# Optimising Plans using Genetic Programming

C Henrik Westerberg and John Levine

CISA, University of Edinburgh,
80 South Bridge, Edinburgh, EH1 1HN
{carlw,johnl}@dai.ed.ac.uk
http://www.dai.ed.ac.uk/homes/carlw/

**Abstract.** Finding the shortest plan for a given planning problem is extremely hard. We present a domain independent approach for plan optimisation based on Genetic Programming. The algorithm is seeded with correct plans created by hand-encoded heuristic policy sets. The plans are very unlikely to be optimal but are created quickly. The sub-optimal plans are then evolved using a generational algorithm towards the optimal plan. We present initial results from Blocks World and found that GP method almost always improved sub-optimal plans, often drastically.

## 1 Introduction

Finding any plan for planning domains is often a difficult task, but we are often more interested in the even harder task of finding optimal or near optimal plans. The current fastest planning systems use heuristics and hill-climbing techniques. However, no heuristic is perfect and plans found in this way are often sub-optimal, in the sense they use more actions to achieve the goal state than are necessary.

We present a domain independent technique, based on Genetic Programming (GP) that attempts to optimise linear plans. The system accepts a seed of plans from which to optimise. This seed could be produced by a current planning system or plans made using heuristics. The amount of computational effort to devote to the optimisation stage can also be set by the user by setting various parameters of the system. The GP algorithm also has *anytime* behaviour, and could return the best current plan at any time during the run.

Using the Genetic Planning optimisation system, we experimented on two domains: Blocks World Domain, and the Briefcase Domain [6]. The Blocks World problems were kindly donated to us Jose Ambité. The results of the Briefcase Domain have been omitted due to space restrictions. During the experimentation we were looking for how much the initial plans could be shrunk depending on the type of heuristics used, the behaviour of the system as it operated, and what changes we could make to the current system to improve its ability.

## 2 Plan Optimisation via Genetic Programming

We present here one possible implementation of using Genetic Programming as a linear plan optimiser. We used two different hand-encoded *policy sets* for the Blocks Domain in order to seed the initial population with correct but overly long plans. We then used a generational algorithm with standard genetic operators in order to optimise those plans [2]. We based our work on a previously implemented generational algorithm for linear planning [8].

The following implementational details have many alternatives, and are not fixed. One of the strengths of our approach is that the Fitness Function and Simulation stage can be altered to look for different cost aspects besides the simplistic plan length.

**Plan Representation:** Plans are represented as linear lists of sequential, instantiated, atomic actions. Each atomic action contains one operator and its arguments.

**Simulation:** The simulation stage takes an individual or plan and then attempts to apply all the actions. During the simulation stage various attributes of the plan can be recorded such as how many actions there are in the plan and what effect the plan had on the initial state. This information can then be used as input by the fitness function.

**Fitness Function:** The fitness function takes the output of the simulation stage and prescribes a fitness value to individual based on the information given to it. In the case of this system the fitness function has two parts. The first part says whether the plan achieves all the goals not. The second part is the number of actions in the plan and is used as a tie-breaker in tournament selection.

### 2.1 Genetic Operators

There is a large choice of genetic operators to be used during the optimisation stage. We have taken the position of keeping things simple and stochastic. One alternative is to implement domain specific operations, such as rewrite rules, for optimising particular domains.

**Crossover:** This system implements 1-point crossover.

**Reproduction:** This is the simplest operator and it copies the selected parent into the next population.

**Shrink Mutation:** This type of mutation simply deletes a randomly selected action from the parent.

**Move Mutation:** This type of mutation moves a randomly selected action to a new randomly selected position.

Mutations occur on children created by either reproduction or crossover. The probabilities of the operators occuring are set by the user. The implementation presented here is based on an existing system and is by no means optimal for generating optimal plans. Improvements that can be made to it and some are suggested in Section 5.

## 3 Policy Set Planning in Blocks World

The Blocks World Domain is important because it is one of the benchmarking domains used to compare different planners. Blocks is also important historically as one of the original planning problem domains. In addition, finding optimal plans for Blocks World problems is known to be NP-hard [3]. We also chose the Blocks World Domain as a fast domain specific planning algorithm that produces optimal plans exists for it, called BWOPT [7].

Our system uses hand-encoded policy sets to produce entire populations filled with correct but suboptimal plans. A GP optimising system probably works better if the initial populations is diverse. To achieve this the policy sets were interpreted non-deterministically.

The policy sets generally function like this. The rules within each policy set are tested sequentially. For the current rule the current world state is examined and all actions that could operate on that state in accordance with the rule are discovered. At that point, one of the actions is selected randomly and added to the new plan. The current world state is updated and the formation of the plan continues until all goals in the goal state are achieved. If the rule allows for no actions, the next rule in the rule set is used and if one rule fires then the other rules are ignored.

