Application of Evolutionary Algorithms to Net Present Value Optimisation of Open Pit Mine Scheduling

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Introduction to the Scheduling Problem

- Open pit mine scheduling is one of the areas where an engineer can improve significantly the value of a mining project.
- Scheduling is generally focused on the sequencing of excavated material between different locations of interest within a mining site.
- There are different types of schedules depending on the time horizon and resolution, such as life of mine, annual, monthly and weekly plans.
- Schedules are commonly optimised to maximise their net present value – the value being calculated by applying a number of associated costs (mining, hauling, processing, etc.) and the revenue of the produced commodities.

NPV Schedule Optimisation Methods

- A special and very common objective function for schedule optimisation is the **net present value (NPV)** of the schedule.
- Traditional optimisation algorithms for mine scheduling are mostly based on some form of linear, dynamic or mixed integer programming and are commonly quite time consuming to setup.
- Evolutionary methods such as genetic programming have been tried by various researchers in the past.
- **Maptek Evolution**, is the first commercial product based on evolutionary algorithms for open pit mine scheduling.

Evolutionary Algorithms

- An evolutionary algorithm (EA) is a subset of evolutionary computation, a generic population-based metaheuristic optimisation algorithm.
- An EA uses mechanisms inspired by biological evolution, such as reproduction, mutation, recombination, and selection.
- Candidate solutions to the optimisation problem play the role of individuals in a population, and the fitness function determines the quality of the solutions.
- Evolution of the population then takes place after the repeated application of the above operators.
- Evolutionary algorithms often perform well approximating solutions to all types of problems because they ideally do not make any assumption about the underlying fitness landscape.

Evolutionary Algorithm Process

1. Generate the initial population of individuals randomly. (First generation)
2. Evaluate the fitness of each individual in that population (time limit, sufficient fitness achieved, etc.)
3. Repeat the following regenerational steps until termination:
   - Select the best-fit individuals for reproduction. (Parents)
   - Breed new individuals through crossover and mutation operations to give birth to offspring.
   - Evaluate the individual fitness of new individuals.
   - Replace least-fit population with new individuals.

Maptek Evolution

evolutionary algorithms – cloud based

- It is one of the most recent scheduling systems commercially available and probably the only one based on evolutionary algorithms.
- As it is focused to open pit mining, it is more straightforward to setup as the user doesn't need to deal with block exposure rules.
- It is also a block scheduler – the units considered for scheduling are regular blocks derived from the resource block model.
- There is no spreadsheet holding the reserve information – the block model itself is imported and manipulated for scheduling purposes.

