

EVOAGENT: Towards Automatic Multi-Agent Generation via Evolutionary Algorithms

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<https://evo-agent.github.io>

Abstract

The rise of powerful large language models (LLMs) has spurred a new trend in building LLM-based autonomous agents for solving complex tasks, especially multi-agent systems. Despite the remarkable progress, we notice that existing works are heavily dependent on human-designed frameworks, which greatly limits the functional scope and scalability of agent systems. How to automatically extend the specialized agent to multi-agent systems to improve task-solving capability still remains a significant challenge. In this paper, we introduce EVOAGENT, a generic method to automatically extend expert agents to multi-agent systems via the evolutionary algorithm, thereby improving the effectiveness of LLM-based agents in solving tasks. Specifically, we consider the existing agent frameworks as the initial individual and then apply a series of evolutionary operators (e.g., mutation, crossover, selection, etc.) to generate multiple agents with diverse agent settings. EVOAGENT can be generalized to any LLM-based agent framework, and can automatically extend the existing agent framework to multi-agent systems without any extra human designs. Experimental results across various tasks have shown that EVOAGENT can automatically generate multiple expert agents and significantly enhance the task-solving capabilities of LLM-based agents.

1 Introduction

Recently, the advent of large language models (LLMs) [1, 2, 3, 4] have shown remarkable capabilities in solving language understanding, reasoning, and generation tasks. Based on the foundation of LLMs, many research works [5, 6, 7, 8, 9, 10, 11] have discovered that by empowering multiple advanced skills (e.g., planning, tool, memory and so on), we can develop more powerful autonomous agents to solve more challenging tasks. Therefore, how to design and leverage LLM-based autonomous agents to tackle more diverse and complex real-world applications has attracted enormous interest.

Generally, many real-world scenarios are usually complex, encompassing a variety of challenging tasks that are beyond the capability of a single agent. To address this point, we notice that human society is composed of vast individuals, each possessing their unique characteristics. By selecting, orchestrating, and cooperating with different individuals, humans can form an efficient team group to handle complicated missions in the real world. Therefore, there has been an increasing trend to develop multi-agent collaboration frameworks (e.g., MetaGPT [10], AutoGen [12], Camel [13],

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Generative Agents [11]) to simulate human behaviors for solving complex tasks. By developing a series of expert agents with diverse settings, multi-agent systems enable us to reveal emergent abilities among multiple agents and synergize their specialized expertise to achieve superior performance, akin to simulating human populations. Nevertheless, it is worthy noting that, in most of (multi)-agent frameworks, their designs heavily depend on handcrafted settings, including character roles, task scopes, skills, and prompt settings. Although we admit that meticulous human design is quite useful for instructing LLM-based agents to understand tasks, it also limits scaling up the number of agents to further improve performance due to expensive human labor. Considering the increasing popularity of LLM-based autonomous agents, how to create a generic agent generation paradigm to automatically build multi-agent systems has emerged as a critical challenge.

In this paper, we introduce a novel method, EVOAGENT, that formulates agent generation as the evolutionary processing [14] in human society. Specifically, to align human society, each agent can be considered as individuals that can procreate its population across successive generations. Motivated by this mechanism, we can simulate such a human behavior to automatically generate multiple agents based on any pre-defined agents. Therefore, EVOAGENT can be considered as a one-shot agent generation method that starts from a specialized agent as the initial agent, and then considers its settings (e.g., role, skills, prompts, and so on) as the variables to be evolved. With a series operation of EAs (e.g., selection, crossover, mutation), EVOAGENT can automatically create multiple evolutionary agents based on the initial specialized agent. Moreover, EVOAGENT is not limited to the infrastructure of agent frameworks, as it is a generic multi-agent generation method. Thus, it can be applied to any agent framework and expanded to multi-agent systems without any extra human effort.

We conduct experiments on multiple datasets, including knowledge-based question answering and multi-modal reasoning (§ 4.1), interactive scientific solving (§ 4.2) and real-world complex planning (§ 4.3). Experimental results indicate that EVOAGENT can generate multiple agents with diverse skills and harness their capabilities to consistently improve model performance in different scenarios. Besides, to validate the scalability of EVOAGENT in creating massive agents, we also apply our method to some conversational scenarios (e.g., debate), and the results also indicate the potential of EVOAGENT in generating multiple diverse agents. Overall, the contributions of this paper can be summarized as below:

- We introduce EVOAGENT, a simple and generic multi-agent generation method to improve the effectiveness of LLM-based agents in solving tasks. EVOAGENT can automatically generate new expert agents and is applicable to any agent framework.
- We formulate the agent generation processing as an evolutionary pipeline, that encompasses multiple operators (e.g., selection, crossover, mutation) to generate agent population without additional human supervision.
- We conduct extensive experiments on various tasks and demonstrate the effectiveness, scalability, and generality of our EVOAGENT. Particularly, EVOAGENT can significantly enhance the performance of LLM-based agents in both challenging open-world scenarios and complex real-world planning by generating more specialized agents.

2 Related Work

LLM-based Autonomous Agents With the emergence of powerful large language models [1, 2, 3, 4], many researchers have endeavored to develop advanced autonomous agents [5, 6, 7] empowered by multiple high-level LLM skills (e.g., personas [11, 15, 16], planning [9, 17, 18, 19], tool [8, 6, 20, 21] and memory [22, 23]). Some of them also extend agent frameworks to multi-agent collaboration (e.g., MetaGPT [24], Generative Agents [11], AutoGen [12], Camel [13], AgentVerse [25] and so on), by designing multiple specific roles. These systems also demonstrate satisfactory performance in addressing massive, challenging tasks. However, it is worth noting that most of the popular agent frameworks heavily relied on handcrafted designs. The abundant human efforts necessitated by these systems also limit the adaptability and flexibility of agents to handle unexpected challenges [26, 27, 25, 10]. In this paper, we propose EVOAGENT, a method that can be applied to any LLM-based agent framework and easily extend to multi-agent systems. By using EA, our method allows us to iteratively generate and optimize multiple agents with diverse settings.

Algorithm 1: Multi-Agent Generation with Evolutionary Algorithm

Require: Initial agent $A_{(0,0)}$, population size N per iteration, number of iterations T , quality-check module $\text{LLM}_{\text{Quality}}(\cdot)$, evolutionary operations $\text{Evo}_{\text{Crossover}}(\cdot)$ and $\text{Evo}_{\text{Mutation}}(\cdot)$, $\text{Evo}_{\text{Update}}(\cdot)$

Input: Initial result R_0 derived from $A_{(0,0)}$

Output: Final result R_T

1 **for** $t = 1$ **to** T **do**

2 **Crossover:** Update the settings of parent agents based on their generated results and initial agent: $\{A'_{(0,t-1)}, A'_{(1,t-1)}, \dots, A'_{(N-1,t-1)}\} \leftarrow \text{Evo}_{\text{Crossover}}(\{R_{(0,t-1)}, R_{(1,t-1)}, \dots, R_{(N-1,t-1)}\}, A_{(0,0)})$;

3 **Mutation:** Generate $N'(N' > N)$ child agents based on parent agents and initial agent: $\{A_{(0,t)}, A_{(1,t)}, \dots, A_{(N'-1,t)}\} \leftarrow \text{Evo}_{\text{Mutation}}(\{A'_{(0,t-1)}, A'_{(1,t-1)}, \dots, A'_{(N-1,t-1)}\}, A_{(0,0)})$

4 **Selection:** Select high-quality agents with quality-check module: $\{A^t_0, \dots, A^t_{N-1}\} \leftarrow \text{LLM}_{\text{Quality}}(\{A_{(0,t)}, A_{(1,t)}, \dots, A_{(N-1,t)}\})$;

5 **Result Update:** Generate new result from new agents: $\{R_{(0,t)}, R_{(1,t)}, \dots, R_{(N-1,t)}\} \leftarrow \{A_{(0,t)}, A_{(1,t)}, \dots, A_{(N-1,t)}\}$

6 Integrate their results as a natural selection processing:
 $R_t \leftarrow \text{Evo}_{\text{Update}}(\{R_{(0,t)}, R_{(1,t)}, \dots, R_{(N-1,t)}\}, R_{t-1})$;

7 **return** R_T ;

Agent Generation Recent studies have shown that assigning personas or roles to LLM-based autonomous agents can influence their behavior and performance in generation tasks [28, 29, 30, 13]. Current methods primarily involve manually assigning these personas and limit multi-agent collaboration to single or fixed roles, which requires significant human effort and hinders generalization [13, 12, 24, 10]. To address this, some frameworks like AgentVerse [25] and AutoAgents [31] have been proposed to automatically generate unlimited agents for collaborative task completion. However, these methods still heavily depend on human-designed interventions, which limits their scalability and functionality. For example, AutoAgents requires agent settings to satisfy a “Planner - Agent Observer - Plan Observer” framework. Meanwhile, AgentVerse formulates a pipeline of “Expert Recruitment - Collaborative Decision Making - Action Execution - Evaluation” to build agents. These architectures also limit the task scope of designing agents. In contrast, EVOAGENT can automatically formulate the current agent frameworks to multi-agent systems with high-quality generated expert agents by using EAs, which is flexible and adaptable to various agent frameworks.