There are several types of policy sets that can characterised by how easy it is to optimise the resulting plan. The three types we are interested in here are:

- **Optimal Policy Sets:** These policy sets always produce optimal plans, for any problem in the domain.
- $\mathcal{DM}$**-Optimal Policy Sets:** These policy sets always produce plans where the optimal plan can be discovered by only deleting and moving actions:
  - $\forall c \in C \rightarrow c^* \in \mathcal{DM}(c)$ where $C$ is the set of all plans constructed by the policy set, $c^*$ is the optimal plan and $\mathcal{DM}(c)$ is the set of all plans which can be created by only moving and deleting actions in $c$.
- **Satisficing Policy Sets:** These policy sets produce correct plans but may produce plans that are missing actions which the optimal plan would need.

**Policy Set 1**

1. Discover all actions achieving well placed blocks *or*
2. Find all actions moving movable non-well placed blocks to a new location

**Policy Set 2**

1. Discover all actions placing movable blocks onto the table *then*
2. Discover all actions achieving well placed blocks

A well placed block is one which no longer has to move, as it is in its target location and all blocks below it are well placed. A movable block is one which is not underneath a block or already on the table. Policy Set 1 does not scale very well for larger problem instances: when the first rule provides no actions,

it "wanders" around at random until the first rule starts to succeed. The first policy set belongs in the class of *Satisficing Policy Sets*. The second policy set unstacks all the blocks and then stacks the blocks back up in the right order. This policy set belongs in the class of $\mathcal{DM}$*-Optimal Policy Sets*. This was the policy set Ambité used in PbR [1].

## 4 Experimental Results

Each experiment was done using the parameters shown in Table 1. We performed 25 runs for each problem, and again for each policy set. We experimented using 50 Blocks World problems. During the run we recorded the average number of actions in the first best individual (from the seeding stage) and the average number of actions in the last best individual.[1] Each point on the x-axis represents a single problem. The order of the problems is first by blocks size, and then by average length of the first best individual.

| Parameter | Setting |
|---|---|
| Termination | Maximum number of generations is 1000 |
| Population Size | 20 plans |
| Initial Length | Maximum 400 actions |
| Tournament Size | 2 |
| Maximum Plan Size | 1000 actions |
| Genetic Operators | 5% crossover and 95% reproduction |
| Shrink Mutation | Applied to 5% of children, 1 delete |
| Move Mutation | Applied to 5% of children, 1 move |

Referring to Figure 1, Policy Set 1 shows significant but not complete improvement in plan length after 1000 generations. An additional termination criterion was implemented, called "no change" which stops a run if there is no change in fitness after X generations. We repeated the experiments setting X to 5000. Taking the 30 block problems as an example, these were shrunk down to the 50 action mark.

Referring to Figure 2, some improvement could be made to the initial plan within 1000 generations even though the initial plans were reasonably close to optimal. The no change results managed to to shrink the plans a little more, and taking the 30 block problems again, these were shrunk down to around the 40 action mark. This difference between the two policy sets is returned to in the conclusions.

Also included in Figure 2 are results from FF [4]. We ran the 3 plans produced for the 30 block problems using the no change setup. The results are indicated with the triangles, and show significant shrinkage.

[1] CPU times are not considered as the system was implemented using Java, and running on Solaris. System times can be dramatically improved if written for C under Linux.