Maptek Evolution

evolutionary algorithms – cloud based

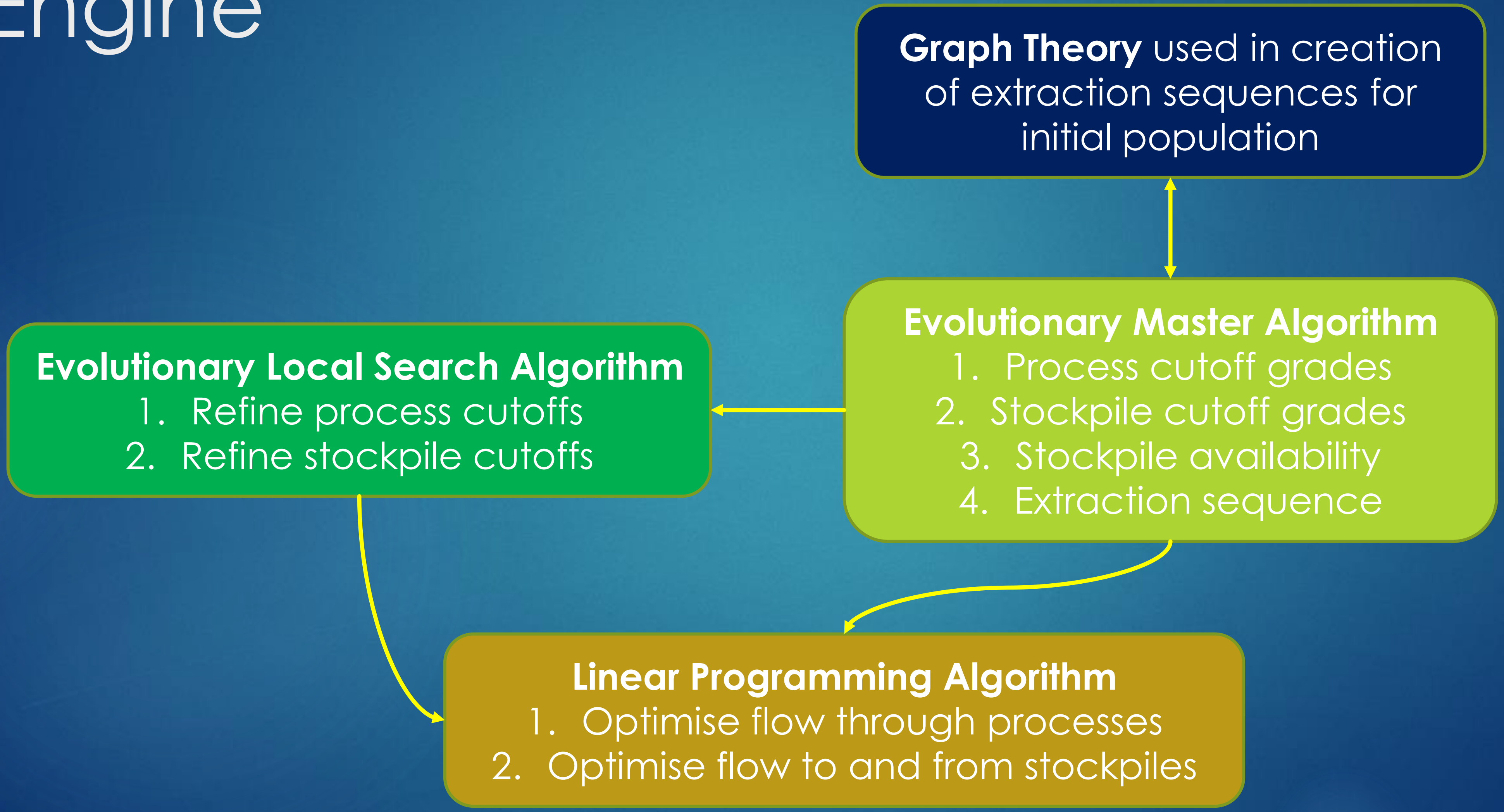
- Blocks need to be flagged in advance relative to modelled pushbacks or phases of the overall pit.
- The scheduling and optimisation functionality of Evolution is cloud-based – the block model and schedule setup are transmitted to a cloud facility for processing.
- The scheduling solutions found are transmitted back to the user for further analysis and approval.
- Optimisation is based on a hybrid system consisting of a core evolutionary algorithm, a local search evolutionary algorithm and a linear programming algorithm, each with different responsibilities.

Maptek Evolution Optimisation Engine

The engine consists of an effective hybridization of two evolutionary and one classical optimisation algorithm:

- **Master evolutionary algorithm**
  - Exploring process cut-off grade search space.
  - Exploring stockpile cut-off grade search space.
  - Exploring extraction sequence search space.
  - Manage Local Search Evolutionary algorithm.
  - Manage Linear Programming Algorithm.
- **Local search evolutionary algorithm**
  - Exploring the immediate neighbourhood of process and stockpile cut-off space for a given extraction sequence.
- **Linear programming algorithm**
  - Optimises the flow of material through available processes.
  - Responsible for optimal reclaim strategy from stockpiles.

