Temperature-Centric Reliability Analysis and Optimization under Process Variation

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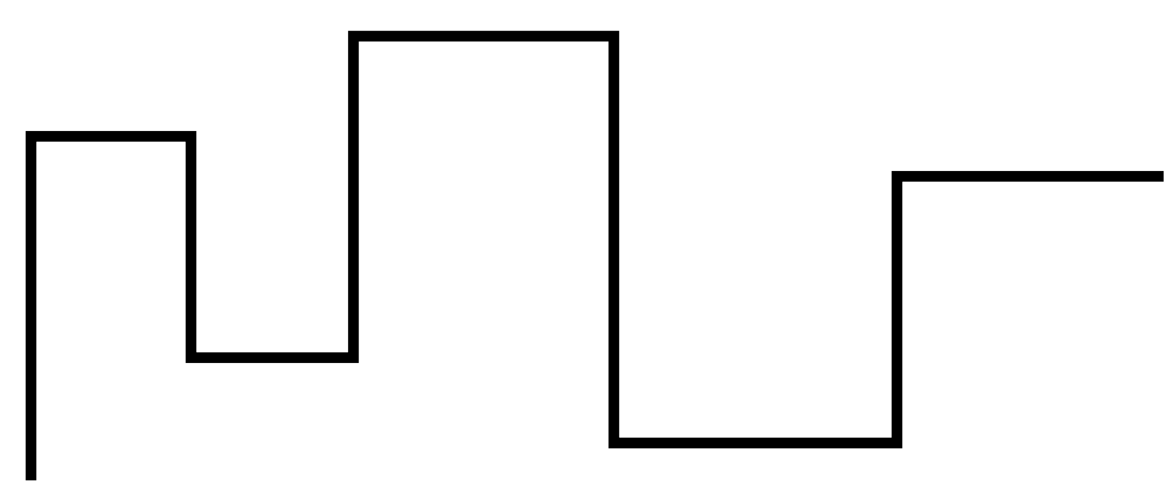
Outline

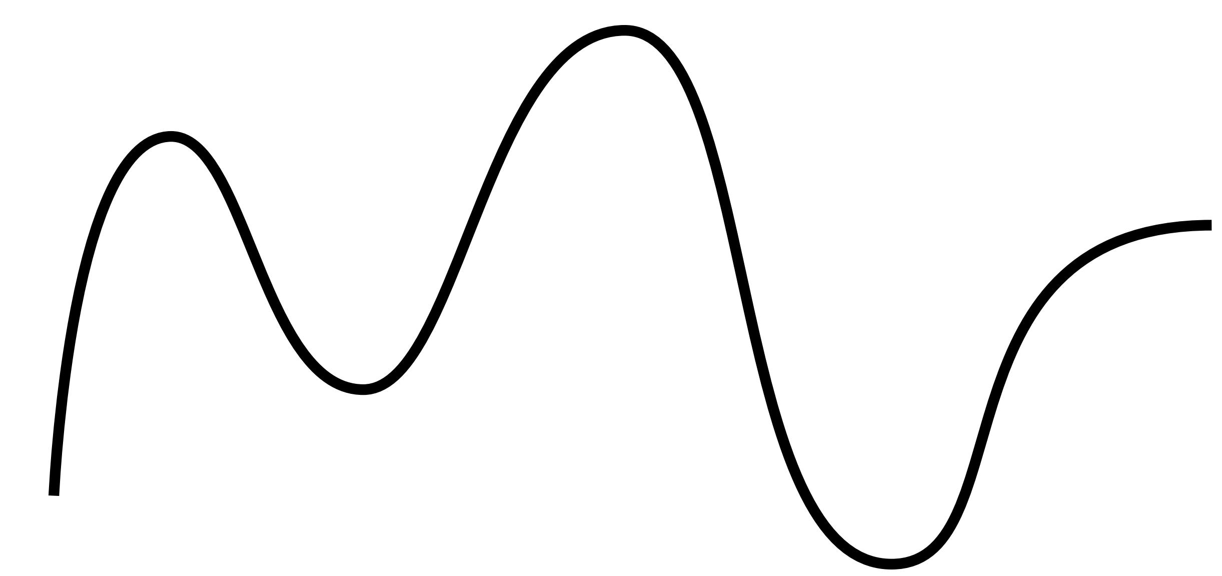
* Temperature analysis
* Process variation
* Reliability analysis
* Reliability optimization

Temperature Analysis

* Transient



Power



Temperature

Temperature Analysis

* Static steady state

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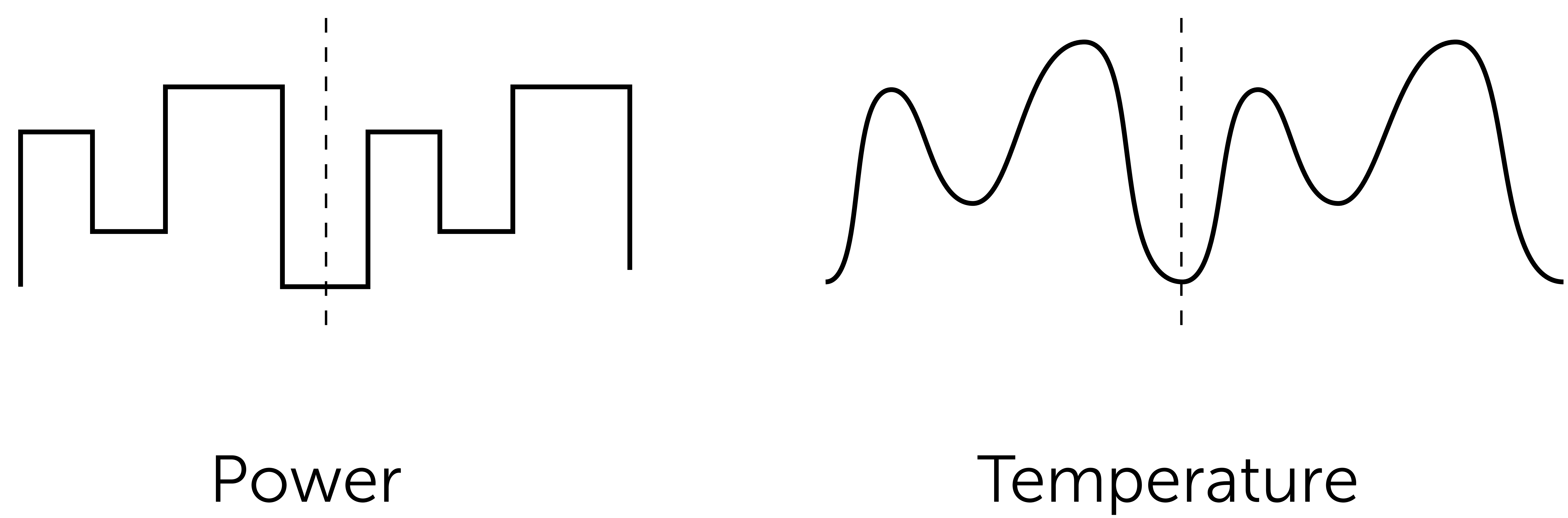
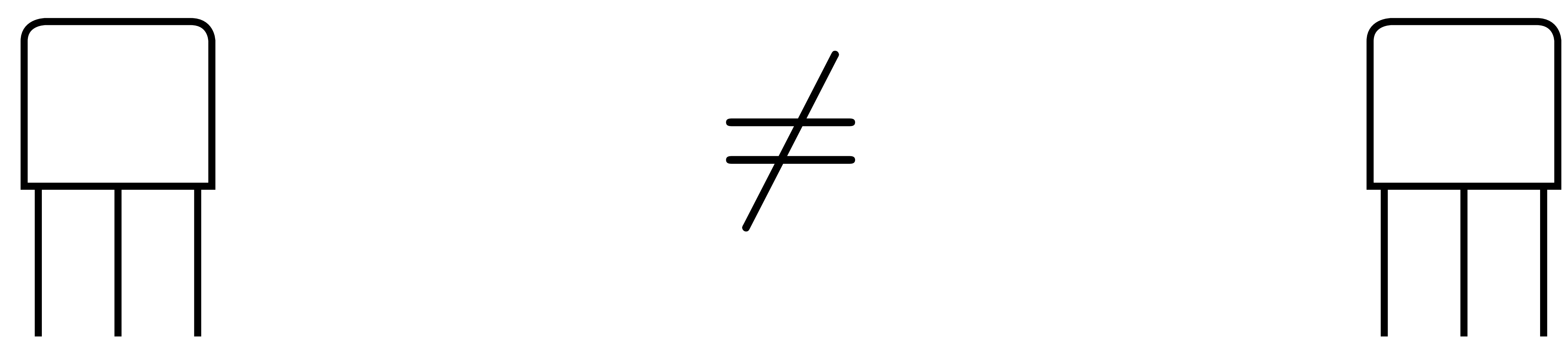
Power　　　　　　　　Temperature

