COMPUTER-AIDED ANALYSIS AND DESIGN MAE 292

Professor Nick Gravish
Spring 2020 / ngravish@ucsd.edu

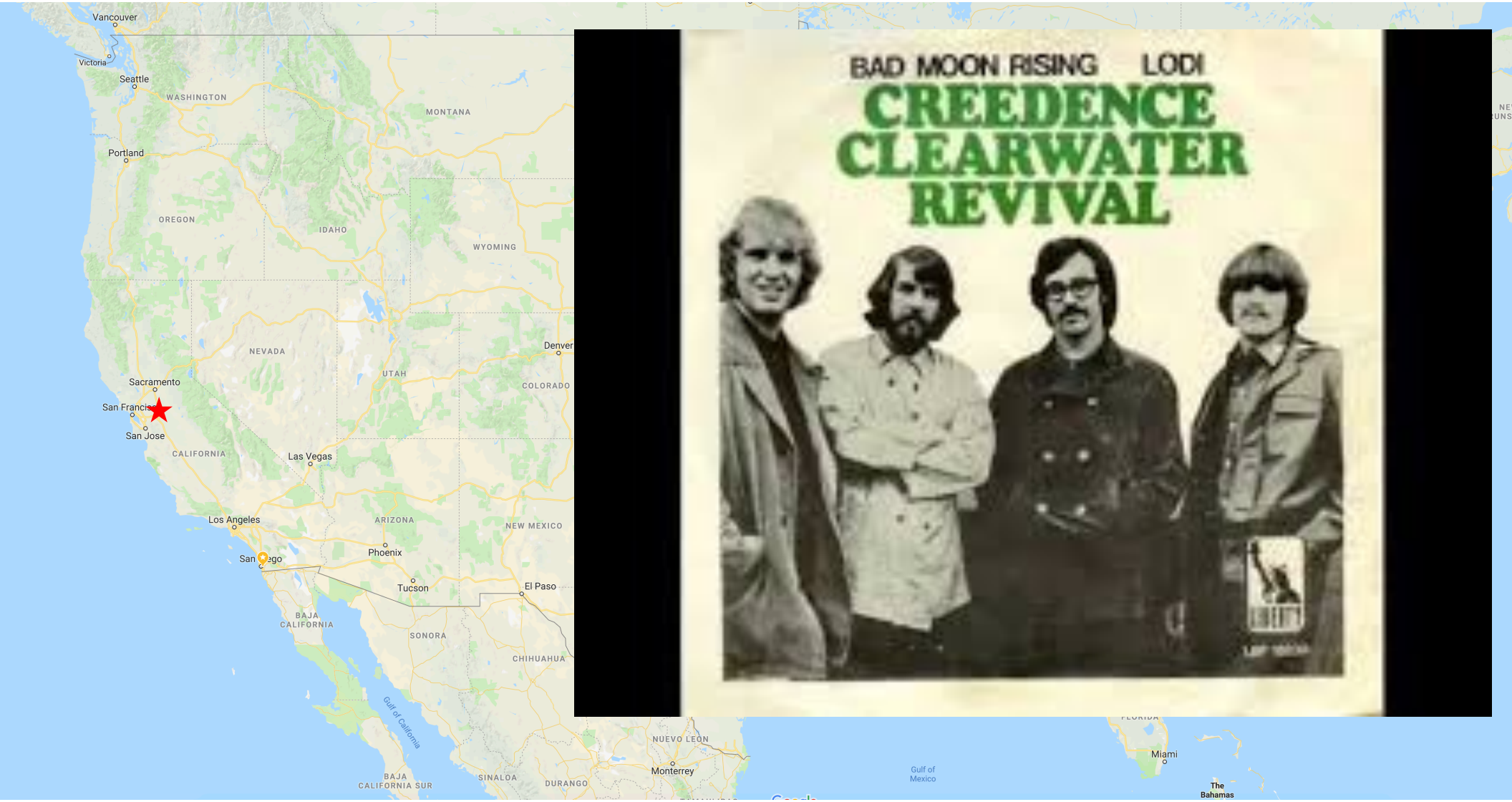
Some brief notes about Zoom and this quarter

- All lectures will be recorded. You can choose to attend or view them after.
- Since lectures are recorded please keep in mind privacy issues. Turn off microphones if not speaking and be cautious of what is on your webcam.
- Webcams are not required for lecture though feel free to leave it on if you want.
- If you have any concerns of accessibility to the material please communicate with me over email and we can set up a teleconference to address.

Outline

- Course Introduction
  - Course summary, objectives, and expectations
  - Assignments
  - Reference materials and resources
- Introduction to Computer Aided Design and Analysis in Mechanical Engineering
- Research Examples
  - Biologically Inspired Robotics (my group's research)
  - Design work by previous students
- Simulation and Modeling
- Highlights of what we will learn in MAE 292
- Schedule

Prof. Gravish's background



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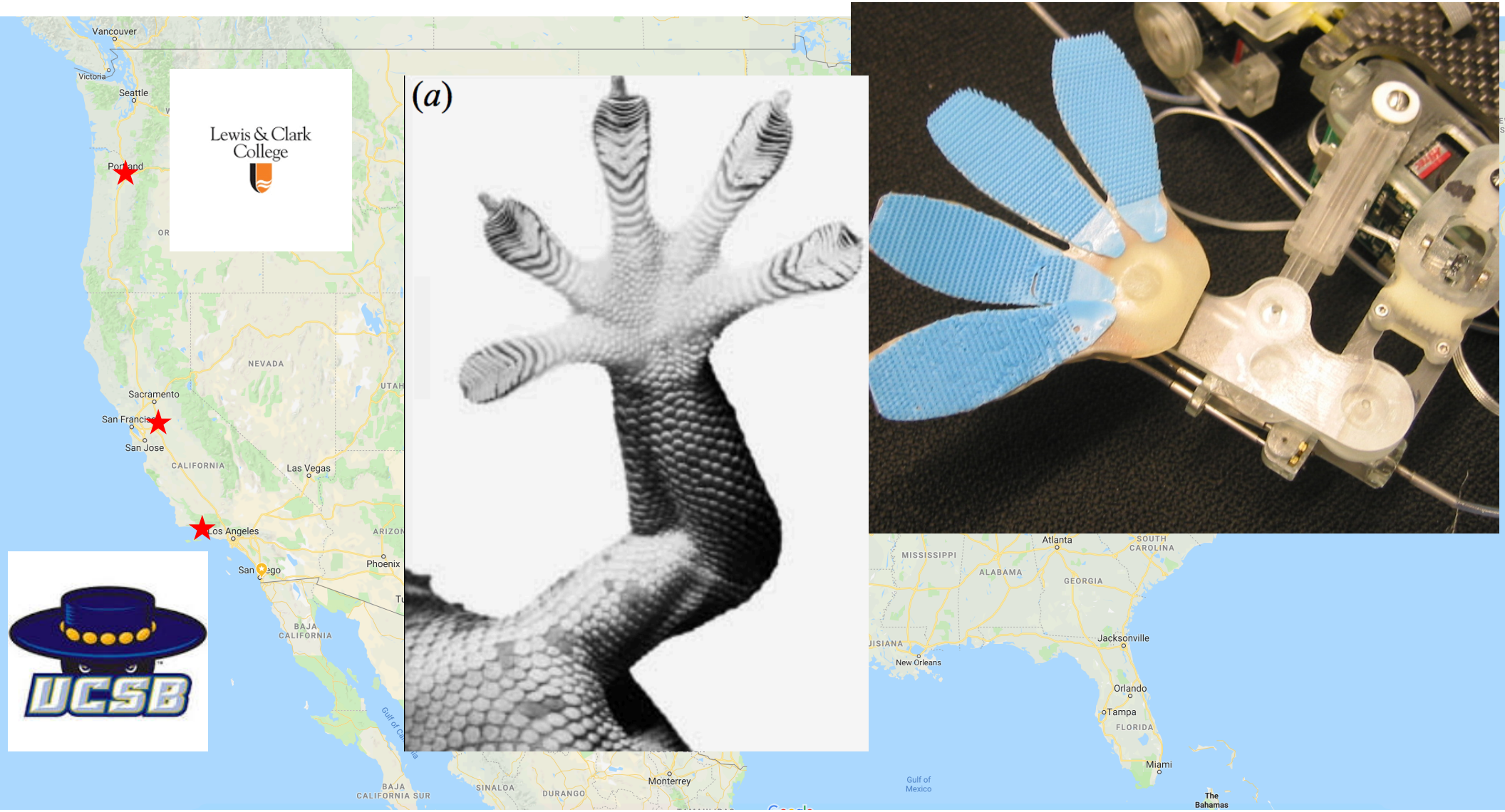

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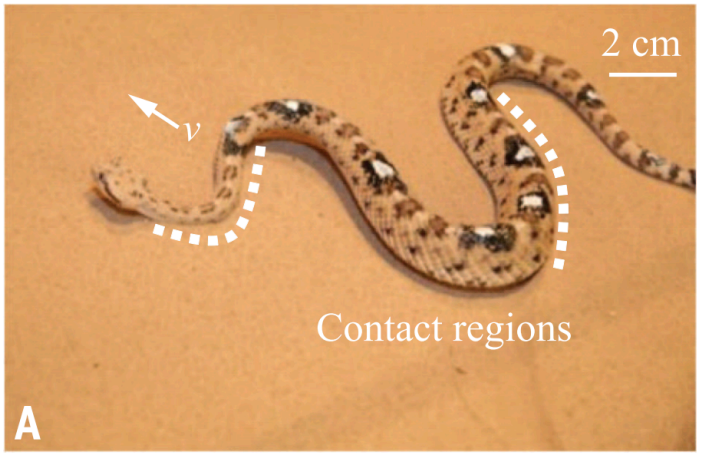

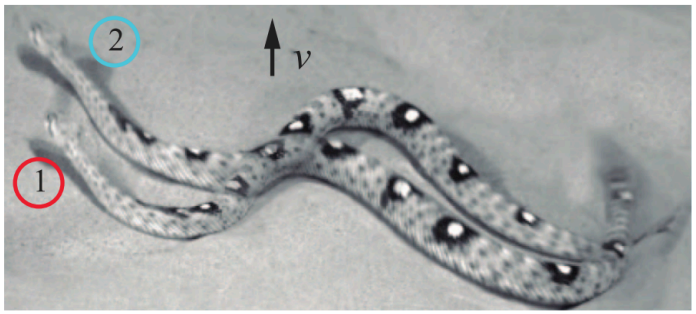

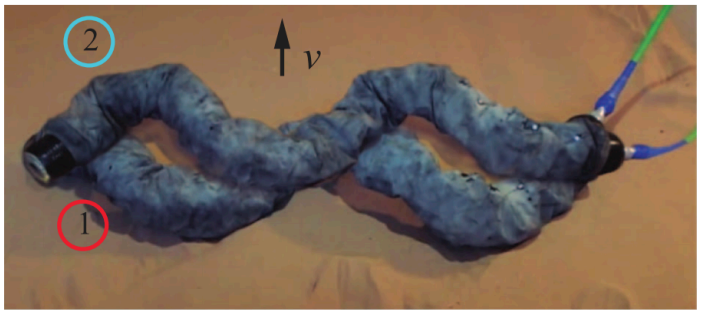

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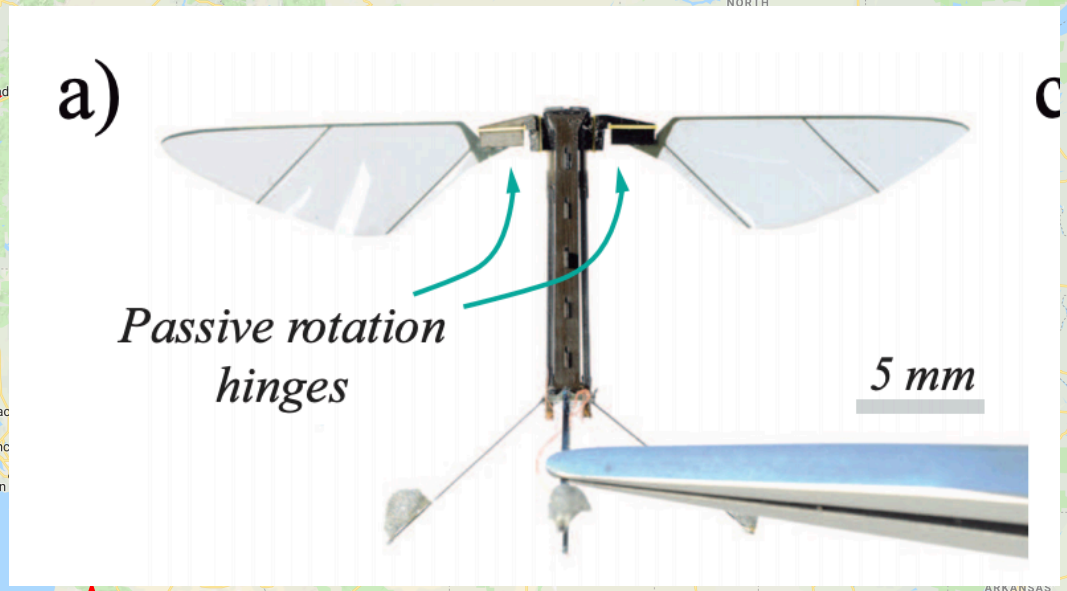


MAE 292 — Summary

This is a lecture based course introducing computational tools to solve problems in mechanical design. The course emphasizes three main tools:

1) Numerical techniques for solving systems of equations and optimization:
    a. How do we optimize a design metric given many variable parameters?
    b. How to quickly solve large constraint equations like we see in linkage systems?

