

Integrating Classical Planners with GPT-based Planning Policies

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Abstract

Recent works on Large Language Models (LLMs) have demonstrated their effectiveness in learning general policies in automated planning. In particular, a system called PLANGPT has achieved impressive performance in terms of coverage in various domains. However, it may produce invalid plans that either satisfy only some goal fluents of the corresponding planning problem or violate the planned actions’ preconditions. To overcome this limitation, we propose a novel neuro-symbolic approach that combines PLANGPT with a planner capable of repairing (or completing) the plan generated by PLANGPT, thereby leveraging model-based reasoning. When PLANGPT generates a candidate plan for a specific planning problem, we validate it using a symbolic validator. If the generated plan is invalid, we execute the repair procedure of the planner LPG to obtain a valid solution plan from it. In this paper, we empirically evaluate the effectiveness of our approach and demonstrate its performances across various planning domains. Our results show significant improvements in the performance of both PLANGPT and LPG, highlighting the effectiveness of combining learning methods with traditional planning techniques.

Introduction

Attention-based architectures such as Transformers (Vaswani et al. 2017), BERT (Devlin et al. 2019), and GPT (Radford and Narasimhan 2018) have driven recent advancements in Natural Language Processing (NLP). These models have achieved impressive results in machine translation and summarisation and have shown promise in understanding factual knowledge and common sense (Geva et al. 2021; Jiang et al. 2020; Petroni et al. 2019; Serina et al. 2023). However, their reasoning abilities, especially for planning tasks, remain limited (Arora and Kambhampati 2023; Valmeekam et al. 2022, 2023b). Current prompting methods and fine-tuning Large Language Models (LLMs) struggle to generate valid plans for automated planning problems (Arora and Kambhampati 2023; Pallagani et al. 2022, 2023; Valmeekam et al. 2023b).

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More promising results were obtained by PLANGPT (Rossetti et al. 2024a,b), a novel GPT-based model specifically trained to generate plans for classical planning domains. However, a limitation of this system is that it cannot correct invalid plans at generation time (plans with unsatisfied preconditions or unachieved goals), returning in these cases an incorrect solution for the planning problem.

As other machine learning models (Chen, Thiébaut, and Trevizan 2024; Chen, Trevizan, and Thiébaut 2024; Hao et al. 2024), PLANGPT is able to learn a general policy which can be used to solve many planning problems. However, they can be also used in combination with a planner: in the work of (Stahlberg, Bonet, and Geffner 2023) general policies are exploited as heuristics by planners; in the work in (Valmeekam et al. 2023a) instead a LLM-generated plans are subsequently corrected by a planner. Following these works, in this paper we combine PLANGPT with the LPG planner (Gerevini, Saetti, and Serina 2003) to address invalid or incomplete plans that may arise during generation. By integrating learning and model-based techniques, our aim is to improve the reliability and accuracy of plan generation by LLMs.¹

Related work

Recent works have studied and analysed the capabilities of LLMs in planning and reasoning in the last few years. In (Arora and Kambhampati 2023; Valmeekam et al. 2022), the authors showed how pre-trained GPT models (GPT-3.5 and GPT-4) can be used to generate plans starting from the problem description without a customised training. Unfortunately, their results highlight that pre-trained LLMs often fail to generate correct plans, even with a neural validator that checks the executability of the actions.

In (Pallagani et al. 2022, 2023), the authors fine-tuned a Code-T5 model (Wang et al. 2021) with solved problems in several planning domains obtaining a new model,

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Plansformer. This model showed interesting results, producing more valid plans than the prompting approach in various domains limited in the number of objects. These approaches use an LLM to generate a plan given the initial state, the goal, and the domain description as input, similar to the context of general policies. The main difference from PLANPPT approach is that the authors of PLANPPT train GPT from scratch with a custom dataset of planning instances.

In another line of work, researchers have exploited different deep-learning architectures to learn general policies. Instead of generating the sequence of actions, these systems compute a heuristic for all the states reachable by applicable actions, starting from the current state and the goal. For instance, in (Ståhlberg, Bonet, and Geffner 2022a,b), authors proposed a Graph Neural Network (GNN) to address the problems in various benchmark domains. Following this work, the authors tried to integrate the learnt general policies with a greedy first search, obtaining a learned domain-specific planner called Muninn (Stahlberg, Bonet, and Geffner 2023). A similar work was presented in (Chen, Thiébaut, and Trevizan 2024; Chen, Trevizan, and Thiébaut 2024; Hao et al. 2024) where the authors use GNNs with other graph representations, ranking of the search state and machine learning methods to compute different heuristics.