3 Method

Generally, human society comprises a broad spectrum of individuals from diverse cultures, encompassing multiple generations. To solve specific tasks, human society usually involves a lot of expert individuals and aggregates their specialized expertise to achieve better answer. Thus, it can be considered as the foundation to facilitate multi-agent collaborations. To fulfill this point, how to automatically create multiple agents would be very critical. Inspired by evolutionism, we formulate agent generation as an evolutionary process to help us generate multiple agents without any human labor.

3.1 Preliminary

Evolutionary algorithm (EA) [32, 33], is a general algorithm to simulate the biological behaviors in evolution, including reproduction, mutation, recombination, and selection. By introducing genetic algorithm [34, 35, 36, 37, 38] of the “survival of the fittest” mechanism, it can also be considered as an optimization method to improve individuals. Therefore, EAs also belong to the non-parametric learning method, which can be applied to any framework. All we need to do is define which parts should be evolved and the corresponding evolutionary operators. We also note some recent

works [39, 40] indicate the potential of EAs that can be applied to optimize discrete prompts. So, in this paper, we explore how to formulate the agent generation problem as an evolutionary task.

3.2 EVOAGENT

By assigning various settings to specific skills (e.g., role-playing, planning, tools and so on), agents could exhibit diverse task-solving capabilities. Therefore, our objective is to produce a population of agents with distinct skills, to establish effective multi-agent systems. To fulfill this point, we treat each specialized agent as an unique individual and denote each skill as the part to be evolved, akin to humans. So, we consider the procedure of agent generation to be evolutionary processing. Specifically, existing frameworks usually describe agent skills as the language. Thus, we can employ LLM to simulate evolutionary operators to update the system settings of agents and create new agents. Here, we formulate the procedure of EVOAGENT as a four-stage pipeline:

STEP 1: Initialization To conduct EAs, we first need to confirm our initial agents.

Here, we enable EVOAGENT to start from a pre-defined agent framework (e.g., MetaGPT [10] and AutoGen [12]), which serves as the initial (parent) agents. Moreover, we also define which parts of this agent should be upgraded. Generally, since EAs is a generic algorithm, EVOAGENT is applicable to any agent frameworks and extends them as multi-agent frameworks. We will then explore how to generate new agents in the next steps.

STEP 2: Crossover & Mutation In the first iteration, we directly use the initial agents as the parents. And then, we design two kinds of evolutionary operators, named *Crossover* and *Mutation*. For *Crossover*, we first enable the parent agents to generate results based on user requests. Then, based on the generated results, we ask LLMs to check which skills should be improved and then update them. This mechanism allows us to generate child agents in new settings without requiring any human labor. Moreover, we also need to guarantee the diversity between the child agents and parents. To this end, we design a *Mutation* operation that requires LLMs to compare the child agents and parent agents and then modify the child agents to make them distinct from their parents while maintaining their task-solving capability. Based on these evolutionary operators, we can generate effective and diverse agents during one iteration. Besides, as we also need to conduct multiple iterations, we will append all agents generated in the previous generation into the next iteration. How to select these agents during each iteration will be introduced next.

STEP 3: Selection Based on the above steps, we can obtain multiple candidate agents with diverse settings. To guarantee the quality of each agent, we also introduce a selection mechanism like EAs. Here, we conduct a *quality-check module* with an LLM to detect whether the generated agents can satisfy it has inherited the characteristics and maintained differences from parent agents. We will select N child agents as the evolved agents in each iteration.

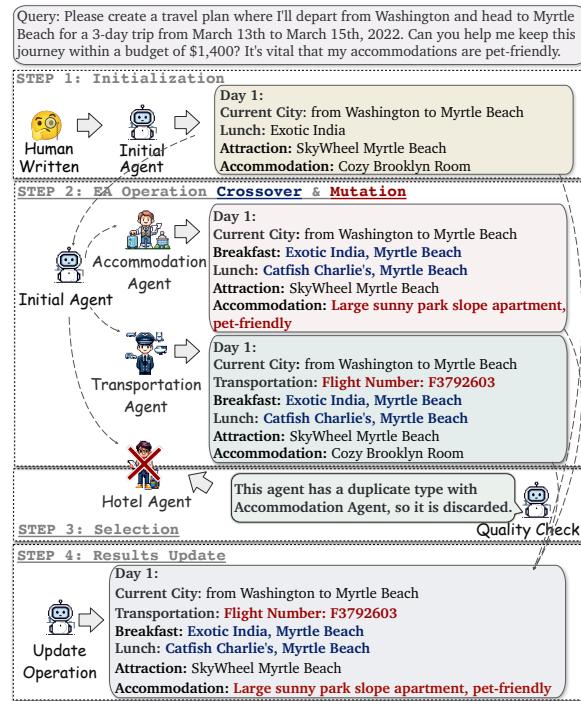


Figure 1: The illustration of EVOAGENT. With the generated multiple expert agents, EVOAGENT can generate a better travel plan to meet user preferences. For EA operators, **Crossover** can improve the results of parent agents by adjusting existing details (e.g., the information marked as **blue**). **Mutation** can introduce new variations to refine the results of parent agents by generating child agents with new characteristics (e.g., the information marked as **red**).

iterations, we will append all agents generated in the previous generation into the next iteration. How to select these agents during each iteration will be introduced next.

Table 1: Results of LLMs with different methods on Logic Grid Puzzle (**Logic**), Trivia Creative Writing (**Writing**) and Codenames Collaborative (**Codenames**). The best results are **bolded**, and the second best ones are underlined.

Model	Method	Logic	Writing	Codenames
LLama2-13B-Chat	Direct	4.00	28.00	0.00
	CoT	26.00	<u>46.00</u>	<u>18.00</u>
	Self-Refine ₃	<u>33.50</u>	31.20	12.37
	SSP	0.00	4.00	1.00
	EVOAGENT _(1,3)	35.50	49.60	27.83
GPT-3.5	Direct	48.00	56.20	<u>76.29</u>
	CoT	47.50	51.00	71.13
	Self-Refine ₃	47.50	<u>59.19</u>	46.39
	SSP	<u>56.00</u>	54.40	61.86
	EVOAGENT _(1,3)	71.50	60.80	79.38
GPT-4	Direct	60.50	75.40	79.38
	CoT	65.50	74.00	80.41
	Self-Refine ₃	64.50	74.60	79.38
	SSP	64.50	79.20	78.35
	EVOAGENT _(1,3)	77.00	84.40	84.53

STEP 4: Results Update Based on the above steps, we obtain many new agents that evolved from parent agents, but with diverse settings. To improve task-solving capabilities, we ask each child agent to generate candidate results and then use LLMs to integrate these candidates with the result from the previous iteration into a new result, akin to a natural selection processing stage. Moreover, we can automatically generate more agents by repeating the operations from step 2 to step 4 until the number of agents has fulfilled our targets.

By introducing EA, EVOAGENT enables us to automatically extend the existing agent framework to a multi-agent system without any extra human designs. The mechanism also makes EVOAGENT can be applied to any agent framework without any prerequisites. The entire process is illustrated in Figure 1. And we also present the details of EVOAGENT in Algorithm 1.

4 Experiment

In this section, we adopt EVOAGENT to multiple applications to illustrate that EVOAGENT can help LLM-based agents better accomplish tasks with multi-agent generation.³ Furthermore, we also demonstrate that EVOAGENT can be applicable in supporting currently widely used multi-agent frameworks, such as MetaGPT [10], AutoGen [12], and Camel [13].

