National Aeronautics and Space Administration

FY23 Innovative Spontaneous Concepts Research and Technology Development (ISC)

Physics informed machine learning (PIML) towards a real-time and interpretable thermal simulator

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Objectives: 1) Create a prototype physics-informed machine learning (PIML) thermal model of a reference spacecraft orbiting a small-body; 2) achieve a reduction in simulation time compared to current models while maintaining better accuracy than data-driven modeling approaches; 3) Develop PIML expertise within JPL.

Background: Modeling thermal states for complex scenarios, such as the surface exploration of airless bodies, requires high computation, whether used in ground-based analysis for spacecraft design or in onboard reasoning for autonomous operations. Simulation bottlenecks prevent onboard reasoning during descent and landing, proximity operations, or in-space assembly. The lack of fast and accurate thermal modeling drives thermal designs to be more conservative and leads to spacecraft with larger mass and higher power usage. Some of these applications can benefit from low-fidelity, rapid, simulators as opposed to state-of-practice simulators which are high-fidelity but require more computation and decision making from trained thermal engineers.

Approach and Results: We setup a high-fidelity reference thermal model and data-processing routines for generating training data. Our hybrid PIML models predict node density and placement of a finite-difference grid given orbital loads. The proposed PIML-A and PIML-B models generate grids that reduce node counts while maximizing accuracy of thermal predictions This process typically requires a trained thermal engineer. The proposed approach can be scaled to many different loading scenarios and models.

Significance/Benefits to JPL and NASA: Leveraging PIML hybrid models for thermal analysis can lead to 1) faster design iterations, 2) reductions in mission costs by circumventing worst-case-based conservative planning, 3) safer thermal-aware navigation and exploration.