These approaches produce a numeric heuristic that evaluates the current state and guides the search, and must be continually called upon by the planner. Instead, in our approach, the model directly generates the sequence of actions. For example, in (Valmeeckam et al. 2023a), a pre-trained LLM generates a candidate plan that is given as the initial seed to a plan repair system. However, a crucial difference to our work is that the generated plan is provided as input to the planner without any modification.

Instead of using pre-trained LLMs, an initial experiment to train a Language Model from scratch, in the automated planning context, is available in (Serina et al. 2022). Moreover, recently authors in (Rossetti et al. 2024a,b) proposed PLANPPT, a general policy based on the GPT architecture trained from scratch on a dataset of planning instances. PLANPPT obtains SoTA performances in generating valid plans in various benchmark domains. However, PLANPPT can generate invalid or incomplete plans that violate an action or do not satisfy the goal. In this paper, to address this limitation, we integrate PLANPPT with a plan repair planner, LPG, to correct invalid plans using different candidate plan initialisations.

Background: Classical Planning, GPT and PLANPPT

Classical Planning

Following the formalisation presented in (Rossetti et al. 2024a) to represent deterministic, fully observable planning problems, a classical planning problem is a pair $P = (D, I)$ where D is a planning domain and I is a problem instance. More specifically, D contains a set of predicate symbols p and a set of actions with preconditions and effects given by atoms $p(x_1, \dots, x_k)$, where each x_i is an argument of the

schema; I is a tuple $I = (O, Init, Goal)$, where O is a (finite) set of objects names c_i , and $Init$ and $Goal$ are sets of ground atoms $p(c_1, \dots, c_k)$ representing the initial state and the goal of the problem. A classical planning problem $P = (D, I)$ encodes a state model $S(P) = (S, s_0, S_G, Act, A, f)$ where each state $s \in S$ is a set of ground atoms from P , s_0 is the set of fluents of the initial state $Init$, S_G is the set of goal states $s \in S$ such that $Goal \subseteq s$, Act is the set of ground actions in P , $A(s)$ is the set of ground actions whose preconditions are true in s , and f is the transition function so that $f(a, s)$, for $a \in A(s)$, represents the state resulting from applying action a to state s . An action sequence a_0, \dots, a_n is applicable in P if $a_i \in A(s_i)$ and $s_{i+1} = f(a_i, s_i)$, for $i = 0, \dots, n$, and it is a solution plan if $s_{n+1} \in S_G$. The plan cost is assumed to be its length; therefore, a plan is optimal if no shorter plan exists.

A plan validator (Howey, Long, and Fox 2004) is a reasoning tool that, given a domain, a problem instance, and a plan, validates whether the plan solves the problem. The validator checks the applicability of each plan action a_i by verifying the truth of its preconditions in the current state s_i ($a_i \in A(s_i)$), and progresses s_i to s_{i+1} ($s_{i+1} = f(a_i, s_i)$). If an action violates the preconditions ($a_i \notin A(s_i)$), then the validator terminates returning an invalid plan. Otherwise the validator verifies whether the last state of the plan reaches the problem goal ($s_{n+1} \in S_G$); in that case, it returns the generated plan as a solution plan, or the invalid plan.

Generalised planning studies the representation and computation of general policies to solve multiple problems in the same planning domain (Hu and De Giacomo 2011; Srivastava, Immerman, and Zilberstein 2008, 2011). A general policy can be defined as a function $\pi(Init, Goal, a_0, \dots, a_{i-1})$ that provides the next action in Act to apply given the initial state $Init$, the goal $Goal$ of the problem instance and the list of i actions previously obtained by π auto-regressively. A policy π solves a set of classical planning instances for the same domain D if each of these instances $I = (O, Init, Goal)$ is solved by the sequence of actions $A_\pi = (a_0, \dots, a_i)$ obtained by applying auto-regressively π , i.e. $a_0 = (Init, Goal)$, $a_1 = (Init, Goal, a_0)$, $a_2 = (Init, Goal, a_0, a_1)$..., $a_i = (Init, Goal, a_{i-1})$.

