From Academia to Industry

or, "Those who can't teach, do"

John Perry, PhD[1]

[1]Peraton Engineering

M@X — Math At Xavier

Outline

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Pro Tip!

I've been to too many talks where after 50 minutes I didn't even understand what the question was.

— Bruno Buchberger

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— Bruno Buchberger
(AKA the modern Euclid)

Lead by example, dood

Can you compare and contrast a mathematician's life in academia and industry?

We would love for you to make a pitch to the students for a job in industry. We are always looking for ways to tell them a degree in math doesn't meanest they need to become teachers.

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— *Anonimo*

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To the student who feels, or will feel, out of place

(Possibly $\emptyset$ but probably not)

You like math, and you used to think you were pretty good. You didn't do so well in [insert class / competition]. You don't understand M@X seminars — not even the titles! You're thinking, "Maybe math isn't for me."

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That was me.

- 2 on AP Calculus exam... then ❤️‍🔥 Math
- fled for 4 years... then returned for a PhD
- struggled 6 years... then a not indecent research career

I'm not smart; I'm *too dumb to quit.*

Career

Pre-History

- BS '93, MS '95, PhD '05
- Internships '92, '93

Alternative Pre-History

Career

Pre-History

- BS '93, MS '95, PhD '05
- Internships '92, '93

Alternative Pre-History

- 🚲🗞️ 1986–1988
- 🍔🍟 1988–1991, 1997
- 🏫⛪ 1997–1998

Career

History

- HS Math 1995–1997
- NCSU 1999–2005
  - MU 1999
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  - DTCC 2001–2004
- NCWC 2005–2006
- USM 2006–2021

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Post-History

- Peraton Engineering, 2021–???

Peraton

Why did I enter academia?

- ❤️‍🔥 computer algebra ❤️‍🔥
  - theoretical research
  - programming & theory
- ❤️‍🔥 teaching math ❤️‍🔥
  - I was effective!
    - really! you should have seen my evaluations!
  - research students!
- Unsure I would thrive in industry
- 💰 ***for doing what I loved*** ❗

Those who can't do, teach*!!!*

Why did I leave academia?

- 💔 computer algebra 💔
  - theoretical research stalled
  - programming > theory
- 💔 teaching math 💔
  - I was ~~effective~~!
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Those who can't teach, do!!!

Outline

What's the most important skill in either?

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Problem solving

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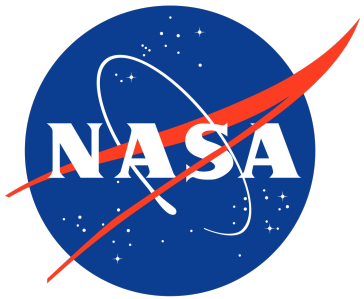
Problem solving



In the real world, no one asks you to compute an integral. They want you to solve a problem. Sometimes the integral is useful for that problem; sometimes it isn't.What matters most is that ***you can solve problems you haven't seen before***.

What's the most important skill in either?

Problem solving

Definition (Research)

The investigation of a question. "Word problems."

- unsolved
- solved

What about...?

	Freedom	Compensation
Academia	99%	😭
Government	20-99%	😕
Industry	0–20%	🤩

(...per my PhD Adviser)

Outline

Institutions

- Community College
- Teaching-Intensive College / University
- Research-Intensive University
- Research Lab (when associated w/university)

Workload & Environment

Teaching

- 2–5 classes/semester
- small / large classes
- student research / projects
- office hours

Research

- Community / Teaching College: none
- Carnegie Research I:
  - grant proposals
  - 1+ papers/year
- follow your own muse

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Workload & Environment

Hours: mostly flexible

Service: varies

- institutional:
- professional:

Work environment

- Smartest, nicest people in the world
- Dumbest, meanest too
  - "False expert"
  - "Too many chiefs, not enough Indians"

Workload & Environment

Hours: mostly flexible

Service: varies

- institutional: as little as you can get away with
- professional: as much as you can get

