Utility-Aware Task Decomposition and Exchange across LLM Agents

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1. Overview

• We introduce a **framework** that enables LLM agents to perform task **decomposition** and **exchange** in a **utility-aware** manner.

• We assess LLMs' capabilities under **competitive** and **cooperative** settings.

2. Motivation

• LLM-based multi-agent environments have attracted increasing attention.

• **Previous** research assumes the presence of either:
  • **a central coordinator**
    or
  • **a shared utility function**

• However, in **real-world** settings, **neither** is often accessible.

• In such cases, agents need to **estimate** utility functions of other agents.

3. Proposed Framework

1. Utility-aware prompt
2. Per-turn proposal validation

1. Utility-aware prompt

During negotiation, agents decompose their tasks while **explicitly estimating** their counterpart's utility. In the figure, Bob **infers** that Alice favors *Marketing* and **incorporates this signal** into the next proposal. This helps the **dialogue** converge more **quickly** to a **mutually satisfactory** exchange.
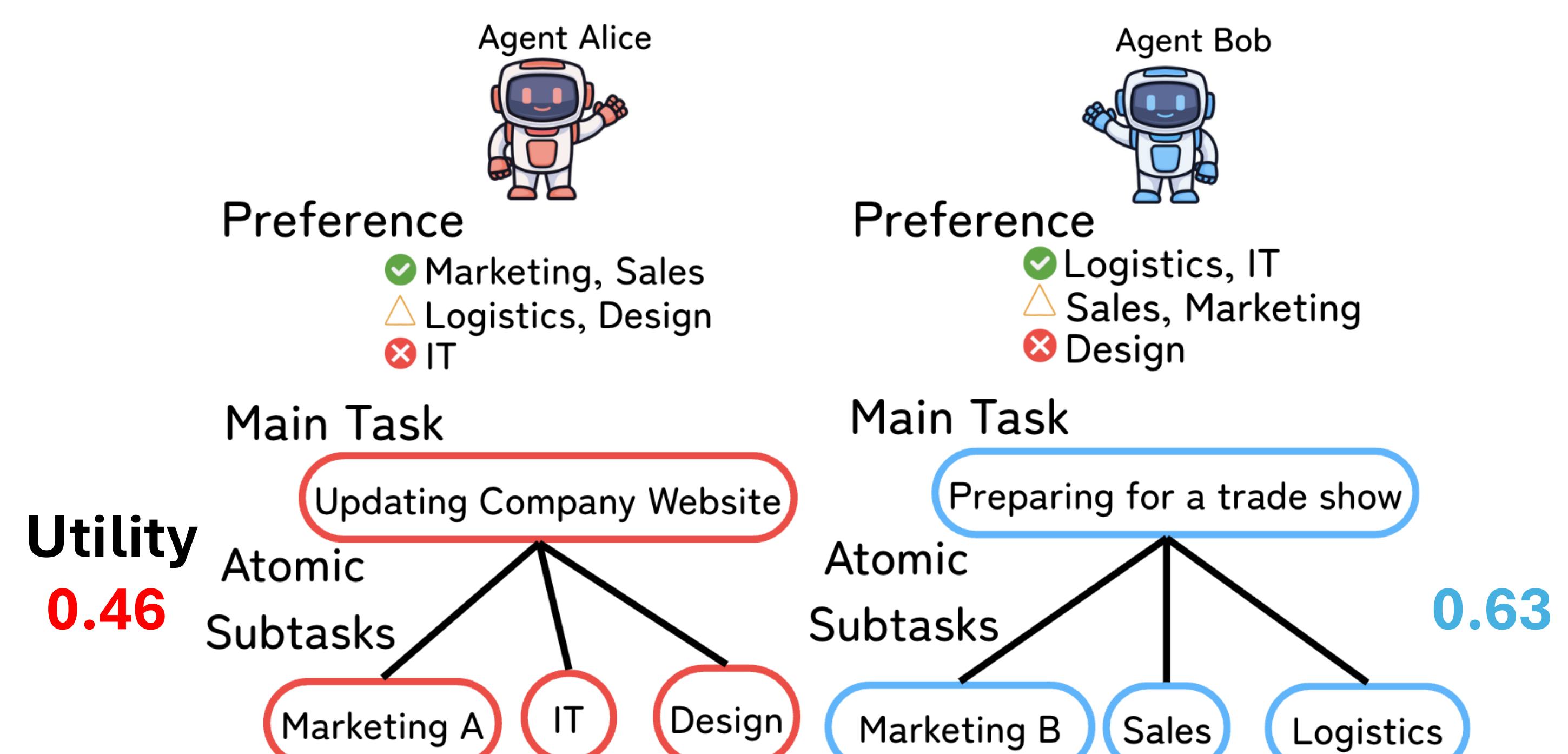
2. Per-turn proposal validation

