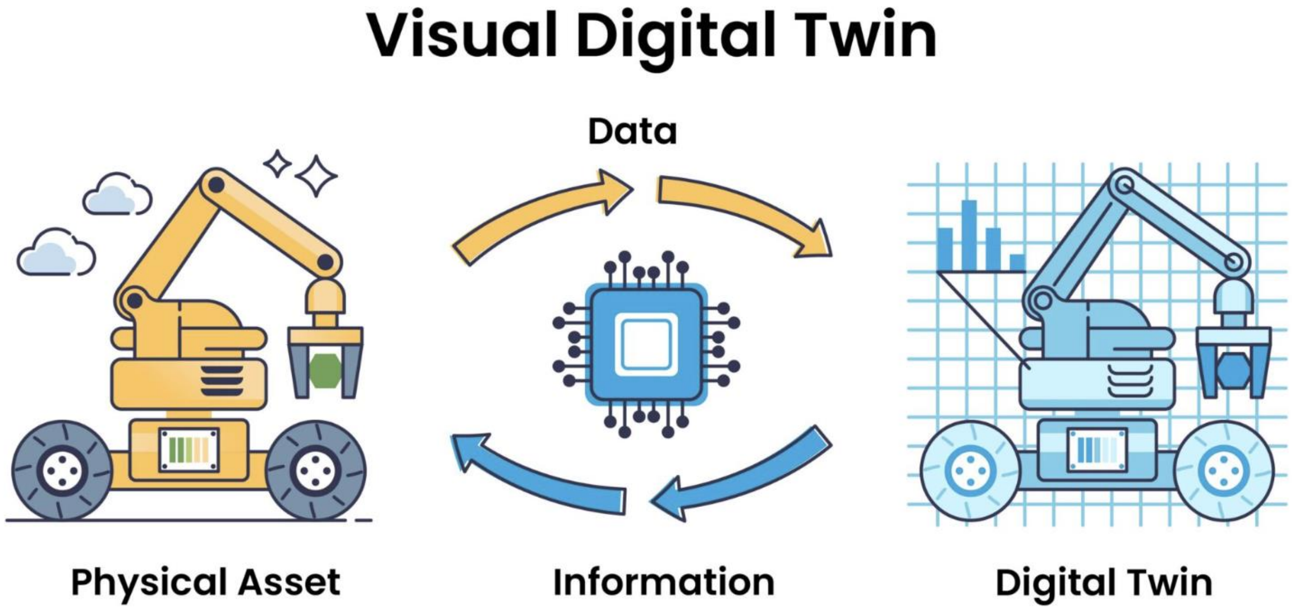
Error-aware digital twin of a thermal fin in heat sink systems