Maptek Evolution Optimisation Engine



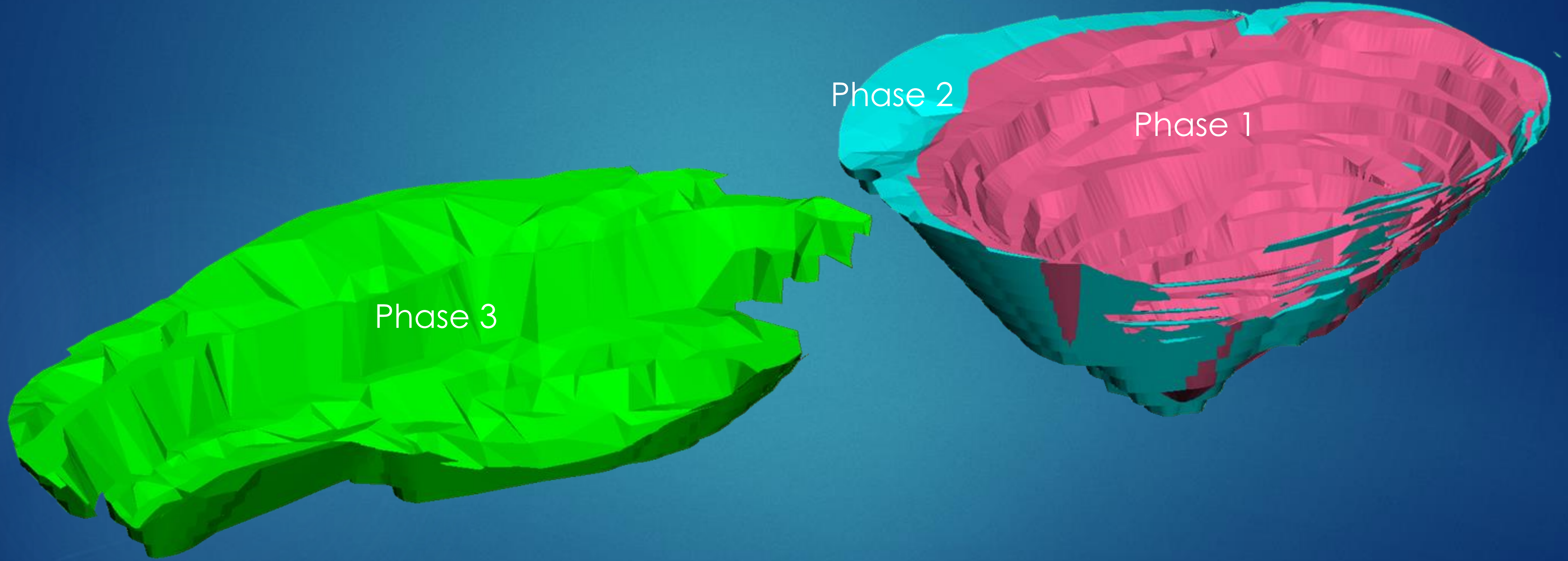
Maptek Evolution Optimisation Steps

1. Creation of the initial population including a geometrically correct extraction sequence. (**Graph Theory**)
2. Calculation of the fitness of each individual and ranking of the population based on fitness (NPV). (**Master and Local Search Evolutionary Algorithms**)
3. Iteration through successive generations by generating an offspring population where each child competes with the parents for the privilege to progress to the next generation. (**Master Evolutionary Algorithm**)
4. The master algorithm calls on the secondary local search algorithm to boost the best individual found so far, by manipulating the threads through cut-off grade space whilst keeping the extraction sequence static. The improved individual is then sent back to the master where it replaces or upgrades its old self (analogue to exploring the local neighbourhood). (**Local Search Evolutionary Algorithm**)
5. Steps 2 to 4 are repeated until no improvement in NPV is registered, in other words when the population loses diversity and converges on a single high quality NPV.