Work environment

- Smartest, nicest people in the world
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Tenure

- what / why / who / when / where
- "Tenure Trap"

Outline

Workload & Environment

Workload

- 80 hours / 2 weeks
  - track own hours
- Occasional travel to clients / other dev teams

Environment

- "Agile"
- Hybrid work: on-site 1 day a week, off-site w/Teams
- Smartest, nicest people in the world
- ***Wide diversity of skills***

Expectations

- Git 'r done!
  - one job w/many parts
  - "There is no I in TEAM!"
  - follow project leader's muse
- Problem solving
- Tenure: Ever heard of "at will employment"?

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Gröbner Basis Computation

Find "nice" basis of $\langle f_1, \ldots, f_m \rangle \in \mathbb{F}[x_1, \ldots, x_n]$

- Extended Buchberger Criteria
- Signature-based computation
- Dynamic computation

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- Extended Buchberger Criteria
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- Dynamic computation

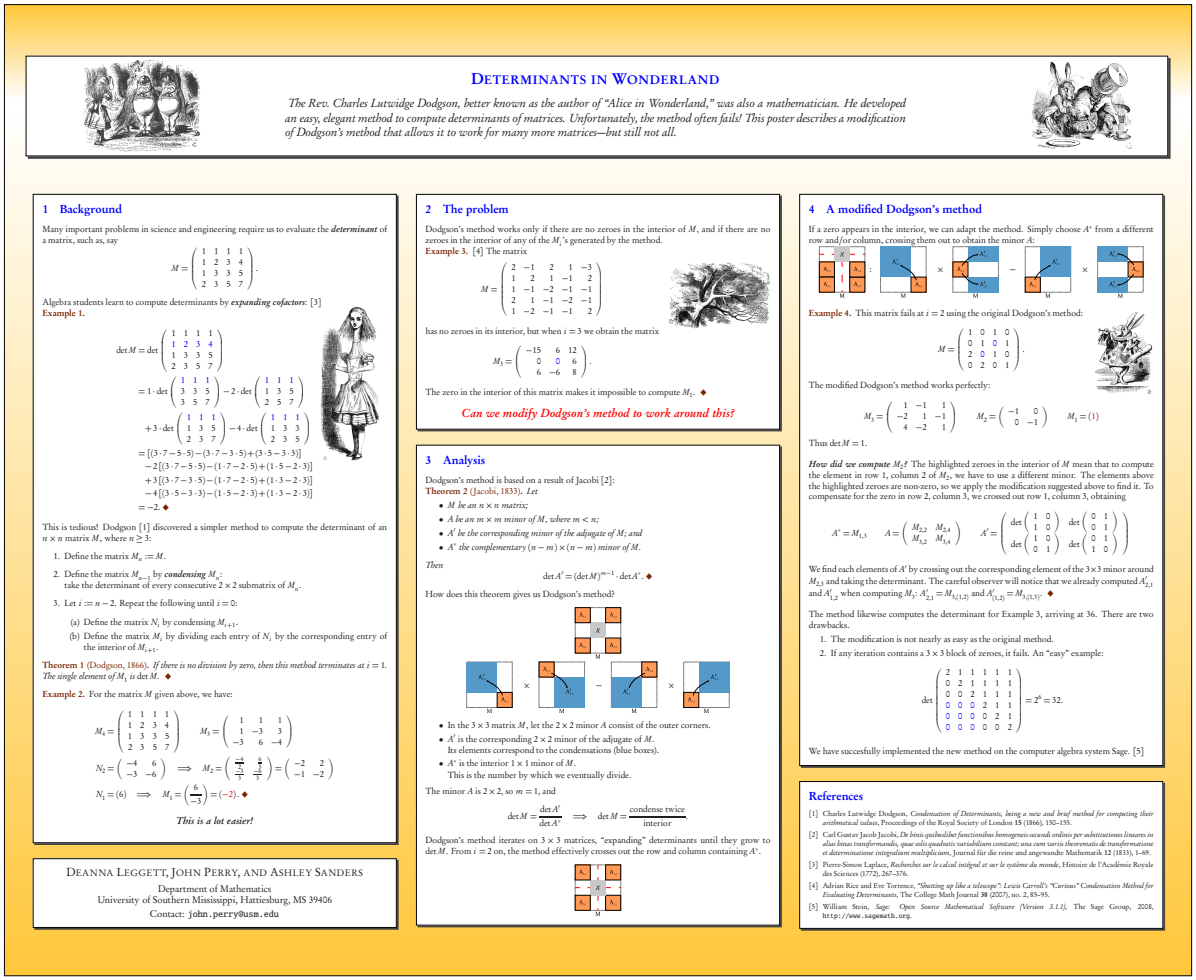
If you don't know what that means, don't feel bad: neither do most of the people in this room.

