Optimization of reservoir management based on approximate dynamic programming

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Motivation

- Shortage of energy resources calls for better petroleum reservoir management policies
- Optimizing decision-making in reservoir management is challenging
  - Large-scale nonlinear dynamic optimization problem
- We propose optimization algorithms based on Approximate Dynamic Programming (ADP) to solve this problem

Introduction to ADP

- Dynamic Programming (DP) potentially achieves global optimum but suffers from the “curse of dimensionality”
- ADP tries to keep DP’s merits but overcome the dimensionality curse
- Approach: approximate the *cost-to-go* function as a linear regression of a set of basis functions:

$$J^*(\mathbf{x}) \approx \tilde{J}(\mathbf{x}) \equiv \sum_{k=0}^{K} r_k \phi_k(\mathbf{x})$$

Selection of Basis Functions

Here we apply Proper Orthogonal Decomposition (POD)

- Run several simulations with randomized controls, get a set of "snapshots" and then normalize them

$$\bar{\mathbf{x}} = \frac{1}{k}\sum_{i=1}^{k}\mathbf{x}(i) \qquad \mathbf{X} = \left[\mathbf{x}(1)-\bar{\mathbf{x}}, \mathbf{x}(2)-\bar{\mathbf{x}}, ..., \mathbf{x}(k)-\bar{\mathbf{x}}\right]$$

- Apply SVD to get "large-energy" singular vectors

$$\mathbf{X} = \mathbf{U}\mathbf{\Sigma}V^T \qquad \mathbf{\Phi} = [\mathbf{u}_1, \mathbf{u}_2, ..., \mathbf{u}_N]$$

- Use 1-D polynomials as the basis functions

$$\phi_0(\mathbf{x}) = 1 \quad \phi_1(\mathbf{x}) = \mathbf{u}_1^T\mathbf{x} \quad \phi_2(\mathbf{x}) = \left(\mathbf{u}_1^T\mathbf{x}\right)^2 \quad \phi_3(\mathbf{x}) = \mathbf{u}_2^T\mathbf{x} ......$$

Computation of the Weights

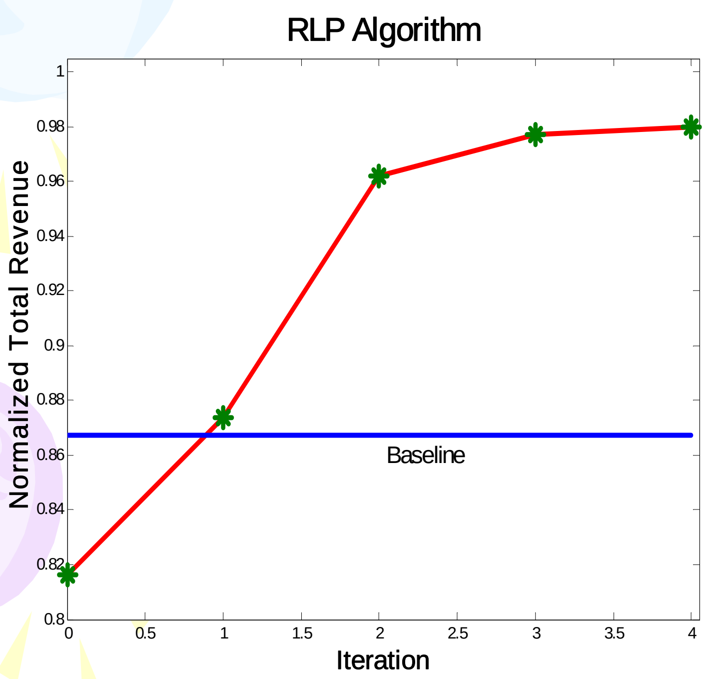
- Various Approximate DP algorithms can be used to compute the weights
  - Temporal-Difference Learning
    - Adjusting the weights based on Temporal Difference
  - Reduced Linear Programming
    - Theoretically, exact cost-to-go function can be solved by an LP with infinite constraints and variables
    - An approximate solution can be solved by reducing to an LP with finite variables and constraints