Generative Pretrained Transformer (GPT)

In this section, we briefly introduce the architecture of GPT, the neural component of PLANPPT and how it works. A GPT model (Radford and Narasimhan 2018; Radford et al. 2019) is the decoder stack of the Transformer architecture (Vaswani et al. 2017) developed to generate sequences of elements for NLP tasks. The authors selected the smallest GPT-2 version because it is the latest open-source version of GPT and, requires less training data and fewer computational resources for training than bigger versions. This model completes the sentence given as input, known as prompt, with the most likely next words. The completion process continues step-by-step, appending the generated word to the input and outputting the most likely next word. For example, given the input “*Rome is the capital*”, GPT predicts the following words “*of*” and “*Italy*”. The main component of GPT-2 is the attention mechanism. This

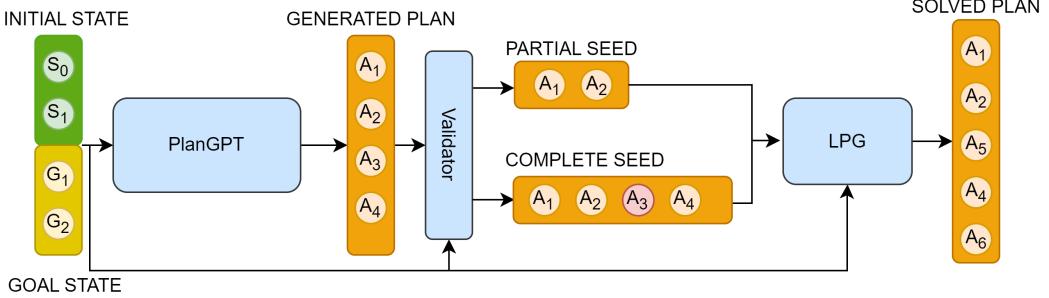


Figure 1: Example of input/output for a planning problem with two fluents in the initial state (S_0 and S_1) and two fluents (G_0 and G_1) forming the goal. PLANGPT generates the plan A_1, \dots, A_4 . The validator verifies the correctness of the candidate plan and, if it finds it invalid, generates the partial and complete seeds. Then LPG generates a valid plan using the seed with the repair option.

neural component tries to correlate each couple of tokens in the prompt to extract the various relationships between the sentence, obtaining a meaningful semantic of the prompt to generate the most valuable token. This generation process requires a preliminary tokenization step using a tokenizer, in this case, WordPiece (Devlin et al. 2019), mapping the words in the prompt into individual words or word fragments called *t*okens.

More formally, this strategy is the standard strategy of GPT called **greedy decoding**. At each step, the model takes the prompt as input and outputs the token with the highest probability from the vocabulary (adding it to the prompt). This generation has the issue of producing less varied outputs, as it always selects the most probable token greedily without exploring other tokens. Another method called **top-p sampling** addresses these limitations. In top-p sampling, instead of always selecting the token with the highest probability, the model creates a reduced set of tokens at each step and then randomly samples the next one from the probability distribution over this reduced set. At each step, the strategy cumulatively sums the probabilities of the tokens in descending order until the sum exceeds a threshold p . This token selection ensures that only the most likely tokens, which account for a probability mass of at least p , are considered for sampling.

PLANGPT

The authors of (Rossetti et al. 2024a) trained from scratch the architecture of GPT-2 on a customised planning dataset, following the idea that LLMs could understand the grammar and solve a planning problem as shown by (Geib and Steedman 2007). In the context of general policies, after training, the model, called PLANGPT, can solve complex planning problems similar to those from the International Planning Competition (IPC), achieving state-of-the-art performance across various classical planning domains using the top-p sampling generation.

PLANGPT receives in input a set of fluents representing the initial state and the goal of a planning and has to compute a plan to solve a problem. In order to do that, it has to predict sequentially all the actions of a plan as if they were words.

Mapping fluents and action into words is done through the tokenization. During tokenization, authors split each fluent (and each action) into its components, the fluent (or action) name, and its associated objects. For example, for fluent (*At Truck1 Loc1*) there are three tokens: *At*, *Truck1* and *Loc1*; for action (*Drive Truck1 Loc1 Loc3*), four tokens: *Drive*, *Truck1*, *Loc1* and *Loc3*. After training, given as input the fluents of the initial state and the goal of a problem, PLANGPT generates the solution plan by generating the next token (the action name or the object name) in an auto-regressive mode with different generation strategies.

At the end of the generation, the validator unites the tokens into actions. Finally, the validator checks the validity of the plan. However, a current limitation of this approach is that if an action fails due to a violation of a precondition or the plan does not satisfy the goal, the plan is considered invalid by the validator, and PLANGPT cannot correct it.