Combinatorial Game Theory

Find a winning strategy for Ideal Nim.

- Nim, Gröbner Basis Computation, Hilbert Basis Theorem
- Published in MAA's Mathematics Magazine
- High School intern funded by Army REUP Grant
- App on Google Play Store!

Linear Algebra



Determinants in Wonderland

The Rev. Charles Lutwidge Dodgson, better known as the author of "Alice in Wonderland," was also a mathematician. He developed an easy, elegant method to compute determinants of matrices. Unfortunately, the method often fails! This poster describes a modification of Dodgson's method that allows it to work for many more matrices—but still not all.

1 Background

Many important problems in science and engineering require us to evaluate the ***determinant*** of a matrix, such as, say

$$M = \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \\ 1 & 3 & 3 & 5 \\ 2 & 3 & 5 & 7 \end{pmatrix}.$$

Algebra students learn to compute determinants by ***expanding cofactors***: [3]

Example 1.

$$\begin{aligned} \det M &= \det \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \\ 1 & 3 & 3 & 5 \\ 2 & 3 & 5 & 7 \end{pmatrix} \\ &= 1 \cdot \det \begin{pmatrix} 1 & 1 & 1 \\ 3 & 3 & 5 \\ 3 & 5 & 7 \end{pmatrix} - 2 \cdot \det \begin{pmatrix} 1 & 1 & 1 \\ 1 & 3 & 5 \\ 2 & 5 & 7 \end{pmatrix} \\ &\quad + 3 \cdot \det \begin{pmatrix} 1 & 1 & 1 \\ 1 & 3 & 5 \\ 2 & 3 & 7 \end{pmatrix} - 4 \cdot \det \begin{pmatrix} 1 & 1 & 1 \\ 1 & 3 & 3 \\ 2 & 3 & 5 \end{pmatrix} \\ &= [(3 \cdot 7 - 5 \cdot 5) - (3 \cdot 7 - 3 \cdot 5) + (3 \cdot 5 - 3 \cdot 3)] \\ &\quad - 2[(3 \cdot 7 - 5 \cdot 5) - (1 \cdot 7 - 2 \cdot 5) + (1 \cdot 5 - 2 \cdot 3)] \\ &\quad + 3[(3 \cdot 7 - 3 \cdot 5) - (1 \cdot 7 - 2 \cdot 5) + (1 \cdot 3 - 2 \cdot 3)] \\ &\quad - 4[(3 \cdot 5 - 3 \cdot 3) - (1 \cdot 5 - 2 \cdot 3) + (1 \cdot 3 - 2 \cdot 3)] \\ &= -2. \blacklozenge \end{aligned}$$

This is tedious! Dodgson [1] discovered a simpler method to compute the determinant of an $n \times n$ matrix M_n where $n \geq 3$:

1. Define the matrix $M_n := M$.
2. Define the matrix M_{n-1} by ***condensing*** M_n: take the determinant of every consecutive 2×2 submatrix of M_n.
3. Let $i := n - 2$. Repeat the following until $i = 0$:
   (a) Define the matrix N_i by condensing M_{i+1}.
   (b) Define the matrix M_i by dividing each entry of N_i by the corresponding entry of the interior of M_{i+1}.

