

Stochastic Methods for Control in Air Traffic Management

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Motivating Task

Terminal Manoeuvring Area trajectory planning required:

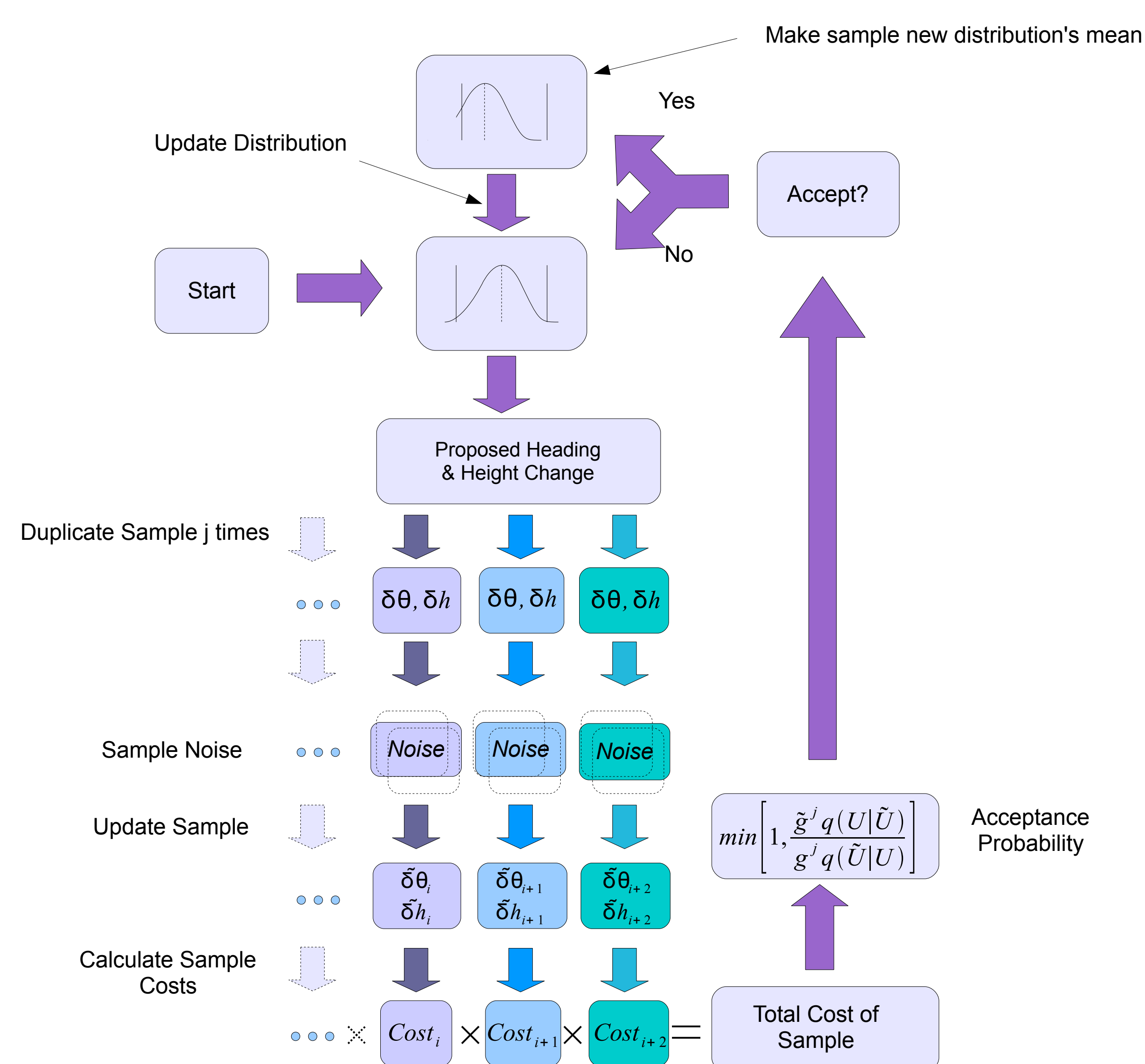
- 3D manoeuvres needed.
- Large numbers of aircraft.
- High level of computational capacity allowable.
- Uncertainty present from a number of sources.

Model Predictive Control

- Define a finite horizon sum-of-stage-cost objective.
- Receding horizon online constrained optimisation.
- Solve till the horizon then execute one step of the plan.
- Move the horizon forwards and repeat the process now with the updated information on what happened in the previous step.

