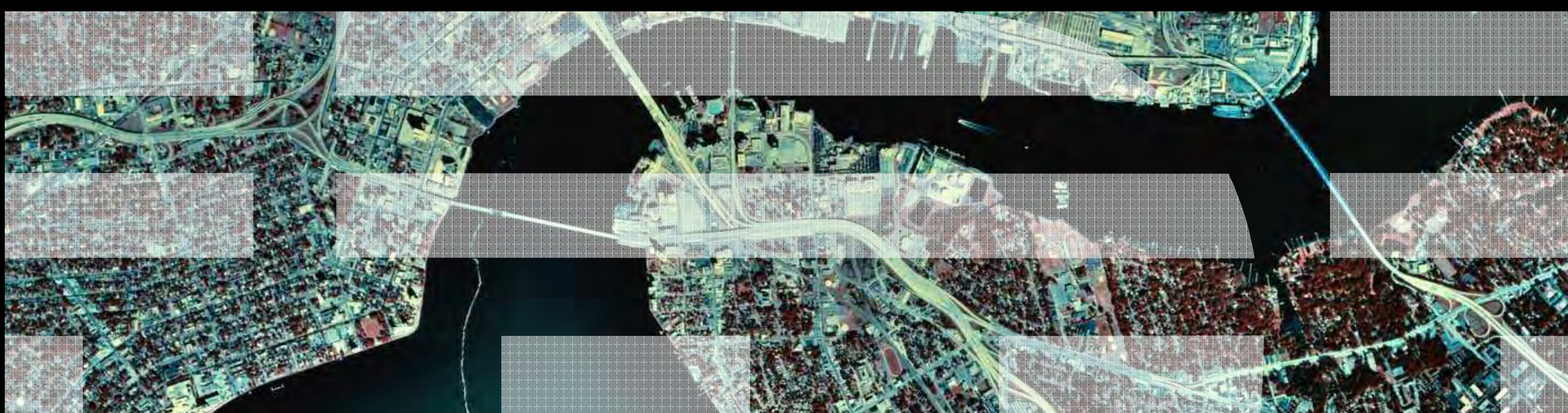
Juan Pablo Vielma

University of Pittsburgh and IBM Research

Risk control in ultimate pits using conditional simulations

Joint work with: Daniel Espinoza *Universidad de Chile* and Eduardo Moreno *Universidad Adolfo Ibañez*



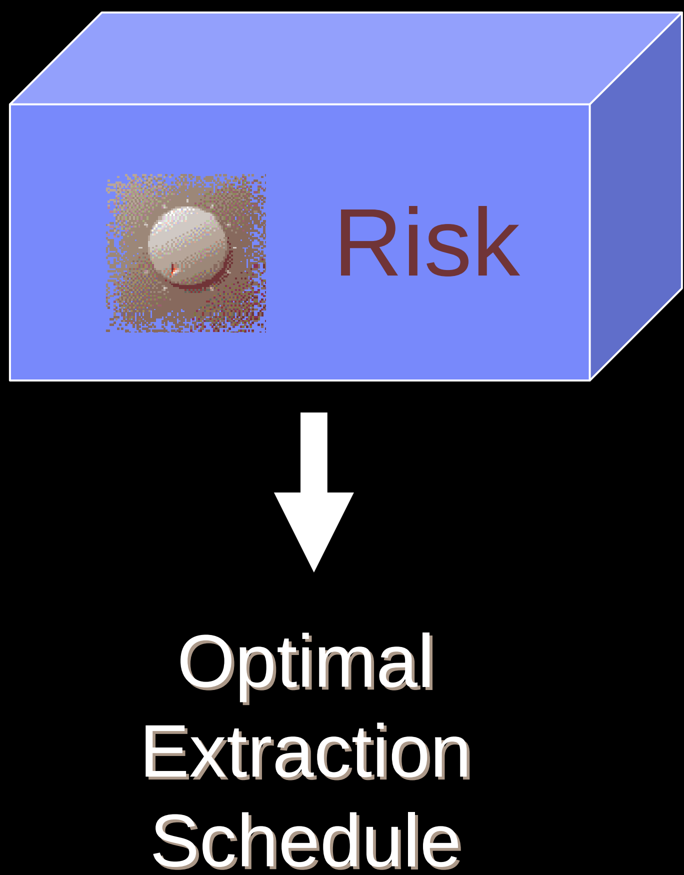
October 7, 2009 – Vancouver, Canada

Agenda

- Introduction
- Ultimate Pit with Risk Control
- Computational Study
- Conclusions

