



Emergent Collective Dynamics: How Individual Attitudes Shape Social Behaviour

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Introduction

Collective intelligence emerges in multi-agent systems, where autonomous agents in Multi-Agent Reinforcement Learning (MARL) balance cooperation and competition to optimize individual outcomes within environments shaped by social influence and resource interdependence.

Strategic interactions are defined by a game-theoretic framework and a payoff matrix (see figure on the right). We study agent attitudes —cooperative, competitive, and individualistic— by parameterizing intrinsic rewards. We measure social influence, i.e. how a partner's behaviour shapes an agent's strategy; and the coherence between an agent's predefined attitude (intent) and its emergent behaviour (action).

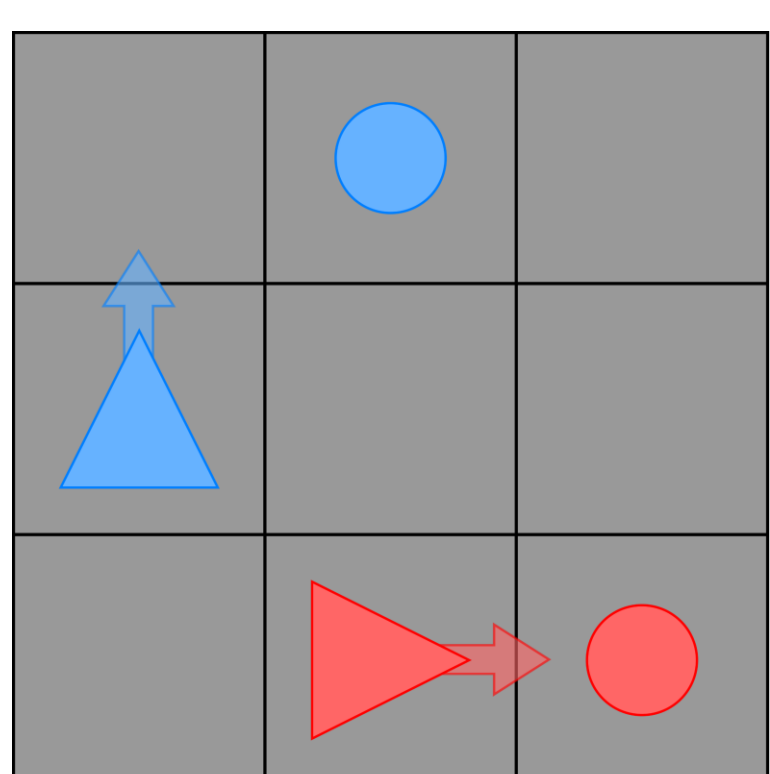
	Own resource	Other's resource
(r_{own}, r_{other})	(+1, 0)	(+1, -2)

Fig 1. Payoff matrix defining the strategic basis of the environments, where a player select a resource to exploit, resulting in reward pairs (r_{own}, r_{other}) .

CoopCoins and SpoiledBroth

CoopCoins (Simplified Environment):

An instantaneous game where two players (red and blue) collect color-coded coins. Collecting one's own coin gives +1, collecting the other's coin penalizes the rival by -2.



SpoiledBroth (Complex Environment):

A sequential game where two players deliver salads. Delivering a salad with one's own ingredient gives +1, while delivering the other's ingredient penalizes the rival by -2.



Fig 2. Cooperation and competition are studied across two environments: *CoopCoins* (left) represents instantaneous, purely economic competition; *SpoiledBroth* (right) represents sequential tasks with cooperative interdependence.

Modelling Individual Attitudes

Individual implemented by adjusting agent i rewards with predefined parameters α^i and β^i , which control the agent's predisposition toward self-interest and rivalry.

