**Optimization Mini-Projects**

Fall 2021

**Learning objectives:**

* Application and refinement of key optimization concepts
* Application and refinement of mathematical communication using technical writing and design principles
* Providing and receiving conceptual and design feedback, while also iteratively improving

**Implementation over stages:**

* **Proposal**: Students choose one MP and propose the product and medium(s) they will use. Student initials that they have read and understand all requirements (a, b, …). [Time estimate: 1 hour of student’s time]
  + Students fill out index cards with a proposal: selection of assignment, proposed medium, and if they need any additional resources. Instructor provides feedback on proposals where necessary.
* **Draft**: Students begin implementing their proposed project. Progress should include at least 1 major visual and 60% of writing. [Time estimate: 2 hours of student’s time]
  + Peers provide partial feedback on drafts: check that every aspect of the target assignment will be satisfied.
* **Final Product**: Students use all feedback and create a final product. [Time estimate: 3+ hours of student’s time]
  + Instructor gives full feedback on final products.

**Rubric:**

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| Measure | Pts | Level |
| *Conceptual accuracy* | **4** | **Advanced:** Showed conceptual accuracy and depth in understanding. |
| **3** | **Proficient:** No major conceptual errors. |
| **2** | **Novice:** Some minor and/or major conceptual errors. |
| **1** | **Beginner:** Fundamental conceptual errors. |
| *Creativity* | **4** | **Advanced:** Product is clearly unique and both highly personal and relatable. |
| **3** | **Proficient:** Product is unique. |
| **2** | **Novice:** Several components are similar to other products. |
| **1** | **Beginner:** Major components are plagiarized. |
| *Design of product* | **4** | **Advanced:** Design choices were superb in communication of ideas and style. |
| **3** | **Proficient:** Design choices facilitated clear communication of ideas. |
| **2** | **Novice:** Minor design choices interfered with communication of ideas. |
| **1** | **Beginner:** Major design choices interfered with communication of ideas. |
| *Assignment requirements* | **4** | **Advanced:** All assignment requirements were met or exceeded. |
| **3** | **Proficient:** All assignment requirements were met. |
| **2** | **Novice:** At least one assignment requirement was not met to satisfaction. |
| **1** | **Beginner:** Multiple assignment requirements were not met to satisfaction. |
| *Peer Feedback* | **4** | **Advanced:** Provided substantive and helpful feedback to peers. |
| **3** | **Proficient:** Provided positive and supportive feedback to peers. |
| **2** | **Novice:** Provided little feedback to peers which lacked substance or actionable items. |
| **1** | **Beginner:** Provided inappropriate feedback to peers. |

**Mini-Project 1 Options: Fundamentals**

Pick one of the following:

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| **Beautiful Example**  *Case study, Design principles*  **Product:** Handout, brochure, mini-poster, etc. (1-2 pages, printed)  **Medium(s):** PowerPoint, Word, Excel, By Hand, or other  **Requirements:** [Note: Every visual needs 1-3 explanatory sentences]   1. Create an “interesting” LP that has 2 variables, at least 8 constraints (including nonnegativity), and at least 6 extreme points. 2. Compute and display all extreme points. Compute and display three *infeasible* basic solutions. 3. Choose 2 objective functions: one with a unique optimal solution and one with multiple optima. Visualize the objective functions and their associated optimal solutions & optimal values in a comprehensible way. 4. Choose one of the objectives from part (b) and make the LP unbounded by removing some constraints. | **Optimization in the News**  *Case study, Modeling, Technical writing*  **Product:** Mini-Research Article (printed, 2-4 pages, professional font, 3-6 sources)  **Medium(s):** Word, Latex  **Requirements:**   1. Find 3 news articles related to a local, national, or global issue you care about. Describe the issue broadly in a “Literature Review” section using appropriate sources. Identify which aspects of the issue can be classified as *decisions*, *constraints*, and *objective(s)*. 2. In a “Data” section, discuss what data should exist about this issue (even if you do not have the data). Define a set of parameters that would be useful for a model. 3. In a “Model” section, define at least two decision variables. Use your list of parameters to define at least two constraints and at least one objective function for this problem. 4. Include a visual aid. For example, either (find) a motivating photograph or (create) a graphical representation of the problem and/or model. Discuss the relevance of the image somewhere in your writing. 5. In an “Analysis” section, answer one of the following questions in-depth with a paragraph:    1. Does this problem naturally have more than one objective? How do these objectives relate to one another?    2. Is there any uncertainty in the parameters that you have proposed? If a model took this uncertainty into account, how would the final solution be improved? 6. In a “Bibliography” section, cite all relevant sources. |
| **YouTube Tutorial Review**  *Educational design*  **Product:** Handout/brochure (printed) **Medium(s):** Word, Latex (printed)  **Requirements:**   1. Find 4 videos about linear programming to watch from YouTube. Report the title of the video, along with the channel, date posted, and length of the video. Report the length of each video in minutes (minimum of 60 minutes total). 2. Rate each video out of 5 stars based communication, visuals, and two other criteria that are important to you. 3. For each video, come up with 3 questions & answers for students watching to check their understanding from what the video covered. |
| **Sample Test Problems**  *Educational design, Problem solving*  **Product:** Handout (2-4 pages, printed) **Medium(s):** Word, Latex, By Hand  **Requirements:**   1. Create 8 test problems including complete solutions that satisfy (b)-(d). Up to four questions may be collected from other sources as long as you *cite* them! 2. At least one modeling question – if it is collected from elsewhere, then *cite it* and edit the context to make it your own! 3. At least three *concept* questions and at least three *calculation* questions. 4. At least one question that requires a visual aid (e.g., an LP feasible set), which you should also provide. The visual aid does NOT need to be created in Latex!! |