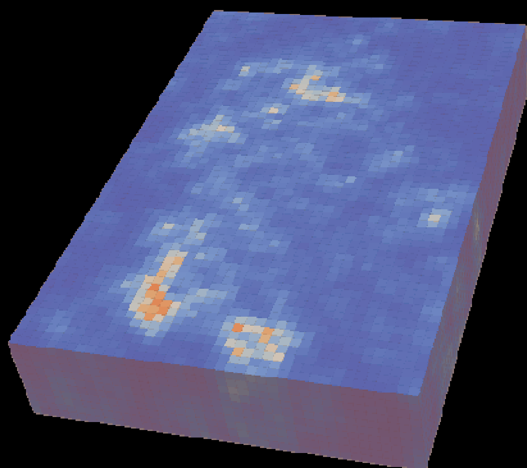
Introduction

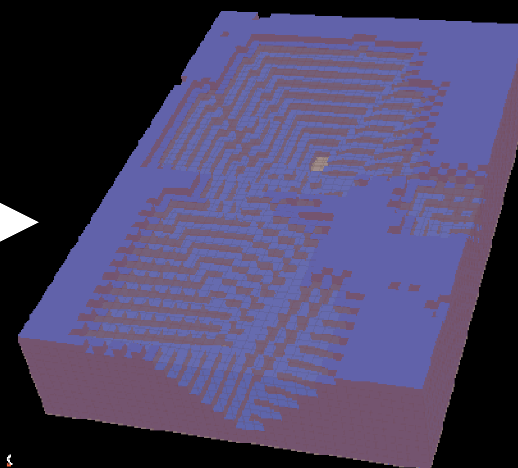
Explicit Risk Control for Open Pit Mine Planning



- Explicit Risk Control:
  - Explore tradeoffs (e.g. efficient frontier)
- First Step:
  - Risk control for ultimate pit problem
  - Only risk from geological uncertainty
  - Geological uncertainty model is from conditional simulation

Traditional Ultimate Pit (U-Pit)



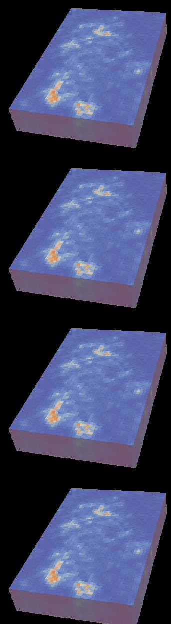


One block model from ordinary kriging

Optimization Software

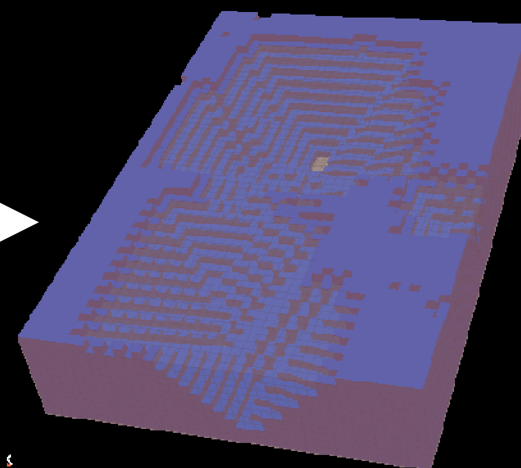
Ultimate Pit

Ultimate Pit Using Conditional Simulation



Multiple block models from conditional simulations

Optimization Software



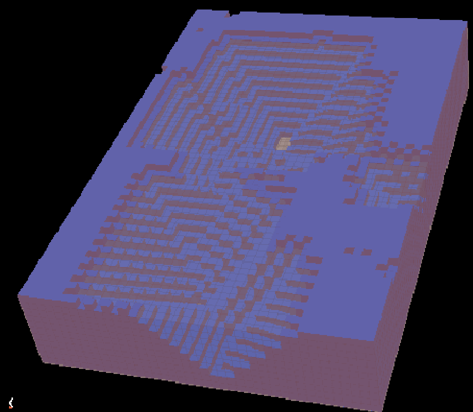
Ultimate Pit

Objectives of Study

- Introduce a version of U-pit with explicit risk control
  - 1 risk parameter: want efficient frontier
  - Use probabilistic constraints
- Compare optimal solutions to other risk mitigating approaches
- Study effect of varying number of conditional simulations

