Machine Learning for Accelerators

Automatic Accelerator Tuning

Emmanuel Goutierre[1, 2]

[1]IJCLab

[2]LISN

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Outline

1. Automatic Accelerator Tuning Problem
   - Mathematical Formulation
   - Challenges

2. Machine Learning meets Accelerator Tuning
   - Surrogate Models to Speedup Accelerator Optimization
   - Reality Gap between Simulator and Accelerator
   - Exploration vs. Exploitation Tradeoff to Discover Internal State

Outline

Automatic Accelerator Tuning Problem

Mathematical Formulation of the Problem: Parameters

Accelerator Description

- $\mathcal{A}$: Set of controllable commands of the accelerator
- Θ : Set of non-controllable commands of the accelerator
- $\mathcal{O}$: Set of observations of the state of the accelerator

Automatic Accelerator Tuning Problem

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- Solenoid strength
- RF phase
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- Elements position
- Accelerating section misalignments
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$\mathcal{O}$

- BPM
- ICT
- Screen station
- ...

Automatic Accelerator Tuning Problem

Mathematical Formulation of the Problem: Optimization Function

What is the objective

- optimize $(\epsilon_x, \epsilon_y, \Delta E, \sigma_x, \sigma_y, \dots) = f(\theta, A)$

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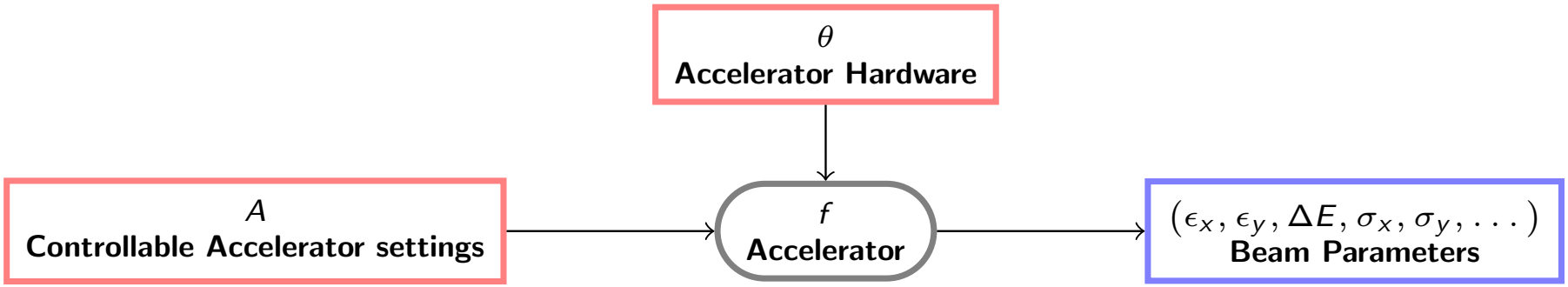

Automatic Accelerator Tuning Problem

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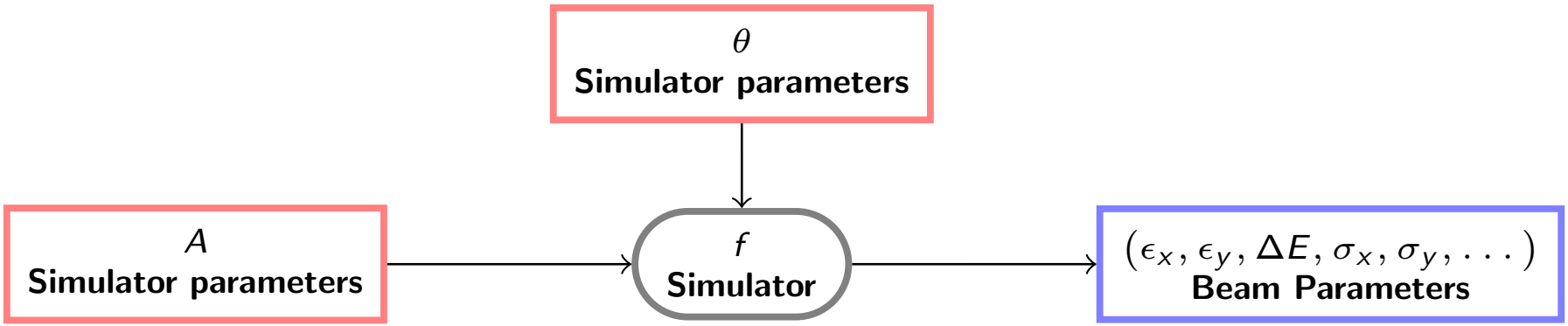

Automatic Accelerator Tuning Problem

Mathematical Formulation of the Problem: Optimization Function

What is the objective

- optimize $(\epsilon_x, \epsilon_y, \Delta E, \sigma_x, \sigma_y, \dots) = f(\theta, A)$
- Multi objective, parametric, black box optimization

Automatic Accelerator Tuning Problem

Mathematical Formulation of the Problem: Problems

Problems . . .

