Multidisciplinary System Design Optimization (MSDO)

Course Summary

Lecture 23

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Outline

- Summarize course content
- Present some emerging research directions
- Interactive discussion

Learning Objectives (I)

The students will

(1) learn how MSDO can support the product development process of complex, multidisciplinary engineered systems

(2) learn how to rationalize and quantify a system architecture or product design problem by selecting appropriate objective functions, design variables, parameters and constraints

(3) subdivide a complex system into smaller disciplinary models, manage their interfaces and reintegrate them into an overall system model

Learning Objectives (II)

(4) be able to use various optimization techniques such as sequential quadratic programming, simulated annealing or genetic algorithms and select the ones most suitable to the problem at hand

(5) perform a critical evaluation and interpretation of simulation and optimization results, including sensitivity analysis and exploration of performance, cost and risk tradeoffs

(6) be familiar with the basic concepts of multiobjective optimization, including the conditions for optimality and the computation of the pareto front

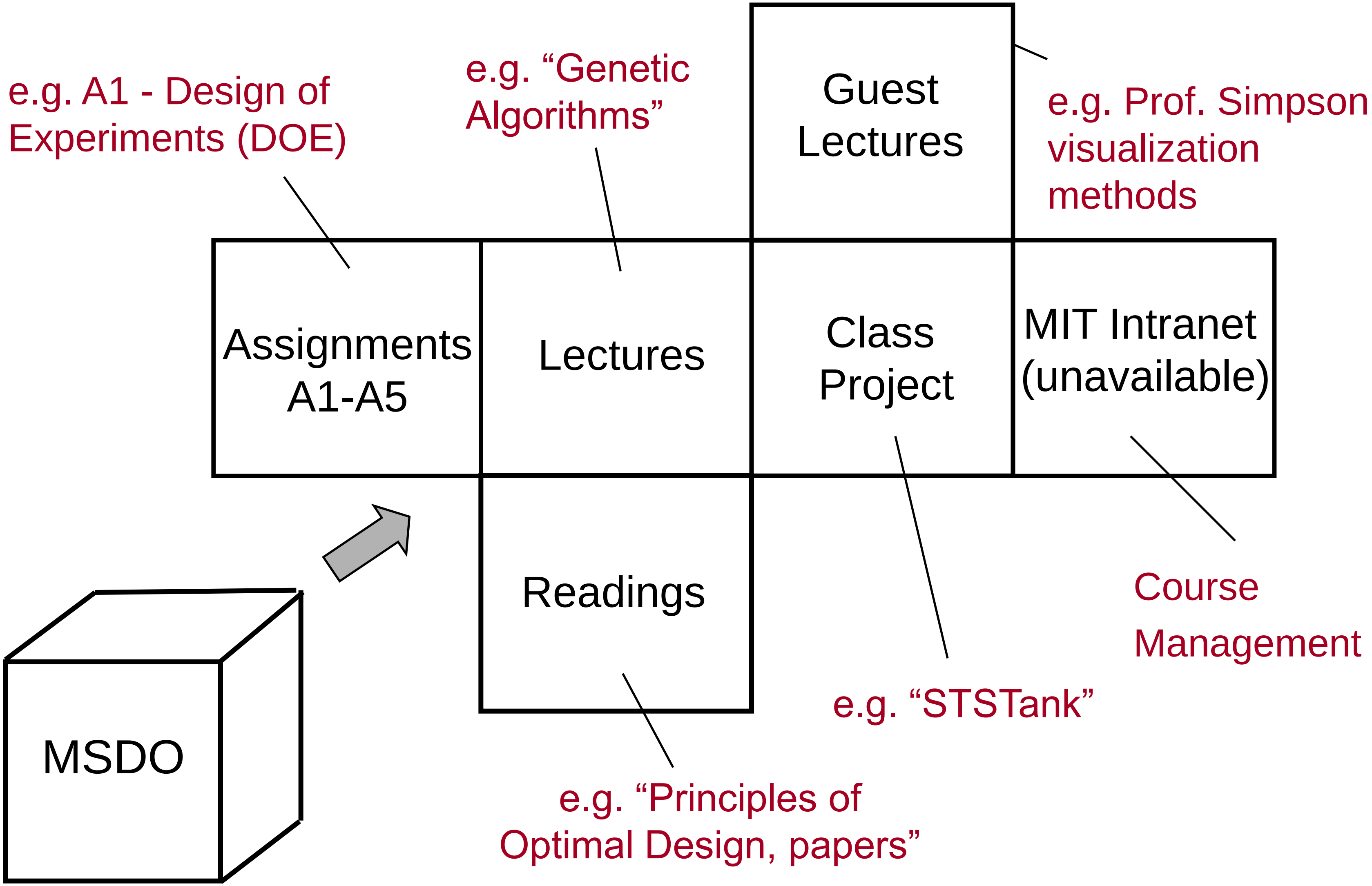
Learning Objectives (III)