2) Computer-Aided Design software for design and visualization,
    a. How do we represent points, curves, surfaces, shapes?
    b. How do we visualize components and their spatial and kinematic relations?

3) Finite-Element Analysis for analyzing mechanical performance of designs.
    a. How do we represent structural primitives of components subject to loading?
    b. How can we solve for stress-strain in a component. Do we need a fancy tool?

We will introduce these core tools through a series of lectures, workshops, and homeworks. Near the end of the quarter you will use all of the methods we have learned to compete in a design challenge.

Expectations

- Prof. Gravish has years of experience in computer-based design and computational analysis, and welcomes your questions whatever they may be in this discipline.

- With the move to all online classes this quarter we can all expect some rough edges: some rescheduling of course material, assignments, and so forth. We aim to minimize disruptions and to keep things on track but please understand this challenging situation we are dealing with.

- We only have 34 hours together — a good weekend party's worth of time — and so this course can only really introduce you to the topic. Becoming an expert will take a few more years.

Details

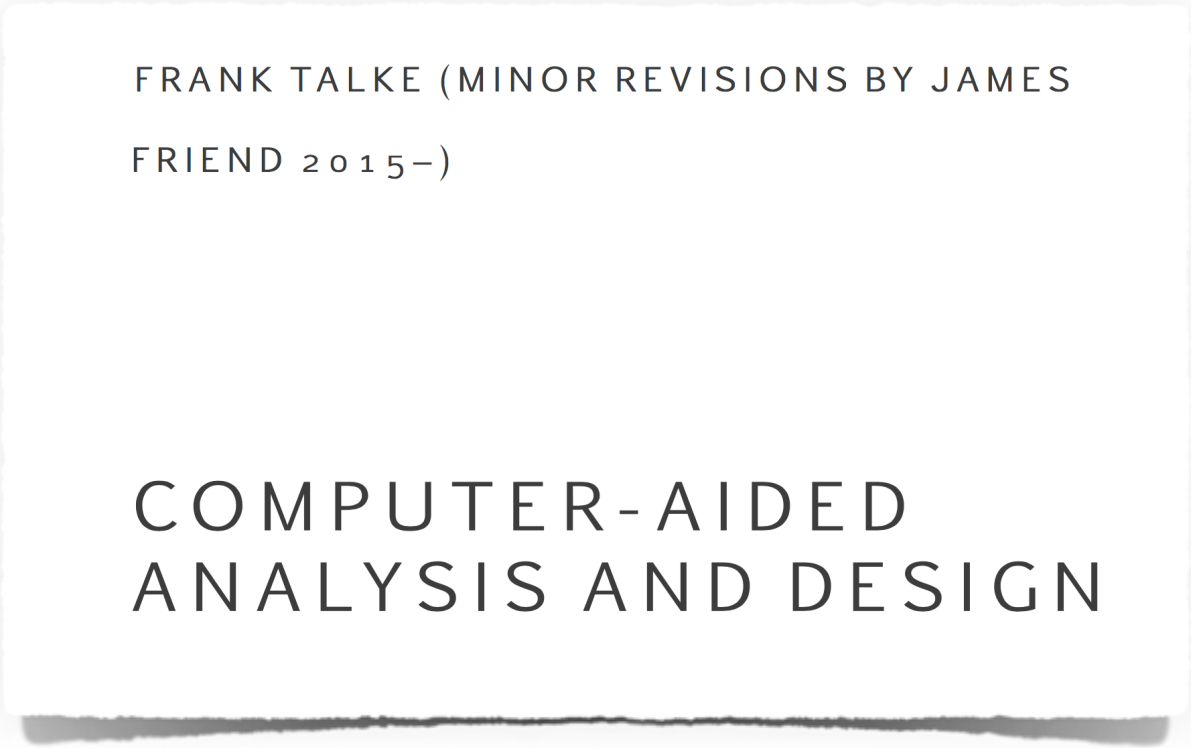
Lecture:
Tu & Th 9:30am - 10:50am
Zoom: https://ucsd.zoom.us/j/502710216
Lectures will be recorded and accessible on Canvas

TA Office Hours:
Mon 1:00pm - 2:00pm
Thurs 1:00pm - 2:00pm
Or by appointment
Zoom: https://ucsd.zoom.us/j/716907285

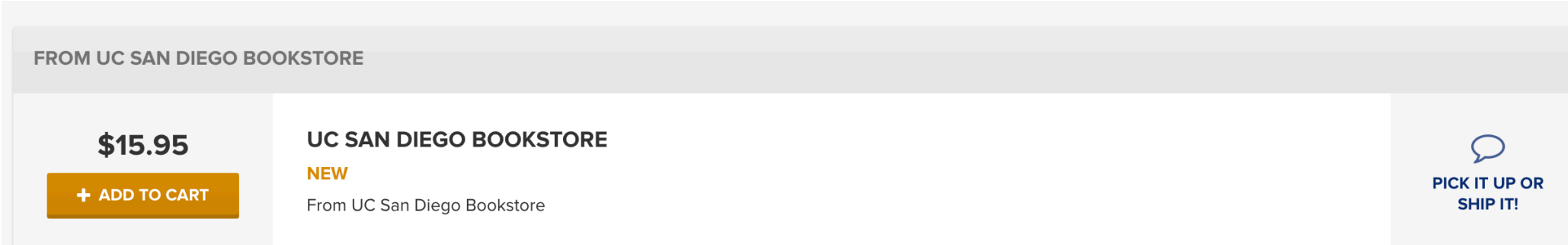
Prof. Office Hours:
Weds 1:00pm - 2:00pm
Or by appointment
Zoom: https://ucsd.zoom.us/j/269412617

Contact information:
Prof: Nick Gravish ngravish@eng.ucsd.edu
TA: Wei Zhou wez237@eng.ucsd.ed

Course reader



Reader is optional and can be purchased at the bookstore for $16
(I will distribute necessary chapters throughout)



Week 1 Software: Matlab

- In week 1 and for HW 1 (and all HW's) we will use Matlab for computing. Please download Matlab from UCSD website.
    - https://blink.ucsd.edu/technology/computers/software-acms/available-software/Matlab.html

- Alternatively, you can try one of several VPN solutions:

    - Virtual Computer - GoVirtual.ucsd.edu
        - "Use popular University-licensed software on your own computer or phone from anywhere with a broadband Internet connection"
        - Go through directions on the site to register
        - Matlab interface my look slightly different but code works the same
        - Be careful about saving data/m-files (see http://acms.ucsd.edu/students/govirtual/faq.html)
    - https://cloudlabs.ucsd.edu/
        - Work in progress

Software Resources

Matlab Resources

- Roger.ucsd.edu (great UCSD resource for books or journals as a student)
  - Search "*Matlab A Practical Introduction to Programming and Problem Solving*" or Authors "*Stormy Attaway*"
    - Select "Go to Electronic Version" and download
    - Electronic Version only works through VPN or at UCSD
  - There are many other Matlab books through Roger as well
- Mathworks.com (go to Matlab Academy options)
  - might need MathWorks account to log in
  - The two hour onramp course can be a good guided introduction where no installation of Matlab is required
- https://stackoverflow.com/
  - Another useful reference for programming questions in Matlab

Grading

Homework	25%
Midterm	25%
Design Project	25%
Final	25%

All homework will be turned in on gradescope. You should have already been added, contact TA if not able to access.

https://www.gradescope.com/

Assignments

- The assignments are tightly tied to the lecture content, and you can expect the exams to be tightly tied to the assignment content, with some additional complexity and variety to make sure you've learned the material well enough to make it your own knowledge and to apply it to new problems.
- Each assignment will be worth the same amount regardless of the number of points.
- We will be using an online grading system (www.gradescope.com) which you will scan/photograph and upload assignments too. This should enable speedy and equitable grading.
- Assignments are due by midnight on the due date (see schedule).
- 50% penalty for homework submitted one day late, no credit if more than one day late.
- A few assignments might have extra credit.
- Feel free to discuss assignments with other students, but you may not exchange or copy assignment solutions or code, nor "work together" (where the same solution is copied and turned in as independent work by more than one student).

Academic integrity

- Integrity is a commitment to honesty, trust, fairness, respect, and responsibility —with the courage to do so even when difficult.
- Integrity of scholarship is essential for an academic community. The University expects that both faculty and students will honor this principle and in so doing protect the validity of University intellectual work. For students, this means that all academic work will be done by the individual to whom it is assigned, without unauthorized aid of any kind.
- From Prof. Gravish: You can expect to be treated fairly, to hear from me my expectations for each individual assignment, for me to monitor student activities for the course and to reduce opportunities for cheating, and to report academic misconduct to the Academic Integrity Office when necessary.
- Consult the UC San Diego policy on academic misconduct here: http://senate.ucsd.edu/Operating-Procedures/Senate-Manual/Appendices/2
- In brief: do your own work or drop the class.

Accommodations for Students with Disabilities

If you have a disability for which you are or may be requesting accommodations, please contact the Office for Students with Disabilities.

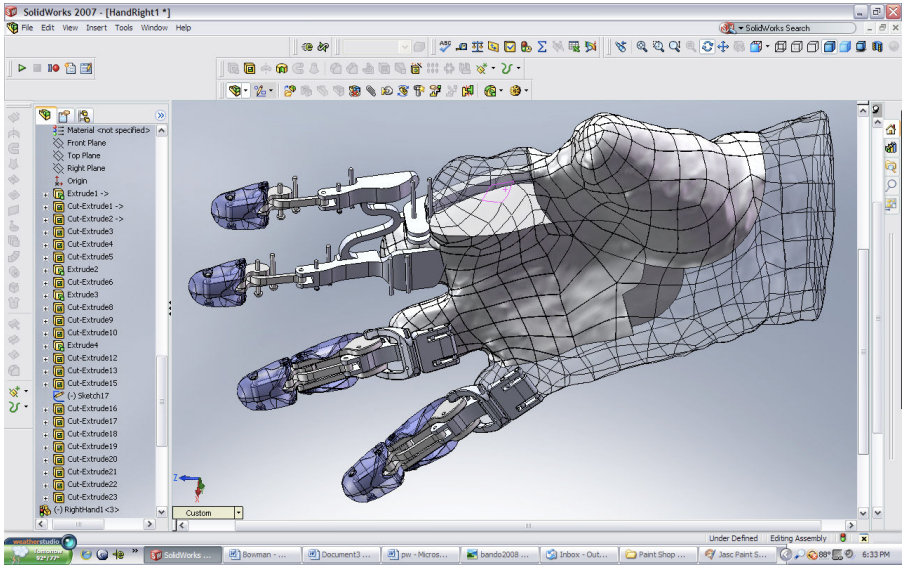
You must have documentation from the the Office before accommodations can be granted.

Schedule

Week	Day	Date		Lecture/Tutorial subject	HW assigned	HW due (in class)
Week 1	Tuesday	3/31/2020	1	Course introduction & syllabus. Introduce points and transforms.		
	Thursday	4/2/2020	2	Continue points and transforms.	HW 1	
Week 2	Tuesday	4/7/2020	3	CAD workflow.		
	Thursday	4/9/2020	4	Functions in CAD; Bezier, Hermite polynomials, Lagrangian polynomials, Splines	HW 2	HW 1
Week 3	Tuesday	4/14/2020	5	Introduction to motion design: Cams and designing motions		
	Thursday	4/16/2020	6	Designing Cam surface profiles: analytical or computational (envelopes)	HW 3	HW 2
Week 4	Tuesday	4/21/2020	7	Closed-chain linkages: mobility, constraint equations		
	Thursday	4/23/2020	8	Solving constraint equations in Matlab applied to four bar linkages		HW 3
Week 5	Tuesday	4/28/2020	9	Motion design in linkage systems / midterm review		
	Thursday	4/30/2020		Midterm		
Week 6	Tuesday	5/5/2020	10	Simmechanics workflow -- Simulating multibody physics for design		
	Thursday	5/7/2020	11	Introduction to optimization in matlab (constrained and unconstrained)	HW 4	
Week 7	Tuesday	5/12/2020	12	Introduction to finite elements		
	Thursday	5/14/2020	13	FEA for trusses and beams	HW 5	HW 4
Week 8	Tuesday	5/19/2020	14	FEA for beams		
	Thursday	5/21/2020	15	Motion design challenge introduction	Design challenge	HW 5
Week 9	Tuesday	5/26/2020	16	Optimization + CAD + FEA: Integrating multiple design tools		
	Thursday	5/28/2020	17	Open chain linkages and robotics		
Week 10	Tuesday	6/2/2020		Design project presentations 1		Design challenge
	Thursday	6/4/2020		Design project presentations 2		
	Tuesday	6/9/2020		Final exam		

A design tradeoff in teaching

- We don't have a lot of time: so we only cover the introduction, and aim to teach you how to **think** about the design process and how to get computers to help you



- Specific examples, not everything (cams but no gears?)

