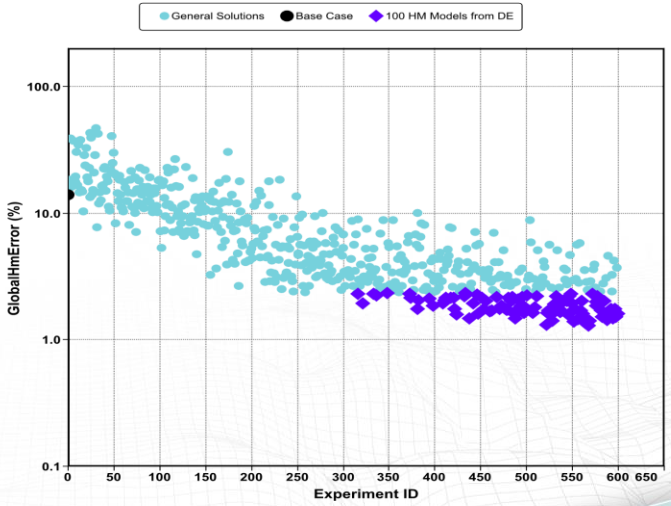
CMOST先进的综合分析功能
Advanced Integrated Analysis Features in CMOST

Alex Novlesky, P. Eng.
Senior Reservoir Engineer



What is CMOST?

CMOST is CMG software that works in conjunction with CMG reservoir simulators to perform the following tasks:

Sensitivity Analysis

- Better understanding of a simulation model
- Identify important parameters

History Matching

- Calibrate simulation model with field data
- Obtain multiple history-matched models

Optimization

- Improve NPV, Recovery, …
- Reduce cost

Uncertainty Analysis

- Quantify uncertainty
- Understand and reduce risk

CMG COMPUTER MODELLING GROUP LTD.

Redesigned CMOST

Multiple Studies Management

Field Data Visualization & Weighting

Intelligent Experiment Management

Interactive Proxy Dashboard

Continuous Parameters

User-defined Nominal Global Objective Functions

50+ New Features

Create Experiments Manually

Objective Function Histogram

Simulation Vector Data Repository

Engine Estimated Finish Time

Parameter Correlations

User-defined Time Series

Parameter Run Progress

Objective Function Using Excel Spreadsheet

Reprocess Experiments

Characteristic Time Durations

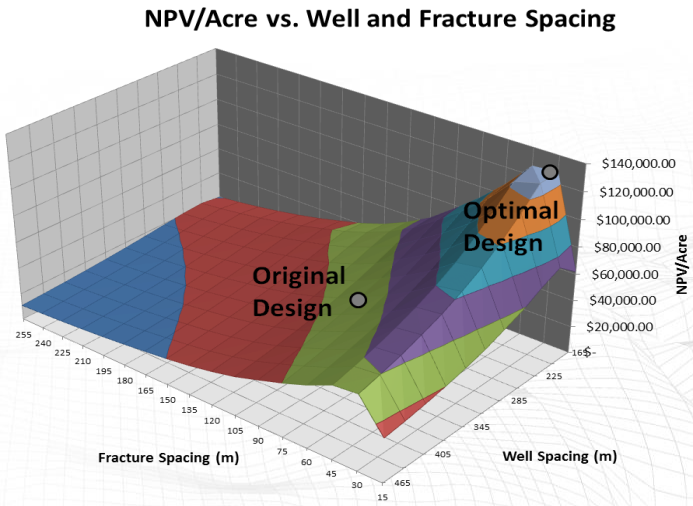
Kernel Proxy Model

External Engine

CMG COMPUTER MODELLING GROUP LTD.

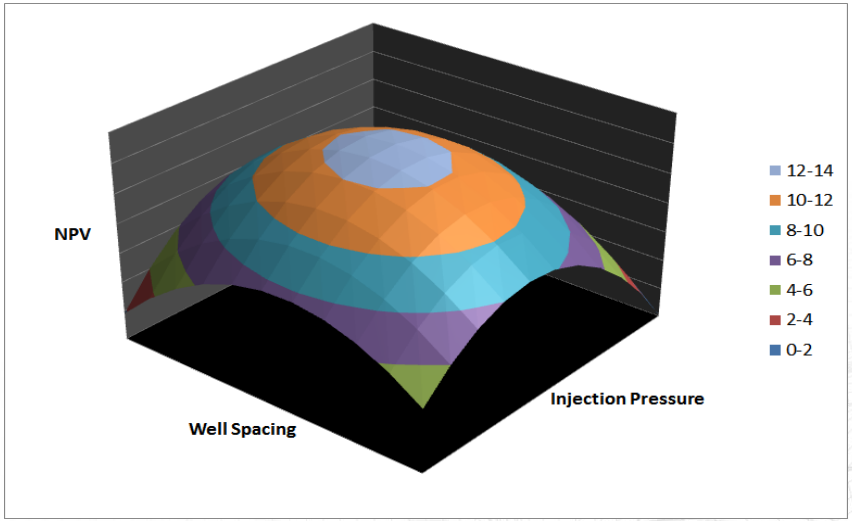
Advanced Features in CMOST

- Proxy Modelling
- Complex Objective Functions
- Advanced Parameterization
- Optimization Options
- Data Visualization
- Upcoming Features