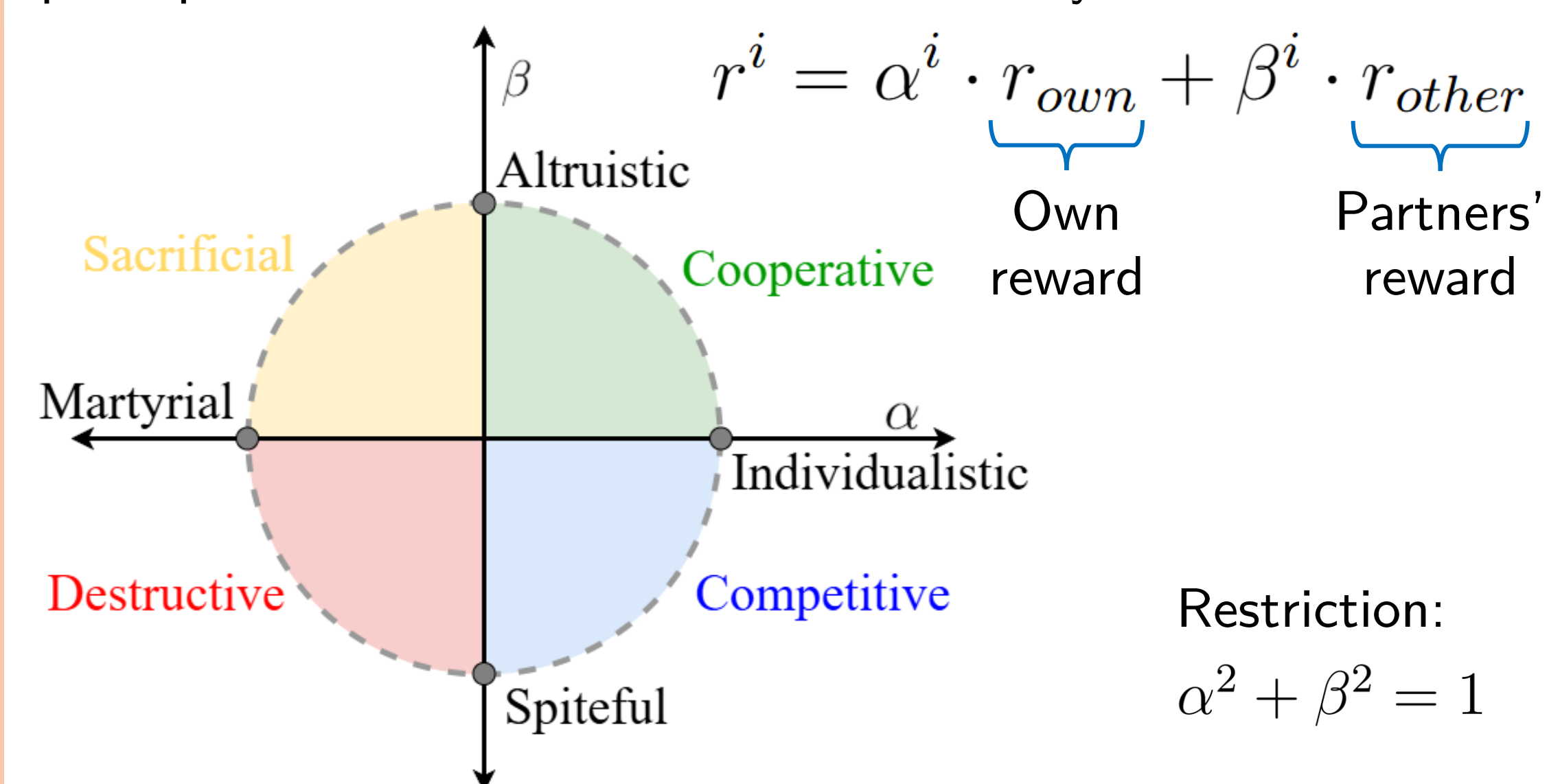


Fig 3. The agents' intrinsic reward functions are modified by the parameters α and β , establishing a spectrum of predefined behavioural attitudes.