(7) understand the concept of design for value and be familiar with ways to quantitatively assess the expected lifecycle cost of a new system or product

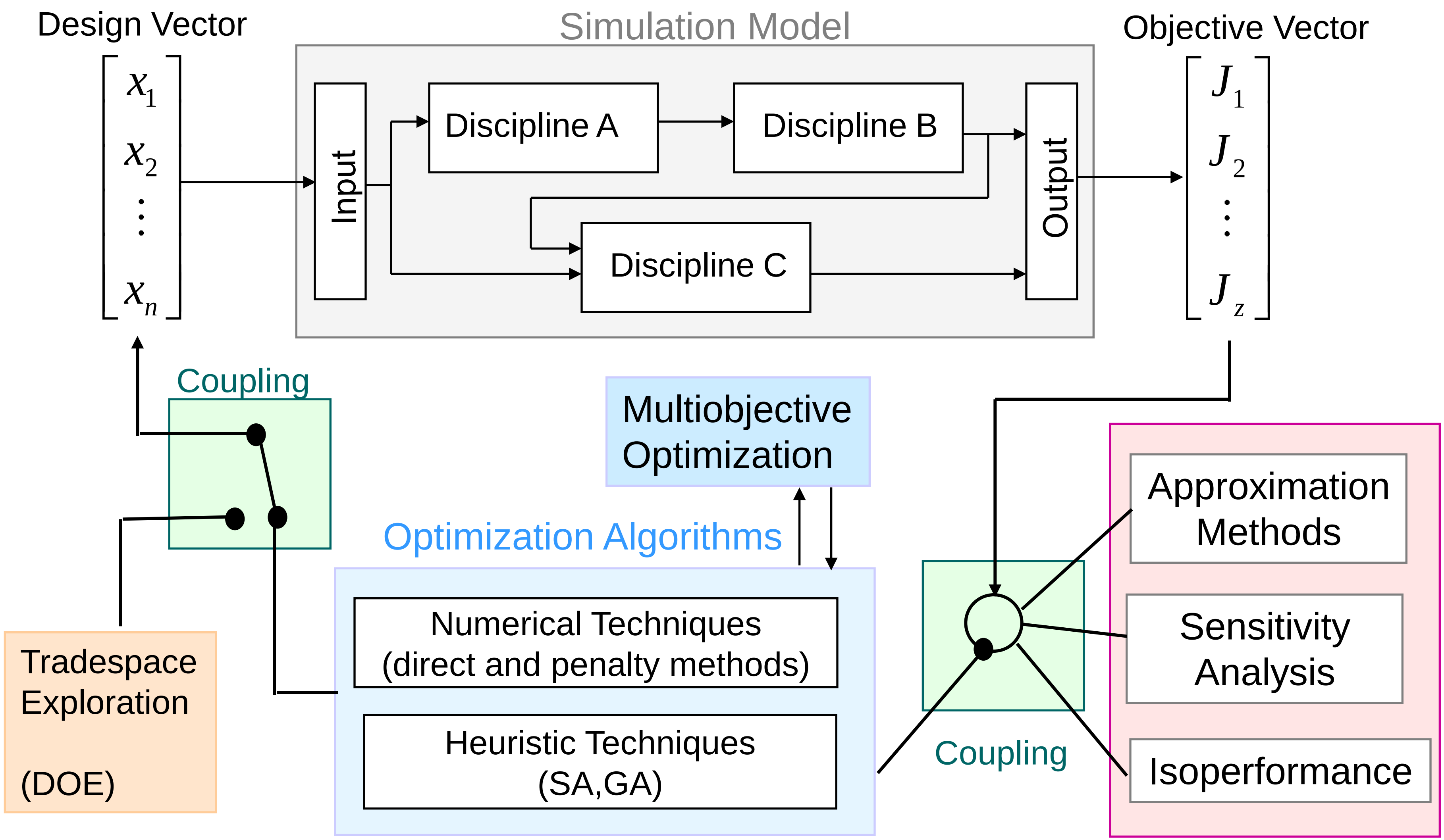
(8) sharpen their presentation skills, acquire critical reasoning with respect to the validity and fidelity of their MSDO models and experience the advantages and challenges of teamwork

⇨ Have you achieved these learning objectives ?