4.1 NLP and Multi-Modal Tasks

Benchmarks To align previous experiences (e.g., Self-Refine [41] and Solo Performance Prompting [42]), we select three NLP knowledge-intensive and reasoning-intensive tasks from [42] and one multi-modal task:

- **Logic Grid Puzzle** is a reasoning task with 200 puzzles featuring 2 to 5 unique occupants in different houses. The aim is to identify house numbers for one occupant with provided clues.
- **Trivia Creative Writing** is a knowledge-intensive task consisting of 100 instances. This task requires a model to write a coherent story while incorporating answers to N trivia questions.
- **Codenames Collaborative** is a reasoning-intensive task with 50 instances. It involves a model identifying target words based on a given hint and a complete list of words.
- **MMMU** [43] is a comprehensive benchmark for college-level, multi-discipline multi-modal understanding and reasoning. MMMU has three levels of difficulty: easy, medium, and hard. We evaluate EVOAGENT against baselines using the multiple-choice questions in the validation set of MMMU, which includes 847 questions spanning 30 different domains.

³The data examples of EVOAGENT on these tasks are provided in Appendix F.

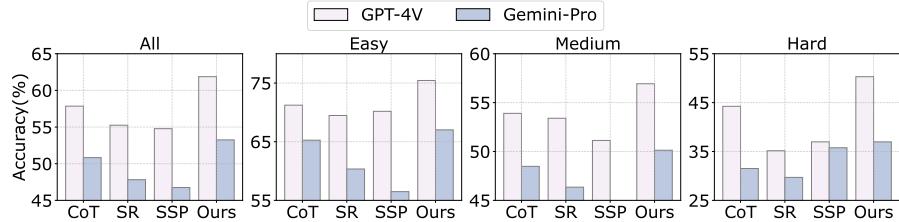


Figure 2: Overall results of GPT-4V and Gemini-Pro with different methods on the MMMU validation set. We also compare the performance of GPT-4V and Gemini-Pro across three difficulty levels.

Baselines For NLP tasks, we select LLama2-13B-Chat [3], GPT-3.5 [44] and GPT-4 [1] as our backbone networks. We compare EVOAGENT with 0-shot learning (Direct), Chain-of-thought (CoT) prompting [45] and Self-Refine [41] and Solo Performance Prompting (SPP) [42]. For Self-Refine, we follow [41] to design feedback and refine prompts with three iterations. SSP is not a multi-agent collaboration framework but a prompting strategy that asks a single LLM to identify and discuss with multiple personas with few-shot learning. For SSP, we follow the original setting [42] to make a fair comparison. For MMMU, we select GPT-4V [46] and Gemini-Pro as the backbone and compare EVOAGENT with CoT prompting, Self-Refine, and SSP.⁴

Evaluation Metrics For all benchmarks, we adhere to the evaluation metrics specified in the original setting. Specifically, for Logic Grid Puzzle and MMMU tasks, we report the accuracy of all questions. For Trivia Creative Writing, we measure the ratio of correctly mentioned answers in the trivia questions. For Codenames Collaborative, we calculate the overlapping ratio between the predicted words from the Guesser and the target words as the metric.

Result & Analysis In our experiments, we adopt the agent settings of [42] (for NLP tasks) and [43] (for MMMU) as the initial agent. For our method, we denote it as $\text{EVOAGENT}_{(N,T)}$, where N is the population size generated in each iteration, and T is the number of iterations. Here, to align with Self-Refine, we set N as 1 and T as 3, which means we conduct three iterations, each of which generates a new expert agent. Our results are reported in Table 1, and we can observe:

1. By utilizing multiple generated agents, EVOAGENT can greatly improve LLM performances in both NLP knowledge and reasoning tasks. We also compare EVOAGENT with some pre-defined agent generation frameworks, e.g., AgentVerse [25] and AutoAgent [31]. The results shown in Appendix B prove that the EVOAGENT is even better than these agent generation frameworks.
2. When using weaker LLMs (e.g., LLama2-13B-Chat), SSP usually produces poor performances, consistent with the findings in [42]. This suggests the limited effectiveness of SPP in smaller and less capable models. However, EVOAGENT can provide consistent improvements among each LLM, proving its strong generalization by using diverse generated agents.

In addition, Figure 2 shows that Self-Refine (SR) and SSP degrade performance compared to CoT prompting in MMMU task. However, EVOAGENT can generate multiple domain-specific agents and thus improve multi-modal models in addressing scientific questions across various difficulty levels.

4.2 Interactive Scientific Solving Simulation

Benchmark Compared with traditional NLP or multi-modal tasks, autonomous agents usually need to perform problem-solving abilities akin to humans in interactive and open-world environments. Currently, we choose ScienceWorld [47], a complex interactive environment requiring skills in long-term memory, sub-task decomposition, and scientific and commonsense knowledge. Here, we evaluate 30 scientific tasks in ScienceWorld to demonstrate the capability of EVOAGENT in solving tasks in more challenging open-world environments.

⁴The detailed model parameters and versions and full prompts for these methods can be found in Appendix A.

Baseline and Evaluation Metrics Following [48], we require LLMs to perform an action at each step by using in-context learning⁵. For evaluation, each task in ScienceWorld includes some sub-tasks, and we report the results by calculating the completed sub-tasks for the whole task.

Result & Analysis For EVOAGENT, we adopt the agent framework with original settings in [48] as the initial agent. Since each step in ScienceWorld requires using EA, we set the population size N as 1 and the iterations T as 1 for efficiency, denoted as EVOAGENT_(1,1). Results in Table 2 show that:

1. EVOAGENT can also extend interactive agents to multi-agent systems in solving complete scientific tasks in dynamic, open-world environments and consistently improve the performance of LLMs.
2. Our method exhibits the most substantial improvement in short-trajectory tasks, with less significant gains in medium and long-trajectory tasks. We argue that the capability of multi-agent systems will also be affected by a longer context. We also expect to investigate the effect of long context on multi-agent systems in the future.

Generally, these results also demonstrate the generalization of EVOAGENT, which can also be used for solving interactive tasks in an open-world environment.

4.3 Real-World Scenarios

Benchmark Moreover, in addition to performing actions in interactive environments, planning in complex and realistic environments is also a crucial skill for building autonomous agents. To validate this point, we also select TravelPlanner [49], a benchmark designed to evaluate language agents in real-world complex planning with multiple constraints.

Baseline and Evaluation Metrics Following [49], we select Mistral-7B [50], GPT-3.5, Gemini-Pro [2] and GPT-4 as our backbone models. We compare EVOAGENT with 0-shot learning (Direct), CoT prompting, SSP, and Self-Refine within each backbone model. Furthermore, we also attempt the ReAct method [51] for GPT-3.5, which introduces a virtual ‘think’ action to generate sub-tasks during the action planning process. For evaluation, we adhere to the original metrics from TravelPlanner, reporting the delivery rate, commonsense constraint pass rate, hard constraint pass rate, and final pass rate for all methods⁶.

Result & Analysis For EVOAGENT, we adopt the original settings in TravelPlanner as the initial agent. Results in Table 3 show that:

1. EVOAGENT can generate specialized agents, such as those focused on culinary experiences, transportation, and attractions. Therefore, the generated travel plans are more aligned with user preferences (hard constraints) and commonsense rules;
2. Although existing paradigms (e.g., CoT, ReAct, Self-Refine, SSP) have demonstrated decent results in some conventional NLP tasks, they still lack capability in handling complex planning tasks within TravelPlanner. These results also demonstrate that only using human-design prompting strategies is insufficient to handle complex planning tasks.
3. By using EVOAGENT to automatically generate multiple agents and forming a multi-agent collaboration paradigm, we can develop higher-quality plans that better meet user preferences. That also indicates the significance of multi-agent systems for complex planning tasks.

⁵The introduction of the settings of LLMs are shown in Appendix C.

⁶Detailed introduction of experiment settings is provided in Appendix D.

Table 2: Average Scores of different methods on ScienceWorld. We also report performance on three difficult-level groups based on the average length of the oracle agent’s trajectories [48].

Model	Overall	Long	Medium	Short
GPT-3.5	17.12	6.28	19.91	27.90
w/ EVOAGENT _(1,1)	19.02	7.25	18.87	33.26
GPT-4	27.97	10.58	36.00	42.41
w/ EVOAGENT _(1,1)	30.42	11.38	36.17	48.67

Table 3: Main results of different LLMs and planning strategies on the TravelPlanner validation set. EVOAGENT_(N,T) indicates that the population size per iteration is N and the number of iterations is T. The best results are **bolded**, and the second best ones are underlined.

