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Multiphysics Topology Optimization of Heat Transfer and Fluid Flow Systems

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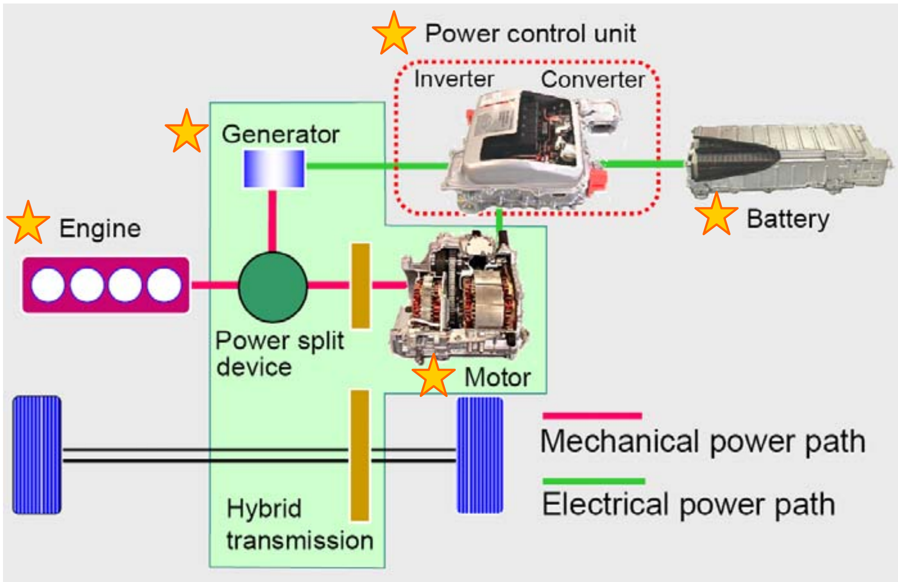
Overview

- Motivation
- Technical Approach
- Single Physics Example
- Multiphysics Example
- Conclusions

Motivation

- Advanced electrical machine design requires efficient thermal / fluid systems

Toyota PRIUS

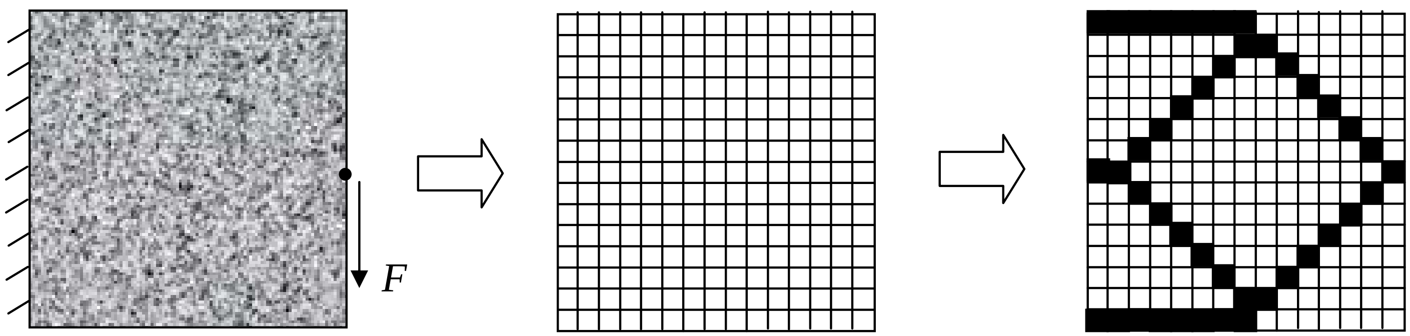


★ = Thermal management location

Toyota Hybrid System (THS) II

Technical Approach

- Topology optimization
  - Local control of density → 0 (void) and 1 (solid)