Temperature Analysis

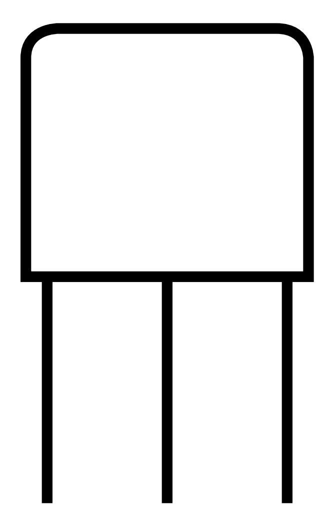
* Dynamic steady state



Process Variation



Process Variation

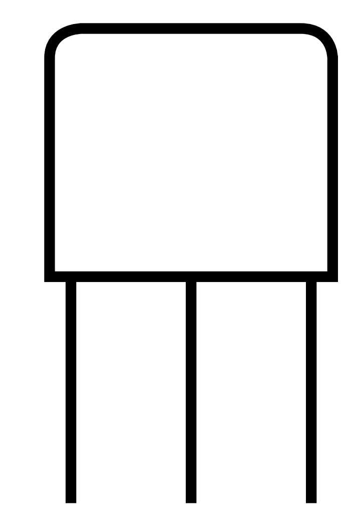


$$L_{\text{eff}} \neq L_{\text{eff}}$$

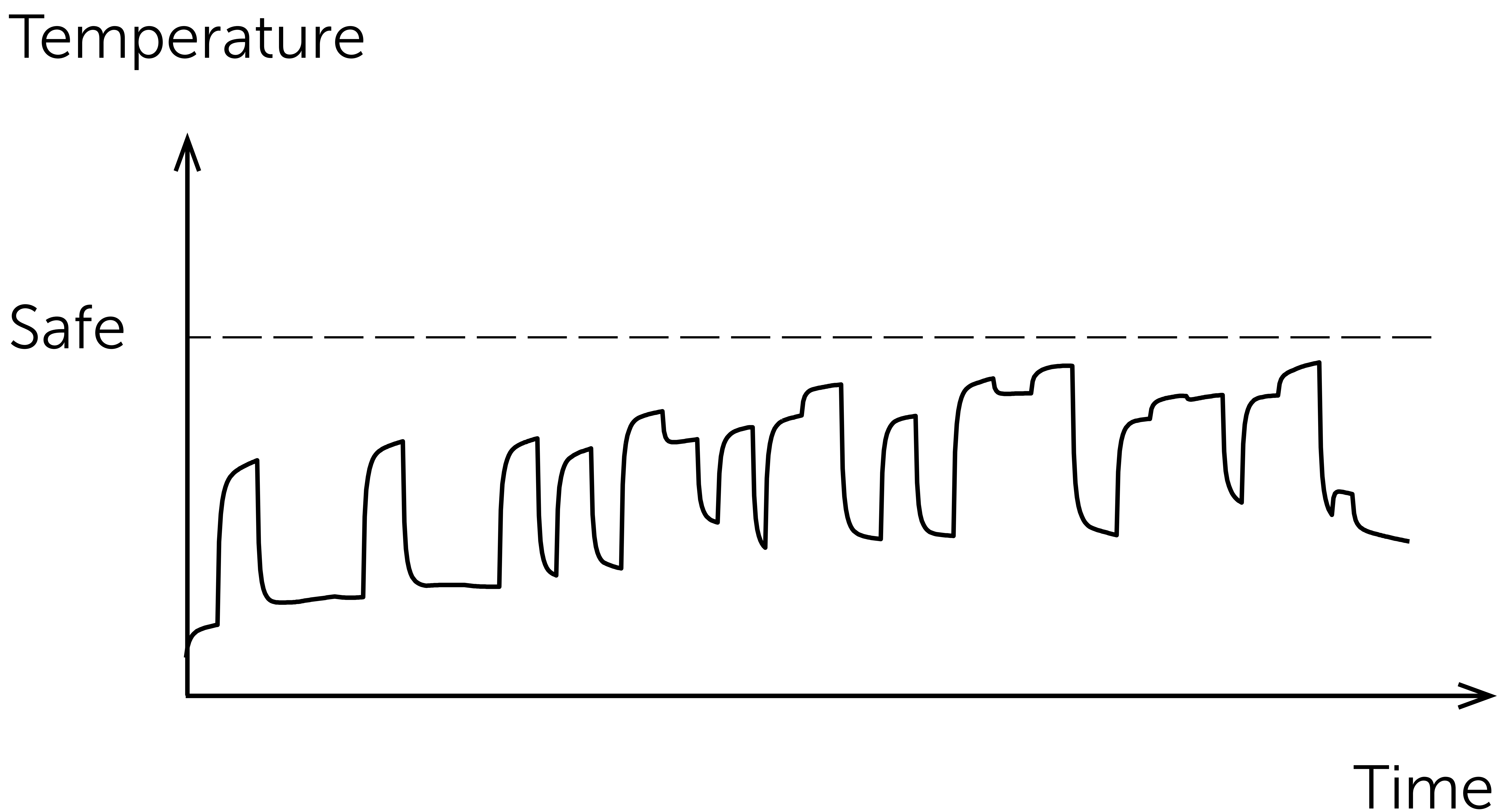
$$T_{\text{ox}} \neq T_{\text{ox}}$$

$$V_{\text{th}} \neq V_{\text{th}}$$

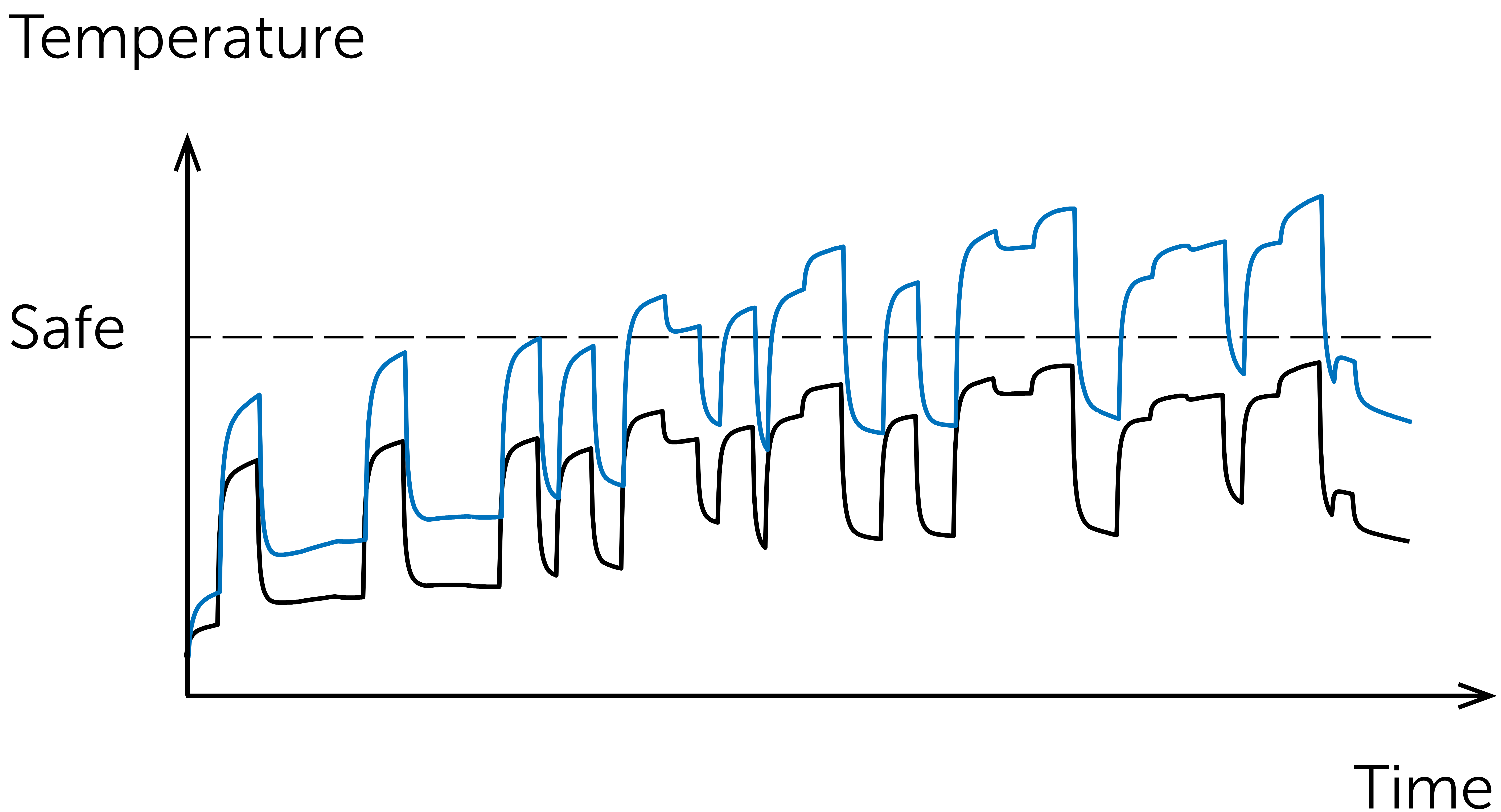
$$\ldots$$



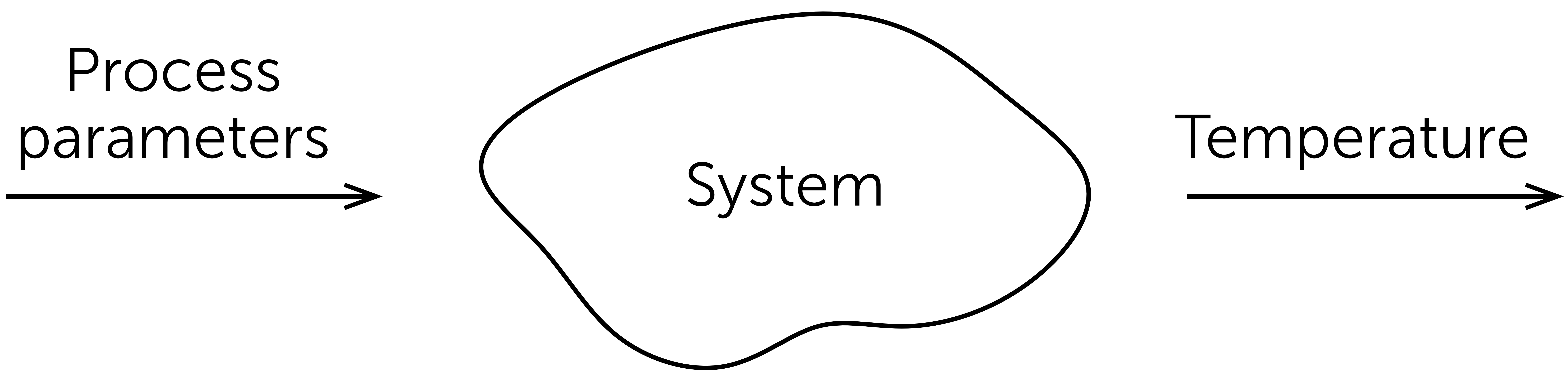
Process Variation



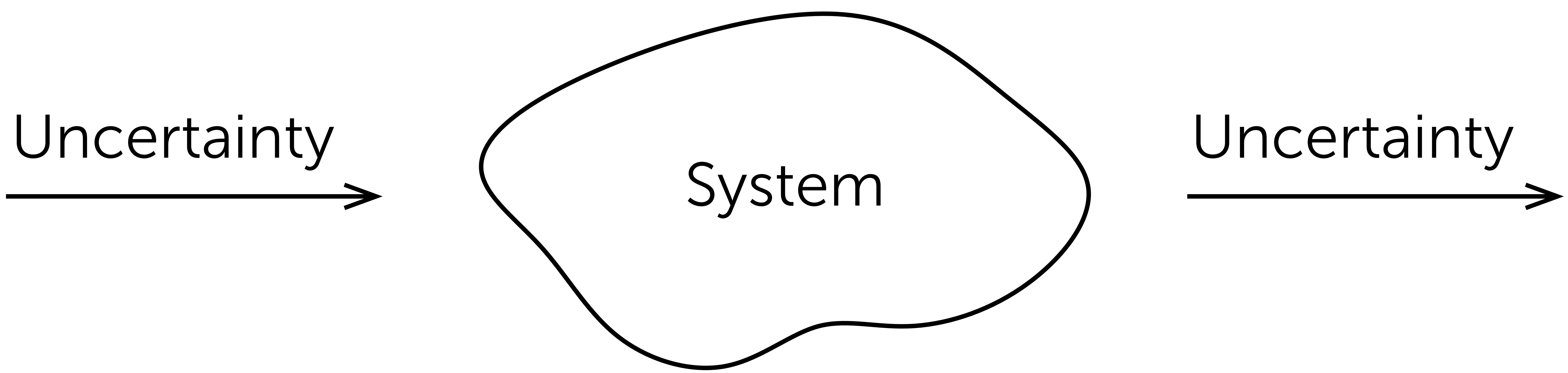
Process Variation



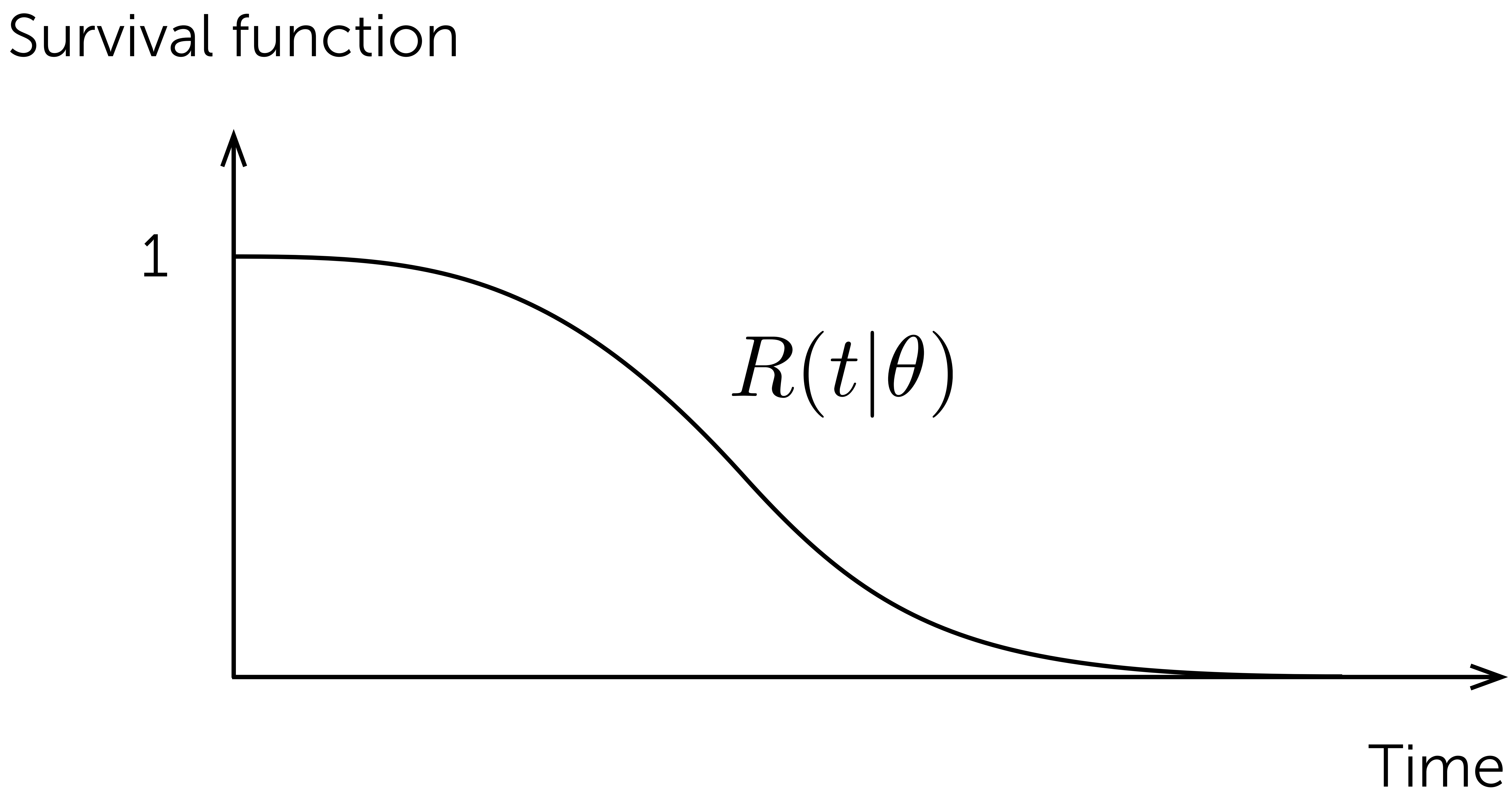
Electronic System



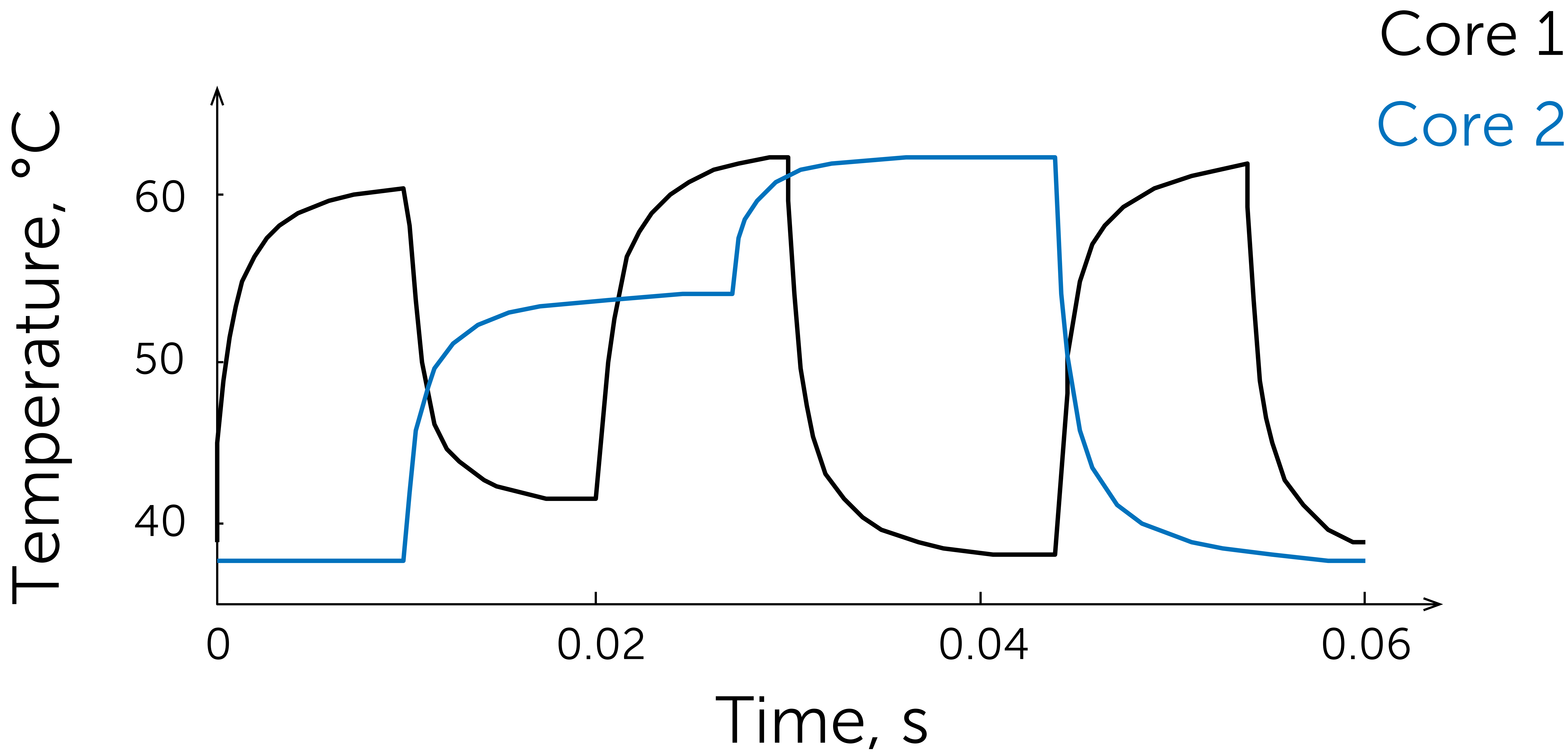
Electronic System



Reliability Analysis



Thermal-Cyclic Fatigue



Thermal-Cyclic Fatigue

$$N = \alpha(\Delta T)^{\beta} \exp\left\{\frac{\gamma}{T_{\max}}\right\}$$

Goal

Given:

* Electronic system
* Process variation

Perform:

* Reliability analysis

Such that:

* Accurate and computationally efficient

Reliability Analysis

$$R(t|\theta)$$

Reliability Analysis

$$R(t|\theta)$$

Reliability Analysis

$$\theta = \{\theta_i\}_{i=1}^{n}$$

Reliability Analysis

$$\theta = \{\theta_i\}_{i=1}^{n}$$

$$\theta = \{\theta_i(\text{system})\}_{i=1}^{n}$$

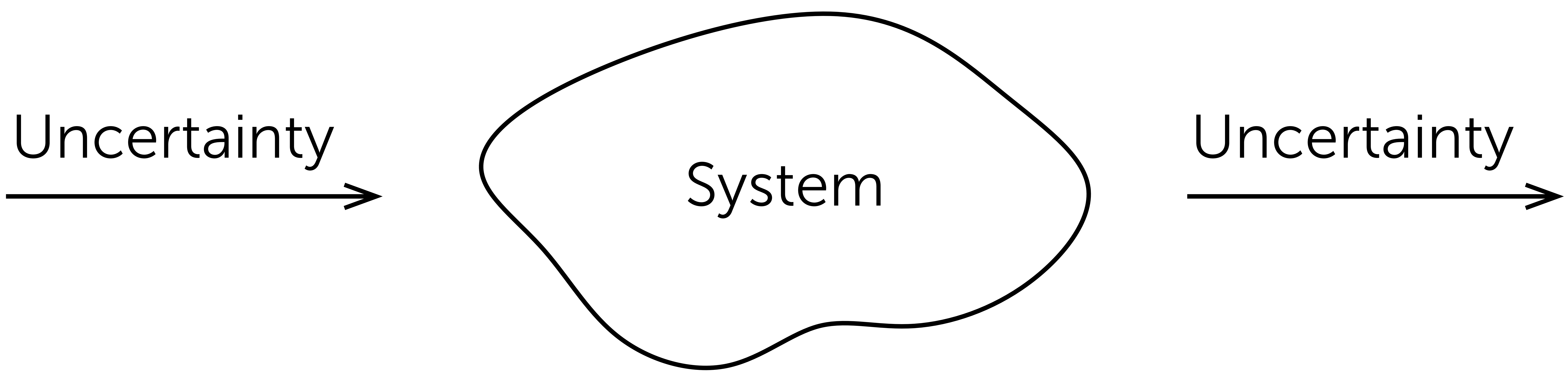
Reliability Analysis

$$\theta = \{\theta_i\}_{i=1}^{n}$$

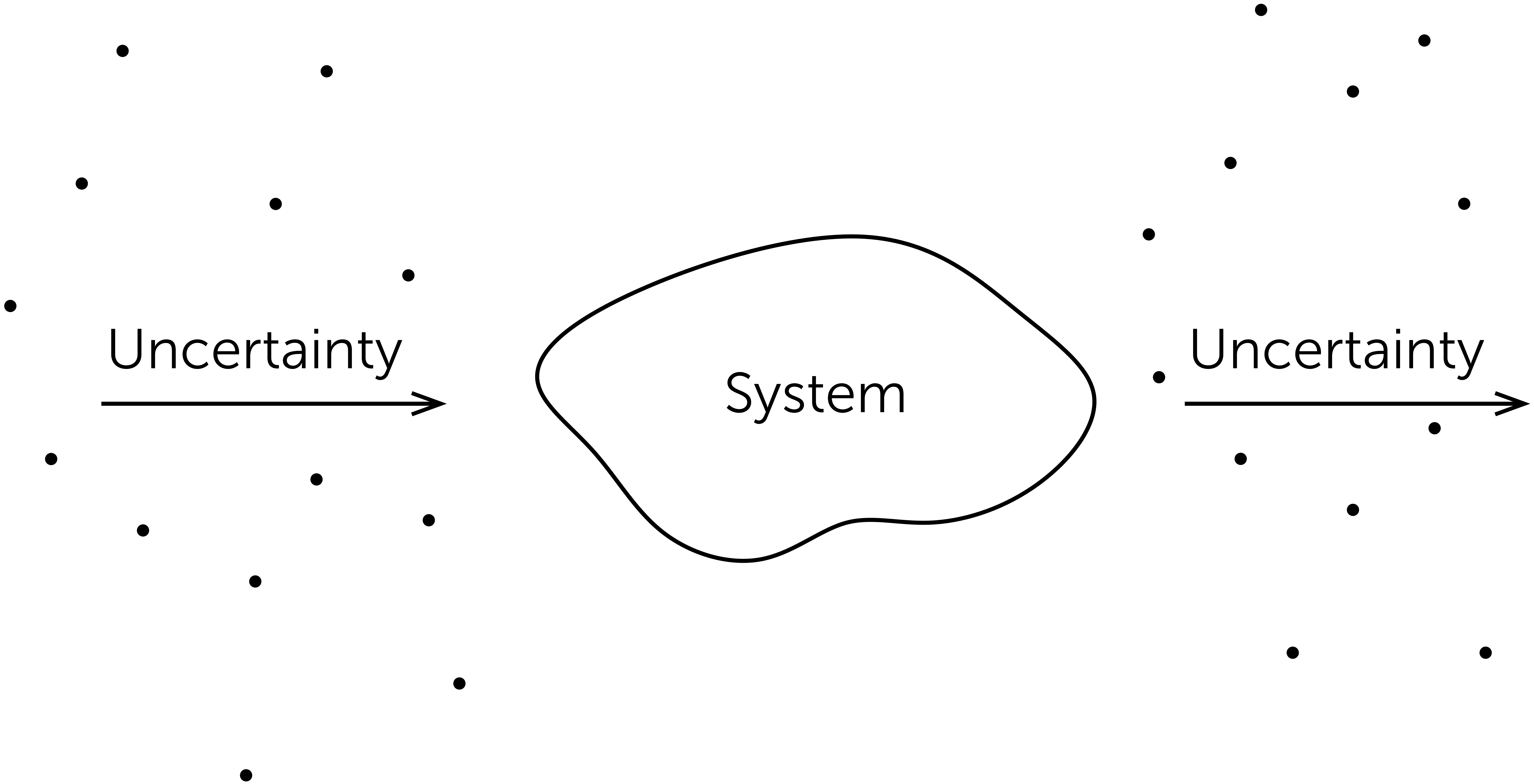
$$\theta = \{\theta_i(\text{system})\}_{i=1}^{n}$$