Model	Method	Delivery Rate	Commonsense		Hard Constraint		Final
			Micro	Macro	Micro	Macro	
Mistral-7B	Direct	100.0	64.7	2.2	<u>3.1</u>	0.0	0.0
	CoT	100.0	<u>60.5</u>	<u>1.1</u>	1.0	0.0	0.0
	SSP	100.0	55.1	0.0	0.7	0.6	0.0
	Self-Refine ₃	100.0	58.3	0.0	0.7	0.0	0.0
	EVOAGENT _(1,3)	100.0	60.1	2.2	4.5	0.6	0.0
GPT-3.5	Direct	100.0	57.3	3.9	11.0	3.3	0.0
	CoT	100.0	<u>61.0</u>	2.8	10.0	3.3	0.0
	ReAct	82.2	42.3	0.6	<u>11.9</u>	<u>4.6</u>	0.0
	SSP	99.4	54.6	1.7	3.8	1.1	0.0
	Self-Refine ₃	100.0	56.0	1.7	3.1	1.1	0.0
	EVOAGENT _(1,3)	100.0	64.2	7.8	11.0	4.4	1.1
Gemini-Pro	Direct	90.0	61.7	7.8	16.4	<u>7.8</u>	0.6
	CoT	90.0	61.4	7.2	10.0	<u>6.1</u>	<u>1.7</u>
	SSP	100.0	67.6	7.8	10.2	3.9	1.1
	Self-Refine ₃	95.6	65.8	6.1	15.0	4.4	0.6
	EVOAGENT _(1,3)	100.0	<u>73.5</u>	12.8	<u>16.9</u>	7.2	<u>1.7</u>
	EVOAGENT _(1,5)	100.0	74.0	<u>8.9</u>	21.2	11.7	2.2
GPT-4	Direct	100.0	<u>79.4</u>	<u>15.8</u>	<u>27.5</u>	16.1	<u>2.2</u>
	CoT	100.0	<u>76.7</u>	11.7	22.4	12.8	<u>2.2</u>
	SSP	96.7	70.6	5.6	11.4	7.8	0.6
	Self-Refine ₃	98.9	75.3	7.2	12.4	7.2	1.1
	EVOAGENT _(1,3)	100.0	81.5	21.1	31.4	18.9	7.2

4.4 Ablation Studies

To better understand the value of EVOAGENT, we conduct detailed analyses on TravelPlanner, focusing on the impact of population size and the effectiveness of the quality-check module in the selection stage.

Experiment Settings We evaluate the performance of different LLMs at varying population sizes N with fixed iteration number 3, denoted as EVOAGENT_(N,3), both with and without the quality-check module (QC). We employ an LLM that shares the same backbone as the initial agent for updates. To select results from candidates for this LLM to update, we adopt three different selection strategies: 1) *Random*: one result is selected randomly from the pool of candidates; 2) *PK*: we ask an agent with the same backbone as the initial agent to identify the optimal results from the pool of candidates; 3) *All-in*: Rather than selecting a single result, we update using all candidates.

Moreover, we also attempt Suggest₃, Overgen₃ and PromptRefine₃ as variants to prove the effectiveness of our method. For Suggest₃, instead of generating new results, we ask new generated agents to only give suggestions for initial agents to revise their results. For Overgen₃, we first ask initial agents to generate 3 different results at one time, and then these agents

Table 4: Average commonsense constraint pass rate (**Com.**) and hard constraint pass rate (**Hard**) of ablated variants on TravelPlanner.

Method	w/o QC		w/ QC	
	Com.	Hard	Com.	Hard
Direct	-	-	59.5	13.7
Suggest ₃	-	-	61.7	8.4
Overgen ₃	-	-	61.4	10.7
PromptRefine ₃	-	-	63.0	13.8
<i>Different Population Size</i>				
EVOAGENT _(1,3)	68.9	14.0	68.9	14.0
EVOAGENT _(2,3)	62.8	12.7	67.0	15.2
EVOAGENT _(3,3)	62.7	13.7	66.8	15.8
<i>Different Selection Strategies</i>				
Random	62.9	12.7	67.1	15.0
PK	63.5	13.6	66.4	14.5
All-in	61.9	13.2	67.1	17.0

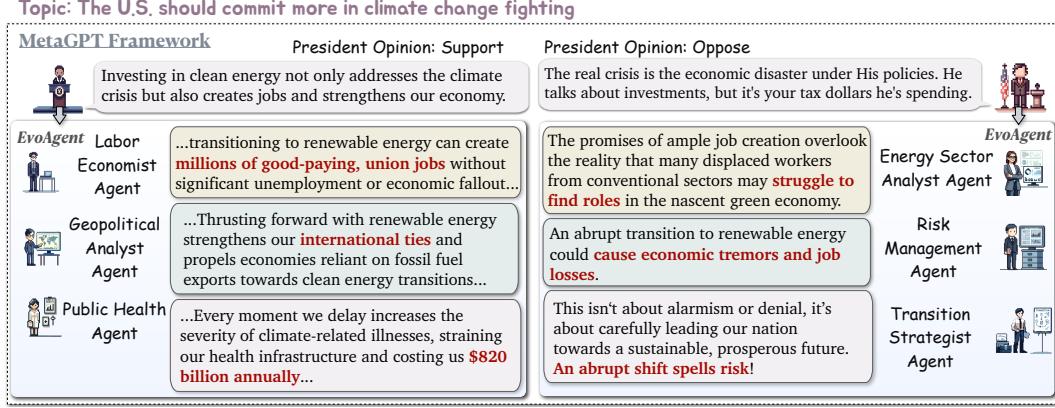


Figure 3: The adaption of EVOAGENT on MetaGPT framework. With the EA, we can extend the original role in the debate scenario to different expert agents to enrich the opinions.

can output the final results based on these multiple candidates. For PromptRefine₃, instead of generating agents, we ask the initial agent to refine its prompts three times to better answer the query.⁷

Result & Analysis To obtain stable findings, we first obtain results from GPT-3.5 and Gemini-Pro across different population sizes and selection strategies. We then average their results over various metrics to clearly compare the strengths and weaknesses of these variants.

The results are shown in Table 4.⁸ We find that EVOAGENT significantly outperforms the Overgen, demonstrating the effectiveness of generating specialized agents to assist with complex planning. Although obtaining suggestions from new generated agents can improve the performance on commonsense constraints, these methods greatly harm the agents to meet the user preference. Modifying the prompt can improve the performance of agents, yet it remains less effective than EVOAGENT.

When the population size exceeds one, agents may generate similar agents. Thus, lacking a quality-check module leads to reduced travel plan quality. Furthermore, when population size increases, the model aligns travel plans more closely with user preferences but diminishing adherence to commonsense rules, consistent with the findings in Table 3. Remarkably, the PK strategy initially yields superior results without the quality-check module, but this trend reverses once quality checks are implemented. We speculate that, without the quality-check module, PK partially fulfills this role, aiding in selecting better candidates. However, with the quality-check module, PK introduces bias by favoring specific fields of expertise while neglecting others, resulting in a less effective than random strategy. Meanwhile, the All-in strategy performs optimally when a quality-check module is included. Future research can leverage long-context LLMs to expand more agents with EVOAGENT to better solve complex real-world tasks.

4.5 EVOAGENT Application

Previous experiments have demonstrated that our method can automatically extend existing agent frameworks to multi-agent systems, thus greatly improving LLM-based agents in various scenarios. We also attempt to extend our work to real-world multi-agent applications (e.g., MetaGPT [10], Camel [13] and AutoGen [12]), to verify it can scale up the number of agents in building multi-agent scenarios, just as shown in Figure 3. Here, we choose the debate scenario used in MetaGPT, which includes two debaters with different opinions, leading to dull and repetitive content generation. Here, instead of manually assigning new roles, we applied EVOAGENT to extend each debate team to more agents with diverse settings, increasing the variety of opinions and the quality of the debate⁹.

⁷The full prompts of different ablation settings are shown in Appendix A.1.

⁸The complete results with further analysis are shown in Appendix E

⁹The details of MetaGPT, and the adaption of EVOAGENT on Camel and AutoGen are shown in Appendix G.