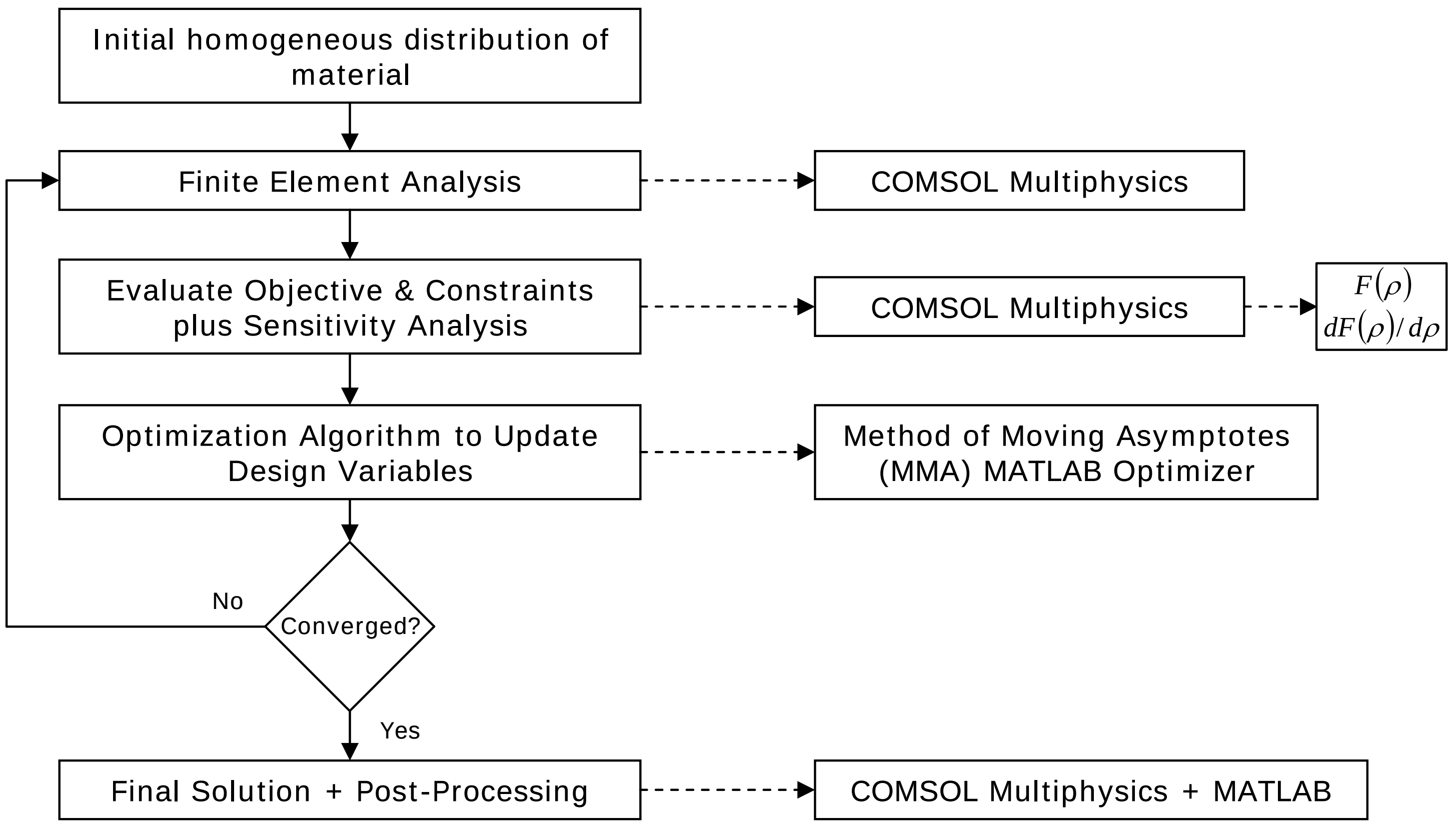
Design Domain + Loads & Boundary Conditions | Discretized Design Domain | Example Optimized Design Domain

$$\left.\begin{array}{ll} \text{Minimize} & F(\rho) \\ \text{Subject to} & R(\rho)=0 \\ & \rho_{\min} < \rho < 1 \end{array}\right\}$$