Markov Chain Monte Carlo (MCMC)

- Samples from probability distributions constructed via a Markov Chain with the desired distribution as an equilibrium.
- The state of the chain after many iterations of updates is sampled to yield a near optimal control action.
- Penalty functions on the cost are used instead of hard constraints to reduce re-sampling.



MCMC algorithm iterative updates for a single step of MPC

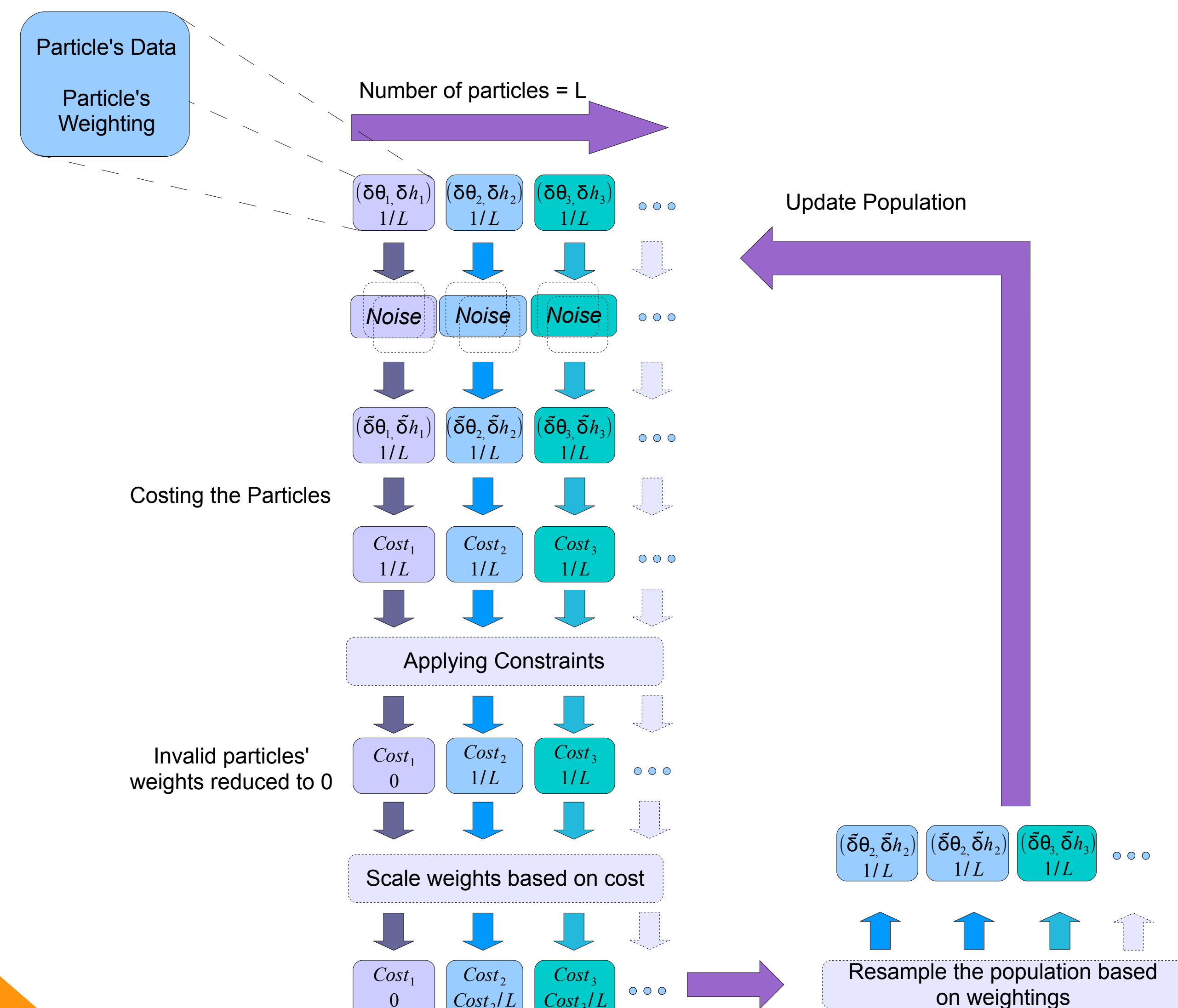
Stochastic Optimisation Methods

- Used to solve the optimisation problem at each MPC time step.
- Allows for modelling uncertainty.
- Able to cope with non-linear dynamics, constraints and an objective function.
- Based on large numbers of individual simulations to sample possible outcomes.
- Often tied to Monte Carlo methods and used for financial market simulation.
- Many different methods though previous ATM work has focused on Sequential Monte Carlo (SMC) and Markov Chain Monte Carlo (MCMC)