**Mini-Project 2 Options: Coding**

Pick one of the following:

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| **Beautiful Example: 3D Visualization**  *Case study, Design principles*  **Product:** Handout, brochure, mini-poster, etc.  **Medium(s):** PowerPoint, Word, Excel, or any of choice (Note: PowerPoint allows you to make documents of any size!)  **Requirements:** [Note: Every visual needs 1-3 explanatory sentences]   1. Construct a primal LP feasible set (with bounded optimal solution) defined with 3 variables and 3 constraints (not including sign restrictions). Compute the dual and display **both** the primal and the dual LP in 3 dimensions. 2. Compute all the extreme points of both LP feasible sets. Use linear algebra notation to represent the primal optimal solution in terms of the primal constraints. Repeat for the dual optimal solution in terms of the dual constraints. 3. Illustrate (with equations) and explain (with words) how your primal-dual pair satisfies complementary slackness. | **Primal-Dual Sensitivity Analysis**  *Coding, Mathematical interpretation, Technical writing*  **Product:** Mini-Research Article (printed, 2-4 pages, professional font)  **Medium(s):** Matlab (required) + Word or Latex  **Requirements:** Organize your write-up according to the following sections:   1. **Problem setting.** Provide a context for an LP such that the objective function is in terms of profit and the constraints have some realistic interpretation. Construct an LP with at least 4 decision variables and at least 4 inequality constraints (parameters can be random). 2. **Dual problem.** Formulate the dual LP, and use Matlab’s linprog function to solve both the primal and the dual LP. 3. **Hypothesis.** Explain the shadow-price interpretation of the optimal dual variables in terms of your primal problem (given the context you created). Predict how the primal optimal **value** will change when you modify the righthand sides of the constraints. Be precise (use numbers). 4. **Experiment.** Test the accuracy of your predictions with experiments: modify the righthand side of the first constraint, first by a 10% increase then by a 10% decrease. Repeat for each constraint. 5. **Results.** Use a well-designed table to summarize the results of your experiment and explain whether they supported or refuted your hypothesis in part d. |
| **Biobjective LP vs. IP**  *Coding, Algorithmic design*  **Product:** Mini-Research Article (printed, 2-4 pages, professional font)  **Medium(s):** Matlab (required) + Word or Latex  **Requirements:**   1. Construct a LP with at least 5 decision variables and at least 5 constraints (parameters can be random). 2. Use dichotomic search and Matlab’s linprog to solve for all nondominated points. Report all efficient solutions. 3. Now use Matlab’s intlinprog, to solve the IP version. Use dichotomic search again to solve for nondominated points. Report all efficient solutions. 4. Visually represent the NDF from part (b) and part (c). Explain differences between the frontiers. 5. In step c, is it guaranteed that you found all possible nondominated points? Discuss how you would propose to algorithmically search for the missing NDPs. | **Triobjective Linear Programming**  *Coding, Algorithmic design,**Design principles*  **Product:** Mini-Research Article (printed, 2-4 pages, professional font)  **Medium(s):** Matlab (required) + Word or Latex  **Requirements:** Dichotomic search uses weighted sum scalarization to solve for the nondominated points of a biobjective LP. Solving weighted sum for three objectives is just as easy, but does dichotomic search generalize so easily? Organize your write-up according to the following sections:   1. **Problem setting.** Provide a context for an LP that has three objective functions. Construct an LP with at least 5 decision variables and at least 5 inequality constraints (parameters can be random). 2. **Brute force approach**. Implement an organized approach to use different weights for solving the weighted sum scalarization. Use Matlab’s linprog to solve each LP. Explain your algorithmic approach, and visualize the results of your brute force search. 3. **Refined search.** How would it be possible for your brute force approach to “miss” an important nondominated point? How could you algorithmically search for such a point? |

