Multidisciplinary Analysis And Optimal Design: As Easy as it Sounds?

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Outline:

- Preliminaries, problem statement
- Aspects of design optimization
- Code architecture, current capabilities
- Planned activities, and collaborative area suggestions

Some Preliminaries:

In the near future, precision, large aperture structures:

- Will be launched without the benefit of full component, system testing
- Will be configured, controlled, diagnosed without direct human interaction
- Will be driven to even greater extents by multidisciplinary effects (e.g. observational time, stability as functions of transient thermal radiation)
- Are likely to be subject to cryogenic, material and mechanical effects that are not yet fully understood nor analytically characterized
- Must be optimal; feasible designs probably will not be good enough

Basic Optimization Problem Statement:

Given:	$\vec{x} = \lfloor x_1 \;\; x_2 \;\; x_3 \;\; \ldots \;\; x_n \rfloor$	Design variables
Minimize:	$F(\vec{x})$	Objective function
Subject to:	$g_j(\vec{x}) \leq 0 \qquad j = 1, \ldots, m$	Inequality contraints
	$h_k(\vec{x}) = 0 \qquad k = 1, \ldots, l$	Equality contraints
	$x_i^l \leq x_i \leq x_i^u$	Side contraints

Definition of an Optimum Solution:

Kuhn-Tucker conditions for constrained optimality (Lagrange's method of multipliers applied to basic optimization problem statement):

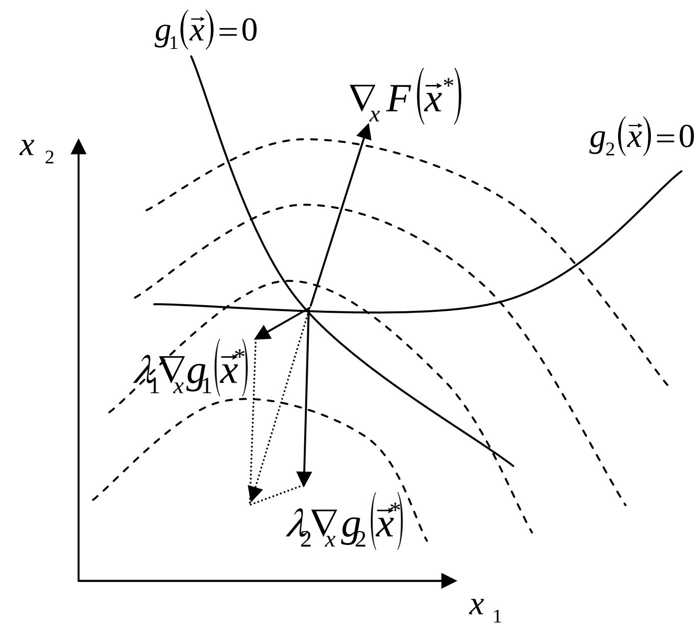
$\left(\vec{x}^*\right)$ is feasible

$\lambda_j^* g_j\left(\vec{x}^*\right) = 0$;

$j \in$ inactive constraint set ; $g_j\left(\vec{x}\right) \leq 0$

$\nabla_x F\left(\vec{x}^*\right) + \sum_j \nabla_x g_j\left(\vec{x}^*\right) = 0$;

$j \in$ active constraint set ; $g_j\left(\vec{x}\right) = 0$



Design Sensitivity Analysis:

- Example: Gradients for linear, discretized systems:

Static Analysis: $$Ku = P \qquad (1)$$

Design: $$K(x^o)\cdot u(x^o) = P(x^o)$$ x^o = current state

$$\left.\frac{\partial}{\partial x_i}\right|_{x^o} \forall x_i : \quad \nabla K(x^o)\cdot u(x^o) + K(x^o)\cdot \nabla u(x^o) = \nabla P(x^o)$$

$$K(x^o)\cdot \nabla u(x^o) = \nabla P(x^o) - \nabla K(x^o)\cdot u(x^o) \qquad (2)$$

Design Sensitivity Analysis, cont.