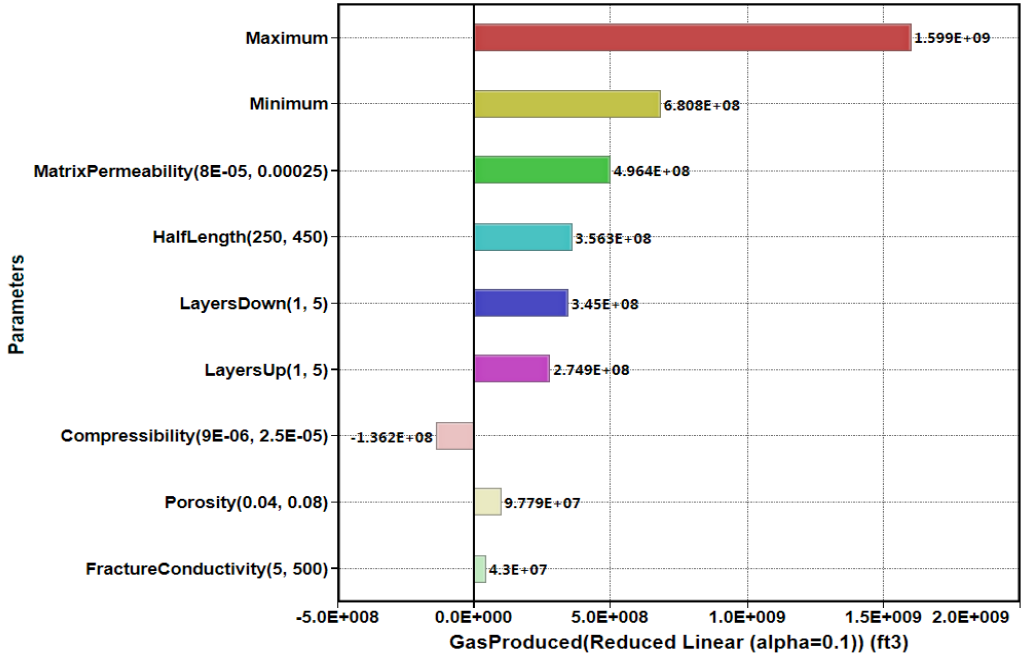


Proxy Modelling

- Desire for maximum information in shortest time
- Simulation can be computationally expensive
- Simulator used as basis
- Proxy modelling fills in gaps and provides trends



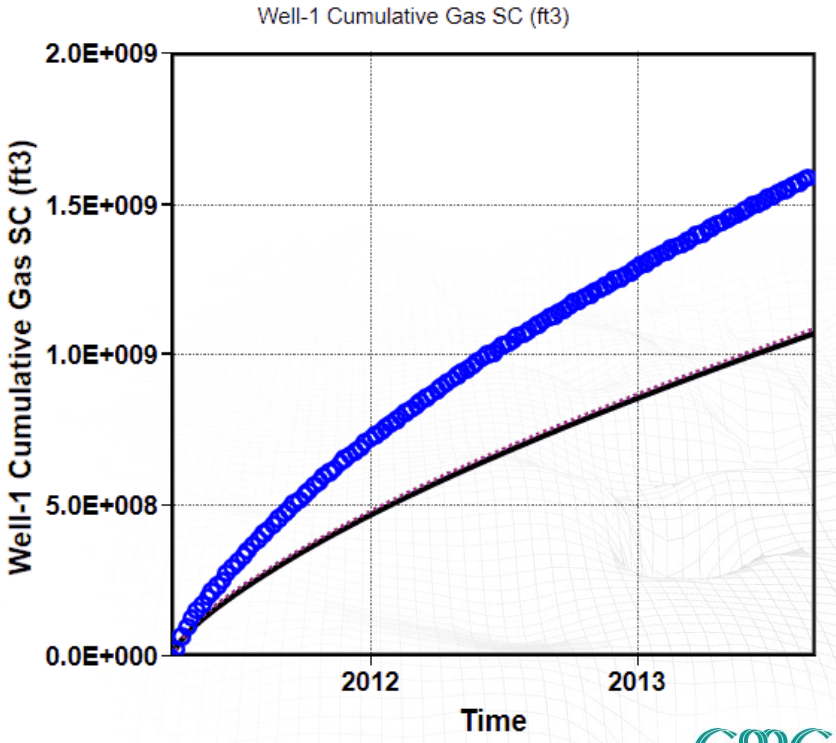
Proxy Modelling in CMOST



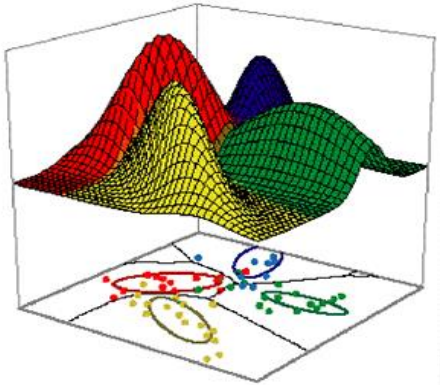
- Determine sensitivity of parameters
- Make predictions without needing additional simulation
- Proxy based optimization algorithms
- Export proxy model for predictions outside of CMOST

Proxy Dashboard

- Interactive prediction tool
- Real-time results using proxy models
- Quickly investigate impact of parameter inputs on simulation results



