Uncertainty Quantification for Electronic System Design

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Outline

- Dynamic Steady-State Temperature Analysis and Reliability Optimization
- Statistical Analysis of Process Variation Based on Indirect Measurements
- Probabilistic Analysis of Power and Temperature Under Process Variation
- Temperature-Centric Reliability Analysis and Optimization Under Process Variation

Outline

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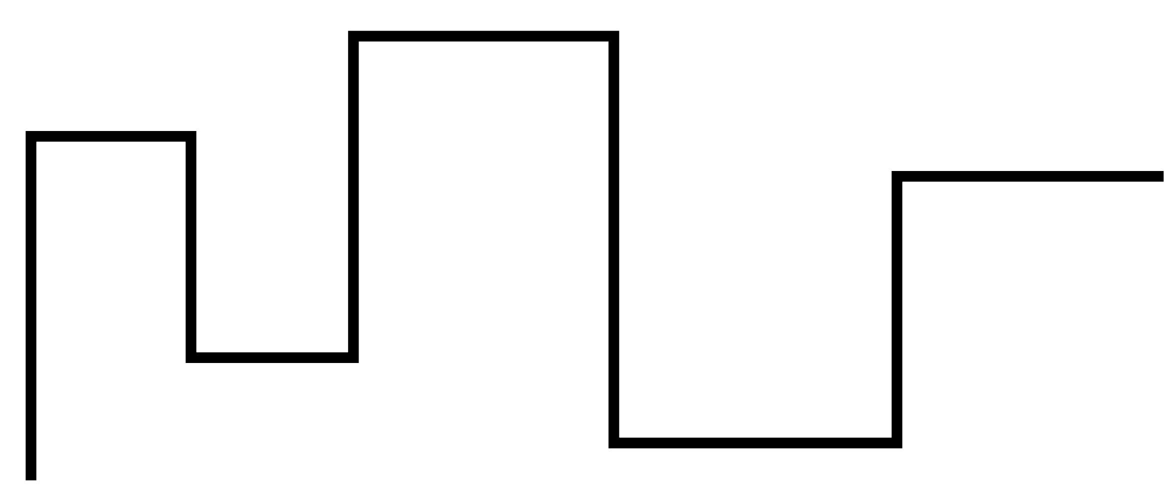
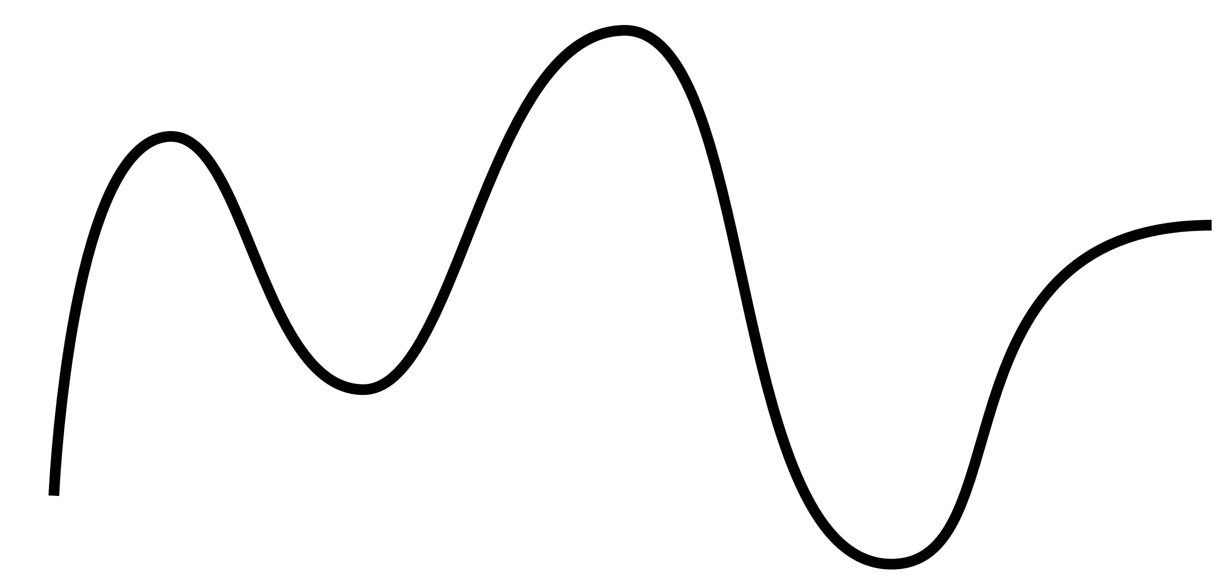
Temperature Analysis

* Transient



Power



Temperature

Temperature Analysis

* Static steady state

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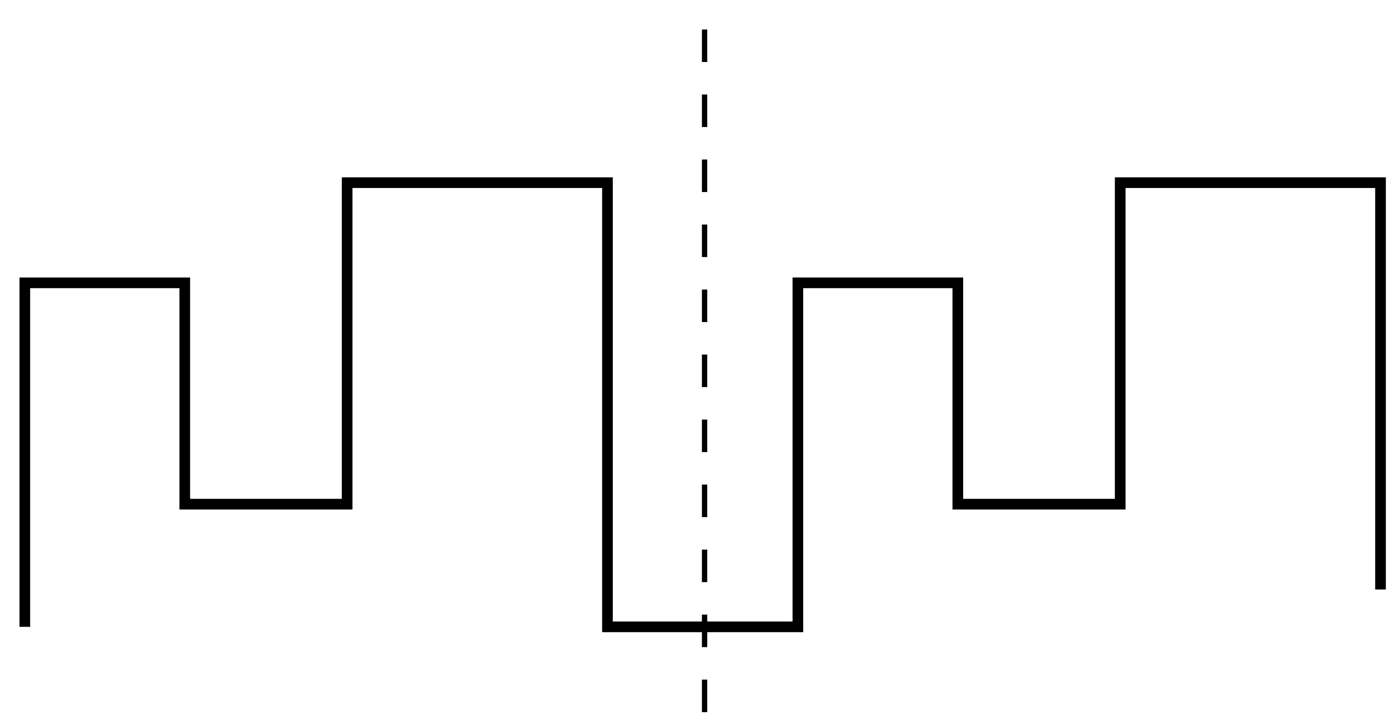
Power

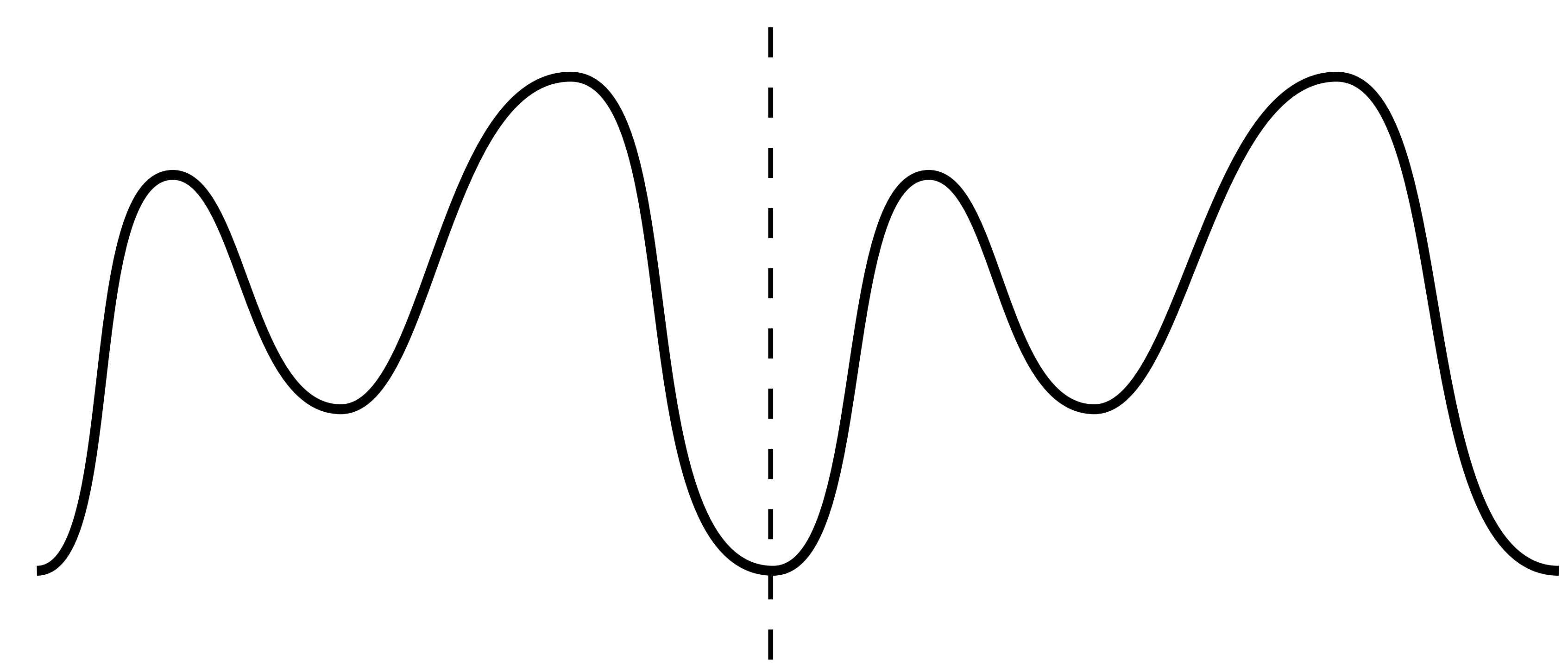
Temperature

Temperature Analysis

* Dynamic steady state



Power



Temperature

Our Goal

Given:

* Multiprocessor system
* Periodic dynamic power profile

Find:

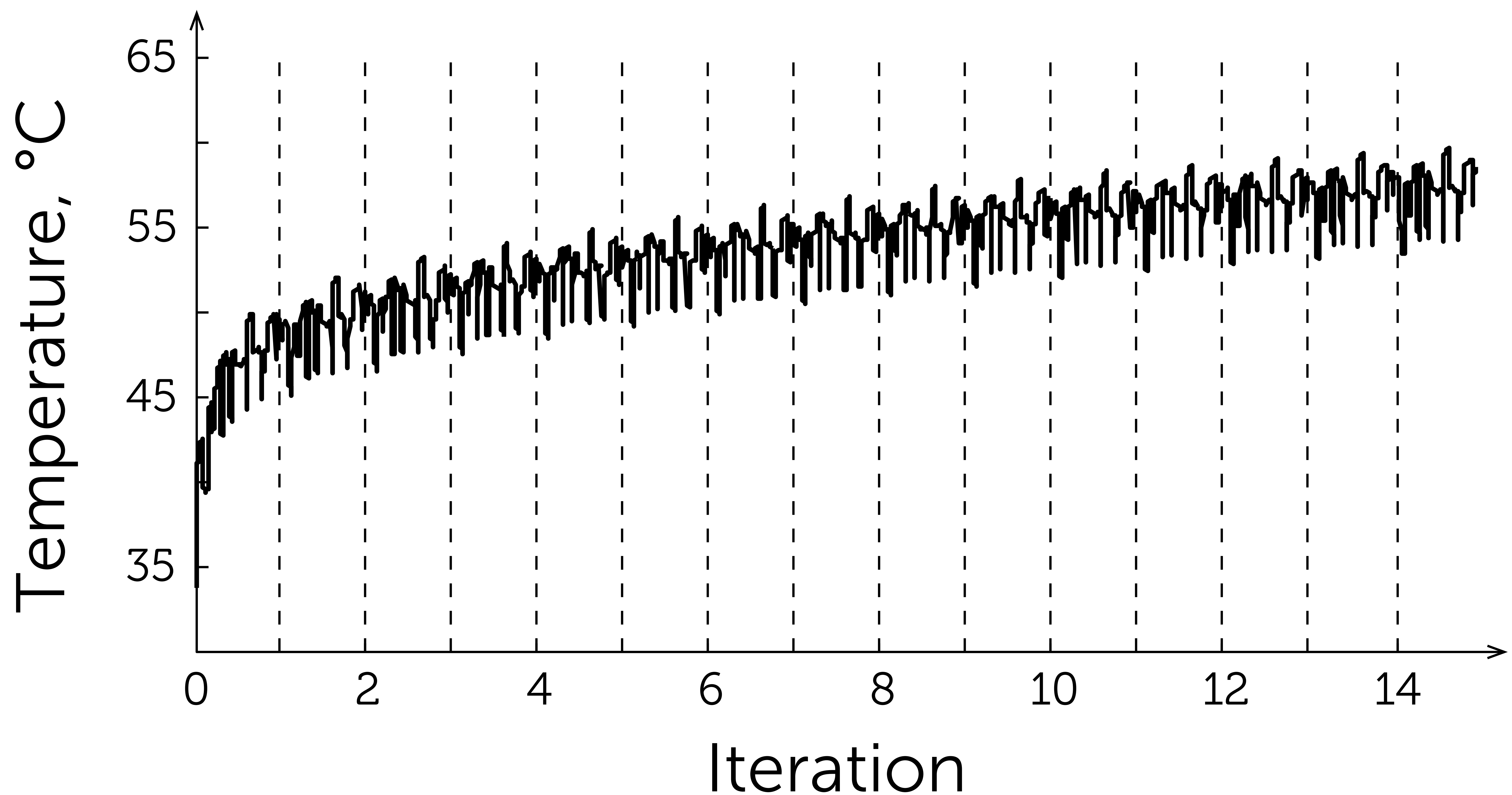
* Dynamic steady-state temperature profile

Such that:

* Accurate and fast

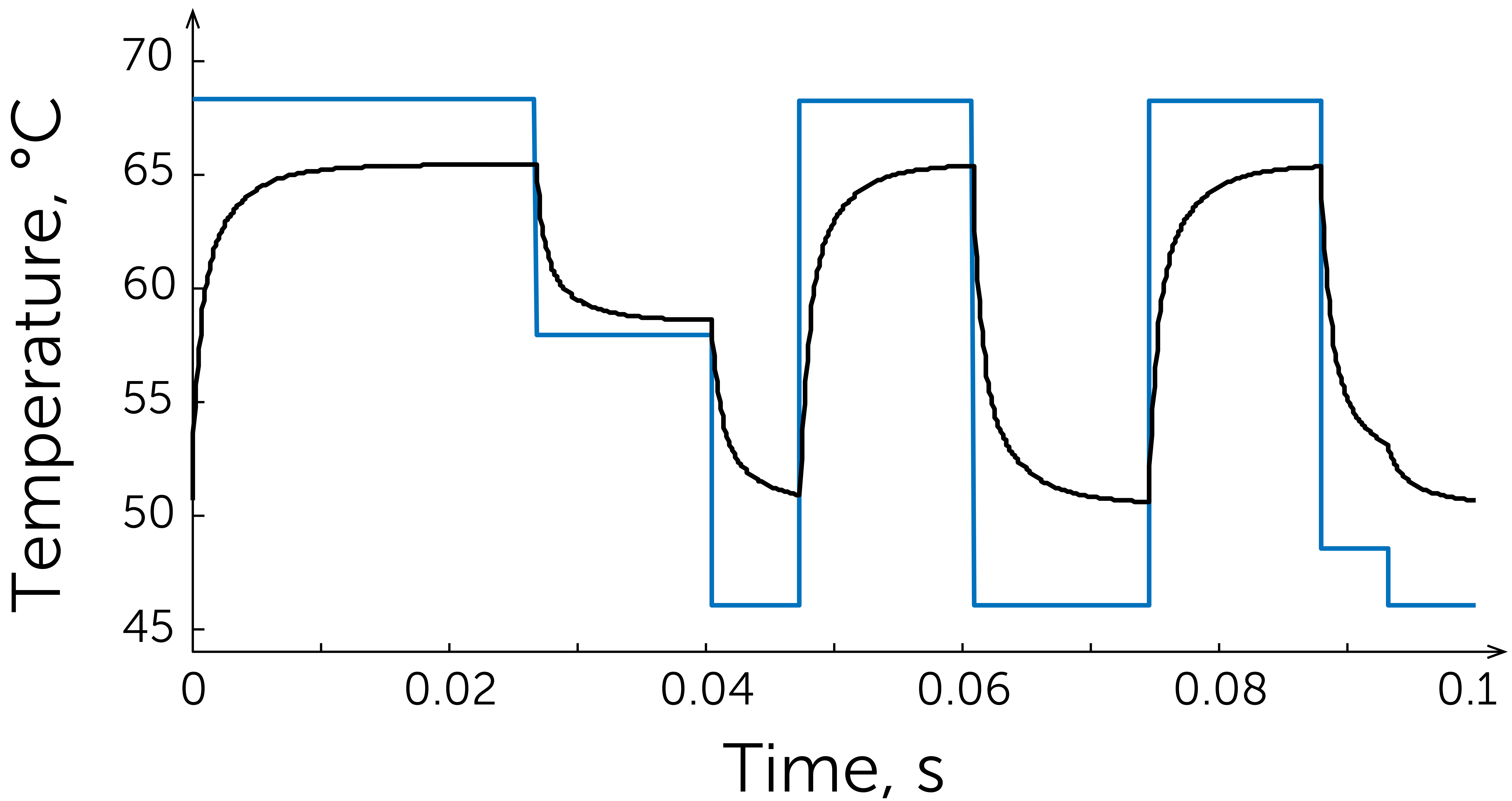
Alternatives

* Repetitive transient analysis



Alternatives

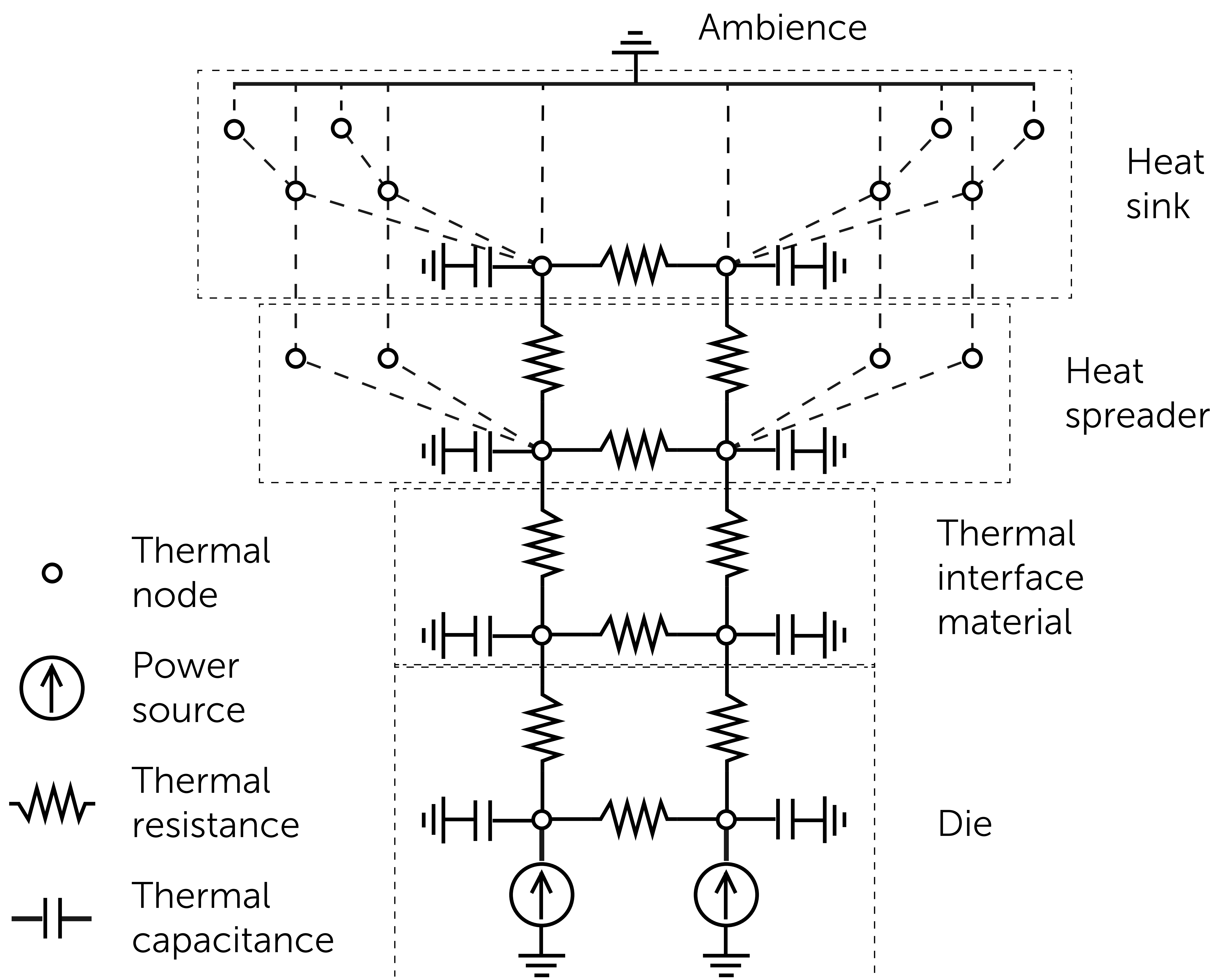
* Static-steady-state approximation



Alternatives

* Slow
* Inaccurate

Our Solution



Our Solution

$$\mathrm{C}\frac{dq(t)}{dt} + \mathrm{G}\left(q(t) - q_{\mathrm{amb}}\right) = p(t)$$