Local search for Planning Graphs

The standard method for solving classical planning problems is the use of a planner. A planner is a system that addresses planning problems without leveraging particular domain properties or biases, but using only the domain definition and search methods. Given as input the domain description D and the problem I , a planner will produce a plan to solve the problem I . In literature, numerous planners such as LAMA (Richter and Westphal 2010), Fast-Downward (Helmert 2006) and LPG (Gerevini, Saetti, and Serina 2003) exploit different kinds of heuristics and search to solve automated planning problems. In this work, we consider using the Local search for Planning Graphs (LPG) (Gerevini, Saetti, and Serina 2003) as it offers the possibility of plan repair and completion.

The basic search scheme of LPG was inspired by Walksat (Kautz and Selman 1999), an efficient procedure to solve SAT problems. The search space of LPG consists of *action graphs*, particular sub-graphs of the planning graph representing partial plans. The search steps are graph modifications, transforming an action graph into another one. LPG exploits a compact representation of the planning graph to define the search neighbourhood and to evaluate its elements

building relaxed planning graphs. This is achieved by an anytime process that produces a sequence of plans, each of which improves the quality of the previous ones.

In addition to generating a plan from scratch, LPG offers a plan repair solution: starting from an invalid or incomplete plan LPG solves the problem by leveraging the knowledge in that plan and correcting it.

PLANGPT seed as input of LPG

The main contribution of this work is integrating the LPG planner in the generation phase of PLANGPT. Given that PLANGPT has the potential to generate invalid plans, we use the LPG repair plan option to correct these invalid plans.

Starting from an already generated plan, instead of an empty seed as usual, LPG can compute an action graph from the current invalid plan that corrects inconsistencies and improves the quality of the final solution, reducing the search time required and exploiting the knowledge in the generated plan.

The proposed architecture includes a neural system, PLANGPT, which produces a plan (valid or not), a symbolic validator that can check its validity, and LPG that can repair it. We refer to this combined system as R-PLANLPG.

Following Figure 1, the generation process of the system starts from the component PLANGPT, which takes the initial state and goals as input and generates a candidate plan. In this example, given the fluents S_0 and S_1 and the goal fluents G_1 and G_2 , PLANGPT generates a plan composed of 4 actions: A_1, A_2, A_3, A_4 . Then, the symbolic validator checks the actions' validity and the satisfaction of the goal. In the example, the validator analyses the actions A_1, A_2, A_3, A_4 , discovering that the action A_3 is invalid.

We implement two strategies to create the LPG candidate seed: the **partial seed**, where the validator discards some actions from the original generated plan, or the **complete seed**, where LPG takes as input the whole generated plan.

In the partial seed, if the plan has an action that violates a precondition, the validator prunes all the actions from the violation, obtaining the candidate plan. Instead, suppose the plan has no preconditions' violations. In that case, the validator produces the candidate plan by selecting all the actions up to the last one that satisfies the problem's last solved goal. Furthermore, the validator checks the presence of loops in the candidate plan computed, i.e. sequences of actions that repetitively reach the same state without progressing towards the goals, and removes them. The idea is to provide LPG with a correct initial candidate plan to complete that satisfies various goal fluents and does not provide any violated preconditions or loops. In Figure 1, for the partial seed, since action A_3 is invalid, the validator prunes actions A_3, A_4 and produces the candidate plan A_1, A_2 .

In the complete seed, instead, the candidate plan for LPG consists of the plan from PLANLPG without any modifications. This approach enabled LPG to take advantage of the knowledge of the plan generated after a precondition violation and, therefore, to provide details on the subsequent phases of the plan. By correcting the violation of the preconditions, if any, it is possible that the remaining plan is valid

and helps LPG in its search. In Figure 1, for the complete seed, the candidate plan is A_1, A_2, A_3, A_4 .

Finally, LPG searches for a solution starting from the input candidate plan and gives the final plan solution as output. In Figure 1, LPG takes as input the complete seed and produces the new plan A_1, A_2, A_5, A_4, A_6 substituting action A_3 with action A_5 and adding action A_6 to obtain a valid solution to the problem. In our experimental evaluation, we also considered an empty candidate plan as input to LPG.