Sequential Monte Carlo (SMC)

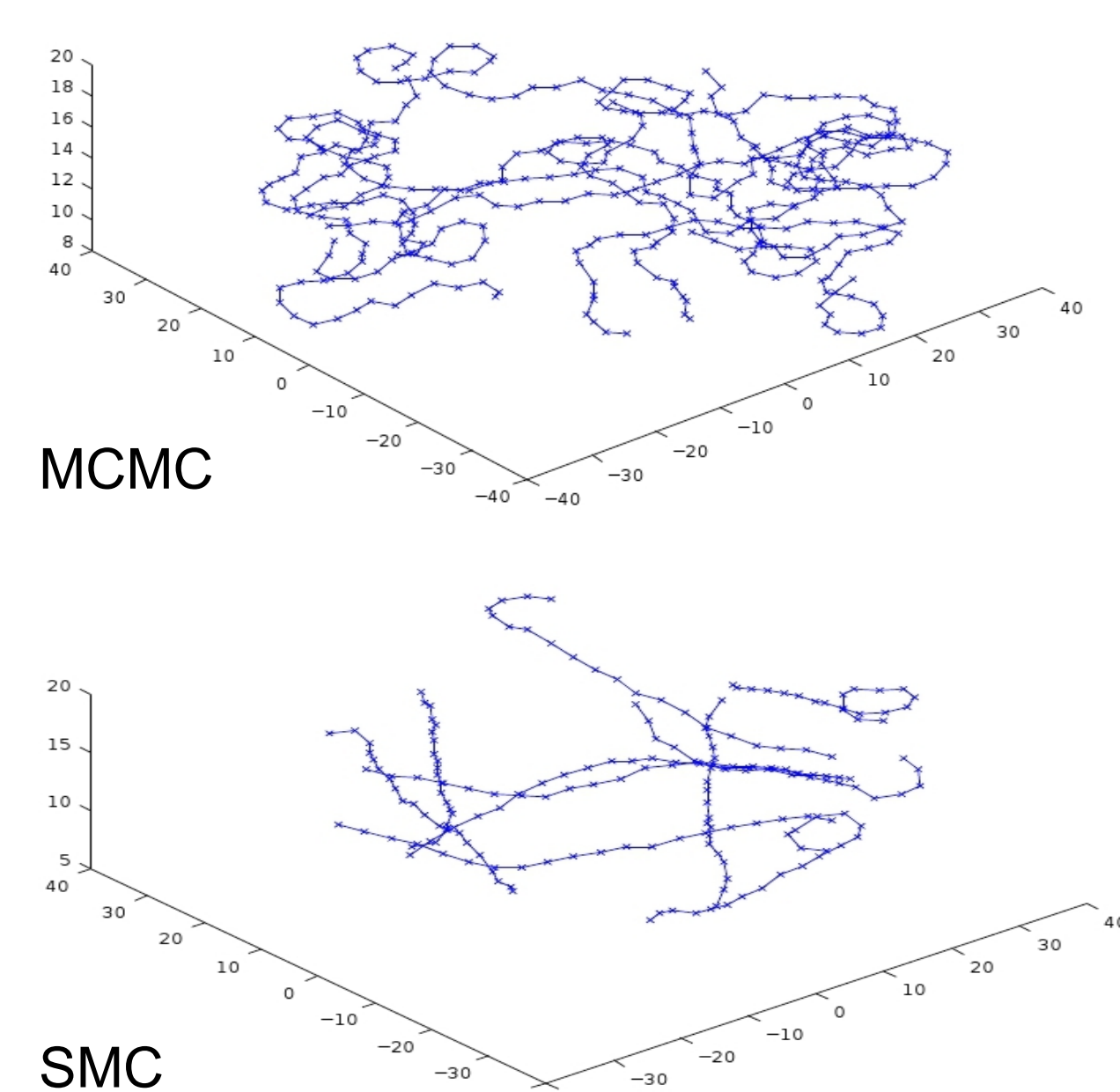
- Often better known as particle filtering for model estimation and signal processing.
- Has a population of particles each containing a potential control action and a weighting on the particle.
- If a particle's control action would break a constraint the particle's weighting is set to 0.
- The population is iteratively re-sampled based on the particles' weighting and cost.
- Final control action chosen as the mode of the particles' population.