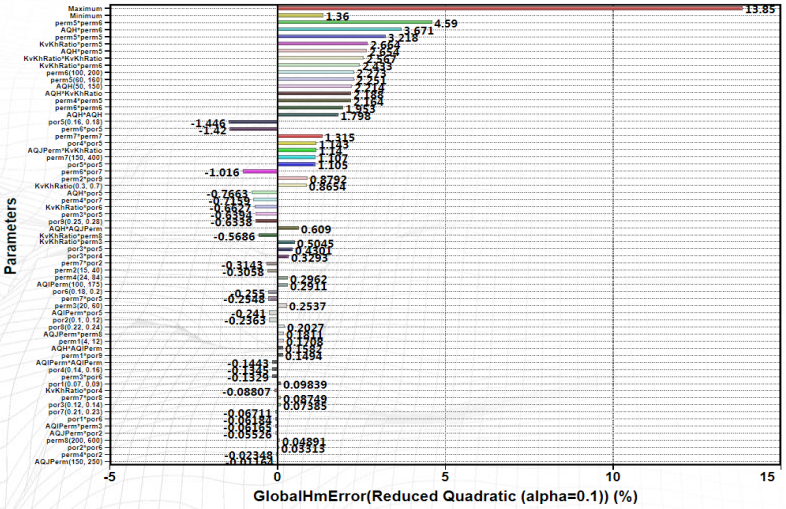
Sobol and Morris Analysis



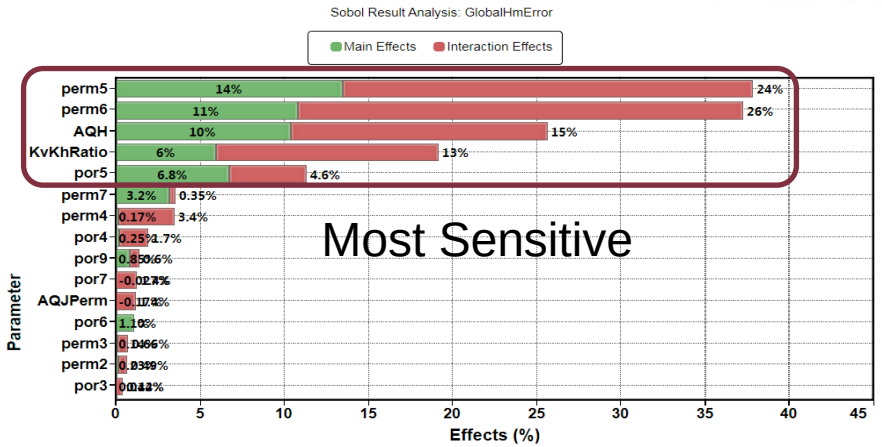
- Reservoir response often non-linear or dependent on multiple parameters
- Difficult to describe with simple trends or polynomial equations
- Sobol and Morris Analysis presents complex relationships in a simplified manner

Sobol Analysis

Sensitivity analysis tool for determining parameters' proportional effect



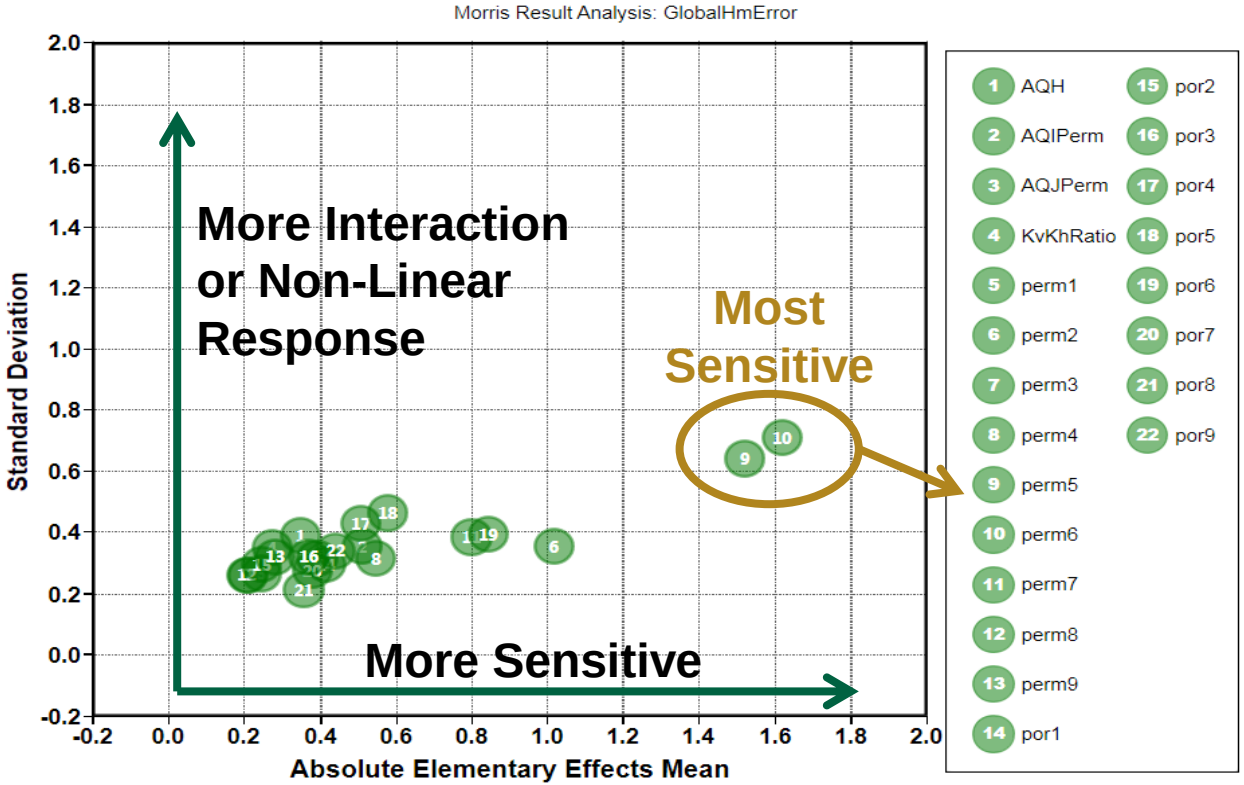
Tornado Plot



Sobol Analysis

COMPUTER MODELLING GROUP LTD.