$$\theta = \{\theta_i(\text{system}(\text{uncertainty}))\}_{i=1}^{n}$$

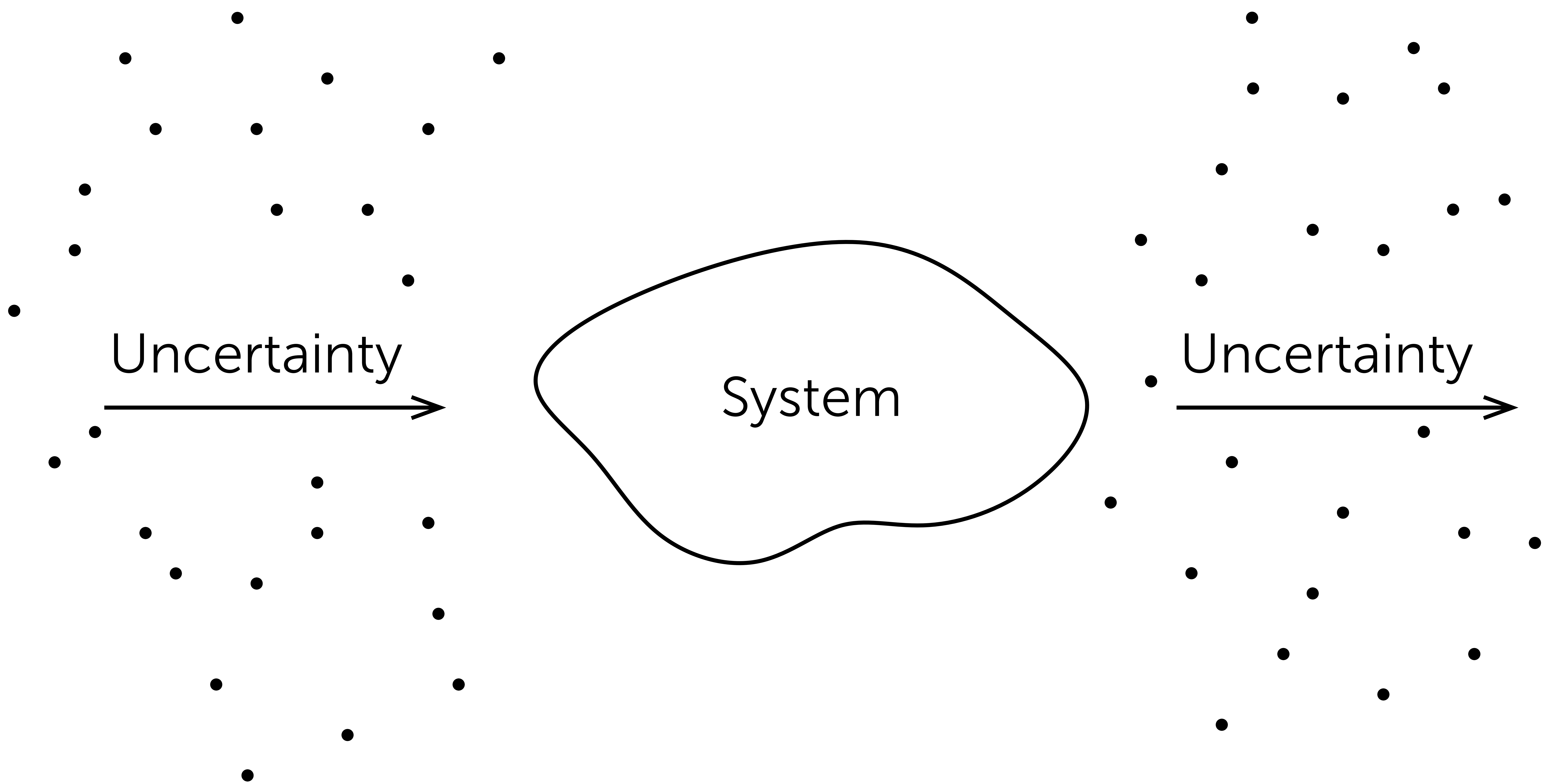
Uncertainty Quantification



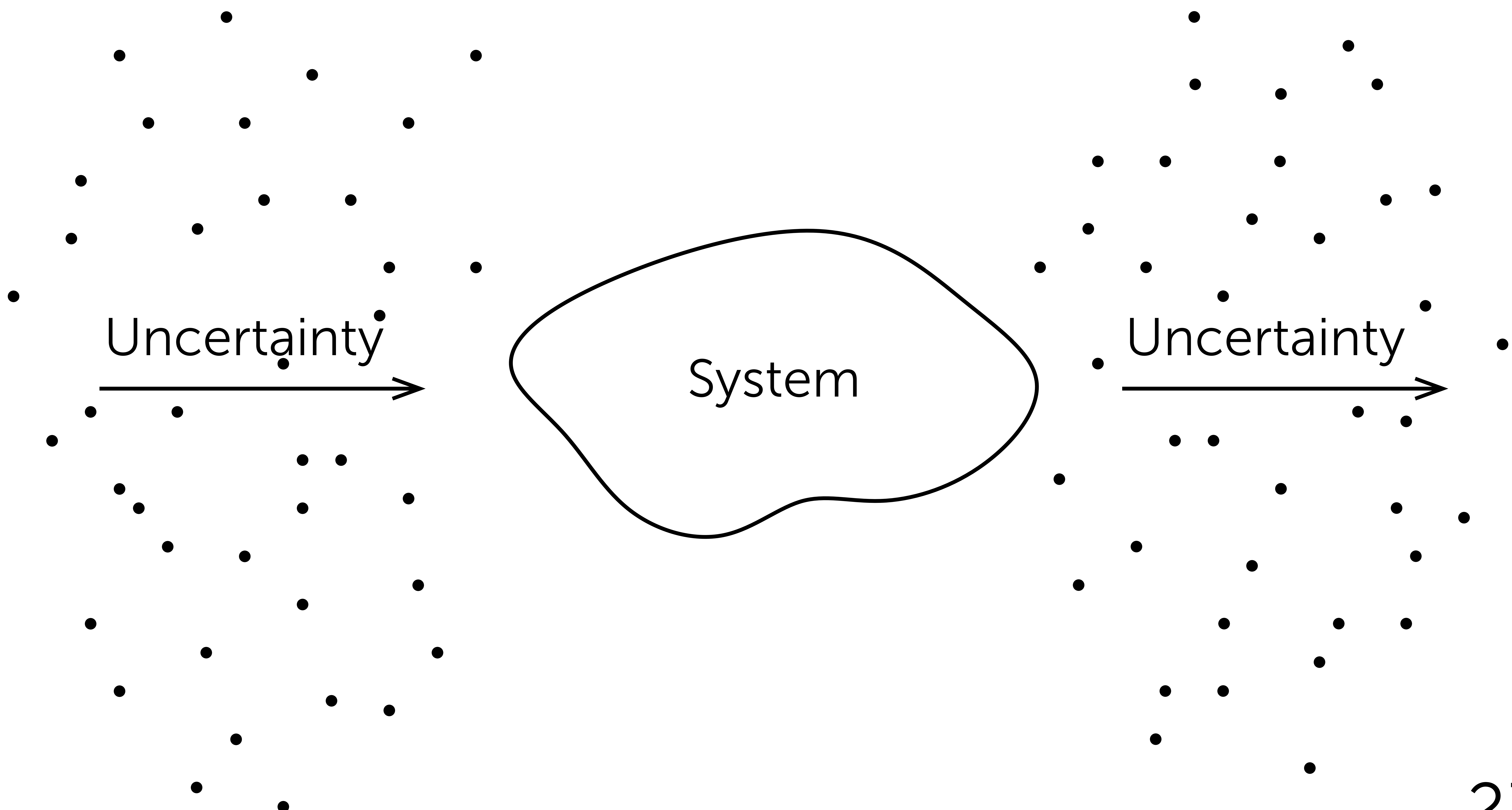
Monte Carlo



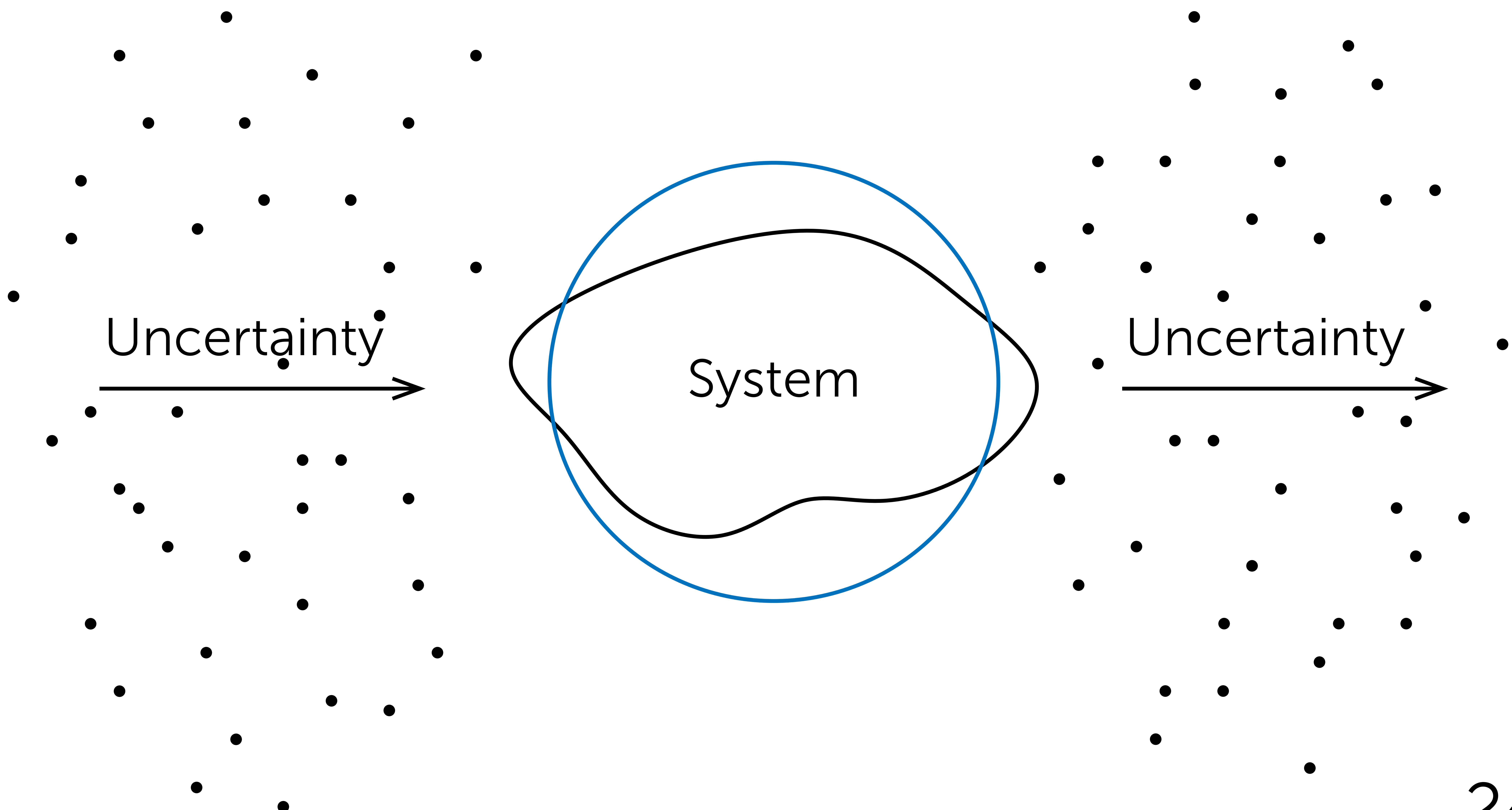
Monte Carlo



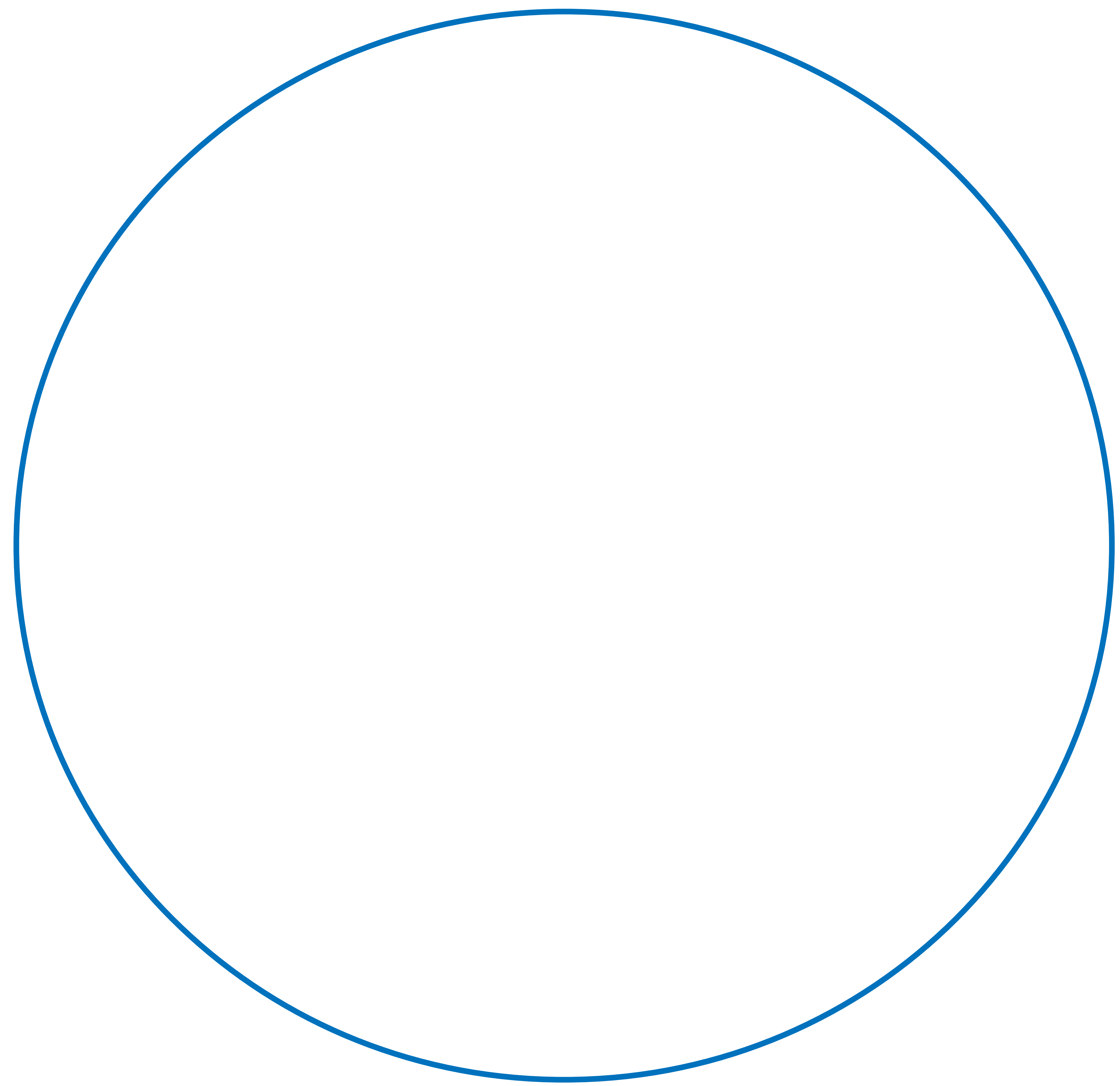
Monte Carlo



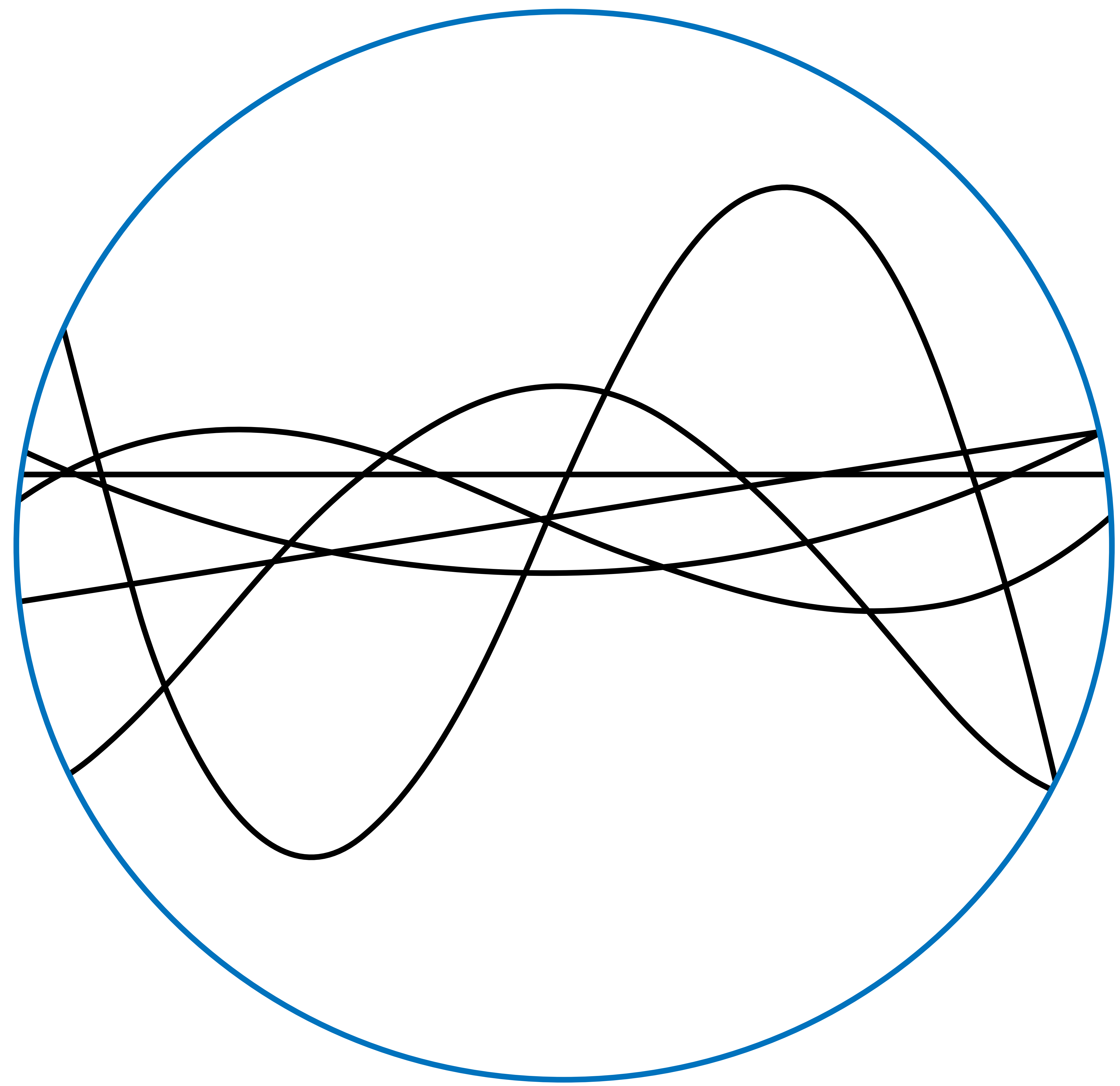
Solution



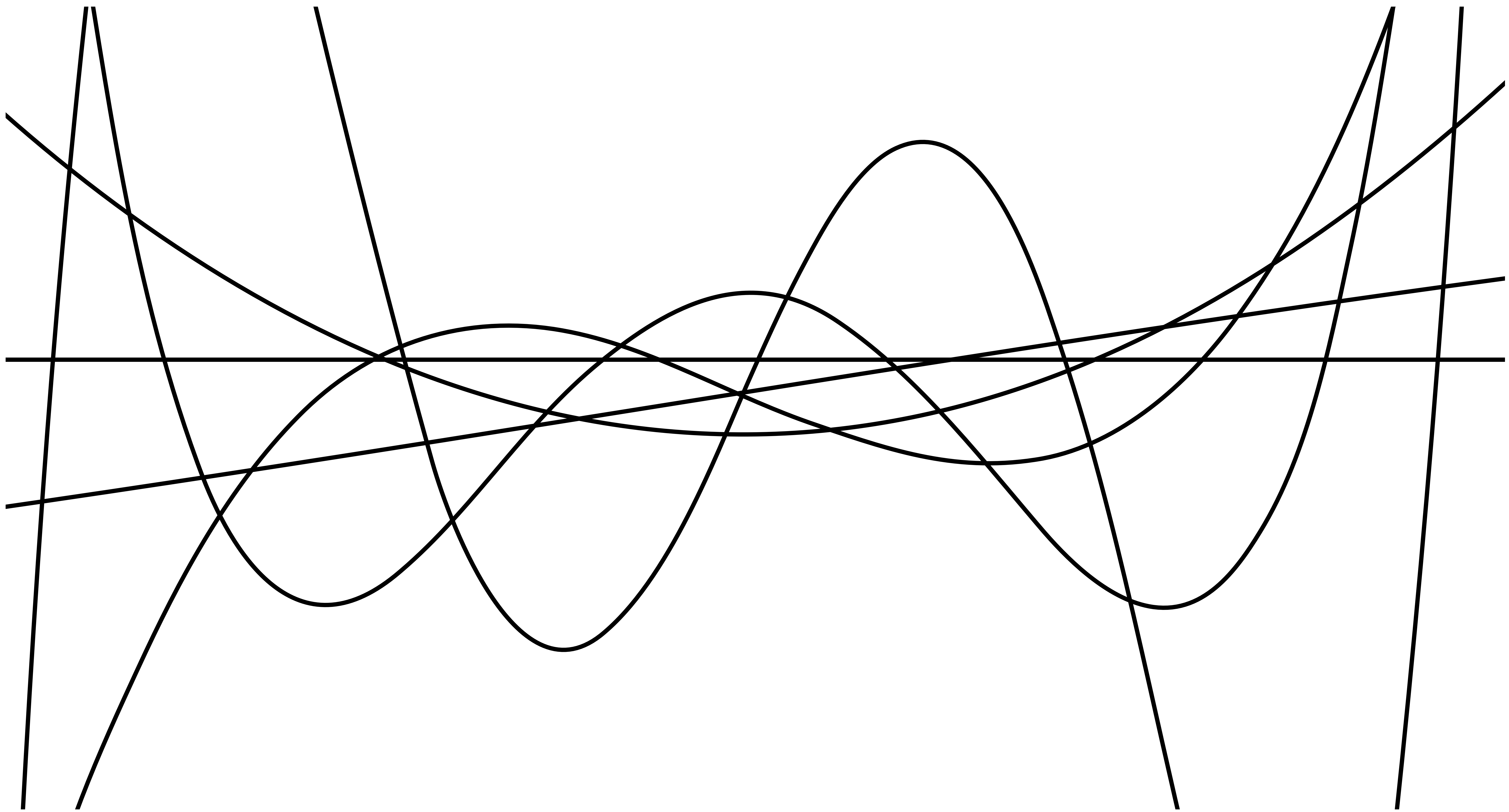
Polynomial Chaos



Polynomial Chaos



Polynomial Chaos



Polynomial Chaos

$$\theta_i(\xi) \approx \sum_j \hat{\theta}_{ij}\, \psi_j(\xi)$$

Orthogonal Polynomials

* Hermite	$\longrightarrow$	Gaussian
* Laguerre	$\longrightarrow$	Gamma
* Jacobi	$\longrightarrow$	Beta
* Gram–Schmidt	$\longrightarrow$	Arbitrary

