Smart Sensors, Smarter Placement: Where Should They Go?

Paula Cordero Encinar, Tobias Schröder, Andrew Duncan

IMPERIAL

How would you decide where to optimally place the weather stations?

Environmental sensors play a crucial role in monitoring weather conditions and the impact of climate change. However, it is challenging to place them in a way such that it maximises the informativeness of their measurements, especially in remote regions like the Antarctica or in the open sea, where deployment costs are high.

Why is this difficult?

The **dynamics** of systems like the Earth are driven by complex stochastic equations.

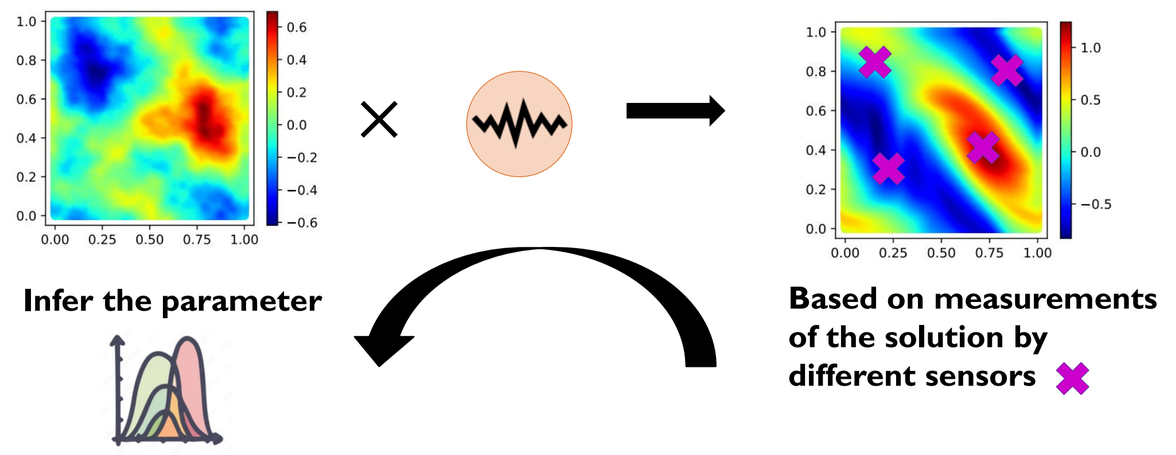
$\mathcal{G}: \mathcal{A} \times \mathcal{B} \to \mathcal{U}$

- $\mathcal{B}$: Unknown source of noise (**randomness**)
- $\mathcal{U}$: Solution space, e.g. **temperature**
- $\mathcal{A}$: Parameter space, **quantity that cannot be measured**

GOALS

Inverse problem: Given noisy observations of the solution $y_i = \mathcal{G}(a)(\boldsymbol{x}_i) + \eta_i$, **infer the parameter $\boldsymbol{a}$**

Sensor placement: Determine measurement positions $\boldsymbol{x}$ that yield the most information about solution and parameter, i.e. maximise the value of the data



CHALLENGES

Efficiency: Existing methods need to be run on very expensive high-performance computing clusters and can take weeks or even months to run