- Example software, not all of it

Course Objectives

By the end of this course, you should be able to understand how to employ computers to help you solve mechanical engineering problems, including how popular engineering analysis computer software tends to be constructed, how to design exemplar structures and devices, and how to perform a variety of important analyses that commonly appear in experimental and theoretical engineering work.

With the knowledge gained from this course, you should be able to continue on and independently learn and then analyze complex engineering problems of your own, making use of computers to save you time and improve your results.

Computer-aided analysis and design

- What is design?
  - Design is a process in which a certain set of requirements has to be satisfied in an “optimized” way
- Requirements can be of many forms:
  - Functionality
  - Low Cost
  - Light Weight
  - Performance
  - Appearance
- All designs are subject to certain problem solving constraints

What is design?

- Ok, lets all take a quick break
- Stand up, stretch your legs, and do the following:

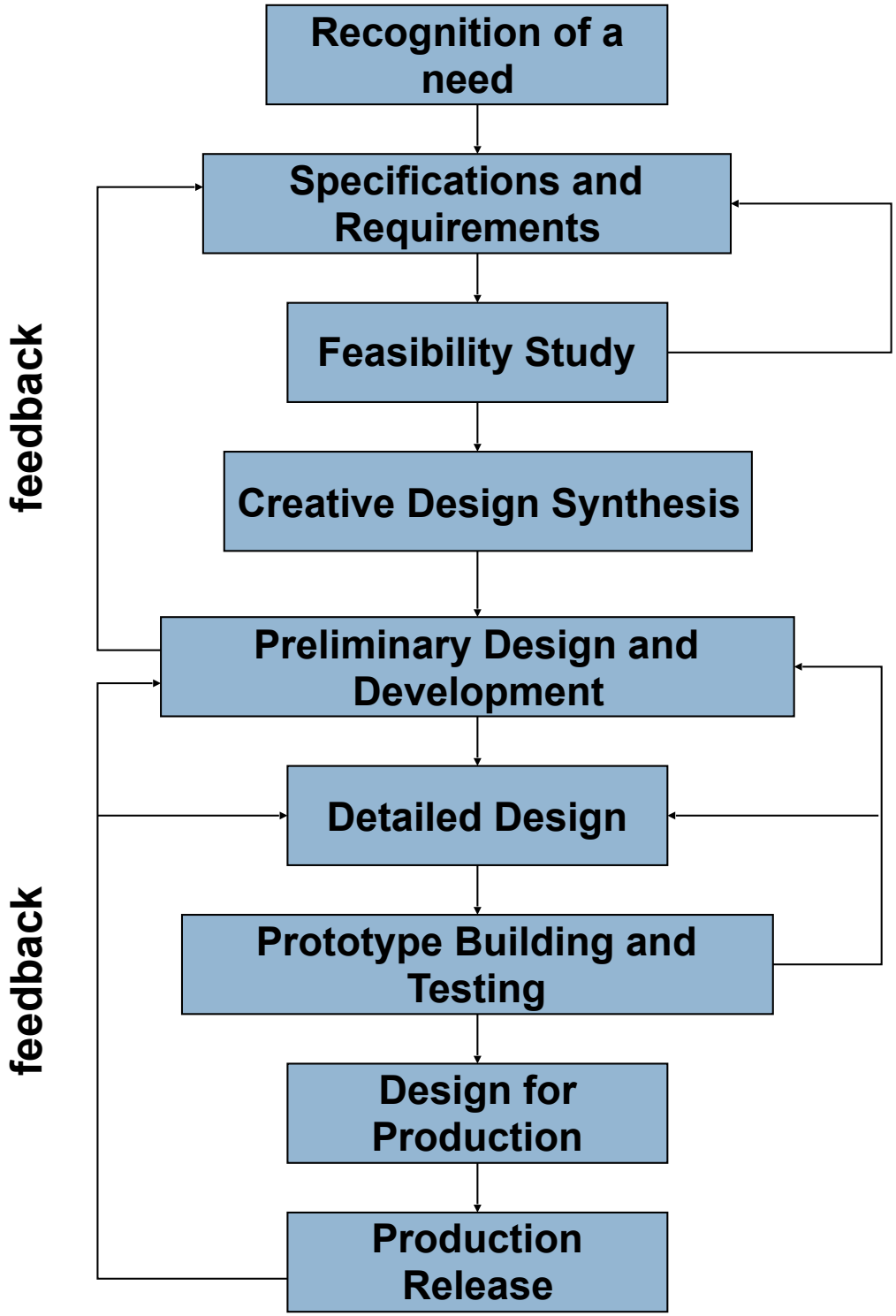
  Look around your desk/room, and find an object that you think has "good design". Write down the name of the object and three reasons why you think it has good design. Enter your object and three reasons into the following google drive document.

https://docs.google.com/document/d/1UrKV2TOmHRb9l38HbQBrJ2Q1UoH7jF6poKgdiSHqHOo/edit?usp=sharing

Design process

- Takes idea
- Refines idea
- Iterates on solution
- Implements prototype solution
- Implements final solution

Design Process



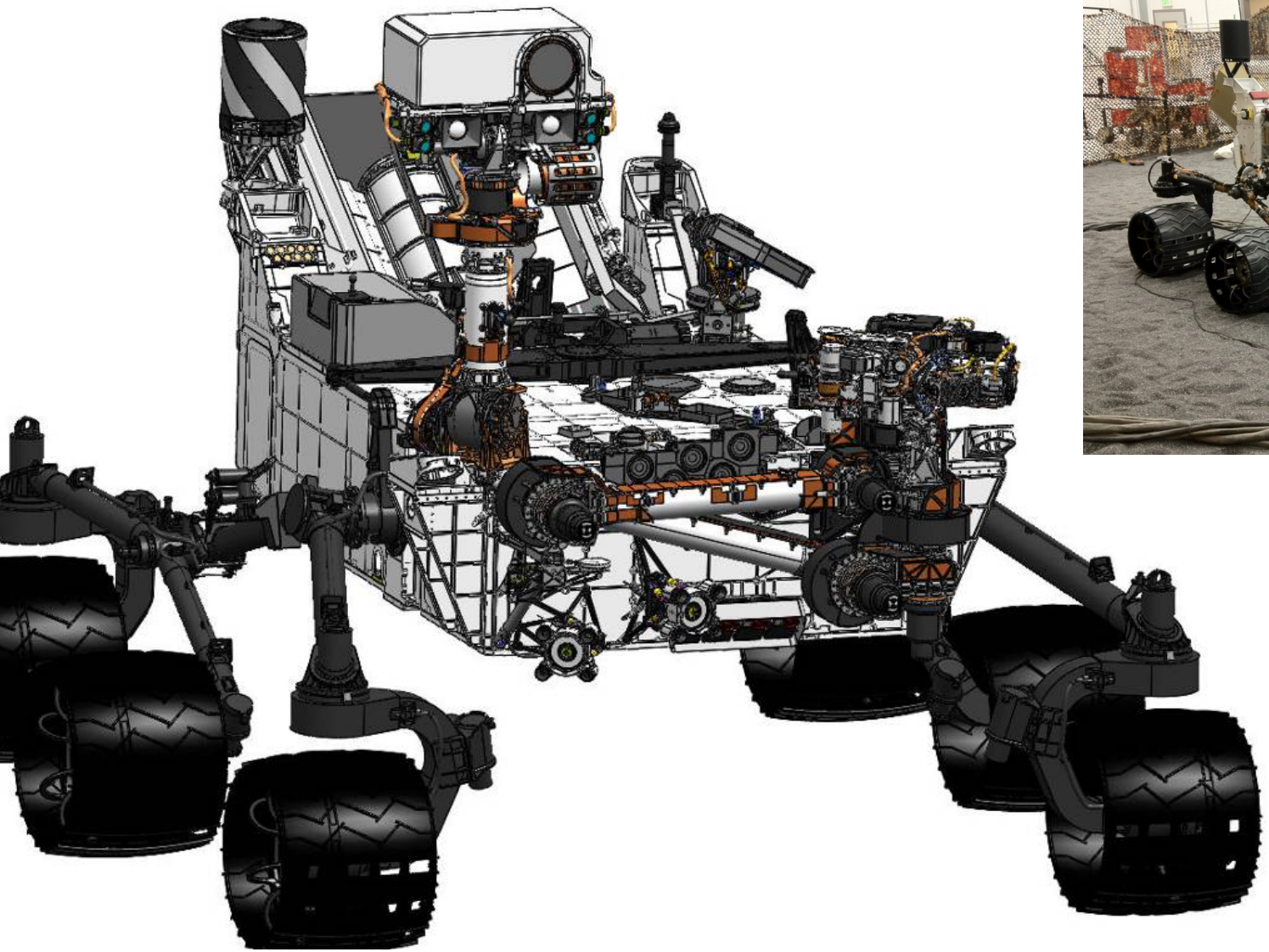
Mechanical engineering design

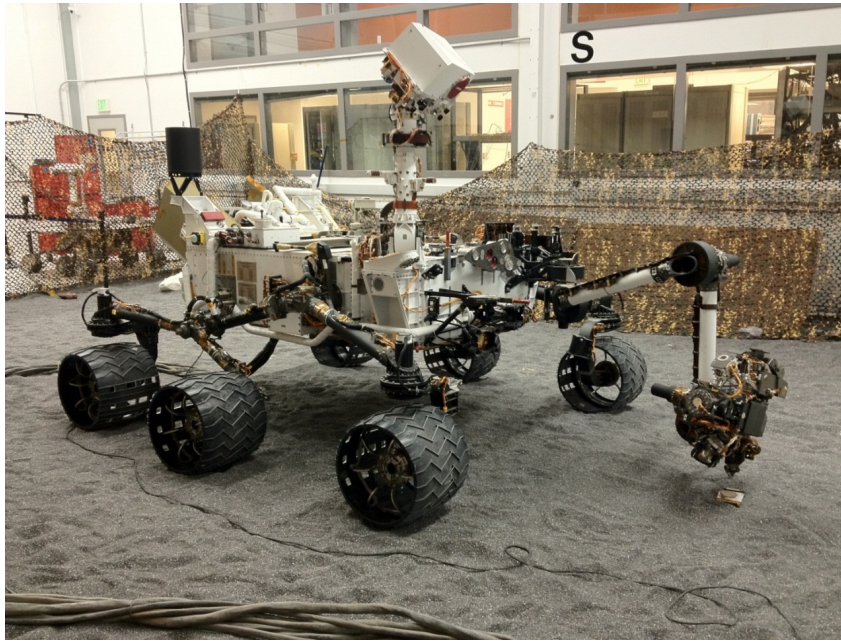
- Design of things and systems of mechanical nature
  - Mechanical Design
  - Electro-Mechanical Design
  - Fluids Sciences
  - Thermal Sciences
  - Control systems

What is computer aided design?