Spectral Projection

$$\hat{\theta}_{ij} = \langle \theta_i, \psi_j \rangle = \int_\Omega \theta_i(\xi)\, \psi_j(\xi)\, f(\xi)\, d\xi$$

Numerical Integration

$$\int_D g(x)\, f(x)\, dx \approx \sum_i g(x_i)\, w_i$$

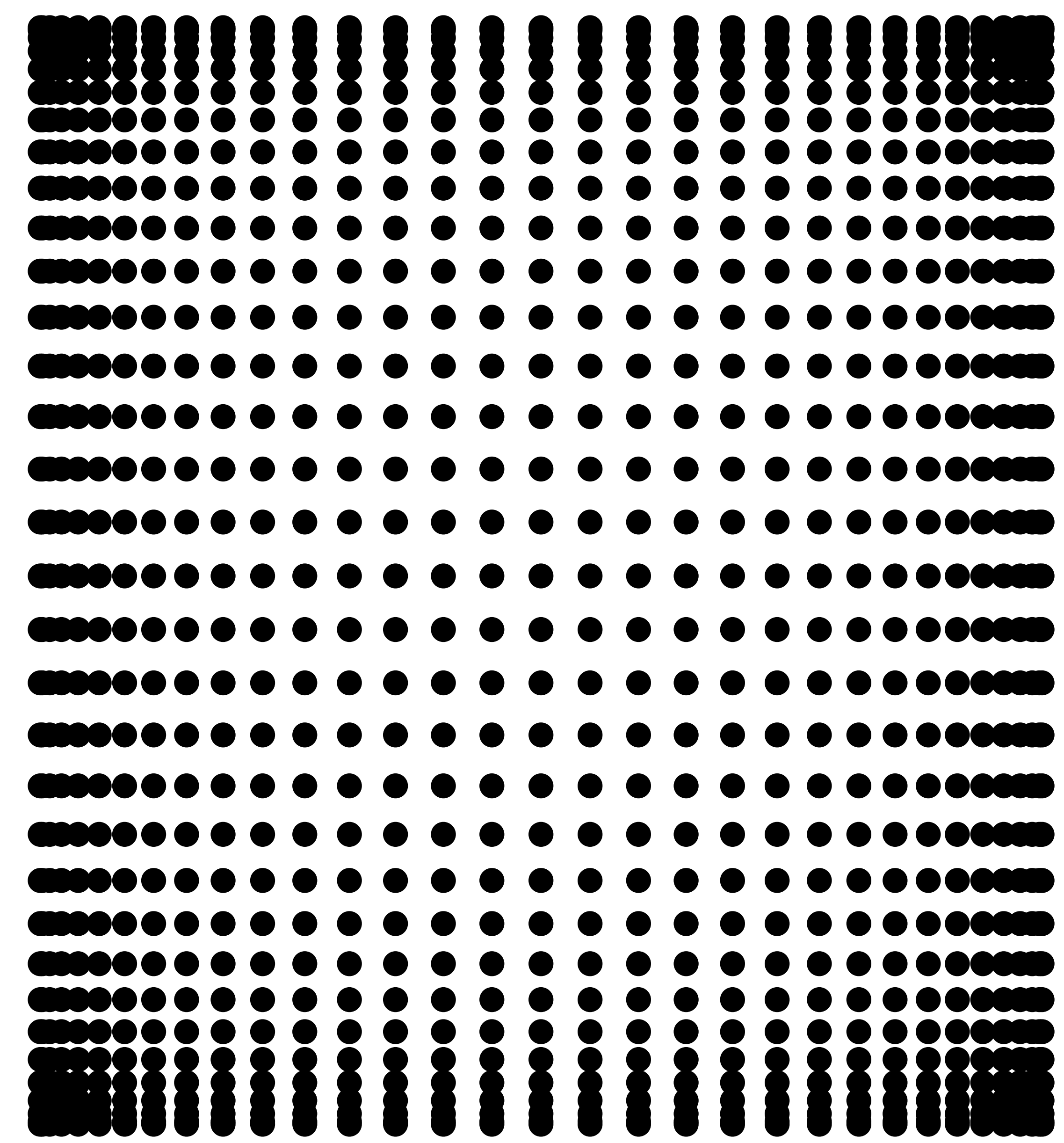
Quadrature Rules

* Gauß–Hermite	→	Hermite
* Gauß–Laguerre	→	Laguerre
* Gauß–Jacobi	→	Jacobi
* Golub–Welsch	→	Arbitrary

Quadrature Rules

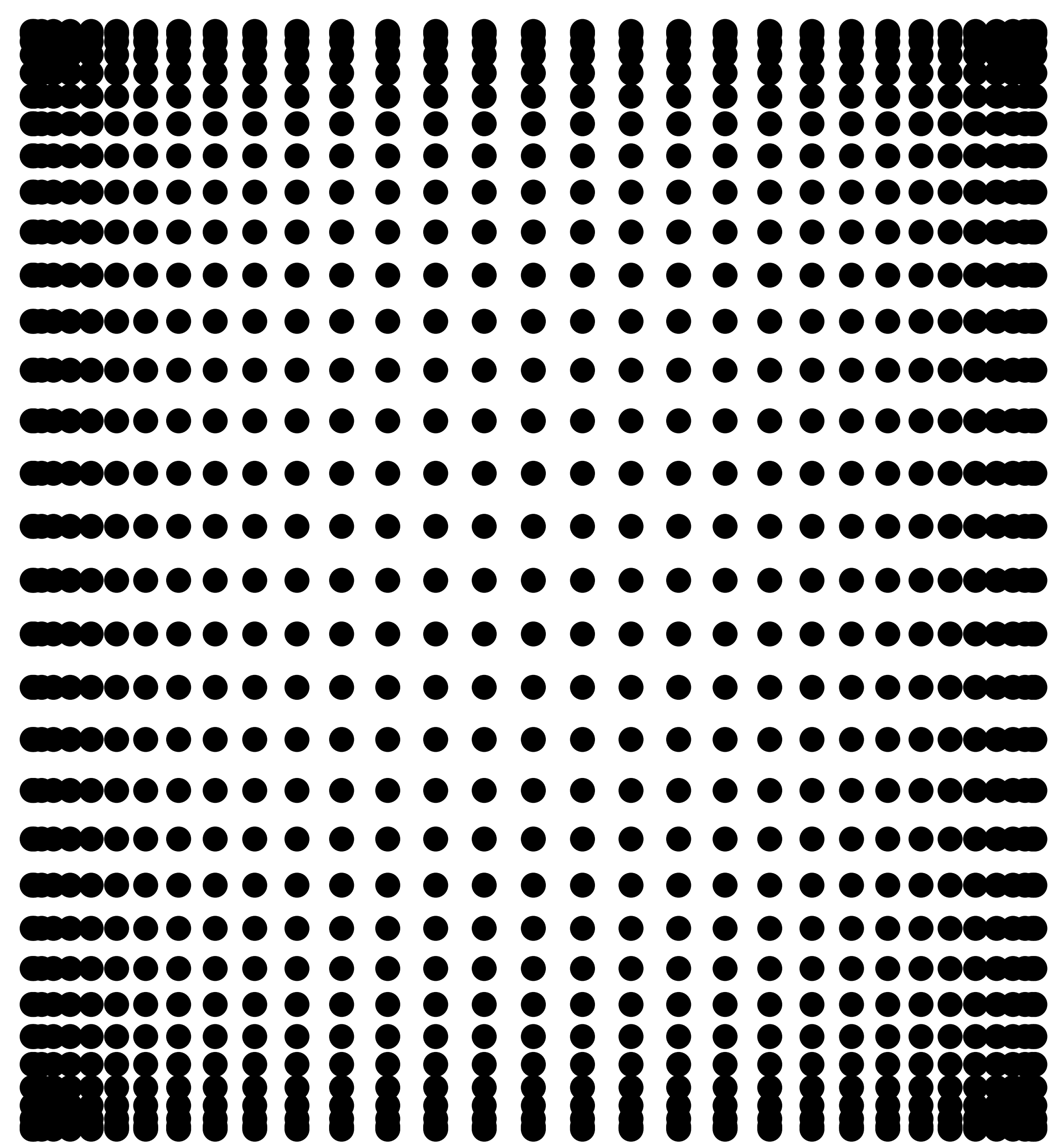
Abscissa	Weight
0.00000	0.94531
± 0.95857	0.39362
± 2.02018	0.01995