Theorem 1 (Dodgson, 1866). *If there is no division by zero, then this method terminates at $i = 1$. The single element of M_1 is $\det M$.* $\blacklozenge$

Example 2. For the matrix M given above, we have:

$$M_4 = \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \\ 1 & 3 & 3 & 5 \\ 2 & 3 & 5 & 7 \end{pmatrix} \qquad M_3 = \begin{pmatrix} 1 & 1 & 1 \\ 1 & -3 & 3 \\ -3 & 6 & -4 \end{pmatrix}$$

$$N_2 = \begin{pmatrix} -4 & 6 \\ -3 & -6 \end{pmatrix} \implies M_2 = \begin{pmatrix} \frac{-4}{1} & \frac{6}{1} \\ \frac{-3}{-3} & \frac{-6}{-3} \end{pmatrix} = \begin{pmatrix} -2 & 2 \\ -1 & -2 \end{pmatrix}$$

$$N_1 = (6) \implies M_1 = \left(\frac{6}{-3}\right) = (-2). \blacklozenge$$

This is a lot easier!

Deanna Leggett, John Perry, and Ashley Sanders
Department of Mathematics
University of Southern Mississippi, Hattiesburg, MS 39406
Contact: john.perry@usm.edu

2 The problem

Dodgson's method works only if there are no zeroes in the interior of M, and if there are no zeroes in the interior of any of the M_i's generated by the method.

Example 3. [4] The matrix

$$M = \begin{pmatrix} 2 & -1 & 2 & 1 & -3 \\ 1 & 2 & 1 & -1 & 2 \\ 1 & -1 & -2 & -1 & -1 \\ 2 & 1 & -1 & -2 & -1 \\ 1 & -2 & -1 & -1 & 2 \end{pmatrix}$$

has no zeroes in its interior, but when $i = 3$ we obtain the matrix

$$M_3 = \begin{pmatrix} -15 & 6 & 12 \\ 0 & 0 & 6 \\ 6 & -6 & 8 \end{pmatrix}.$$

The zero in the interior of this matrix makes it impossible to compute M_1. $\blacklozenge$

Can we modify Dodgson's method to work around this?

3 Analysis

Dodgson's method is based on a result of Jacobi [2]:

Theorem 2 (Jacobi, 1833). *Let*

- *M be an $n \times n$ matrix;*
- *A be an $m \times m$ minor of M, where $m < n$;*
- *A' be the corresponding minor of the adjugate of M; and*
- *A^* the complementary $(n-m) \times (n-m)$ minor of M.*

Then

$$\det A' = (\det M)^{m-1} \cdot \det A^*. \blacklozenge$$

How does this theorem gives us Dodgson's method?

- In the 3×3 matrix M, let the 2×2 minor A consist of the outer corners.
- A' is the corresponding 2×2 minor of the adjugate of M. Its elements correspond to the condensations (blue boxes).
- A^* is the interior 1×1 minor of M. This is the number by which we eventually divide.

The minor A is 2×2, so $m = 1$, and

$$\det M = \frac{\det A'}{\det A^*} \implies \det M = \frac{\text{condense twice}}{\text{interior}}.$$

Dodgson's method iterates on 3×3 matrices, "expanding" determinants until they grow to $\det M$. From $i = 2$ on, the method effectively crosses out the row and column containing A^*.

4 A modified Dodgson's method

If a zero appears in the interior, we can adapt the method. Simply choose A^* from a different row and/or column, crossing them out to obtain the minor A:

Example 4. This matrix fails at $i = 2$ using the original Dodgson's method:

$$M = \begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 2 & 0 & 1 & 0 \\ 0 & 2 & 0 & 1 \end{pmatrix}.$$

The modified Dodgson's method works perfectly:

$$M_3 = \begin{pmatrix} 1 & -1 & 1 \\ -2 & 1 & -1 \\ 4 & -2 & 1 \end{pmatrix} \qquad M_2 = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} \qquad M_1 = (1)$$

Thus $\det M = 1$.

