Working Toward…
Incorporating High Dimensional **Uncertainty** and Operational **Constraints** Into Long-Term **Generation Expansion** Models Using **Approximate Dynamic Programming**

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FERC: Technical Conference on Planning Models

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Outline

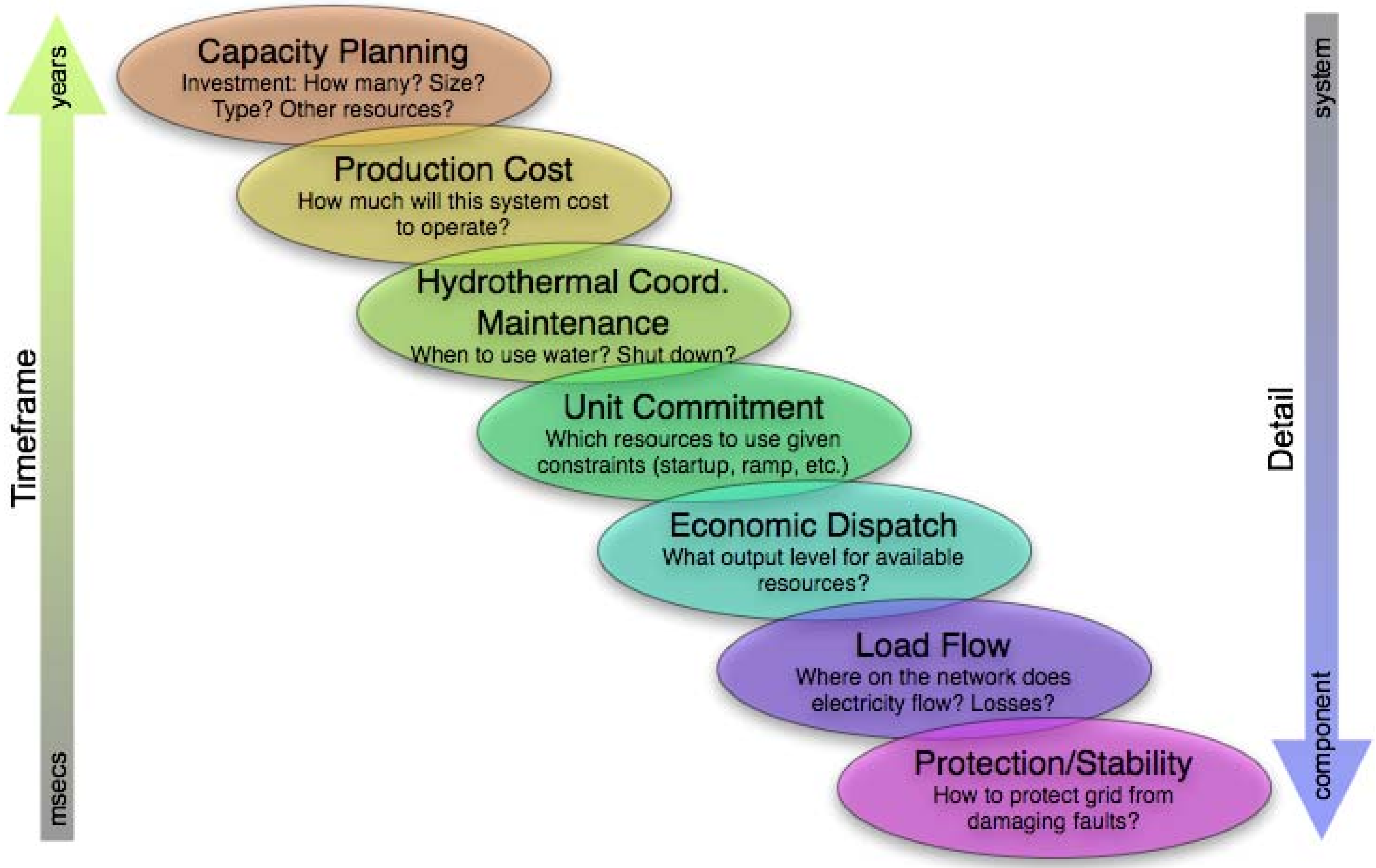
- What problem are we solving?
- Planning vs/+ Operations
- Stochastic Dynamic Problems
- (Approximate) DP
- Current Research in MIT-ESD

Caveat: More concepts than results
(stay tuned...)