$$s_{i+1} = \mathrm{E}s_i + \mathrm{F}p_i$$

$$s_{\mathrm{start}} = s_{\mathrm{end}}$$

Our Solution

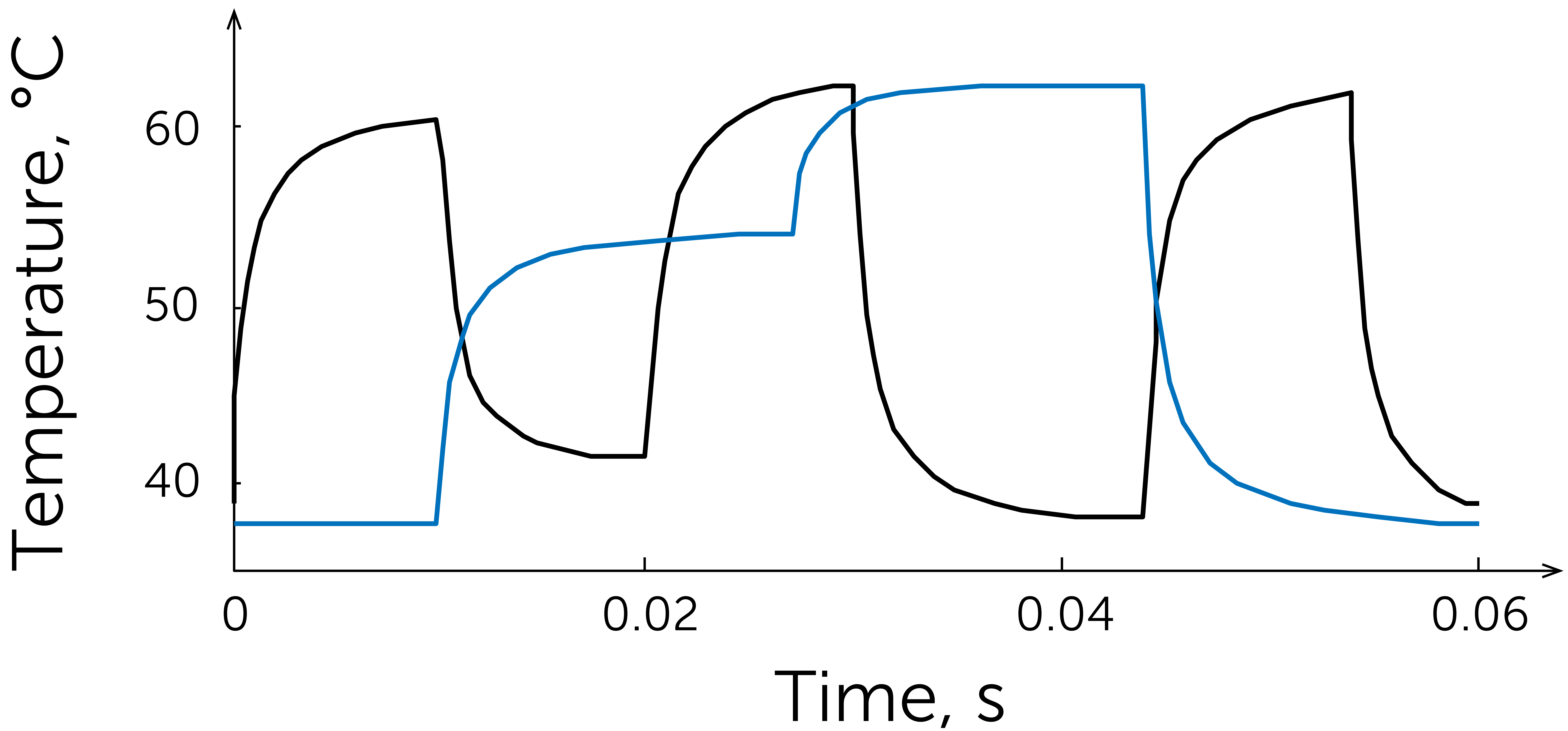
$$\mathbb{AX} = \mathbb{B}$$

Our Solution

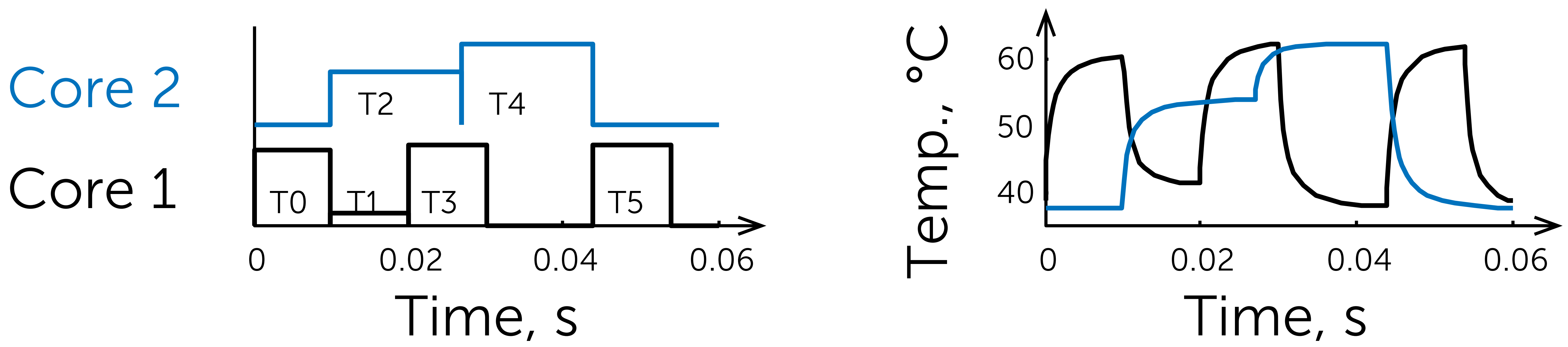
* Analytical
* Exact
* Fast

Reliability Optimization

* Thermal-cyclic fatigue

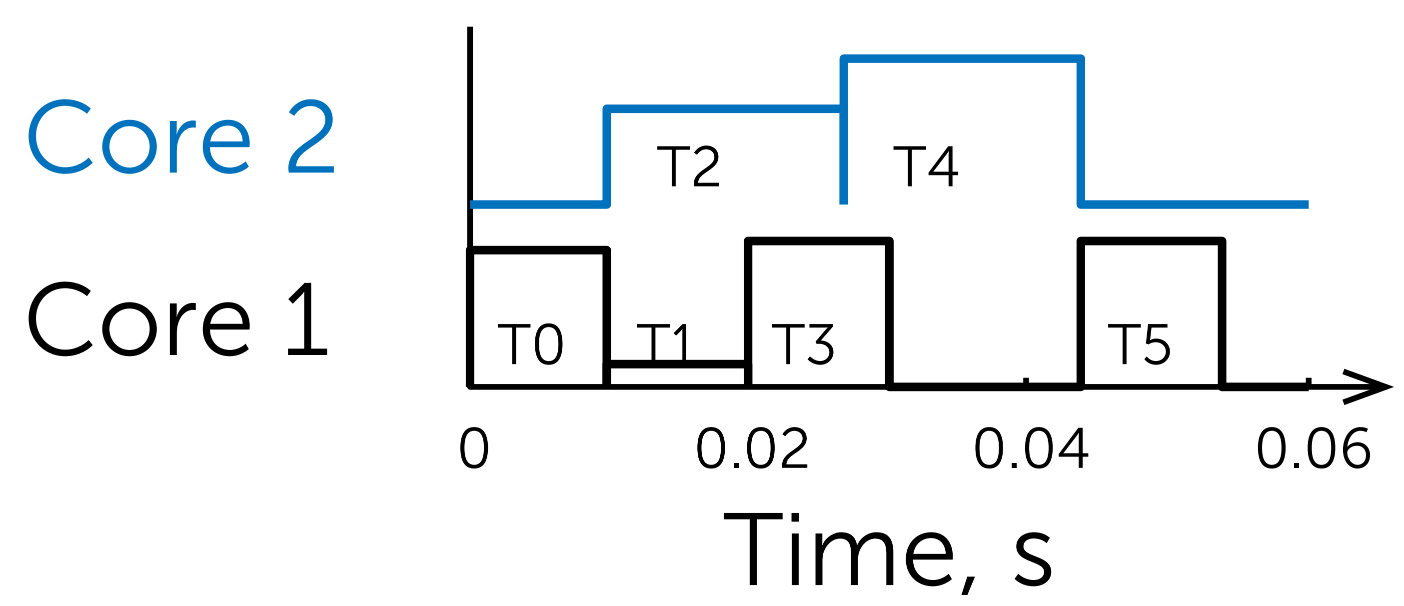


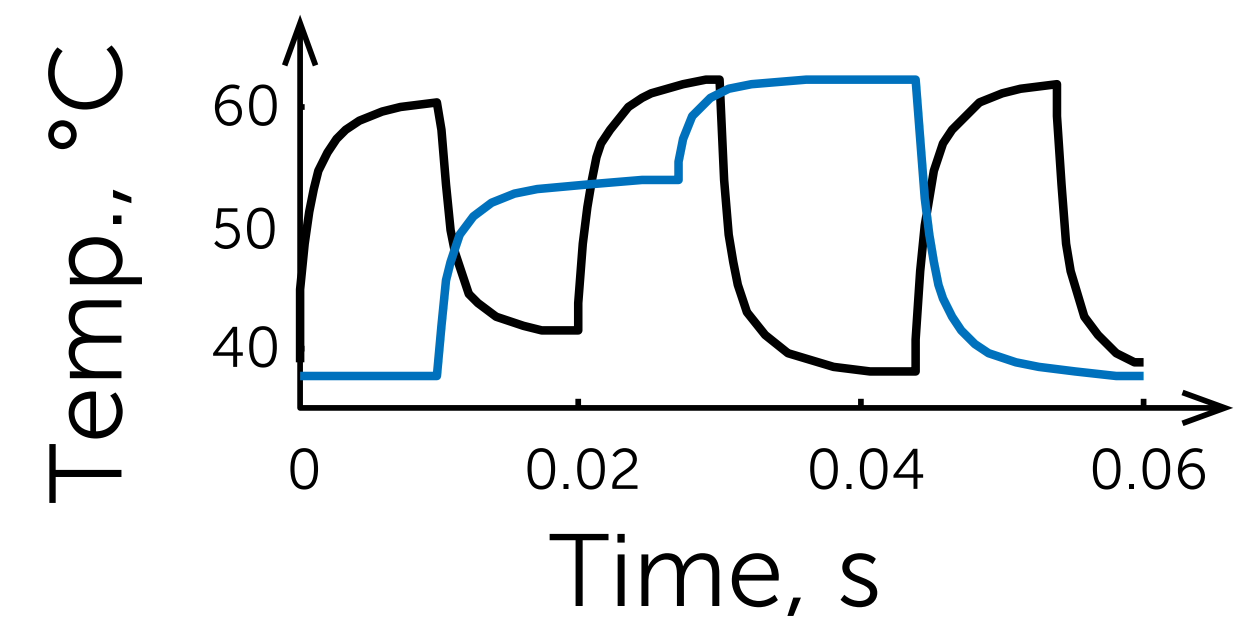
Reliability Optimization



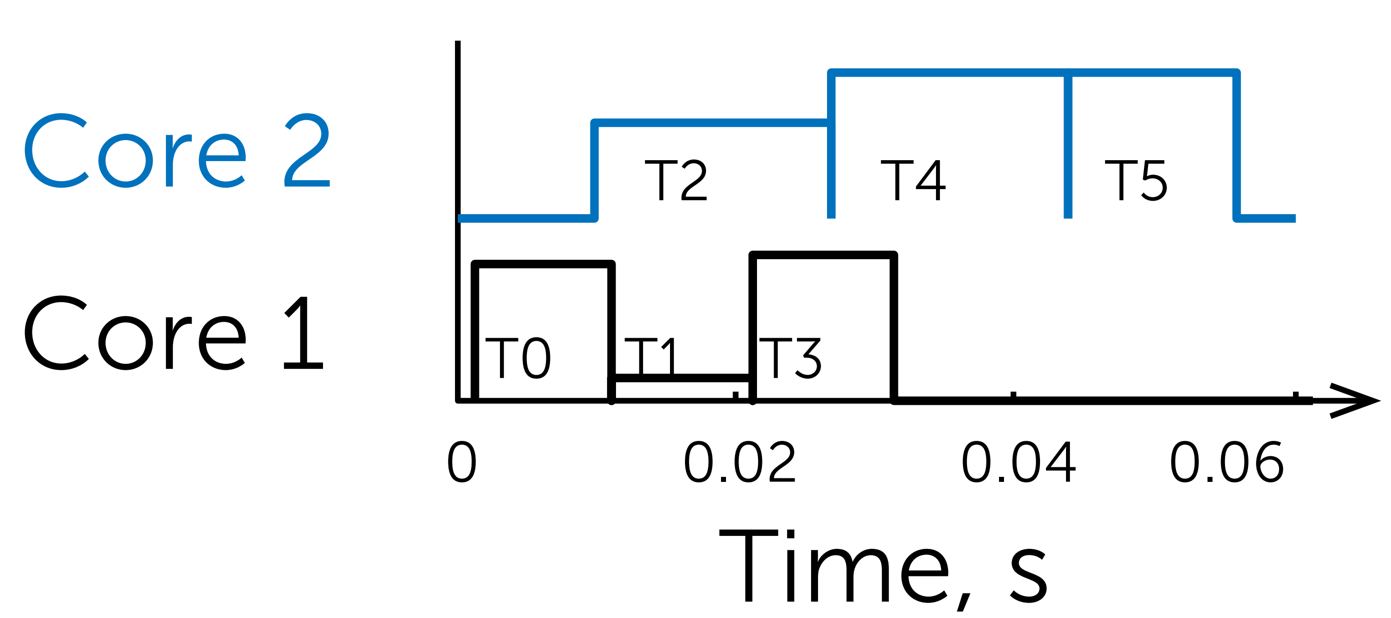
3 cycles

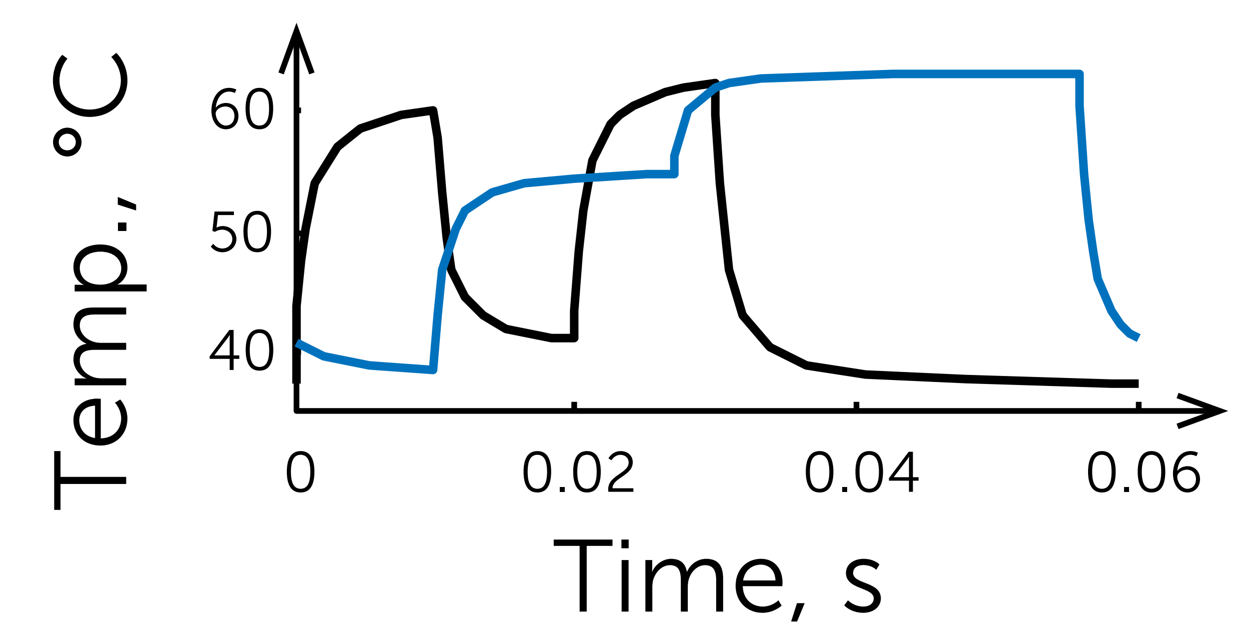
Reliability Optimization





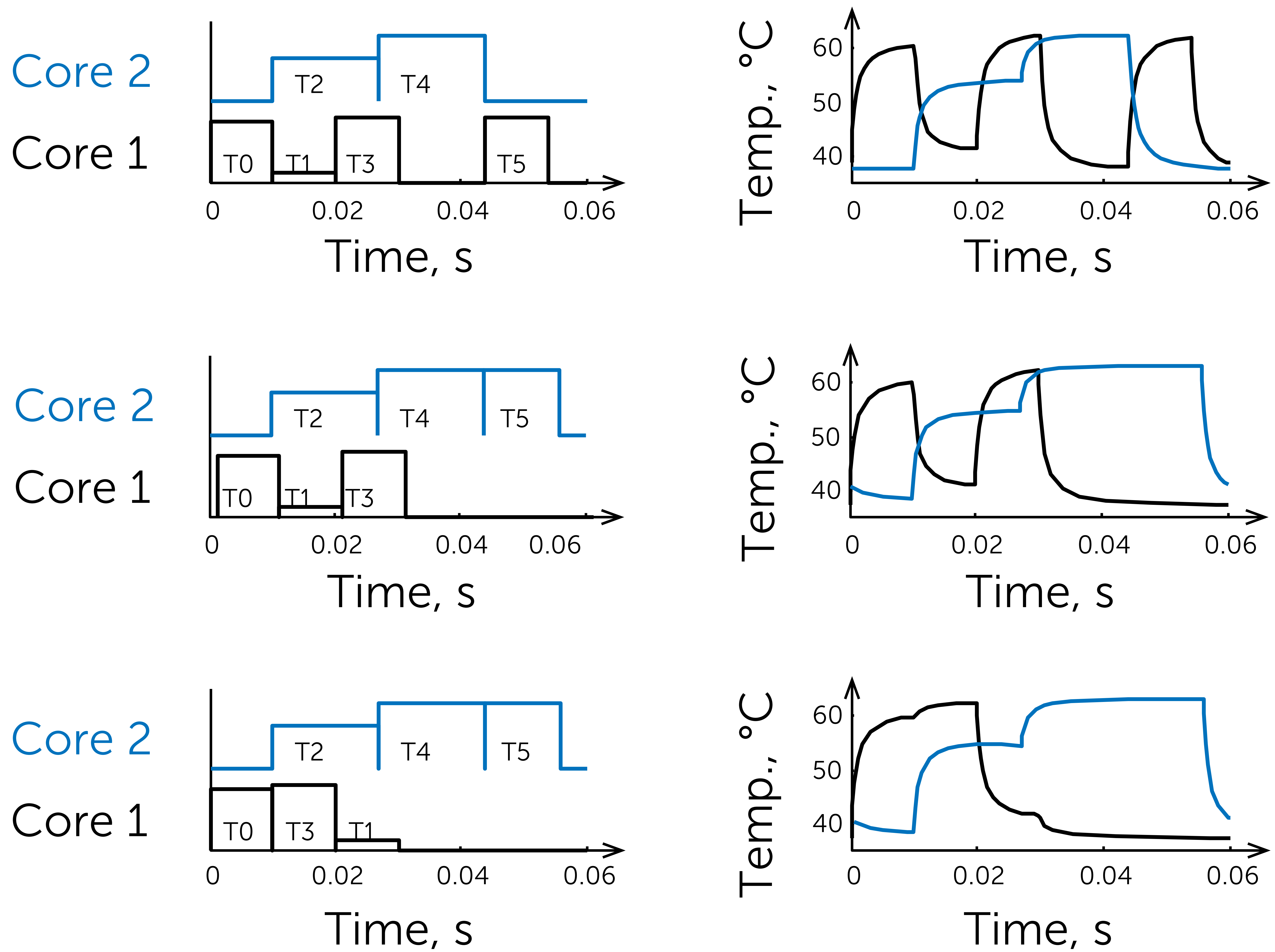
3 cycles





2 cycles,
+45% lifetime

Reliability Optimization



3 cycles

2 cycles, +45% lifetime

1 cycle, +55% lifetime

Our Goal

Given:

* Multiprocessor system
* Periodic application

Find:

* Schedule

Such that:

* Lifetime maximized
* Energy minimized

Our Solution

* Dynamic steady-state temperature analysis
* Genetic algorithm with multiple objectives