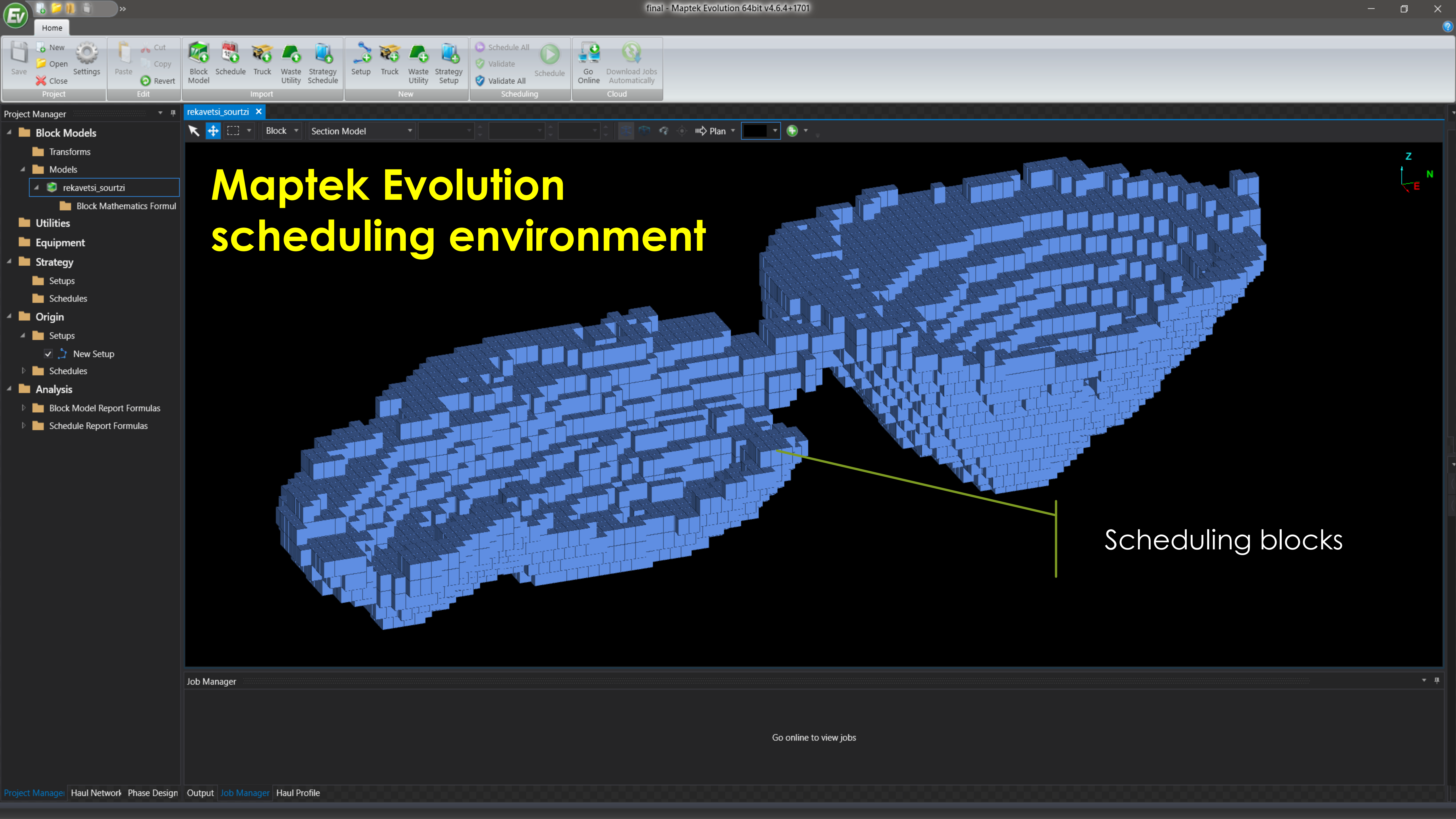
Case Study Details

- The case study is based on two adjacent nickel open pit mines from central Greece were selected, which are mined in parallel.
- They have both been operational for some time.
- The material left for mining in the first is split in two phases while the second is considered as a single phase.