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Automatic Accelerator Tuning Problem

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4. θ is partially unknown

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Mathematical Formulation of the Problem: Problems

Problems . . .

1. The function f to optimize is rarely directly observed in real life
2. Simulators computational time can be huge
3. Simulations are not perfectly representing the reality
4. θ is partially unknown
5. θ is potentially not fixed on an accelerator

Outline

Surrogate Models to Speedup Accelerator Optimization

Problem

- Simulators computational time can be huge (2)

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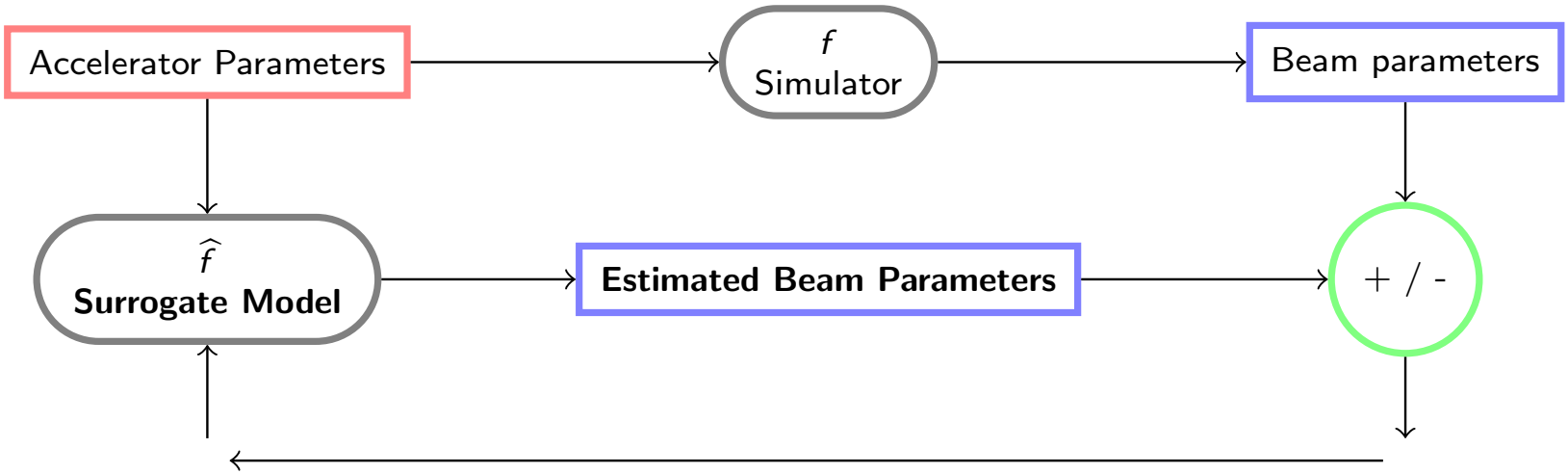
Solution

- Compute surrogate model



Surrogate Models to Speedup Accelerator Optimization

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- Simulators computational time can be huge (2)

Solution

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Tool

- Supervised Learning and Neural Networks[a]

[a] Edelen et al., 2020.