- Computer aided design uses a computer as a tool in the design process, e.g. for:
  - Making Drawings (e.g. SolidWorks/Fusion 360/Onshape)
  - Numerical analysis (e.g. FEA)
  - Refining a Solution
  - Iterating on a Design Point
  - Optimizing a Solution (minimizing cost function)
  - Implementing a Solution in Hardware (e.g. CAM)

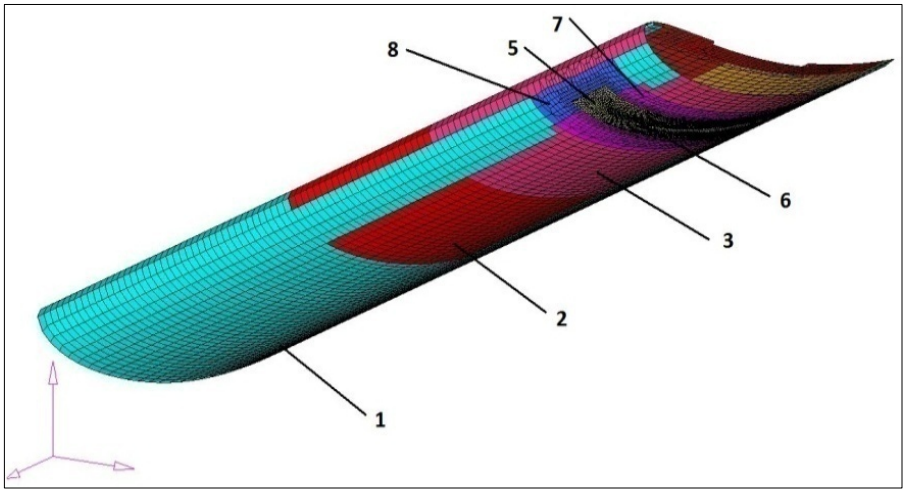
CAD is of great importance in the design of systems like the Mars Rover

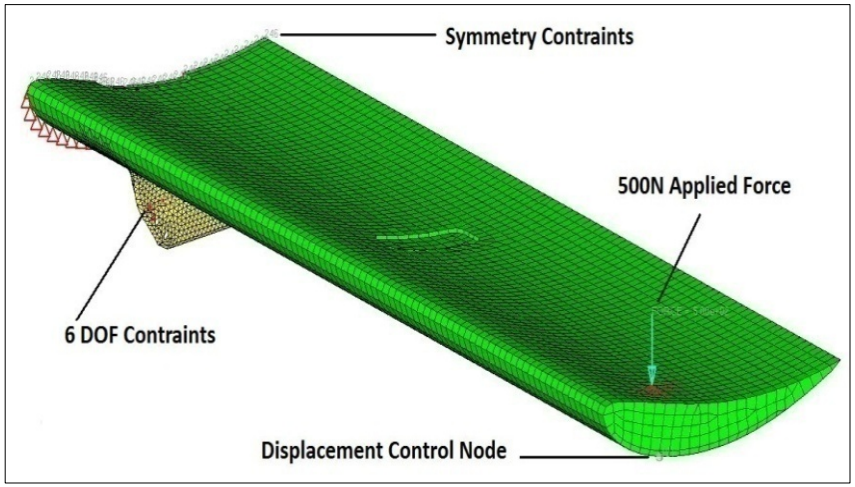


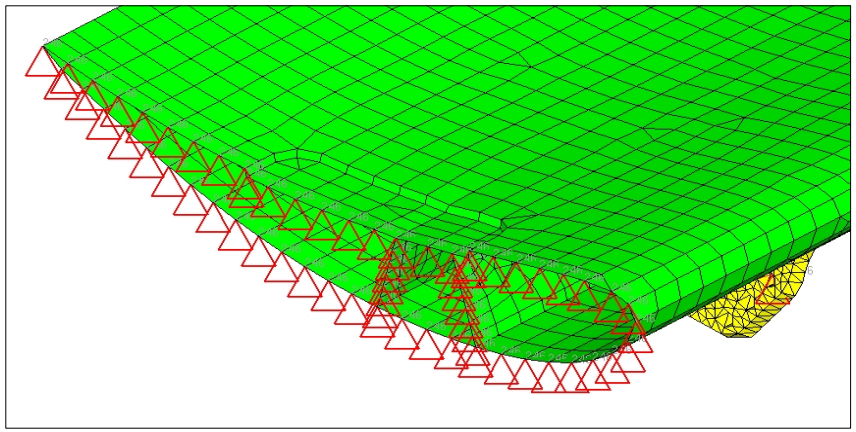


Car design requires combination of many disciplines of engineering and CAD

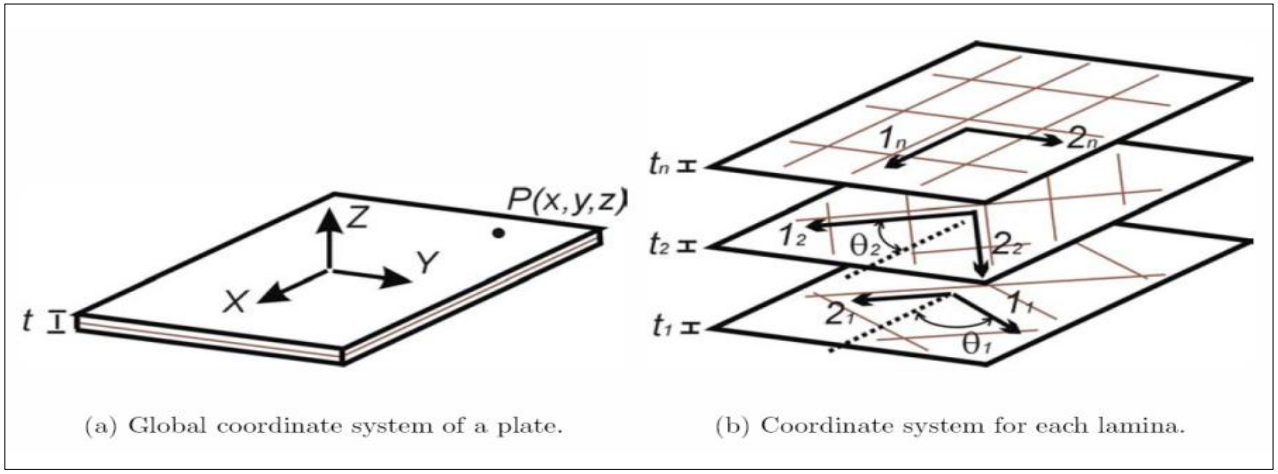
Race car wing made from laminated carbon fibers



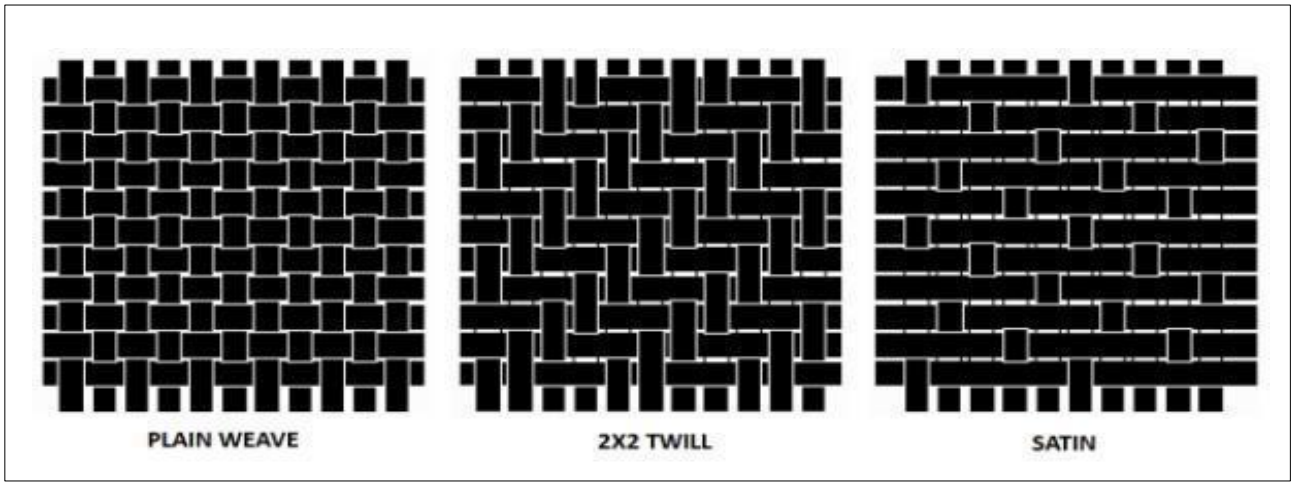




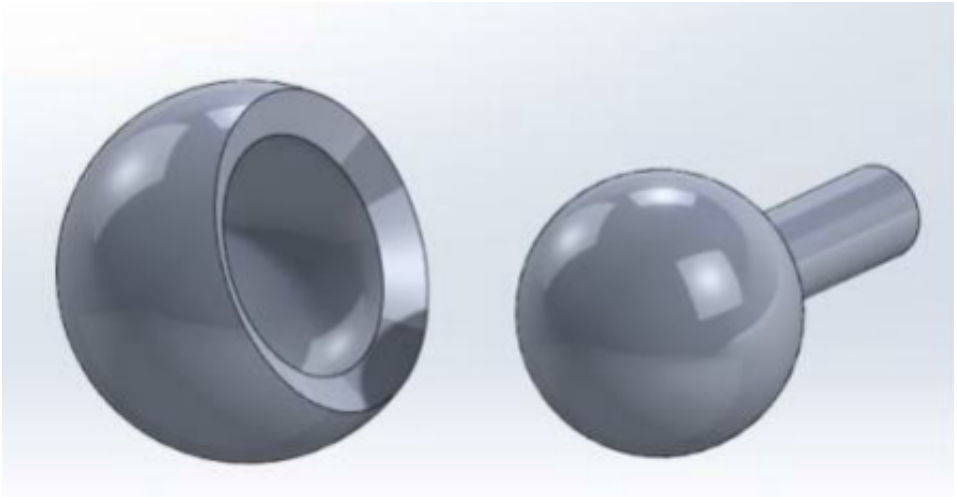
Need to know about mechanics of layered materials

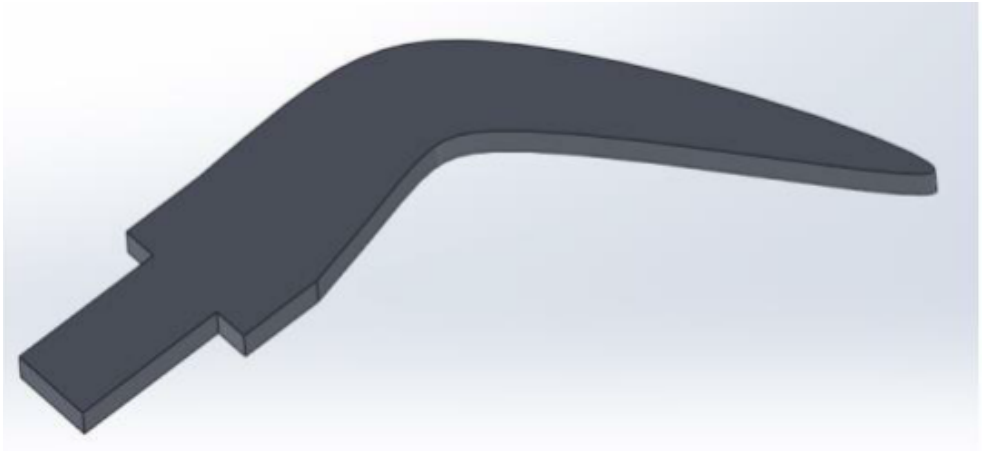


(a) Global coordinate system of a plate. (b) Coordinate system for each lamina.

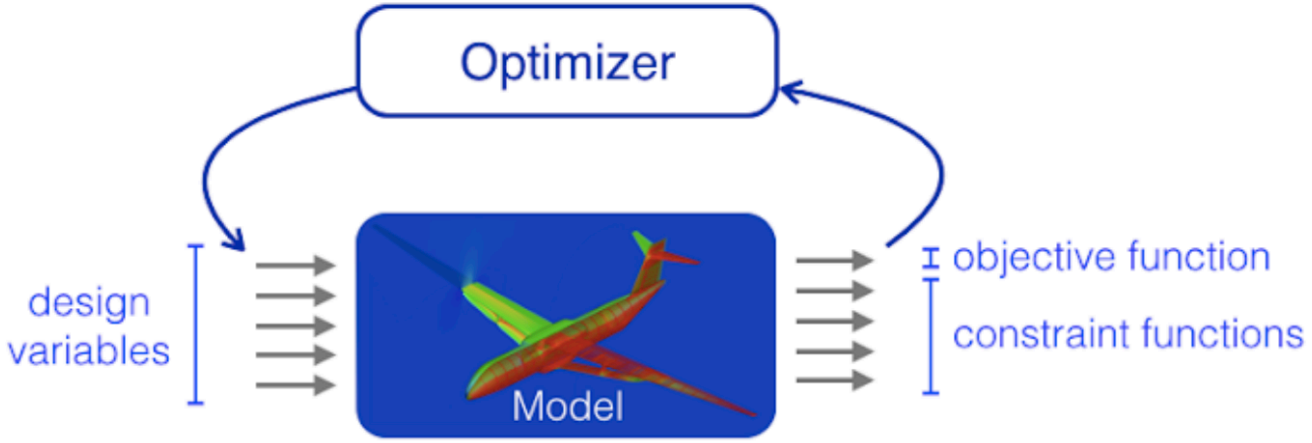


Other example of interest for Bio-engineers: Hip implants





CAD and analysis enable optimization



Optimization problem:	minimize	objective function
	with respect to	design variables
	subject to	constraint functions (<=0 or =0)

Image stolen with full credit due to Prof. Hwang (https://lsdo.eng.ucsd.edu)

Engineering design is multi-disciplinary

- Machine design requires physics — friction, stress, elasticity, all factor into effective vs ineffective systems.
- Complex machines require theory and computational models. How do you optimize systems with hundreds of variables???? (hint: not by hand)
- Multi-domain knowledge!
- The tight integration between mechanical components and electronics require multi-faceted skills.