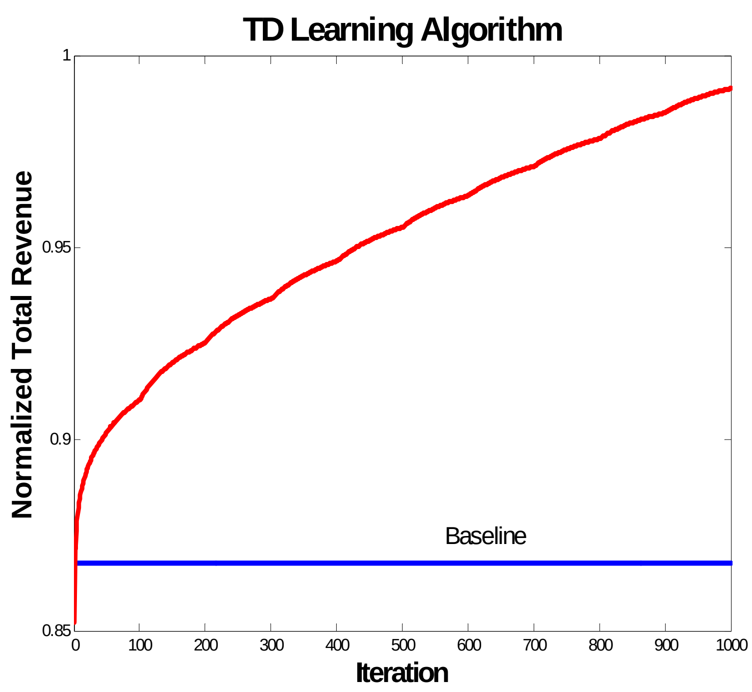
Our contribution

- Propose a systematic algorithm to choose basis functions based on POD
- Extend the classical TD-learning algorithm to "Full-Simulation" based TD learning algorithm
- Apply RLP to a deterministic optimization system

Validation of ADP

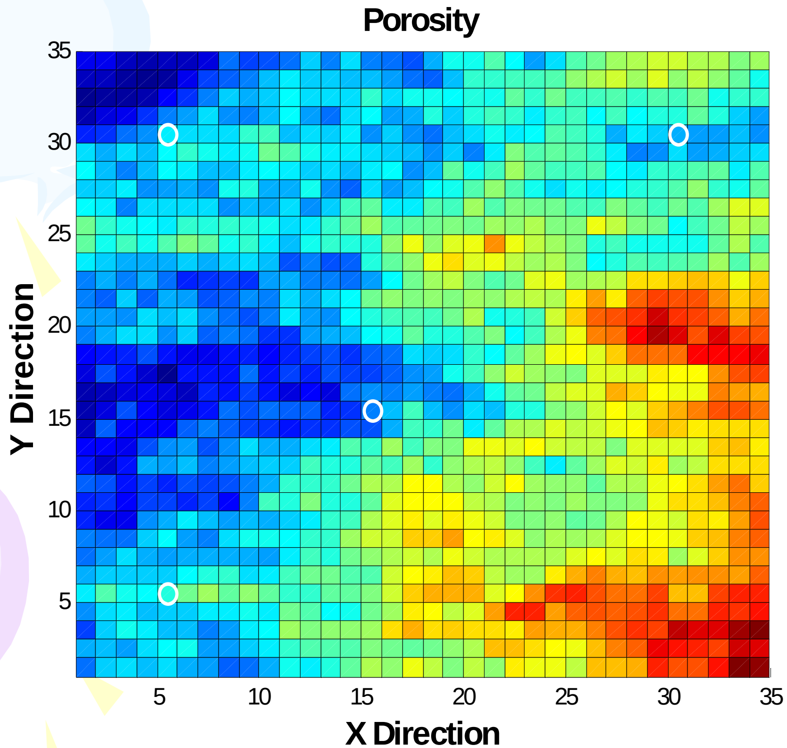
- Primary production in reservoir engineering with special structure is analytically solvable
- Performance of ADP could be verified in this case