- Remarks:
  - Since (1) and (2) have the same form, the same solution procedure can be used for (2)
  - K^{-1} is already on hand from the solution of (1)
  - In practice, $\nabla K \cdot u$ is formed as:

$$\sum_{e} \nabla k^{e}\left(x^{o}\right) \cdot u^{e}\left(x^{o}\right)$$

  - $\nabla P = 0$ for design changes that don't affect loads

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Practical Considerations:

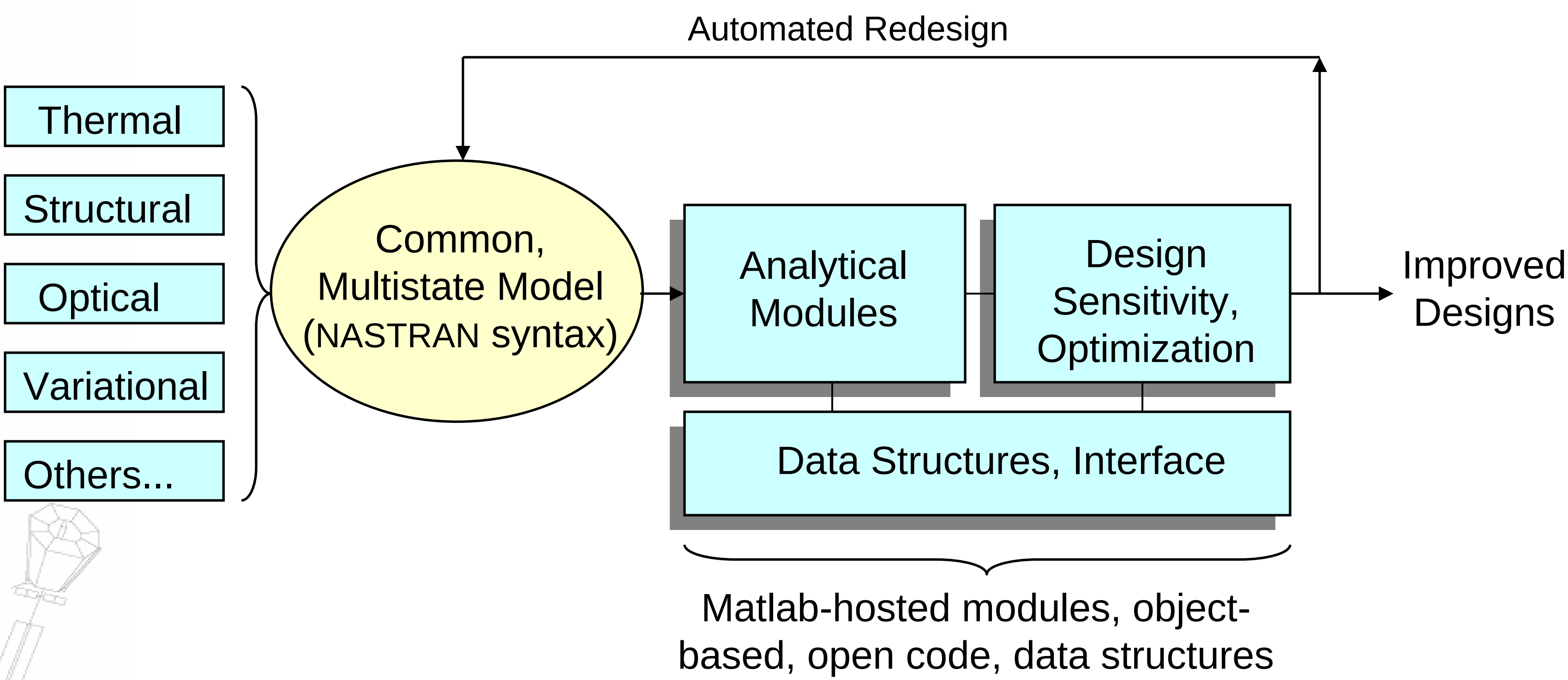
- Parameterized analyses must be capable of accurately computing all necessary physical phenomena: $F(\vec{x}), \quad g_j(\vec{x})$
- Analyses must be:
  - Fully data-driven (model, loads, states, etc. fully self-described)
  - Robust (efficient large-problem numerics, adaptive integration, stable convergence characteristics) and <u>validated</u>!
  - Capable of yielding accurate variational data: $\nabla_x F(\vec{x}), \quad \nabla_x g_j(\vec{x})$
- Code architectures should be:
  - Scalable, portable, maintainable
  - Distributed (to facilitate parallel remote computing)
  - Extensible, from data structure up through hosting level