Multiple domains of physics need to be considered

link

Multiple domains of physics need to be considered

Designing a vacuum requires knowledge of:

1. **Mechanisms.**
2. **Motors.**
3. **Fluid mechanics.**

link

Design Considerations

1. Strength
2. Reliability
3. Thermal considerations
4. Corrosion
5. Wear
6. Friction
7. Processing
8. Utility
9. Cost
10. Safety
11. Noise
12. Noise
13. Styling
14. Shape
15. Size
16. Flexibility
17. Control
18. Stiffness
19. Surface finish
20. Lubrication
21. Maintenance
22. Volume

How do we incorporate Cost $$$

- Often cost is one of the most important factors in design decisions
- Is this because engineers are cheap or greedy?

How do we incorporate Cost $$$

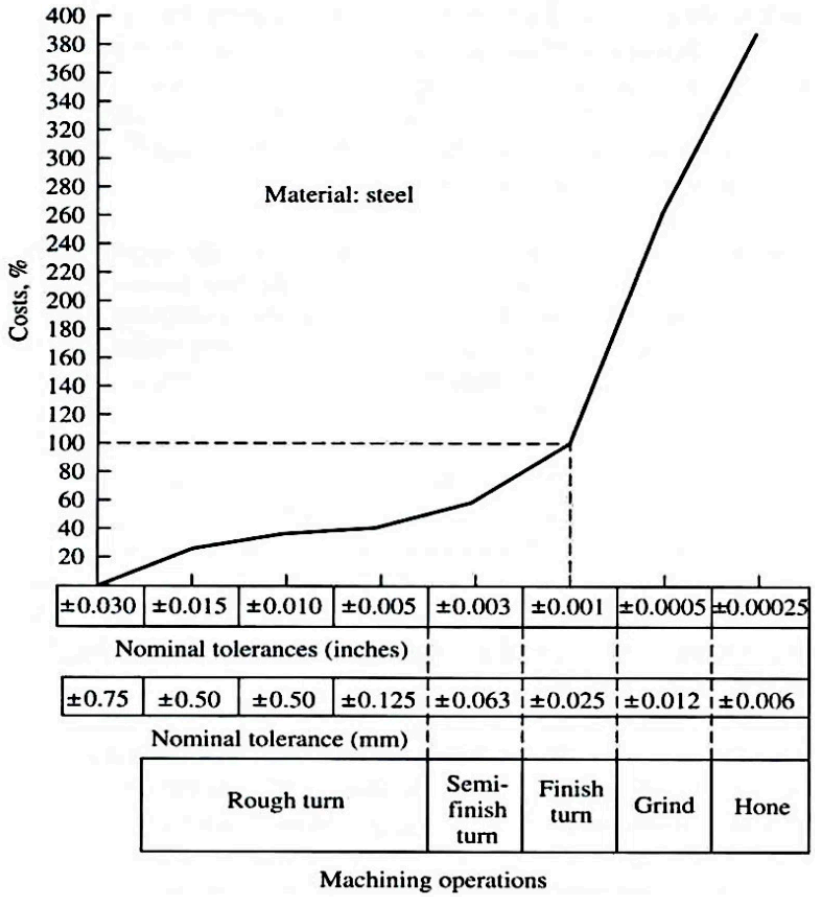
- Not necessarily…
- The cost of something takes into account many other factors (e.g. how difficult is it to make)
- Often an engineering solution is possible, but not practical (e.g. flying cars), and cost is often a limiting factor

http://wheels.blogs.nytimes.com/

A Note On $$$ Cost $$$

- Engineering design is often about how to make something inexpensively enough to be practical

- Example: a $199 robot vacuum cleaner



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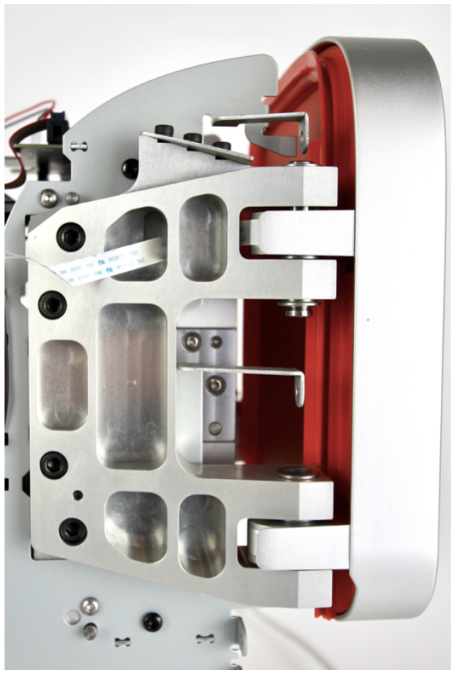
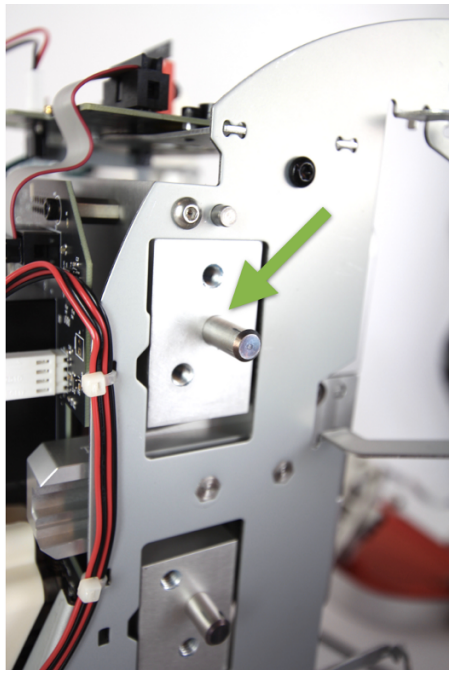
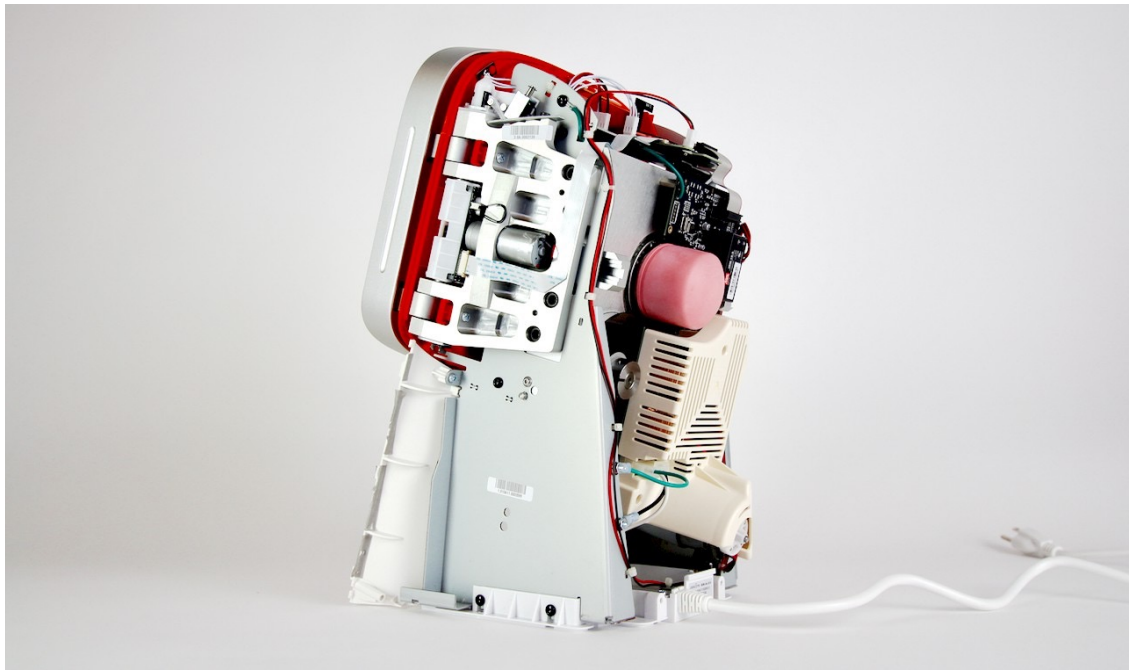






https://blog.bolt.io/heres-why-juicero-s-press-is-so-expensive-6add74594e50

Design in engineering takes practice

- You have to design a vehicle that can carry you from your car or home to this class, safely but quickly. What features does it require, and how feasible is it?

- You need to design a car you can drive to the beach and park *in the ocean*, because San Diego parking is terrible near the beach in the summer. Is this feasible? What issues arise in the preliminary design? What details in the design are likely to arise?

- Design a chair for elderly people to sit comfortably and aid in standing up. What are the features required? What are the safety concerns? Should it be passive (springs and mechanisms) or actuated (motors).

Computer-aided design

- Computer-aided design is not limited to
  - Drafting
  - Numerical analysis
  - Programing
  - Optimizing studies
  - Graphics

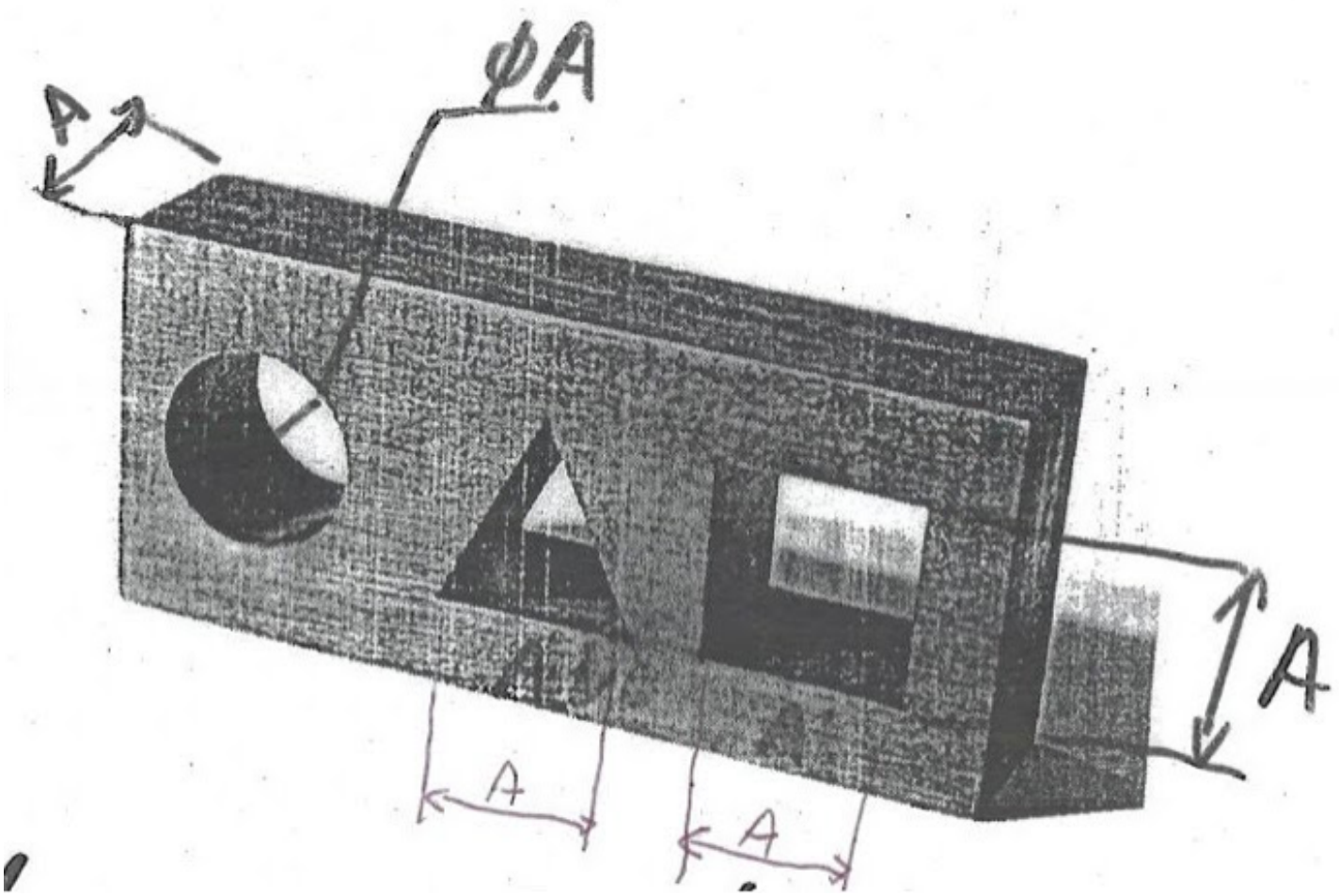
- Computer-aided mechanical design is synthesis of above areas
- Computer-aided design must include human experience

Computer-aided design

- CAD software is a tool!
- But computer-aided design is a workflow, a set of representations and manipulations of geometry. These are typically the same across almost all CAD packages.
- Requires intuition for spatial visualization and understanding of how components work together.

Mid-lecture brain teaser

Mid-lecture brain teaser



Can you visualize and sketch a single object that could pass all the way through each of the holes and entirely block the passage of light?