Thermal Modeling Process

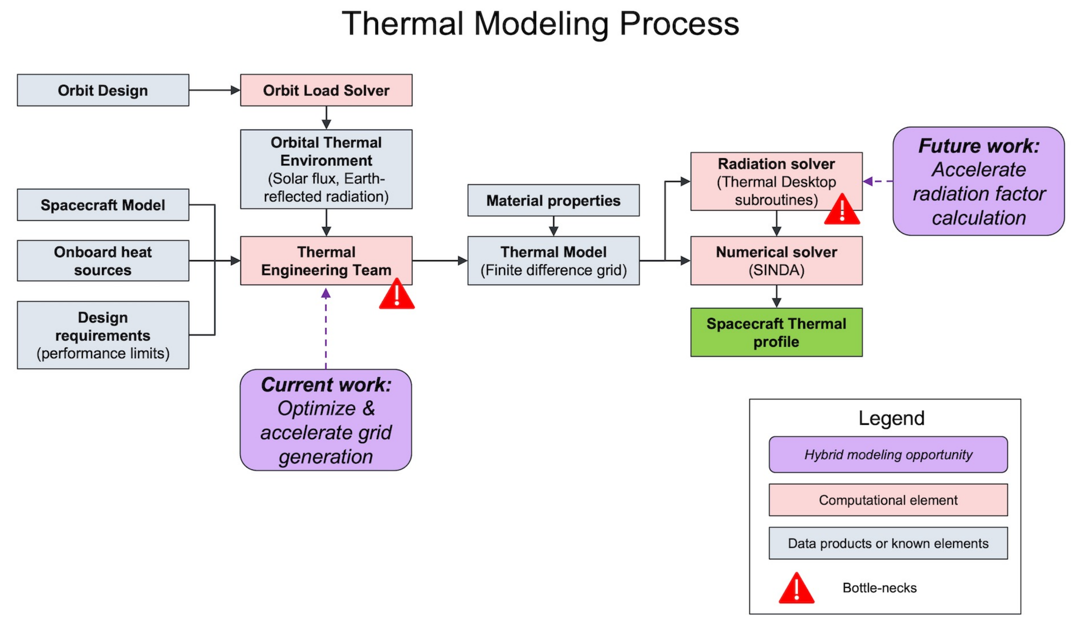

Figure 1

Governing Heat Transfer Equations: finite difference formulation

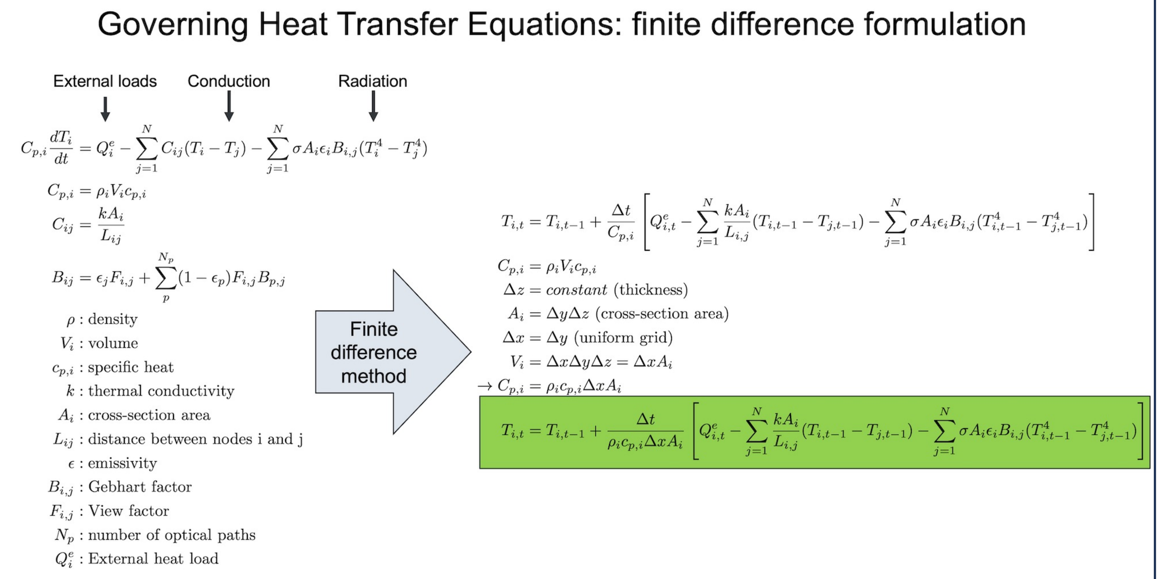

Figure 2

Model Architectures

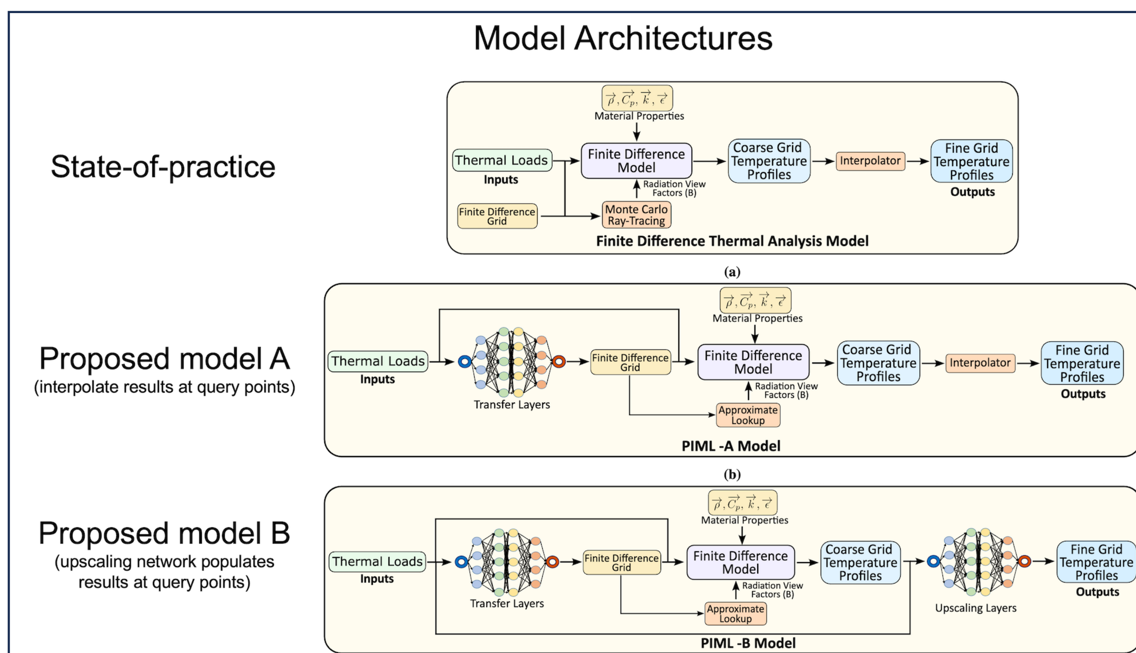