Multiple Dimensions

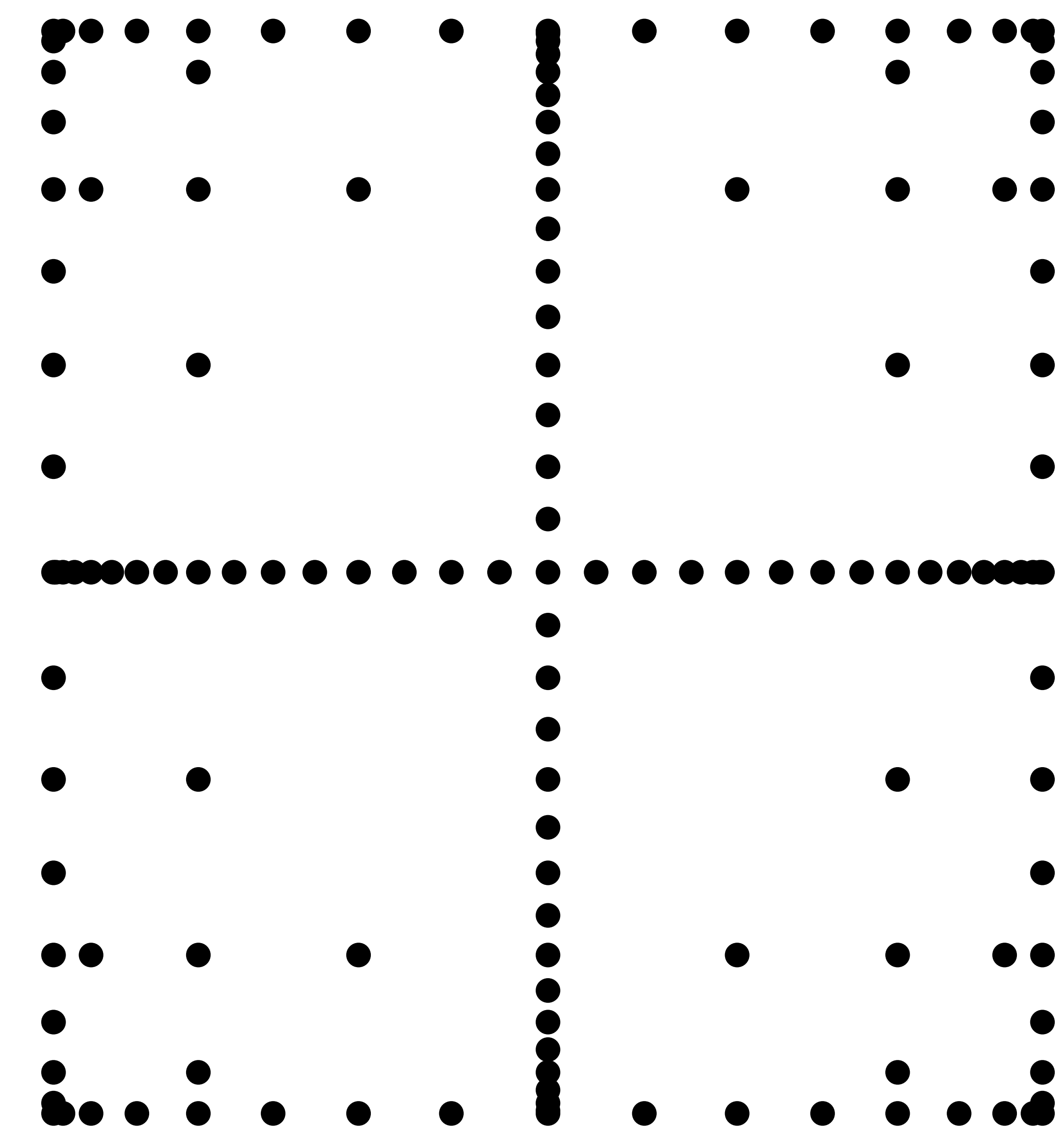


Full-tensor
product

Multiple Dimensions

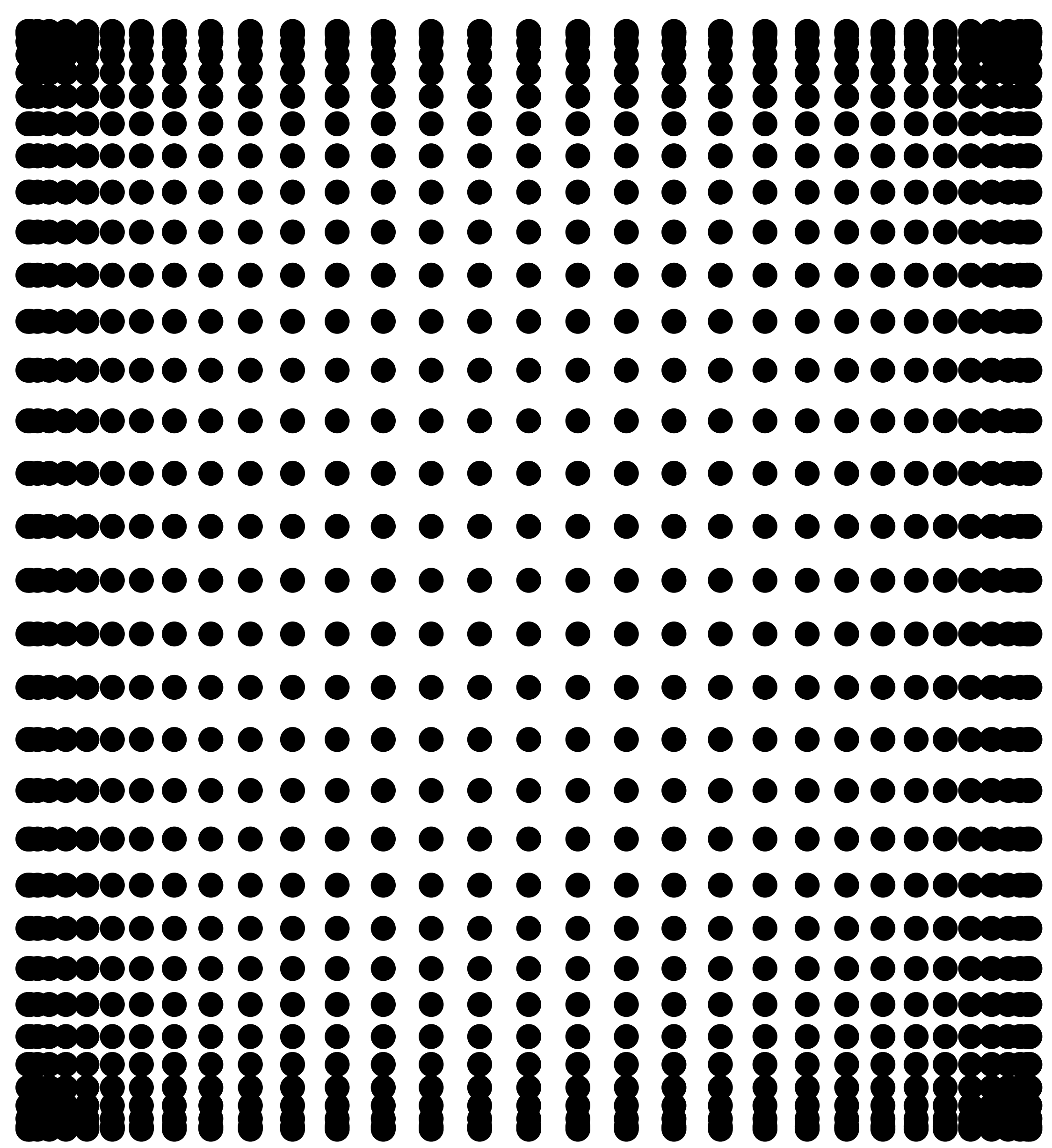


Full-tensor
product

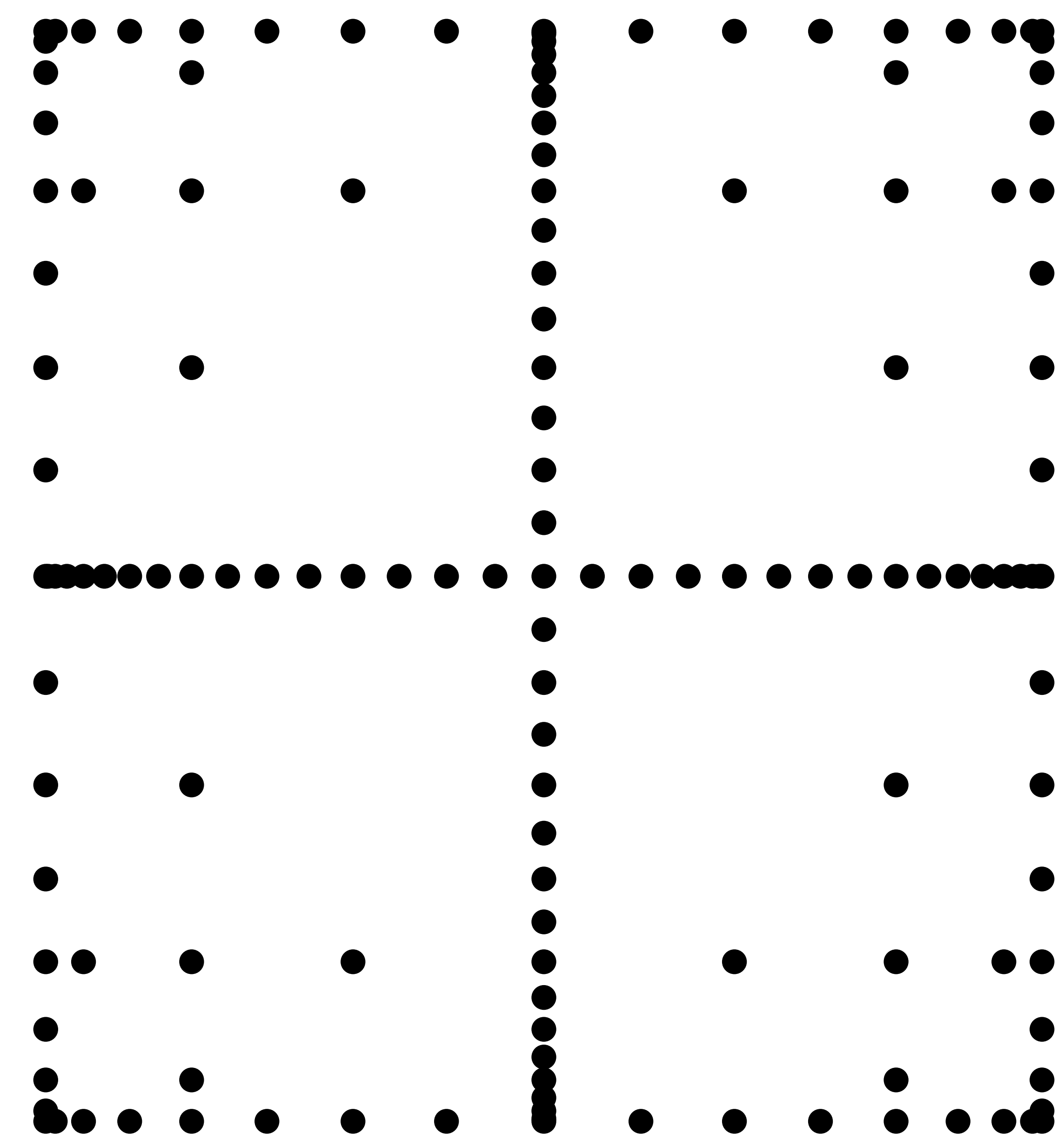


Isotropic
sparse grid

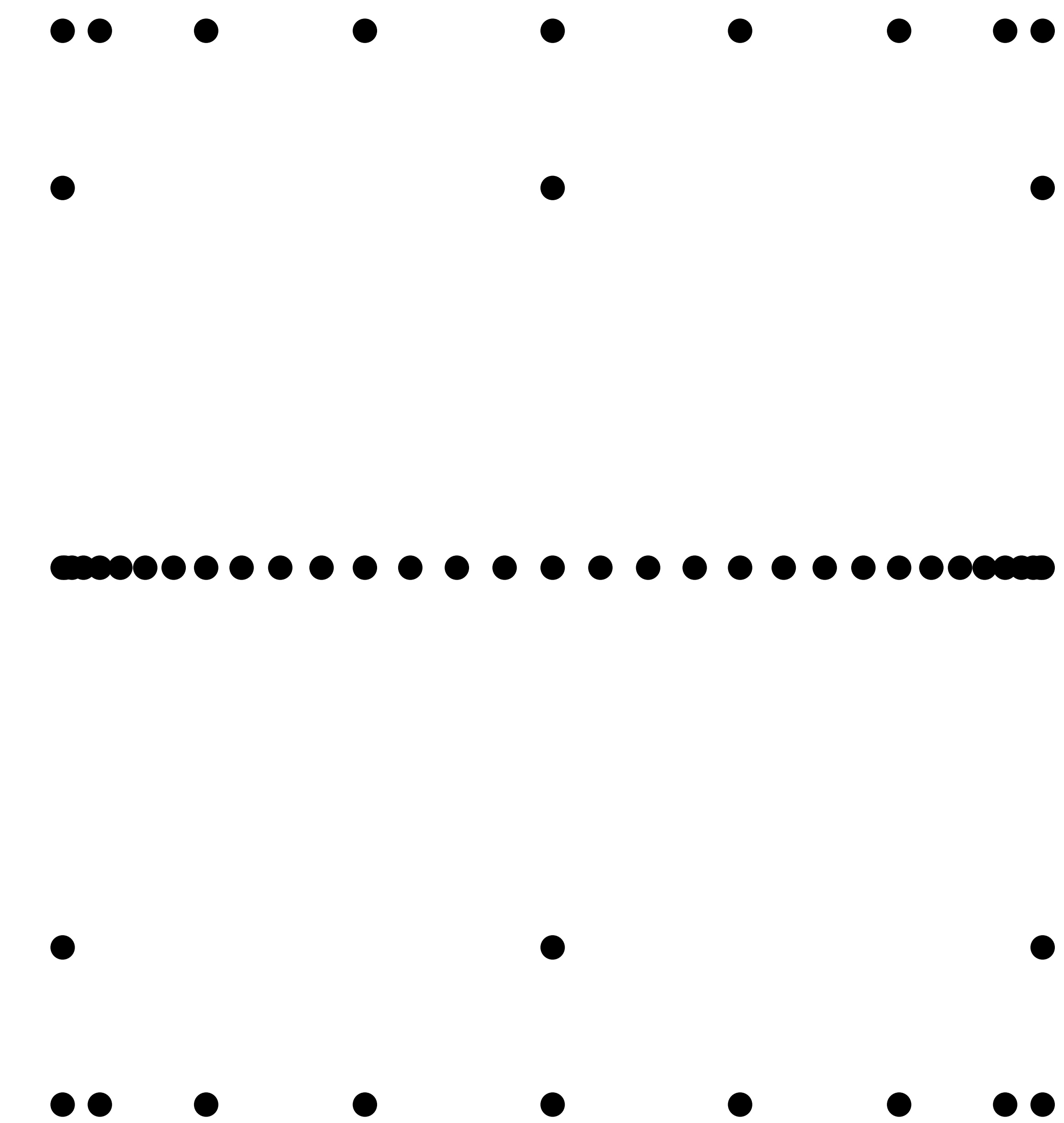
Multiple Dimensions



Full-tensor
product grid

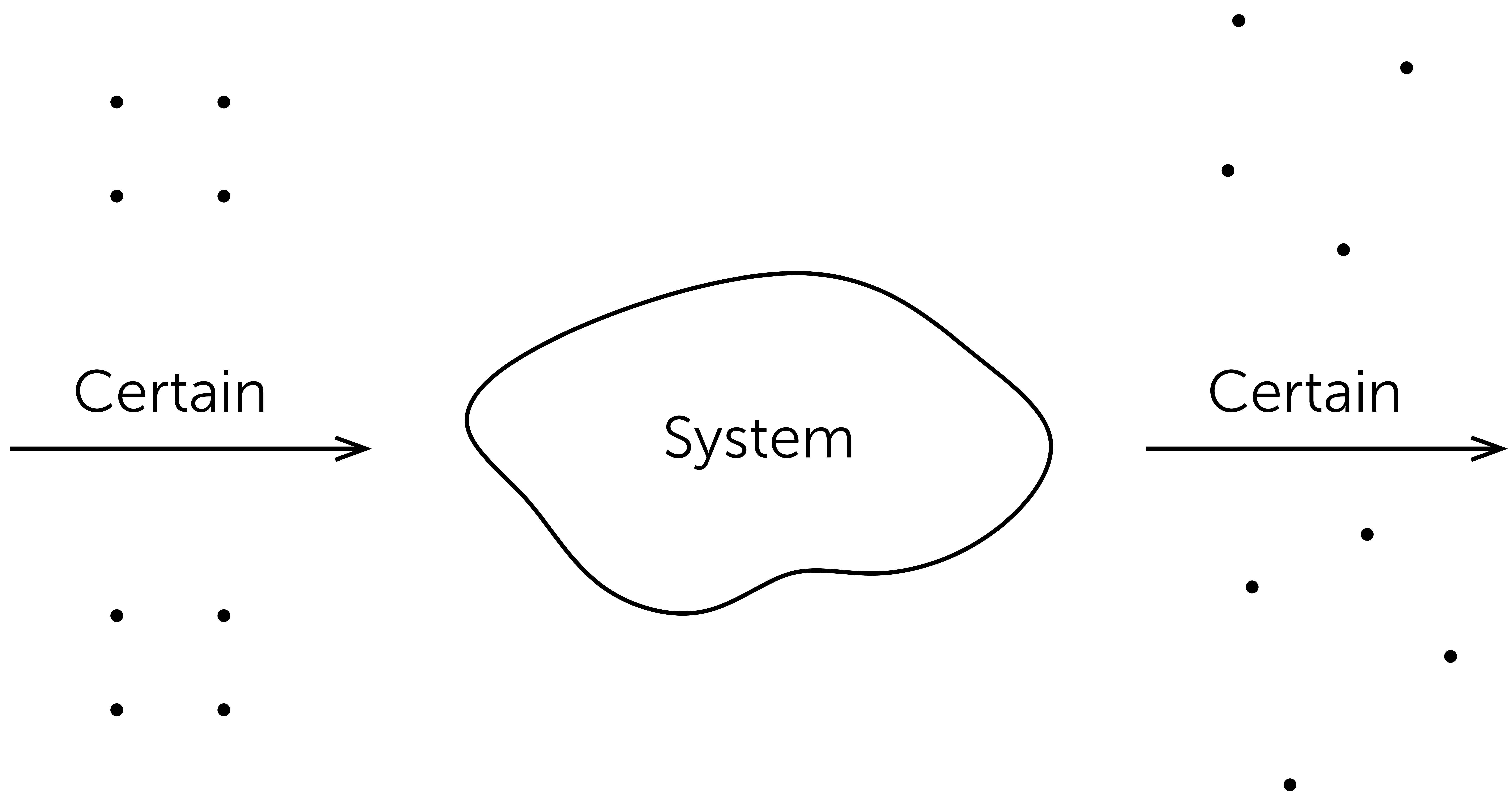


Isotropic
sparse grid

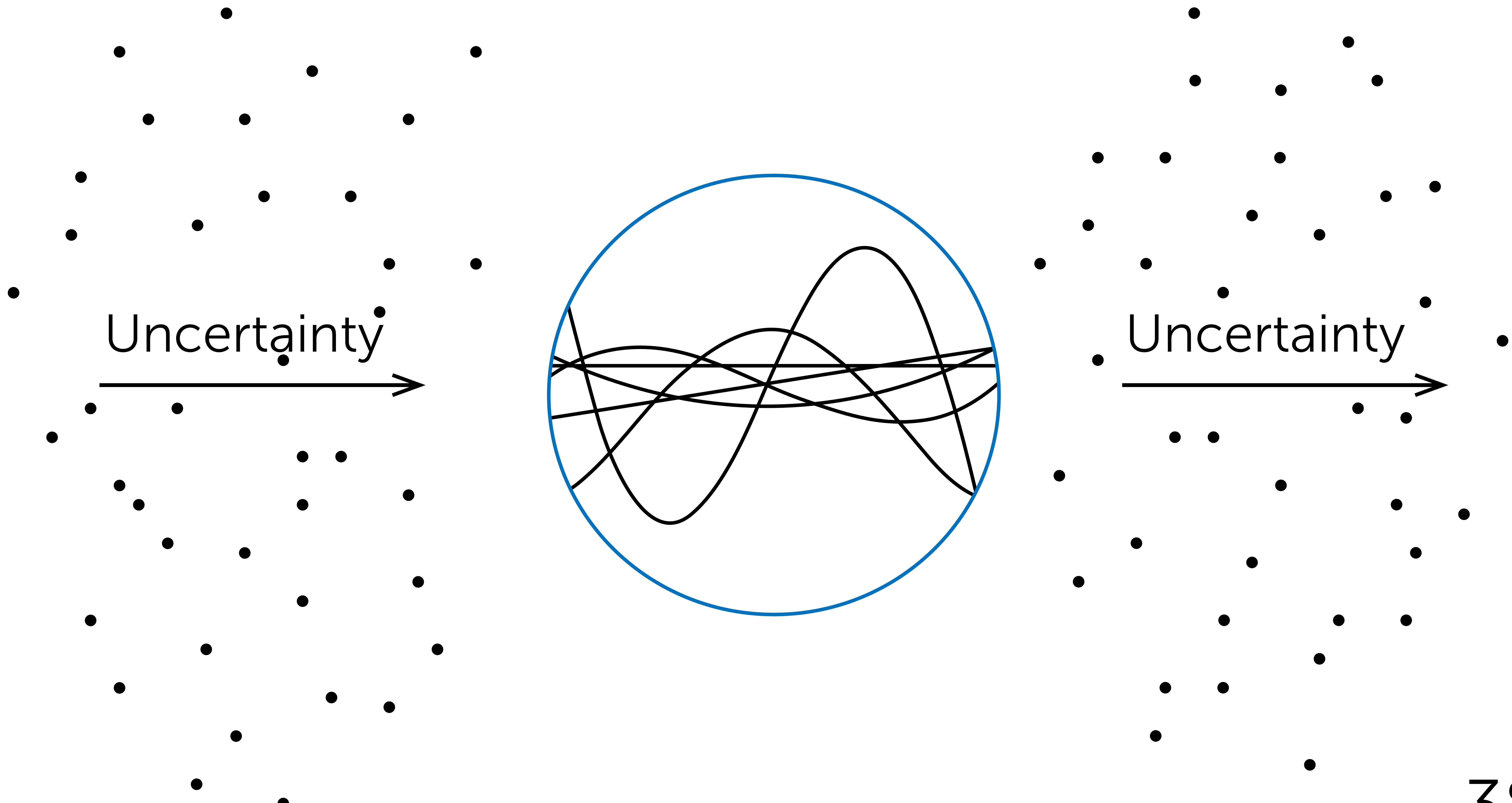


Anisotropic
sparse grid

Spectral Projection



Post-Processing