- The corresponding solid models of the three phases were used to flag the blocks in the resource block model for Evolution.
- Appropriate reserve fields were calculated to ensure that all necessary quantities and qualities are used in scheduling.

Case Study – Open Pits



MAPTEK Vulcan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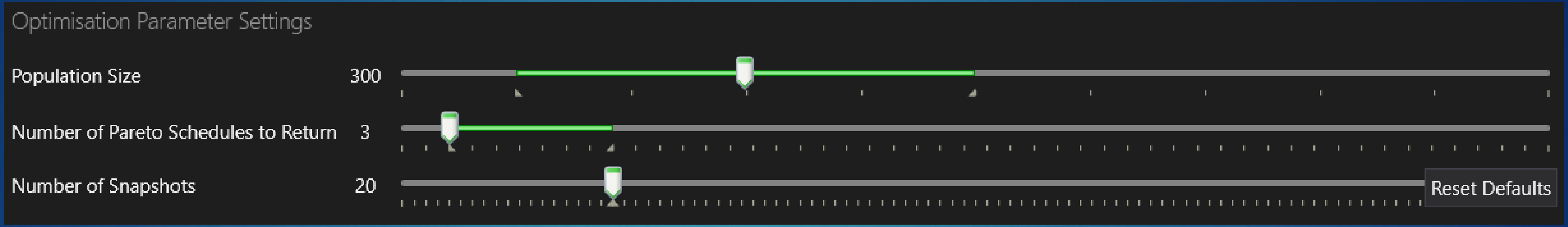
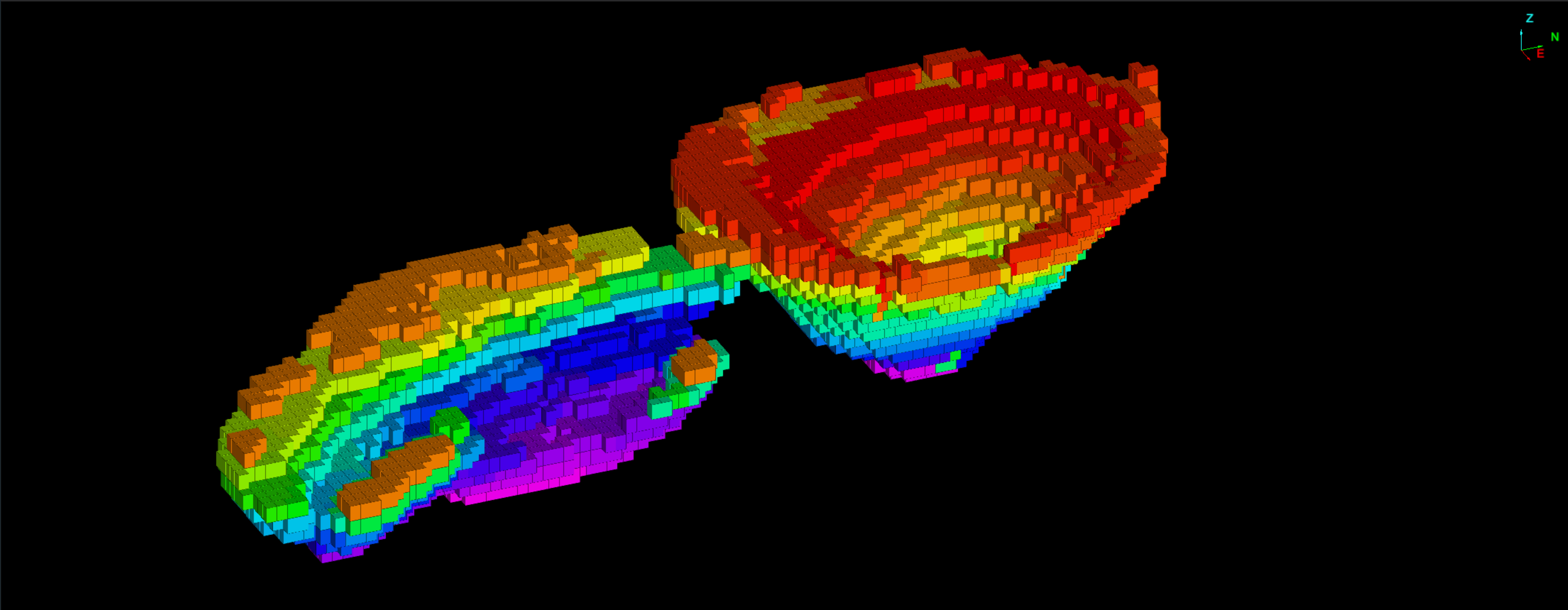
Optimisation parameter settings