Outline

Dynamic Steady-State Temperature Analysis and Reliability Optimization

Statistical Analysis of Process Variation Based on Indirect Measurements

Probabilistic Analysis of Power and Temperature Under Process Variation

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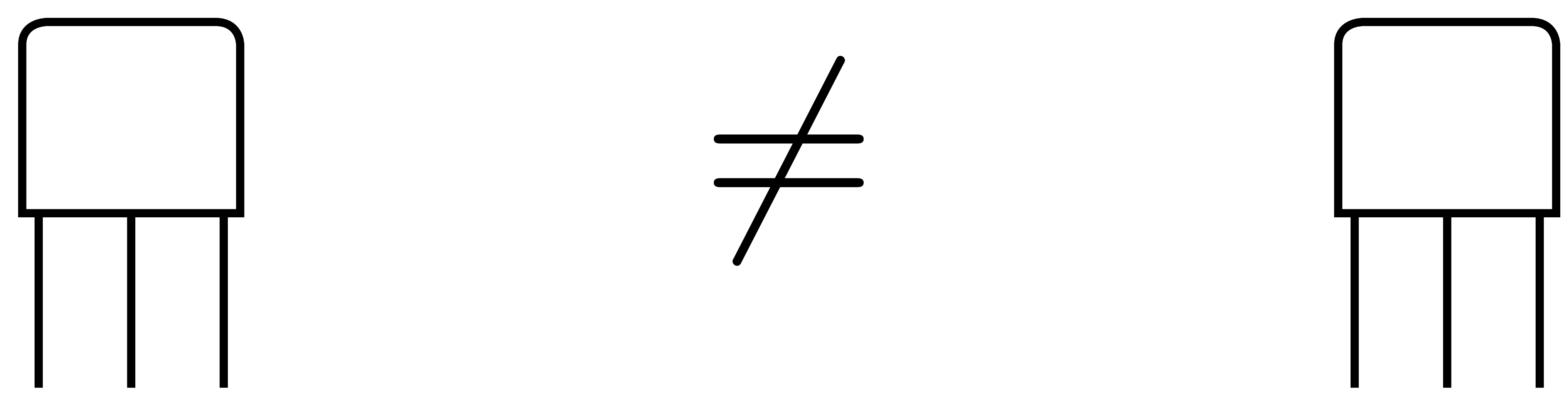
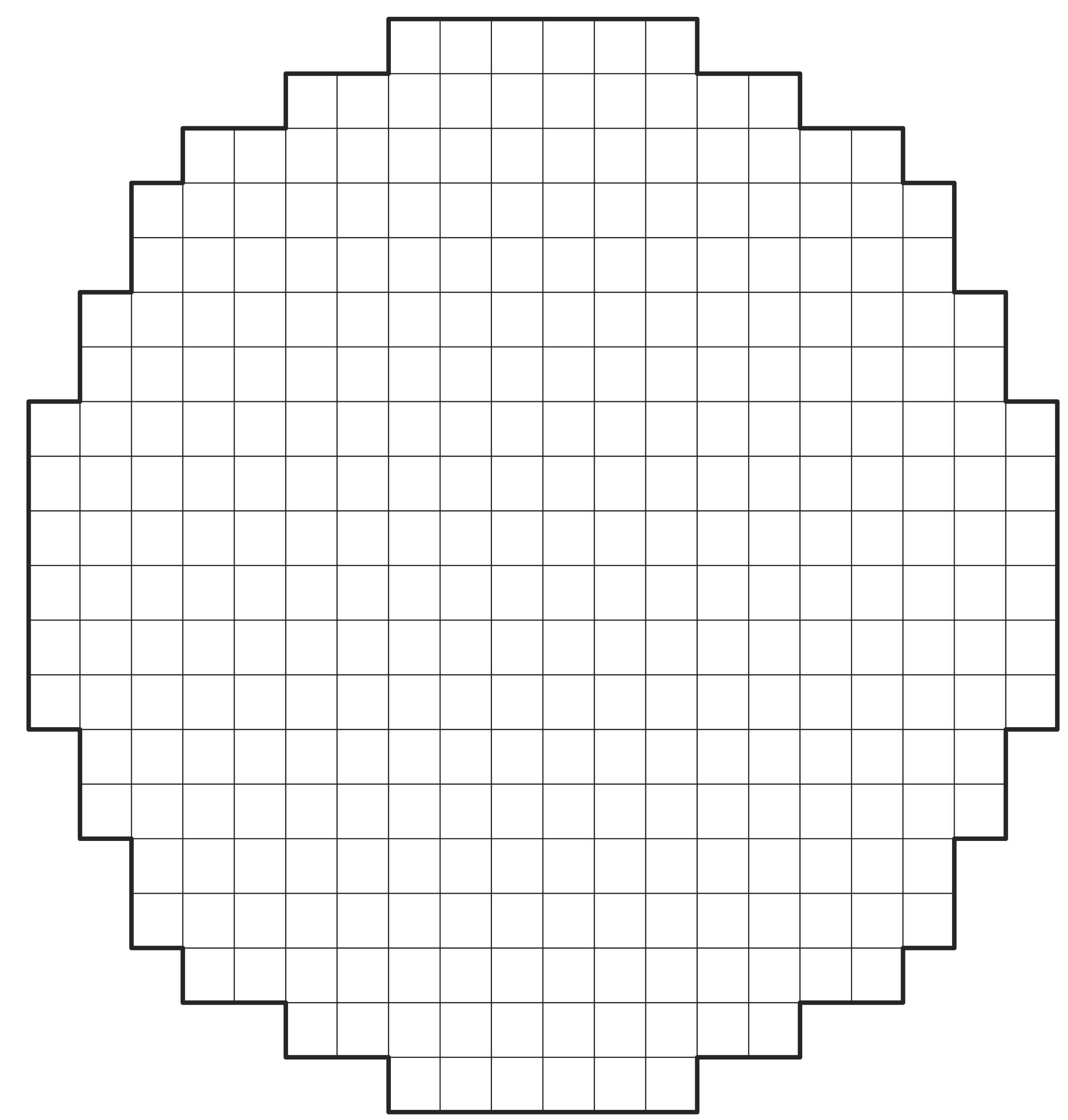
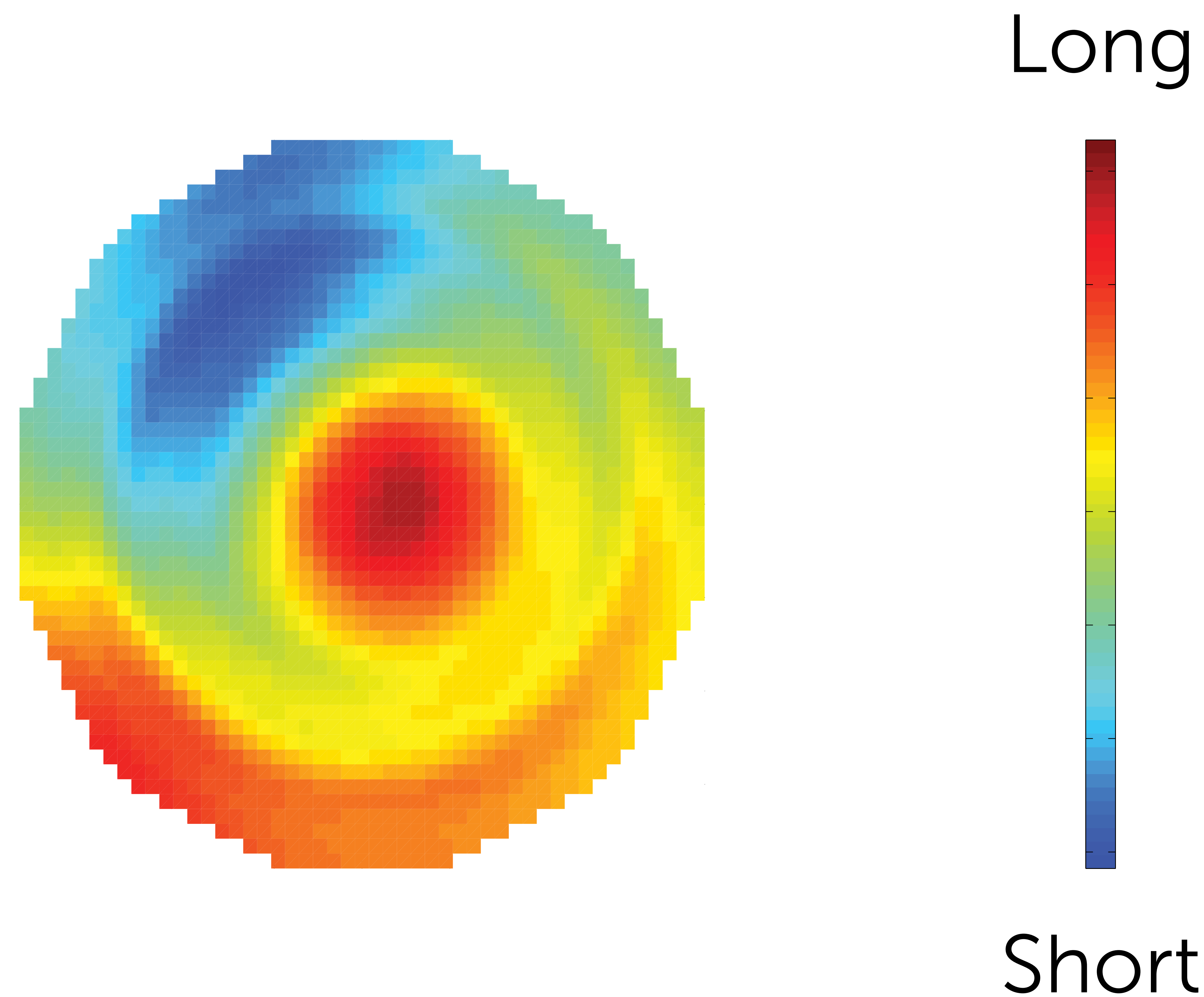
Process Variation