Dayoung Kang

Background: Digital twin

1. Physical entity
2. Digital replica
   - Finite element model
3. Data flow
   - Inverse identification



Source: https://www.prevu3d.com/news/understanding-digital-twins/

Motivation

Digital twin of a heat sink system

- Required for effective thermal management of electronic devices

Error-aware digital twin

- Surrogate model is much cheaper to evaluate but not reliable

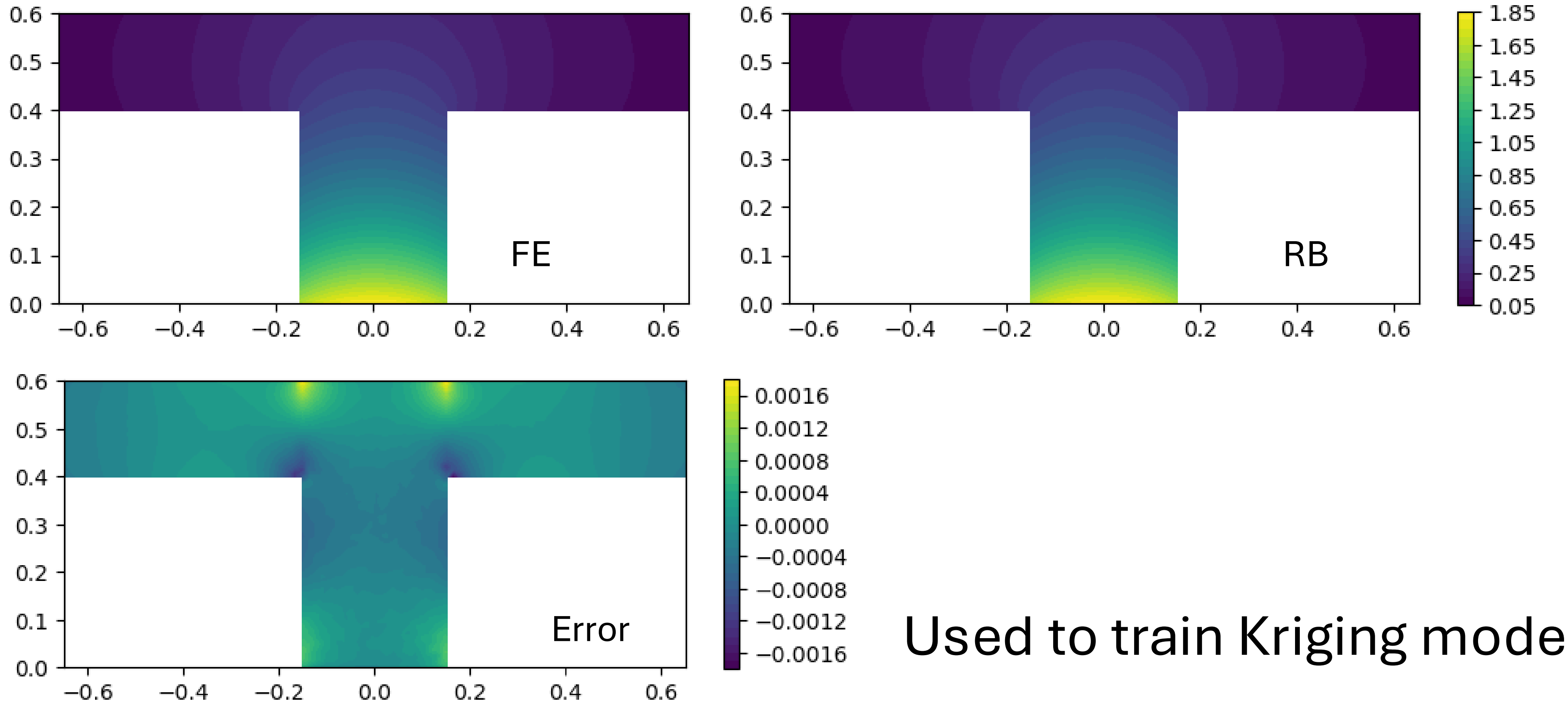
Goal

Error-aware digital twin of a heat sink (benchmarked on a thermal fin)

