Preliminary Application of an Oil Shale Basin Retorting Simulation

Matthew Minnick
Ph D. Graduate Student, RESPEC Inc.
Dr. Wendy Zhou
Department of Geology and Geological Engineering
Colorado School of Mines
Observations

- GAO Report
- Local and State Municipalities
- General Public
- Black Box Non-Spatial Attempts
Objectives

The objective of this model is to simulate a basin-wide commercial extraction process with a broad range of scenarios given a large range of spatial and temporal uncertainty to understand and visualize the commercial development of the basin.

“Make Well Informed People Smarter”
Methods

- Multi-Agent Geospatial Simulation Analysis
- Database Driven I/O
- MATLAB
- Integrated with a Surface Water and Groundwater Model
Assumptions

- Uncertainty of Input Parameters
- Correct choice of Machine Learning Algorithm
- Application and Calibration of Surface Water and Groundwater model
- Choice of Reward Targets and or Distribution of Objective Functions
Model Development Overview

The Perceptual Model: deciding on the Processes

The Conceptual Model: deciding on the equations

The Procedural Model: coding, I/O, visualization

Model Calibration: values of parameters

Model Validation: good idea but difficult in practice

Success?

Yes

Beven, 2004
Perceptual Model
In-Situ Extraction Method

Shell’s Freeze wall

American Shale Oil Process
Diagram illustrating the geothermal process for generating electricity from oil shale. The figure shows layers of the Earth's crust with specific labels:

- **Illitic oil shale**
- **Mahogany zone**
- **Dissolution surface**
- **Nahcolitic oil shale cap rock**

Key components include:

- **Heat injection well**
- **Production well**

The diagram also indicates a **2000 ft** distance and notes **Better water quality**.
Procedural Model

- Multi Agent Simulation
  - Time Step
    - Markov Chain Spatial In-Situ Retort Process
    - Groundwater Model (MODFLOW.exe)
    - Surface Water Model (WARMF.exe)
      - Stream Flow Diversion
      - Reservoir Storage
    - CO₂ Production
    - Oil Production
    - Groundwater Drawdown
Agents

**agere** (Latin) – to do

**Agent** - a *computational* entity such as a software program or robot that can be viewed as *perceiving and acting upon* its environment and that is *autonomous* in that its behavior at least partially depends on its own experience (computer science)

**Agent** - system that decides for itself what it needs to do in order to satisfy its objectives

**Characteristics**
- Autonomous
- Goal-oriented
- Interacting – agents “sense” or are “aware” of other agents

**Key behavioral processes**
- Problem solving
- Planning
- Decision-making
- Learning
Simulation Grid

Grid Modifications
- Topography
- Land Use
- Mineral Leases
- Dynamic Perturbations
Data

3377 Grid Cells
Components

1. Agents and their objectives
2. Numeric Rewards that reinforce positive actions or demerit actions that lead to undesirable outcomes
3. Quality Function for each Retort Cell
4. Search Function
5. Integration of WARMF and MODFLOW
Agents and Objectives

- **Agents**
  - Oil Shale Companies

- **Objectives**
  - Maximize Economic Return
    - Find Highest Oil Content Cell per target Layer
    - Minimize Depth
Example of Rewards

- **Positive**
  - Value of Oil Extracted in each Cell
  - Net Water Produced (Process State Dependent)

- **Negative**
  - Cost of Drilling Deeper Layers
  - Net Water Consumption (Process State Dependent)

- Rewards Normalized to Common Scale
Quality Function

Retort Quality set to 0.0 at start of simulation

\[ Q(s_{t,k+1}) \rightarrow Q(s_{t,k-1}) + \alpha [r + Q(s_{t,k}) - Q(s_{t,k-1})] \]

Time Step \( t \)
- \( k \) current time step
- \( k + 1 \) next time step
- \( k - 1 \) previous time step

\( r \) reward
\( \alpha \) learning rate
Search Function and Time Step

- No *a priori* knowledge of Quality values
- Agent Selects $n$ Retort Cells (Random Seed for Start?)
- Time Simulation
  - What are the appropriate time steps to sufficiently capture and simulate the state of the system?
- Epsilon Greedy Search Function
Epsilon Greedy Search Function

\[ \epsilon, \alpha = 1 - \left[ \frac{1}{1 + e^{\frac{-k0.001(k-10,000)}{2}}} \right] \]

Hybrid Search Implementation ?
Pseudo Code

Set $Q(s)$ 0.0 for all Retort Cells

Repeat for each episode

  Repeat for $n$ Number of Cells
    for all agents
      while extracted Barrels < target number
        select cells based on search function $\epsilon$
        update values of $Q(s)$

  After $n$ Cells
    for all agents
      if economic return > economic goal
        if retorting time < target
          goal = achieved
        else
          goal = not achieved
      calculate rewards
      update value of $Q(s)$
Random Search Run
Implementation of Reinforcement Learning
Web-GIS Flex API Interface

- Time Series Animation of Basin Retorting
Final Interface Concept
Limitations and Uncertainty's

- Global Uncertainty's in Characterization of the System Inherent to each Simulation Run
- Simulation Specific Limitations and Uncertainty's
- Important to Document and Present these Limitations and Uncertainty's

“It is important to understand this is a general process simulation tool used to quickly evaluate different possible scenarios in highly uncertain complex system and does not intend to be used for policy decisions nor address the acquisition of the resource for development.”
Model Development Overview

- Revise Perceptions
- Revise Equations
- Debug Code
- Revise parameter Values

The Perceptual Model: deciding on the Processes

The Conceptual Model: deciding on the equations

The Procedural Model: coding, I/O, visualization

Model Calibration: values of parameters

Model Validation: good idea but difficult in practice

Success?

Yes

No

(Beven, 2004)
Conclusions

- Viable Proof of Concept
- Modeler Manifesto
  - Yes, the Model is Wrong, but it may be useful!
References

Questions?