In spite of FEA technology maturity, no commercial toolset (singly or in combination) offers the analytic, design optimization, and extensibility (R&D) features required for optimal solutions to these classes of problems.

New Analytical Environment:

Finite element-based capability for high-fidelity multidisciplinary analysis, design sensitivity, and optimization:

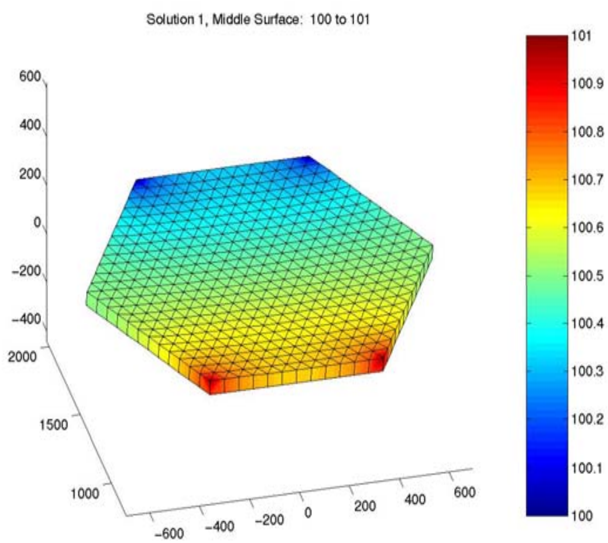
- Analysis is fundamentally integrated; models then are, by definition
- Open, extensible platform for collaborative methods development
- Still under construction, but architecture and much functionality already in place

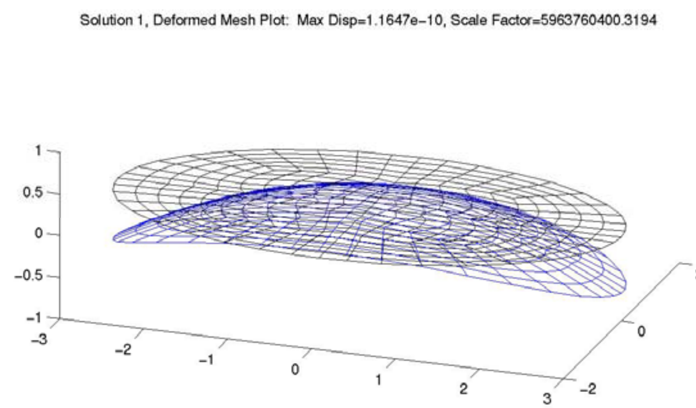


Current Capability Highlights:

Basic Thermal, Structural Elements:

- 1-D, 2-D elements have both thermal, structural properties; single mesh for both analysis types
- Solutions can be coupled; grids have both thermal and structural degrees of freedom
- “Linear”, quadratic, cubic triangular and quadrilateral elements
- Point, edge, surface loads (fluxes, pressures, etc.)