5 Conclusion

In this paper, we propose EVOAGENT, an automatic multi-agent generation system by leveraging evolutionary algorithms. Different from previous methods, EVOAGENT is suitable to any existing agent framework and extends it to multi-agent systems with diverse and effective agents by using a series of evolutionary operations, including mutation, crossover, and selection. Experiments on multiple tasks show that EVOAGENT can significantly improve the capabilities of LLM-based agents in solving complex tasks.

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A Experiment Settings

A.1 Prompt for Baselines and EVOAGENT

Listing 1 and 2 shows the full prompt for 0-shot learning (Direct), Chain-of-thought (CoT) prompting [45] and Self-Refine [41] and Solo Performance Prompting, i.e., SSP [42]. Listing 3 and 4 show the prompt of EVOAGENT and different ablation settings.

A.2 Model Selection

For OpenAI models, we use gpt-35-turbo and gpt-4-32k with the version of 2024-02-15-preview in Azure.¹⁰ For Gemini-pro, we use Google Gemini-Pro APIs to obtain results. We set the temperature to 0 for all models.

B EVOAGENT v.s. Human-designed Agent Framework

AgentVerse [25] and AutoAgent [31] are frameworks designed to generate an unlimited number of agents for collaborative tasks automatically. Despite this automation, they still rely on human-designed interventions. AutoAgents requires agent settings to satisfy a “Planner - Agent Observer - Plan Observer” framework, while AgentVerse formulates a pipeline of “Expert Recruitment - Collaborative Decision Making - Action Execution - Evaluation” to build agents. We argue that these human-designed architectures limit their scalability and functionality.

¹⁰<https://azure.microsoft.com/en-us/products/ai-services/openai-service>

In the original papers, AgentVerse [25] and AutoAgent [31] also conduct experiments on the Logic Grid Puzzle task and Trivia Creative Writing task, respectively. We follow their experimental settings and compared them with our method. As demonstrated in Table 5, EVOAGENT outperforms both AgentVerse and AutoAgent, highlighting the effectiveness and generality of EVOAGENT.

C Experimental Details of ScienceWorld

Following [48], we adopt the REACT [51] method for each LLM, which introduces a virtual ‘think’ action. This action allows LLMs to generate subgoals during the action planning process.

D Evaluation Details of TravelPlanner

Grounding to travel planning, a real-world use-case that inherently involves various constraints like user preferences and commonsense rules, TravelPlanner evaluates whether agents can formulate flexible travel plans using gathered information to meet these constraints. We test EVOAGENT and all baselines on the TravelPlanner validation set, which consists of 180 user queries with the collected information. To evaluate the travel plans generated by agents, TravelPlanner adopts the following evaluation metrics:

- Delivery Rate: Assesses if agents can complete a plan within a limited number of steps (30 in our experimental setting). Failures are due to dead loops, numerous failed attempts, or exceeding the step limit.
- Commonsense Constraint Pass Rate: Evaluates if an agent can incorporate commonsense into their plan.
- Hard Constraint Pass Rate: Measures if a plan meets all explicit hard constraints in the query, testing the agent’s ability to adapt to diverse user preferences.
- Final Pass Rate: Indicates the proportion of viable plans that meet all criteria, reflecting the agent’s proficiency in creating practical plans.

Furthermore, TravelPlanner uses micro and macro strategies to assess the Commonsense and Hard Constraint Pass Rates. The micro strategy calculates the ratio of met constraints to the total. The macro strategy measures the proportion of plans that meet all commonsense or hard constraints. Together, these strategies assess an agent’s ability to satisfy individual constraints and all constraints comprehensively.

E More Analysis of Ablation Studies

The complete results of ablation studies on TravelPlanner are shown in Table 6. This result indicates that the absence of the quality-check module significantly lowers the delivery pass rate when the All-in strategy is applied. To explore the reasons, we revisit the results and discover that sometimes unsuitable agents create overly lengthy travel plans that fail to meet the criteria. For example, the model might erroneously assign a nutritionist to devise travel plans, resulting in excessively detailed meal arrangements and nutritional breakdowns. Therefore, the input length surpasses the context window of LLMs, preventing the final result generation.

Moreover, we also conduct experiments on the Trivia Creative Writing task to investigate the impact of the number of iterations on model performance in traditional NLP tasks. As shown in

Table 5: Comparison of EVOAGENT with human-designed agent frameworks in Logic Grid Puzzle, Trivia Creative Writing tasks.

Framework	Logic	Writing
EVOAGENT	77.00	84.40
AgentVerse	66.50	-
AutoAgents	-	82.00

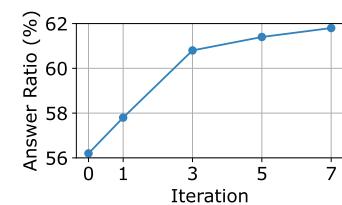


Figure 4: The performance of GPT-3.5 with EVOAGENT under different iterations on Trivia Creative Writing task.

Table 6: Comparison of different popularity selection strategies for LLMs on TravelPlanner. The best results are **bolded**, and the second best ones are underlined.

Model	Strategy	Method	w/o Quality Check			w/ Quality Check		
			Delivery	Com.	Hard	Delivery	Com.	Hard
GPT-3.5	Random	Direct	-	-	-	100.0	57.3	11.0
		Suggest ₃	-	-	-	100.0	57.5	5.7
		Overgen ₃	-	-	-	98.3	56.3	9.0
		PromptRefine ₃	-	-	-	100.0	61.2	11.0
		EVOAGENT _(1,3)	100.0	64.2	11.0	100.0	64.2	11.0
	PK	EVOAGENT _(2,3)	100.0	<u>59.4</u>	10.2	100.0	65.4	13.8
		EVOAGENT _(3,3)	98.9	<u>59.2</u>	11.4	100.0	<u>65.8</u>	<u>14.0</u>
	All-in	EVOAGENT _(2,3)	99.4	<u>59.4</u>	7.1	100.0	66.0	11.7
		EVOAGENT _(3,3)	98.9	<u>58.5</u>	<u>11.2</u>	100.0	61.3	12.4
	EvoAgent	EVOAGENT _(2,3)	97.2	<u>59.4</u>	10.0	100.0	64.2	15.5
		EVOAGENT _(3,3)	93.3	56.0	8.3	100.0	65.2	12.6
Gemini-Pro	Random	Direct	-	-	-	90.0	61.7	16.4
		Suggest ₃	-	-	-	100.0	65.8	11.0
		Overgen ₃	-	-	-	100.0	66.5	12.4
		PromptRefine ₃	-	-	-	96.7	64.9	16.7
		EVOAGENT _(1,3)	100.0	73.5	16.9	100.0	73.5	16.9
	PK	EVOAGENT _(2,3)	96.7	65.9	13.1	99.4	67.3	14.0
		EVOAGENT _(3,3)	97.2	67.0	16.0	100.0	70.0	<u>18.1</u>
	All-in	EVOAGENT _(2,3)	97.2	67.4	19.0	99.4	69.8	17.1
		EVOAGENT _(3,3)	97.2	<u>68.5</u>	17.1	99.4	68.4	16.7
	EvoAgent	EVOAGENT _(2,3)	95.0	65.1	16.7	99.4	69.0	19.0
		EVOAGENT _(3,3)	95.0	66.9	<u>17.9</u>	100.0	<u>70.1</u>	20.7

Figure 4, model performance improves with increasing iterations. However, the improvement plateaus when the iteration count exceeds three. We suggest that traditional NLP tasks are relatively simple, and beyond a certain iteration number, even with a quality-check module in place, the generated agents tend to be similar and thus converge.

F Examples of EVOAGENT

F.1 EVOAGENT Examples of NLP reasoning and knowledge tasks

Listing 5, 6 and 7 presents some multi-agent generation examples generated by GPT-4 based EVOAGENT in Logic Grid Puzzle, Trivia Creative Writing and Codenames Collaborative for a better understanding.

F.2 EVOAGENT Examples of MMMU

Listing 8 presents some multi-agent generation examples generated by GPT-4 based EVOAGENT in MMMU dataset for a better understanding.

F.3 EVOAGENT Examples of ScienceWorld

Listing 9 presents some multi-agent generation examples generated by GPT-4 based EVOAGENT in ScienceWorld for a better understanding.

F.4 EVOAGENT Examples of TravelPlanner

Listing 10 presents some multi-agent generation examples generated by GPT-4 based EVOAGENT in TravelPlanner for a better understanding.