Capacity Planning is a Hard Stochastic Dynamic Problem

- Stochastic
  - Growth, Prices, Outages, Hydro
  - Renewables, Demand Response, Policy, Technology
- Dynamic
  - New information over time
  - Sequential decision making (recourse)
- Hard...

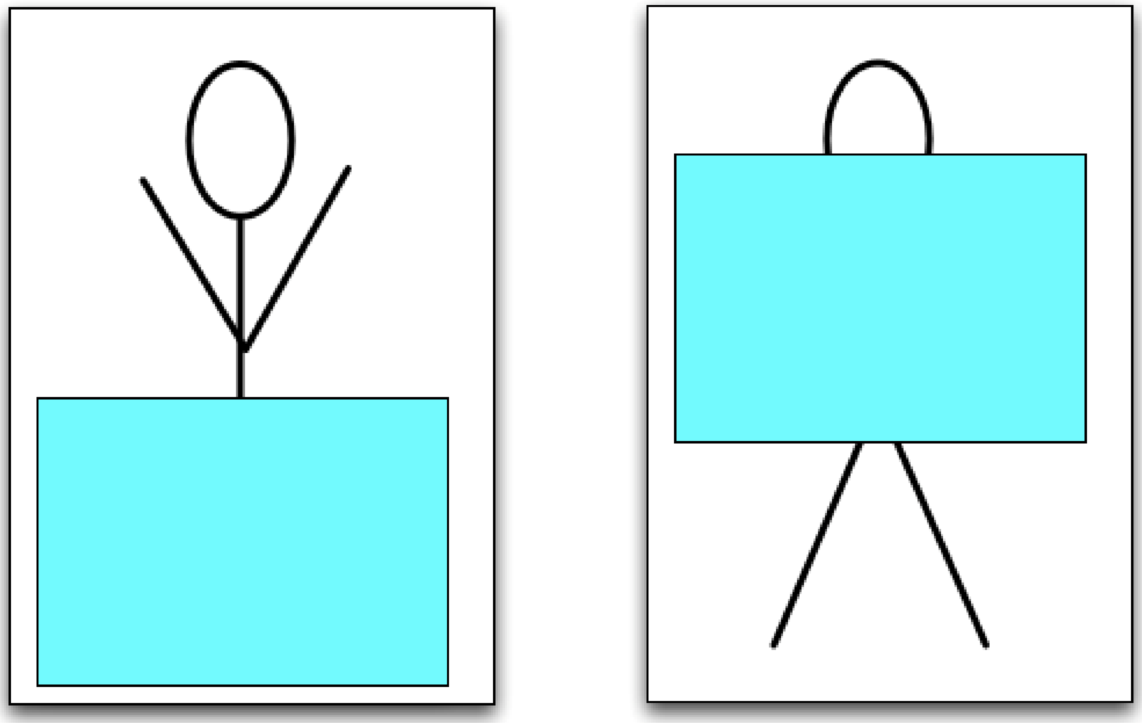
Electric Power Model Types



The short blanket problem

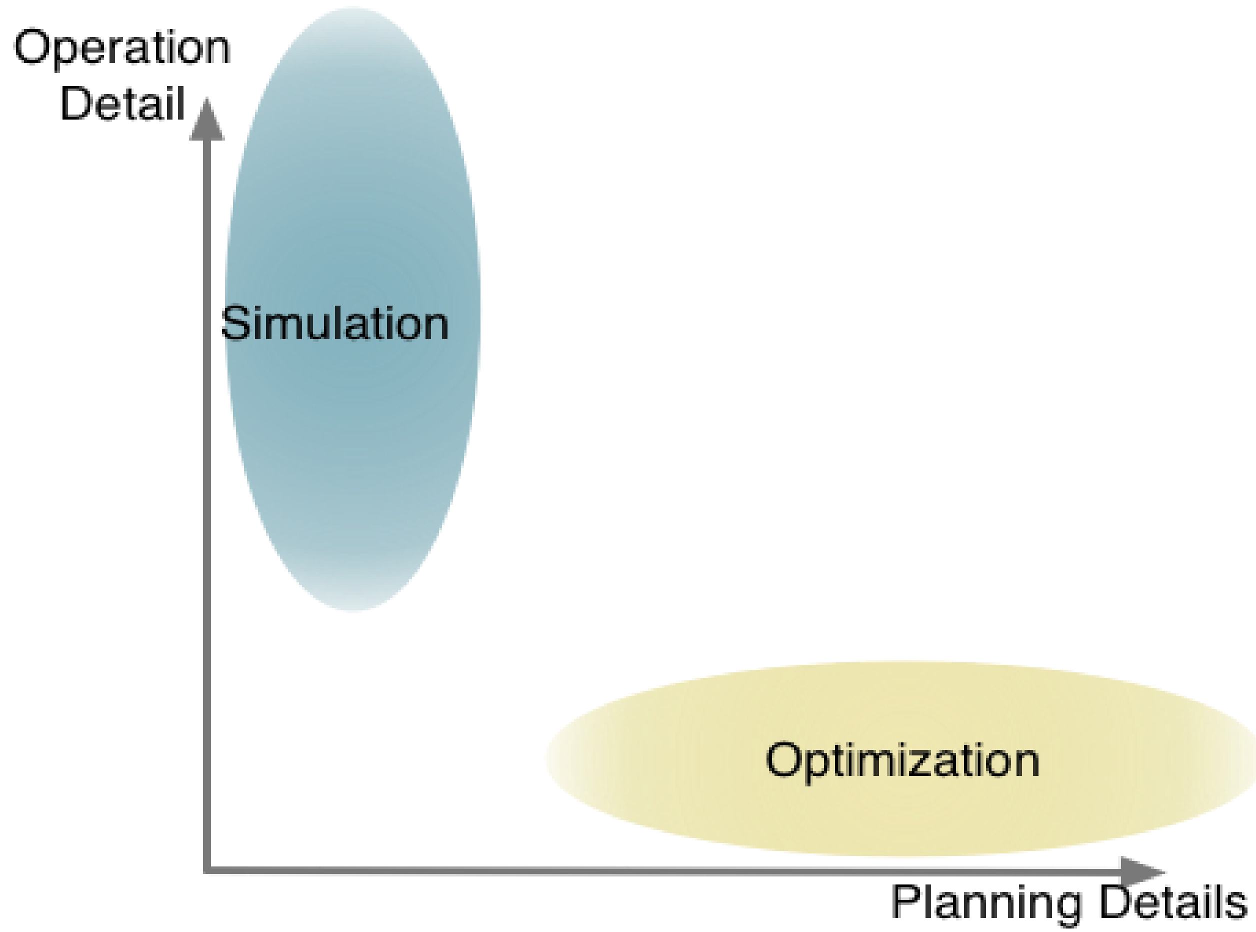
Investment Decisions

Operational Details