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Current Capability Highlights, cont.:

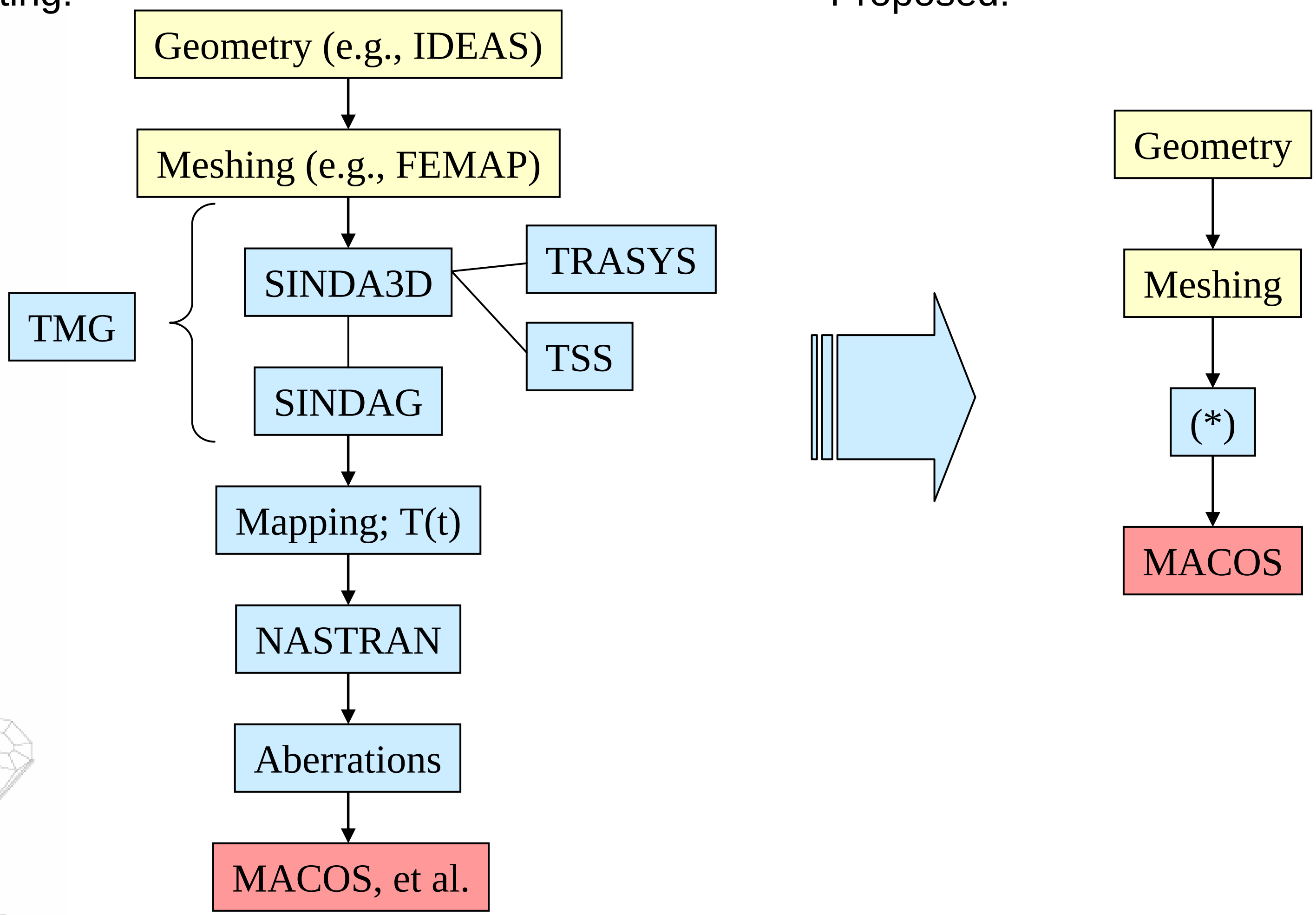
Nonlinear Heat Transfer Solutions:

- Vehicle orbit positioning
  - Time-dependent loads from sun, planet(s) relative positions
- View factor calculation
  - Third-body shadowing, adaptive contour integration for highly-discretized models, large number of exchange elements
  - Multicavity, with partial updates for time-dependent relative positioning
- Radiation matrix generation
  - Surface effects, exchange relationships expressed in finite element basis
  - Multicavity, partial updates for temperature, time-dependent relations
- Matlab-hosted solutions feature:
  - Fixed/adaptive time stepping with bounds on time step, delta temperature
  - Full/modified Newton, adaptive tangent matrix update strategies, mixed implicit/explicit methods for radiation contribution.
  - Nonlinear iteration/convergence using temperature vector predictor with variable relaxation and L2 norms on residual and/or temperature correction vector

Current Capability Highlights, cont.:

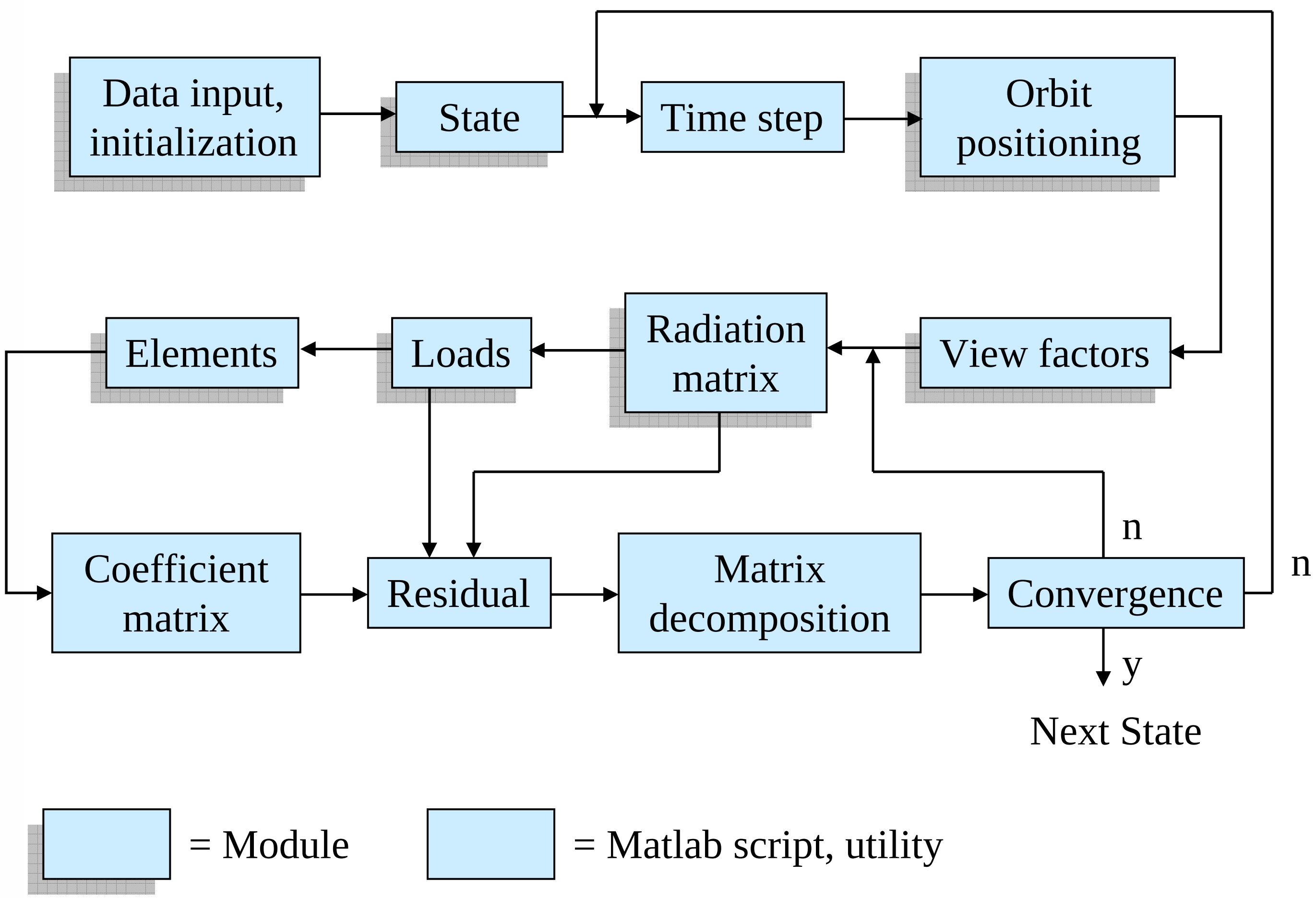
Nonlinear Heat Transfer Solution Process:

Existing: Proposed:



Current Capability Highlights, cont.:

Thermal Solution Data Flow:



Current Capability Highlights, cont.:

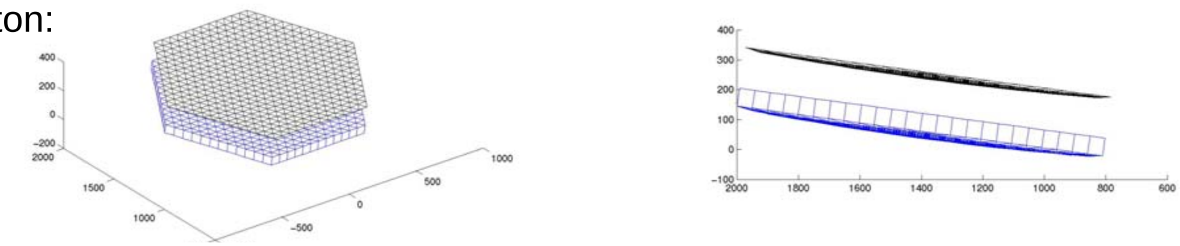
Optical Modes Generation

- Best-fit rigid body vector generation, projection, and automated optical element “partitioning” based entirely on Nastran input extensions:

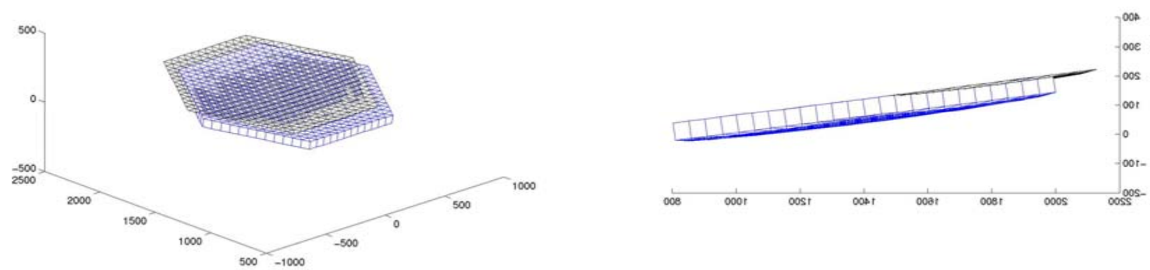
  `COPTC, EID, CID, GID, {GRID, ELEM, PROP}, SETID`

- Basis for Zernike, surface map generation.

  - Piston:



  - Y-decenter:



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Some Closing Remarks:

Automated design synthesis places unique demands on virtually all aspects of code development:

- Parameterization, analysis automation, scalable solutions, computational environment extensibility…

Significant work remaining, collaborative areas:

- Analytical methods development
  - Nonlinear structural analysis
    - Microdynamic effects, nonlinear materials characterization (temperature-, time-dependency, hysterisis, etc.)
  - Radiative heat transfer
    - Specular surface characterization, wavelength-dependent exchange
- Numerics
  - Parallel computational strategies:
    - Diffuse view factor generation
    - Specular exchange factors (efficient ray trace algorithms)
    - Design sensitivity analysis, approximate design model creation, optimization strategies…