**Mini-Project 3 Options: Mastery**

Pick one of the following:

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| **Pokemon IP**  *Modeling, Technical writing*  **Product:** Mini-Research Article (printed, 2-4 pages, professional font)  **Medium(s):** Matlab (required) + Word or Latex  **Requirements:** The Pokemon game is designed with 18 elemental [types](https://pokemondb.net/type) (e.g., fire, water), each of which has a numeric multiplier against other types. For example, 1 (normal effective), 2 (super effective), 0.5 (not very effective) and 0 (not effective). Note that the matrix of multipliers is NOT symmetric!   1. Propose a research question which may be solved by an IP that uses this multiplier data as parameters. Example 1: *Which type combination of two (or three) types is the “most powerful”?* Example 2: *If a new elemental type were added to the list, which would make the system more “balanced”?* 2. Explain a complete IP model which attempts to answer your research question. (For example 2, your model must include restrictions on the multipliers, e.g., at most Ni of each type of multiplier, where you choose Ni.) 3. Explain why you chose the objective function that your model uses. Give some examples of feasible solutions and their objective values. 4. Use Matlab to solve the IP model. Report not only optimal solution and values but also “computational metrics”, e.g., how long intlinprog took to solve the problem. 5. Provide a visual representation of the solution to your research question. | **Research Blog Post**  *Case study, Modeling, Technical writing*  **Product:** Blog post  **Medium(s):** Word\* or Latex, PowerPoint, etc.  **Requirements:**   1. Find an optimization research article that presents a *model* for a problem that you find interesting. Write a blog post that could be read by another undergraduate optimization student and satisfies (b)-(d). Include a proper citation for the article and a link to any images you get from online. 2. Describe the motivation for the problem/model in your own words, using at least one non-mathematical visual. 3. List and explain at least three decision variables. What kind of variables are they, and what lower/upper bounds apply to them? List and explain at least two “simple” constraints and at least one “advanced” constraint. 4. Create your own graphic that helps to communicate one mathematical component of the paper to the reader.   \*Optional: If you want your blog post to be published on my [Medium page](https://perinita.medium.com/) then you must provide (1) a Word document and (2) *high resolution* images (example: Google images 🡪 Tools 🡪 Size = Large). You will be highlighted as the “Guest Author” for the article! |
| **Concept Map**  *Educational design, Design principles*  **Product:** Handout, brochure, mini-poster  **Medium(s):** Word, Latex, PowerPoint  **Requirements:**   1. Construct a “zoomed out” concept map for 16 of the most important concepts in the class. 2. Construct a “zoomed in” concept map that focuses on a subgraph of the map from a and add 12 more specific concepts. 3. Choose 3 links in each concept map and discuss each in 2-4 sentences.   [Note: Standard concept maps use labeled nodes to represent concepts, and the edges between the two represent relationships that are described by short descriptions/phrases. Feel free to adapt the formatting.] | **Helpful Handouts**  *Educational design, Design principles*  **Product:** Handout/brochure  **Medium(s):** Word, Latex, PowerPoint  **Requirements:** Come up with 3 pages specially designed for optimization notes or problems. For example, use small multiples to facilitate drawing multiple LP feasible sets, multiobjective image sets, branch and bound, or networks.   1. Provide a “blank” version for anyone to use. 2. Make a bulleted list of the design decisions you made for this document: explain *why* it looks the way it does and *how* it should be used! Discuss at least 4 key decisions. 3. Use your pages to illustrate at least two beautiful examples (one for a concept and one for a computation). |