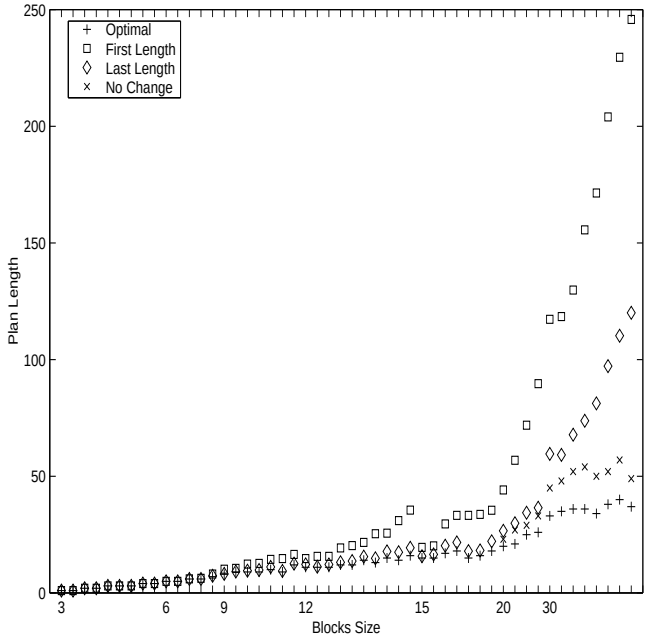


**Fig. 1.** Policy Set 1 on the Blocks World Problems

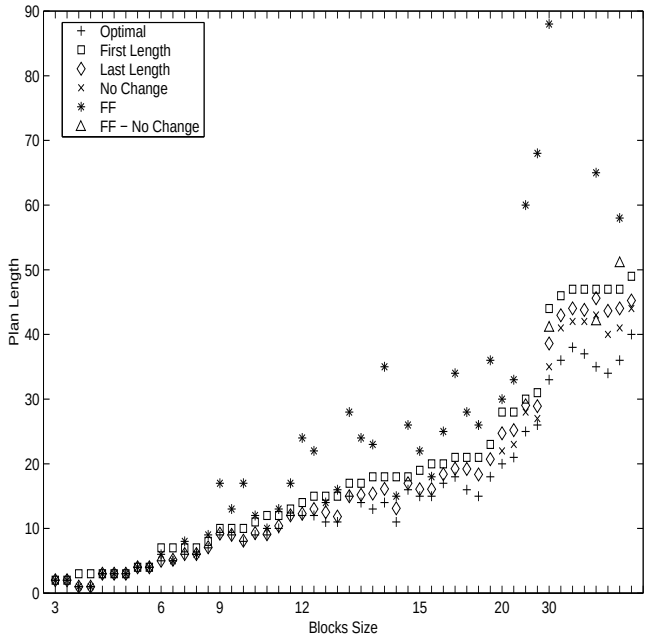


**Fig. 2.** Policy Set 2 on the Blocks World Problems

## 5 Conclusions and Future Work

The most successful current planners use heuristics and hill-climbing techniques. However, since no heuristic is perfect, such techniques often produce suboptimal plans, as in the case of FF. We have presented a linear plan optimisation technique, based on GP, which attempts to optimise plans. The system is domain independent, and can be used as addition to existing linear plan synthesisers. The system uses simple operations like mutation and crossover in order to accomplish this. The system could optimise plans to varying degrees of success depending on where the plans came from. A tentative conclusion is that plans made by $\mathcal{DM}$-Optimal policy sets can be optimised further towards the shortest plan than those made by satisficing policy sets.

We want to improve on the Generational framework suggested here for plan optimisation. There are a number of alternatives, such as a steady state algorithm, that we could adopt to decrease the length of the resulting plans. Also the system could be redesigned to optimise single plans.

We also want to broaden the definition of optimal to mean more than just plan length. More complicated domains with time, plan execution by an agent, resources, and so on, would make plan optimisation a multi-dimensional problem. It seems plausible that a genetic technique would be suitable for this kind of optimisation due to the way fitness functions and simulation are used.

## References


1. Ambité, J.L., Knoblock, C.A.: Planning by Rewriting: Efficiently Generating High-Quality Plans. In Proceedings of the 14th National Conference on Artificial Intelligence, Providence RI USA, 1997
2. Banzhaf, W., Nordin, P., Keller, R.E., Francone, F.D.: Genetic Programming: An Introduction. San Francisco CA, Morgan Kaufmann Publishers, 1998
3. Bylander, T.: The computational complexity of propositional STRIPS planning. In Journal of Artificial Intelligence, 69(1-2):165-204, 1994
4. Hoffmann, J., Nebel, B.: The FF Planning System: Fast Plan Generation Through Heuristic Search. In Journal of Artificial Intelligence Research, Volume 14, Pages 253-302, 2001
5. Koza, J. R.: Genetic Programming. The MIT Press, Cambridge MA USA, 1992
6. Muslea, I.: SINERGY: A Linear Planner Based on Genetic Programming. In Proceedings of the 4th European Conference on Planning, pages 312-324, Toulouse France, Springer, Sep 1997
7. Slaney, J., Thiébaux, S.: BLOCKS WORLD TAMED Ten thousand blocks in under a second. Technical Report TR-ARP-17-95, Automated Reasoning Project, Australian National University, Oct 1995
8. Westerberg, C.H., Levine, J.: "GenPlan": Combining Genetic Programming and Planning. In Proceedings for the UK Planning and Scheduling Special Interest Group, Milton Keynes UK, Dec 2000
9. Westerberg, C.H., Levine, J.: Investigation of Different Seeding Strategies in a Genetic Planner. In Applications of Evolutionary Computing, Proceedings of EuroGP, pages 505-514, Lake Como Italy, Springer, Apr 2001