Experimental Results

Starting from the available trained PLANLPG (Rossetti et al. 2024a), we extended its generation process with the integration of a validator and the LPG planner in the eight benchmark domains used in (Rossetti et al. 2024a): BLOCKSWORLD, DEPOTS, DRIVERLOG, FLOORTILE, LOGISTICS, SATELLITE, VISITALL and ZENOTRAVEL.

For each domain, we used more than 6000 testing problems (T_{set}). The planning problems in T_{set} are similar to those used in the International Planning Competition (IPC) and are created using the available PDDL generators (Seipp, Torralba, and Hoffmann 2022). The choice to use this dataset is to compare a larger number of problems since the test set of IPC contains only between 30 and 100 problems for each domain. The PLANLPG models are run on an NVIDIA A100 GPU with 40 GB. Regarding the planners, for each problem, we generate solution plans on an Intel (R) Xeon (R) Gold 6140M CPU @ 2.30GHz with a standard time limit of 300s.

To evaluate our experiments, we use classical planning metrics such as the coverage, the plan length and the *IPCScore-Quality* (IPCQ) and *IPCScore-Agile* (IPCA) as defined in the last International Planning Competition (IPC 2023):

- **Coverage:** the percentage of valid plans over the total number of generated plans.
- **Plan Length:** the score of a problem is the number of actions of a solution plan. The score of a model is the mean of its score for the problems solved by all the models.
- **IPCScore-Quality:** The score of a problem is the ratio C^*/C where C is the cost of the plan discovered by the model and C^* is the cost of a reference plan (the cheapest plan obtained by all models for that problem). The score of an unsolved problem is 0. The score of a model is the sum of its scores for all problems.
- **IPCScore-Agile:** The score of a problem on a solved task is 1 if the task was solved within 1 second and 0 if not solved within the resource limits. If the problem is solved in T seconds ($1 \leq T \leq 300$) then its score is $1 - \log(T)/\log(300)$. The score of a model is the sum of its scores for all problems.

In the following, we evaluate PLANLPG and LPG in terms of coverage and plan length compared on T_{set} considering different execution time thresholds. Next, we evaluate R-PLANLPG, combining the repair process of LPG using partial, and complete seed on the invalid plans generated by PLANLPG in terms of coverage, plan length, and

domain	< 10s		< 20s		< 1m		< 5m	
	LPG	PLANPPT	LPG	PLANPPT	LPG	PLANPPT	LPG	PLANPPT
BLOCKSWORLD	99.3	99.3	99.9	100.0	100.0	100.0	100.0	100.0
DEPOTS	77.6	76.0	99.4	94.5	99.8	94.8	99.9	94.9
DRIVERLOG	61.1	61.0	98.1	96.3	99.8	97.8	99.9	97.9
FLOORTILE	40.8	41.2	58.0	62.6	93.2	99.3	93.5	99.6
LOGISTICS	98.0	77.2	99.9	77.3	99.9	77.3	99.9	77.3
SATELLITE	100.0	98.1	100.0	98.1	100.0	98.1	100.0	98.1
VISITALL	99.8	99.8	100.0	99.9	100.0	99.9	100.0	99.9
ZENOTRAVEL	100.0	99.9	100.0	99.9	100.0	99.9	100.0	99.9

Table 1: Percentage coverage of PLANPPT and of LPG over T_{set} . For each time frame we highlight in bold the best results.

execution time to find the best solution compared to LPG with an empty seed. Finally, we compare the performances of R-PLANPPT with LAMA, FD, PLANPPT and LPG in the IPC benchmark problems for our domains in terms of coverage, IPCQ and IPCA.

PLANPPT vs LPG

This section compares PLANPPT (using top p sampling) and LPG (initialised with an empty seed) over the T_{set} on coverage and plan length, evaluating different execution times. PLANPPT generates a single solution, while LPG produces multiple solutions in an interval of 5 minutes of incremental quality. Considering that PLANPPT was trained on suboptimal planning instances solved by LPG, this comparison demonstrates the model’s capabilities relative to its teacher, highlighting instances where it can surpass the performances of LPG. Table 1 shows the coverage of PLANPPT and LPG considering different execution time thresholds: 10 seconds, 20 seconds, 1 minute and 5 minutes. Both systems obtain high coverage in under 10 seconds of execution with almost perfect scores on BLOCKSWORLD, SATELLITE, VISITALL and ZENOTRAVEL. Instead, DEPOTS and DRIVERLOG obtain lower levels of coverage due to the high number of states to evaluate in the search, while FLOORTILE’s performances are affected by the numerous dead-ends of the domain. After 20 seconds, we can observe that even DEPOTS and DRIVERLOG obtain high coverages, while FLOORTILE obtains high coverages only after 1 minute for both systems. Finally, considering the time threshold of 5 minutes, LPG obtains higher coverages than PLANPPT having a difference up to 5% (0% in BLOCKSWORLD, 5% in DEPOTS, 2% in DRIVERLOG and SATELLITE, and 0.1% in VISITALL and ZENOTRAVEL). We can observe a notable difference in the LOGISTICS domain where LPG obtains a higher coverage than PLANPPT (98% vs 77%). This domain is very complex for PLANPPT since it belongs to the C3-fragment of the first-order logic. Lastly, we observe that PLANPPT obtains higher coverage than LPG (99% vs 93%) in FLOORTILE, because the LPG search is affected by the numerous dead-ends present in this domain.

