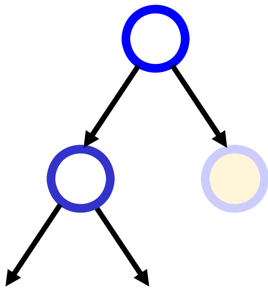
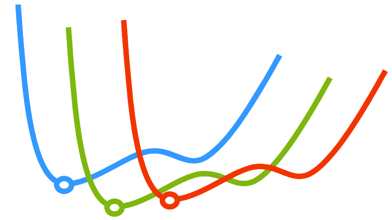
  

Quantum Computation for Machine Learning, AI, and Optimization

Nick Sahinidis

Carnegie Mellon University

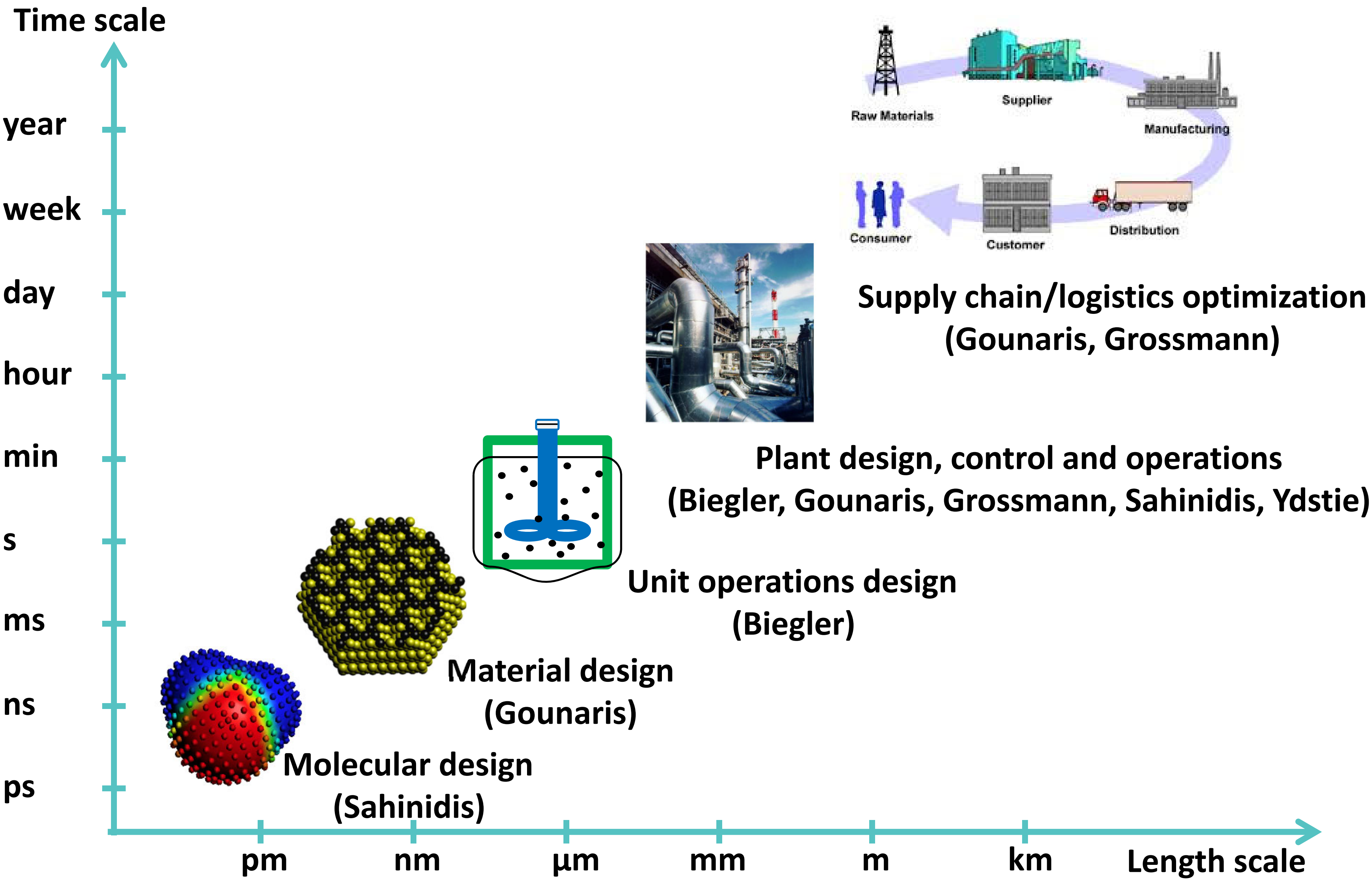
Center for Advanced Process Decision-making