How did we compute M_2? The highlighted zeroes in the interior of M mean that to compute the element in row 1, column 2 of M_2, we have to use a different minor. The elements above the highlighted zeroes are non-zero, so we apply the modification suggested above to find it. To compensate for the zero in row 2, column 3, we crossed out row 1, column 3, obtaining

$$A' = M_{1,3} \qquad A = \begin{pmatrix} M_{2,2} & M_{2,4} \\ M_{3,2} & M_{3,4} \end{pmatrix} \qquad A' = \begin{pmatrix} \det \begin{pmatrix} 1 & 0 \\ 1 & 0 \end{pmatrix} & \det \begin{pmatrix} 0 & 1 \\ 0 & 1 \end{pmatrix} \\ \det \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} & \det \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \end{pmatrix}$$

We find each elements of A' by crossing out the corresponding element of the 3×3 minor around $M_{2,3}$ and taking the determinant. The careful observer will notice that we already computed $A'_{2,1}$ and $A'_{1,2}$ when computing M_3: $A'_{2,1} = M_{3,(1,2)}$ and $A'_{(1,2)} = M_{3,(1,3)}$. $\blacklozenge$

The method likewise computes the determinant for Example 3, arriving at 36. There are two drawbacks.

1. The modification is not nearly as easy as the original method.
2. If any iteration contains a 3×3 block of zeroes, it fails. An "easy" example:

$$\det \begin{pmatrix} 2 & 1 & 1 & 1 & 1 & 1 \\ 0 & 2 & 1 & 1 & 1 & 1 \\ 0 & 0 & 2 & 1 & 1 & 1 \\ 0 & 0 & 0 & 2 & 1 & 1 \\ 0 & 0 & 0 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 2 \end{pmatrix} = 2^6 = 32.$$

We have succesfully implemented the new method on the computer algebra system Sage. [5]

References

[1] Charles Lutwidge Dodgson, *Condensation of Determinants, being a new and brief method for computing their arithmetical values*, Proceedings of the Royal Society of London **15** (1866), 150–155.

[2] Carl Gustav Jacob Jacobi, *De binis quibuslibet functionibus homogeneis secundi ordinis per substitutionem binarum aliis binis transformandis, quae solis quadratis variabilium constant; una cum variis theorematis de transformatione et determinatione integralium multiplicium*, Journal für die reine und angewandte Mathematik **12** (1833), 1–69.

[3] Pierre-Simon Laplace, *Recherches sur le calcul intégral et sur le système du monde*, Histoire de l'Académie Royale des Sciences (1772), 267–376.

[4] Adrian Rice and Eve Torrence, *"Shutting up like a telescope": Lewis Carroll's "Curious" Condensation Method for Evaluating Determinants*, The College Math Journal **38** (2007), no. 2, 85–95.

[5] William Stein, *Sage: Open Source Mathematical Software (Version 3.1.1)*, The Sage Group, 2008, http://www.sagemath.org.