Morris Analysis



Determine average effect and variability of parameter sensitivity

CMOST Objective Functions

Objective functions are functions used to assess the results of the simulation

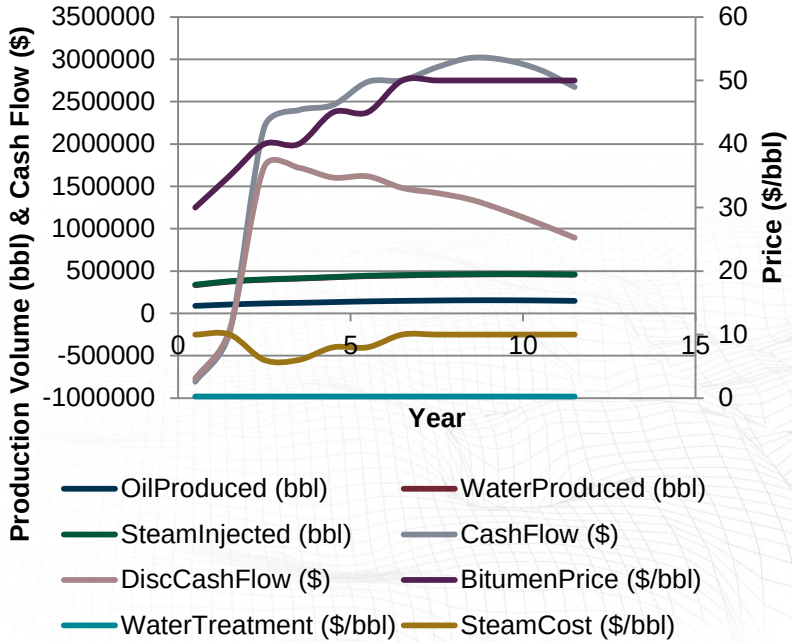
- Raw Simulation Results
- History Match Error
- NPV
- Etc.

Built-in functions can’t cover all possibilities

- Tax and Royalty Regimes vary depending on region
- Emerging areas of R&D

Objective Functions using Excel

- Link CMOST to Excel to calculate results
  - Incorporate complex royalty and tax regimes
  - Add variable cost and price forecasts
  - Use advanced functions in excel such as VBA
- Write simulation results and parameter values to spreadsheet



Jscript and Python Scripts

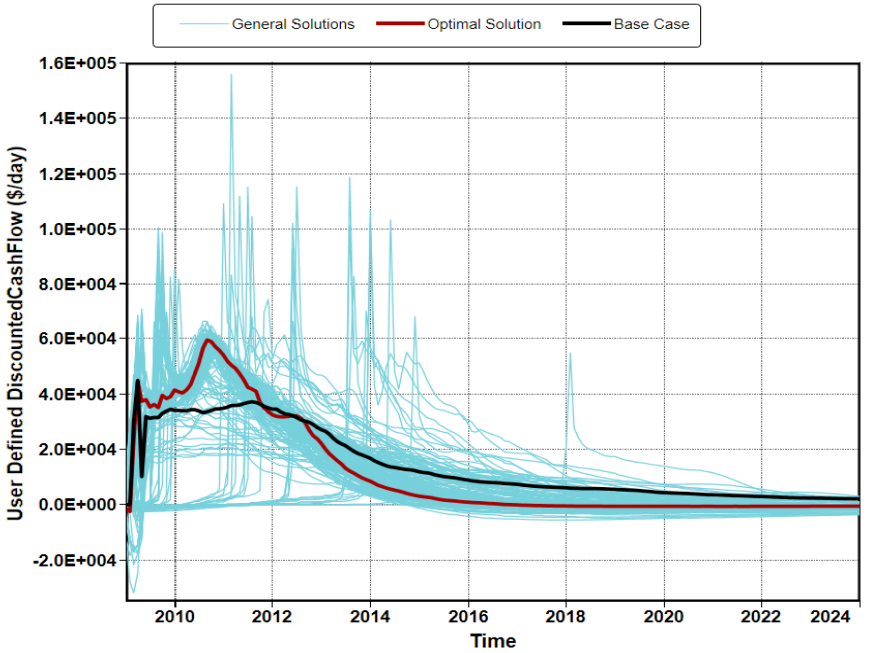
Create advanced objective functions or parameters

- 4D Seismic Chamber Matching Function
- Calculation of NPV or other Economic Indicator
- Calculation of parameter values using logical statements or loops

```
57
58  //Please Write Your Code Below This Line
59  var SLT="**$  Sl  krg  krog"
60  var krog, krg;
61
62
63  for(var Sl=0.00; Sl<0.99; Sl+=0.05)
64  {
65  krg=krg_max1*Math.pow(1-Sl,Ng1);
66  krog=kro_max1*Math.pow(Sl,L_og1)/(Math.pow(Sl,L_og1)+E_og1*Math.pow(1-Sl,T_og1));
67
68  SLT+="\r\n"+"     "+Sl.toFixed(3)+"  "+krg.toFixed(5)+"  "+krog.toFixed(5);
69  }
70
```

User Defined Formula

- Create advanced plots
  - E.g. NPV vs. Time
- Numerical Integration or Differentiation
- Jscript or Python Scripting



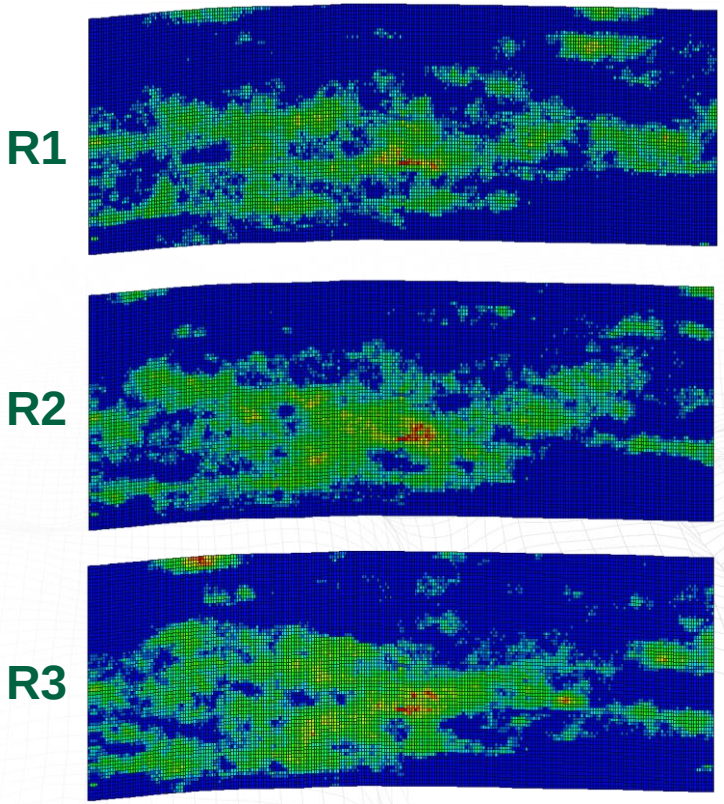
Parameterization

- Any value in the dataset can be set as a parameter
- Modification of arrays or tables of data can be more challenging
  - Property Changes Based on Facies Type
  - Relative Permeability Tables
  - Changing property distributions (realizations)

Include File Substitution

Parameterize sections of the dataset

- Geological Realizations
- Relative Permeability Tables
- Other Tabular Input
  - Viscosity vs. Temperature
  - Compaction Tables
  - Etc.