Sahinidis@cmu.edu

Carnegie Mellon University

CAPD CENTER

PROCESS SYSTEMS ENGINEERING



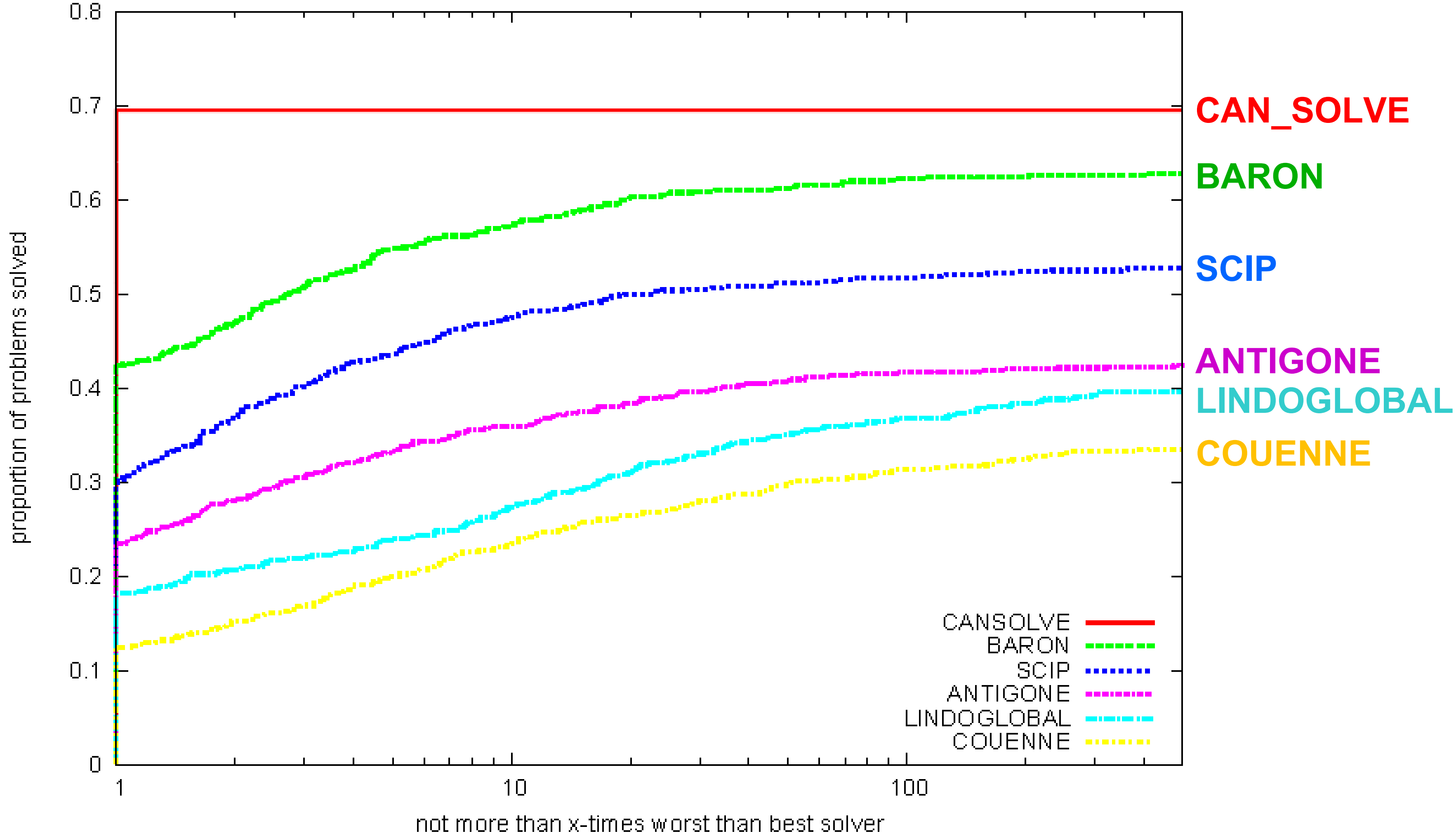
GLOBAL MINLP OPTIMIZATION

$$\begin{aligned} \min \quad & f(x,y) \\ \text{s.t.} \quad & g(x,y) \le 0 \\ & x \in R^n, \;\; y \in Z^p \end{aligned}$$

- Multimodal objective
- Nonconvex constraints
- Integrality conditions

NP-HARD PROBLEM

GLOBAL MINLP SOLVERS ON MINLPLIB2



Comparisons based on solver ability to prove global optimality

ADIABATIC QUANTUM COMPUTATION

$$\min f(y)$$

- **Here, $y \in \{0,1\}^n$ and f is a polynomial**
  - Each binary variable is mapped into a quantum spin (qubit)
  - The objective defines many-body interaction between spins
  - Exponentially faster than classic algorithms
- **When f is quadratic, we have a Quadratic Unconstrained Binary Optimization (QUBO) problem**
  - Ising model
- **Integer nonlinear optimization problems and decision-making problems can be cast into QUBOs**
  - All of Karp's 21 NP-complete problems
  - Quadratic assignment, set partitioning, …
  - Unsupervised machine learning
  - Supervised machine learning

CHALLENGES IN HYBRID ALGORITHMS

- **Cast integer nonlinear optimization problems into QUBO problems**
  - Lucas (2014); Glover et al. (2019)
- **Embed QUBO into quantum hardware**
  - Nonconvex integer nonlinear optimization
- **Solve QUBO**
  - Is it possible to obtain exact solutions?
  - Approximate solutions still of value
  - Randomization
- **Recover solutions**
- **Programming challenges**
- **Hardware issues such as error correction**