Simulation model:
Finite element (FE) and reduced basis (RB) models

Input: Biot numbers and heat flux

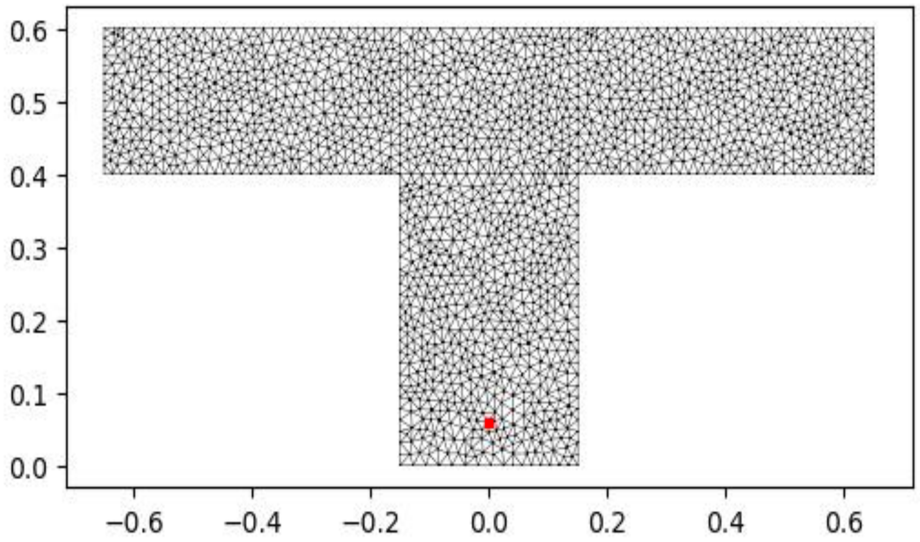
Output: Temperature field



Used to train Kriging model

Digital twin scenario 1: Fin overheated

1. Obtain sensor measurement from a fin



Our quantity of interest: heat flux

But actual heat flux is unknown

Digital twin scenario 1: Fin overheated

2. Run error-aware inverse identification based on sensor measurement

$$\frac{1}{2}\|y - \underbrace{(u_{\mathrm{rb}}(\mu) + \varepsilon(\mu))}_{\text{Error-corrected RB output}}\|_2^2,$$