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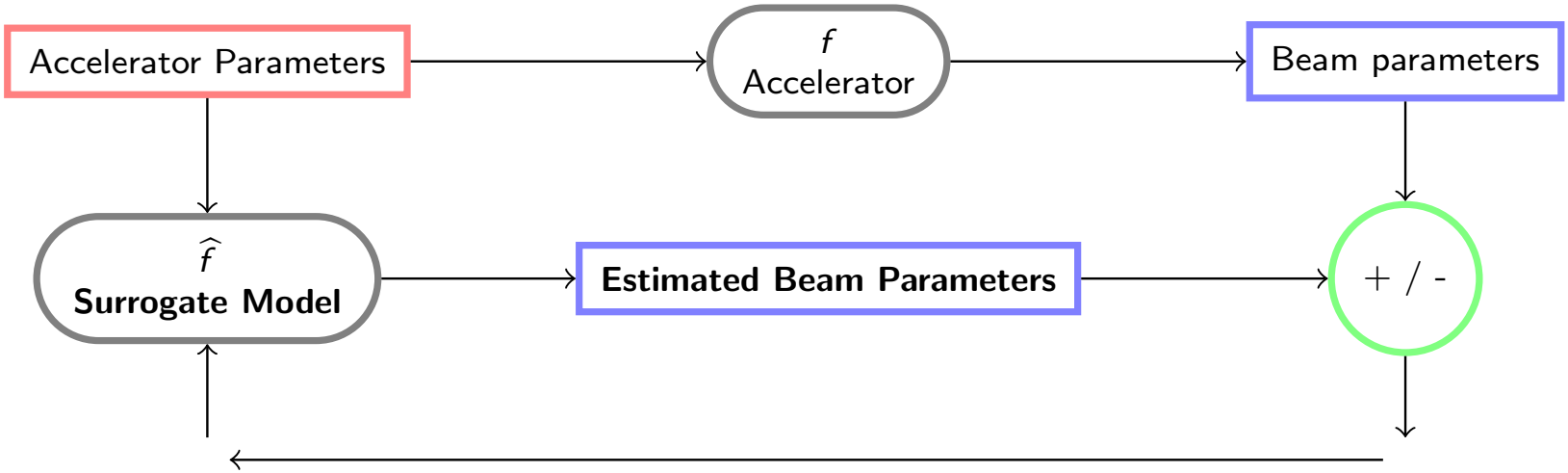
- Incorporate experimental data



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Solution

- Incorporate experimental data
- Learn to discriminate real data from generated data

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Tool

- Fine Tuning
- Generative Adversarial Networks

Exploration vs. Exploitation Tradeoff to Discover Internal State

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- Partially unobserved and changing environment (1, 4, 5)

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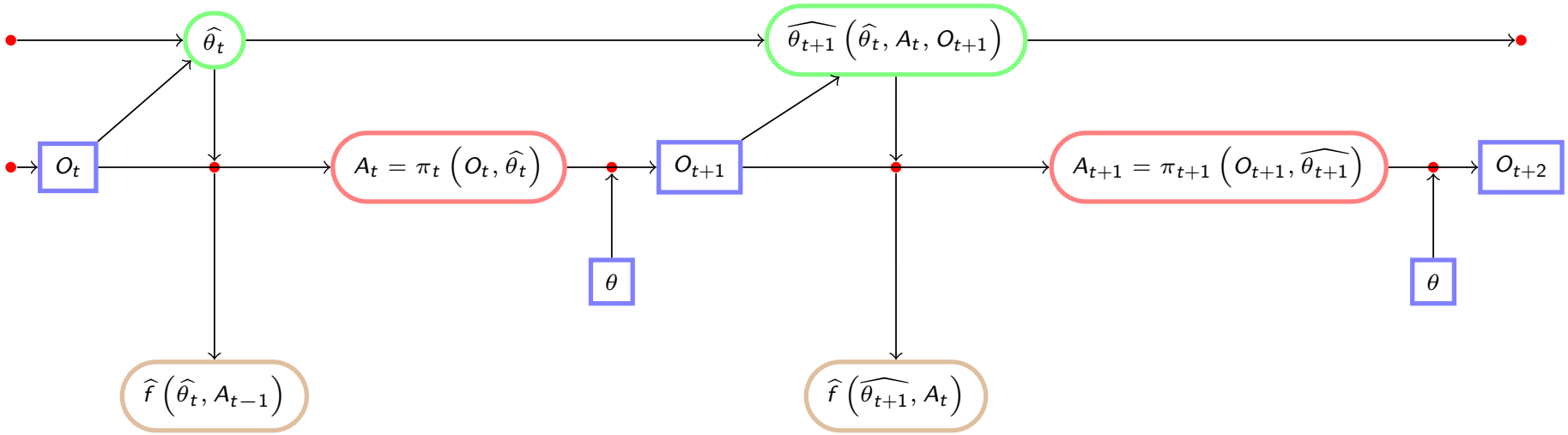
Solution

- Partially Observable Markov Decision Process



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Solution

- RL (Reinforcement Learning)

Questions?