Ultimate Pit with Risk Control

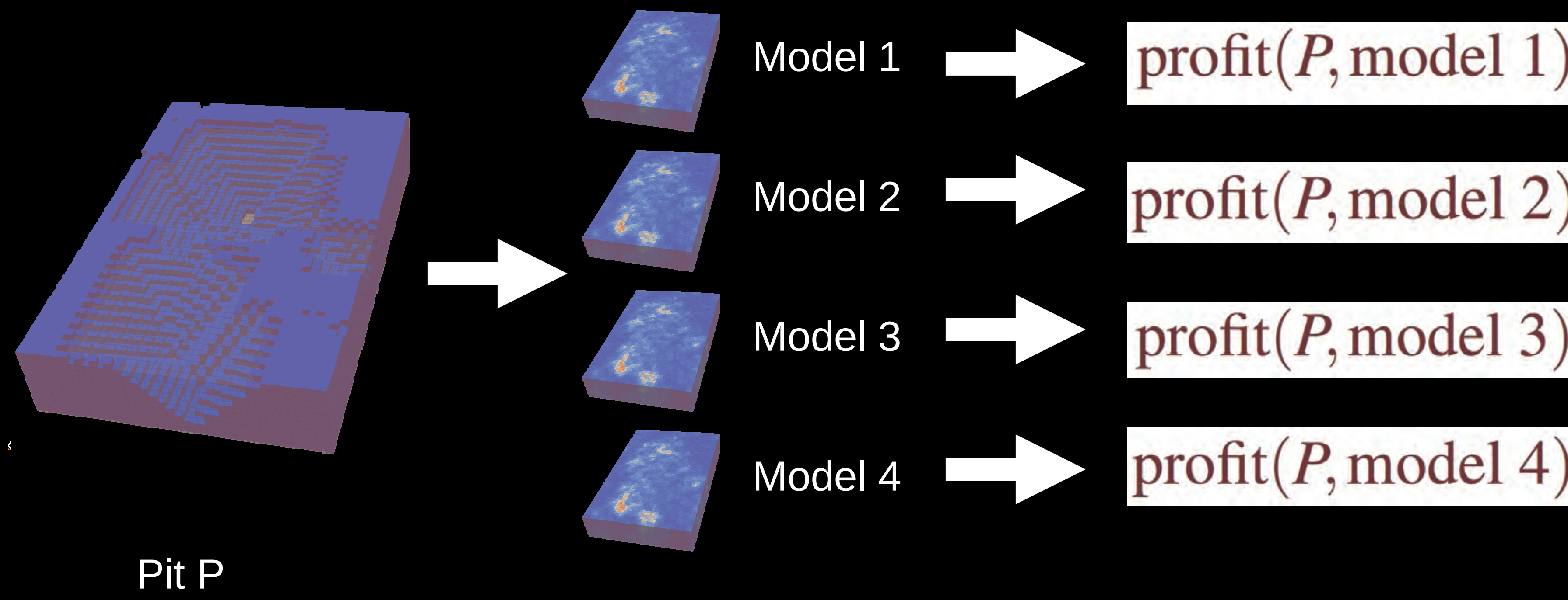
Ultimate Pit Optimization



$$\max \quad \text{profit}(P)$$
$$s.t. \quad P \text{ is a pit}$$

- Pit:
  - Group of blocks satisfying precedence constraints.
- Profit of Pit:
  - Sum of profits of blocks in pit.
- Ultimate Pit:
  - Pit that maximizes profit

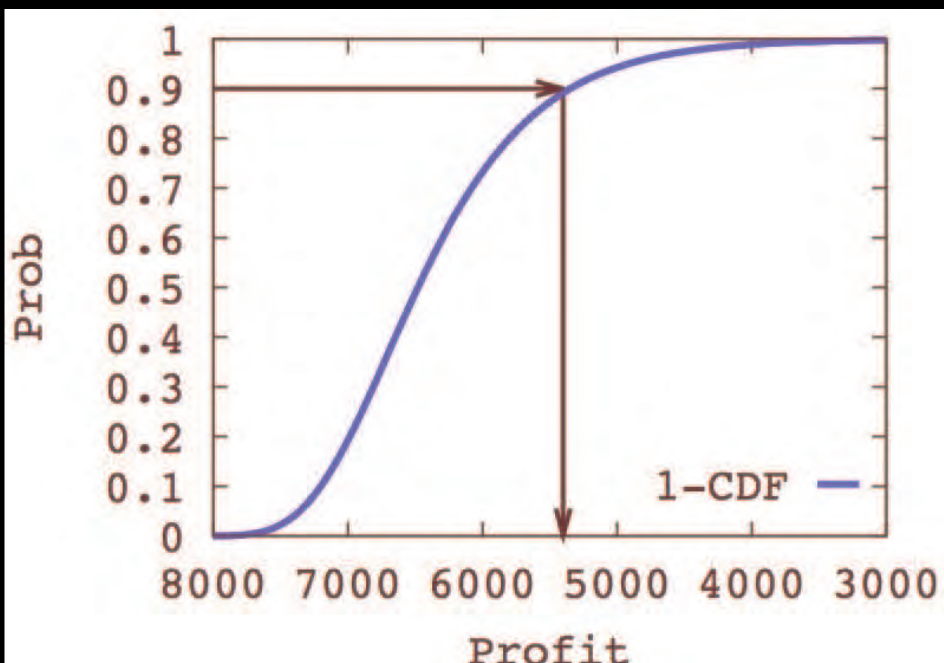
Profit and Block Models



- Profit of pit = random variable with 4 equally likely realizations

Risk Control for Random Profit

$$\text{profit}_\delta(P) := \max \quad z$$
$$s.t.$$
$$\text{Prob}(\text{profit}(P) \geq z) \geq \delta$$