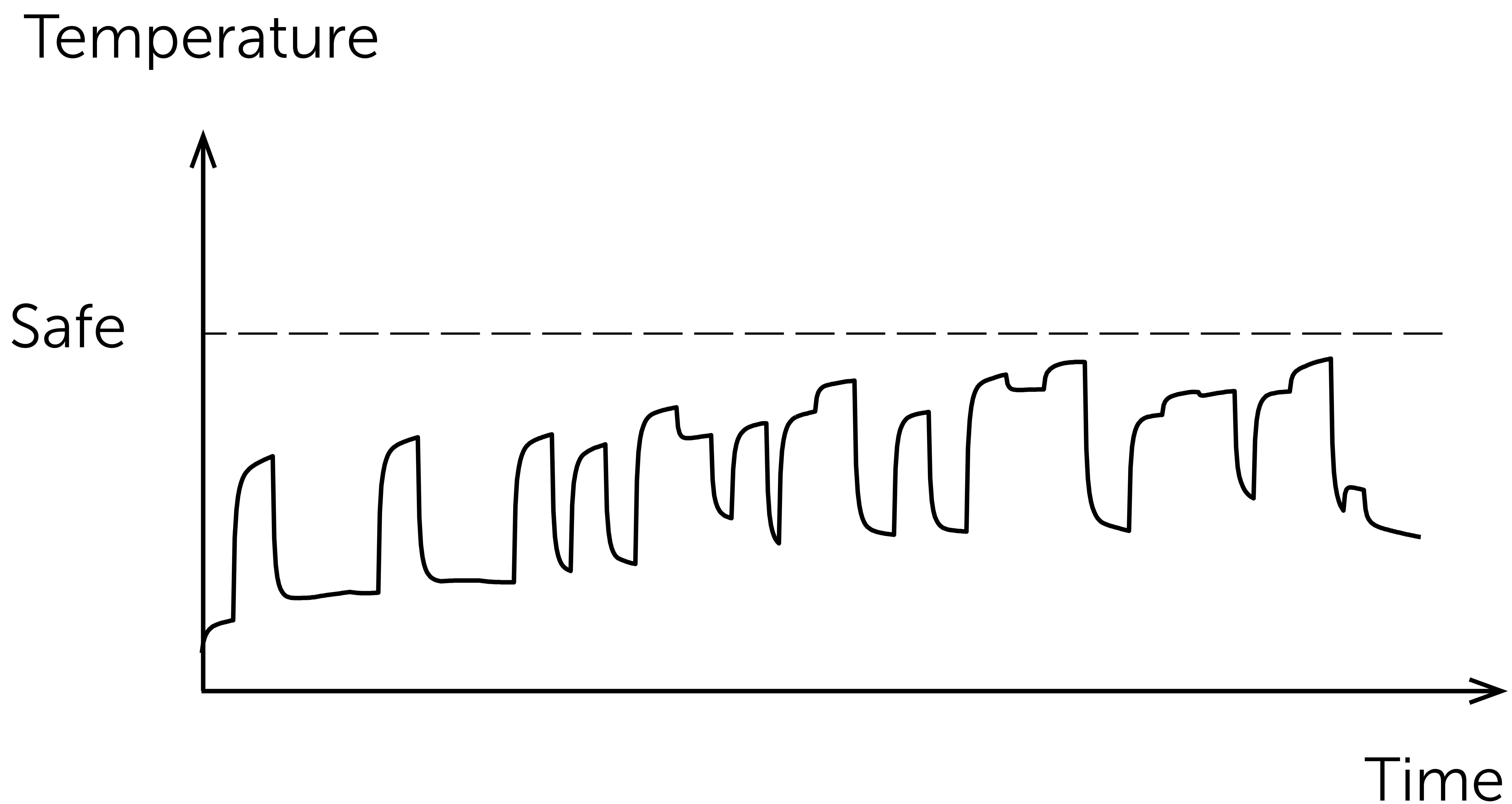
Process Variation



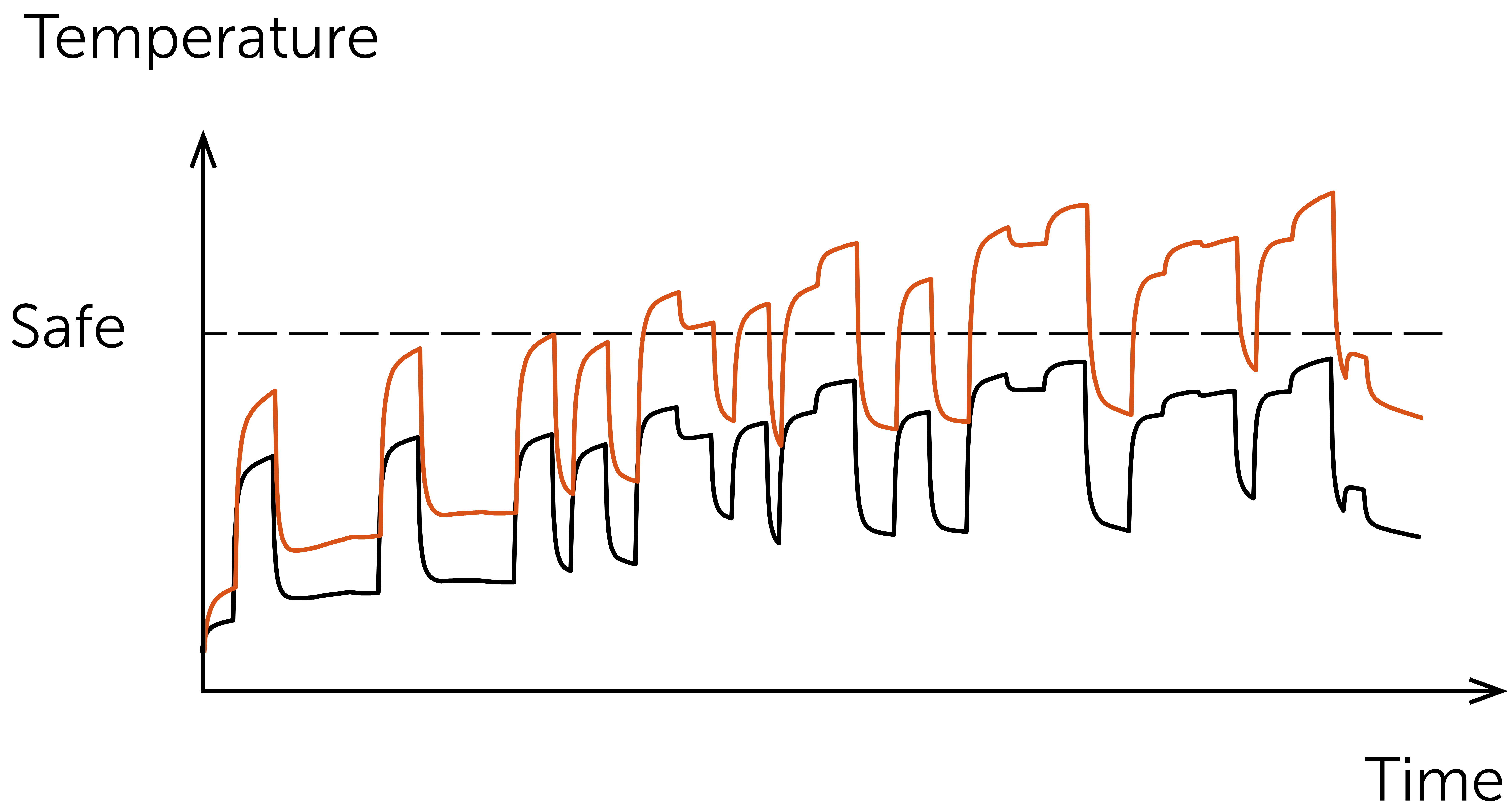
Process Variation



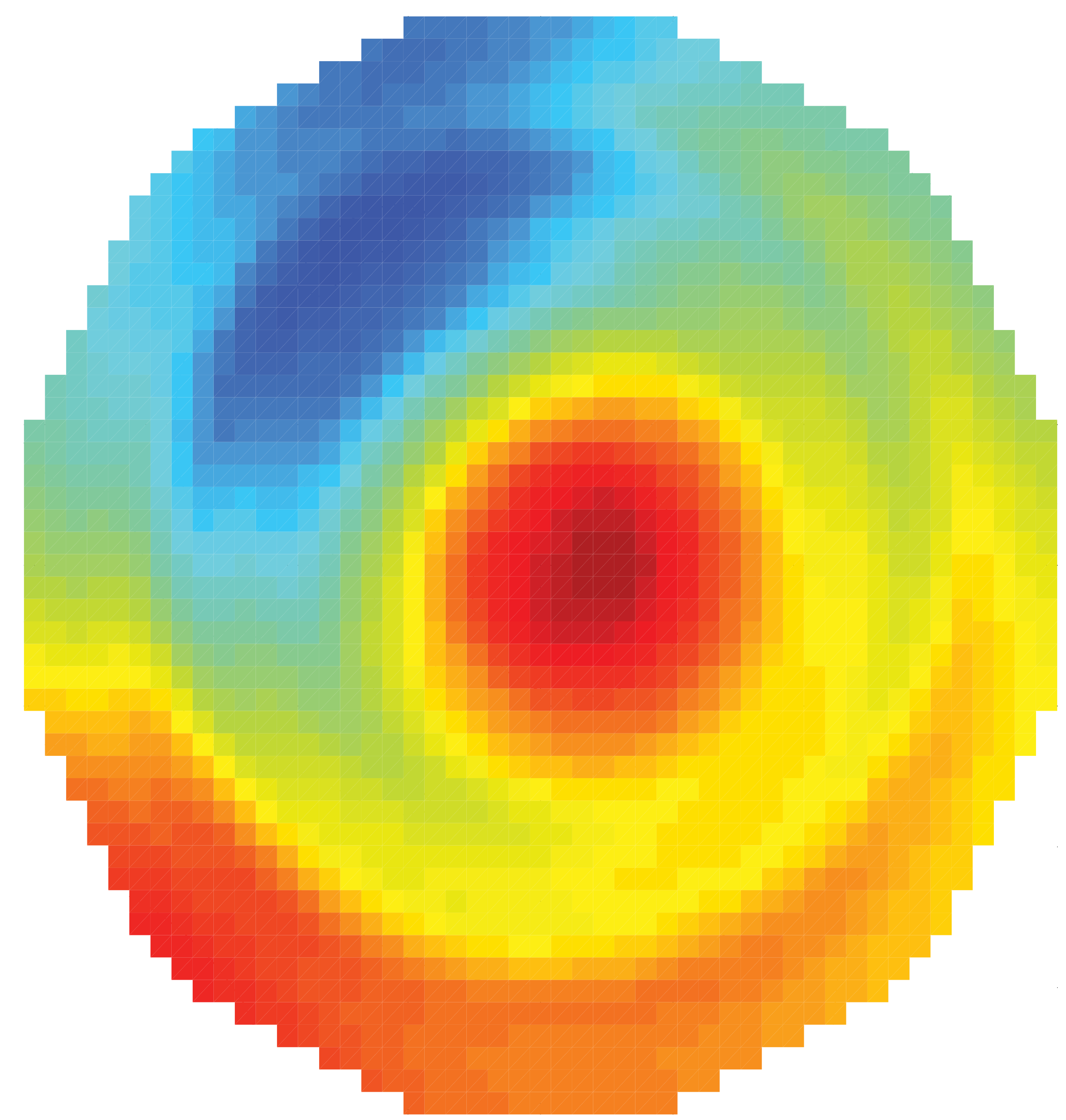
Process Variation



Process Variation



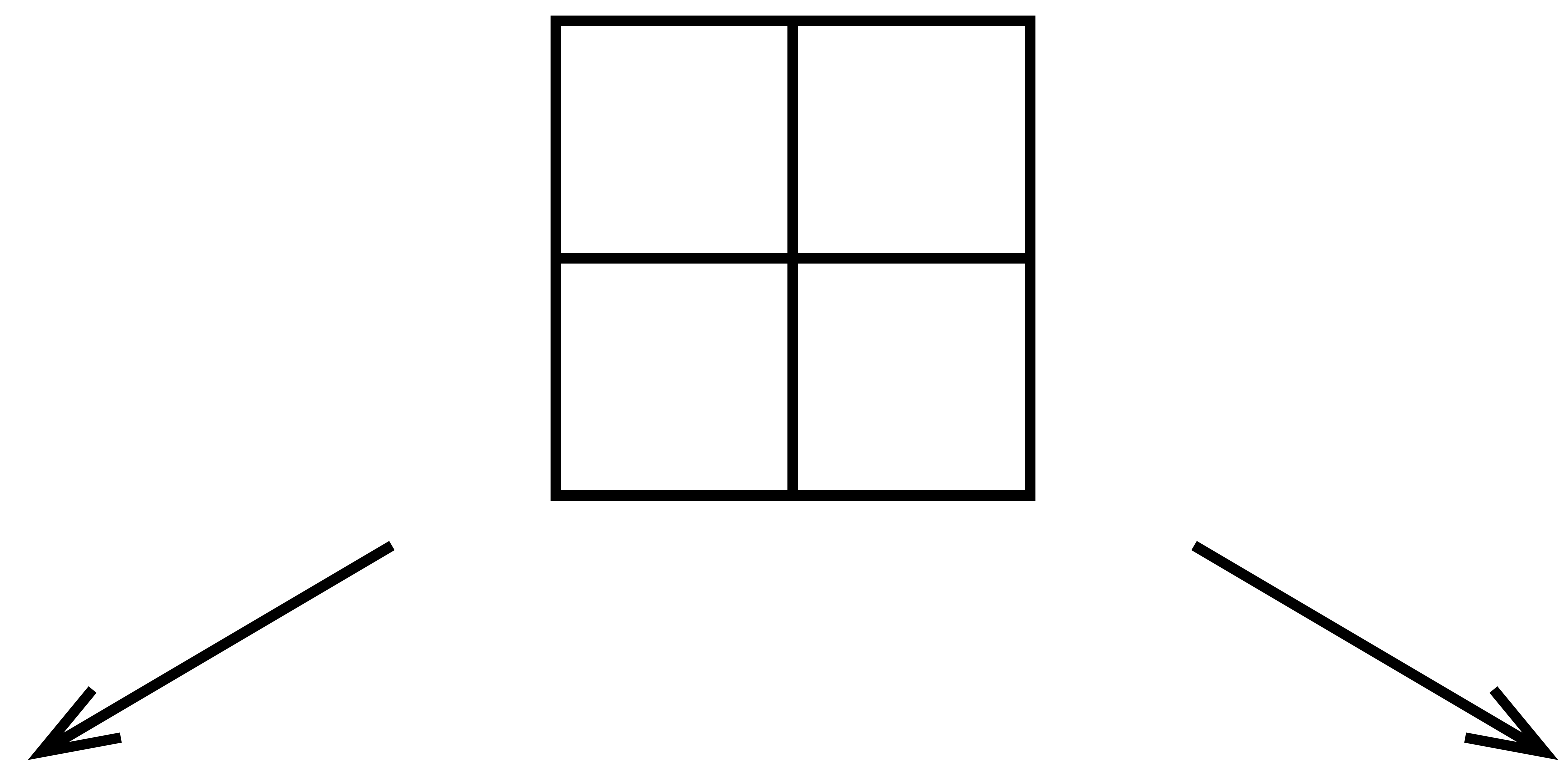
Our Goal



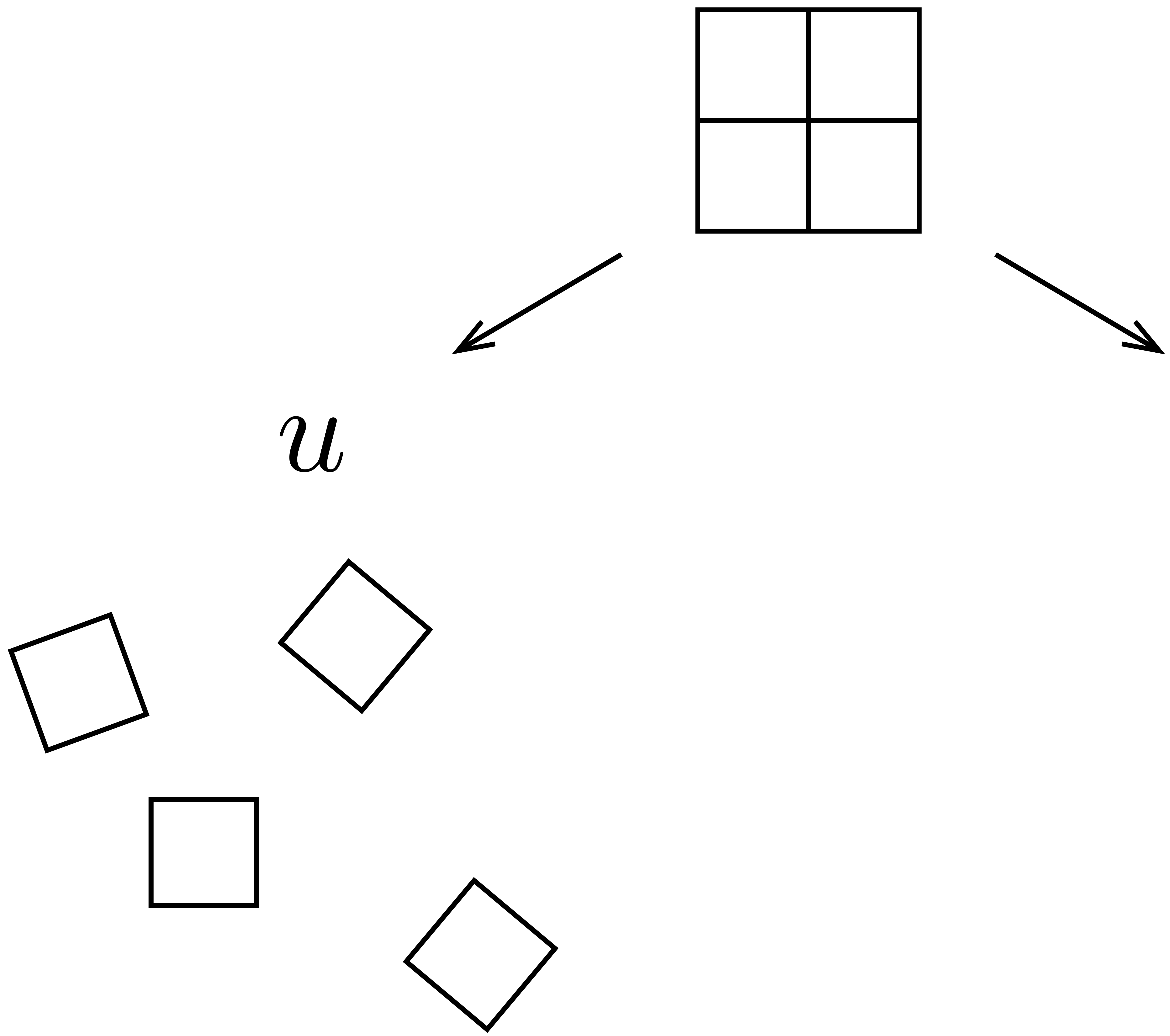
Our Goal

Quantity of interest

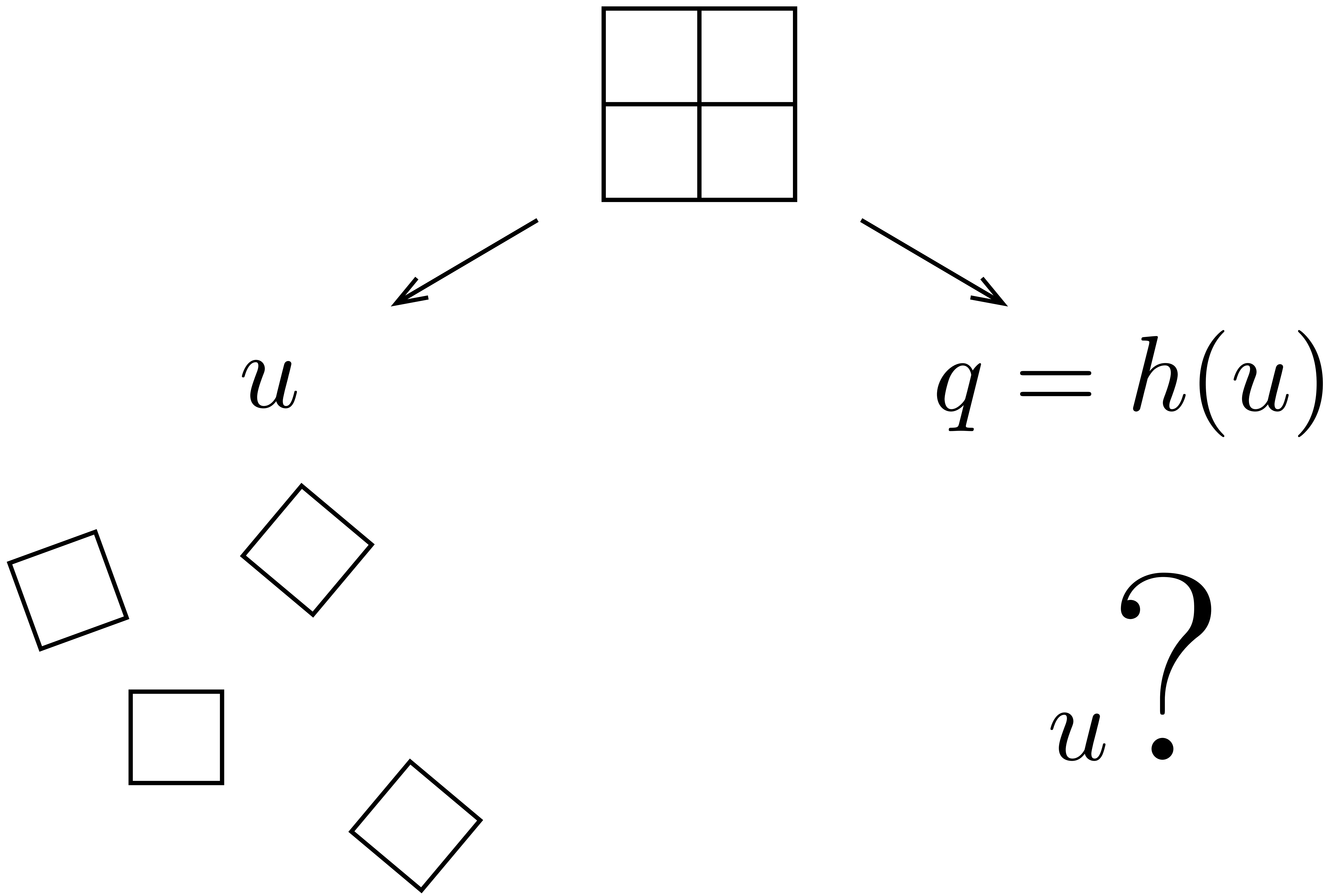
Alternatives



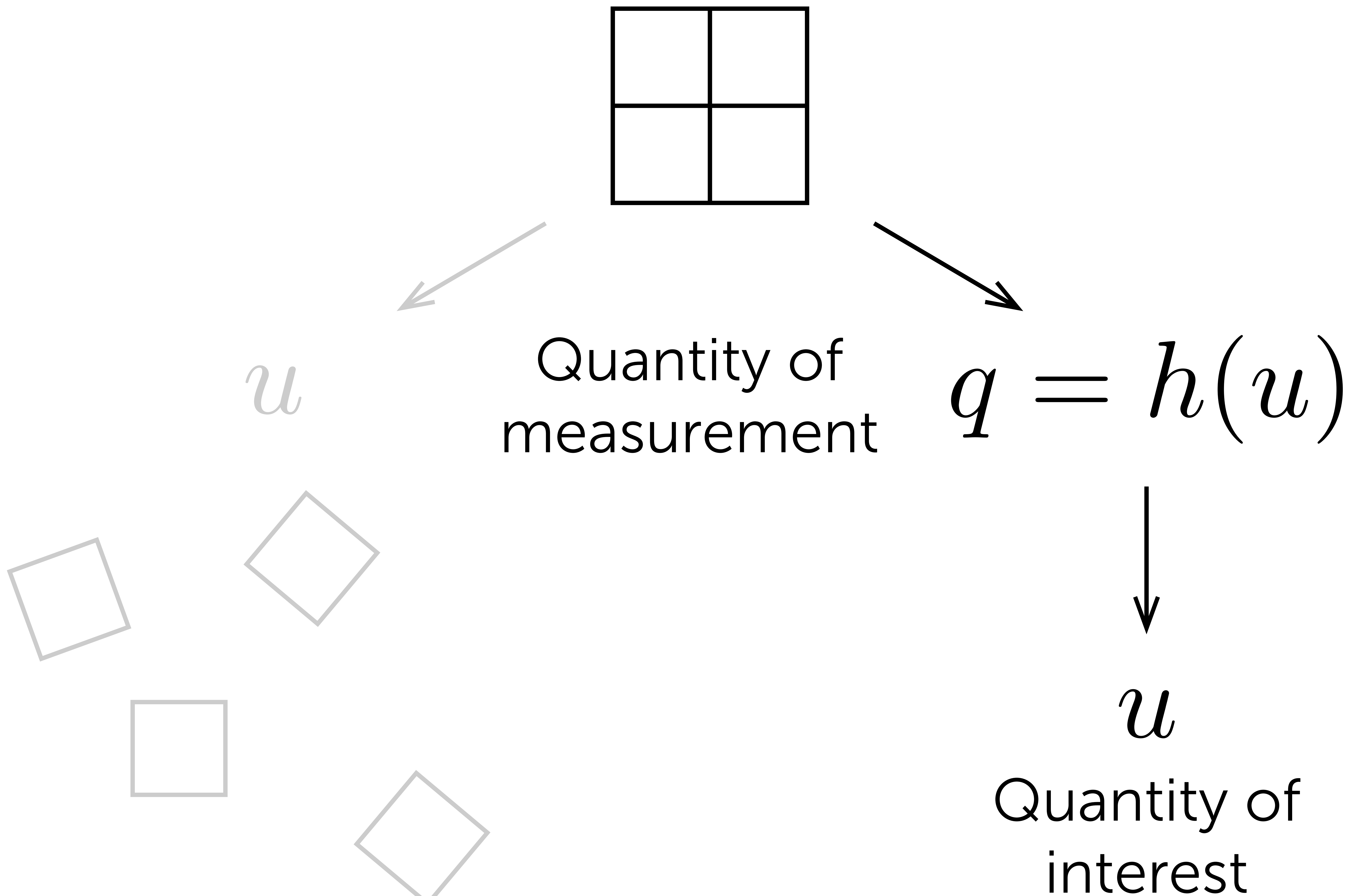
Alternatives



Alternatives



Our Solution



Our Solution

$$\mathcal{Q} \longrightarrow \boxed{} \longrightarrow u$$

Our Solution

$$\mathcal{Q} \longrightarrow \boxed{} \longrightarrow u$$

Indirect

Incomplete

Noisy

Our Solution

$$\mathcal{Q} \longrightarrow \square \longrightarrow u$$

Indirect	Primary
Incomplete	Comprehensive
Noisy	Efficient

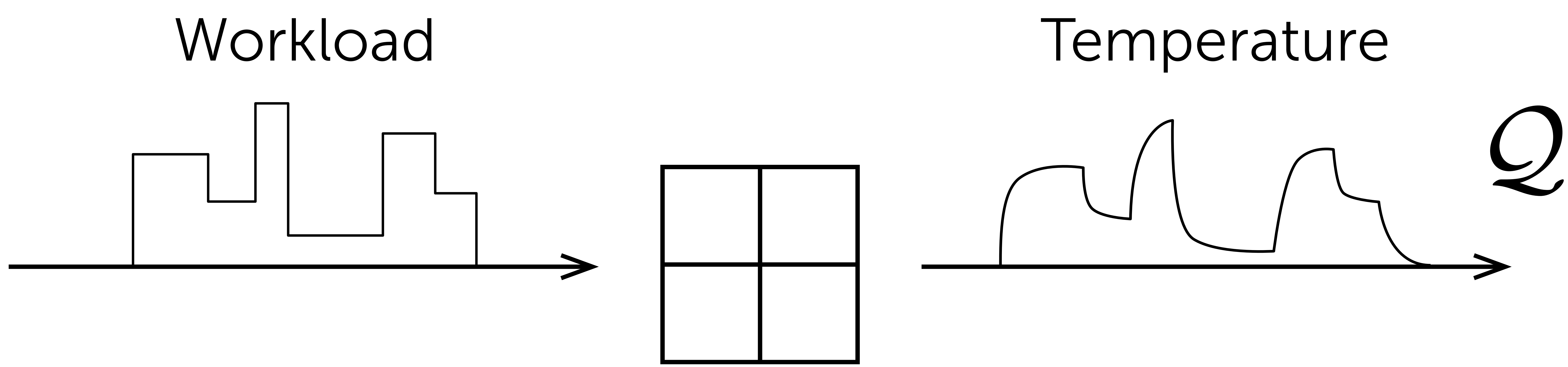
Bayesian Inference