Allow density design variables to vary continuously for gradient-based optimization

Technical Approach

- Topology optimization
  - COMSOL + MMA in MATLAB environment



Technical Approach

- Governing equations
  - Heat transfer

Eq. 1	$-\nabla \cdot (k(\rho)\nabla T) = Q$	=> Pure Heat Conduction
Eq. 2	$\rho C(\mathbf{u} \cdot \nabla T) = \nabla \cdot (k(\rho)\nabla T) + Q$	=> Convection - Diffusion

  - Fluid mechanics

Eq. 3	$\nabla \cdot \mathbf{u} = 0$	=> Fluid Incompressibility
Eq. 4	$\rho(\mathbf{u} \cdot \nabla \mathbf{u}) = -\nabla P + \eta \nabla^2 \mathbf{u} - \alpha(\rho)\mathbf{u}$	=> Brinkman - type Equation

Technical Approach

- Design variable interpolation
  - Thermal conductivity

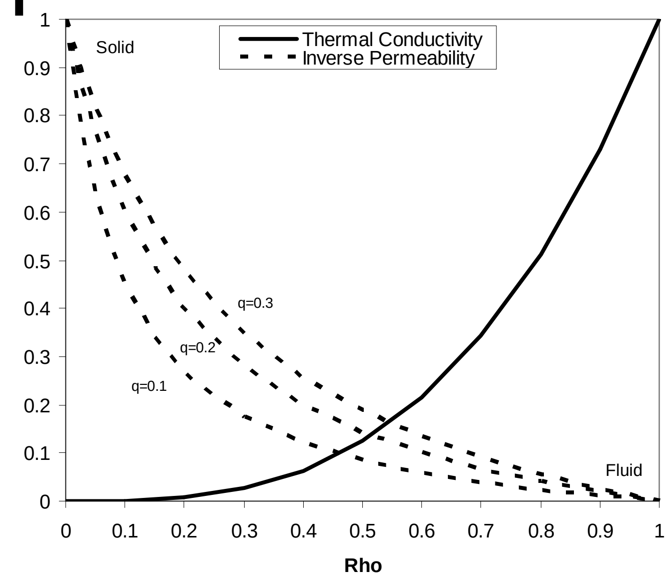
Eq. 5 $$k(\rho) = \left(0.001 + 0.999 * \rho^{p}\right) * k_{\max}$$

=> SIMP (ref. Bendsoe and Sigmund, 2004)

  - Inverse permeability

Eq. 6 $$\alpha(\rho) = \alpha_{\min} + \left(\alpha_{\max} - \alpha_{\min}\right) * \left(\frac{q * (1-\rho)}{(q+\rho)}\right)$$

=> RAMP (ref. Olesen et al., 2006)



- Thermal / fluid objective function

Eq. 7 $$F(\rho) = w_1 B(\rho) + w_2 C(\rho)$$

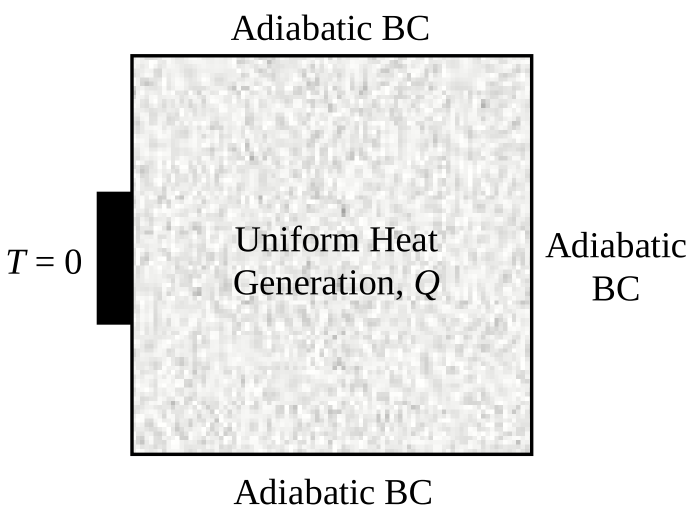
Related to total fluid power dissipated in porous medium