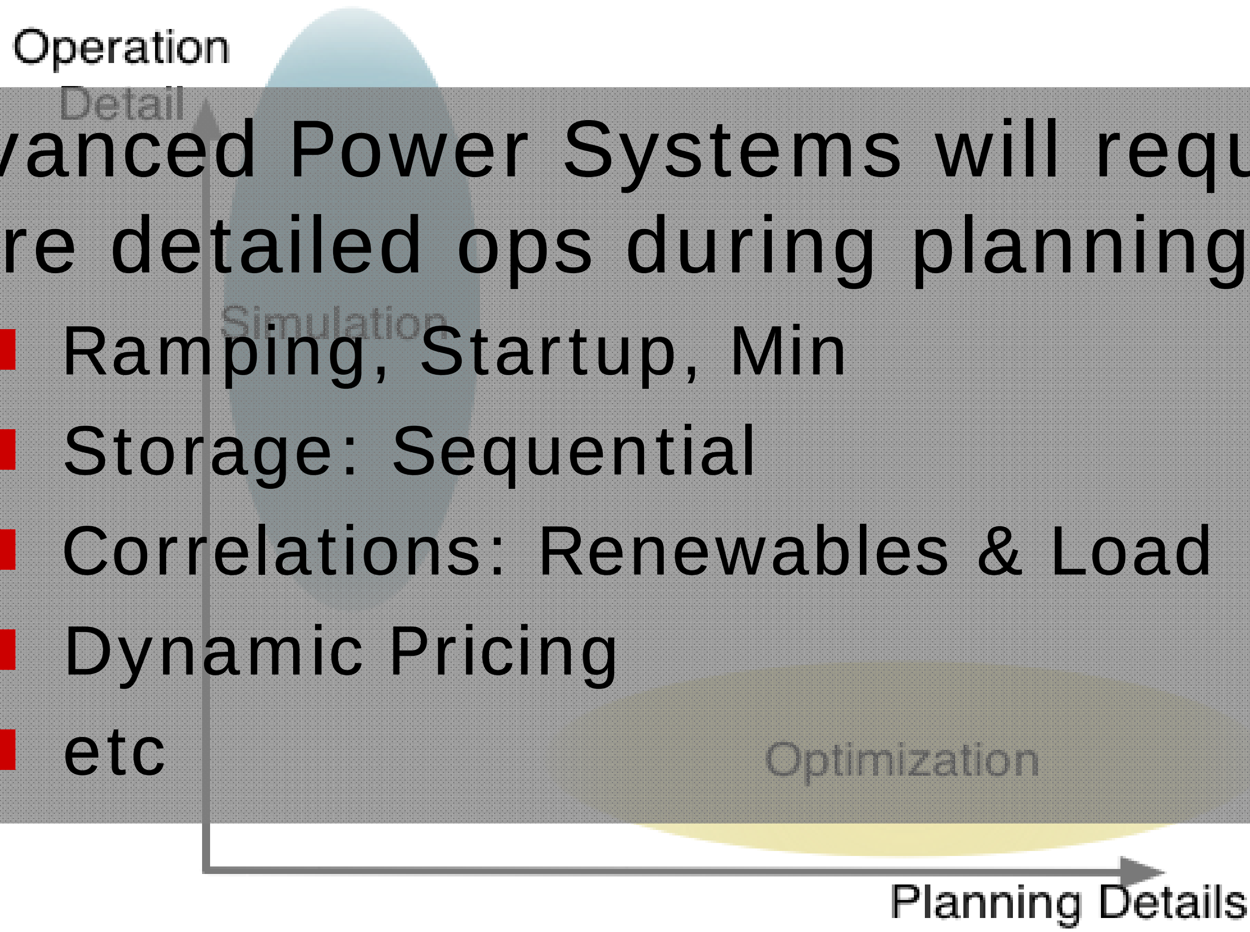


- **Need to approximate**

Operations vs Planning



Operations vs Planning



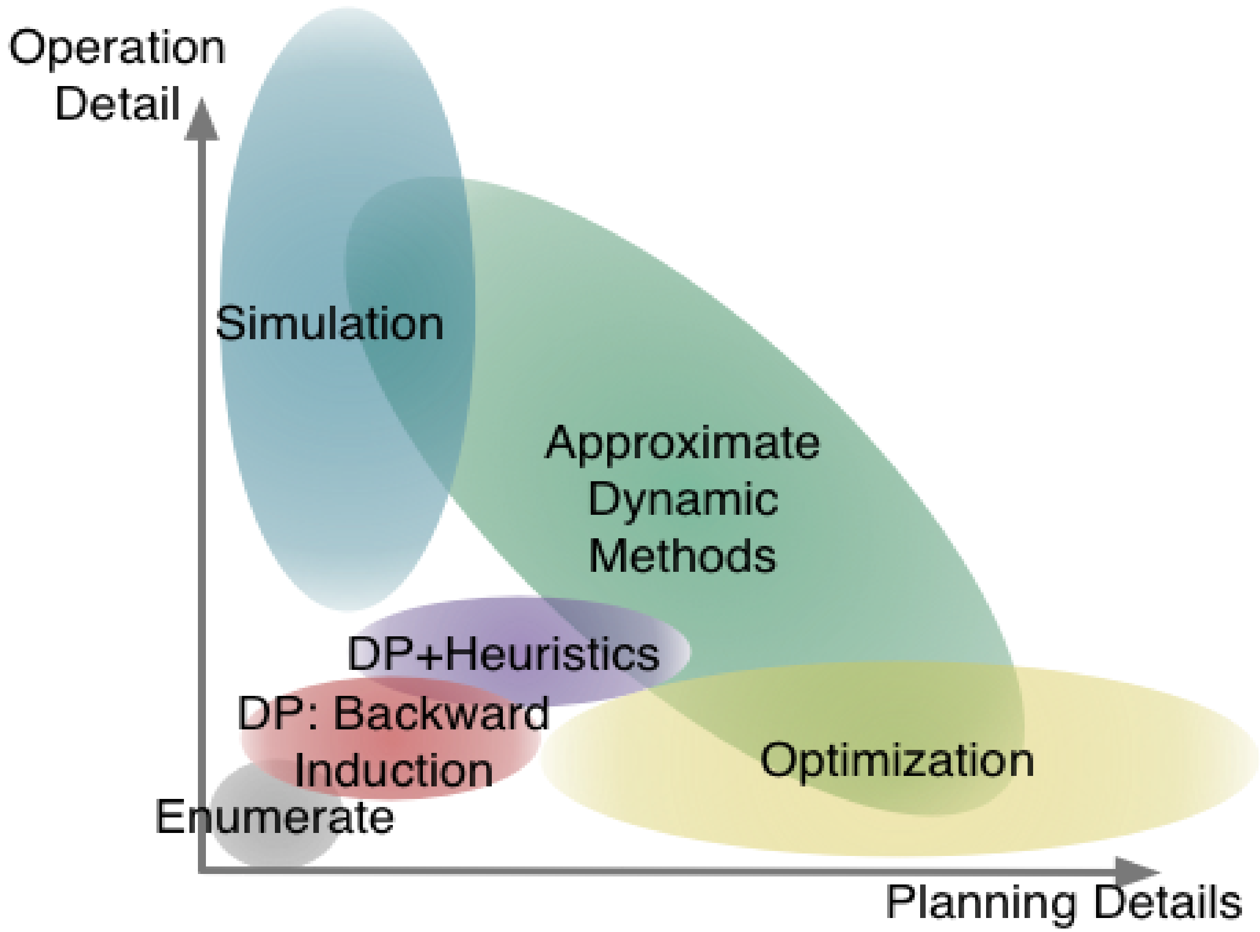
Advanced Power Systems will require more detailed ops during planning