Figure 3

Auto-differentiation Architecture

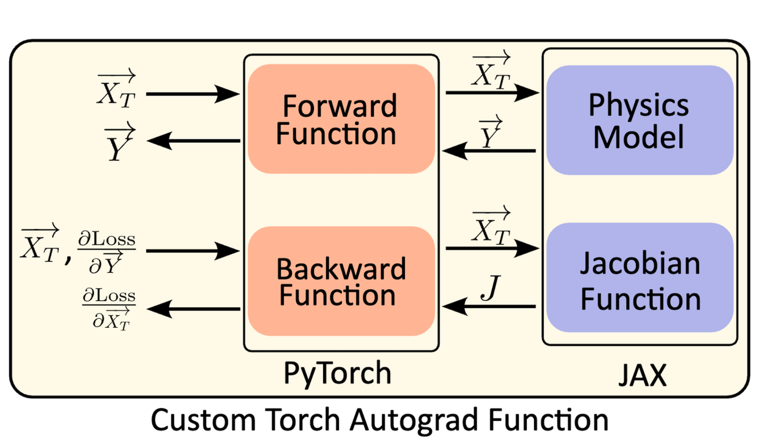

Figure 4

Example Problem

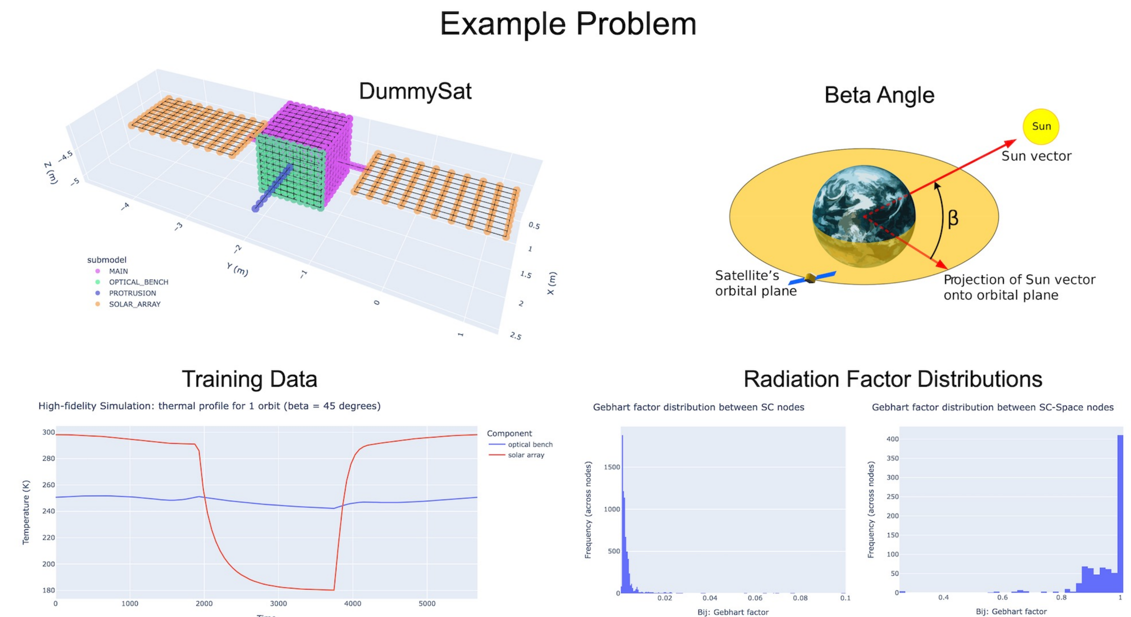

Figure 5

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