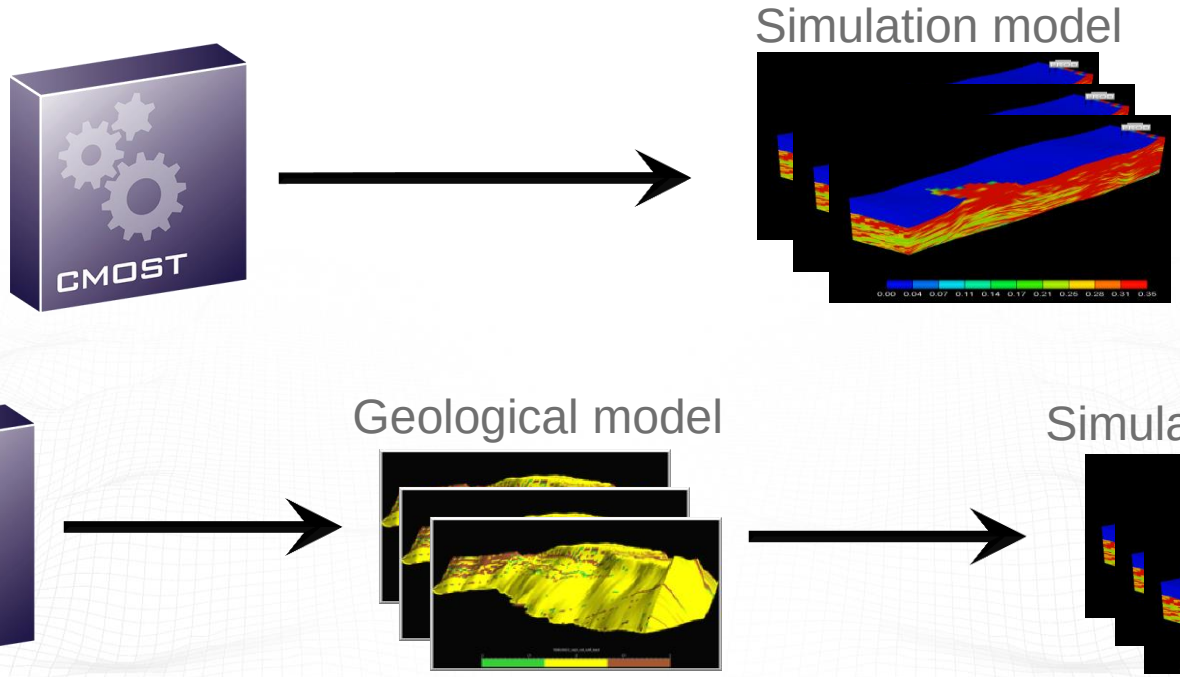


Pre-Simulation Commands

- Couple CMOST to external programs to generate datasets
  - Geological software
  - Builder
  - User Defined

- Create new geological realizations
- Recalculate builder formulas
- Generate Relative Permeability Tables
- Adjust hydraulic fracture spacing

Coupling with Geological Software



Multi-Objective Optimization

Often multiple objective functions when optimizing or History Matching

- Reduce Costs and Increase Revenue
- Matching multiple wells or data types

Traditional approach:

Optimize an aggregated global objective function

- Total NPV
- Weighted Average for History Match

Multi-Objective Optimization

Weighting not always know beforehand

- Uncertainty about costs or prices
- Weighting for HM can be arbitrary
- Sometimes optimize unrelated functions
    - E.g. Numerical tuning: Runtime & Material Balance Error

Multi-Objective Optimization approach:

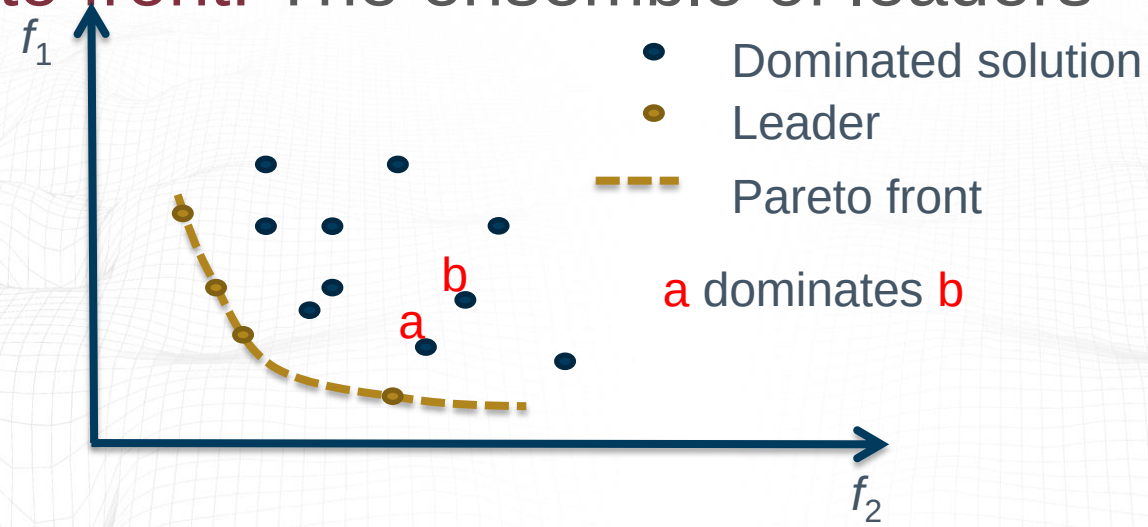
- Find a set of alternative optimal solutions
- Trade-off between multiple objective functions