- Ramping, Startup, Min
- Storage: Sequential
- Correlations: Renewables & Load
- Dynamic Pricing
- etc

Stochastic Dynamic Modeling

- Scenario Analysis (SA)
  - Exogenous uncertainty
- Stochastic Programming (SP)
  - Fixed Scenario trees
- (Stochastic) Dynamic Program. (DP)
  - Backward Induction via Bellman's
- Approximate DP (ADP)
  - Machine learning

Operations + Planning



Why Dynamic Programming

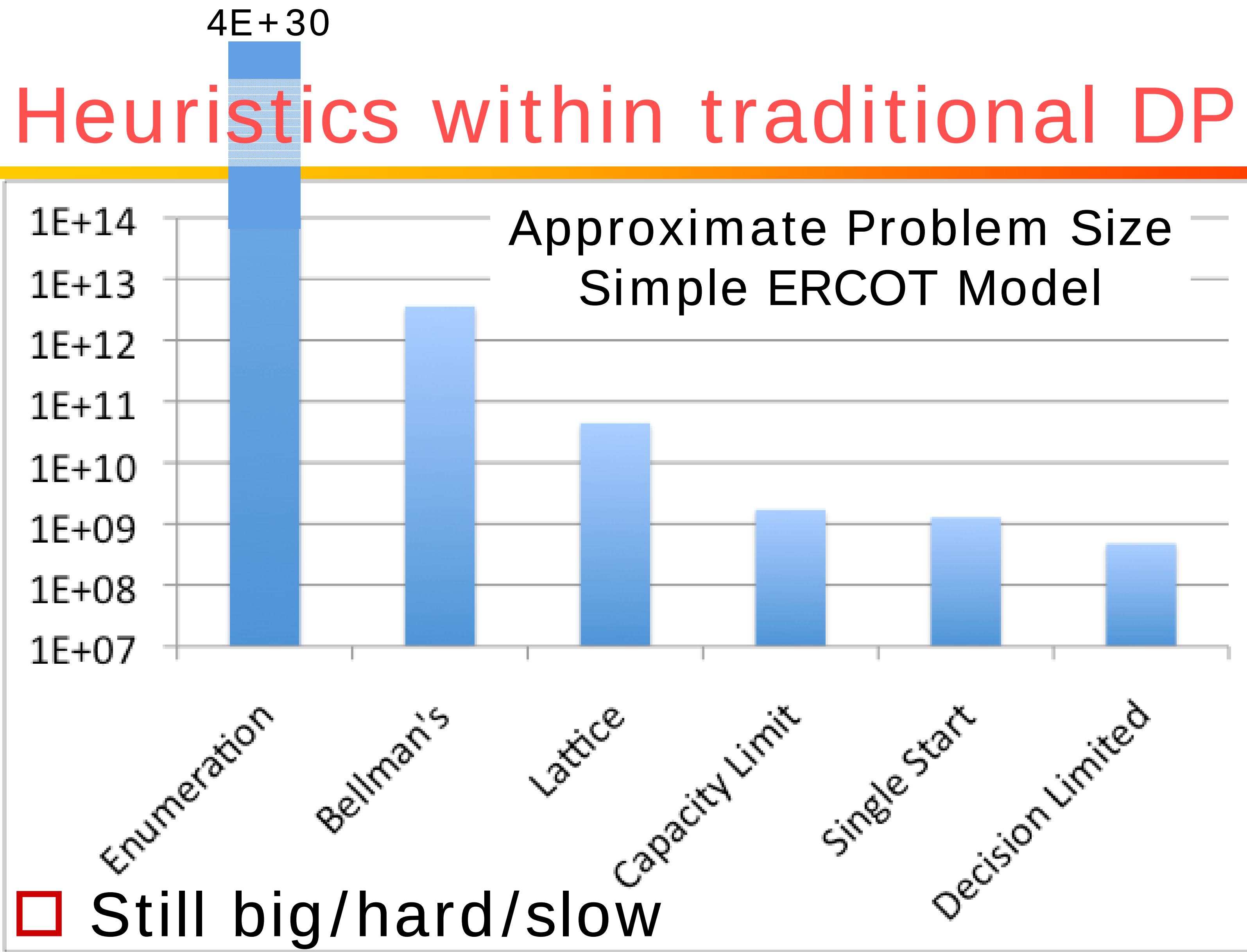
- Endogenous Uncertainty (vs SA)
  - Get rid of crystal ball
  - Actionable decision(s)
  - Value for flexibility
- Decision dependant uncertainty (vs SP)
  - Generation depends on Transmission
  - Efficiency investment
  - Fuel costs (Economic equilibrium)
  - Learning by doing
  - Climate Change