For every proposal, an invalid proposal is detected **before** being delivered to the counterpart. When flagged, the proposer receives **targeted feedback**.

4. Experimental Setup

• 10 runs for each setting

• five invalid proposals in a **single** turn to terminate the negotiation (**Error**)

• Baseline:
  • **Removal** of the utility-aware prompt
  • **No** per-turn validation

Our task: agents decompose and exchange their tasks through negotiation to achieve mutually satisfactory outcomes.

Agent Alice — Agent Bob

Preference
✅ Marketing, Sales
🔺 Logistics, Design
❌ IT

Preference
✅ Logistics, IT
🔺 Sales, Marketing
❌ Design

Main Task: Updating Company Website — Utility 0.46
Atomic Subtasks: Marketing A, IT, Design

Main Task: Preparing for a trade show — 0.63
Atomic Subtasks: Marketing B, Sales, Logistics

Negotiation Flow

Prompt
Be utility-aware in decomposition/exchange:
 - Which subtasks are high-value to the other but low-cost to you?
 → Proposing trades that give low-cost items and request high-value items increases total utility.

<Turn 1> (Consideration)

Utility-aware prompt

Alice: <CONSIDER>I'm reluctant to carry out **IT** work, a part of my task. Maybe Bob can undertake it.</CONSIDER>

Bob: <CONSIDER>I can handle this task myself, so I'll **keep it** for now.</CONSIDER>

<Turn 2 onward> (Proposal phase)

Alice: <PROPOSAL>I can decompose my task. I'm not strong at the **IT** subtask, so I propose transferring my IT work to you. I will keep **Marketing A**, **Design** and **HR**.</PROPOSAL>

Proposal Validation
❌ Unknown atomic task(s). You don't have **HR**. Retry proposal again.

Alice: <PROPOSAL>I can decompose my task. I'm not strong at the **IT** subtask, so I propose transferring my IT work to you. I will keep **Marketing A** and **Design**.</PROPOSAL>

0.65 ↓ 0.47

Proposal Validation
✅ Valid Proposal

Bob: <REJECT>That's too costly for me.</REJECT>
<PROPOSAL>I'm strong in **IT**, so I can take some of your **IT** workload. After decomposing my tasks, I identified **Marketing B** as low value for me. Since I guess you prefer **Marketing**, how about this: I take part of your **IT** work, and you take my **Marketing B** task.</PROPOSAL>