- Quantile/VaR profit
  - –Restricts variability
  - –One risk parameter

U-Pit with Risk Control

$$\max \quad \text{profit}_\delta(P)$$
$$s.t.$$
$$P \text{ is a pit}$$

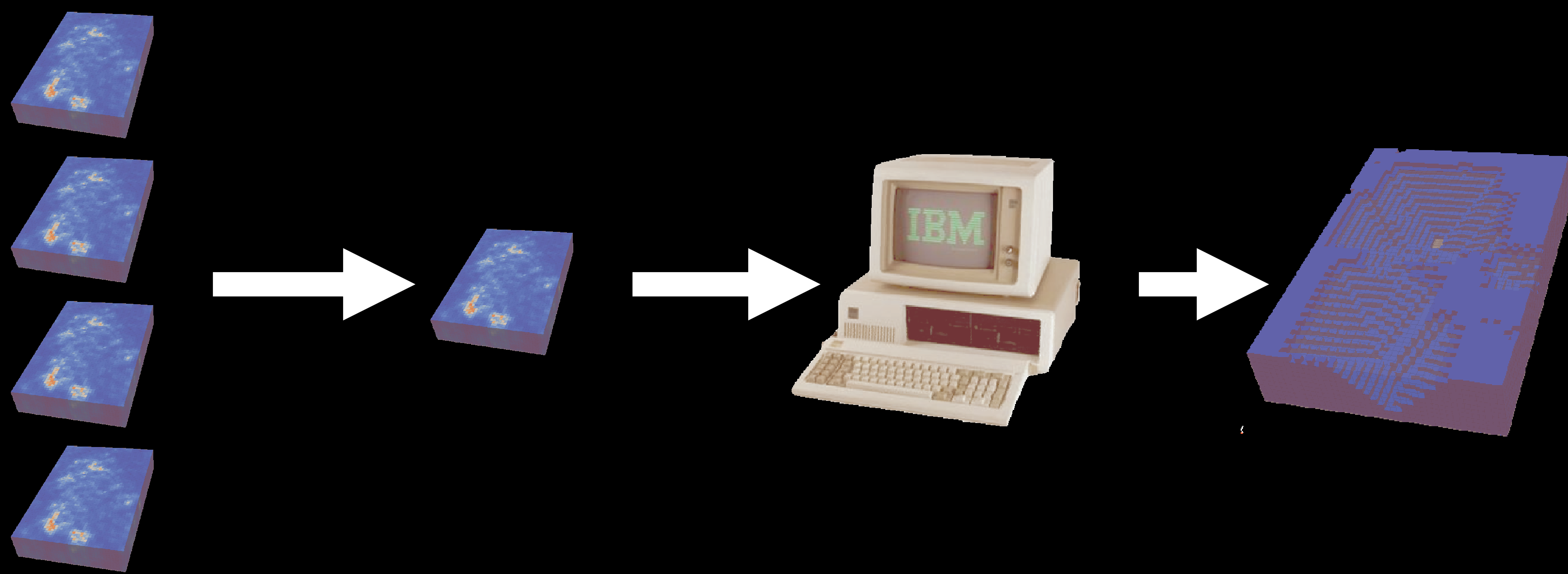
- Solve for several deltas
  - –Tradeoffs,
  - –Efficient Frontier,
  - –Sensitivity, etc.
- Can be modeled as an Integer Programming (IP) problem
  - –We denote it as SIP

Computational Study

Test Instance and Software

- Section of Andina copper mine in Chile
- 34140 blocks
- 10 conditional simulations using TBSIM
- Use CPLEX v11 and max-flow solver in EGLIB
- Methods: SIP and three existing approaches