DP Challenges

- Curse(s) of Dimensionality

- Backward Induction assumes Markov
- Expensive sub-problem (Operations)

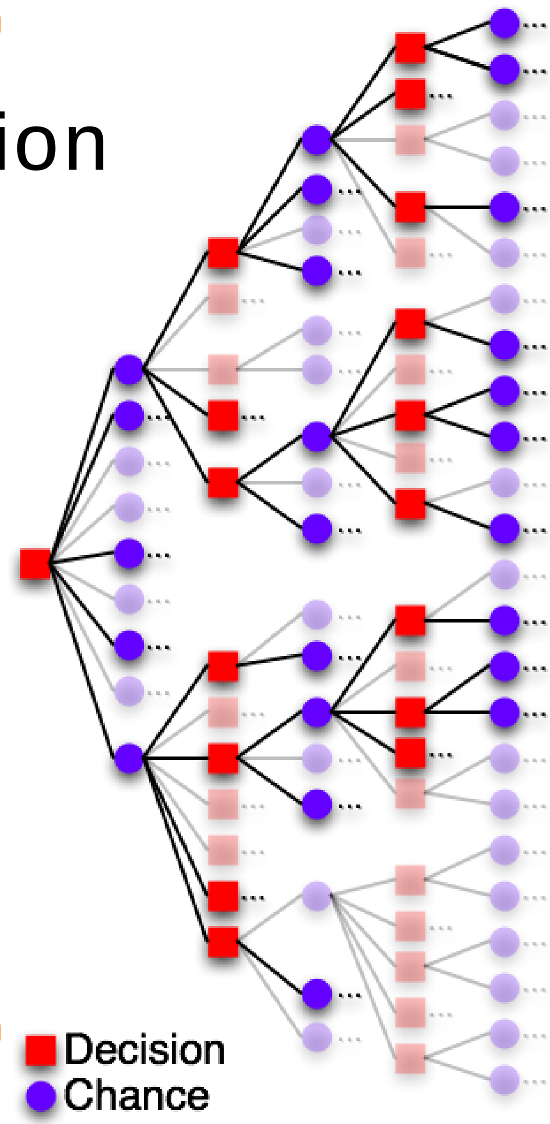
Heuristics within traditional DP



- Still big/hard/slow

Introducing ADP

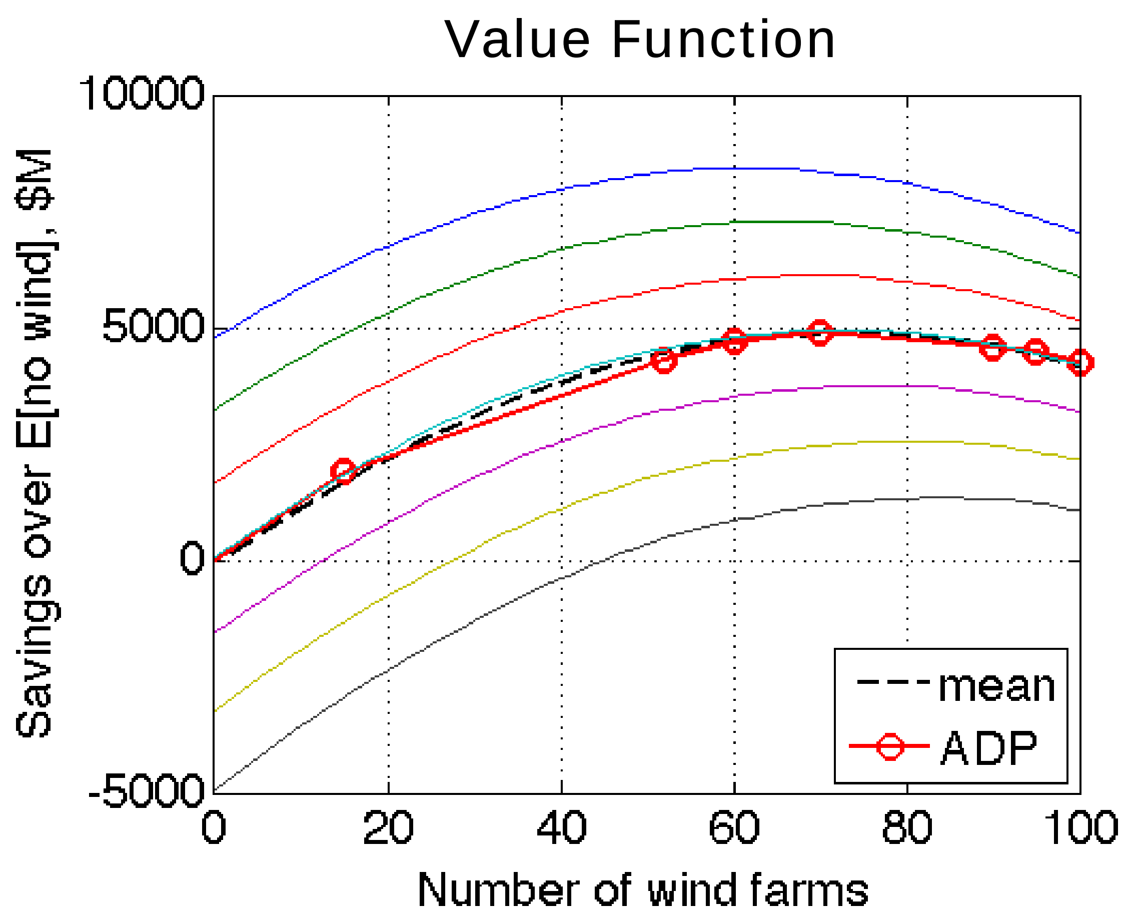
- Simulation+AI+Optimization
  - Forward Sampling
  - Learning
  - Ignore Dead Ends



ADP: Approximating Values

- Recursive Regression
- Update nearby
- Scenarios collapse to single value

- Size: 700 -> 11



Advantages of ADP

- Complex, n-Dimensional Uncertainty
  - Monte Carlo: fast (initial) convergence
- Path Dependency (vs DP)
- Multi-objective for free