MSDO Pedagogy



Exploration and Optimization MSDO Framework



Conceptual Class Schedule

Module 1: Problem Formulation and Setup

Module 2: Optimization and Search Methods

--- Spring Break ---

Module 3: Multiobjective and Stochastic Challenges

Module 4: Implementation Issues and Applications

Problem Formulation and Setup

(NLP)

$$\min \mathbf{J}(\mathbf{x},\mathbf{p})$$ → **objective**

$$\text{s.t.} \quad \mathbf{g}(\mathbf{x},\mathbf{p}) \le 0$$

$$\mathbf{h}(\mathbf{x},\mathbf{p}) = 0$$ → **constraints**

$$x_{i,LB} \le x_i \le x_{i,UB}$$ → **bounds**

$$\text{where} \quad \mathbf{J} = \begin{bmatrix} J_1(\mathbf{x}) & \cdots & J_z(\mathbf{x}) \end{bmatrix}^T$$

$$\mathbf{x} = \begin{bmatrix} x_1 & \cdots & x_i & \cdots & x_n \end{bmatrix}^T$$ → **design vector**

Module 1: Problem Formulation & Setup

- Design variables
- Constraints
- Objective functions
- Parameters
- Fidelity vs. expense
- Breadth vs. Depth
- MDO uses & applications

Module 1: Subsystem Model Development and Coupling

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- MDO frameworks
  - distributed analysis vs. distributed design
  - CO, CSSO, BLISS
- Simulation Development Process
  - define modules: subsystems or disciplines
  - design vector, constants vector
- N^2 diagrams
  - feedback vs feedforward, sorting
- Benchmarking
  - test model fidelity against a real system

Module 2: Exploration and Optimization Algorithms

- Visualization
- DOE (full factorial, orthogonal arrays, one-at-a-time)
- GA, SA & Gradient-based techniques:
  - basic understanding of algorithms
  - how to choose an algorithm
  - reasons for algorithm failure
  - optimality criteria
  - implementation of several algorithms
- Sensitivity Analysis
  - Jacobian and Hessian, scaling
  - finite difference approximation

Module 3: Multi-Objective Optimization

- Isoperformance and Goal Programming
  - Iso: find set of performance-invariant solutions
  - GP: minimize deviation from target point
- Domination
  - weak vs strong, domination matrix, ranking
- Pareto Front Computation
  - concave versus convex, jumps, multiple dimensions
- MO Algorithms
  - weighted-sum-approach, NBI, AWS
  - multiobjective heuristics: SA , GA
  - utility theory

Module 4: Implementation Issues, Applications

- Approximation Methods
  - reduced-basis methods
  - response surface methodology
  - Kriging
  - multifidelity optimization
- Design for Value
  - cost models
  - market/revenue models
- Robust Design
  - robustness
  - reliability
  - probabilistic methods

Tools

- Generic Technical Computing Environments
  - MATLAB®, Mathematica®, Maple®, Excel
- Programming Languages for Simulation
  - C, C++, FORTRAN, Java™, Visual Basic®
- Special Purpose CAD/CAE
  - Fluent, NASTRAN, SolidWorks®, Pro/Engineer®…
- Multidisciplinary CAE codes
  - FEMLAB
- "Connectivity" Data Exchange Codes
  - ModelCenter, DOME (MIT)/CO (Oculus), ICEmaker, FIPER
- Optimization
  - iSIGHT, ModelCenter, CPLEX, Excel Plug-Ins, MATLAB Toolboxes, AMPL

Challenges of MSDO

- Deal with design models of realistic size and fidelity that will not lead to erroneous conclusions
- Reduce the tedium of coupling variables and results from disciplinary models, such that engineers don't spend 50-80% of their time doing data transfer
- Allow for creativity, intuition and "beauty", while leveraging rigorous, quantitative tools in the design process. Hand-shaking: qualitative vs. quantitative
- Data visualization in multiple dimensions (ATSV helps!)
- Incorporation of higher-level upstream and downstream system architecture aspects in early design: staged deployment, safety and security, environmental sustainability, platform design etc...

AIAA MDO TC View

Analysis and Approximations	Design Problem Formulations and Solutions	Information Processing and Management	Organization and Culture
Cost-fidelity trade-off	Design problem formulation	Software engineering	MD Training
Approximations	Problem de- /re- composition	Data and software standards	MD process insertion
High-fidelity results inclusion	Optimization algorithms	Data visualization, storage, management	MD in integrated product teams
Parametric product data models	Optimization procedures	MD environment	MD in existing organization
SD analysis and sensitivity analysis	SD optimization	Human interface	
MD analysis and sensitivity analysis	MD optimization	MD computing	

** Based on Special Session on Industry Needs at 1998 AIAA/MA&O*

Interesting Research Directions

(1) Design of Families of Systems/Products

(2) Design of Reconfigurable Systems

(3) Massively Parallel Computing (Grid Computing)

(4) Multifidelity Optimization (reduced-order modeling, surrogates, variable-complexity design descriptions)

(5) Design Under Uncertainty

(6) Further Refinement of Search Algorithms

(7) Visualization and Data/Process Coupling

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