A Combinatorial Genetic Algorithm for the Configuration of the 2dF/AAOmega Spectrograph at the Anglo-Australian Observatory

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ABSTRACT

To help unravel the structure of the universe, astronomers have developed systems which observe large clusters of objects at the same time. One such system is the 2-degree field spectrograph at the Anglo Australian Observatory. This system uses 400 fibres which can observe and measure the spectra of up to 400 astronomical objects in parallel. These optical fibres are positioned by a robotic arm. During placement, complex fibre entanglements often occur, reducing the overall efficiency of the system. This work aims to develop a combinatorial genetic algorithm which can help increase the efficiency of these systems by evolving sequences of fibre re-positionings. We present an integer-based representation developed for this GA which has the ability to automatically satisfy hard constraints during sequence seeding, mutation and recombination. We also present some initial results in re-configuring fibre placements.

Categories and Subject Descriptors

I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Search, Scheduling.

General Terms

Algorithms

Keywords

Scheduling optimisation, astronomical scheduling, genetic algorithm, permutative representation, constraint handling.

1. THE 2dF SYSTEM

Over the last few decades astronomy has shifted to a focus of the observation of large numbers of objects for surveys which can help unravel the structure of the universe. This has led to the development of systems which can measure the properties of hundreds of astronomical objects in parallel. One of the major examples is the two degree field (2dF) [1] system at the Anglo Australian Observatory (http://www.aao.gov.au/AAO/2df) (AAO). The parallel observations are achieved by using 400 retractable fibres with small prisms on each end placed by a robotic arm onto an observation plate.

During an observing session, the array of fibres has to be re-configured from one set of object coordinates to another. The problem from an algorithmic point of view is to determine the order of placement, and the order of movement to the next set of astronomical objects, to maximise the number of fibres used for observing, along with minimising the time needed to re-configure the fibres on the 2dF instrument. As fibres are placed on the drum, a complex entanglement of fibres results - something which is difficult for classical approaches to solve efficiently. This type of problem where we wish to optimise an ordering of events fits into the family of combinatorial optimisation problems, where genetic algorithms have proved to be very successful.

The current approach to configuring the 2dF system involves two separate steps. Firstly the astronomer prepares a list of objects for observation, and the `configure` package is used to allocate fibres to a maximum number of targets, while minimising fibre overlaps, and satisfying constraints; each fibre and button has angular and length limitations and so not all targets are accessible to each fibre. To move to a new field configuration `delta` is used: fibres are picked up and moved to new target positions, or, more often, firstly parked (moved to the edge of the drum), then moved to their final location. This whole process often forms a time bottleneck, and hence we are left with the question of how to optimise the entire observing process through maximising the target allocation while minimising the change over time.

2. 2dF CONFIGURATION GA

The problem definition for the real-world 2dF involves the allocation for 400 fibres along with more complicated constraints. For the purpose of this work a simpler definition is used to demonstrate the applicability of a GA approach:

Problem Definition. Given two field configurations S_1 and S_2 of $N = 40$ positions of real astronomical objects, find the ordering of fibre moves to move from an all fibres parked configuration to field S_1, and then move fibres to S_2 with the aim of maximising the number of fibres moved
Subject to:
A. Each fibre cannot be moved more than $\pm 14.32^o$ away from its normal at the edge of the drum, and **B.** No parking of fibres allowed.

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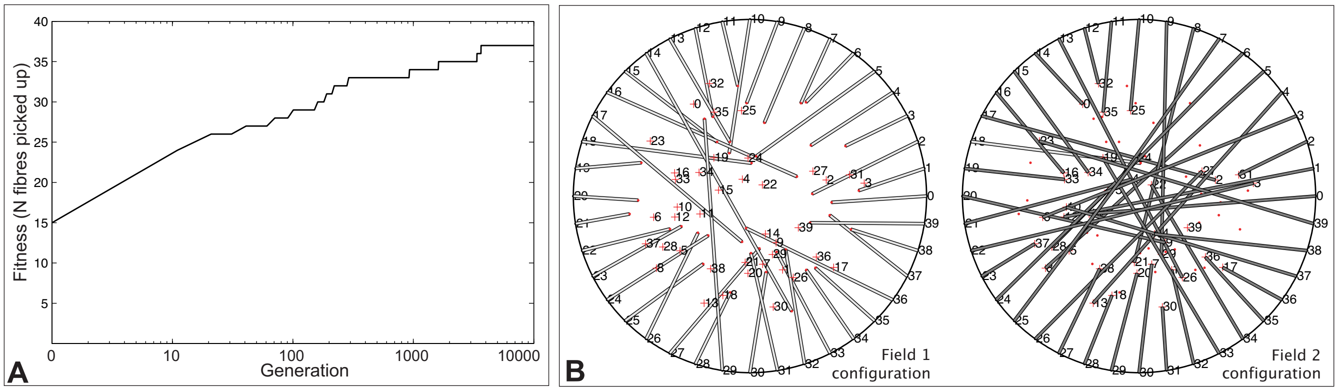