Outline

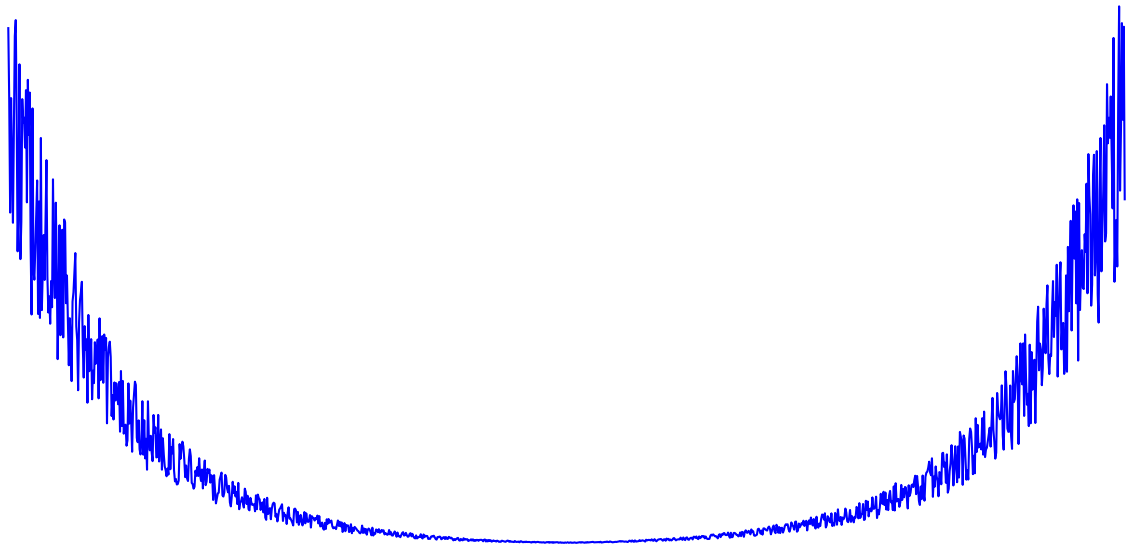
Reverse engineering #1

What does this formula do?

$$\frac{\frac{A_1+A_2+A_3+A_4}{4} + \frac{B_1+B_2}{2} + \frac{R_1+R_2+R_3}{3}}{3}$$

Reverse engineering #2

What function is this? (roughly)



$f(x)$

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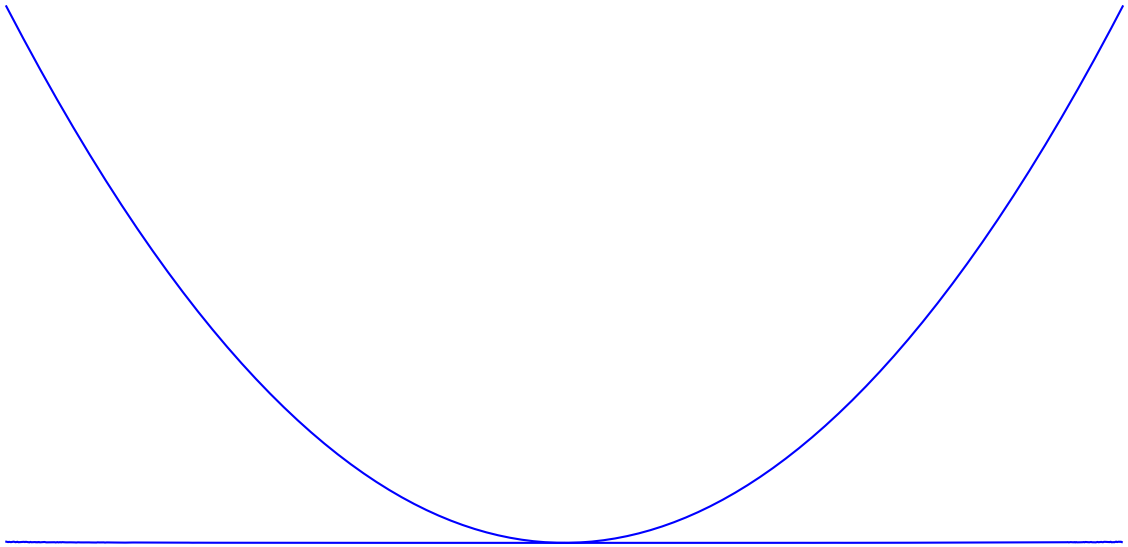