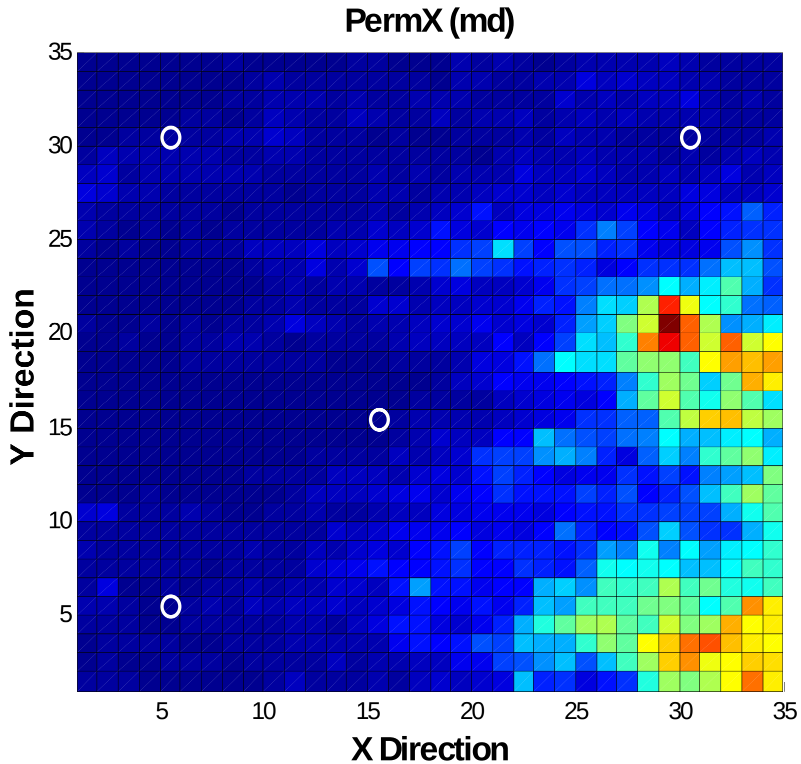




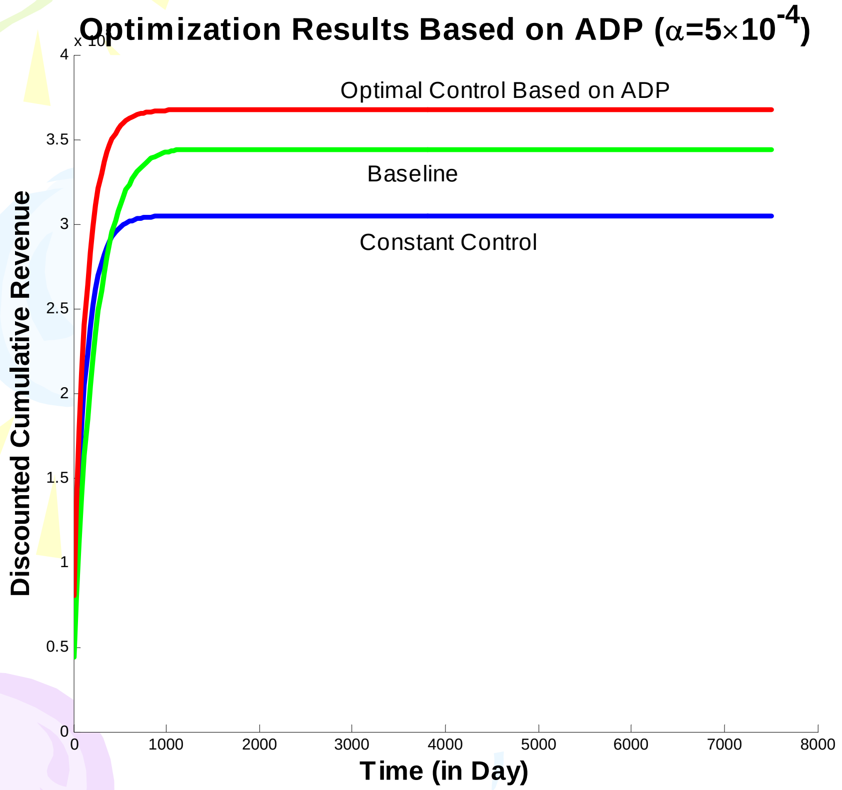
Application: General Primary Production Problem

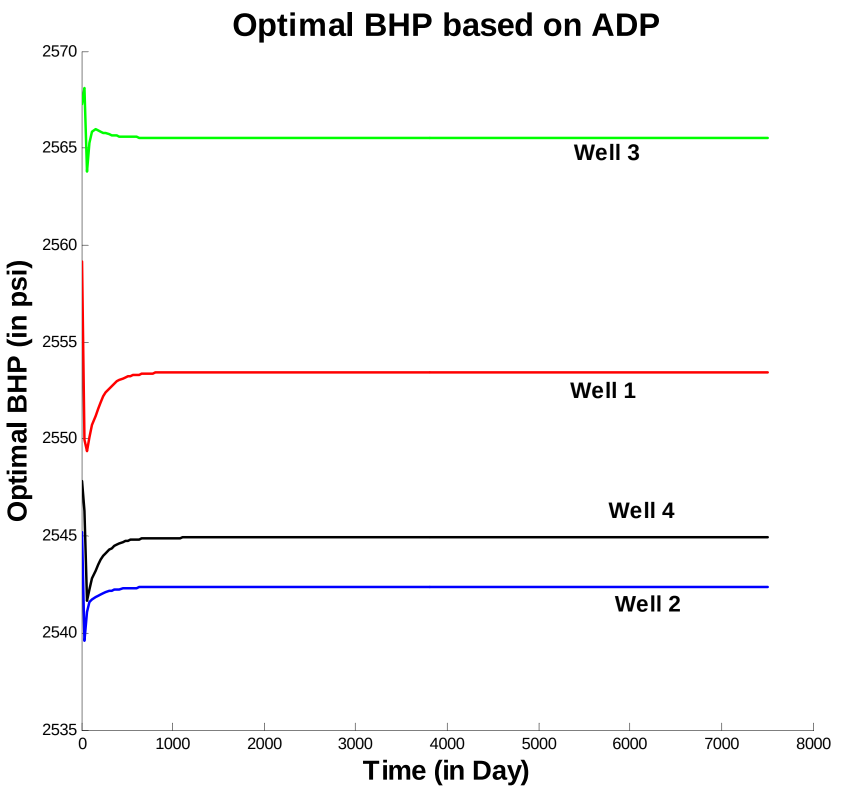
- Modified Portion of SPE-10
- 35×35×1 blocks, 4 production wells
- Geological Model is shown below





Preliminary Results





Future Work

- Extend the proposed algorithm to some other applications, such as power grid
- Perform some theoretical work to analytically justify the results