$$p(u|\mathcal{Q}) \propto p(\mathcal{Q}|u) \times p(u)$$

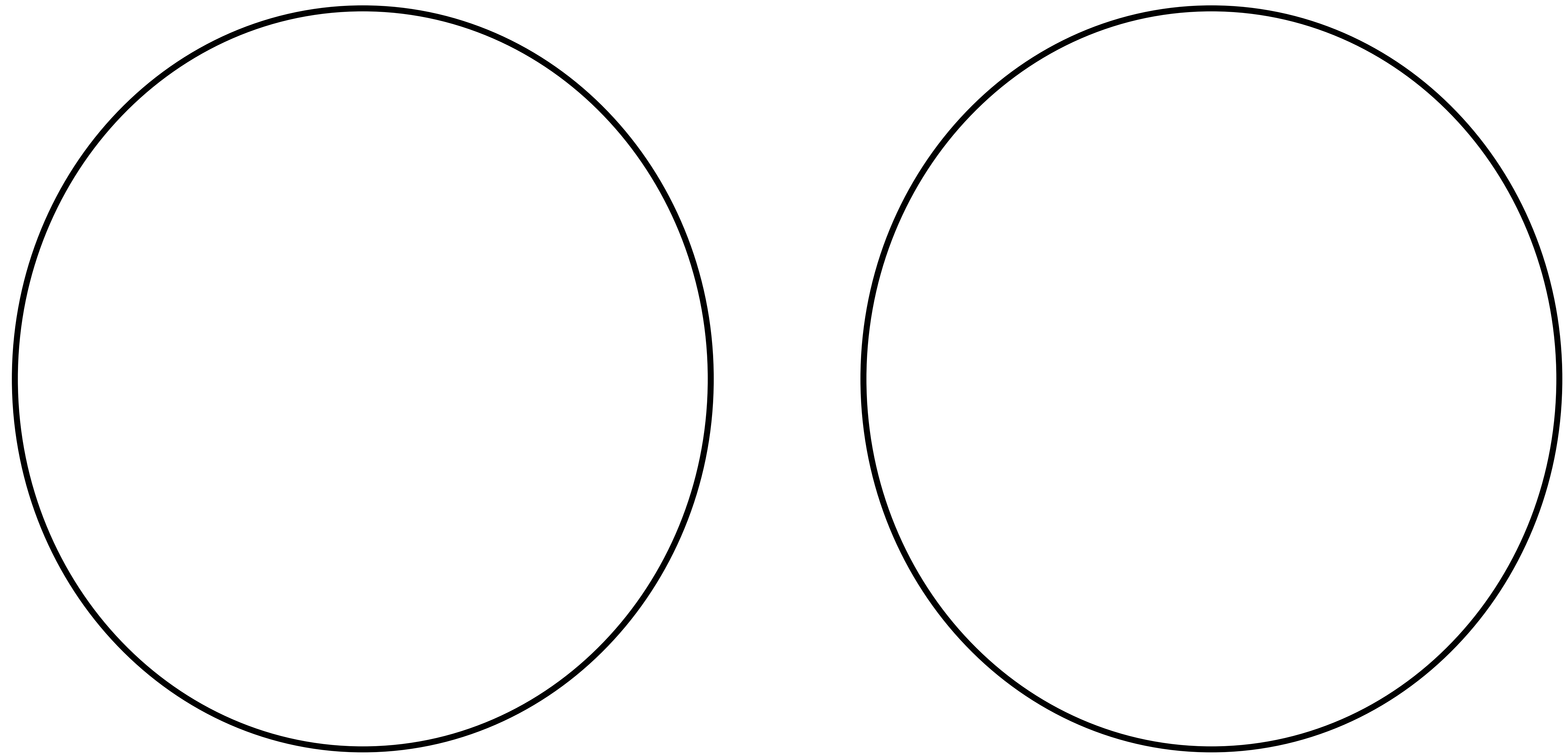
Illustrative Example

u Channel length

q Temperature



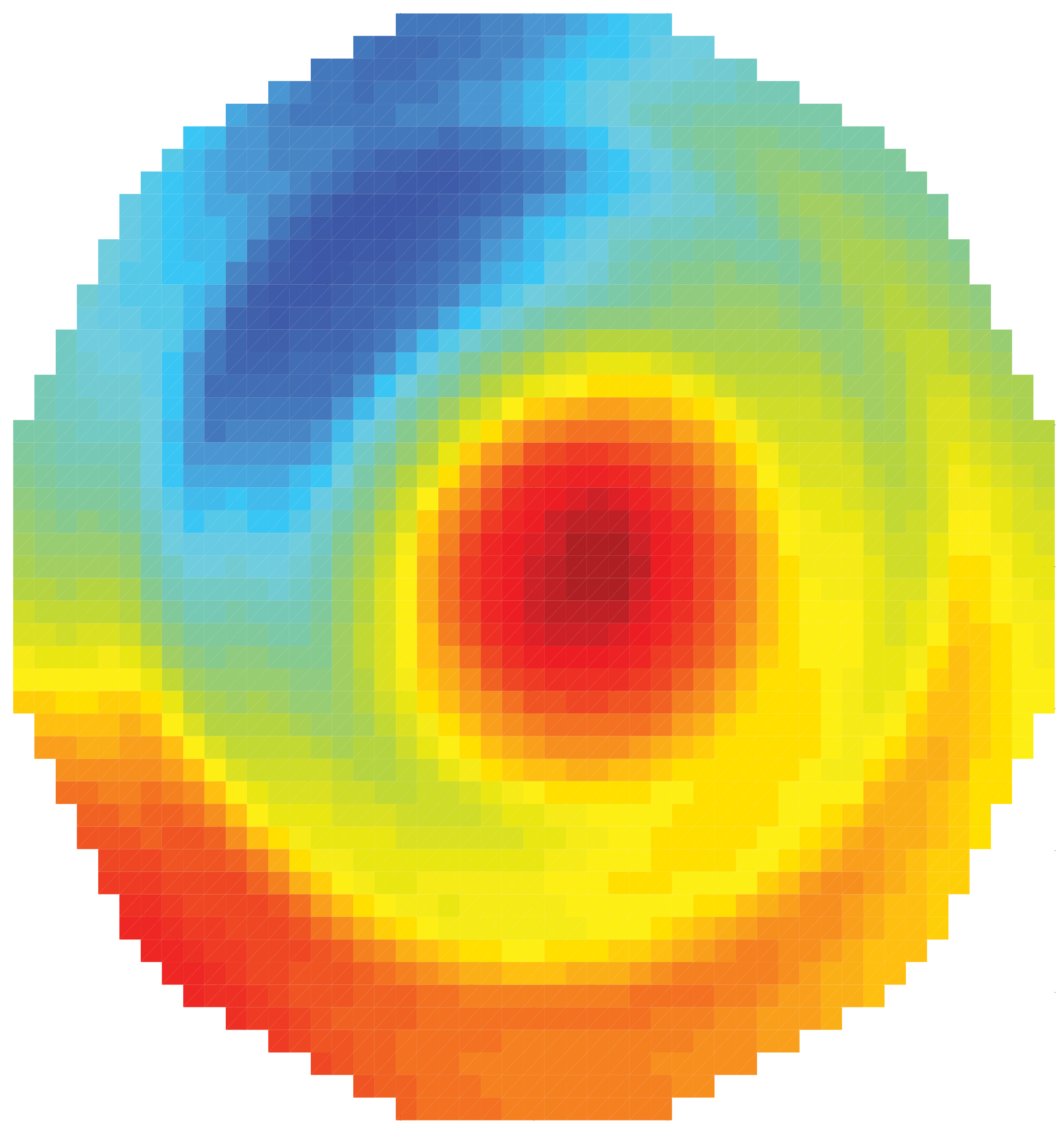
Illustrative Example



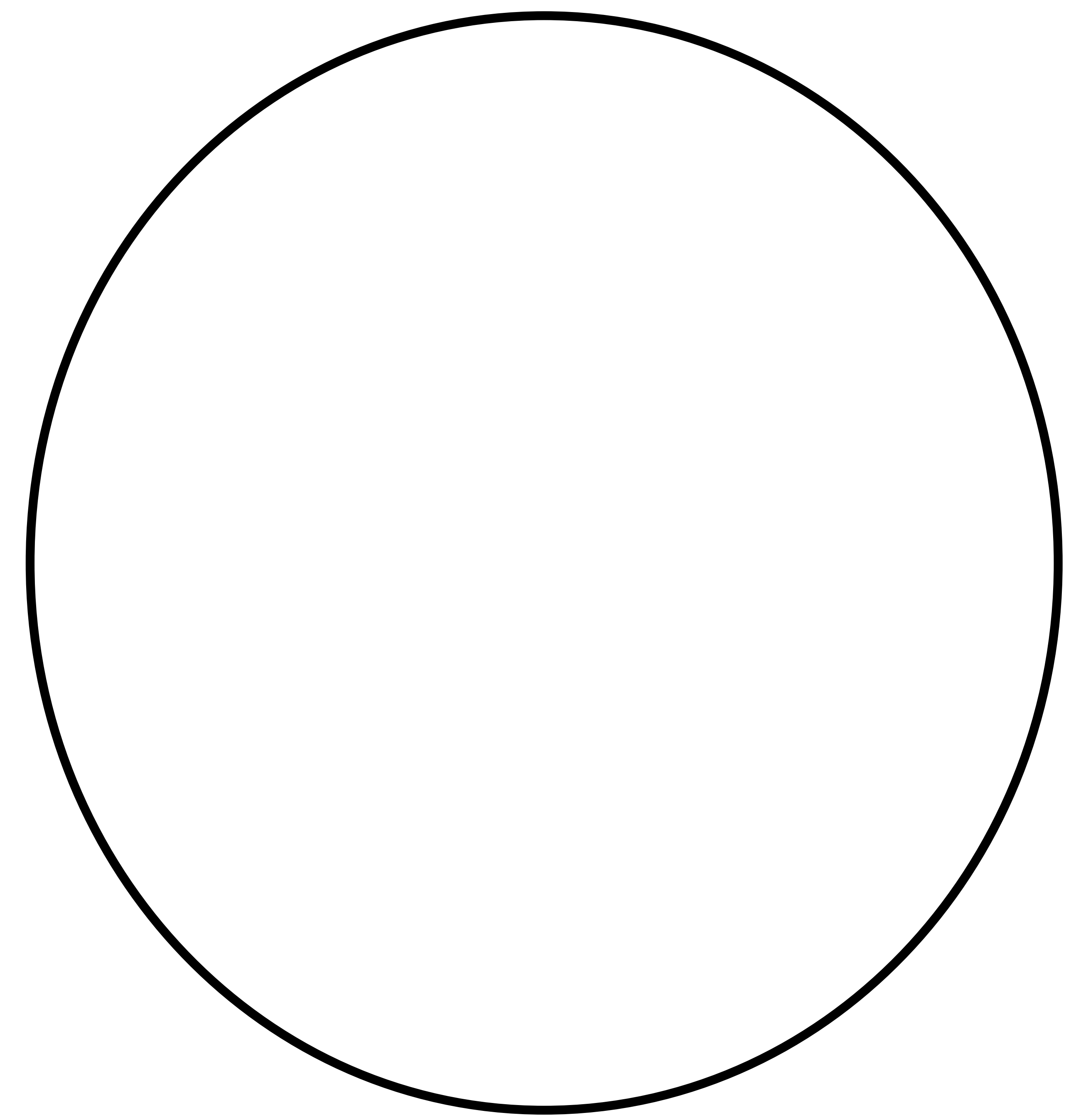
True

Inferred

Illustrative Example

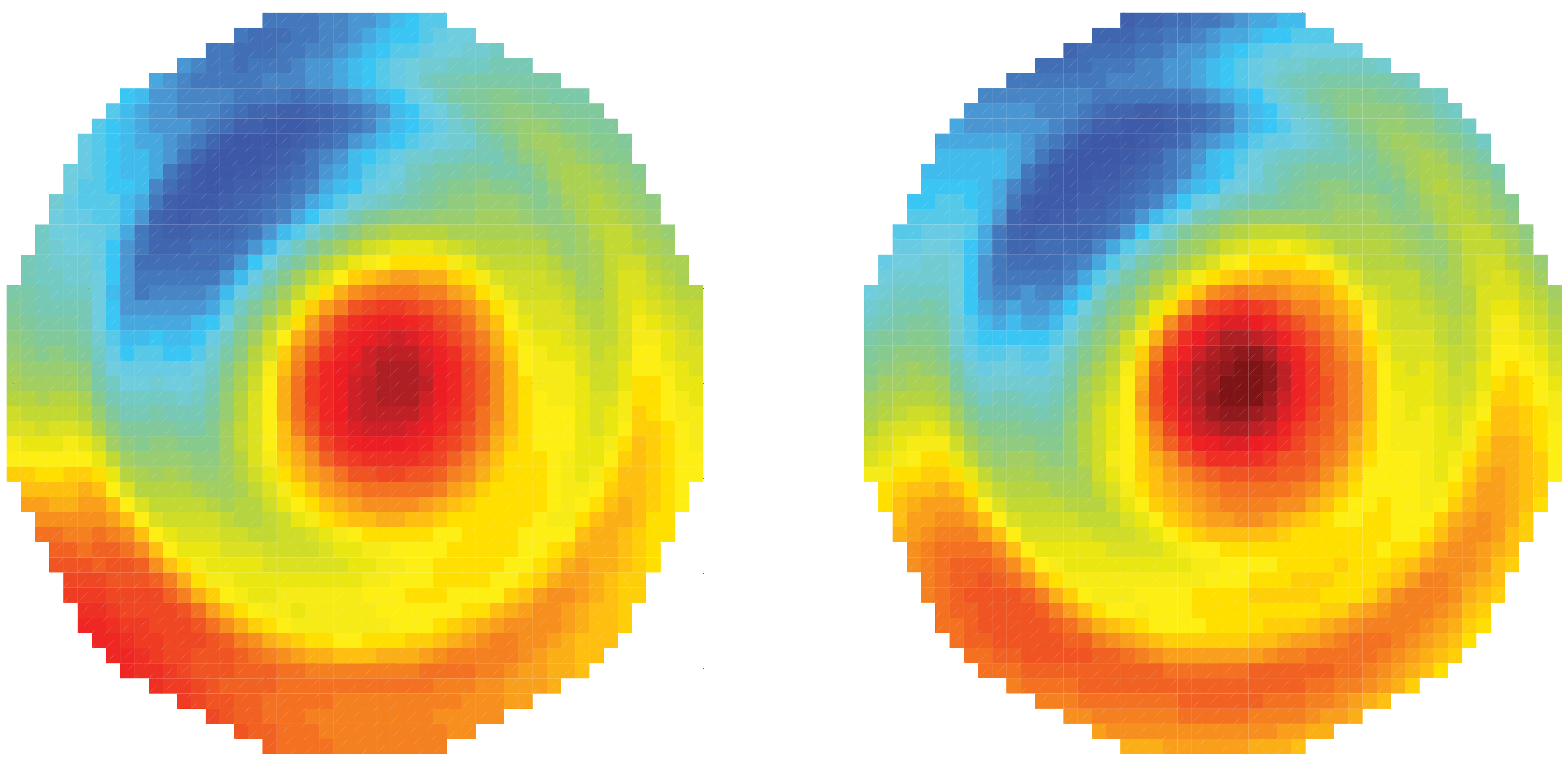


True



Inferred

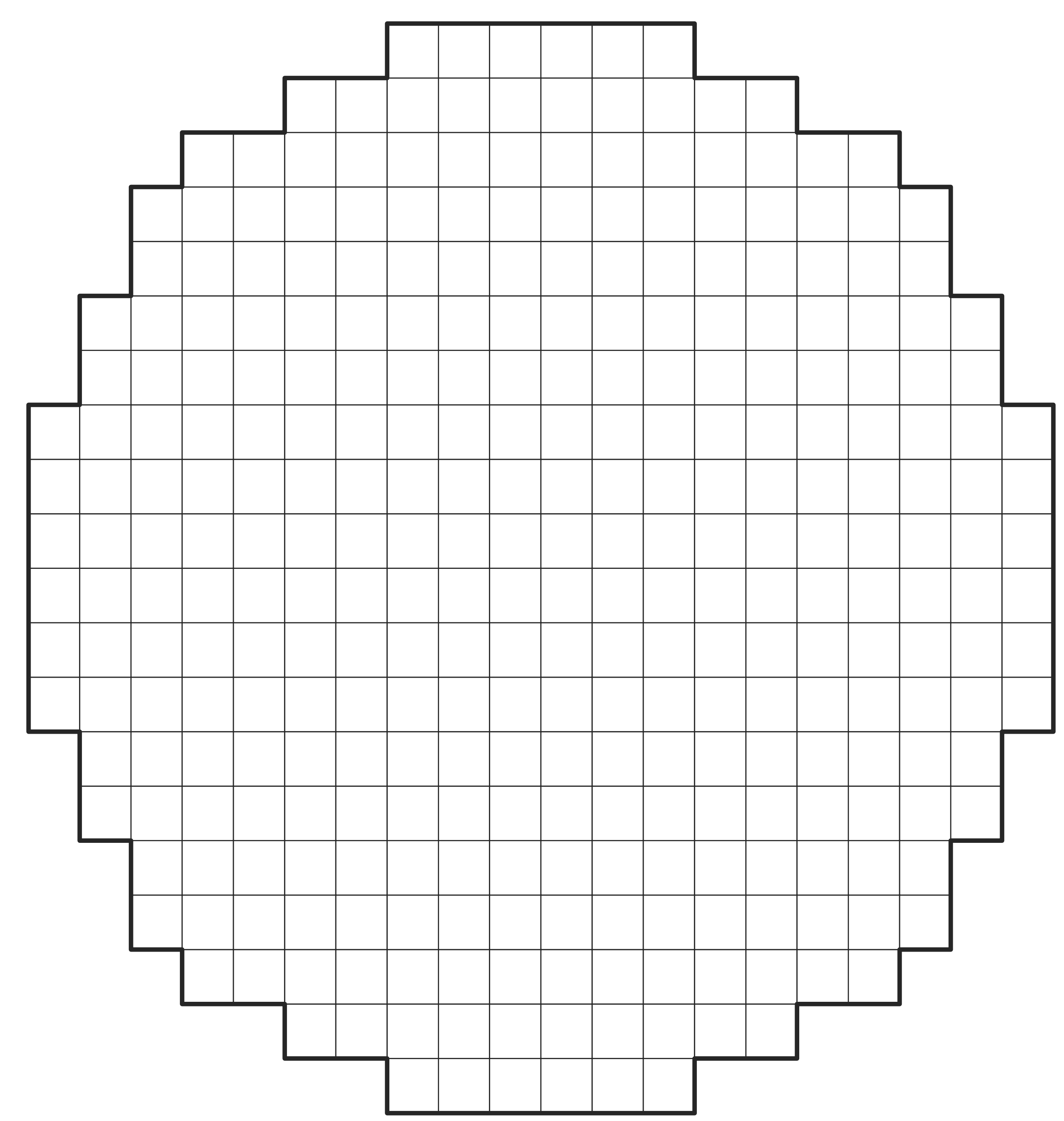
Illustrative Example



True   Inferred

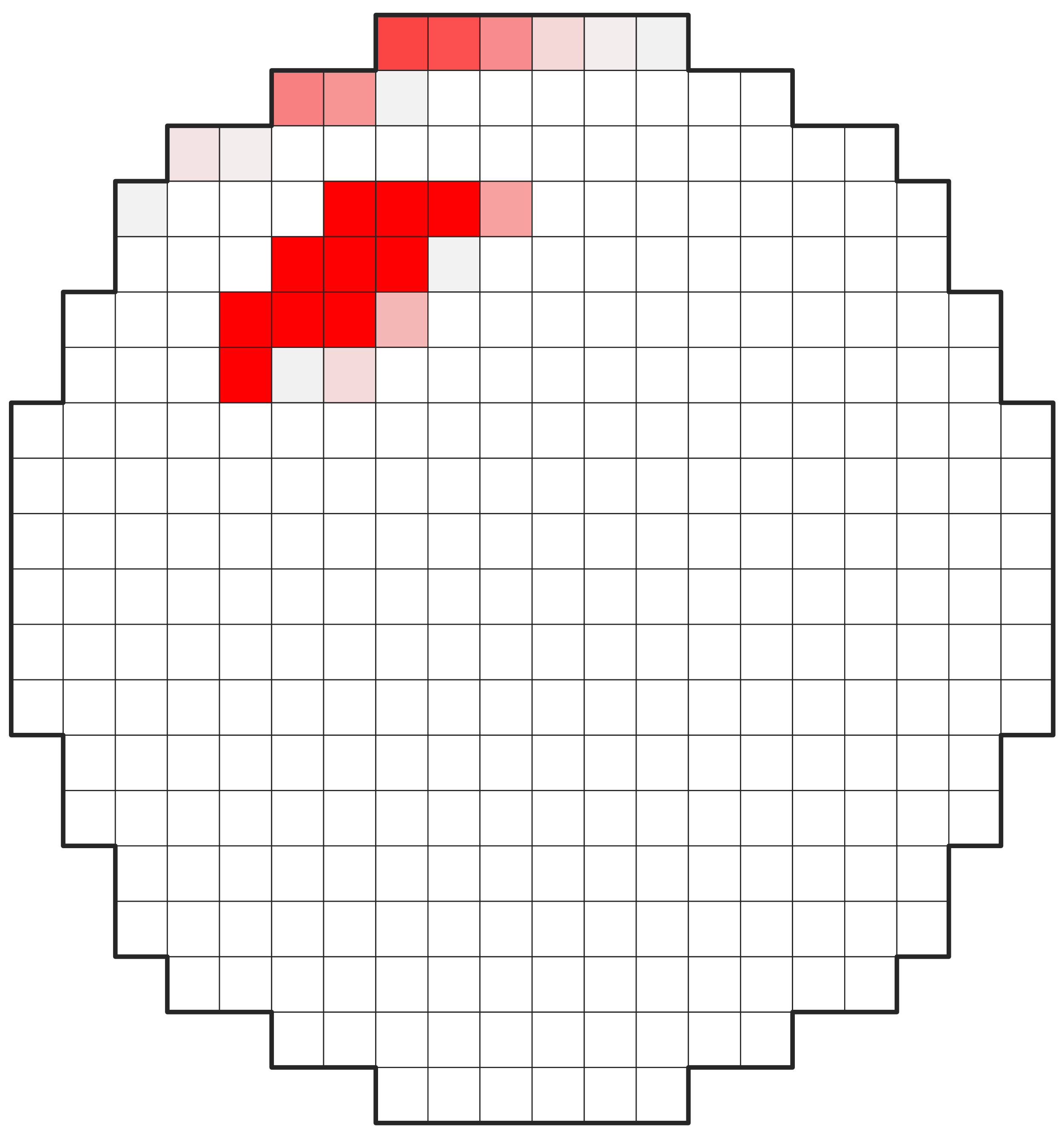
Illustrative Example

$$P(u < u_*)$$



Illustrative Example

$$P(u < u_*)$$



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Our Goal

Given:

* Multiprocessor system
* Process variation

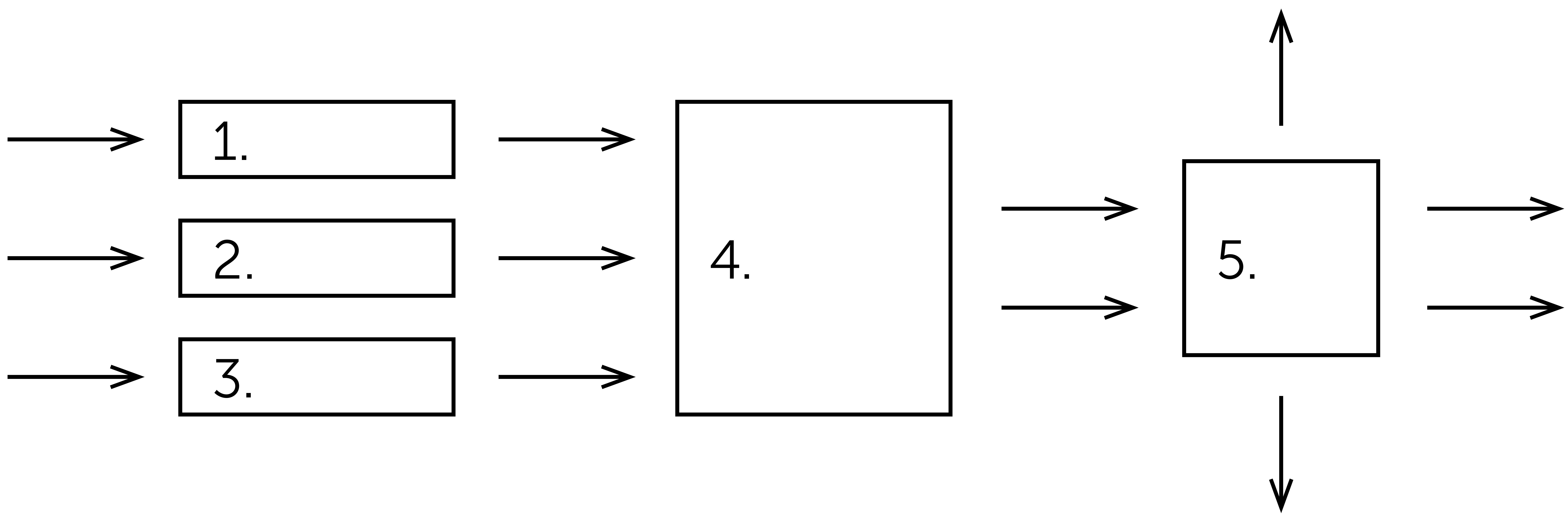
Find:

* Probability distributions of transient power and temperature profiles

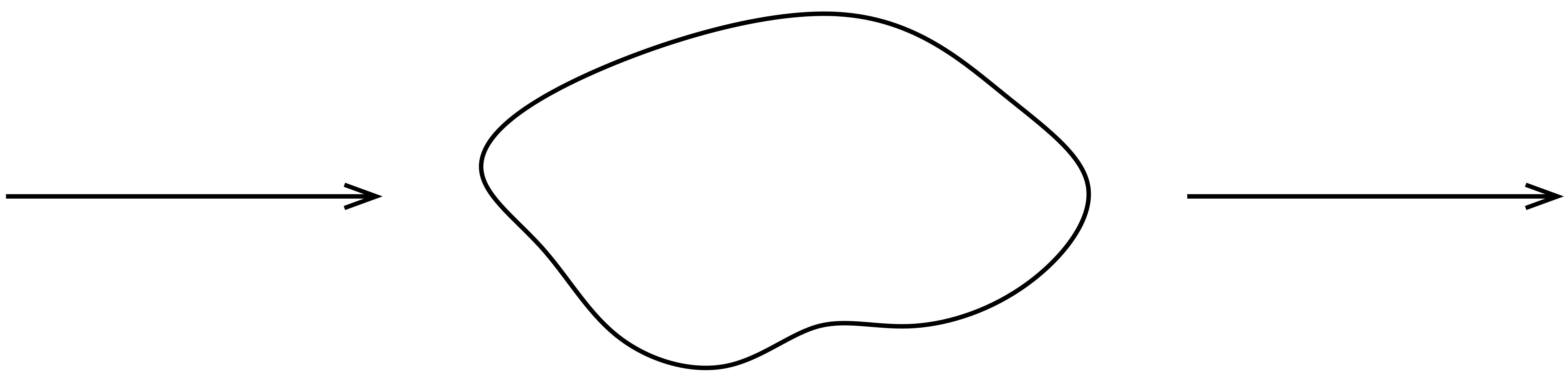
Such that:

* Accurate and fast

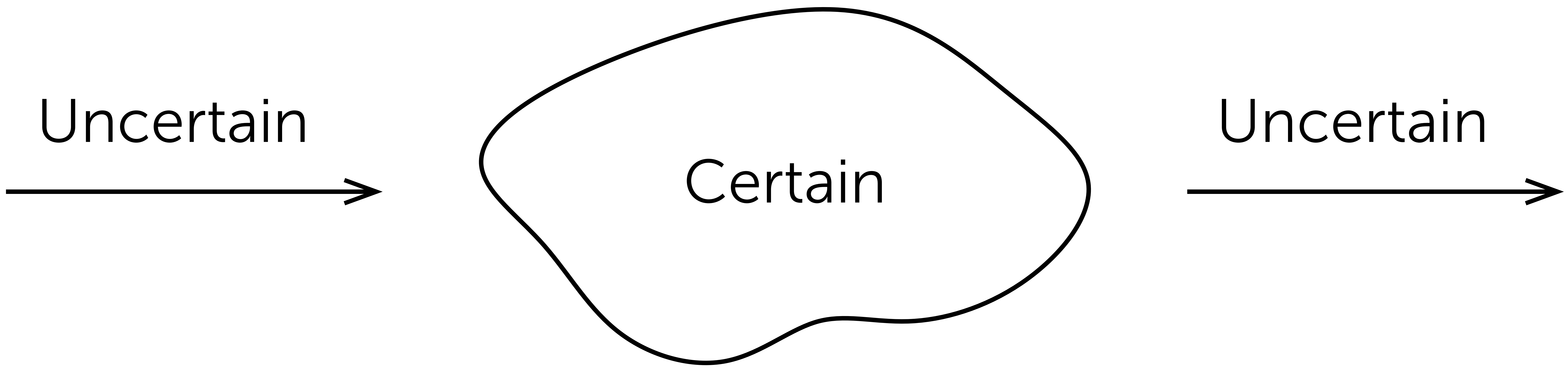
Our Solution



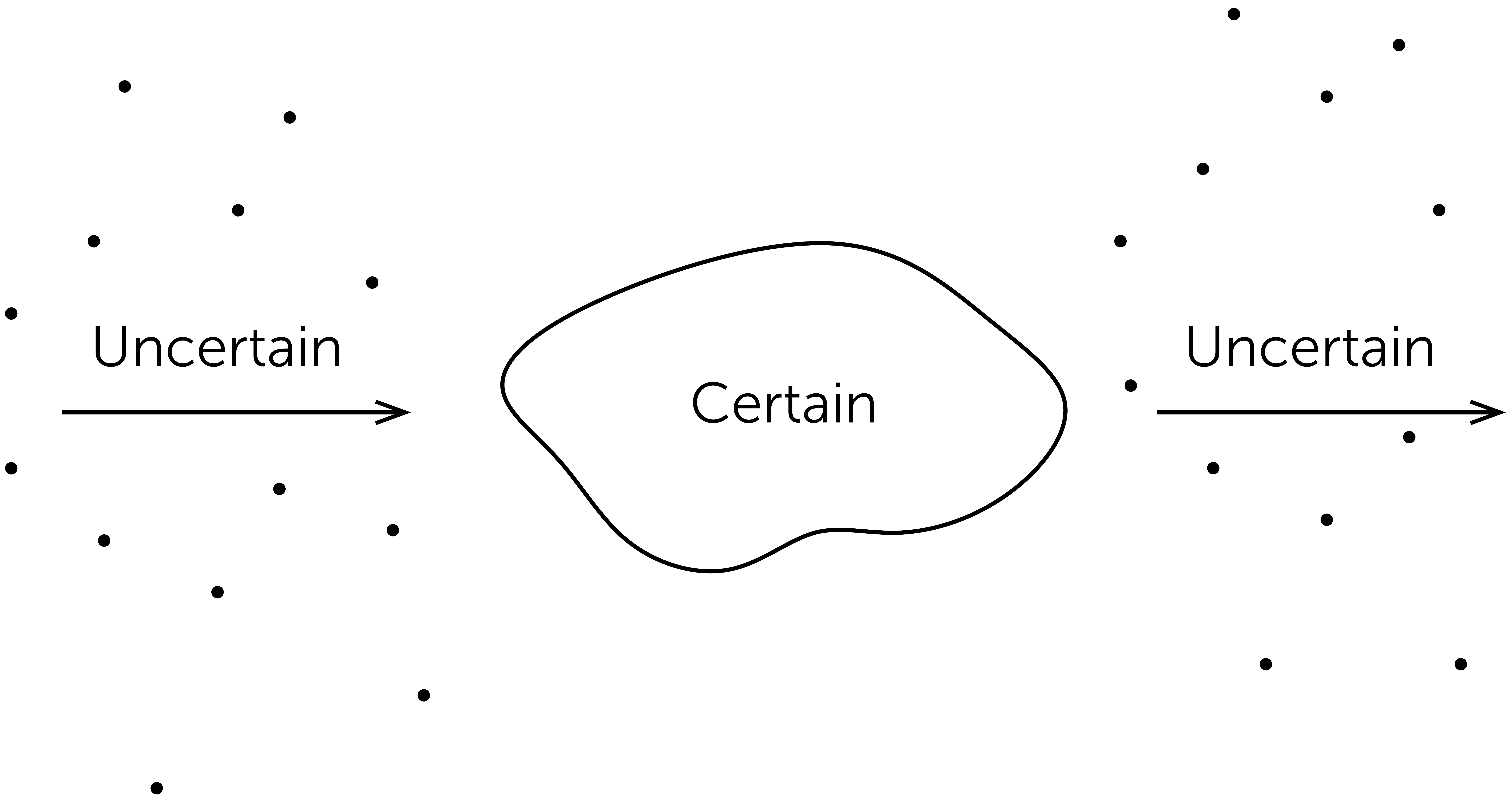
Uncertainty Quantification



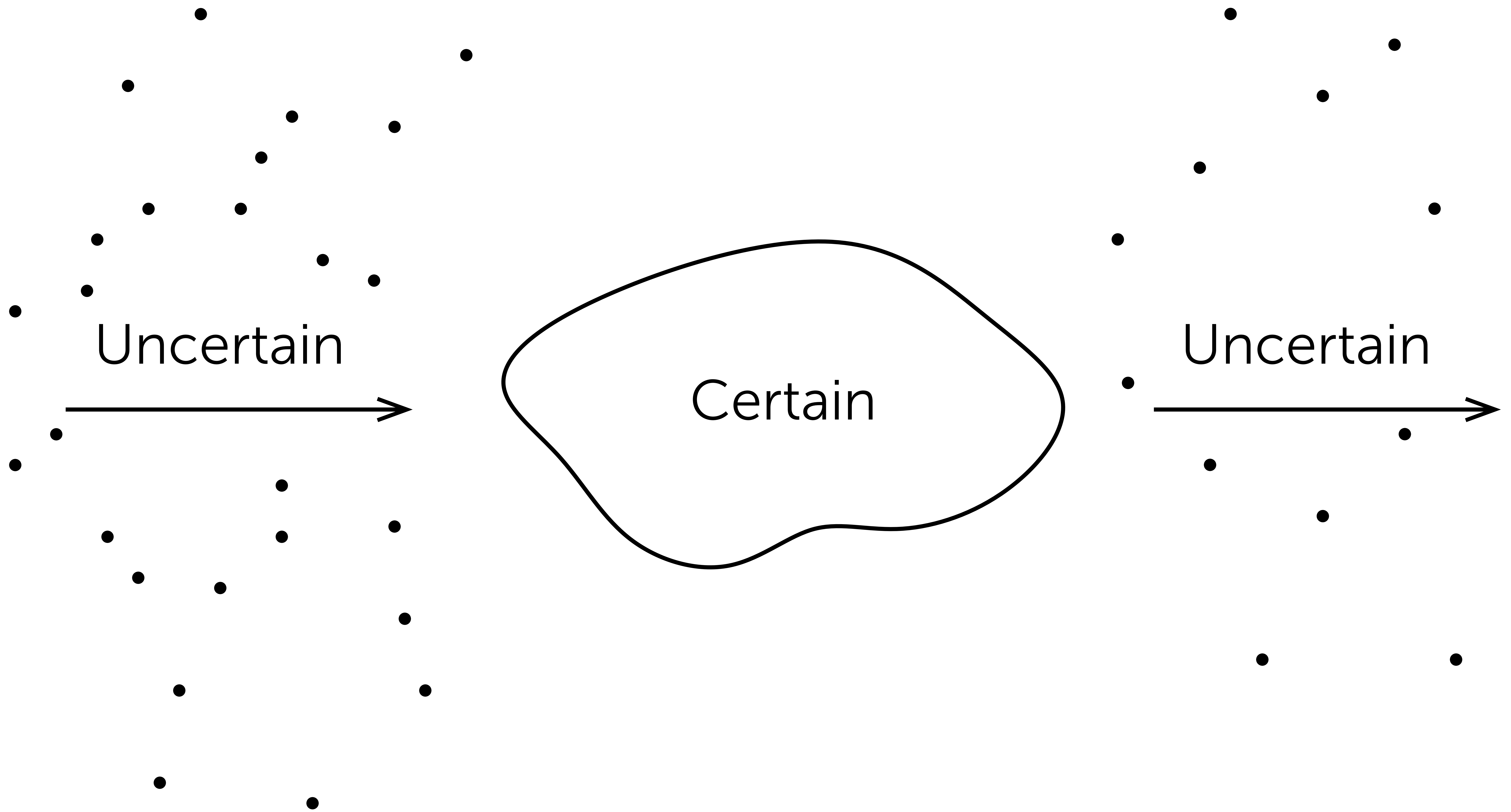
Uncertainty Quantification



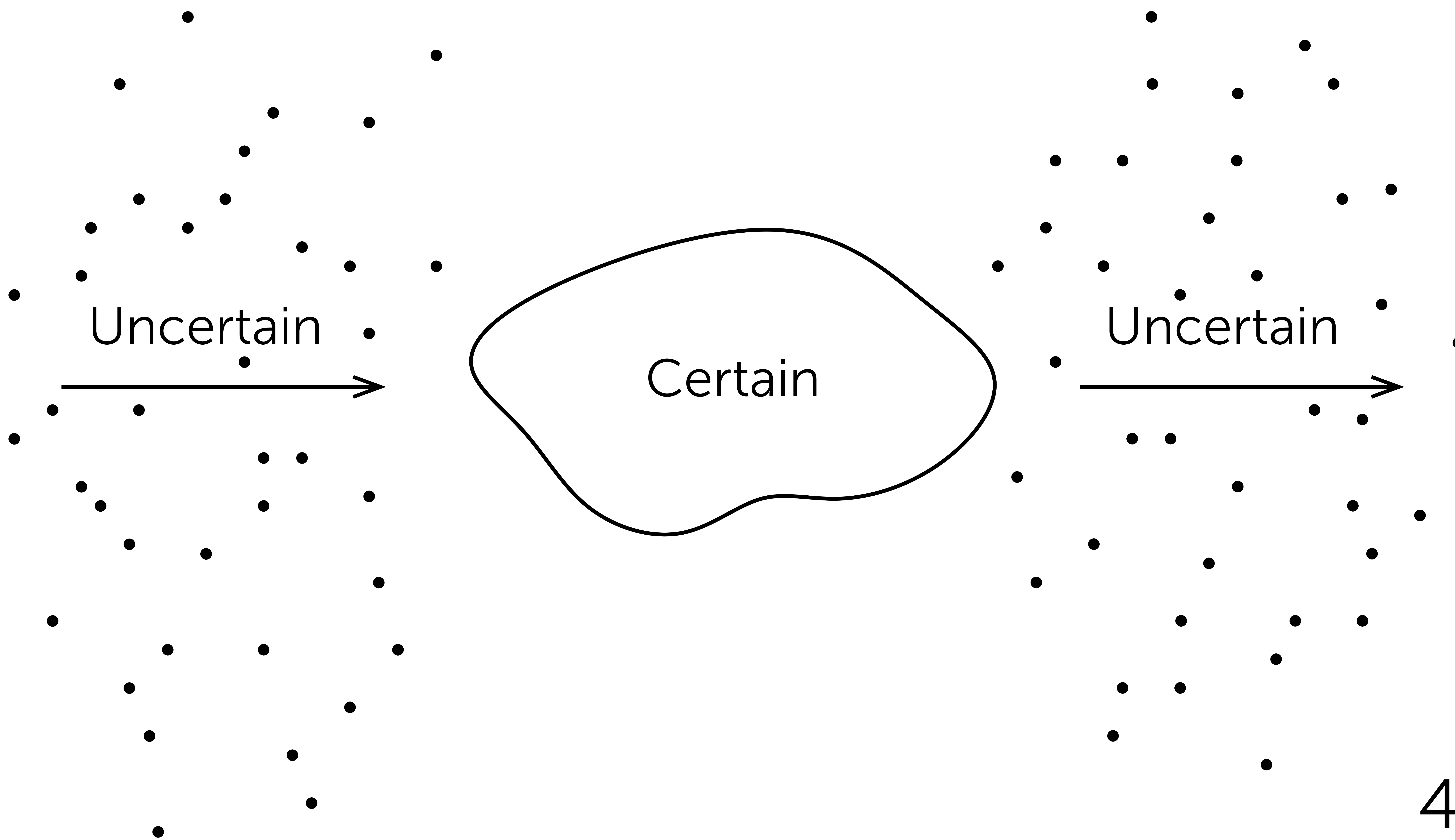
Monte Carlo



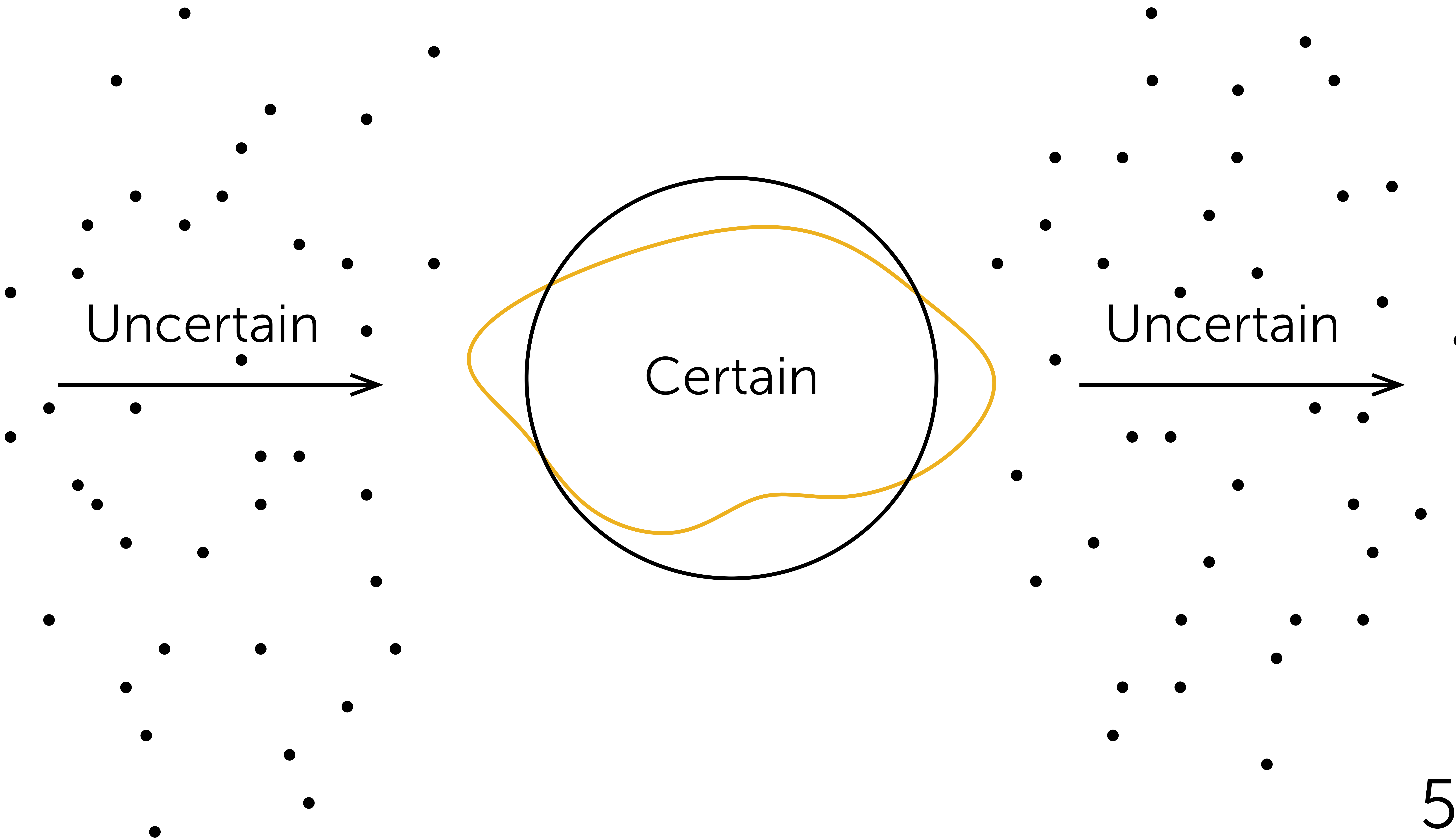
Monte Carlo



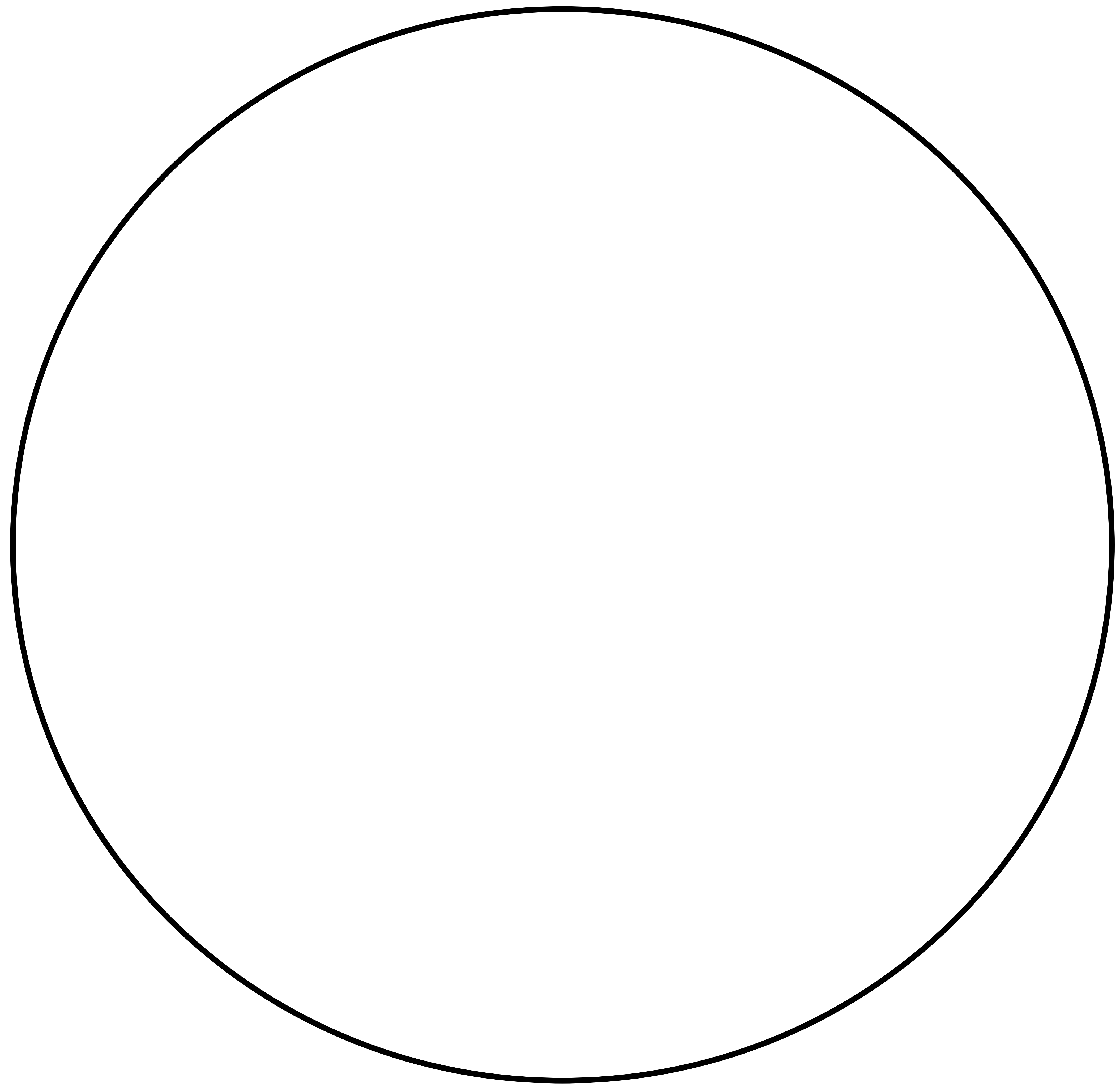
Monte Carlo



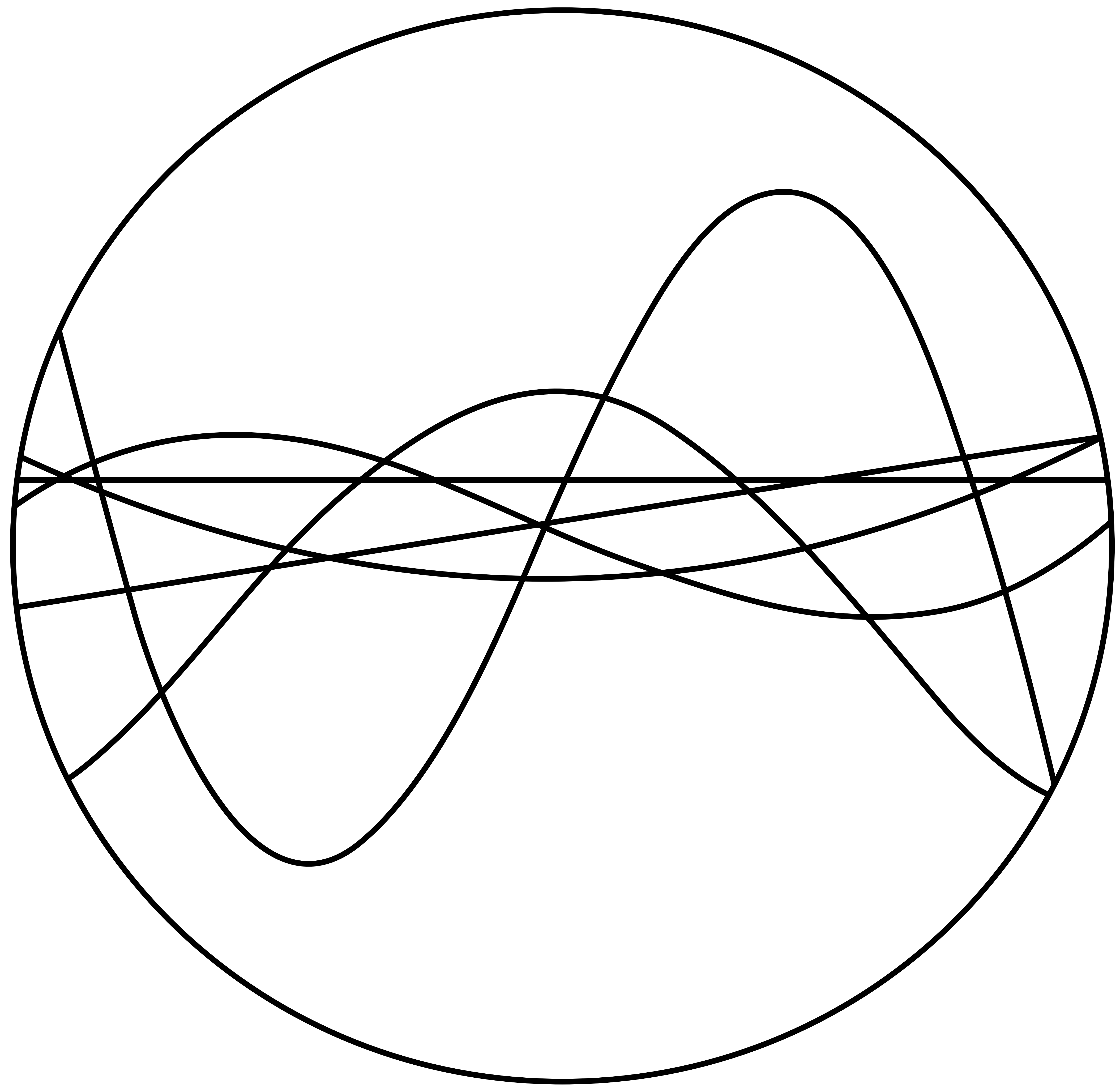
Our Solution



Polynomial Chaos



Polynomial Chaos

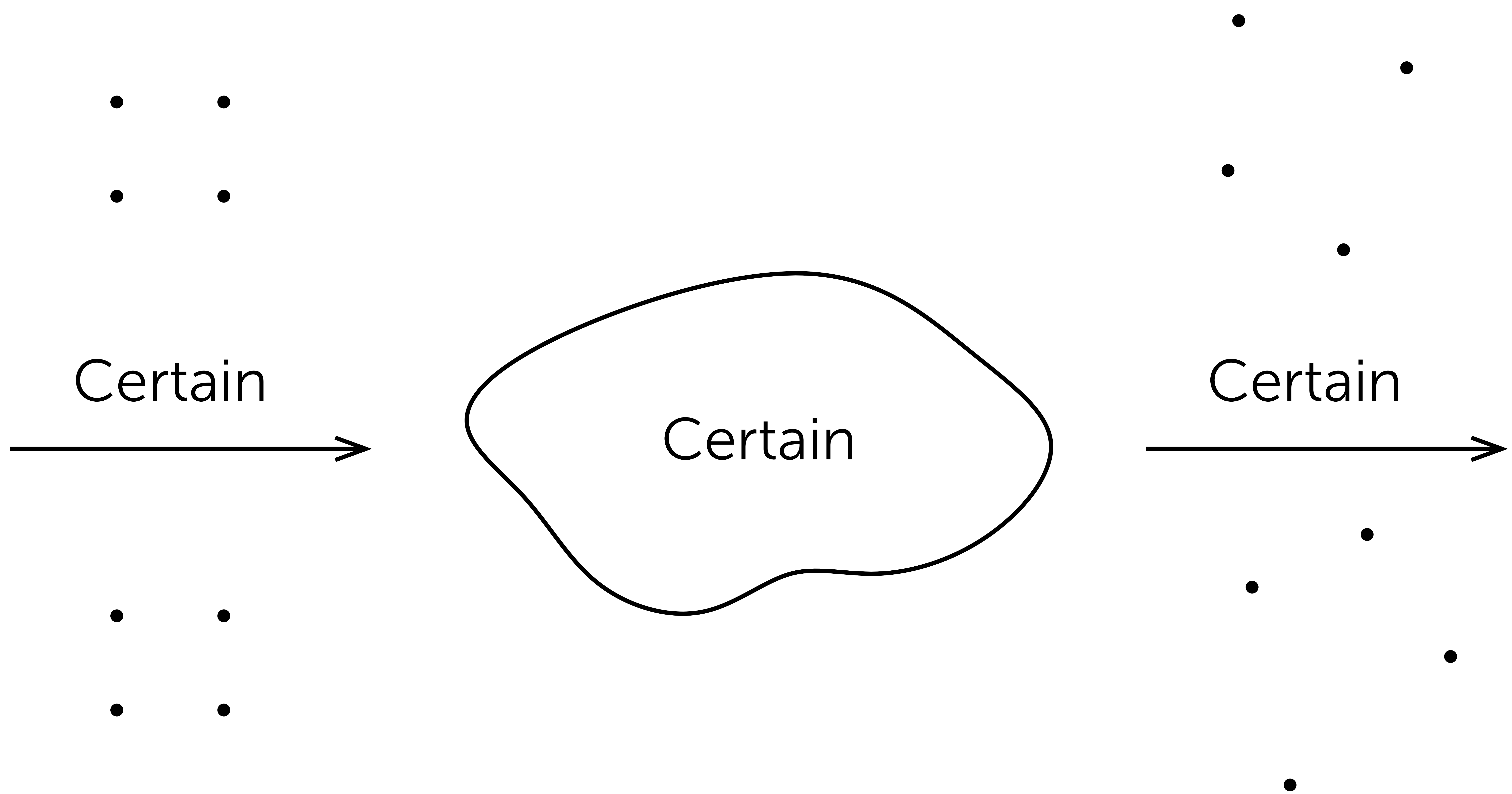


Polynomial Chaos

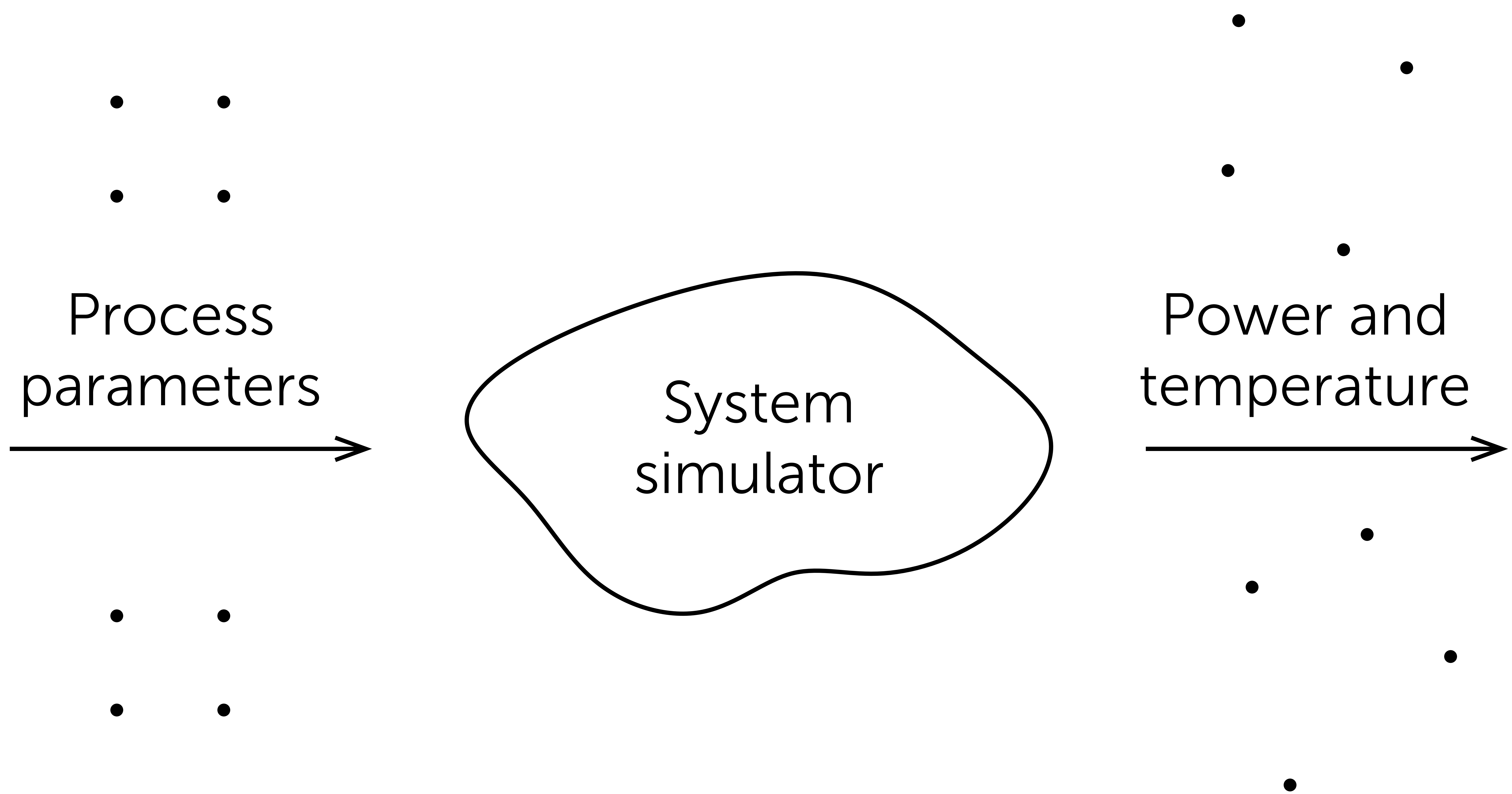
$$\theta(\xi) \approx \sum_{\alpha} \hat{\theta}_{\alpha} \psi_{\alpha}(\xi)$$