Post-Processing

$$\theta_i(\xi) \approx \sum_j \hat{\theta}_{ij}\, \psi_j(\xi)$$

$$\mathbb{E}\left[\theta_i\right] \approx \hat{\theta}_{i0}$$

$$\mathbb{V}\mathrm{ar}\left[\theta_i\right] \approx \sum_{j>0} \hat{\theta}_{ij}^2$$

Reliability Analysis

$$R(t|\theta)$$

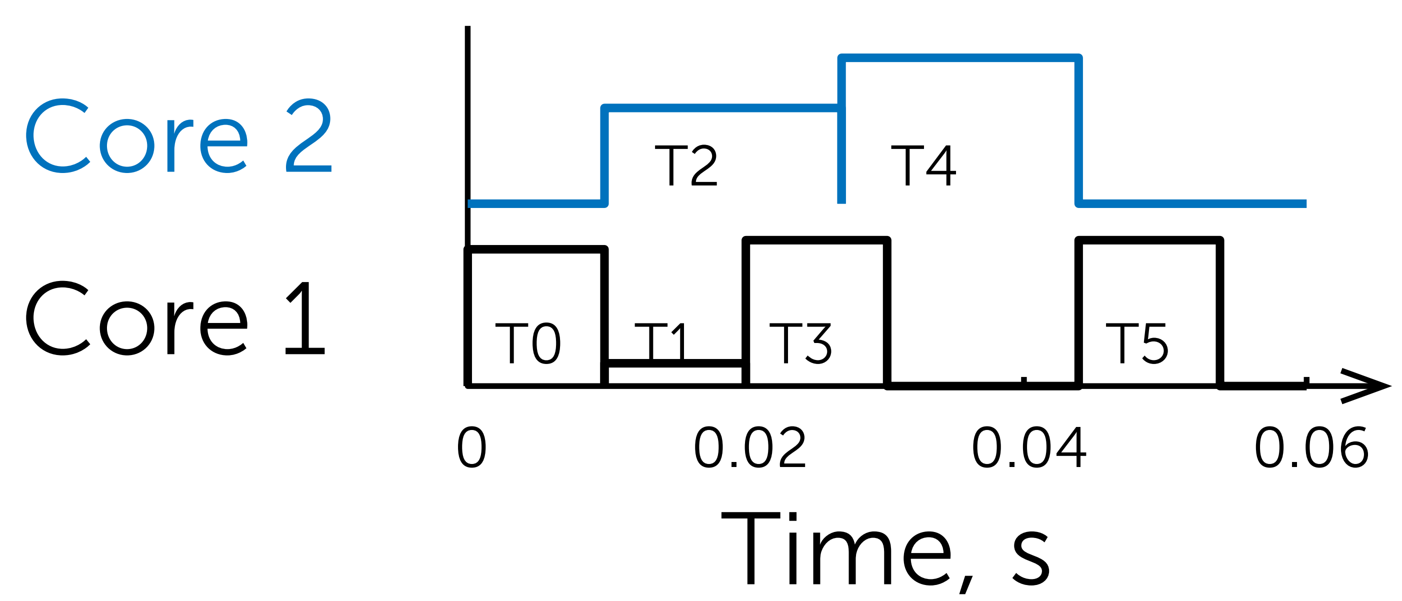
Reliability Analysis

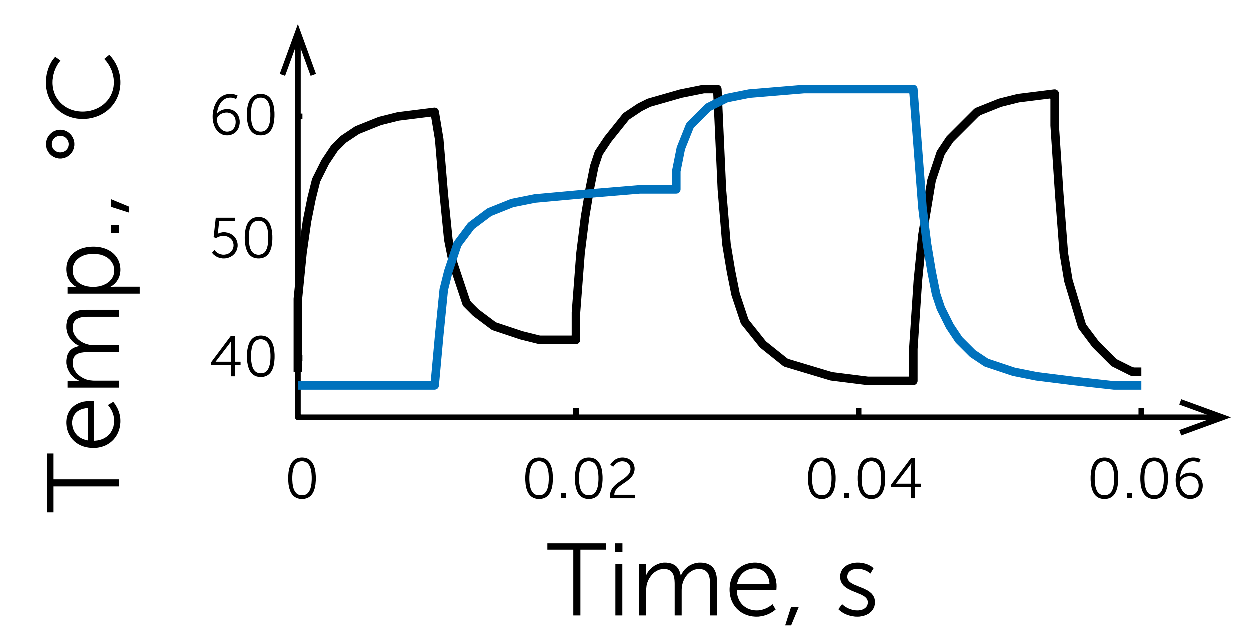
$$R(t|\theta)$$

Reliability Optimization

* Multiprocessor platform
* Process variation
* Periodic application
* Thermal-cyclic fatigue