  - Find environmental, political near-best from the value space
- Performance
  - vs Dynamic Programming!
  - vs Stochastic Programming??

ADP challenges

- Always an Approximation
- Heuristics require tuning
- Transparency?

The operations sub-problem

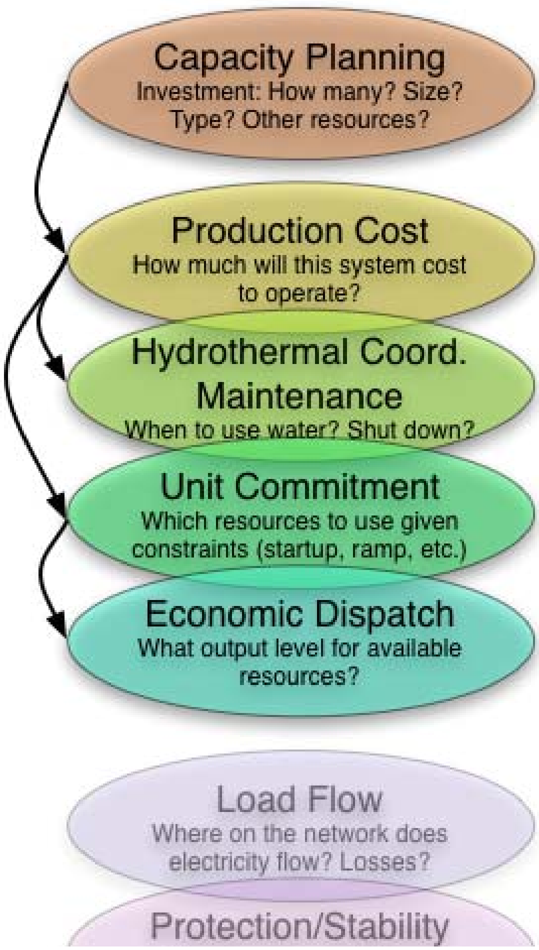
- Do we need to run…
  - All 8760? (x10?)
  - Every scenario?
- Sample of relevant periods
  - Typical weeks?
  - Joint Distribution of load & uncertainty
- Iterative refinement (ADP learning)
  - Start with improved LDC estimate
  - Refine with sampled week of production cost
  - Increase detail (SCUC) on later passes