How Multi-Objective Optimization Works

Domination: “Better” in every objective function

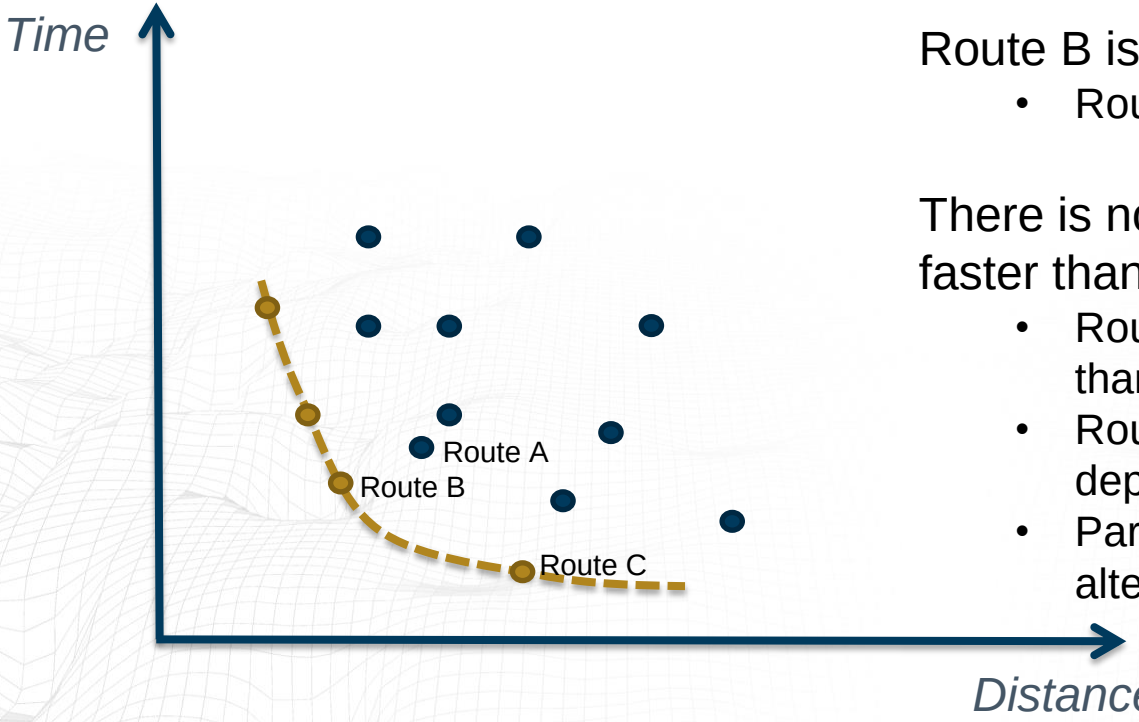
Leader: A non-dominated solution

Pareto front: The ensemble of leaders



Road Trip Example

Goal: Shortest route with fastest time



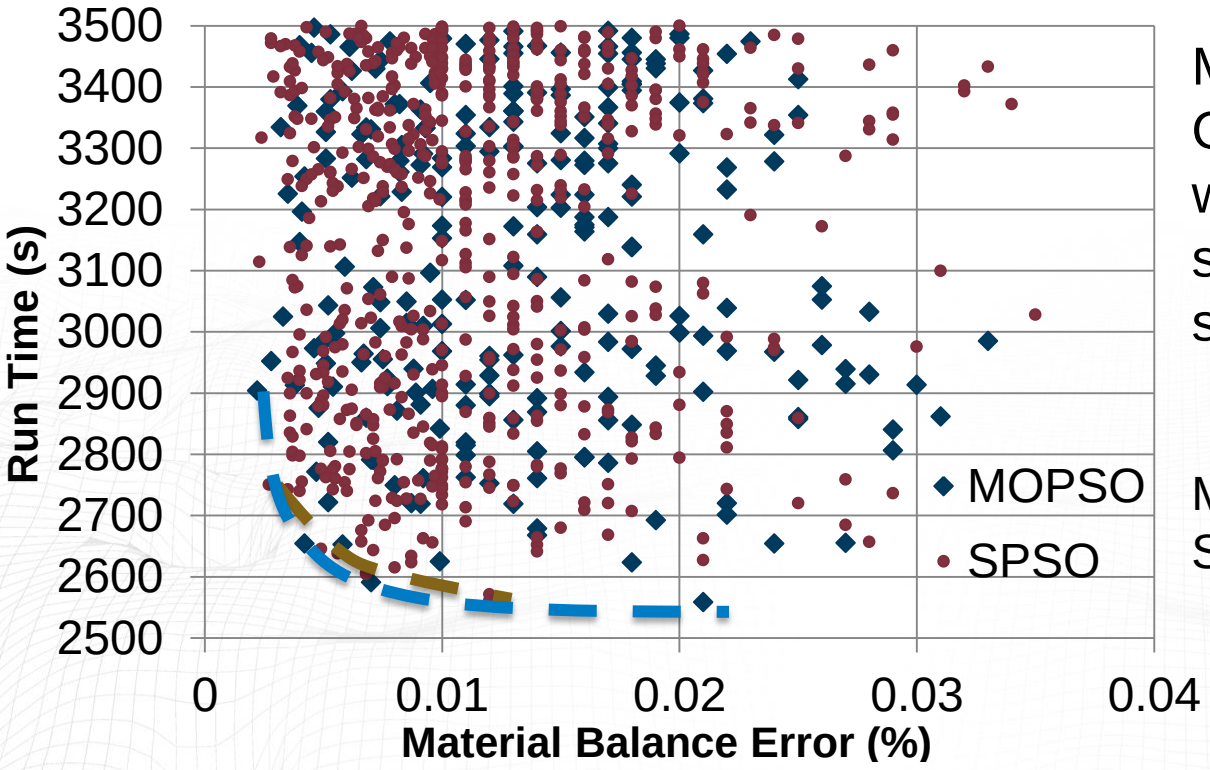
Route B is shorter and faster than Route A