Related to mean temperature of domain

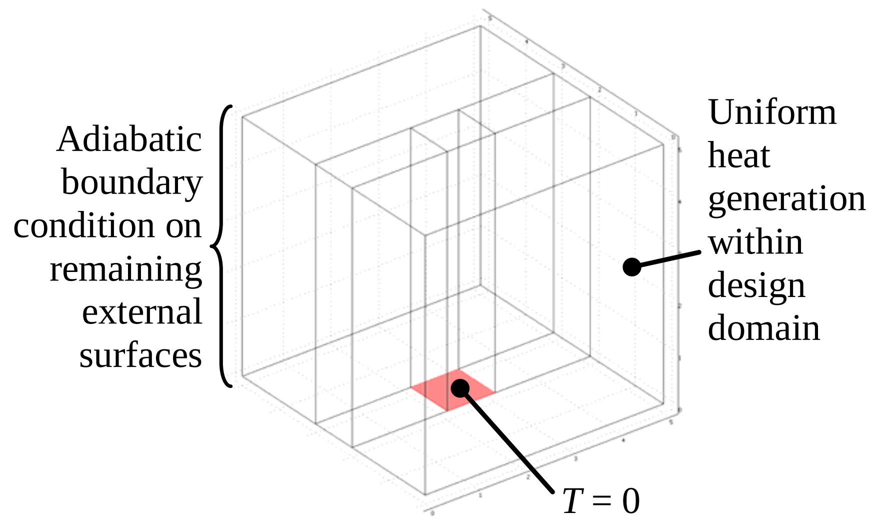
Weighting values (2X)

Single Physics Example

- Optimization for pure heat conduction
  - Model descriptions



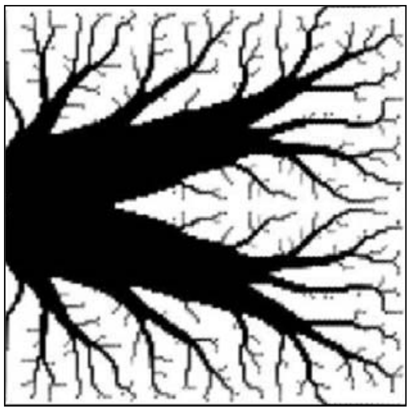
<u>2-D Domain</u>



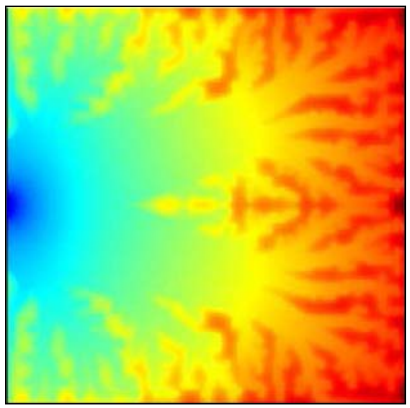
<u>3-D Domain</u>

Single Physics Example

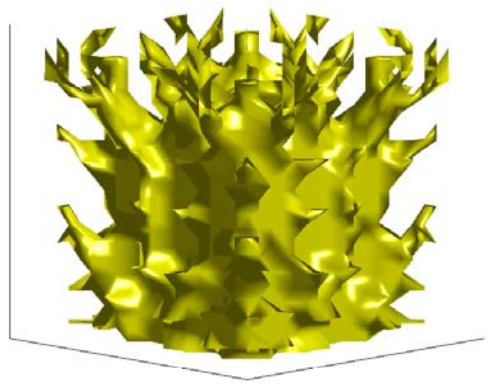
- Optimization for pure heat conduction
  - Results