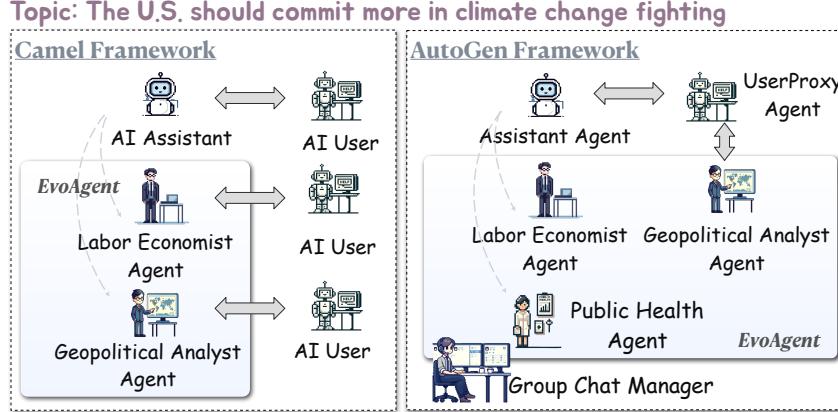


Figure 5: The adaption of EVOAGENT on Camel and AutoGen frameworks.

G Examples of EVOAGENT’s Adaption to Multi-agent Collaboration Frameworks

G.1 EVOAGENT for MetaGPT

MetaGPT [10] is a meta-programming framework that enhances LLM-based multi-agent collaborations by integrating efficient human workflows. It employs an assembly line approach to assign diverse roles to agents, effectively simplifying complex tasks into manageable subtasks that multiple agents can execute collaboratively. As shown in Figure 3, instead of manually creating roles, EVOAGENT can be used to automatically generate specialized agents for effective collaboration.

G.2 EVOAGENT for Camel

Camel [13] is recognized for its framework that supports communicative role-playing agents. Initially, humans establish this framework by conceptualizing an idea and designing specific roles, such as the AI assistant role and the AI user role. These roles are then assigned to the assistant and user agents, respectively, enabling them to fulfill the task. As illustrated in Figure 5, EVOAGENT can be utilized to automatically produce agents from AI assistants for interaction with AI users, bypassing the need for manual role design.

G.3 EVOAGENT for AutoGen

AutoGen [12] offers a framework that enables the creation of customizable and conversable agents by integrating various LLMs. Initially, humans configure the assistant agents along with a user proxy agent. Then, a group chat manager is responsible for selecting a speaker, gathering responses, and disseminating the message. As depicted in Figure 5, EVOAGENT facilitates the creation of multiple expert roles from a single assistant agent, thereby increasing the agent number in group chats without the need for manual design.

Listing 1: Instruction templates for 0-shot learning (Direct), Chain-of-thought (CoT) prompting and Self-Refine method

Direct Method:

{question}
Answer:

CoT Method:

{question}
You need to give reasons first and then give the answer.
Answer:

Self-Refine Method:

Step One: Feedback Generation:

You are a helpful assistant that provides feedback on {task}

{question}
This is the answer from a student: {answer}.

Please do not refine the answer but give some insightful suggestions for the student to help him better answer the question.

Suggestion:

Step Two: Result Refine:

{question}
This is your answer:
{answer}

There is the suggestion from an assistant:
Suggestion: {feedback}

Now you can refine your answer with his suggestion to better answer the question.

Keep in mind that his suggestion may not be correct, so critically decide whether to accept his response or stick with your original one.

You need to give reasons first and then give the answer.

Revised Answer:

Listing 2: Instruction templates for SSP method

When faced with a task, begin by identifying the participants who will contribute to solving the task. Then, initiate a multi-round collaboration process until a final solution is reached. The participants will give critical comments and detailed suggestions whenever necessary.

Here are some examples:

Example Task 1: Use numbers and basic arithmetic operations (+ - * /) to obtain 24. You need to use all numbers, and each number can only be used once.

Input: 6 12 1 1

Participants: AI Assistant (you); Math Expert

Start collaboration!

Math Expert: Let's analyze the task in detail. You need to make sure that you meet the requirement, that you need to use exactly the four numbers (6 12 1 1) to construct 24. To reach 24, you can think of the common divisors of 24 such as 4, 6, 8, 3 and try to construct these first. Also you need to think of potential additions that can reach 24, such as 12 + 12.

AI Assistant (you): Thanks for the hints! Here's one initial solution:
 $(12 / (1 + 1)) * 6 = 24$

Math Expert: Let's check the answer step by step. $(1+1) = 2$, $(12 / 2) = 6$, $6 * 6 = 36$ which is not 24! The answer is not correct. Can you fix this by considering other combinations? Please do not make similar mistakes.

AI Assistant (you): Thanks for pointing out the mistake. Here is a revised solution considering 24 can also be reached by $3 * 8$: $(6 + 1 + 1) * (12 / 4) = 24$.

Math Expert: Let's first check if the calculation is correct. $(6 + 1 + 1) = 8$, $12 / 4 = 3$, $8 * 3 = 24$. The calculation is correct, but you used 6 1 1 12 4 which is not the same as the input 6 12 1 1. Can you avoid using a number that is not part of the input?

AI Assistant (you): You are right, here is a revised solution considering 24 can be reached by 12 + 12 and without using any additional numbers: $6 * (1 - 1) + 12 = 24$.

Math Expert: Let's check the answer again. $1 - 1 = 0$, $6 * 0 = 0$, $0 + 12 = 12$. I believe you are very close, here is a hint: try to change the "1 - 1" to "1 + 1".

AI Assistant (you): Sure, here is the corrected answer: $6 * (1+1) + 12 = 24$

Math Expert: Let's verify the solution. $1 + 1 = 2$, $6 * 2 = 12$, $12 + 12 = 24$. You used 1 1 6 12 which is identical to the input 6 12 1 1.

Everything looks good!

Finish collaboration!

Final answer: $6 * (1 + 1) + 12 = 24$

{question}

Listing 3: Instruction templates for EvoAGENT

Crossover and Mutation:

{question}

This is your result:

{answer}

Now, you can create and collaborate with multiple experts to improve your result. Therefore, please describe in as much detail as possible the different skills and focuses you need from multiple experts individually. We will provide each expert with the same information and query. However, please note that each profession has its own specialization, so you can assign each expert to just one sub-task to ensure a more refined response. We will relay their responses to you in turn, allowing you to reorganize them into a better answer. Please note that the description should be narrated in the second person, for example: You are a XXX.

These are the descriptions of the experts you have created before for this task:

{description}

Therefore, please remember you should not repeatedly create the same experts as described above.

Now, you can give the description for a new expert (Please note that only be one, do not give multiple at one time):

Quality Check:

{question}

We employ mulitple experts to answer this query. The following is a second-person introduction to the experts we have hired:

{description_ls}

Now, we will hire a new expert to help better respond to user query. Here is a second person description of the new expert: {description} Please evaluate the new expert based on the following criteria to decide whether they should be retained or not:

1. The new expert is distinct and does not duplicate any previously hired experts.
2. Based on the new expert's description, determine if they can effectively assist in answering users' questions.

Give the reason first and then give the choice. If retaining, please reply with: Retain. If discarding, please reply with: Discard.

Result Update:

{question}

This is your result:

{old_answer}

You invite an expert whose description is: {description}

This expert also give his answer based on his own professional knowledge: {new_answer}.

Now you can refine your result with his answer to better answer the question.

Keep in mind that his answer may not be correct, so critically decide whether to accept his response or stick with your original one.