Proposal Validation
✅ Valid Proposal

0.58 0.72

Alice: <ACCEPT>That sounds fair. I accept your offer.</ACCEPT>
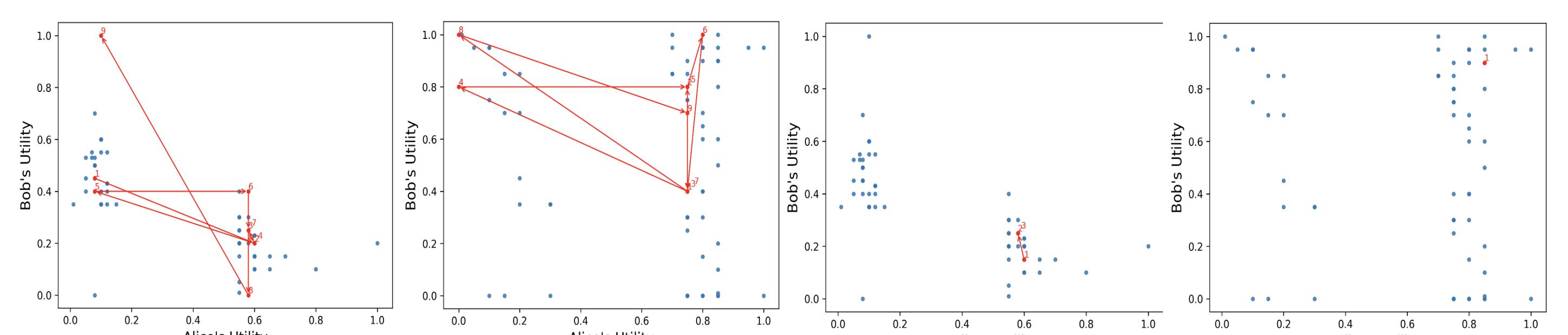
5. Result

(a) Cooperative

Model	Setting	Agreement	Error	Turns	Alice	Bob	SW	L_2 to Pareto
o4-mini	Proposed	100 ± 0%	0 ± 0%	3.0 ± 1.4	0.78 ± 0.07	0.74 ± 0.15	1.52 ± 0.20	0.27 ± 0.15
	Baseline	83.3 ± 15.2%	40 ± 15%	4.8 ± 4.0	0.81 ± 0.10	0.79 ± 0.12	1.60 ± 0.22	0.21 ± 0.15
GPT-4.1-mini	Proposed	100 ± 0%	80 ± 13%	2.0 ± 0.0	0.75 ± 0.00	0.70 ± 0.00	1.45 ± 0.00	0.32 ± 0.0
	Baseline	28.6 ± 17.1%	30 ± 14%	7.7 ± 3.9	0.75 ± 0.00	0.70 ± 0.00	1.45 ± 0.00	0.32 ± 0.0
GPT-4.1-nano	Proposed	0 ± 0%	100 ± 0%	—	—	—	—	—
	Baseline	0 ± 0%	50 ± 16%	10 ± 0.0	0.75 ± 0.00	0.70 ± 0.00	1.45 ± 0.00	0.32 ± 0.0

(b) Competitive

Model	Setting	Agreement	Error	Turns	Alice	Bob	SW	L_2 to Pareto
o4-mini	Proposed	100 ± 0%	10 ± 9%	3.2 ± 2.0	0.62 ± 0.14	0.26 ± 0.06	0.88 ± 0.13	0.022 ± 0.013
	Baseline	60.0 ± 21.9%	50 ± 16%	6.8 ± 4.0	0.58 ± 0.00	0.25 ± 0.00	0.83 ± 0.00	0.028 ± 0.0
GPT-4.1-mini	Proposed	0 ± 0%	100 ± 0%	—	—	—	—	—
	Baseline	0 ± 0%	0 ± 0%	10 ± 0.0	0.58 ± 0.00	0.25 ± 0.00	0.83 ± 0.00	0.028 ± 0.0
GPT-4.1-nano	Proposed	0 ± 0%	100 ± 0%	—	—	—	—	—
	Baseline	0 ± 0%	40 ± 15%	10 ± 0.0	0.58 ± 0.00	0.25 ± 0.00	0.83 ± 0.00	0.028 ± 0.0

(c) Initial utilities

Scenario	Alice	Bob	SW	L_2 to Pareto
Cooperative	0.75	0.70	1.45	0.32
Competitive	0.58	0.25	0.83	0.028

(a) Competitive (baseline) (b) Cooperative (baseline) (c) Competitive (utility-aware strategy) (d) Cooperative (utility-aware strategy)

• The proposed framework enables **stronger** models to converge **faster** and more **reliably**, especially in **competitive** settings.

• We will continue the empirical analysis under a wider range of conditions.