“Average” Approach



Multiple block models

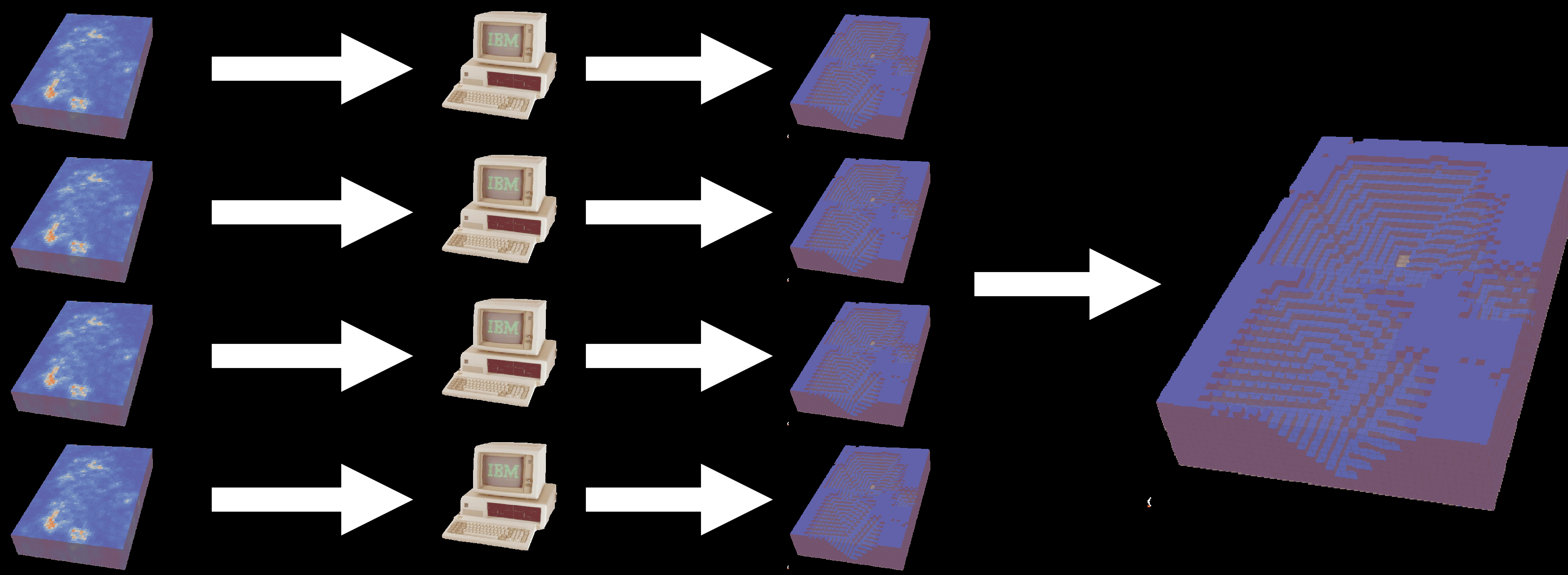
One average model

Optimization software

Ultimate pit

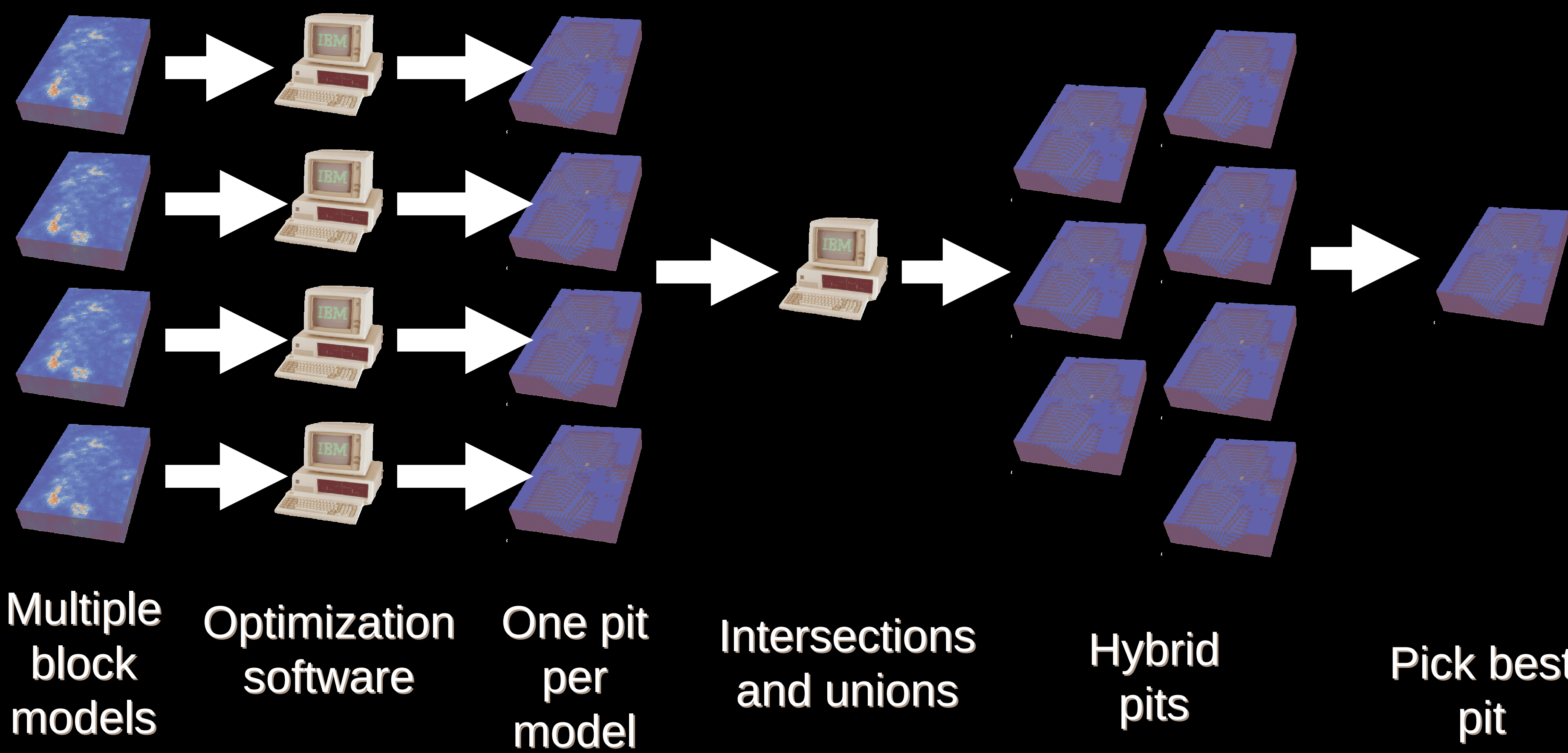
- Traditional U-Pit with kriging block model