Format of Particle

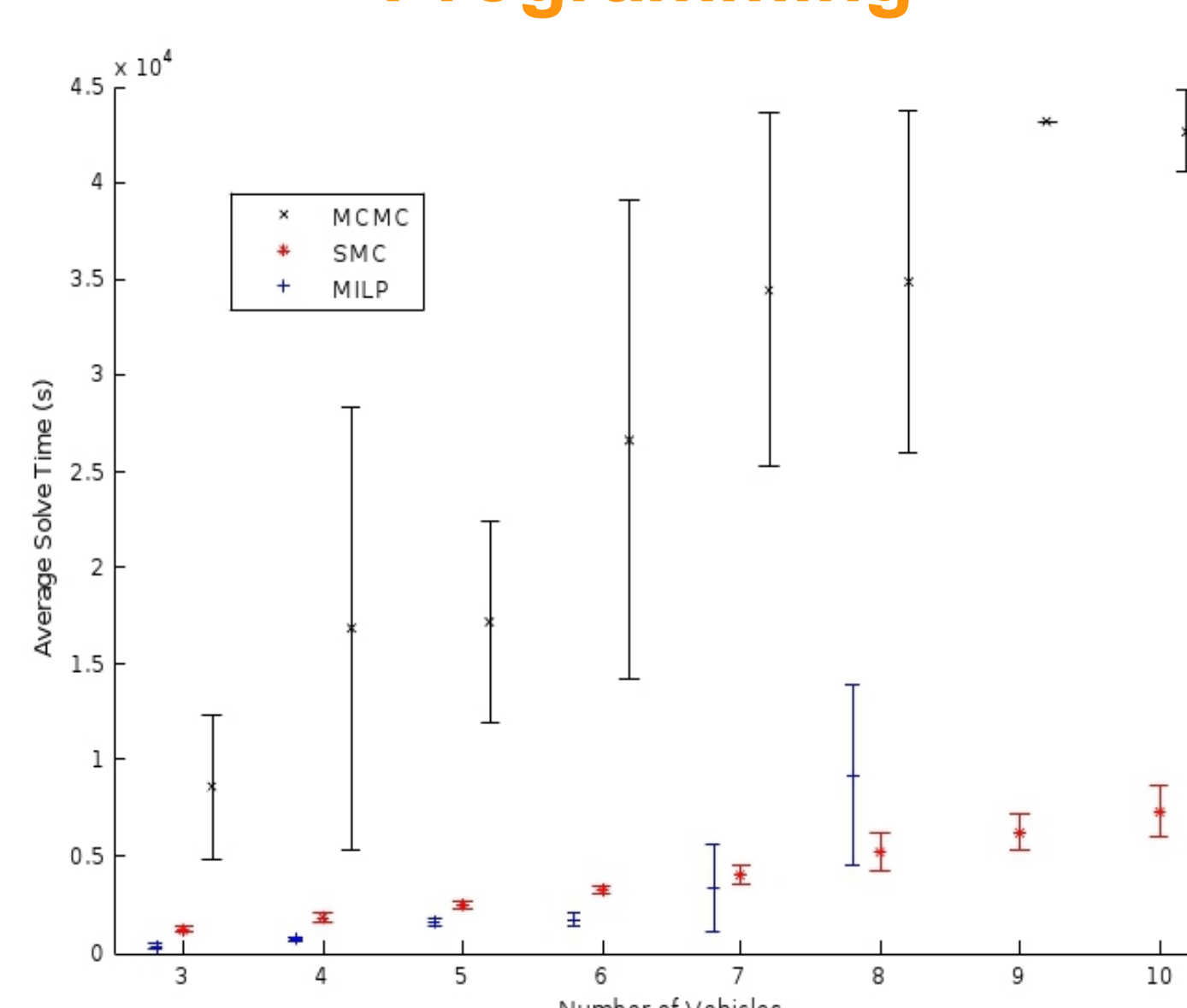


SMC algorithm iterative updates for a single step of MPC

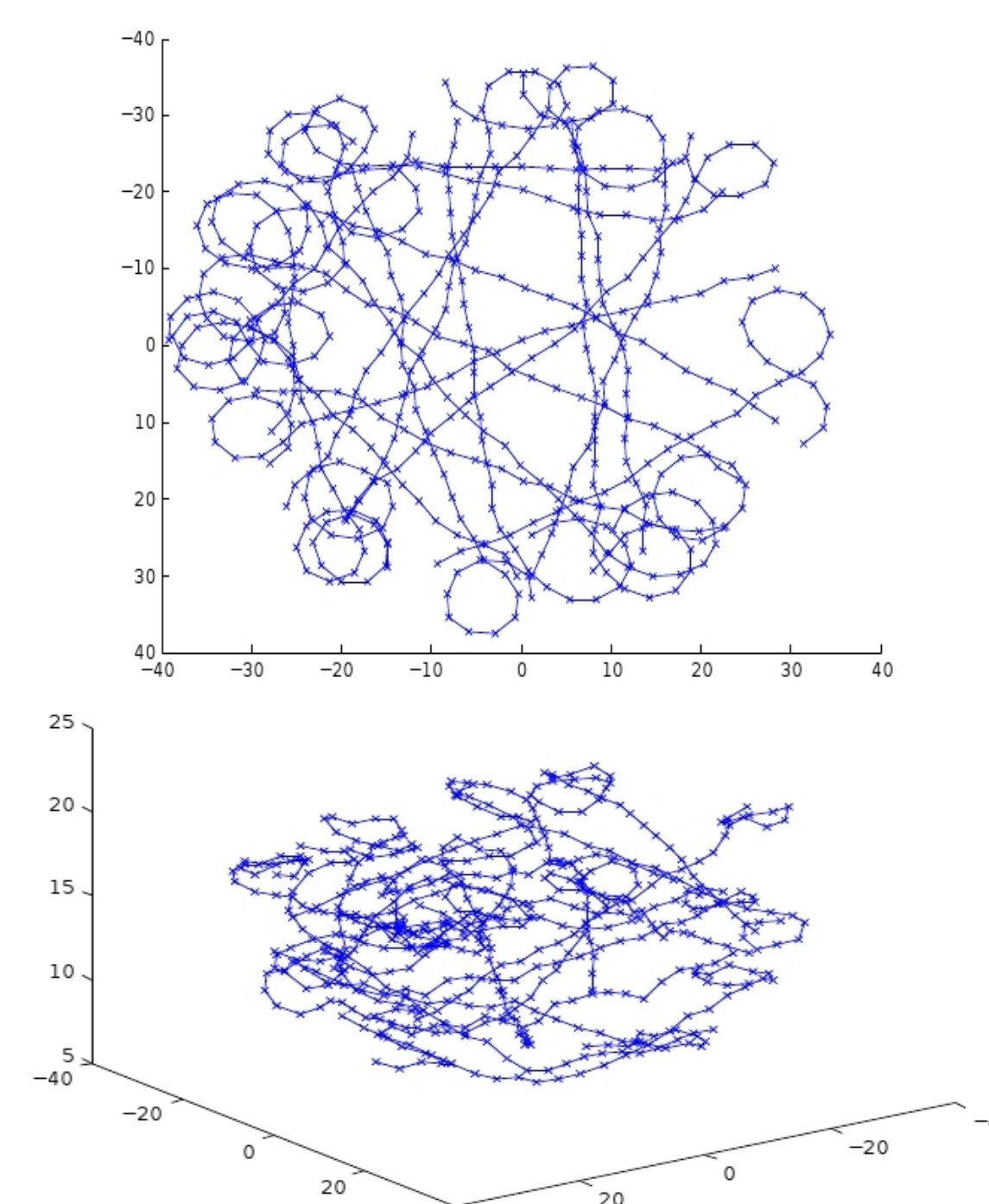
Path Comparison



Solve time comparison for MCMC SMC and Mixed-Integer Linear Programming



SMC for 20 Vehicles Result



Future Directions

- Both methods are easily parallelised so there are many options for faster computation using GPUs and FPGAs.
- SMC appears to have suited the problem in question better than MCMC.
- Complex realistic dynamics models are easily substituted into both methods.