Table 2 shows the results of the plan length of PLANPPT and LPG of the problems solved by both systems considering the time ranges of 10 seconds, 20 seconds, 1 minute

and 5 minutes. In general, we observe that, in less than 10 seconds, PLANPPT obtains plans of shorter length; after 1 minute, the two systems are comparable in different domains. Given more time, LPG obtains a better quality in all domains, except for FLOORTILE, where PLANPPT obtains the best plan length. Given that PLANPPT generates a single plan and stops the generation, we expect that LPG obtains shorter plans in the long run because it continues to produce solutions of incremental quality. In BLOCKSWORLD and DEPOTS, within 1 minute, PLANPPT obtains shorter plans of an action. After 1 minute, LPG produces plans of similar length. In DRIVERLOG, we can observe that LPG obtains better plans after 1 minute with a more significant number of actions (5 after 1 minute and 12 after 5 minutes). Overall, in the domain of LOGISTICS, there is always a difference of 3 actions between the systems. In VISITALL, this difference is around 3 to 5 actions in favour of LPG. In ZENOTRAVEL, first PLANPPT has a higher quality, but then LPG obtains lesser and lesser actions up to a difference of 4 actions. In SATELLITE, the two systems obtain the same plan length. Finally, we can observe that in FLOORTILE, PLANPPT generates plans having better quality for each timeframe: a difference of 8 actions before 10 seconds, 11 before 1 minutes, since PLANPPT has already generated all the plans, and 3 after 2 minutes when LPG completes its search. This surprising result in the FLOORTILE domain implies that learning a policy from valid plans can be helpful when the search uses a negative-effect relaxation in the heuristics leading to explore numerous undetected dead-ends.

PLANPPT as initial seed of LPG

In Table 3, we show the integration of PLANPPT and LPG, R-PLANPPT, using different initialisation strategies (partial and complete plan seed) given to the planner LPG to solve the unsolved problem of PLANPPT and comparing against LPG with an empty seed. We show the coverage, plan length, and the average execution time used by LPG to obtain the best solution for each seed. We analyse DEPOTS (356), DRIVERLOG (158), LOGISTICS (1504) and SATELLITE (123) since these domains have at least 100 invalid plans generated by PLANPPT. The execution time of the generation of PLANPPT and the validation (in the partial and complete seed) is added to the LPG computation time

domain	< 10s			< 20s			< 1m			< 5m		
	LPG	PLANGPT	LPG	PLANGPT	LPG	PLANGPT	LPG	PLANGPT	LPG	PLANGPT	LPG	PLANGPT
BLOCKSWORLD	40.4	38.0	39.4	38.2	38.3	38.2	37.5	38.2				
DEPOTS	35.0	33.9	38.8	37.6	37.9	37.7	36.8	37.7				
DRIVERLOG	69.5	67.5	85.9	84.7	80.2	85.6	73.4	85.7				
FLOORTILE	51.5	43.8	76.5	55.8	70.4	58.8	61.9	59.0				
LOGISTICS	19.3	21.7	19.1	21.7	18.8	21.7	18.5	21.7				
SATELLITE	29.8	29.9	29.8	29.9	29.7	29.9	29.7	29.9				
VISITALL	41.7	44.8	40.9	44.9	39.9	44.9	38.9	44.9				
ZENOTRAVEL	41.3	40.3	39.8	40.3	38.3	40.3	36.3	40.3				

Table 2: Plan length of PLANGPT and of LPG over Tset for the problem solved by both systems. For each time frame we highlight in bold the best results.