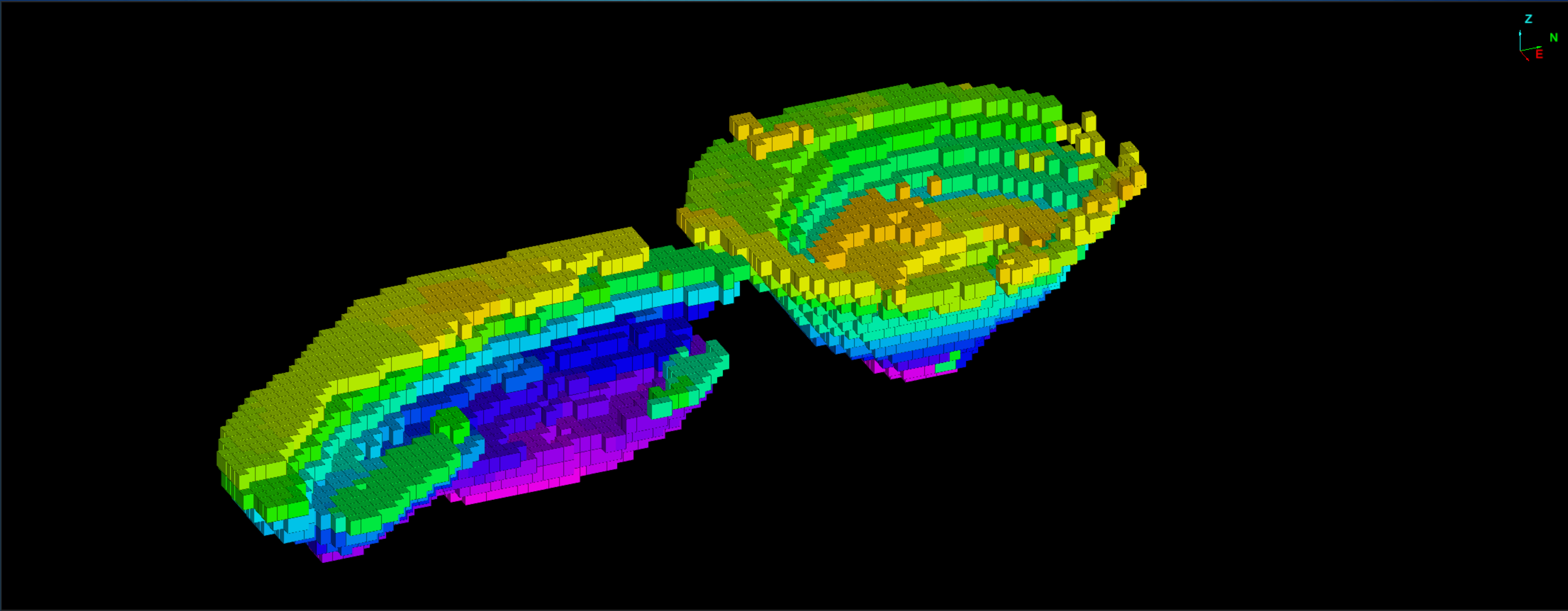


- **Population Size:**
  - This setting determines how many sequences are used throughout the optimisation.
  - The larger the population the higher the quality and more consistent the result will be.
  - However, this increase in quality and consistency comes at an increase in processing time (quality-time trade-off).
- **Number of Pareto Schedules to Return:**
  - This setting controls how many schedules the user wants Evolution to return.
  - When a multi-objective optimisation is executed, the trade-off front can grow very large (a sizeable fraction of the population).
  - Evolution uses this setting to run a clustering algorithm over the trade-off front to find representative schedules to return.
  - If less schedules is present on the front, than specified, all schedules on the front are returned.
- **Number of Snapshots:**
  - This setting is used within the blending objective to determine how many units the block sequence is subdivided into within the blend objective.