Social influence of and on the different attitudes

Social influence in CoopCoins

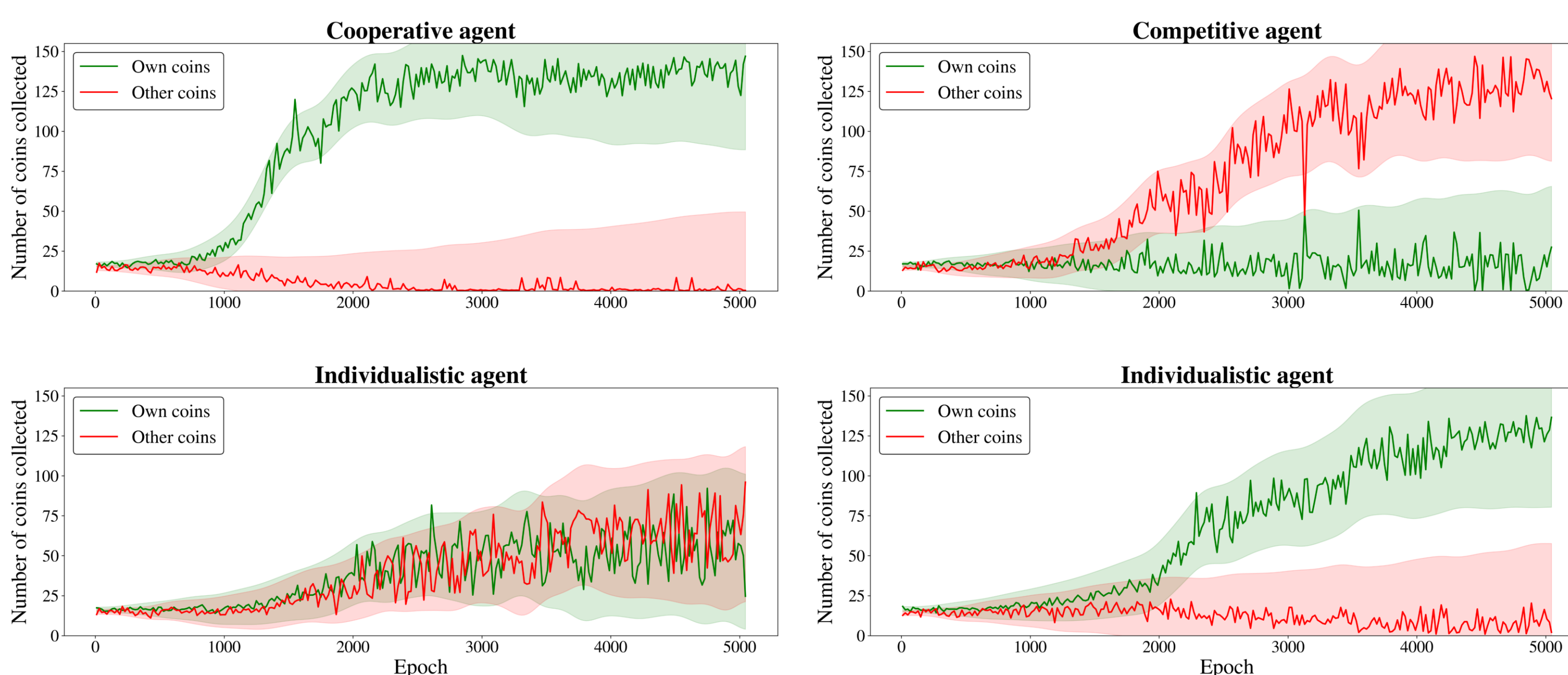


Fig 4. Number of collected coins by an individualistic agent (bottom row) when trained with a cooperative partner (left) or a competitive one (right) in *CoopCoins*.