“Simulations” Approach



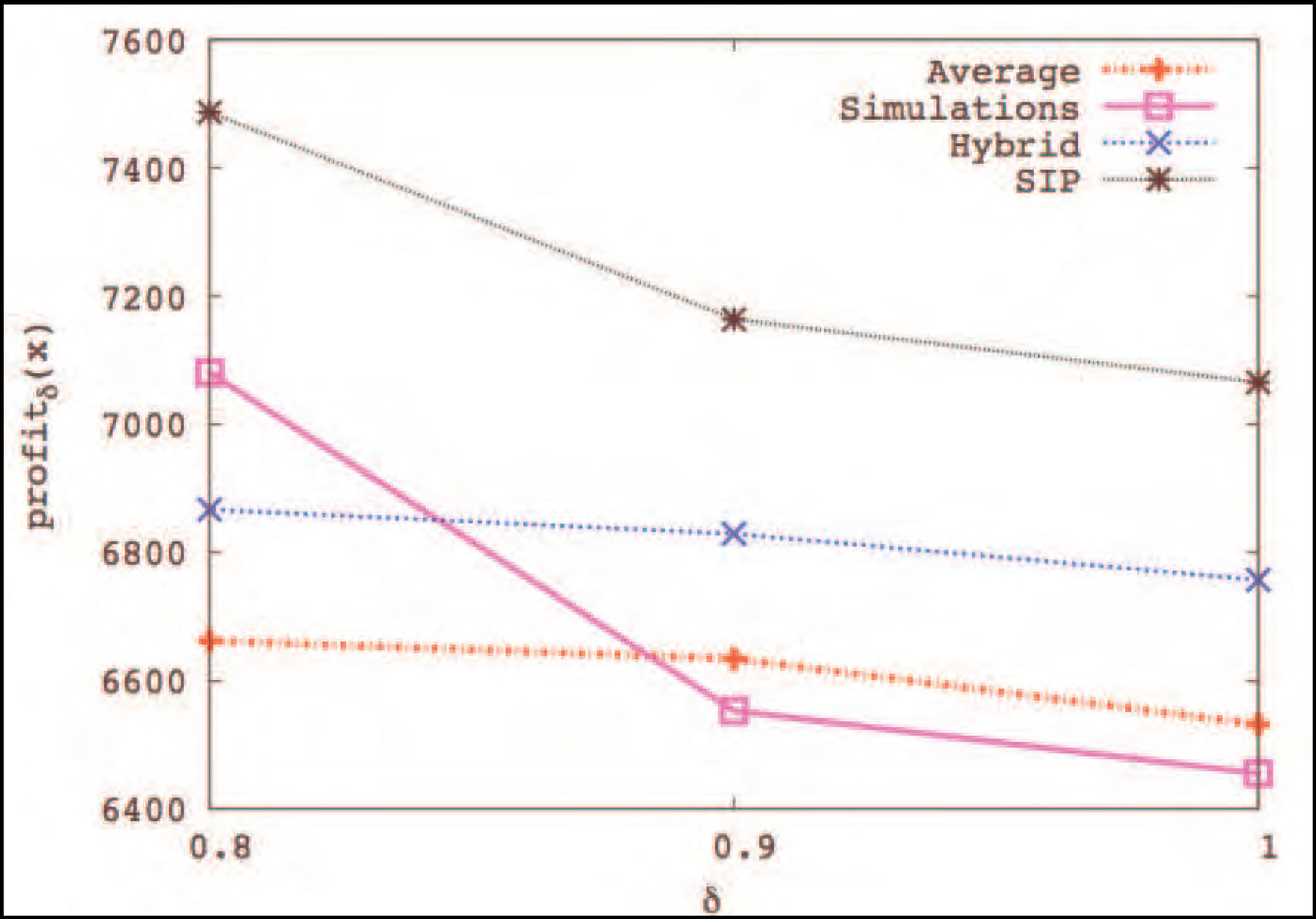
- Similar to Dimitrakopoulos et al. (2007).

“Hybrid” Pit Approach

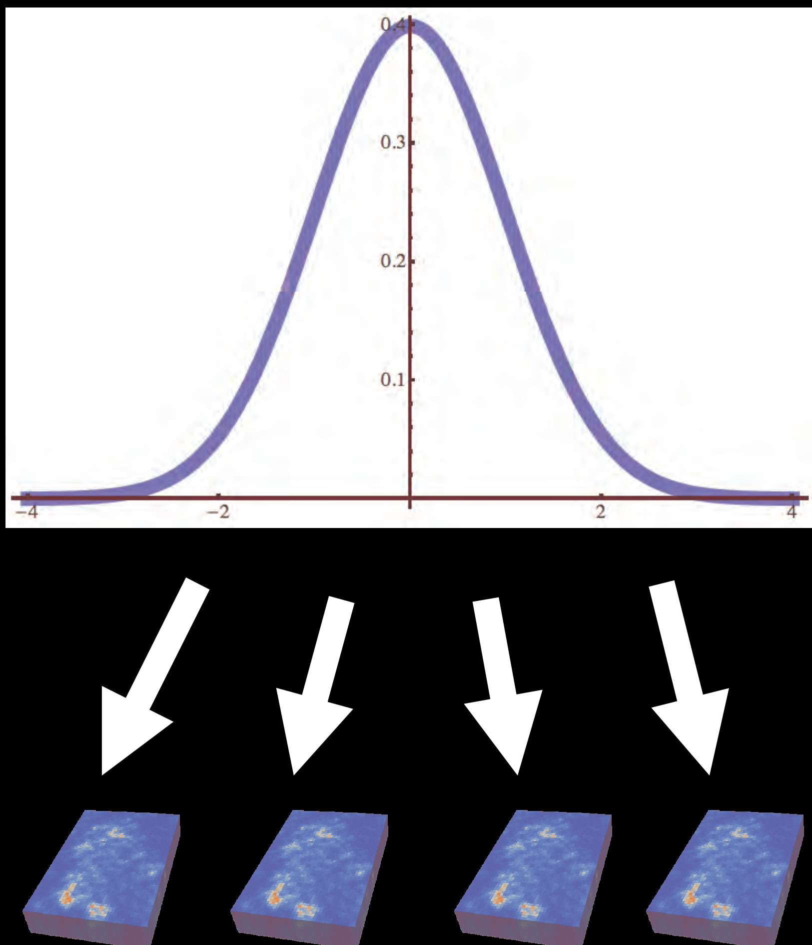


- Introduced in Whittle and Bozorgebrahimi (2007).

