian			Average		
		$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ	$\bar{x}$	M	σ
M_1	ag_{days}	**0.32**	**0.24**	0.12	0.33	0.32	0.13	0.36	0.38	0.16	**0.32**	0.33	0.11
	ag_{berries}	**0.37**	**0.31**	0.13	0.4	0.39	0.13	0.43	0.44	0.17	0.39	0.4	0.13
M_2	ag_{days}	18.18	15.0	15.21	**30.87**	**21.0**	27.65	30.66	15.0	42.03	28.35	**21.0**	22.31
	ag_{berries}	2.12	1.0	2.5	4.0	**2.0**	4.61	**4.33**	**2.0**	7.43	3.52	**2.0**	3.68
M_3	ag_{days}	196.79	**200.0**	21.59	**199.49**	**200.0**	8.43	198.62	**200.0**	15.04	180.83	**200.0**	47.47
	ag_{berries}	44.0	45.0	6.64	**47.01**	**48.0**	5.97	44.04	44.0	5.14	39.53	41.0	9.78
M_4	ag_{days}	**508.94**	**555.0**	132.19	488.77	495.0	129.45	439.8	424.0	166.67	444.87	465.0	161.07
	ag_{berries}	**104.28**	**112.0**	28.04	98.64	102.0	27.79	87.97	89.0	35.34	85.7	94.0	30.77
M_5		**127.25**	**200.0**	86.62	122.19	176.0	82.21	109.95	104.0	84.47	111.22	86.0	81.61