Design requires experience

- Note: design is non-unique which makes evaluation and value judgement difficult
- Caution: computer does not have experience!
- Do not blindly trust your computer results
- Good design requires good engineering judgement!

Always Remember: GIGO

Garbage In, Garbage Out

- A computer is only a tool.
- The computer does not replace experience.
- It is a means to a goal. It is not the goal.

Highlights of what we will learn in MAE 292

CAD operations

Scaling

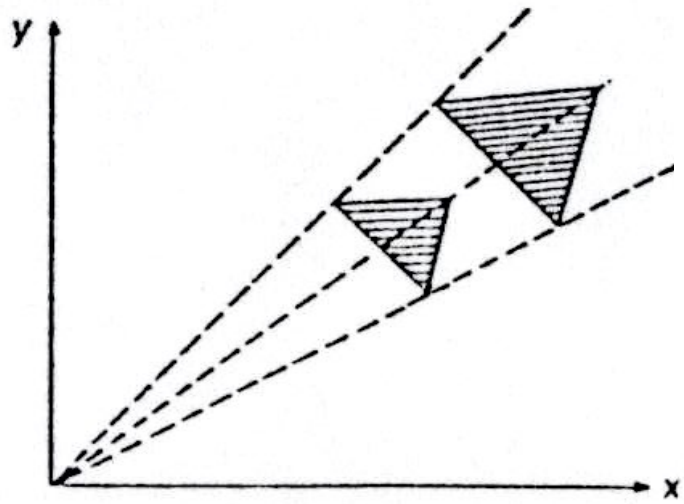
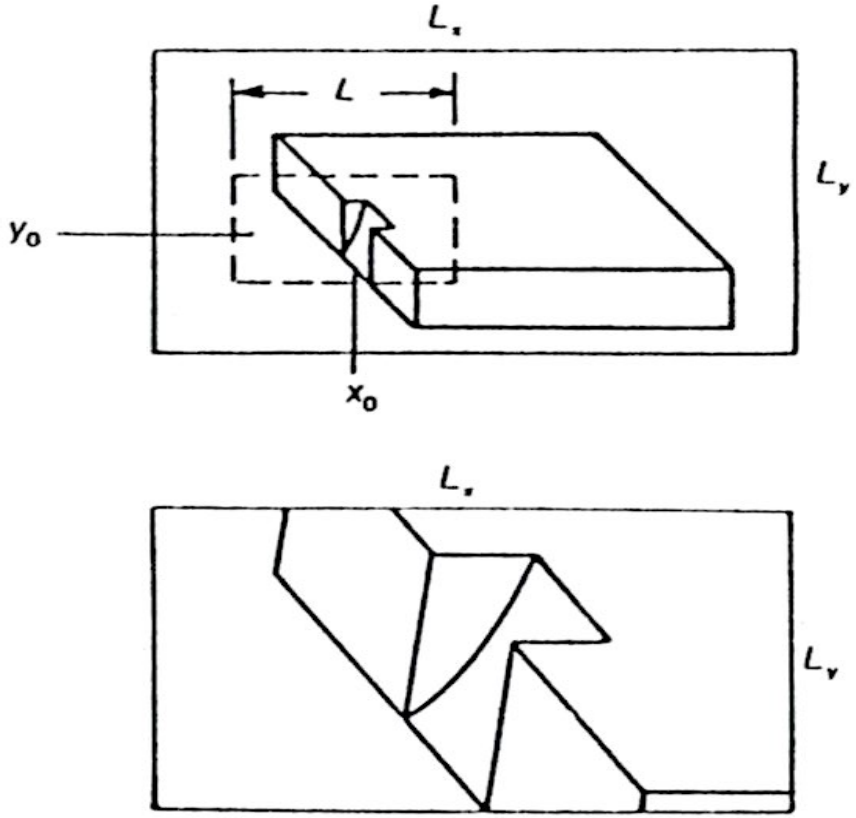
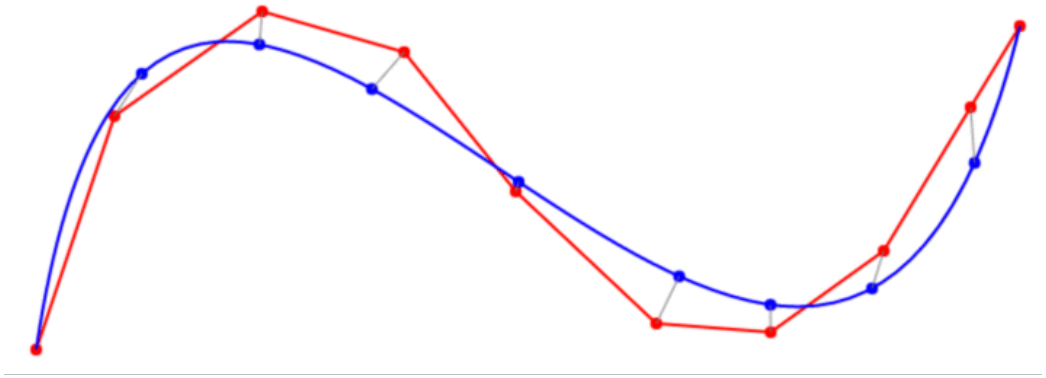