Results for 10 Simulations

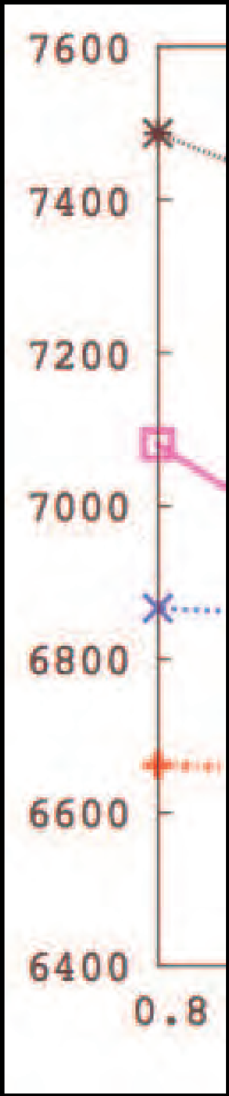


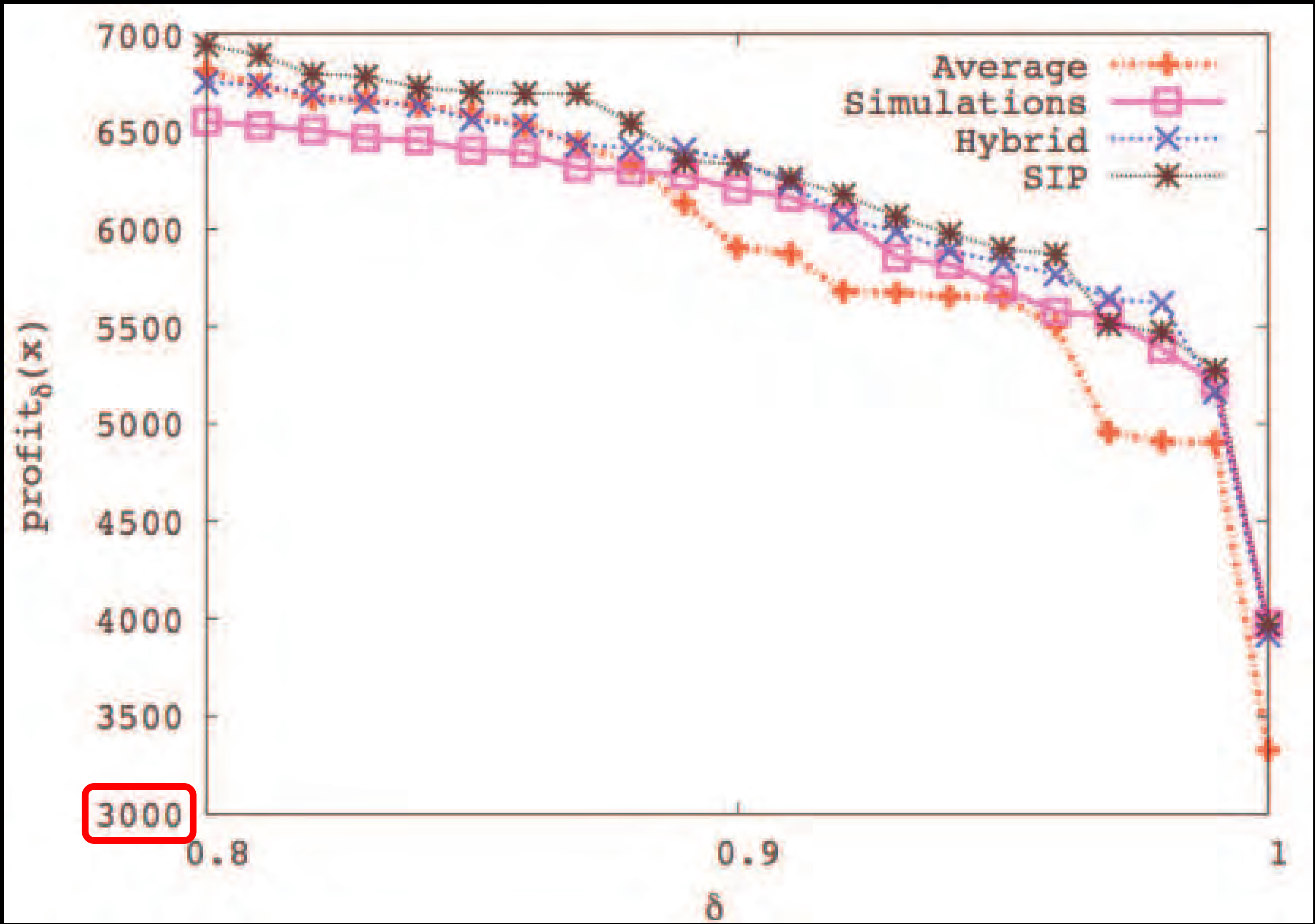
Simulations: Only Samples of Random Var



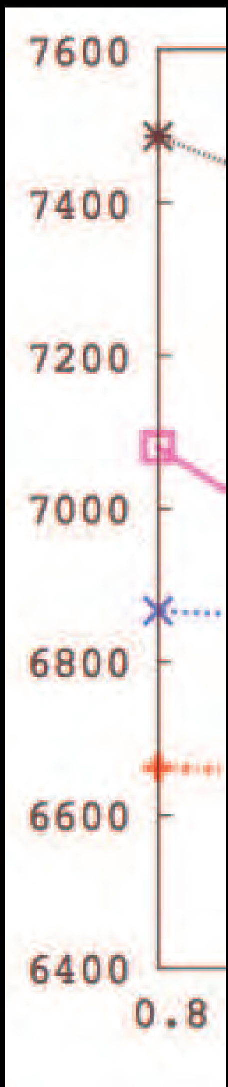
- Are 10 samples enough?
- Possible Test:
  - –Reevaluate solutions using 100 samples