Other

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| **Lesson Plan Design**  *Educational design*  **Product:** Lesson plan + video of highlights  **Medium(s):** Word + Video recording (YouTube, Zoom, etc.)  **Requirements:**   1. Choose a challenging topic of the class. Outline a lesson plan for a single lecture (~50-minutes) to present that topic with appropriate context. 2. Provide at least 4 definitions related to the course topic; for two definitions, provide a useful visual. 3. Create at least one engaging activity or one dynamic visualization. As appropriate, provide sources and appropriate directions.   Record a video of the “highlights reel.” In the video, present (b) the two definitions with your visuals (b) and how you incorporate (c) into the lesson. Video should be at least 5 minutes. | **Research Blog Post**  *Case study, Modeling, Research*  **Product:** Blog post  **Medium(s):** Word for text, PowerPoint, etc.  **Requirements:**   1. Find an optimization research article that presents a model for a problem that you find interesting. Write a blog post that could be read by another undergraduate optimization student and satisfies (b)-(d). Include a proper citation for the article and a link to any images you get from online. 2. Describe the motivation for the problem/model in your own words, using at least one non-mathematical visual. 3. List and explain at least three decision variables. What kind of variables are they, and what lower/upper bounds apply to them? List and explain at least two “simple” constraints and at least one “advanced” constraint. 4. Create your own graphic that helps to communicate one mathematical component of the paper to the reader. |
| **Concept Map**  *Educational design, design principles*  **Product:** Handout, brochure, mini-poster  **Medium(s):** Word, Latex, PowerPoint  **Requirements:**   1. Construct a “zoomed out” concept map for the most important concepts in the class. 2. Construct a “zoomed in” concept map that focuses on more specific details for a subgraph of the previous concept map. 3. Choose 3 links in these concept maps, and discuss each in a short paragraph.   [Note: Standard concept maps use labeled nodes to represent concepts, and the edges between the two represent relationships that are described by short descriptions/phrases. Feel free to adapt the formatting.] | **Helpful Note Pages**  *Educational design, design principles*  **Product:** Handout/brochure  **Medium(s):** Word, Latex, PowerPoint  **Requirements:**   1. Come up with pages specially designed for optimization notes or problems. For example, use small multiples to facilitate drawing multiple LP feasible sets, simplex tableaus, or networks. Provide a “blank” version for others to use. 2. Make a bulleted list of the design decisions you made for this document: explain *why* it looks the way it does and *how* it should be used! Discuss at least 4 key decisions. 3. Use your pages to illustrate at least two beautiful examples (one for a concept and one for a computation). |

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| **Beautiful Examples**  *Case study, Design principles*  **Product:** Handout, brochure, mini-poster, etc.  **Medium(s):** PowerPoint, Word, Excel, or any of choice (Note: PowerPoint allows you to make documents of any size!)  **Requirements:**   1. Construct a primal LP feasible set defined with 3 variables and 3 inequality constraints (excluding nonnegativity). Compute and display all extreme points. 2. Choose 2 objective functions: one with a unique optimal solution and one with multiple optima. Plot the biobjective image set in objective space. Identify all efficient solutions and nondominated images. 3. Compute a dual for one of these objectives. Write its LP formulation and represent it visually in the same manner as (a). Illustrate complementary slackness with this primal/dual. | **Practice Problem Rehearsal**  *Problem solving, Scripting, Technical writing*  **Product:** Handout  **Medium(s):** Latex (required)  **Requirements:**   1. Choose 10 unassigned problems from Chapter 6 (duality) to solve completely. 2. Write up the solutions in Latex with clear and accurate explanations. 3. Include at least two helpful visual aids. |
| **Design Module for Dashboard**  *Educational design, design principles, coding*  **Product:** Code + Description  **Medium(s):** Matlab, Python, or R  **Requirements:**   1. Choose one of the following topics: duality, multiobjective LPs, robust LPs, or stochastic LPs. 2. Design the components of a new interactive module for the dashboard. Sketch out the module, including text, buttons, sliders, etc. 3. Describe the purpose and function of the module in writing. Describe what each button, slider, etc. should do. Come up with at least two thoughtful questions to prompt the user (one concept and one calculation) and provide your own answer to those questions. 4. Use code to generate a beta version of your module’s graphical visualization. Values from the interactive features (e.g., buttons or sliders) can be fixed and instead focus on the graph’s design. Use appropriate labels, legends, and color scales.   You will be provided with relevant libraries and small functional examples. For example: R + ggplot2, … | **Optimization Solver**  *Coding*  **Product:** Matlab code + Description  **Medium(s):** Matlab (previous experience with Python required)  **Requirements:**   1. Build an IP/LP model in python to be solved by Gurobi solver. The model should contain at least 6 variables, and at least 6 constraints (not counting sign constraints). 2. For a fixed objective function, solve the model with continuous variables and discrete variables. Compare the optimal solutions and the objective values. 3. For a fixed objective function, experiment with removing one or more constraints. Show when the model becomes unbounded.   Your write-up should include the model for (a) as well as the results of analysis for (b) and (c). The code should also be partitioned into parts a/b/c and be commented to be read by someone else. |