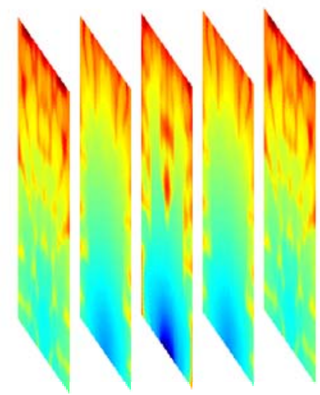
Optimal Topology



Temperature Distribution



Optimal Topology



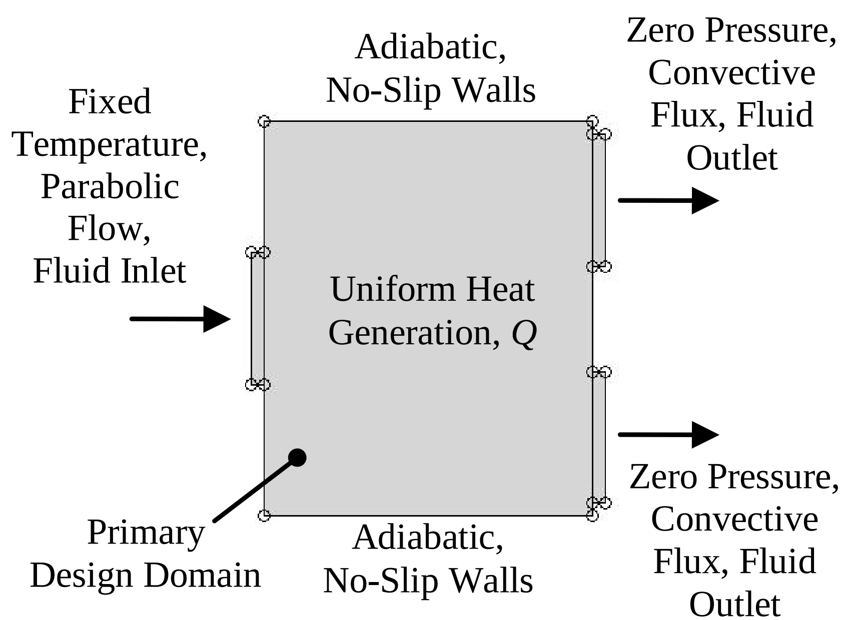
Temperature Distribution

<u>2-D Domain</u>

<u>3-D Domain</u>

Multiphysics Example

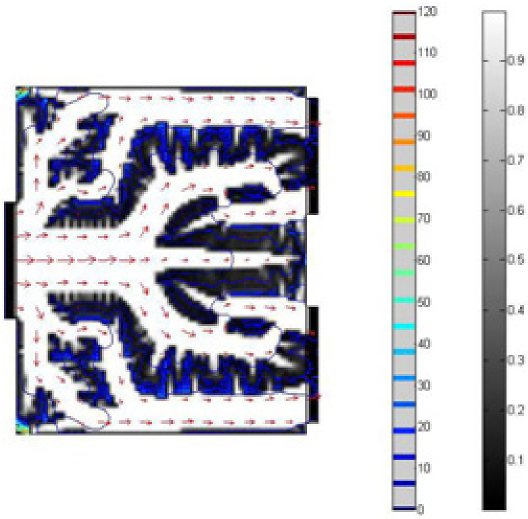
- Optimization for heat transfer & fluid flow
  - Model description – three terminal device