domain	LPG			R-PLANGPT					
	Empty			Partial			Complete		
	cov	length	time	cov	length	time	cov	length	time
DEPOTS	100.0	55.2	128.9	100.0	56.4	84.9	97.8	54.8	105.9
DRIVERLOG	99.9	127.6	169.6	100.0	128.8	101.1	87.4	128.2	126.6
LOGISTICS	99.5	52.6	104.5	99.8	51.8	86.9	97.3	51.9	89.9
SATELLITE	100.0	40.5	14.8	100.0	40.6	18.7	100.0	40.8	18.2

Table 3: Percentage coverage (cov), plan length (length), CPU time of problem unsolved by PLANGPT and corrected by the complete system R-PLANGPT, using the partial and complete seed strategies. In the first columns we show also the results obtained by LPG without seed on the same set of problems.

to show a fair comparison to the empty seed, which does not require PLANGPT. On the other side, the LPG search time limit is 5 minutes.

From Table 3, concerning coverage, the quality of the empty and partial seeds is comparable, solving most of the problems unsolved by PLANGPT. However, we have a drop in performances with the complete seed. More specifically, we observe that using the partial seed in DRIVERLOG and LOGISTICS slightly enhances the coverage of LPG. On the contrary, in SATELLITE, using a seed is not helpful to LPG. However, using the complete seed, we observe a drop of the coverage in SATELLITE (−2.2%), DEPOTS (−12.5%) and LOGISTICS (−2.2%). LPG struggles to correct very long plans (also with cycles) or plans with multiple violations and, therefore, the useful actions that can be extracted from the plan are insufficient to compensate for this problems. Although individually LPG and PLANGPT cannot compute a valid solution for 20 problems in FLOORTILE, when combined using the partial seed, R-PLANGPT solves these problems, obtaining valid plans exploiting the knowledge of PLANGPT and refining the plan with the LPG search.

Concerning the plan length, the quality of the plans for the 3 seeds is comparable overall, with a mean difference of a single action. For DEPOTS and SATELLITE, the best seed is the complete seed. In the case of DRIVERLOG, LPG without PLANGPT obtains the best length. While for LOGISTICS, the best seed is the partial seed.

Regarding the time to generate a solution, using the partial or complete seeds allows a notable reduction in the heuristic search of LPG to obtain the best solution. We observe that the time between the plan generated by LPG from scratch

compared to the candidate plans of partial seed decreases with a delta from 44s in DEPOTS, 68s in DRIVERLOG, 18s in LOGISTICS. Also in the complete seed, we note a decrease in the execution time, but it is less remarkable than the partial seed, because LPG must correct and remove loops in the candidate plan: 23s in DEPOTS, 43s in DRIVERLOG and 15s in LOGISTICS. The only exception is in SATELLITE, where having a seed for LPG does not lower the time for the heuristic search, but neither increases it. This result shows how introducing a plan seed (which contains helpful information on the plan) helps the planner to carry out a more targeted heuristic search, reducing its execution time.

Therefore, from our results, the partial seed is a better strategy for the combined system R-PLANGPT because the cutting strategy can obtain a helpful prefix seed, which the planner can use to start from. The integration of PLANGPT and LPG produces plans of comparable plan length with a significant decrease in the generation of the solution.

Comparison with SoTA Planners on IPC

In Table 4, we compare the different state-of-the-art classical planners with LPG, PLANGPT, and the combined system R-PLANGPT with the partial seed strategy using a time limit of 5 minutes. It is important to note that the system R-PLANGPT uses different configurations for each domain, so it is a domain dependent approach, and the classical planners considered are domain independent. We used the IPCQuality and IPCAgile metrics. We evaluated the system using the IPC competition problems. Each domain contains 20 planning instances except for BLOCKSWORLD with 35 instances, DEPOTS, 22 and LOGISTICS, 30.