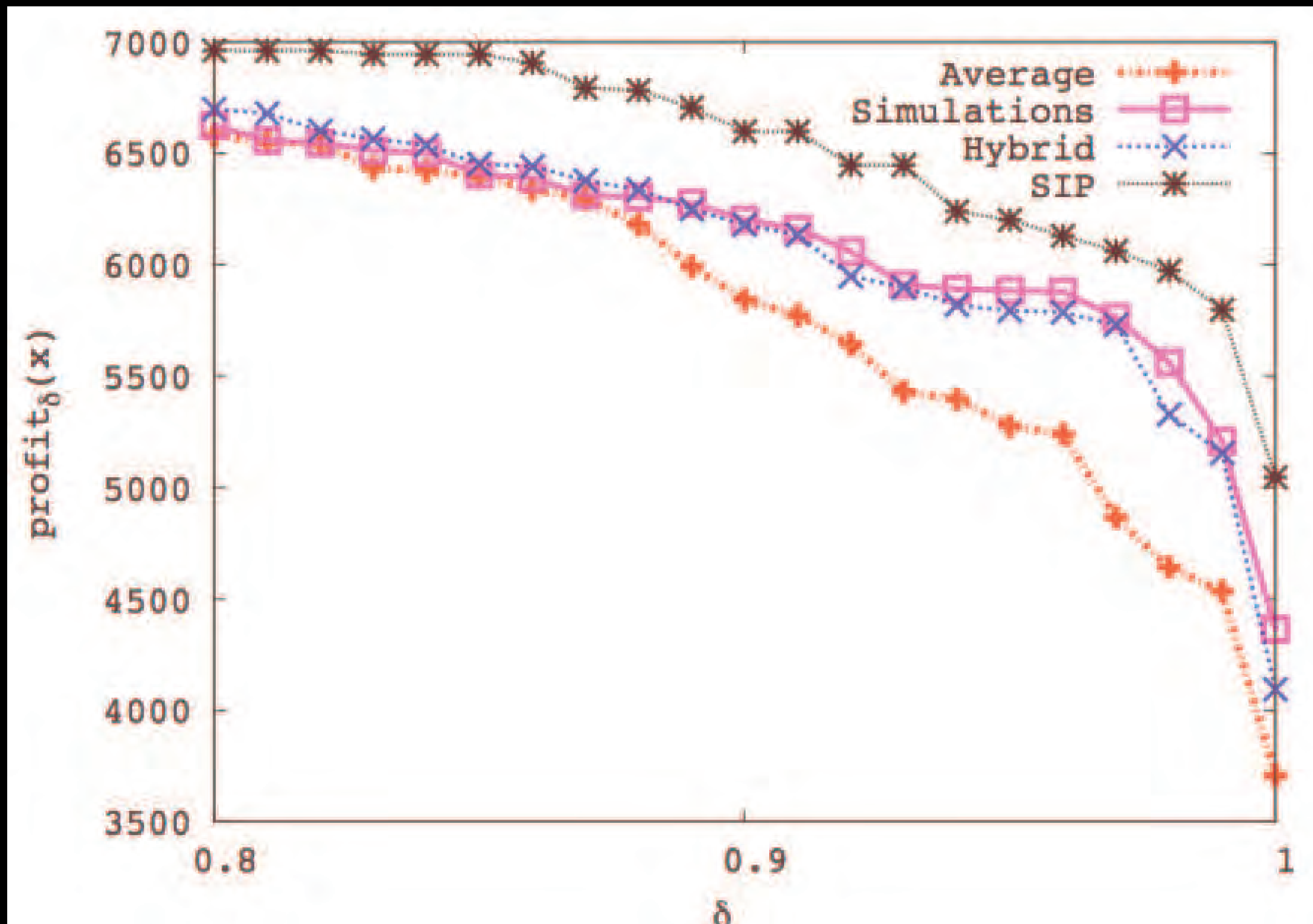
10 Sim Sols Reevaluated with 100 Sims





Results for 100 Simulations





Conclusions

Conclusions

- Propose probabilistic version of Ultimate Pit
  - Very hard to solve for large number of simulations
  - Other approaches are good heuristics but are suboptimal
- Study effect of varying number of simulations
  - Profit of 10 simulation solutions can be cut in half when evaluated with 100 simulations
  - Optimal profits can drop almost 30% from 10 to 100 simulations
- Future work
  - Other risk controls: Conditional value at risk?
  - Efficient solution of SIP
  - Use Sample Average Approximation to mitigate # of simulations effect
  - Other mines, other risk sources
  - Risk control for the complete schedule generation