CURRENT RESEARCH

Mort Webster's Lab
MIT's Engineering Systems Division

(My) Current Research: Unit Commitment in Planning

Designing Advanced Power Systems: Renewables, Active Demand, Storage



- Approx. Dynamic Program
- Sampling & Reuse of:
  - ⇐ Simple Heuristic
  - ⇐ 7-day (Stochastic?) UC
  - ⇐ With UC

Current Research: Technology Change

Integrating Policy-Induced Technology Change Dynamics into U.S. Electricity Generation Capacity Planning

Nidhi R. Santen

Main Objectives:

1. Develop an integrated modeling approach for evaluating the effect of uncertain R&D-induced electricity technology improvements on optimal policy planning.
2. Evaluate the trade-offs between "development-focused" and "adoption-focused" climate and technology policies, considering uncertainty in R&D returns.

Approach:

1. Empirically characterize uncertainty in R&D returns for several supply- and demand-side electricity technologies using patent citation data.
2. Couple an induced technology change model with a national-scale capacity planning model using patent citations to calibrate novel relationships between R&D returns and generation technology costs, technology availability years, and demand growth.
3. Use ADP to model sequential policy decisions under uncertain R&D returns, and study optimal near-term policies and associated electricity generation capacity evolutions.


Source: http://www.usmc.mil


Source: http://www.nmfs.noaa.gov

Current Research: Transmission Planning

Heuristics for Dynamic, Long-term Transmission Planning

Pearl Donohoo

- State of the art planning is static or dynamic optimization of simplified systems without foresight and limited treatment of uncertainty beyond reliability analysis
- Dimensionality precludes
- Transmission infrastructure is long lived, requiring robustness to variety of future generation and market configurations
- Relationship between transmission development and generation development is persevered, despite restructuring which decouples the investment

Current Research: Electrification in Africa

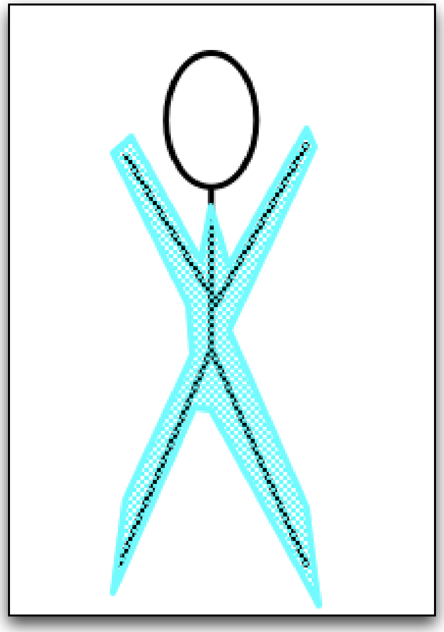
Incorporating Demand Dynamics into Long-term Electrification Planning: the Case of Tanzania

Rhonda Jordan

- National Goals in Tanzania:
  - Meet Existing & Future Electricity Demand
  - Increase Access
  - Improve/Maintain Quality of Service
- Extreme poverty
  - High sensitivity to price & service quality
  - Demand MUST be endogenous
- How should the Ministry meet targets?
  - What production? New capacity? New grid & off-grid connections? What subsidy should be offered?

Conclusions

- Approximation inherent in all methods
- Trade some ops detail for improved stochastic planning models
- ADP shows promise
  - Capture rich problem detail
  - AI + Simulation + Optimization
  - A custom trimmed loosely woven blanket?
- Looking for "real-world" partners



Questions?

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