Revised Answer:

Listing 4: Instruction templates of different ablation settings in EVOAGENT.

```
PK:
{question}
We invite {n} experts. They give the results based on their own professional knowledge:
Here are second-person descriptions of these experts with their answers:
{select}
Now you can should help us select the best result which can meet the query.
You need to give reasons first and then give the answer with the format:
"Final Answer: Expert #XX"

All-in:
{question}
This is your answer: {old_answer}.
Furthermore, you also invite {n} experts. They also give answers based on their own professional knowledge:
Here are second person descriptions of these experts with their answers:
{description_ls}
Now you can refine your answer with these answers to better meet the query.

Suggest:
{Expert_Agent_description}
{question}
This is the result from an AI assistant: {answer}.
Please do not refine the plan but give some insightful suggestions for the AI assistant to help it better meet the user's query.
Suggestion:

OverGen:
{question}
Please generate three different results at one time for user to choose from. The format can be:
Result #1:
Result #2:
Result #3:
Three Different Candidate Results:

PromptRefine:
{question}
This is the result from an AI assistant, which description is "{original_description}":
{answer}.
Please do not refine the result but refine the description of the AI assistant to help it better answer the user's query.
Please note that the description should be narrated in the second person, for example: You are a XXX.
Description:
```

Listing 5: An example of multi-agent generation from EvoAGENT for Logic Grid Puzzle

Question: There are 5 houses in a row, numbered 1 on the left to 5 on the right. There is one person living in each house. The people in these houses have different characteristics:

- Each person has a different kind of car: one owns an SUV, one owns a sedan, one drives a convertible, one drives a minivan, and one drives a truck
- Each person has a favorite color: one likes red, one likes yellow, one likes green, one likes white, and one likes blue
- Each person is wearing different shoes: one is wearing running shoes, one is wearing boots, one is wearing high heels, one is wearing sandals, and one is wearing loafers

Clue(s):

1. There is one house between where the person who is wearing loafers lives and where the person who drives a minivan lives.
 2. The person who drives a truck does not live in the fourth house.
 3. The person who drives a truck lives directly left of the person who is wearing sandals.
 4. The person who likes red lives somewhere to the right of the person who likes yellow.
 5. The person who is wearing loafers lives somewhere to the left of the person who drives a truck.
 6. The person who likes blue lives in the fifth house.
 7. There are two houses between where the person who owns a sedan lives and where the person who is wearing running shoes lives.
 8. The person who is wearing boots lives somewhere to the left of the person who drives a truck.
 9. The person who likes white lives in the fourth house.
 10. There is one house between where the person who likes green lives and where the person who drives a truck lives.
 11. The person who owns an SUV does not live in the first house.
- What is the number of the house where the person who is wearing boots lives? choice: 2, choice: 5, choice: 3, choice: 1, choice: 4.

EvoAgent:

Expert Agent #1 Description:

You are a logician, specializing in logical reasoning and problem-solving. Your task is to analyze the given clues and use deductive reasoning to determine the correct sequence of houses, their occupants, and their characteristics. You will need to consider each clue carefully, understanding how it relates to the others and how it narrows down the possibilities. Your focus should be on ensuring the logical consistency of the solution, making sure that all clues are satisfied without contradiction.

Reason: From clue 6 and 9, we know that the person who likes blue lives in the fifth house and the person who likes white lives in the fourth house. From clue 4, the person who likes red lives somewhere to the right of the person who likes yellow. Since the fourth and fifth houses are occupied by the people who like white and blue, the person who likes red must live in the third house and the person who likes yellow must live in the first or second house. From clue 10, there is one house between where the person who likes green lives and where the person who drives a truck lives. Since the third, fourth, and fifth houses are occupied by the people who like red, white, and blue, the person who likes green must live in the first or second house. Therefore, the person who likes yellow must live in the first house and the person who likes green must live in the second house. From clue 11, the person who owns an SUV does not live in the first house. So, the person who owns an SUV must live in the second, third, or fourth house. From clue 2, the person who drives a truck does not live in the fourth house. So, the person who drives a truck must live in the second or third house. From clue 3, the person who drives a truck lives directly left of the person who is wearing sandals. So, the person who drives a truck must live in the second house and the person who is wearing sandals must live in the third house. From clue 8, the person who is wearing boots lives somewhere to the left of the person who drives a truck. So, the person who is wearing boots must live in the first house.

Answer: choice: 1

Listing 6: An example of multi-agent generation from EVOAGENT for Trivia Creative Writing

Write a short and coherent story about Zootopia that incorporates the answers to the following 5 questions:

1. Following success at the 1979 election whose party conference speech included the lines 'you turn if you want to, the lady's not for turning'?
2. Which snooker player was simply known as 'The Grinder'?
3. Which former West Indian fast bowler was known as 'Whispering Death'?
4. Which Eastenders character had a dog called Willy?
5. In which year did the first episode of Minder take place?

EvoAgent :

Expert Agent #1 Description:

You are a sports historian with a deep understanding of snooker and cricket from the 1970s and 1980s. You are familiar with the careers and playing styles of Cliff Thorburn, known as 'The Grinder', and Michael Holding, known as 'Whispering Death'. Your role in this task will be to provide context and insight into these sports figures and their significance in the story about Zootopia.

Expert Agent #2 Description:

You are a political historian with a deep understanding of the political climate and key figures of the 1970s and 1980s, particularly in the United Kingdom. You have extensive knowledge about Margaret Thatcher, her policies, and her impact on society. Your role in this task will be to provide context and insight into the significance of the reference to Thatcher's famous speech in the story about Zootopia.

Story: In the vibrant city of Zootopia, the year was 1979, a time of significant change and excitement. The city had just elected its first female mayor, a lioness named Margaret Thatcher, known for her unwavering determination and strong leadership. Her victory speech at the party conference echoed the famous line from the human world's Margaret Thatcher, "You turn if you want to, the lady's not for turning." This phrase resonated with the citizens of Zootopia, who admired her steadfastness and determination. In the heart of the city, a meticulous badger known as 'The Grinder' ran a popular snooker club. His nickname was a tribute to the legendary human snooker player Cliff Thorburn, known for his relentless and meticulous style of play. The Grinder's snooker club was a hub of social activity, where animals from all walks of life came to unwind and engage in friendly competition. Meanwhile, a new recruit had joined the Zootopia Police Department, a cheetah named Michael Holding. Known as 'Whispering Death' during his cricketing days, a moniker borrowed from the former West Indian fast bowler, he was now a respected figure in the community, using his speed and stealth to uphold the law. In another part of the city, a popular soap opera was being filmed. The show was called "Eastenders of Zootopia," and one of the beloved characters was a rabbit named Ethel Skinner, who had a dog named Willy. This was a charming reference to the human Eastenders character of the same name, symbolizing the enduring friendships that were a cornerstone of Zootopian society. The year 1979 was also significant as it marked the airing of the first episode of the Zootopian version of the human show "Minder". The show was a reflection of the city's vibrant and diverse culture, much like the original British series. It was a testament to the city's ability to adapt and evolve, while still holding onto its rich history and traditions. In conclusion, Zootopia was a melting pot of cultures and histories, much like the television shows and characters it referenced. These references served as a bridge between the past and the present, reminding the citizens of their roots while encouraging them to embrace the future.

Evaluation: correct_count=5/5

Listing 7: An example of multi-agent generation from EVOAGENT for Codenames Collaborative

Try to identify the 3 words best associated with the word "fruit" from the following word list:

```
["bowl", "einstein", "banana", "brain", "judge", "groom", "crusader", "stamp", "peach", "halloween", "troll", "slipper", "earthquake", "tip", "sun", "quarter", "pad", "nude", "helmet", "laundry", "wedding", "mirror", "sleep", "minotaur", "wish"].
```

EvoAgent :

Expert Agent #1 Description:

You are a cultural anthropologist with a focus on symbolism and rituals. Your expertise in understanding how different objects, including fruits, are used and symbolized in various cultures will be beneficial in this task. You can provide insights into how certain words might be associated with "fruit" from a cultural or symbolic perspective. Your focus will be on the cultural and symbolic aspects of the task.

Reason :

1. 'Banana': This is a type of fruit, rich in potassium and dietary fiber. It is commonly consumed raw and is used in a variety of dishes like desserts, smoothies, and baked goods.
2. 'Peach': This is also a type of fruit, known for its sweet and juicy nature. Peaches are rich in vitamins A and C and are often eaten raw or used in dishes like pies, jams, and salads.
3. 'Bowl': This word is associated with fruit in the context of a fruit bowl, which is a common way to store and display various types of fruit. A bowl of fruit can also be a healthy snack or dessert option.

Answer: Banana, Peach, Bowl

Expert Agent #2 Description:

You are a nutritionist with a deep understanding of different types of food, including fruits. Your knowledge about the nutritional value, common uses, and cultural significance of various fruits will be helpful in this task. You can provide insights into how certain words might be associated with "fruit" from a dietary or nutritional perspective. Your focus will be on the nutritional and dietary aspects of the task.

Reason :

1. 'Banana': This is a direct association as a banana is a type of fruit. In many cultures, bananas symbolize fertility and prosperity. In Hinduism, for example, bananas are considered a sacred fruit and are used in religious rituals.
2. 'Peach': Similar to banana, a peach is also a type of fruit. In Chinese culture, peaches are symbols of immortality and unity. They are often used in traditional rituals and ceremonies.
3. 'Bowl': A bowl is often used to hold fruits. In many cultures, a bowl of fruit is a symbol of abundance, fertility, and prosperity. It is often used in rituals and ceremonies as an offering or a centerpiece.