Figure 3.5 Plane scaling

Zooming

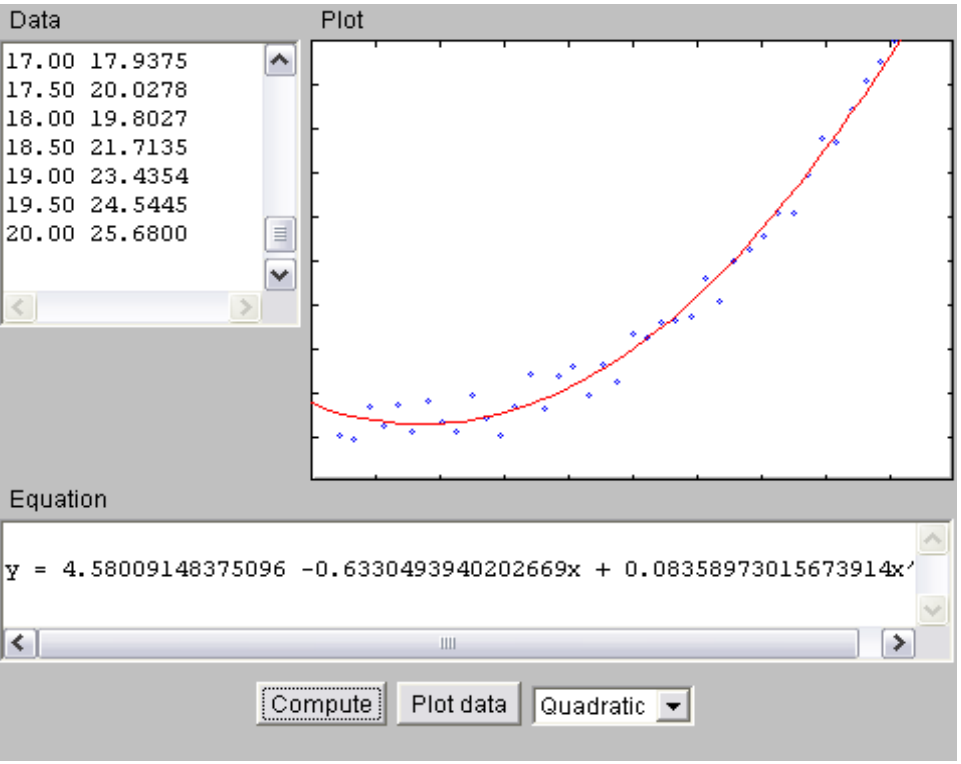


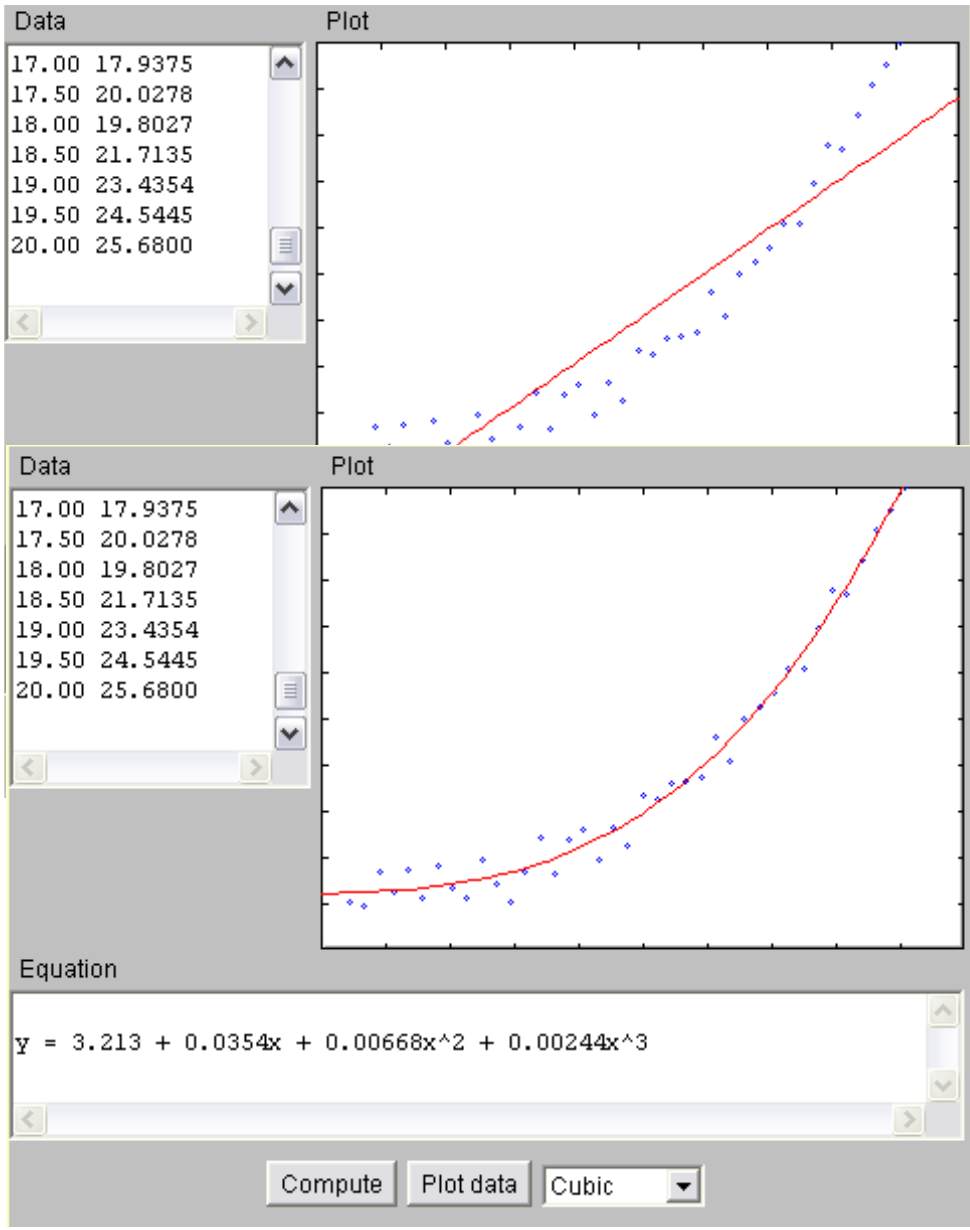
Representations of curves



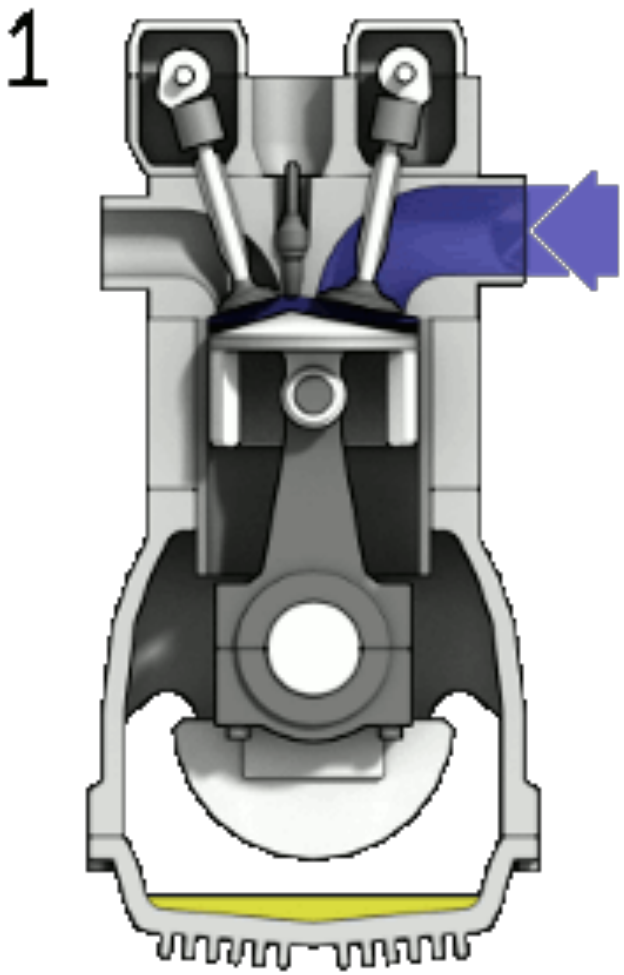
Generation of curves from data

- Regression problems

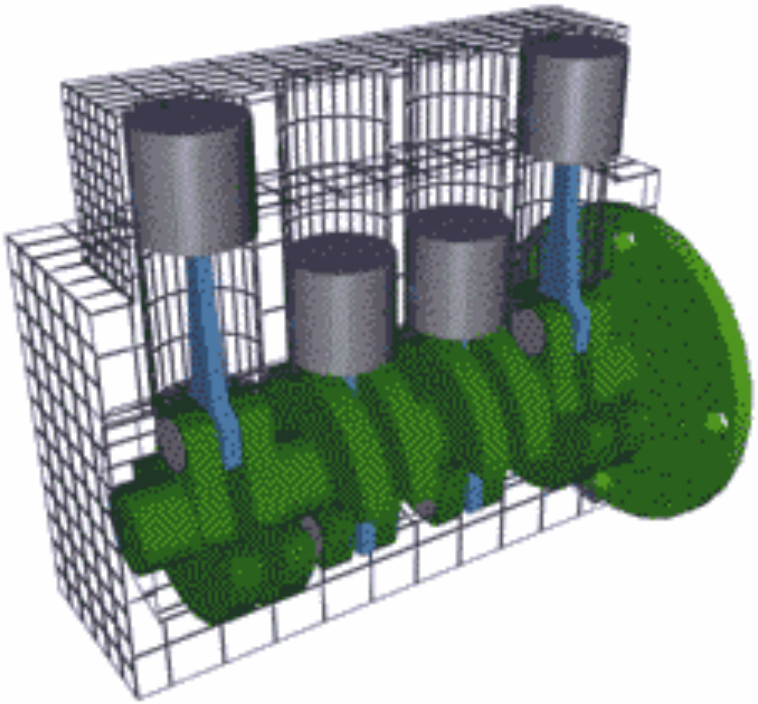




Cams: Use of curves to describe and prescribe motion

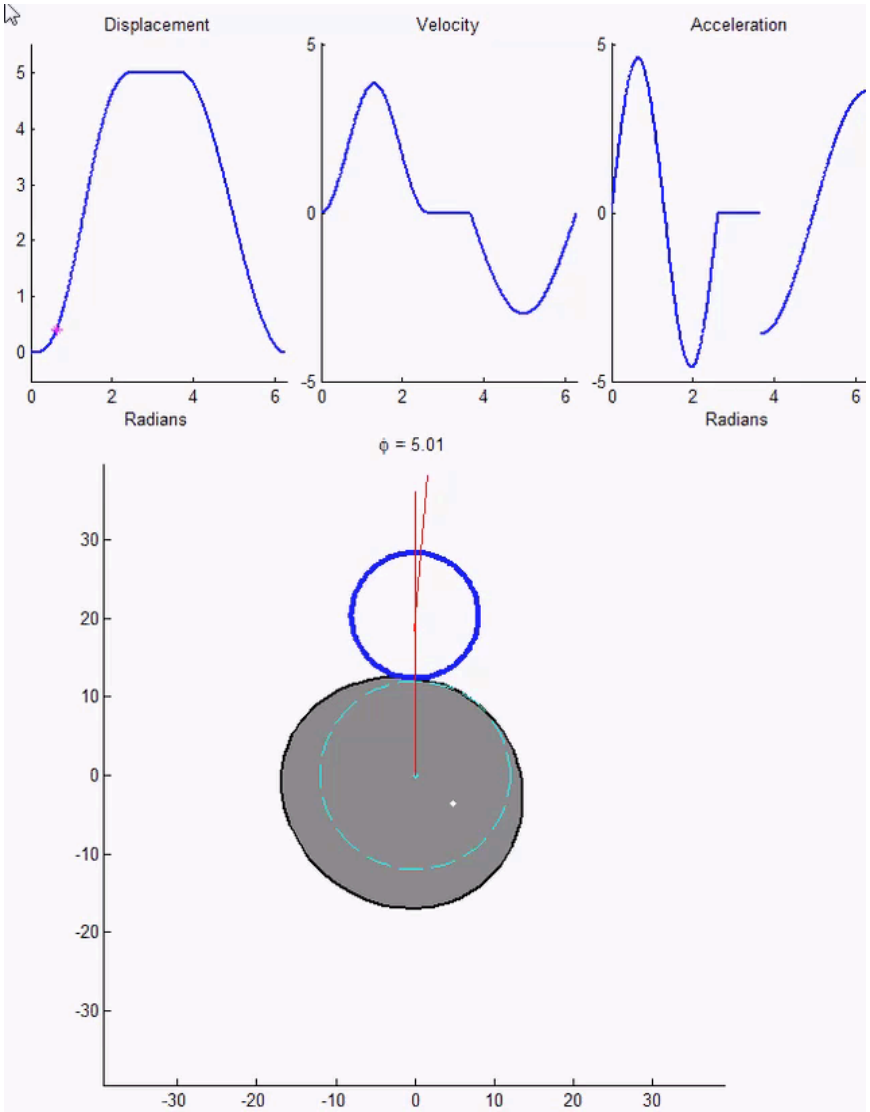


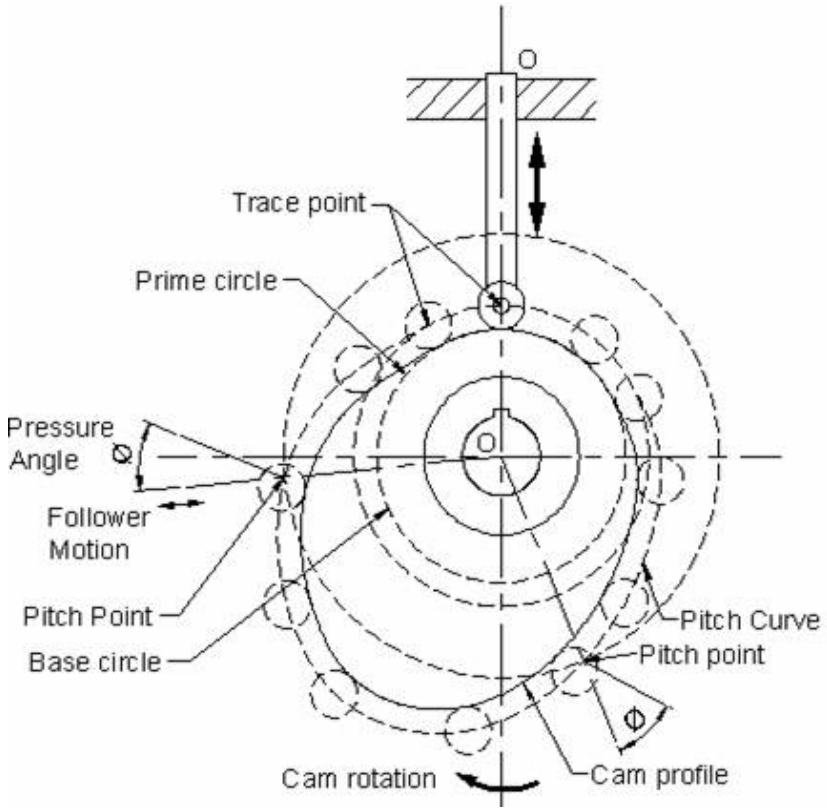
Four-Stroke Engine
(Nikolaus August Otto 1867)



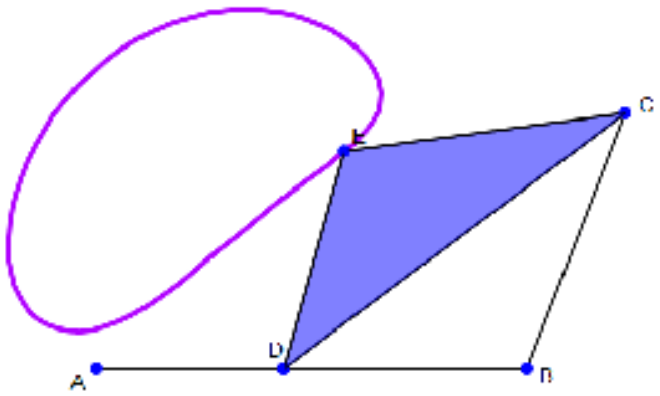
In-Line, 4-Cylinder Engine

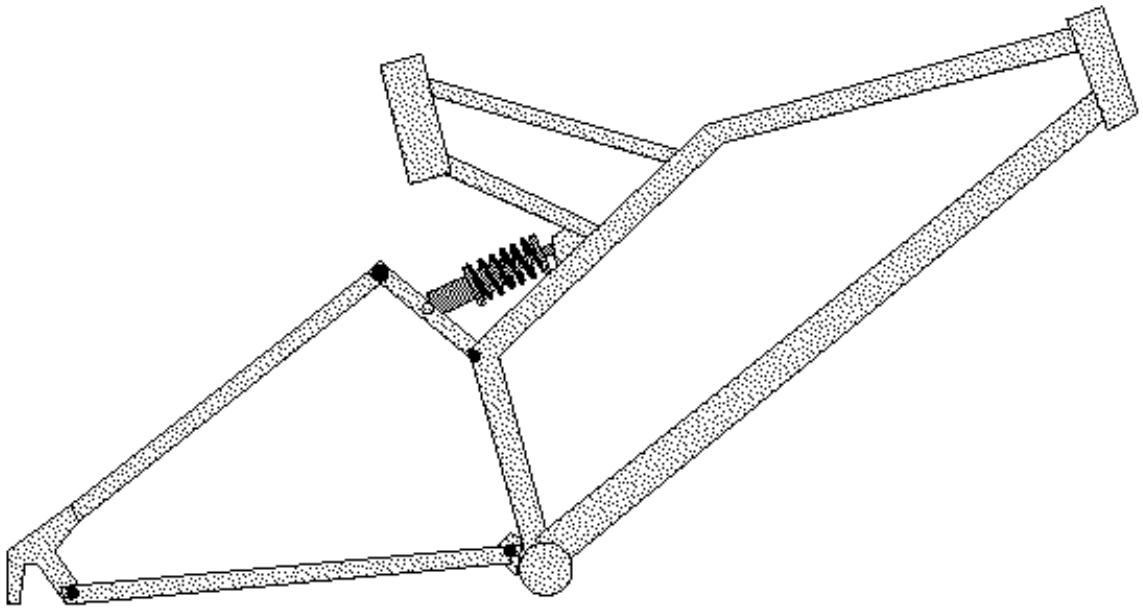
Cams: Use of curves to describe and prescribe motion





Motion design in linkage systems





Mountain bike suspension!