Social influence in SpoiledBroth

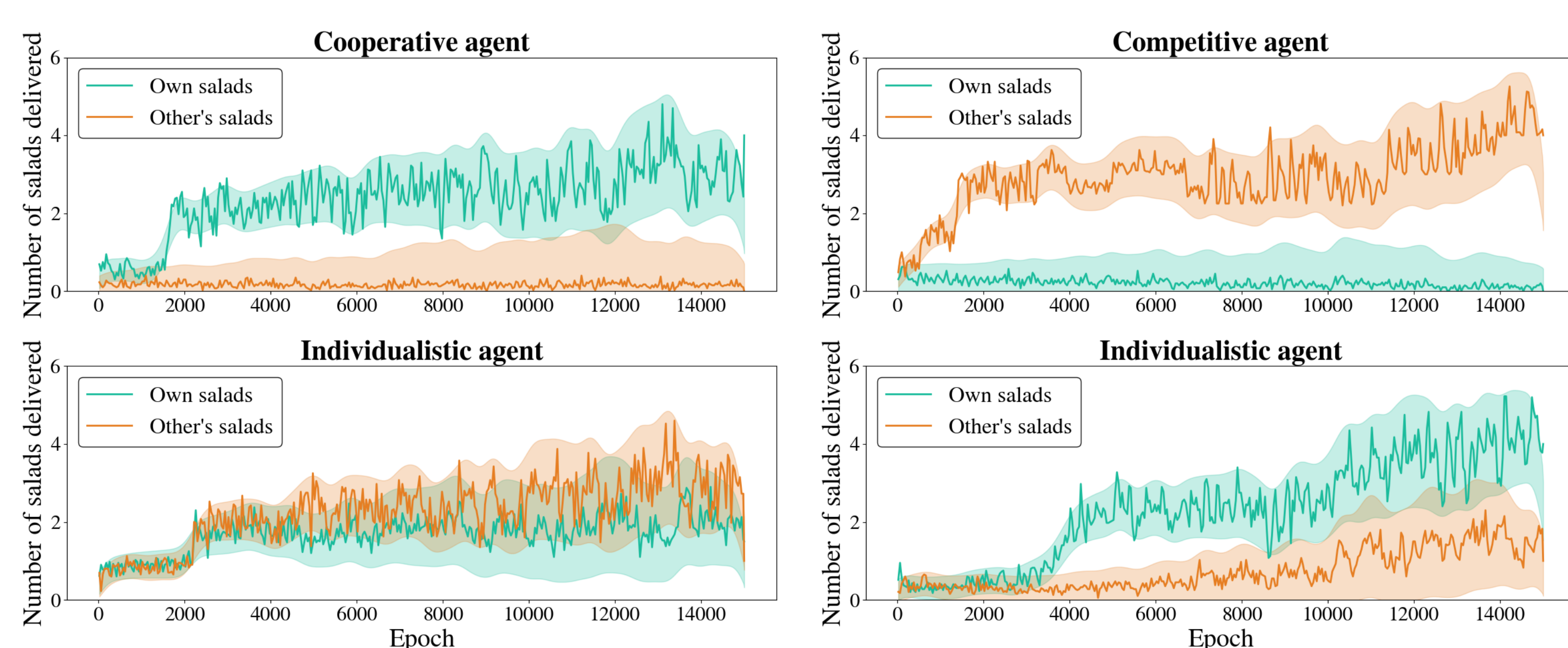


Fig 5. Number of salads delivered by ingredient type for an individualistic agent (bottom row) trained with a cooperative partner (left) or a competitive one (right) in *SpoiledBroth*.

Social influence shapes the Individualistic agent's behaviour: when paired with a Cooperative partner, it collects resources randomly; when paired with a Competitive one, it defends its own resources to minimize penalties from the rival's actions.

Coherence: Attitude vs. Behaviour

Attitude is an agent's intrinsic predisposition, set by its internal reward parameters (α and β).

Behaviour is the emergent pattern of actions shaped by training and external rewards (r_{own} and r_{other}).

Coherence $c^i(r_{own}, r_{other})$ measures how consistently an agent's attitude aligns with its behaviour, capturing the stability of its intent across social contexts.

$$c^i(r_{own}, r_{other}) = \alpha^i \cdot r_{own} + \beta^i \cdot r_{other}$$

Rank	Attitude	Angle	Coherence
1	Spiteful	270°	59.688
2	Altruistic	90°	51.188
3	Sacrificial	135°	47.208
4	Competitive	315°	38.551
5	Martyrial	180°	37.123
6	Cooperative	45°	15.009
7	Destructive	225°	-3.531
8	Individualistic	0°	-55.552

Fig 6. Agents ranked by mean coherence, showing how strongly each attitude aligns with behaviour when interacting across all partner types.

Opponent-oriented attitudes ($\alpha = 0$) show the highest behavioural coherence: by prioritizing the partner's outcome, these agents remain least affected by social influence, yielding robust and predictable behaviour.

References

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