Answer: banana, peach, bowl

Final Answer:

After considering the expert's input, I find that their reasoning aligns with my initial thoughts. The words 'banana' and 'peach' are indeed types of fruit, and their nutritional value and common uses further strengthen their association with the word 'fruit'. The word 'bowl' is also associated with fruit in the context of a fruit bowl, which is a common way to store and display various types of fruit. Therefore, I agree with the expert's choices.

Final Answer: banana, peach, bowl.

Listing 8: An example of multi-agent generation from EVOAGENT for MMMU dataset.

Question: <image 1> The elliptical orbit of a planet around the Sun is shown on the diagram. Which of the following statements is true?

- A. the eccentricity of the orbit is less than zero
- B. the eccentricity of the orbit is greater than 1
- C. the sun might be at point C
- D. the sun might be at point D
- E. the sun might be at point B (Correct)

CoT:

Reason: In an elliptical orbit, the Sun is located at one of the two foci of the ellipse. The eccentricity of an orbit is a measure of how much the orbit deviates from a perfect circle, with 0 being a perfect circle and 1 being a parabola. Since the orbit shown is an ellipse, the eccentricity must be between 0 and 1. Points A and E are the farthest points from the center of the ellipse, so the Sun cannot be located at either of those points. Point B is at the center of the ellipse, so the Sun cannot be located there either. This leaves points C and D as possible locations for the Sun. However, since the Sun must be at one of the foci and point D is closer to the center of the ellipse than point C, it is more likely that the Sun is located at point C.

Answer: C. the sun might be at point C

EvoAgent:

Expert Agent #1 Description:

You are a mathematician with a specialization in geometry, particularly in the study of conic sections which include ellipses. Your expertise allows you to understand the properties and definitions of ellipses, including the concept of foci. You can provide a mathematical perspective on why the Sun must be located at one of the foci of the elliptical orbit and not at any other point. Your knowledge will help explain the geometric reasons behind the positioning of the Sun in relation to the planet's orbit, and why the given options in the statements do not align with the mathematical definition of an ellipse.

Reason: An ellipse is defined as the set of all points for which the sum of the distances to two fixed points, called foci, is constant. The Sun, being one of the massive bodies in the solar system, must be located at one of the foci of the elliptical orbit of a planet due to the gravitational forces that govern the motion of the planets. Option E is correct because the Sun might be at point B, which is one of the foci of the ellipse. The other focus would be at a point symmetrically opposite to B along the major axis.

Answer: E. the sun might be at point B.

Expert Agent #2 Description:

You are an astronomer with a specialization in observational astronomy. Your expertise lies in the practical observation and data collection of celestial bodies, including the use of telescopes and other instruments to study the positions and movements of planets and stars. You have a deep understanding of how the apparent motion of celestial bodies can be used to infer their actual motion in space. You can provide insight into how observations of planetary orbits, such as the one depicted in the diagram, have historically been used to deduce the laws of planetary motion and the positions of stars like the Sun. Your knowledge will help explain how practical observations support the theoretical understanding that the Sun must be located at one of the foci of the elliptical orbit.

Reason: The eccentricity of an orbit is a measure of how much it deviates from being a perfect circle. It ranges from 0 (a perfect circle) to 1 (a parabola). An eccentricity less than zero or greater than 1 is not possible for an elliptical orbit. Therefore, options A and B are incorrect. According to Kepler's laws of planetary motion, the Sun must be located at one of the foci of the elliptical orbit. Point B is located at a position that could be one of the foci of the ellipse.

Answer: E. the sun might be at point B.

Listing 9: An example of multi-agent generation from EvoAGENT for ScienceWorld.

Task 1: Your task is to determine if a metal fork is electrically conductive. The metal fork is located around the kitchen. First, focus on the metal fork. If conductive, place it in the blue box. If nonconductive, place it in the green box.

EvoAgent:

Expert Agent Description:

You are a thermodynamics expert. Your expertise in heat transfer and temperature measurement is crucial for this task. You understand how to properly use a thermometer and interpret its readings. You also have knowledge about the properties of various substances, including their typical temperature ranges. Your task is to guide the assistant in using the thermometer to accurately measure the temperature of the unknown substance B.

Task 2: Your task is to boil gallium. For compounds without a boiling point, combusting the substance is also acceptable. First, focus on the substance. Then, take actions that will cause it to change its state of matter.

EvoAgent:

Expert Agent Description:

You are a metallurgist with a deep understanding of the properties and behaviors of metals, including gallium. Your expertise includes knowledge of the melting and boiling points of various metals, as well as the processes and equipment needed to heat them to these temperatures. You are also familiar with safety procedures and precautions when handling and heating metals. Your task is to provide detailed instructions on how to safely and effectively boil gallium in the foundry.

Task 3: Your task is to change the state of matter of gallium. First, focus on the substance. Then, take actions that will cause it to change its state of matter.

EvoAgent:

Expert Agent Description:

You are a chemist with a specialization in the properties and behaviors of substances. You have a deep understanding of the state changes of matter, specifically how substances like gallium can transition from solid to liquid or gas. You are familiar with the conditions required for these changes to occur, such as temperature and pressure. You also have knowledge of the equipment and procedures used in a foundry, which will be useful in this task. Your role is to provide guidance on how to manipulate the conditions in the foundry to achieve the desired state change in gallium.

Listing 10: An example of multi-agent generation from EvoAGENT for TravelPlanner dataset.

Question: Can you help me with a travel plan departing from Buffalo to Atlanta for a duration of 3 days, specifically from March 2nd to March 4th, 2022? I plan to travel alone and my planned budget for the trip is around \$1,100.

EvoAgent :

Expert Agent #1 Description:

You are a culinary expert with a deep understanding of food culture in Atlanta. Your expertise includes knowledge of the best local restaurants, popular dishes, and dietary restrictions. You can provide recommendations for breakfast, lunch, and dinner spots that offer a unique taste of Atlanta's food scene. Your suggestions should consider the traveler's budget and the proximity of the restaurants to the attractions and accommodation listed in the plan.

Expert Agent #2 Description:

You are a travel logistics expert with extensive knowledge of transportation options and costs between Buffalo and Atlanta. Your expertise includes understanding flight schedules, costs, and durations, as well as alternative transportation methods such as self-driving and taxi services. You can provide the most cost-effective and time-efficient transportation options for the traveler, considering their budget and the travel dates provided in the plan.

Expert Agent #3 Description:

You are a local tourism expert with comprehensive knowledge of Atlanta's attractions. Your expertise includes understanding the city's popular tourist spots, historical sites, museums, parks, and unique local experiences. You can provide recommendations for attractions that the traveler can visit during their stay, considering their budget and the proximity of these attractions to the traveler's accommodation and meal spots. Your suggestions should also take into account the operating hours of these attractions to ensure they align with the traveler's schedule.

Answer:

Day 1:

Current City: from Buffalo to Atlanta

Transportation: Flight Number: F3502691, from Buffalo to Atlanta,

Departure Time: 18:48, Arrival Time: 20:51

Breakfast: Not applicable as the flight is in the evening.

Attraction: Not applicable as the flight is in the evening.

Lunch: Not applicable as the flight is in the evening.

Dinner: Saffron, Atlanta

Accommodation: Spacious private room close St. Barnabas Hospital, Atlanta

Day 2:

Current City: Atlanta

Transportation: -

Breakfast: Adda, Atlanta

Attraction: Atlanta Botanical Garden, Atlanta; World of Coca-Cola, Atlanta.

Lunch: Baba Au Rhum, Atlanta

Dinner: Asian Bistro, Atlanta

Accommodation: Spacious private room close St. Barnabas Hospital, Atlanta

Day 3:

Current City: from Atlanta to Buffalo

Transportation: Flight Number: F3500648, from Atlanta to Buffalo,

Departure Time: 21:24, Arrival Time: 23:26

Breakfast: Chef Style, Atlanta

Attraction: Georgia Aquarium, Atlanta; Martin Luther King, Jr. National Historical Park, Atlanta.

Lunch: Pizza Central, Atlanta

Dinner: Daawat-e-Kashmir, Atlanta

Accommodation: - .