Motion design in linkage systems

Numerical optimization

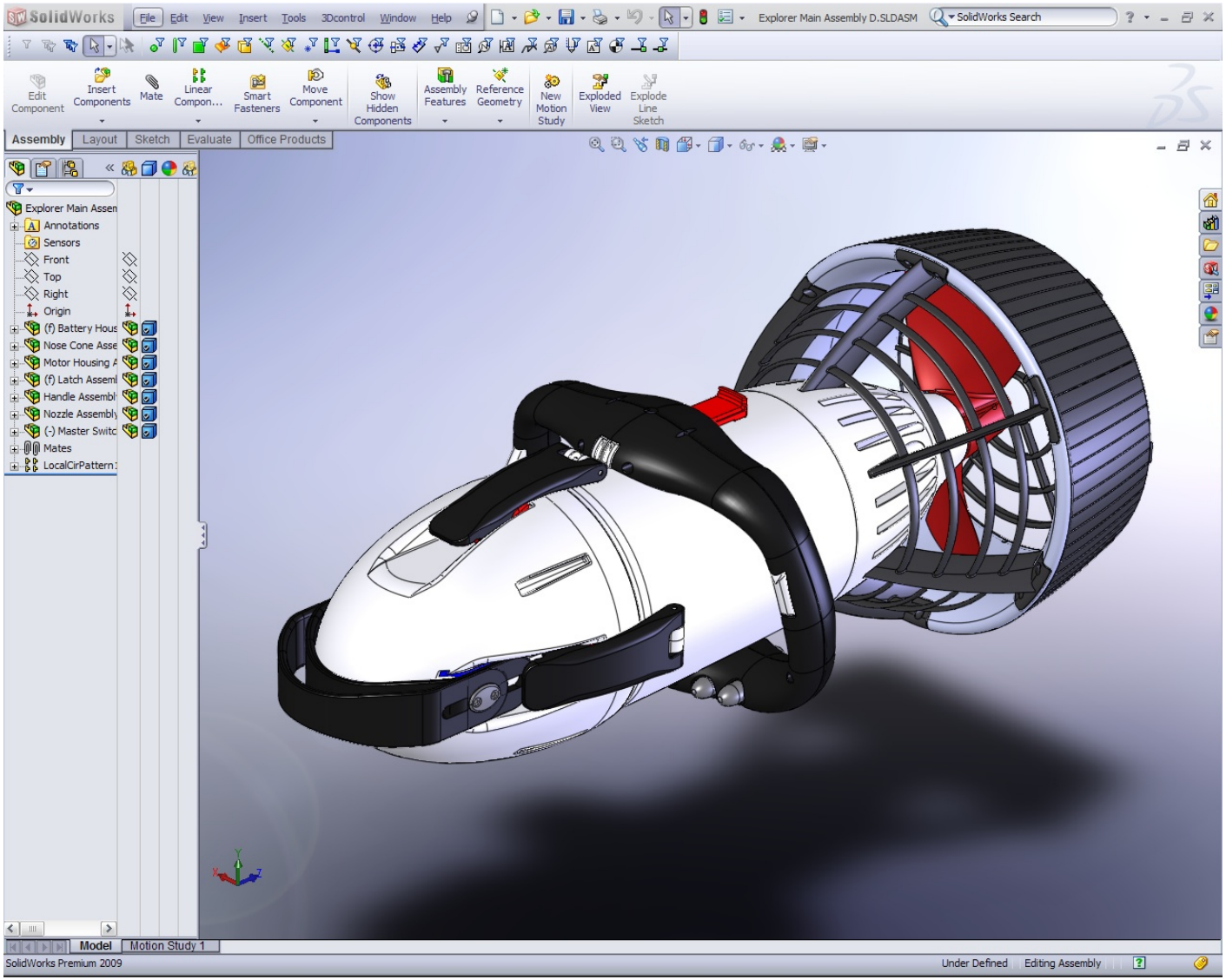
COMPUTATIONAL DESIGN OF MECHANICAL CHARACTERS

S. COROS[1] B.THOMASZEWSKI[1]
G. NORIS[1] S. SUEDA[2] M. FORBERG[2]
R. SUMNER[1] W. MATUSIK[3] B. BICKEL[1]

[1]DISNEY RESEARCH ZURICH [2]DISNEY RESEARCH BOSTON [3]MIT CSAIL

Numerical optimization

We will learn CAD

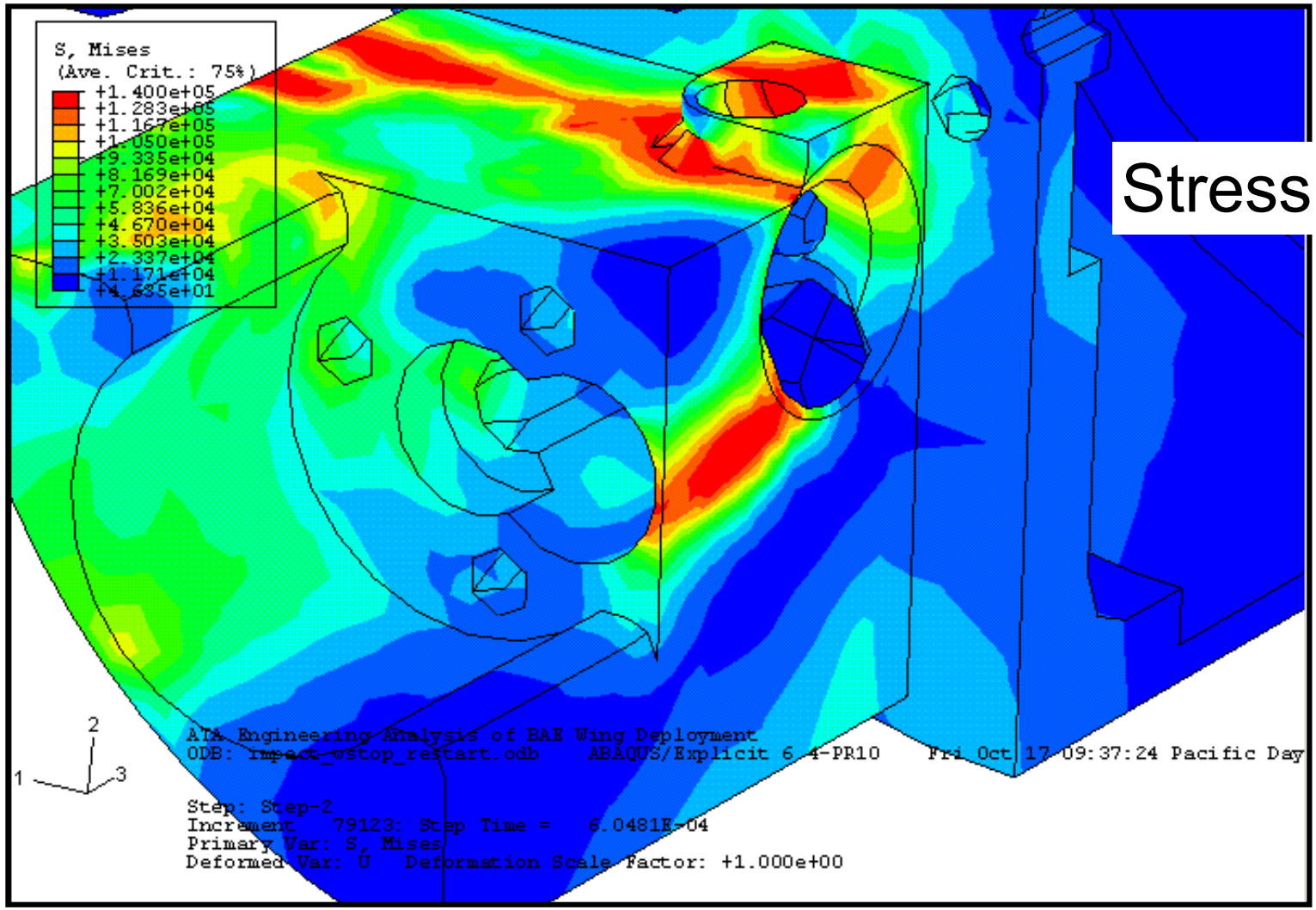


CAD Packages

All CAD packages have similar features:

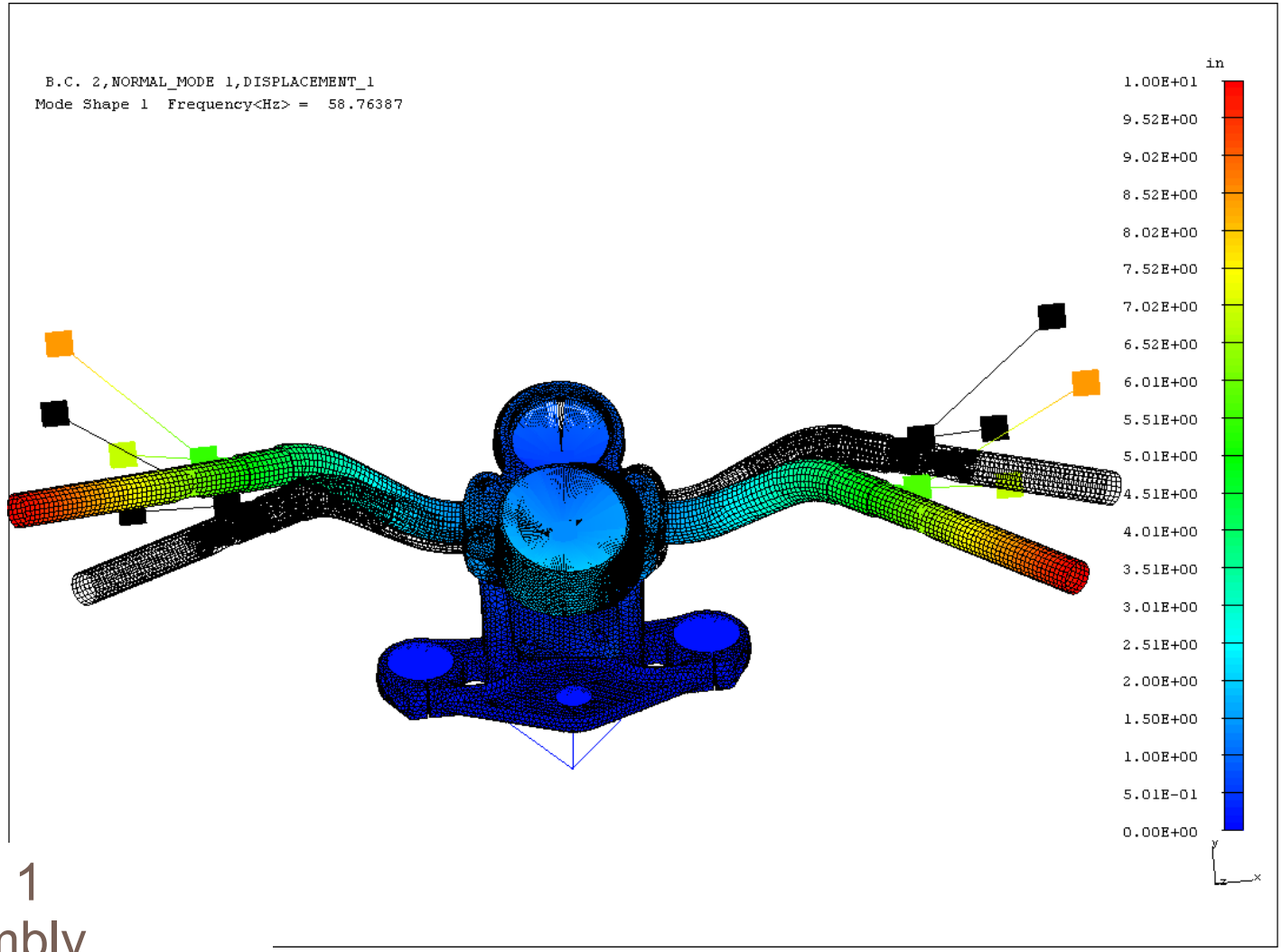
- Design of parts
- Assembly of parts
- Generation of 2-D drawings
- Finite element analysis of parts

Finite Element Analysis



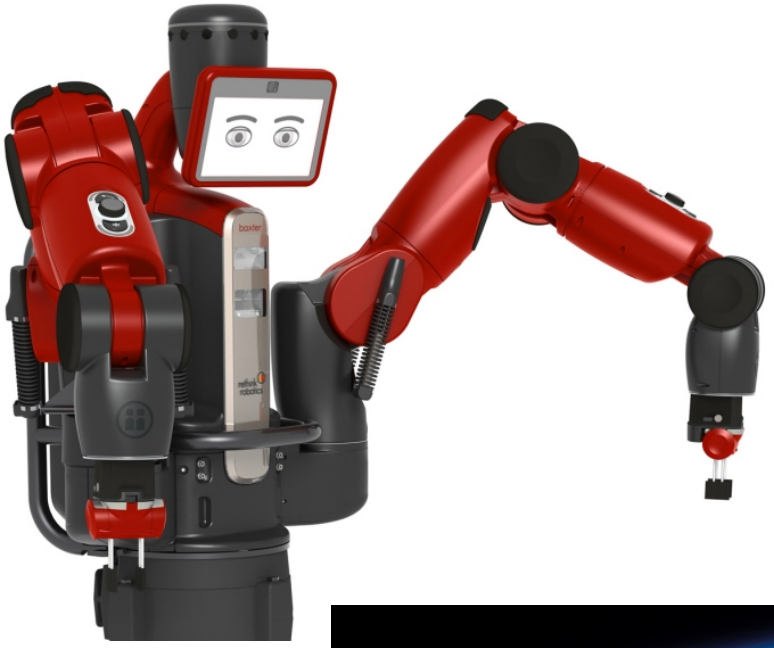
Stress Analysis

Dynamic Finite Element Analysis



Mode Analysis: Mode 1 handlebar riser assembly twisting (58.7 Hz)

We will learn about open linkages (often used in robotic systems)



Design project

- This will culminate in a two-week long design challenge at the end of the quarter. The design challenge will integrate:
  - Numerical optimization
  - CAD
  - FEA
- You will present your results in an online presentation at the end of the quarter.
- We will announce the design project topics in week 5.

Summary

- In MAE 292, we will learn how to solve design problems
- We will primarily use Matlab to develop software to solve these design problems
- We will compare our results with results using commercially available software
- At the end of the class, you will be confident about working on design problems that you may have to solve in industry writing your own program or using commercially available software

Note

- MAE 292 will require a serious effort
- However, you will learn very useful engineering and design skills that you need in your future career.
- Come and see me and the TAs if you have questions or need help
- I am excited to teach Computer-Aided Design and Analysis, and I hope you’re excited to learn!

Next couple of lectures

- Download and install Matlab (version > 2016)
- Read over the reader chapters on canvas.