$$\hat{\theta}_{\alpha} = \langle \theta, \psi_{\alpha} \rangle$$

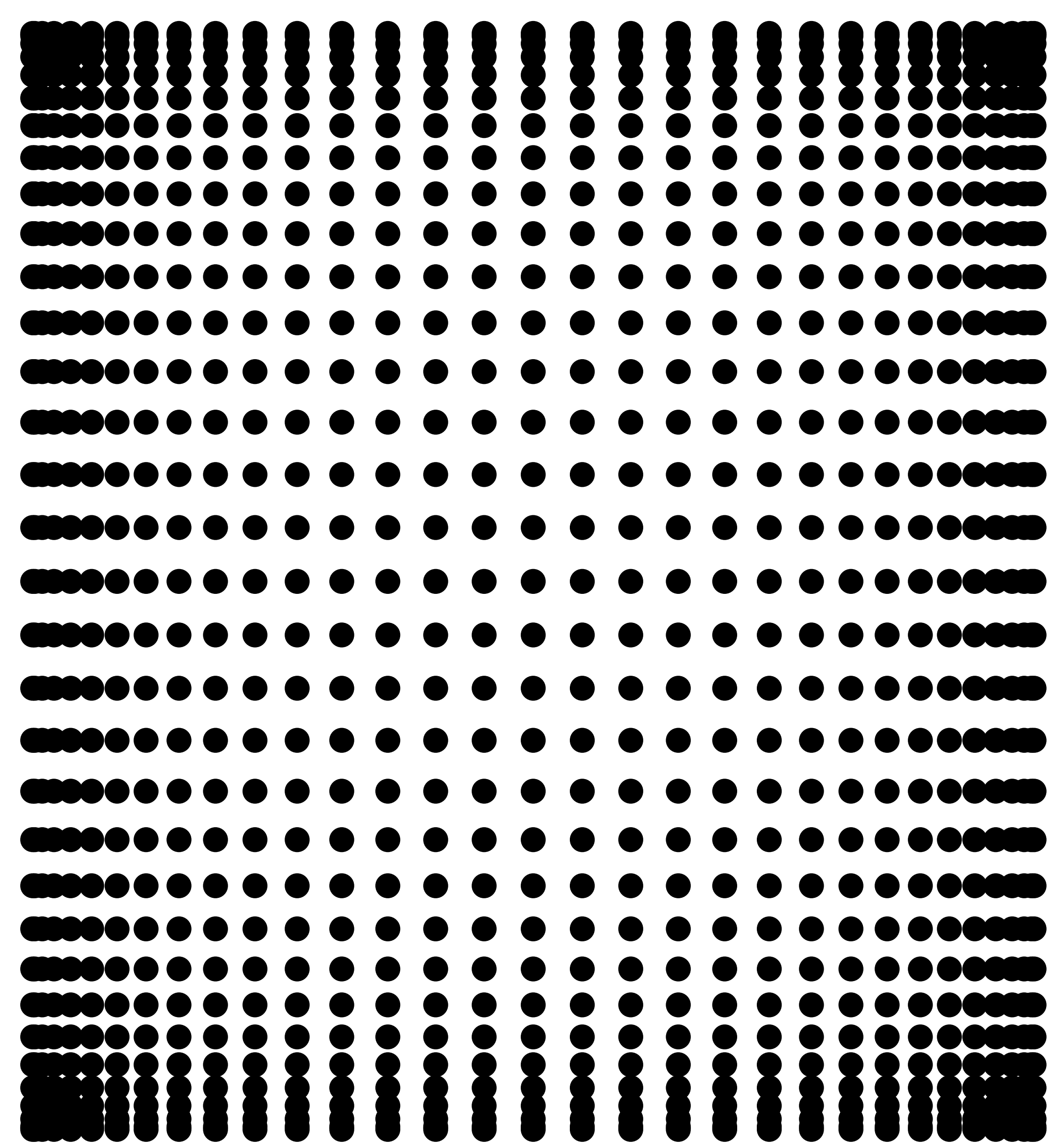
Quadratures



Power and Temperature

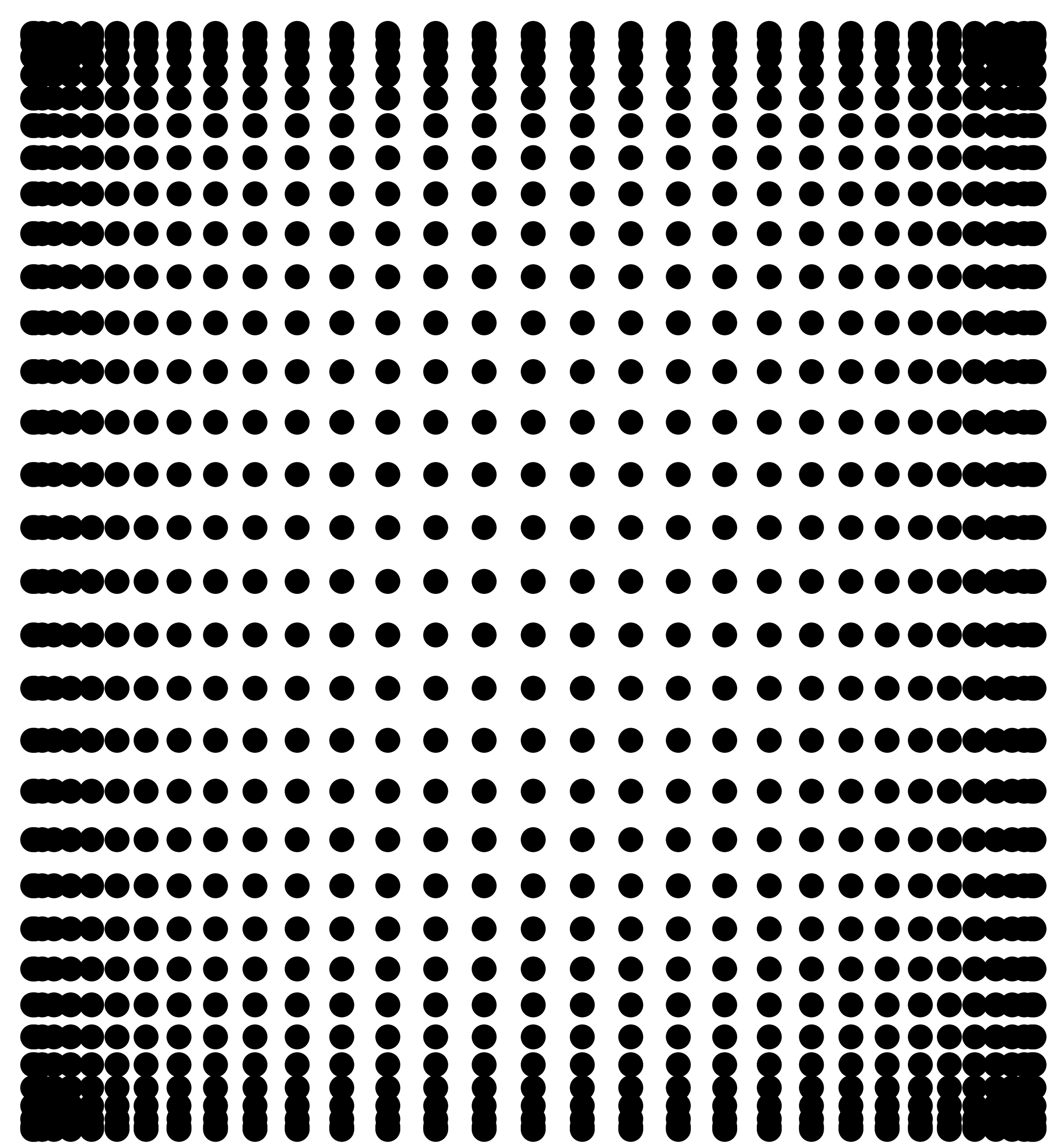


Quadratures

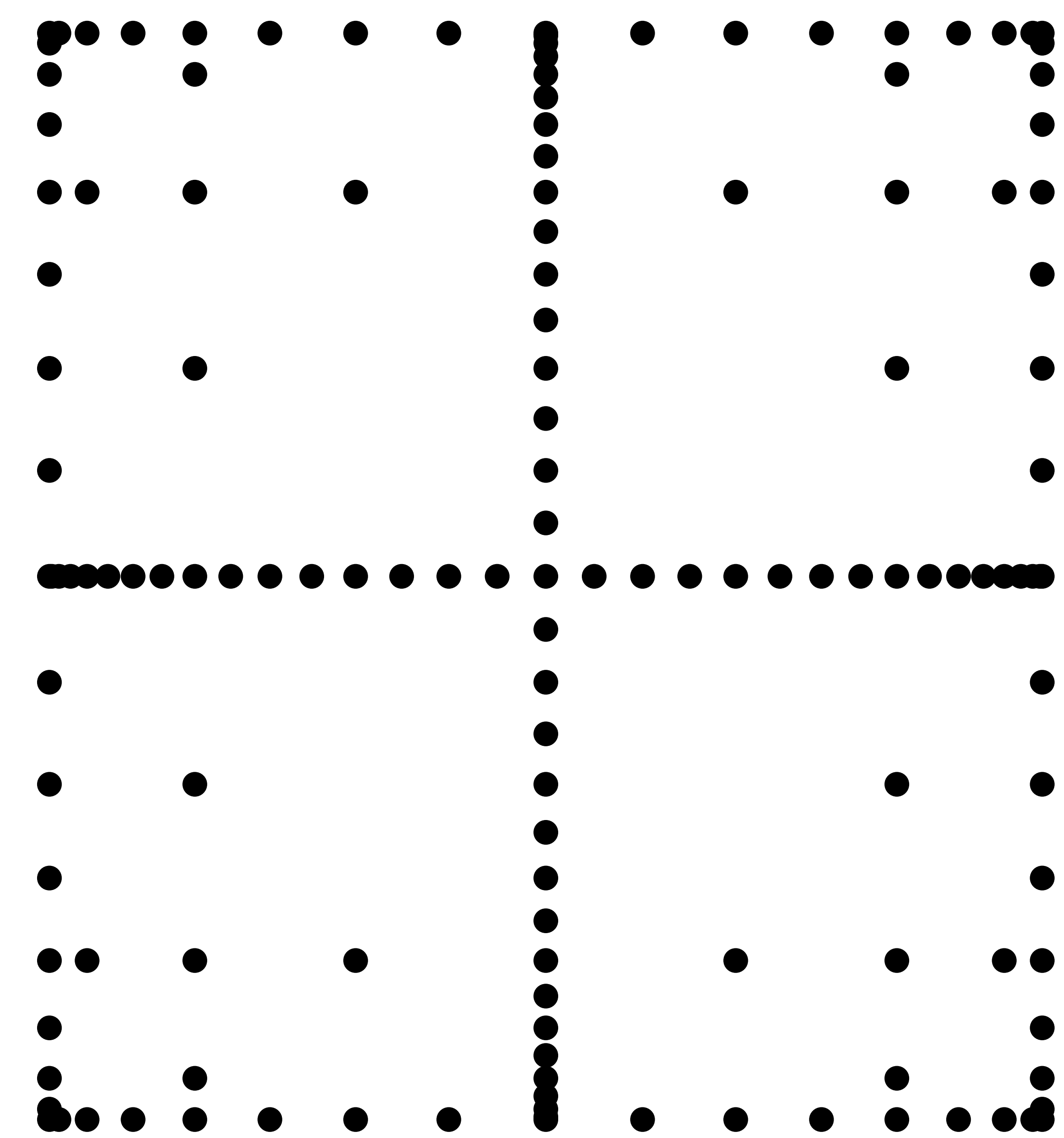


Tensor product

Quadratures



Tensor product



Sparse grid

Our Solution

* Arbitrary probability distributions
* Spacial correlations
* Leakage-temperature interplay

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Our Goal

Given:

* Multiprocessor system
* Process variation

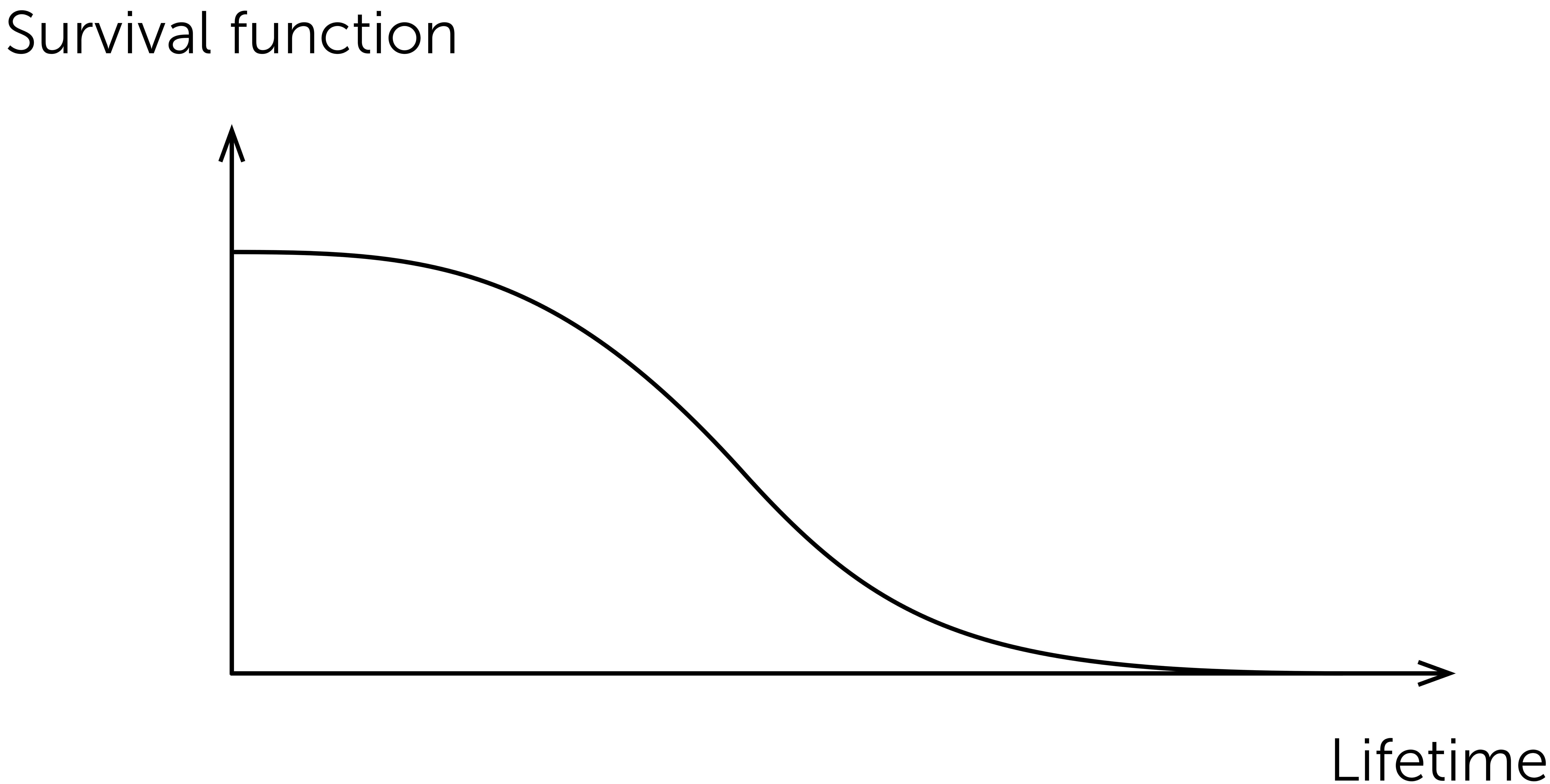
Perform:

* Reliability analysis

Such that:

* Accurate and fast

Reliability Analysis



Survival Function

$$R(t|\theta)$$

Survival Function

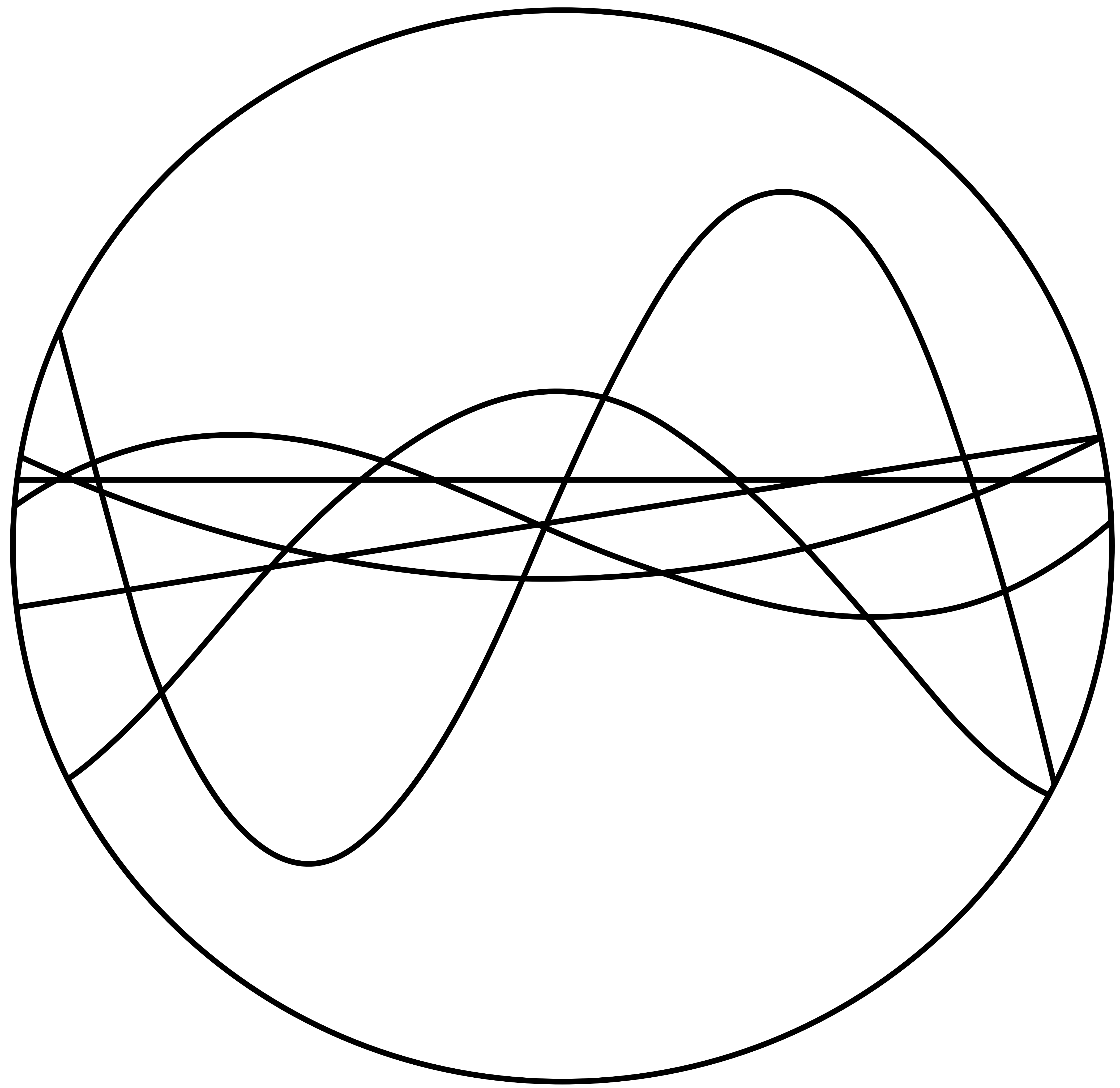
$$R(t|\theta)$$

$$\theta = (\theta_1, \theta_2, \ldots)$$
$$\theta_i = f_i(\text{system simulation})$$

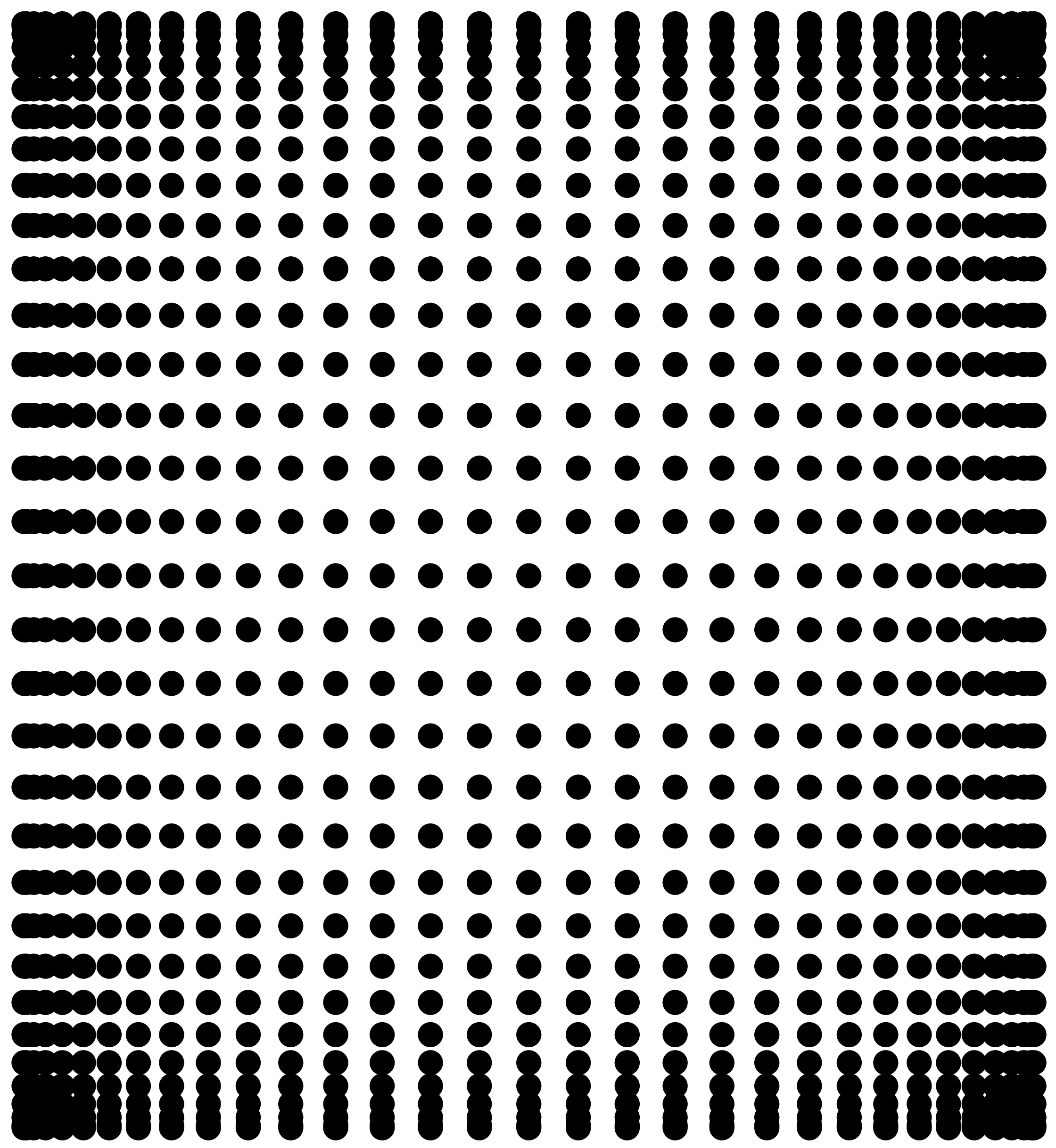
Our Solution

$$\theta_i(\xi) \approx \sum_{\alpha} \hat{\theta}_{i,\alpha} \psi_\alpha(\xi)$$

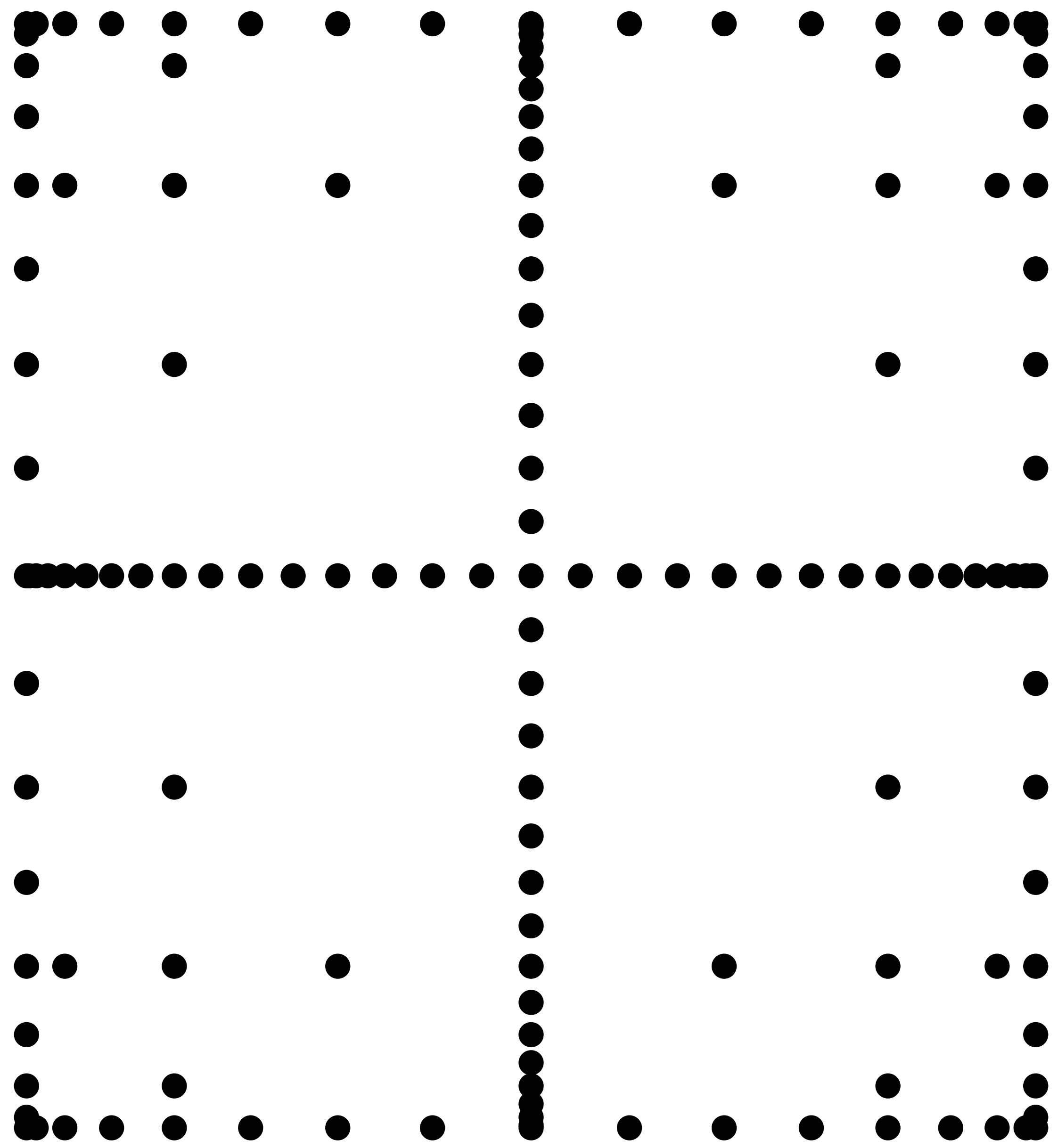
Polynomial Chaos



Quadratures

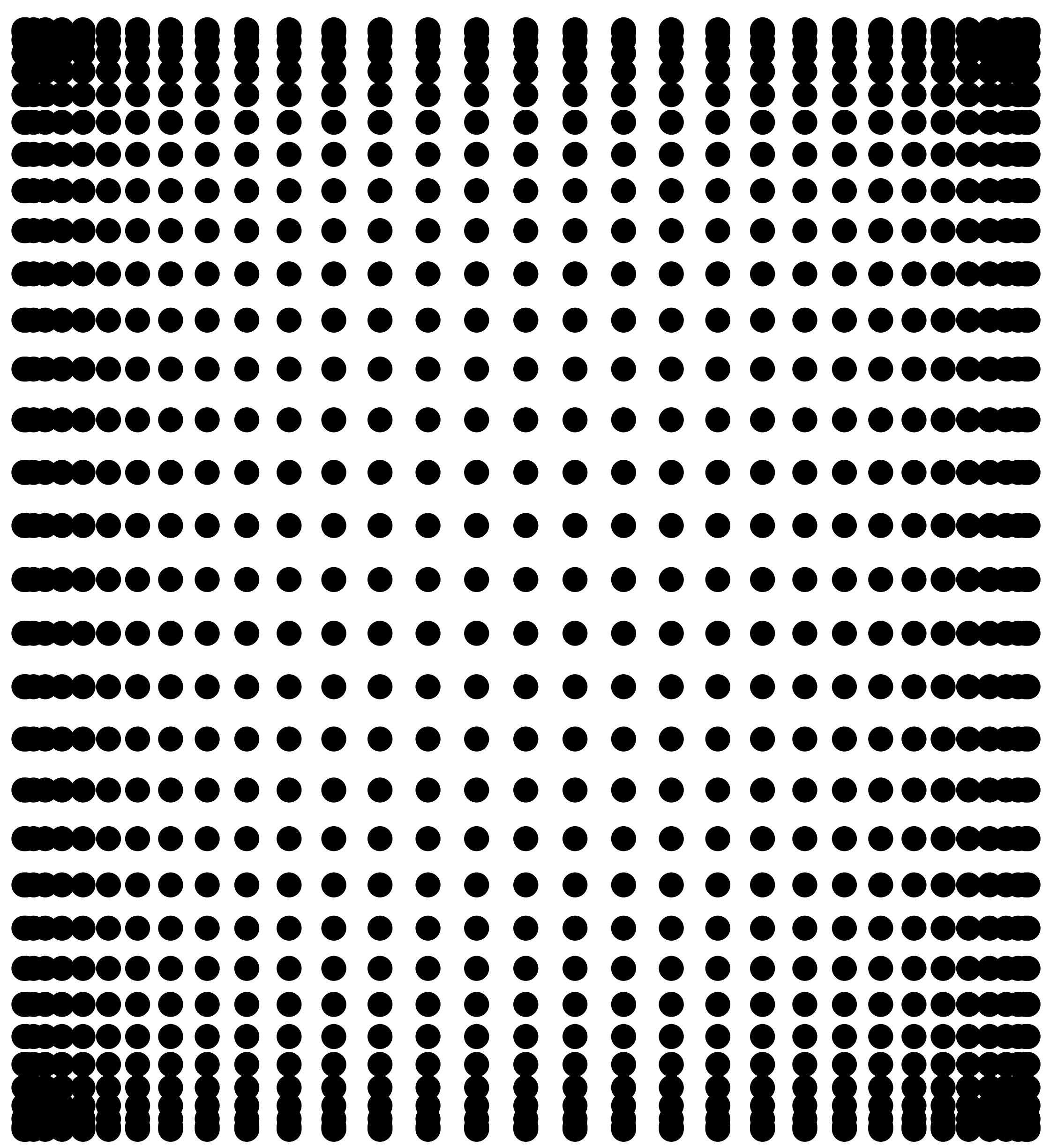


Tensor product

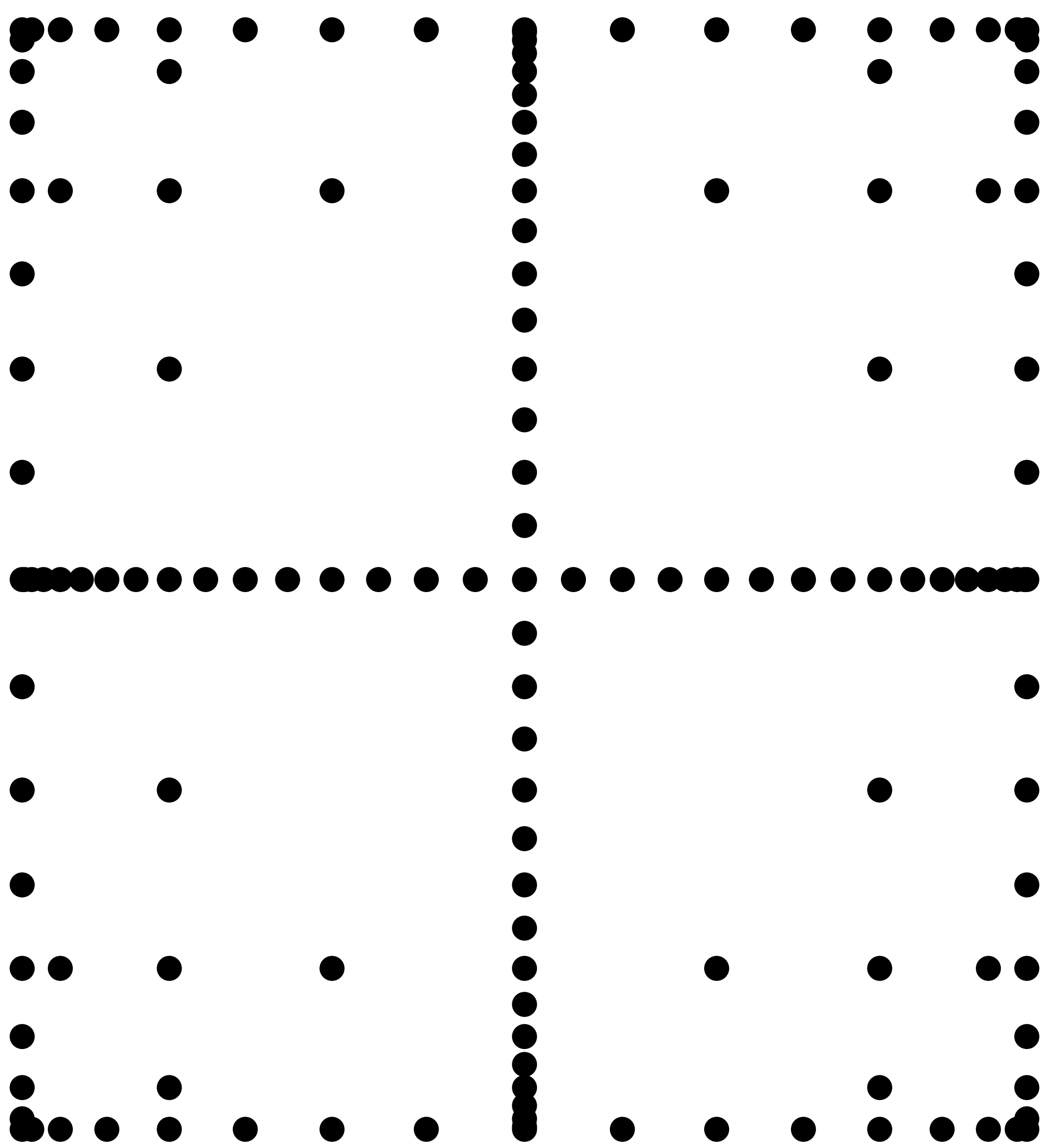


Sparse grid

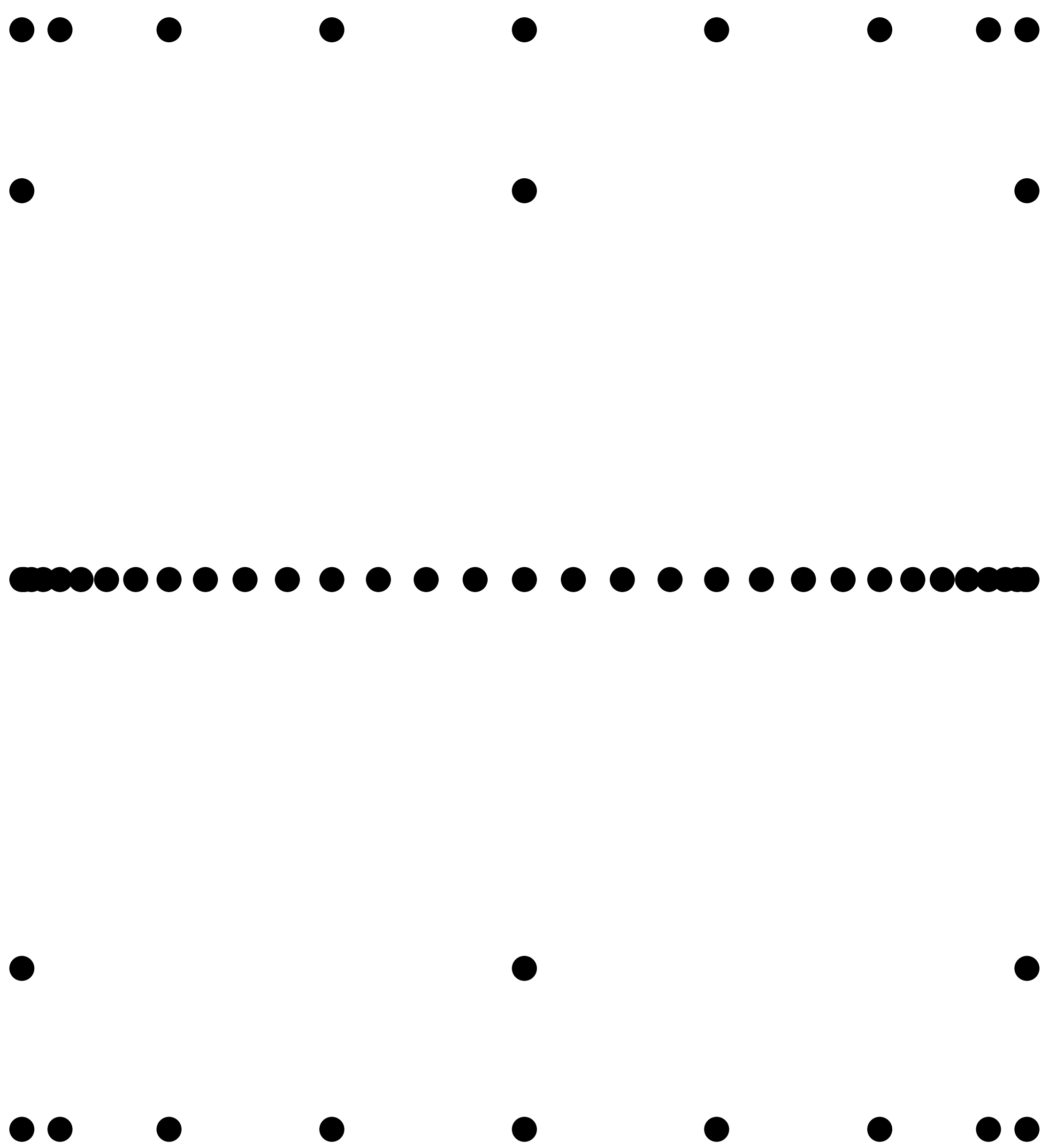
Quadratures



Tensor product



Sparse grid



Sparser grid

Reliability Optimization

* Thermal-cyclic fatigue
* Dynamic steady-state temperature analysis

Our Goal

Given:

* Multiprocessor system
* Process variation

Find:

* Schedule

Such that:

* ...

Our Goal

Such that:

* Expected energy minimized
* Probability of burn constrained
* Probability of wear-out constrained

Thank you! Questions?

https://users.ece.cmu.edu/~iukhov