- Route B is always better than Route A

There is no route that is both shorter AND faster than Route B

- Route C is a longer distance but faster than Route B
- Route C is an alternative to Route B depending on weighting
- Pareto front gives ensemble of alternatives

Numerical Tuning Example
Multi-Objective vs. Single Objective



Multi-Objective Optimization gives wider range of possible solutions with fewer simulations

Multi-Objective: 500 runs
Single Objective: 1000 runs

Optimization Customization

New CMOST optimization algorithms added regularly

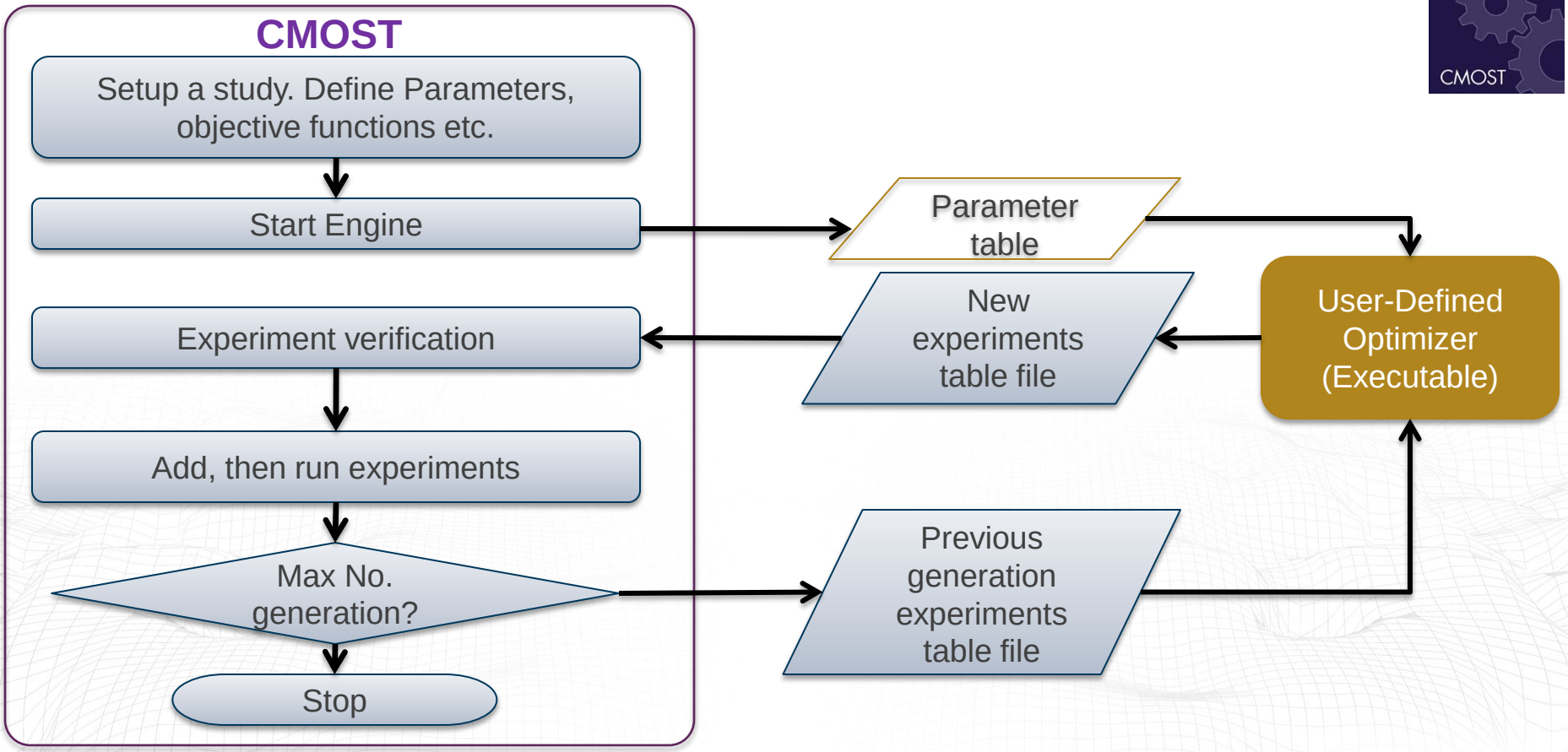
- CMG DECE
- Particle Swarm Optimization (PSO)
- Random Search
- Latin Hypercube + Proxy Optimization
- Differential Evolution
- CMG Bayesian Engine (Coming 2016)

Multitude of other options in literature & new algorithms in development

- External Engine allows users to create their own methods that links to CMOST

External Engine

- Run CMOST using your own algorithms
- External Engine decides what experiments to run
- CMOST creates & runs experiments


CMOST
Setup a study. Define Parameters, objective functions etc.
Start Engine
Experiment verification
Add, then run experiments
Max No. generation?
Stop
Parameter table
New experiments table file
Previous generation experiments table file
User-Defined Optimizer (Executable)