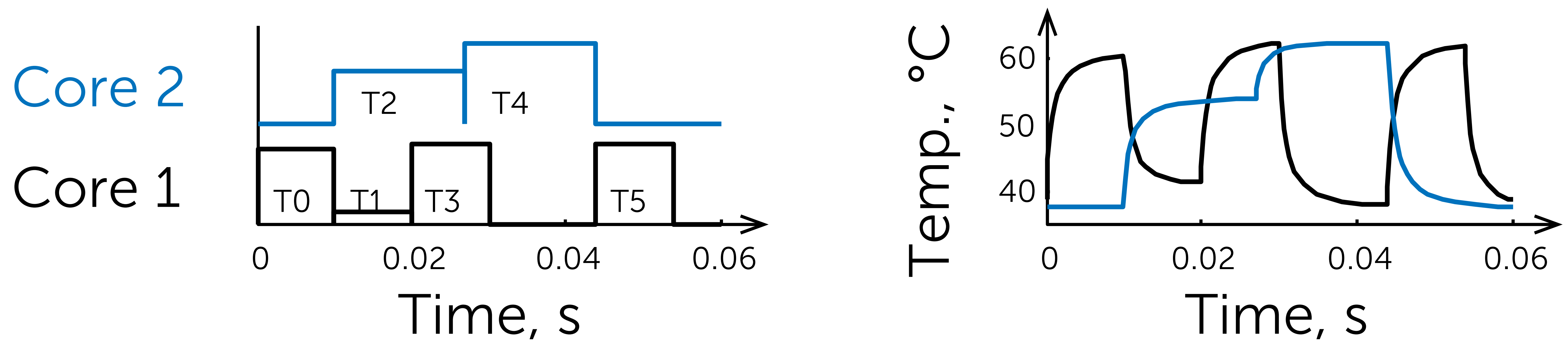
Reliability Optimization



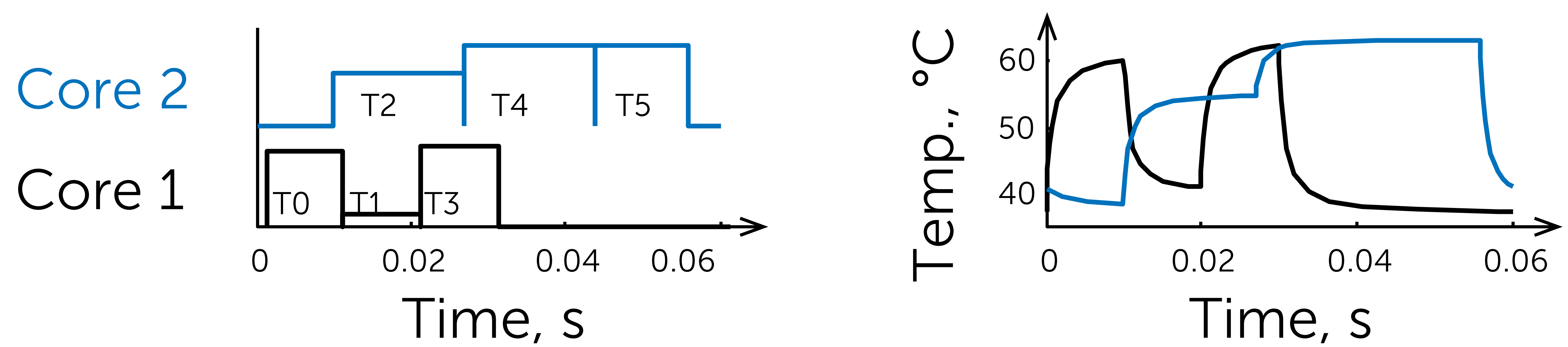


3 cycles

Reliability Optimization

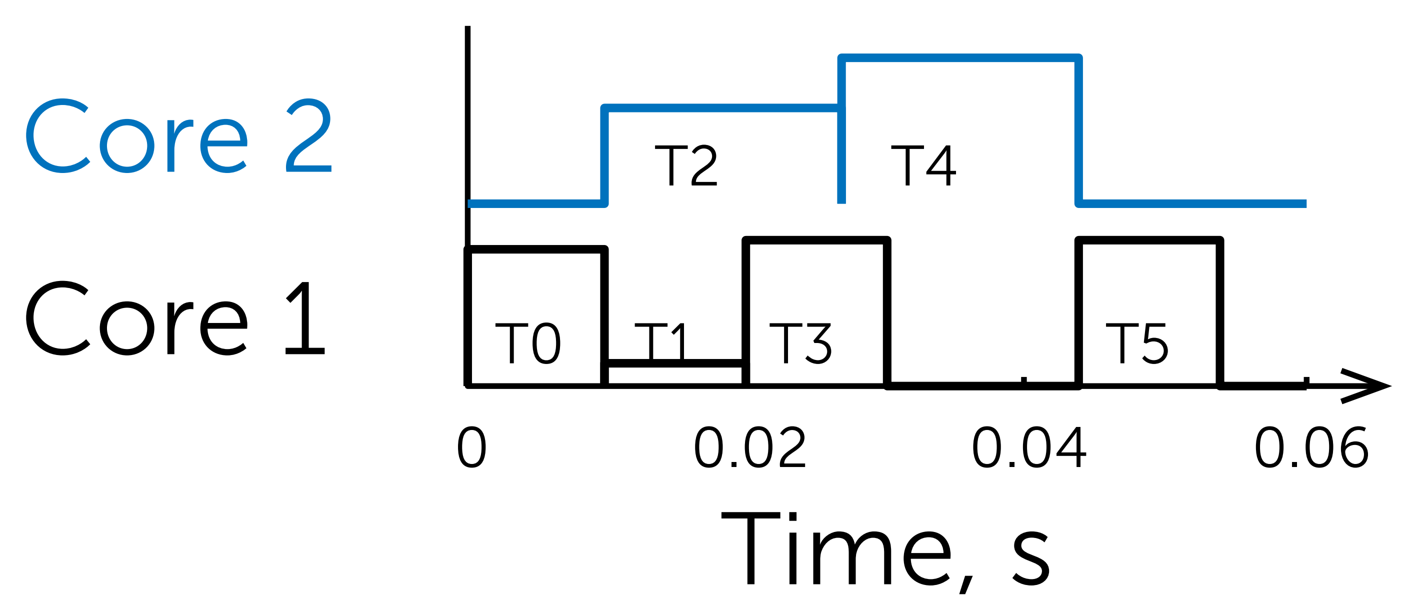


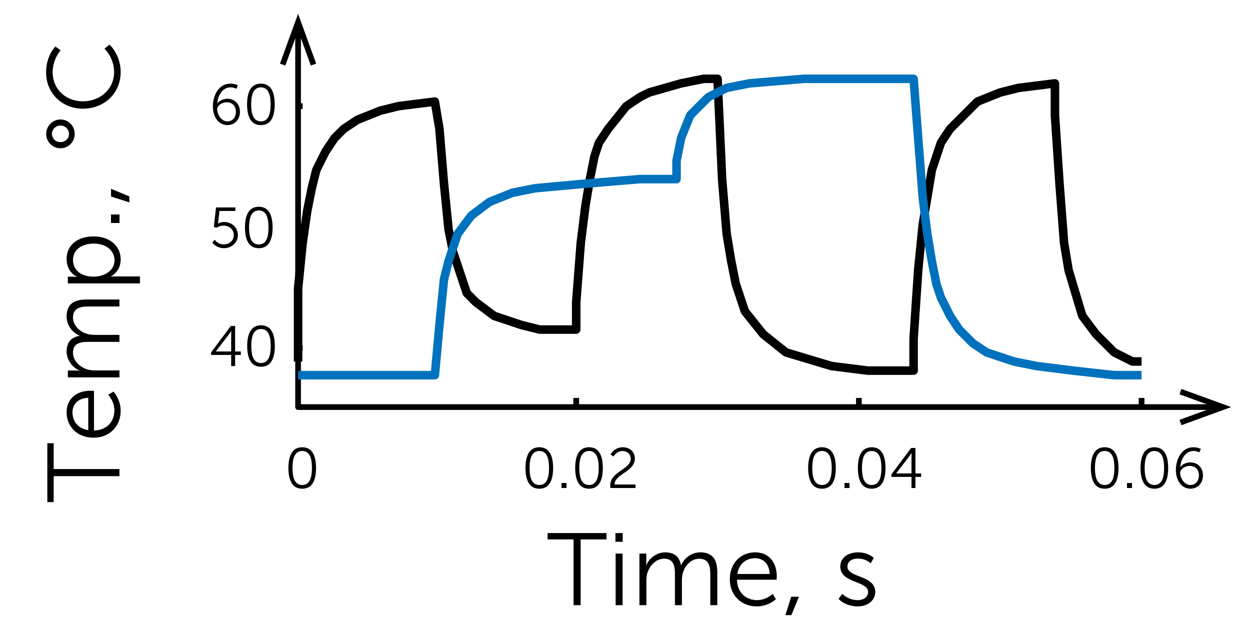
3 cycles



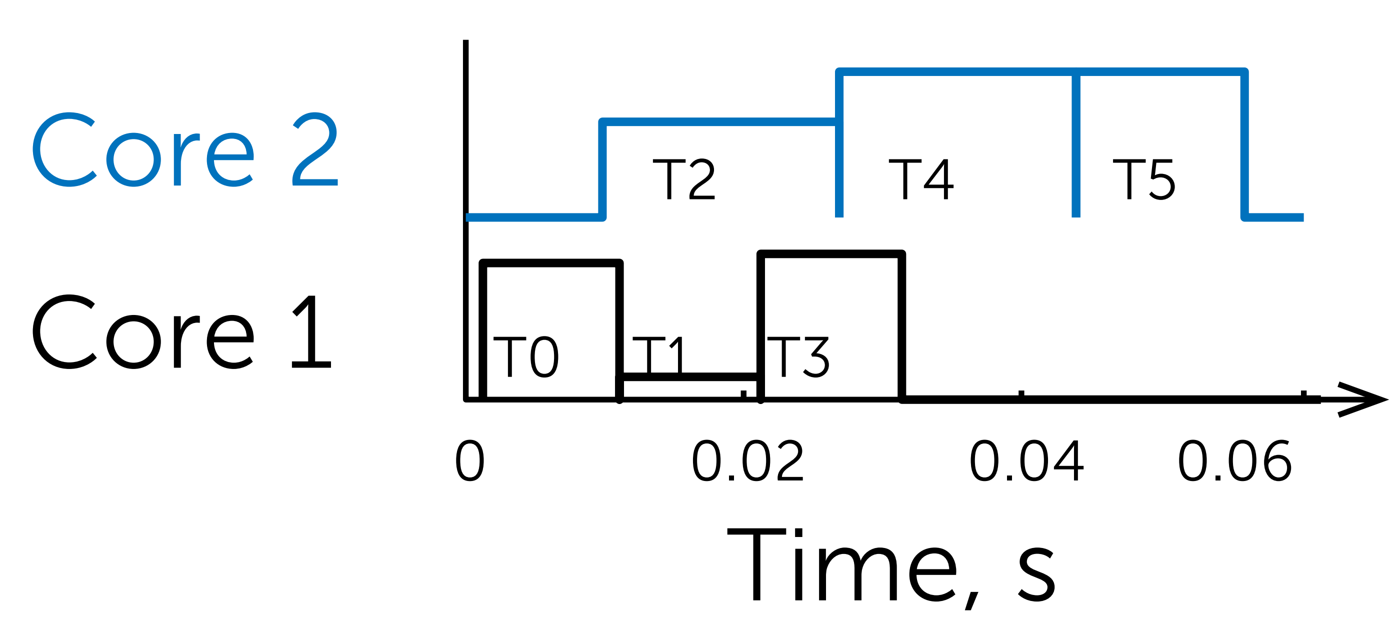
2 cycles,
+45% lifetime

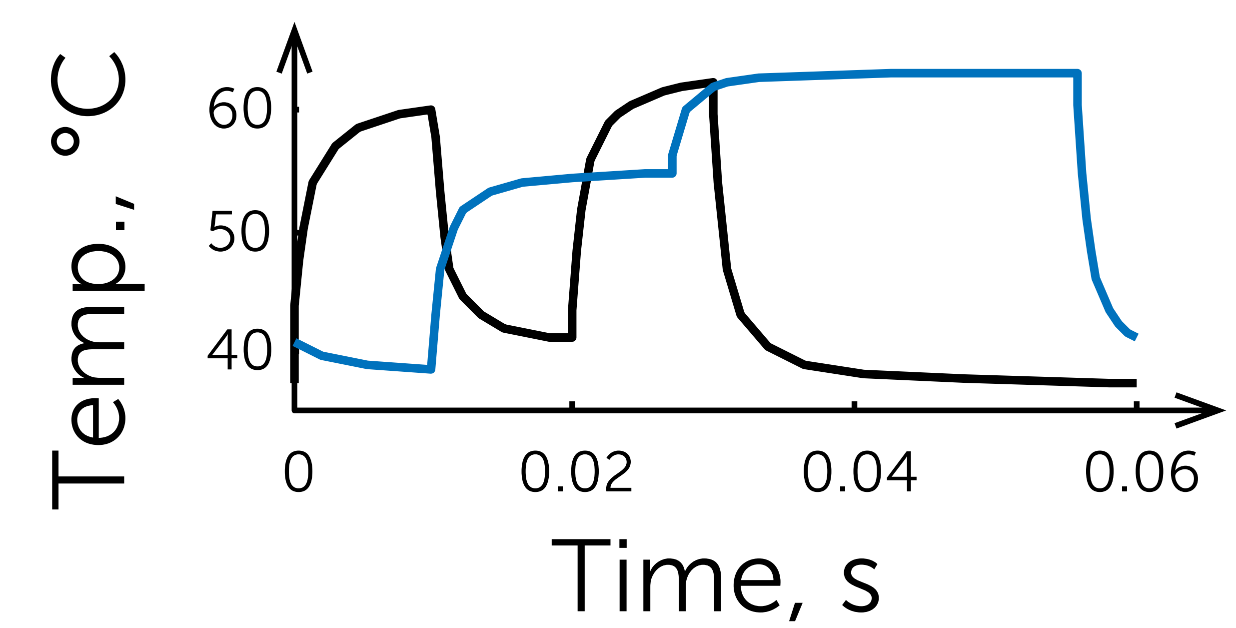
Reliability Optimization



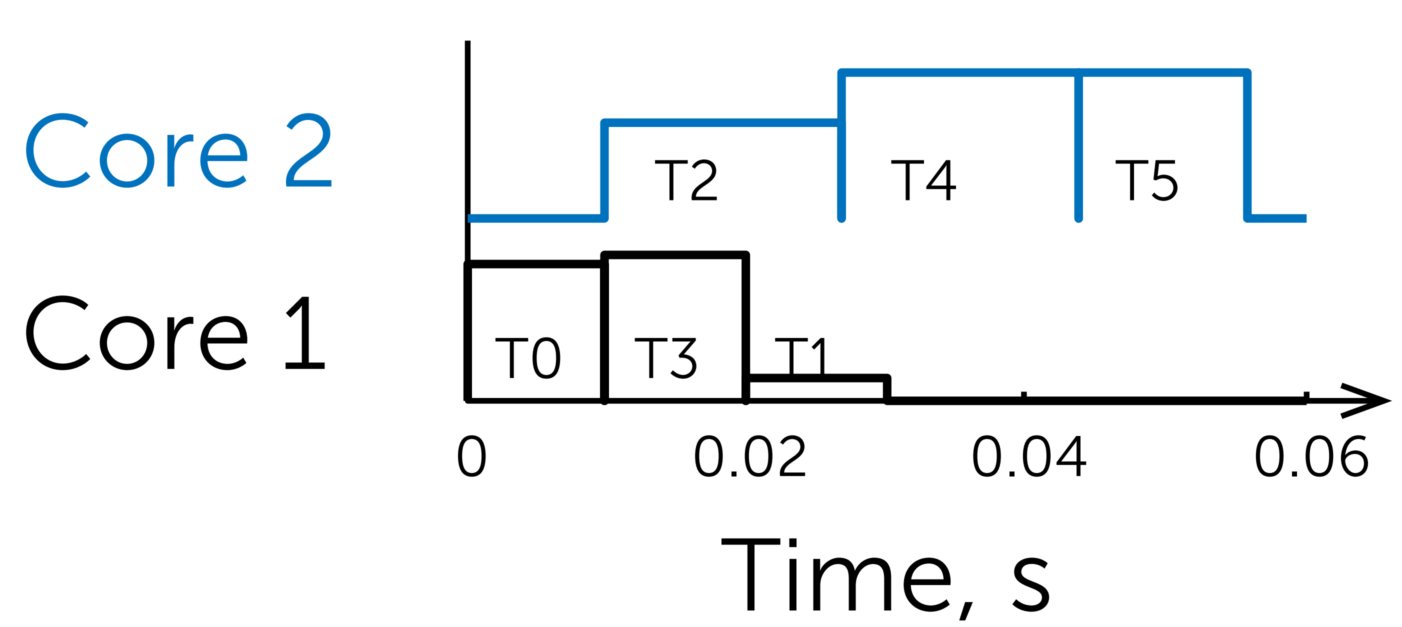


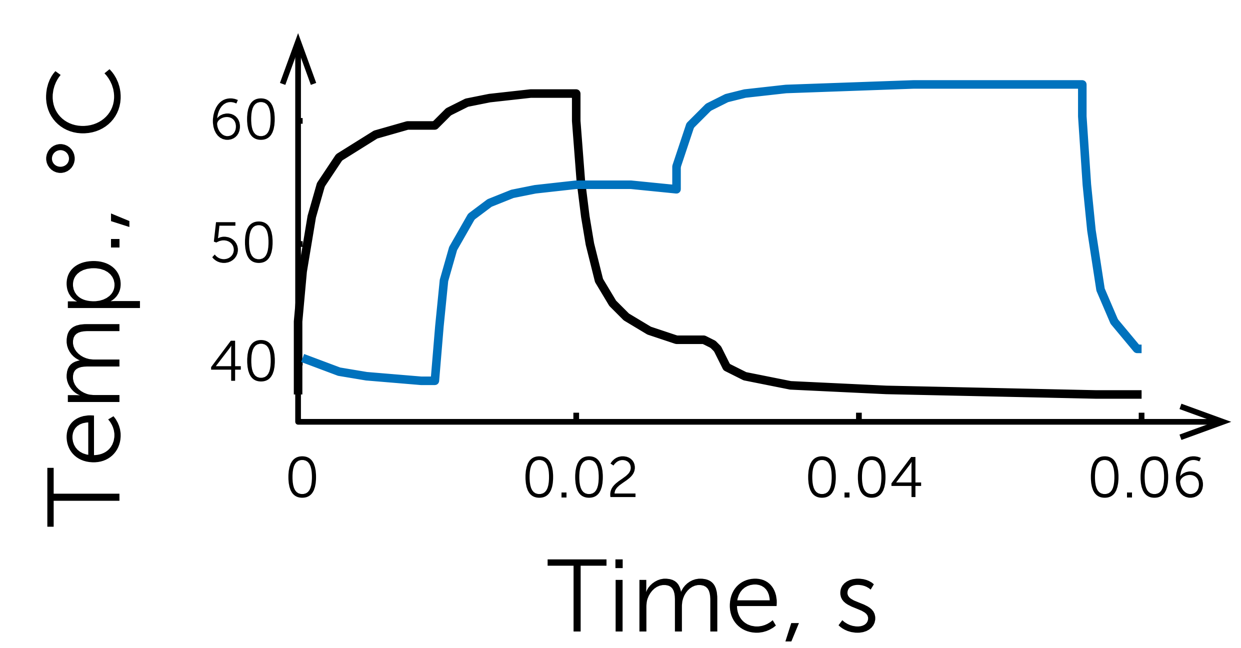
3 cycles





2 cycles,
+45% lifetime





1 cycle,
+55% lifetime

Objective

$$\min_{\mathcal{S}} \mathbb{E}[\text{Energy}]$$

$$\text{Execution time}(\mathcal{S}) < \text{Deadline}$$

$$\mathbb{P}\left(\text{Temperature}(\mathcal{S}) > \text{Maximal}\right) < p_{\text{burn}}$$

$$\mathbb{P}\left(\text{Lifetime}(\mathcal{S}) < \text{Minimal}\right) < p_{\text{wear}}$$

Experimental Setup

* 2 process parameters
* 2, 4, 8, 16, and 32 cores
* 40, 80, 160, 320, and 640 tasks
* 10 test cases per pair cores/tasks

Probabilistic vs. Deterministic

Cores	Prob., min	Det., min	Fail, %
2	1	1	40
4	5	2	60
8	17	4	70
16	56	8	100
32	300	9	100

Thank you! Questions?

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