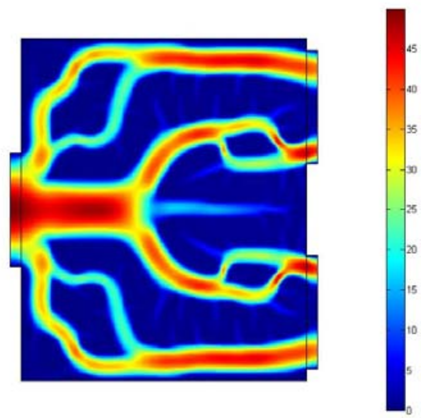
<u>2-D Domain</u>

Multiphysics Example

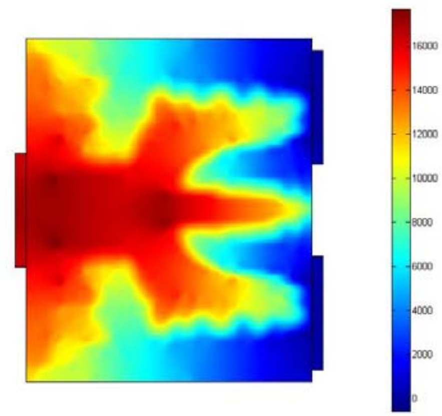
- Optimization for heat transfer & fluid flow
  - Results for $w_1 >> w_2$ in objective function



Optimal Topology, fluid velocity arrows, and temperature contours



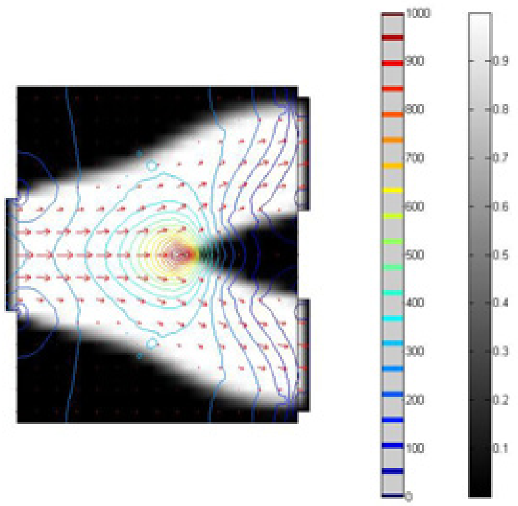
Fluid velocity contours



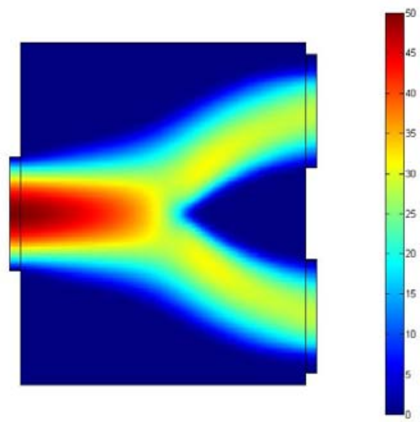
Fluid pressure contours

Multiphysics Example

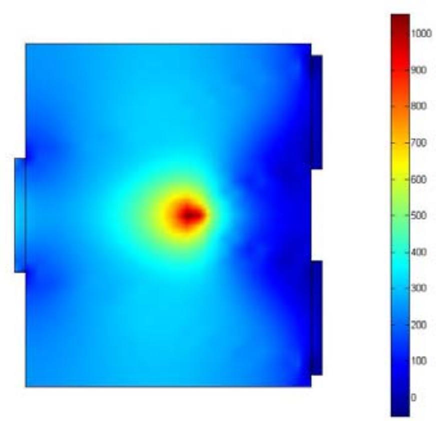
- Optimization for heat transfer & fluid flow
  - Results for $w_2 >> w_1$ in objective function



Optimal Topology, fluid velocity arrows, and temperature contours



Fluid velocity contours



Fluid pressure contours

Conclusions

- Multiphysics topology optimization demonstrated
  - COMSOL + MMA in MATLAB environment
  - Heat transfer and fluid flow objectives
- Ongoing work
  - Evaluation of interpolation schemes for oscillation suppression during solution
  - Efficient methods for determining weighting values
  - Novel applications to 3-D thermal / fluid heat transfer systems

Questions?

Thank you!