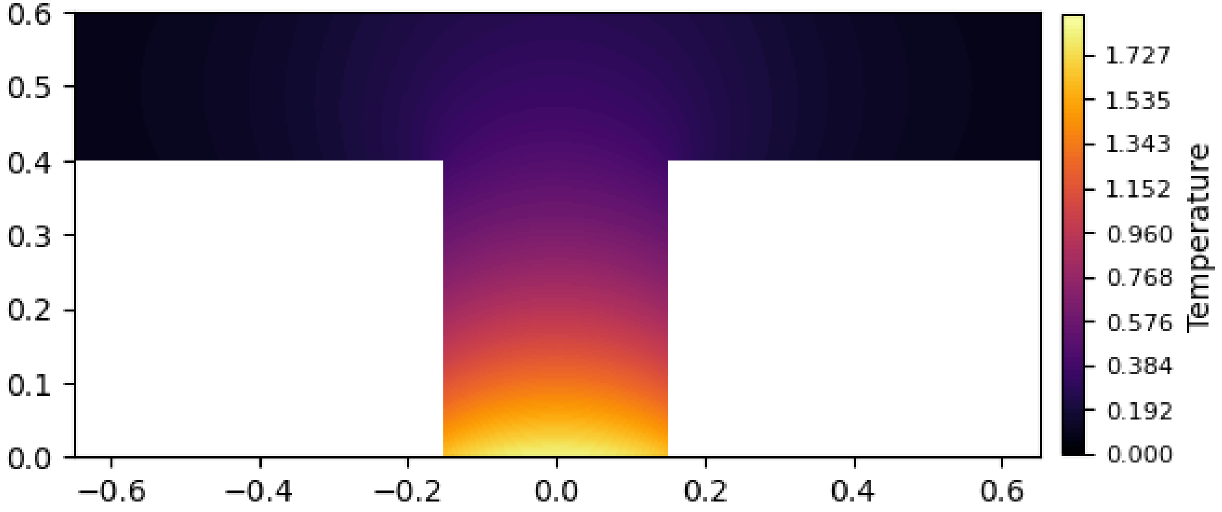
y: sensor measurement

u_{rb}: (reconstructed) reduced basis (RB) solution at sensor point

ε: reduced basis model error estimated from Kriging model

Digital twin scenario 1: Fin overheated

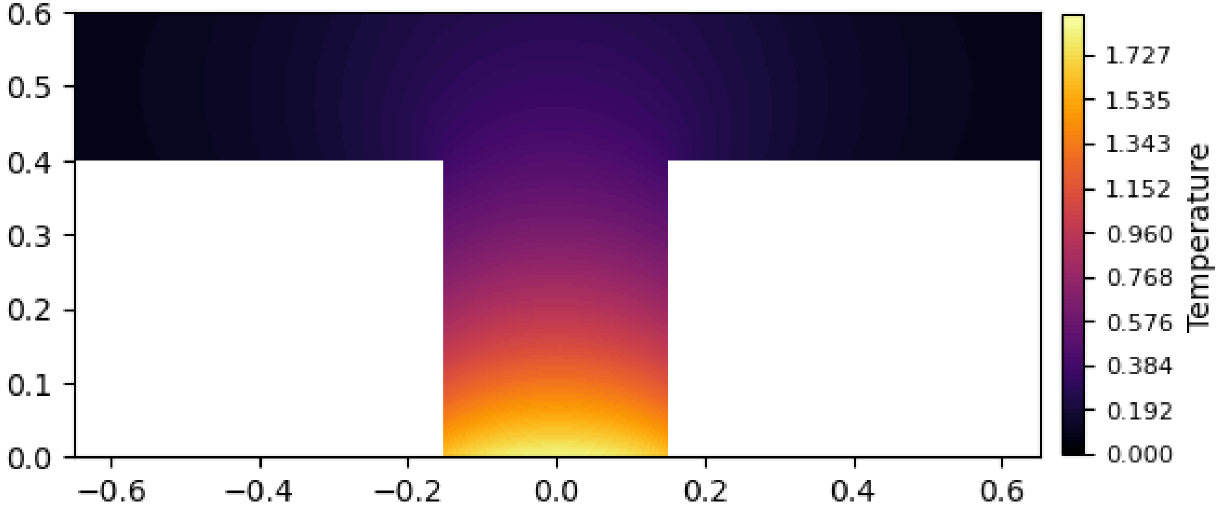
3. Monitor temperature field based on the identified thermal update



Digital twin model	Absolute error	Estimation time (s)
FE-based	3.6e-06	2.31
RB-based	2.8-04	0.29
Error-aware RB-based	3.3-06	0.19

Digital twin scenario 1: Fin overheated

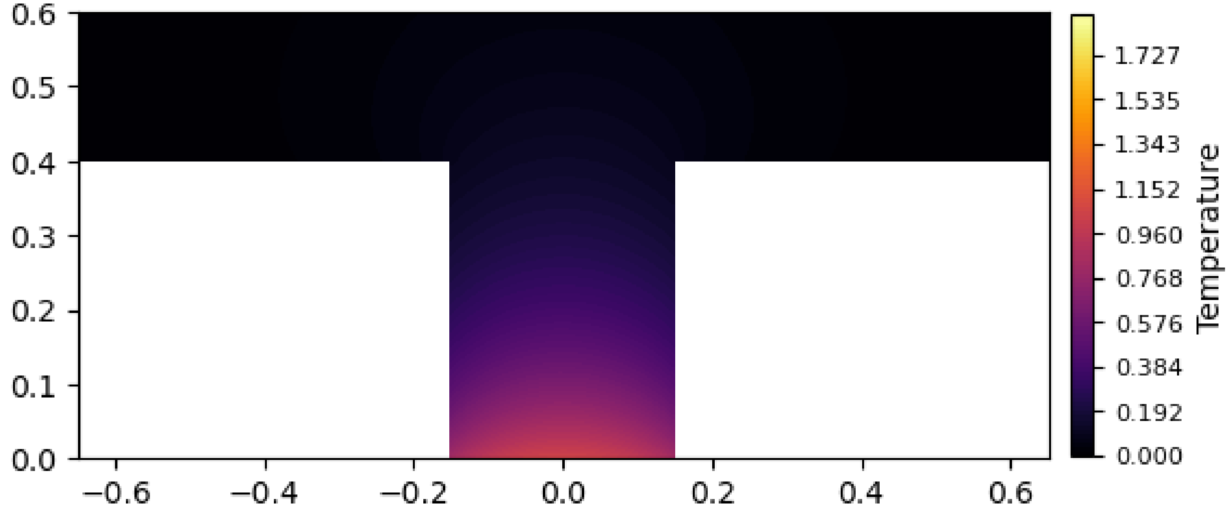
3. Monitor temperature field based on the identified thermal update



Digital twin detects that the maximum temperature exceeded the threshold

Digital twin scenario 1: Fin overheated

4. Increase cooling intensity



Temperature within a safe range