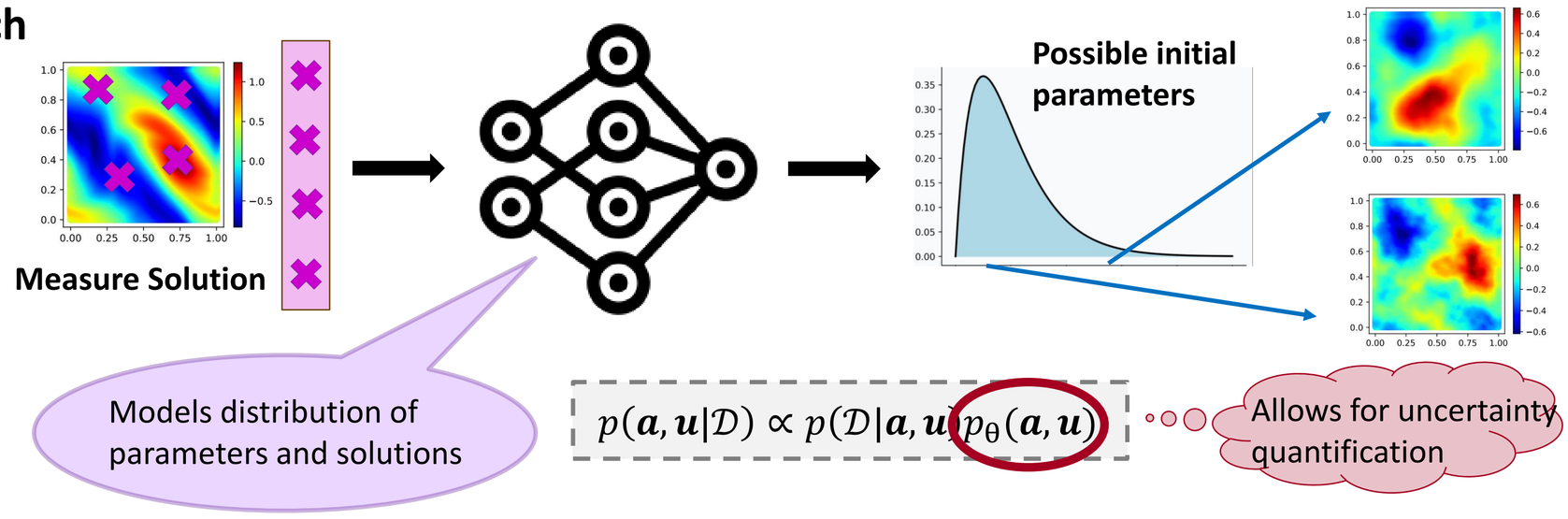
Resolution invariant: We want to learn the functions at any point not only in a grid

Complex and random dynamics: Different initial parameters can lead to the same output

SOLUTION

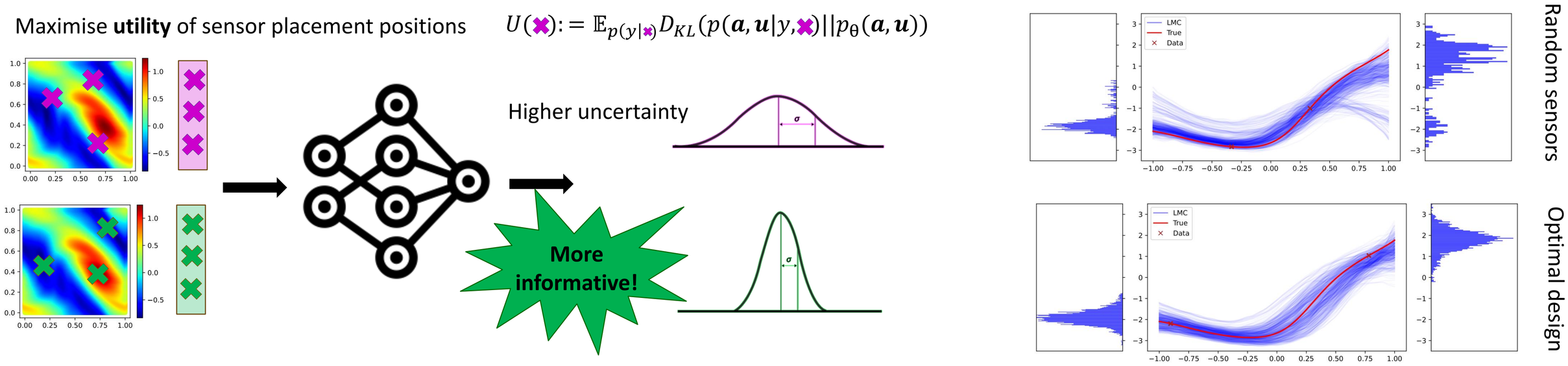
We use a machine learning model $\boldsymbol{p_\theta}$ to represent complex probabilitistic relationships between parameters and solutions. This provides a **surrogate** to the complex stochastic model. Our approach can run on small to medium-sized computer systems and takes minutes.

Bayesian Approach



Bayesian Experimental Design: How to find optimal sensor placement positions to improve inference?

Maximise **utility** of sensor placement positions $U(\times) := \mathbb{E}_{p(y|\times)} D_{KL}(p(\boldsymbol{a}, \boldsymbol{u}|y, \times)||p_\theta(\boldsymbol{a}, \boldsymbol{u}))$



Ongoing research

? If we have different sensors and some of them are more precise than others, how do we place them?

What if we have to select not a set of sensor points ✖ but the route that a submarine follows to take measurements?