domain	FD		LAMA		LPG		PLAN GPT		R-PLAN GPT	
	IPCQ	IPCA	IPCQ	IPCA	IPCQ	IPCA	IPCQ	IPCA	IPCQ	IPCA
BLOCKSWORLD	27.61	35.00	33.93	34.88	35.00	35.00	34.73	34.20	34.73	34.20
DEPOTS	15.15	14.65	19.45	20.22	18.59	21.85	17.42	14.27	21.40	17.17
DRIVERLOG	18.79	19.06	19.73	18.96	18.59	18.79	17.08	15.95	17.46	16.32
FLOORTILE	2.00	1.46	2.00	1.44	17.36	15.99	19.64	10.39	19.64	10.39
LOGISTICS	26.41	30.00	26.55	30.00	24.99	29.90	14.02	13.05	27.12	22.53
SATELLITE	18.51	20.00	18.64	20.00	19.74	20.00	11.94	11.61	19.68	17.12
VISITALL	19.07	15.46	19.60	12.38	19.46	19.86	16.53	16.41	17.46	16.48
ZENOTRAVEL	18.85	20.00	19.82	20.00	19.22	19.38	15.71	16.01	17.51	17.50
TOTAL	146.39	155.63	159.72	157.88	172.95	180.77	147.07	131.89	175.00	151.62

Table 4: Comparison of IPCQ and IPCA metrics between classical planners (FD, LAMA and LPG), PLAN GPT and R-PLAN GPT with the partial seed using the IPC test set.

Regarding coverage, FD and LAMA solve all the problems except for DEPOTS (77% and 95%) and FLOORTILE (10%). The last instances of DEPOTS are complex because they have many objects. Although FLOORTILE is complex because it contains multiple dead-ends that are not detected by delete-relaxation heuristics. PLAN GPT managed to solve with high coverage in almost all the domains (90% in DEPOTS and 95% in DRIVERLOG and VISITALL) with the exceptions of LOGISTICS (53%) and SATELLITE (70%), providing various invalid plans. In SATELLITE, PLAN GPT struggles when a precondition is bound to an object selected by a previous action which is far away from the current one. For instance, in LOGISTICS, PLAN GPT struggles to correlate the positions of the truck and the object simultaneously. In contrast, in SATELLITE, PLAN GPT struggles to select an instrument with the correct mode to take an image. The best-performing systems proved to be LPG and R-PLAN GPT, which solved all the provided planning problems.

Regarding the IPCQ metric, we observe that R-PLAN GPT reaches the highest score in DEPOTS (21.40), FLOORTILE (19.64), and LOGISTICS (27.12). In the case of FLOORTILE, the results are provided by the solution plans generated by PLAN GPT. In the case of DEPOTS and LOGISTICS, instead, the integration with the plan-repair procedure of LPG produces the shortest plans. LAMA reaches the best quality in DRIVERLOG (19.73), VISITALL (19.60), and ZENOTRAVEL (19.82), while LPG obtains the shortest plan in BLOCKSWORLD (35.00) and SATELLITE (19.74). Finally, PLAN GPT obtains the best quality in FLOORTILE and comparable performances in the other domains.

Regarding the IPCA metric, we observe that all the planners are faster than PLAN GPT and, therefore, than R-PLAN GPT. PLAN GPT is generally slower to compute a solution because it generates only a single solution with higher quality. In SATELLITE, all the planners compute the plans in less than 1 second. In BLOCKSWORLD FD and LPG take less time to compute one solution compared to the other systems. The same behaviour happens in LOGISTICS and ZENOTRAVEL with FD and LAMA. FD is the faster planner in DRIVERLOG (19.06), while LPG obtains the best results in DEPOTS (21.85), FLOORTILE (15.99) and VISITALL (19.86).

In conclusion, considering the IPC test set, we evaluated the ability of learned general policies derived from LLM, combined with a plan-repair planner, to provide enhanced results in various domains and show comparable performances with SoTA planners. More in-depth, the FLOORTILE domain is particularly appealing because planners based on delete-relaxation heuristics struggle to acquire a solution, while R-PLAN GPT obtains perfect coverage.

Conclusions

In this work, we investigated the possibility of integrating a neural solution based on the GPT architecture, PLAN GPT, with a symbolic one, LPG. Firstly, we analysed the comparison between LPG and PLAN GPT, where PLAN GPT showed comparable performance to LPG in some domains in a limited time window and better coverage and quality in the case of FLOORTILE. Then, we proposed our combined system, R-PLAN GPT. We showed that PLAN GPT can give information, as a seed, for LPG and guide the heuristic search to a solution in less time than LPG alone. In fact, R-PLAN GPT corrects the majority of the test problems using the partial or complete seed obtained from the invalid plans generated from PLAN GPT. Finally, we evaluated R-PLAN GPT in the context of the IPC competition against state-of-the-art classical planners with comparable performances. Current and future work includes training PLAN GPT on other challenging domains for planners, integrating the domain knowledge in the training phase, and overcoming the current limits due to the maximum number of objects in the vocabulary and the length of the context window.

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