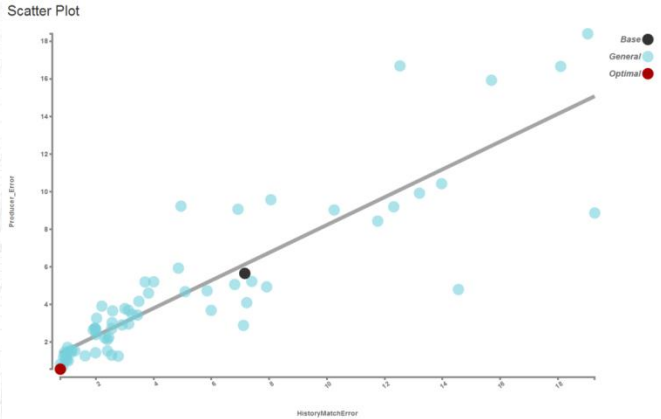
Data and Trend Visualization

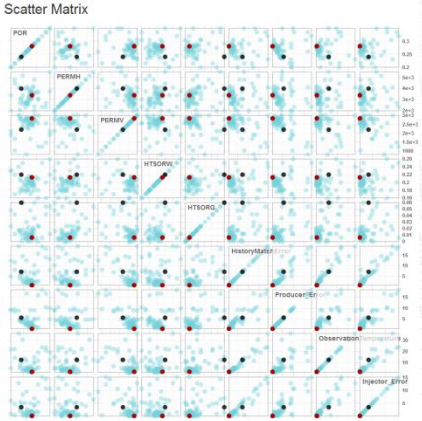
- Large amounts of data analyzed by CMOST
- Very large amount of combinations of parameters and objective function to assess for trends
- Interactive Data Visualization Tool allows quick overview of large amounts of information

Interactive Data Visualizer

Interactive plots allow for visualization of data trends

- Scatter Plots
- Scatter Matrix

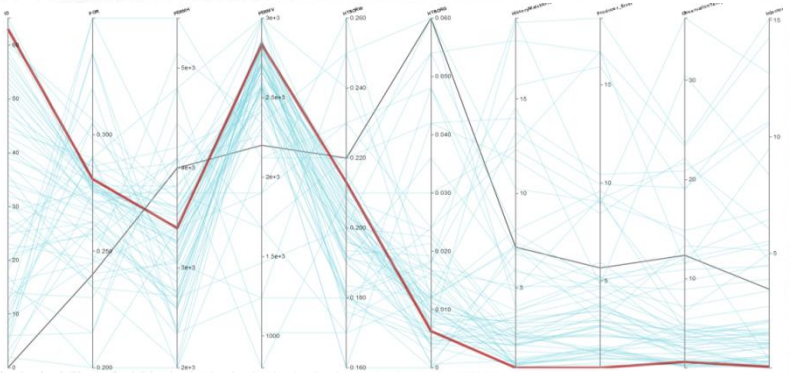


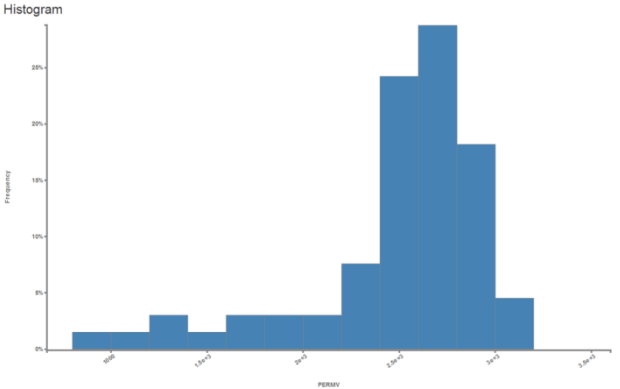


Interactive Data Visualizer

Interactive plots allow for visualization of data trends

- Parallel Coordinates
- Data Histograms





Licensing Multiplier

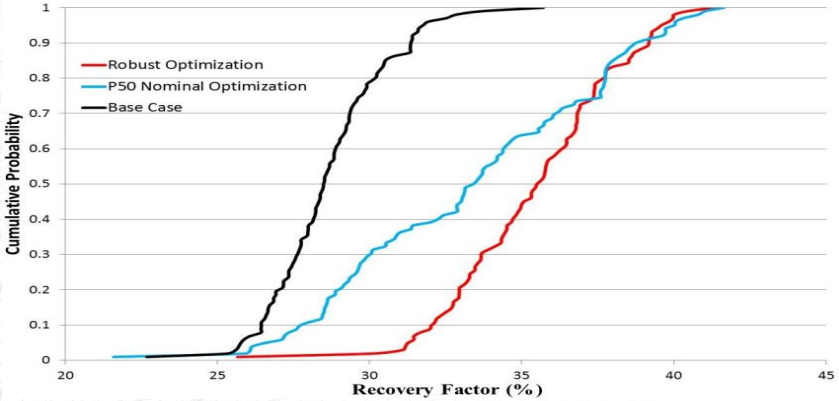
- CMOST uses only partial licenses when running simulations
  - E.g. Run 2 STARS simulations while using only 1 STARS license
  - Applies to other license types (Parallel, Dynagrid, etc.)

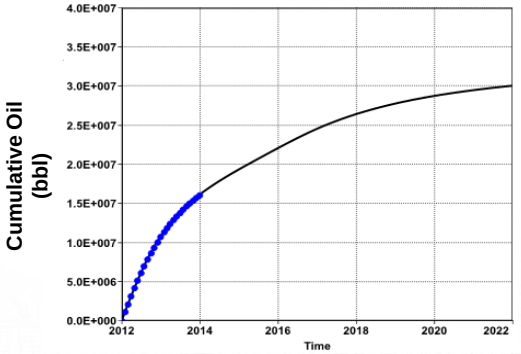
• IMEX	4:1	x 4
• GEM	2:1	x 2
• STARS	2:1	x 2

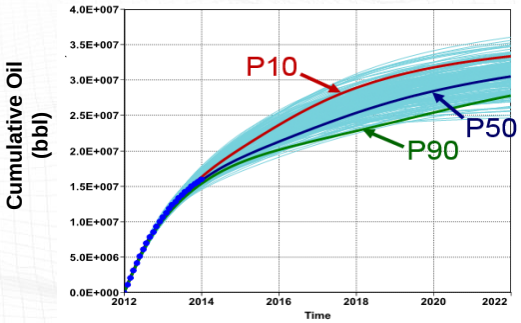
Coming in 2016.10

Brand new features in CMOST

- CMG PAR
- Probabilistic Forecasts
- Robust Optimization







Conclusions

- Complete more in depth analysis more efficiently
- CMOST tools allow for customization of workflows
- Proxy modelling allows for quick estimation without needing additional simulations