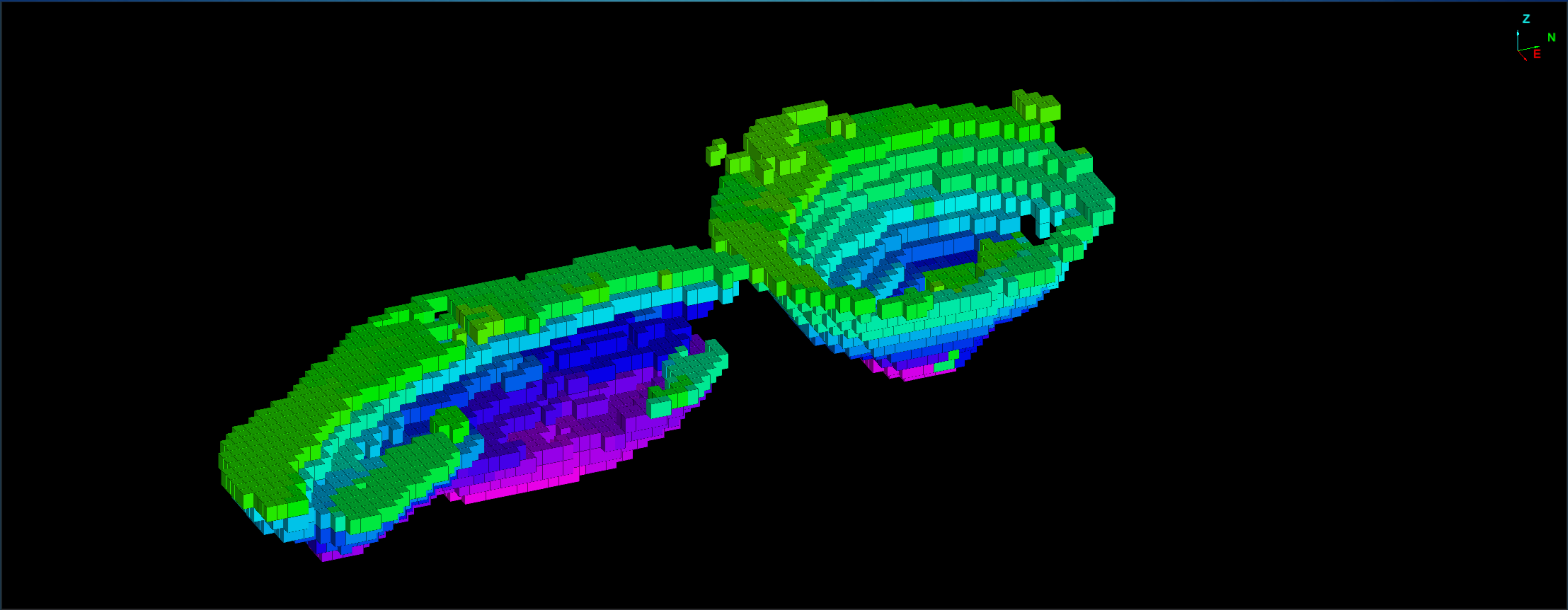
Before Scheduling



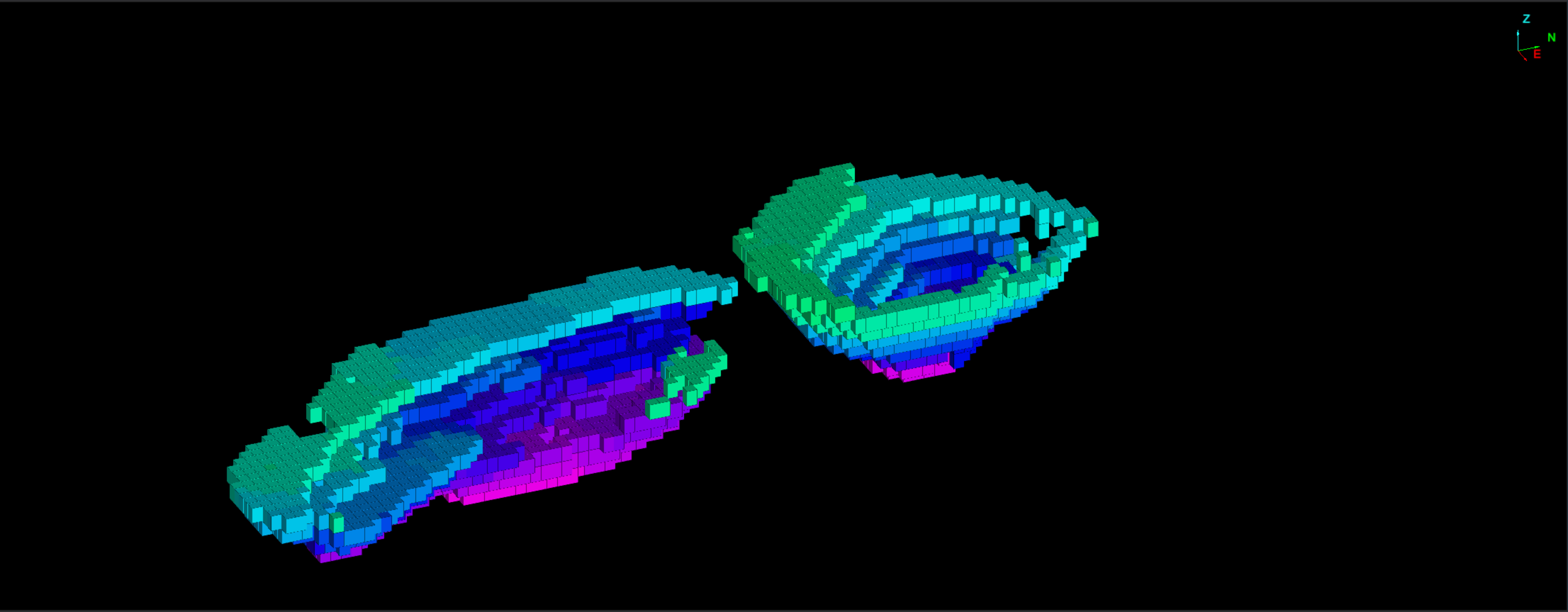
After period 10



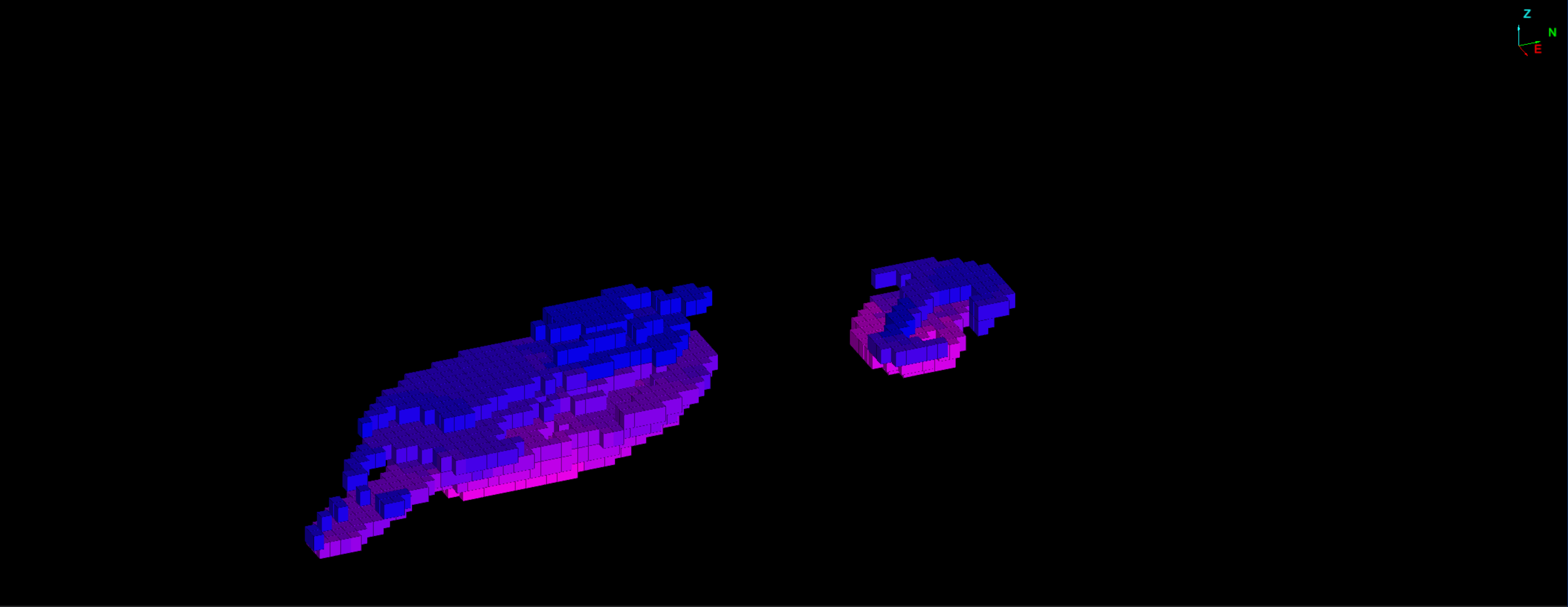
After period 20



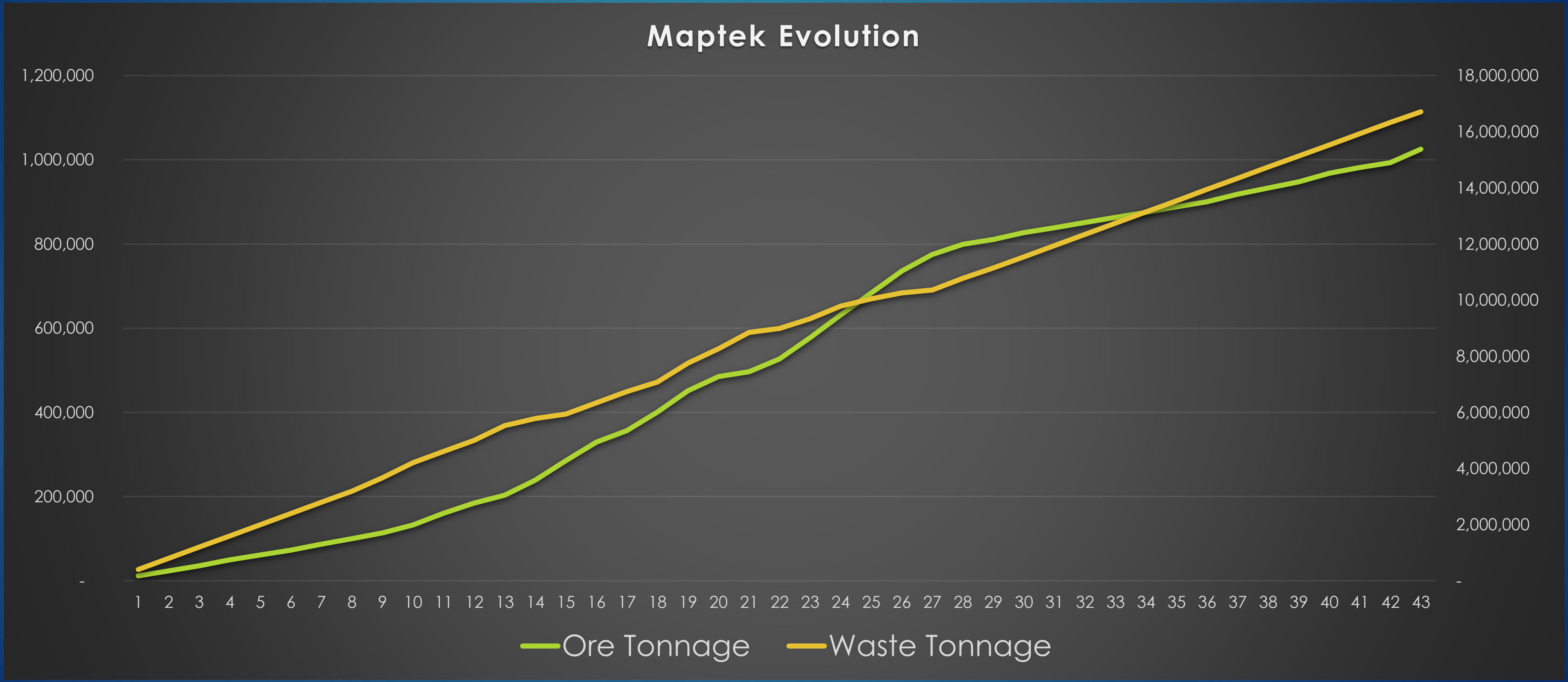
After period 30



After period 40



Optimised Schedule



Cumulative figures

Conclusions

- This paper discusses the application of one of the first commercial products based on evolutionary algorithms to open pit mine scheduling, called Maptek Evolution.
- The open pit planning tools provided work off a single dataset to generate strategic scheduling, medium and long term planning across the life of an operation.
- Evolution consists of a hybrid system with two evolutionary and one classical optimisation algorithm.
- The study produced useful conclusions for the effectiveness and robustness of the evolutionary optimisation approach.
- Maptek Evolution proved that it can match the effectiveness of traditional optimisation algorithms.

Thank you for your attention!