Figure 1: A. Change of fitness over time of a typical GA run for an $N = 40$ case. The GA rapidly evolves to designs with more than $N/2$ moves, and eventually converges to a ceiling value of 39 after 10,000 generations. B. Optimal sequence with 39/40 fibres moved. The Field 1 configuration shows the fibres after they have been positioned at the sources S_1. The Field 2 configuration shows 39 fibres (dark gray) which have been moved to their new S_2 positions, where only Fibre 18 (light gray) could not be picked up due to overlaps.

The GA aims to optimise both fibre movements and fibre interchanges simultaneously, which is currently done separately using `configure` and `delta`. A direct permutation representation with integer variables is used to encode the ordering of fibre placement of fields S_1, S_2, along with the correspondence between fibres and sources. This is represented using a *F-S* (Fibre-Source) listing, $F_{1,i} \rightarrow S_{1,i}$, $F_{2,i} \rightarrow S_{2,i}$ where $i \in [1, ..., N]$. An example with $N = 5$ is

```
F1 [0,1,2,3,4] F2 [2,4,3,0,1]
S1 [1,4,3,2,0] S2 [0,4,3,2,1]
```

which is read as an instruction set *Pick up and move Fibre 0 to Source 1 of Field 1*, *Pick up and move Fibre 1 to Source 4 of Field 1*, etc.

Although the ordering of the fibre placements is not constrained, the mappings from *F-S* are limited due of the fibre angle limits. Operators were developed which can initialise, mutate and recombine feasible individuals. Feasible individuals are initialised through the use of *Constrained Fibre* and *Constrained Source* listings, which also allow us to ascertain if a particular set of sources or field positions is incompatible with the hard constraints. Candidate solutions are then randomised by applying multiple instances of the mutation operator. Mutation can either swap complete *F-S* pairings, or swap the sources of two random fibres. This latter operator ensures that both fibres can see the relevant (swapped) sources. Recombination is a variant of the *order crossover* [2] operator. It is modified to ensure that the hard constraints are maintained, and that as much information about *F-S* mappings is transferred from parent to child. Finally, the candidate solutions are evaluated using a 2dF simulator. It evaluates the number of fibres which can be moved to new positions before fibre overlaps prohibit further movement.

3. DISCUSSION

The 2dF-GA was run for a total of 20,000 generations using a population size of 50 parents and 50 children. A random initial population was used and elitist selection took place at each generation, where $k = 2$ tournament selection was used to select parent pairings to breed children. An example of fitness evolution over time is shown in Figure 1A. Similar results are obtained over multiple runs using different random seeds. The GA typically converged to 30 successfully moved fibres within 1000 generations. None of the runs achieved a perfect 40 for this particular object position data set. Sequences with 37 or 38 fibre moves within 10,000 generations were evolved but the seemingly ceiling value of 39 was evolved at approximately 20,000 generations. Overall, solutions tended to be multi-modal - that is different genotypes often map to the same fitness value. The GA tended to evolve a simple ordering where it minimised the overlaps that occurred as a result of the first set of moves, and then move to a more complicated set of overlaps (Figure 1B). The ability to also satisfy constraints automatically solved the problem of having to deal with the hard constraints using other, less efficient methods such as penalty schemes.

Currently the GA does not use parking. Its inclusion is expected to greatly help the convergence to better designs (e.g. parking Fibre 18 in Figure 1B would result in a perfect solution) - it might be impossible to move from one configuration to another without parking at least one fibre. It is expected real-world solutions will be a trade-off between the number of parks and targets achieved. Improvements in recombination and mutation, along with the proper encoding of parking into the genotype will help scale the algorithm up to $N = 400$ fibres for use on the real-world system. The final step is the optimisation of fibre moves for multiple sets of object positions representing a whole night of astronomical observations.

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4. REFERENCES

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