16.888/ESD.77J Multidisciplinary System Design Optimization (MSDO)
Spring 2010

Assignment 1

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Issued:	Lecture 2
Due:	Lecture 6

You are expected to solve **Part (a)** individually and **Part (b)** in your project team[1]. Each person must submit their own Part (a) but you should submit Part (b) as a group. Please indicate the name(s) of your teammate(s).

Topics: Multidisciplinary analysis, problem formulation, modeling and simulation, system decomposition

Part (a)

(a1) Motivation

Summarize in 5-10 sentences why you decided to take this class. What do you expect to learn? How does this knowledge fit in with your career or research plans?

(a2) Chapter 1 – Principles of Optimal Design

In Sections 1.1 and 1.2 of *Principles of Optimal Design* (POD), the authors discuss *hierarchical levels* in system definition and *hierarchical system decomposition*. To answer the questions below, consider <u>one</u> of the following engineering systems: a wind turbine power system, a cable stayed bridge, a plug-in-hybrid electric car, or a submarine.

(a2-1) Describe the *system boundary* that you would choose in setting up a model for your system. What are the inputs and outputs that cross this boundary and characterize your system?

(a2-2) Propose a *component decomposition* for your system (use a similar level of detail to that shown in Fig. 1.10).

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[1] Teams should consist of two or three students.

(a2-3) Propose an *aspect decomposition* for your system (use a similar level of detail to that shown in Fig. 1.12).

(a2-4) Sketch and interpret the following function:

(a) $f(\mathbf{x}) = x_1^2 + 5x_2^2 - 2x_1^3 x_2 + x_1^4 + 2x_2^4$
on the interval $-5 \le x_i \le 5$

(b) $f(\mathbf{x})$ same as above but add the constraint
$g(\mathbf{x}) = (x_1 - 3)^2 + 2x_2^2 + 3x_1 x_2 - 2 \le 0$

(a3) Simple Unconstrained Optimization/Math Review

Reference: Nocedal and Wright, *Numerical Optimization*, Springer, 1999.

(a3-1) Given the function:

$$f(\mathbf{x}) = x_1^4 - x_1^2 x_2 + x_2^2 + \frac{1}{2} x_1^2$$

Compute the gradient (vector of first derivatives) and Hessian (matrix of second derivatives) of $f(\mathbf{x})$. Show that $x^*=(0,0)$ is the only local minimizer of this function, and that the Hessian matrix at that point is positive definite.

(a3-2) Make a contour plot of the objective value, $f(\mathbf{x})$, versus the design variables x_1 and x_2 and verify the local minimum graphically.

(a3-3) Show that the function,

$$f(x) = 2x_1^2 - 4x_1 x_2 + 1.5x_2^2 + x_2$$,

has only one stationary point, and that it is neither a maximum or minimum, but a saddle point.

(a3-4) How many stationary points does the function,

$$f(\mathbf{x}) = \frac{1}{3}x_1^3 + x_1 x_2 + \frac{1}{2}x_2^2 + 2x_2 - 5$$,

have? Classify all of the stationary points as either maximum, minimum, or saddle points.

Part (b)

(b1)
Pick a multidisciplinary system to analyze. You may choose a system aligned with your own research (preferred option) for which you have disciplinary models available, or you may choose one of the design problems listed below:

1. General aviation aircraft design

2. Space shuttle external fuel tank
3. Communications satellite constellation design
4. Supersonic jet design
5. Space-based fire detection

For the multidisciplinary design problem that your team has chosen, write a short (~1-2 pages) project proposal. You should address the following:
- Include a formal problem statement.
- Identify design variables, parameters, inequality constraints, equality constraints, bounds and objectives.
- What do you hope to achieve by the end of the semester?
- What is your current status and what do you see as potential difficulties?

Assemble all your design variables, parameters, constraints and objectives into a "master" table, showing, if applicable, in the columns the symbol, description, upper and lower bound, nominal initial value and unit of measurement.

Note: It is fine if this is a new problem and you are not yet sure what all relevant variables are, this problem will evolve over the course of the semester. A draft is perfectly acceptable at this point. However, you will need a model and simulation capability early in the semester (A2).

(b2) Coupling and N^2 Diagram
For the problem that you have chosen identify the modules (see guidelines from Lecture 3), and identify the inputs and outputs for each module. For simplicity, limit the number of modules to below eight (8) at this point.

Place the modules on the main diagonal of an N^2-matrix, initially in a random order. Identify feedforward and feedback paths by using the identifiers for each variable from the "master" table you assembled in **(b1)**.

Rearrange the N^2-matrix to minimize the number of feedback loops.

(b3) Block diagram
Sketch a block diagram that shows how the modules from **(b2)** work together and how you would wrap a trade space exploration tool or optimizer around your simulation model. You don't actually have to implement this (yet).

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