$f(x)$ compared to x^2

Reverse engineering #2

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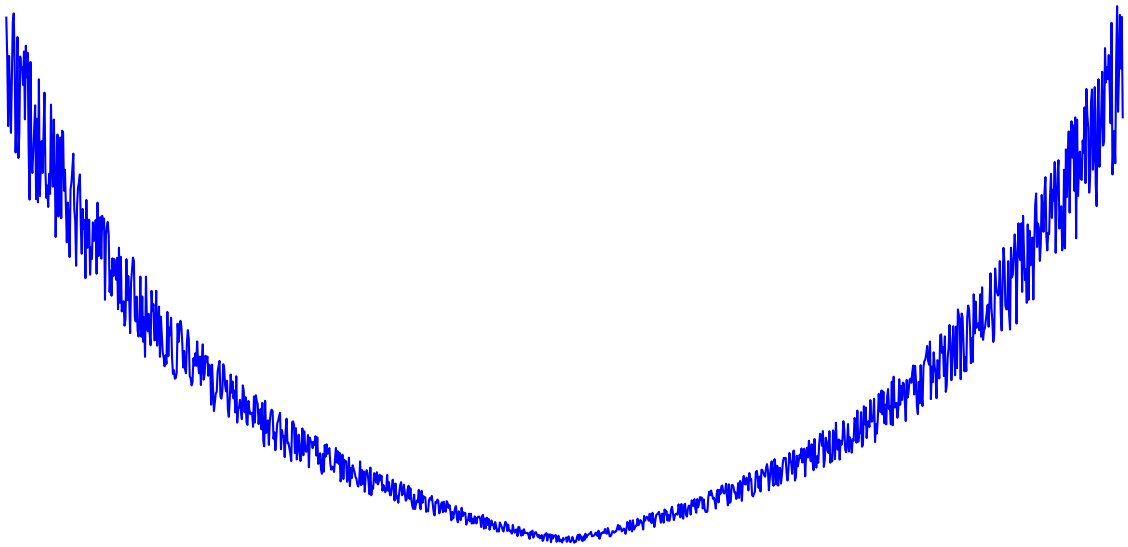

$$\sqrt{f(x)}$$

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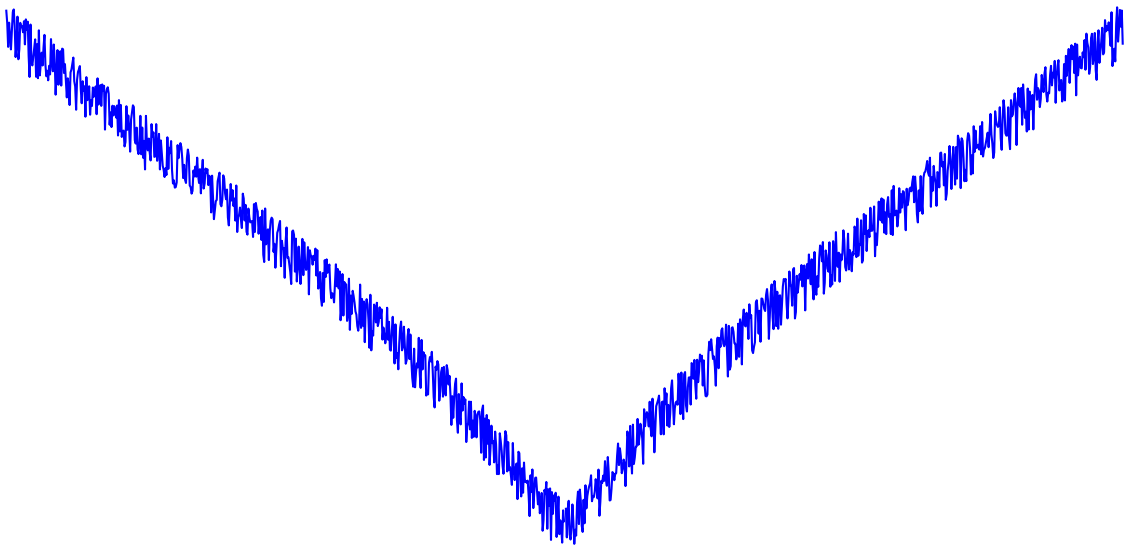
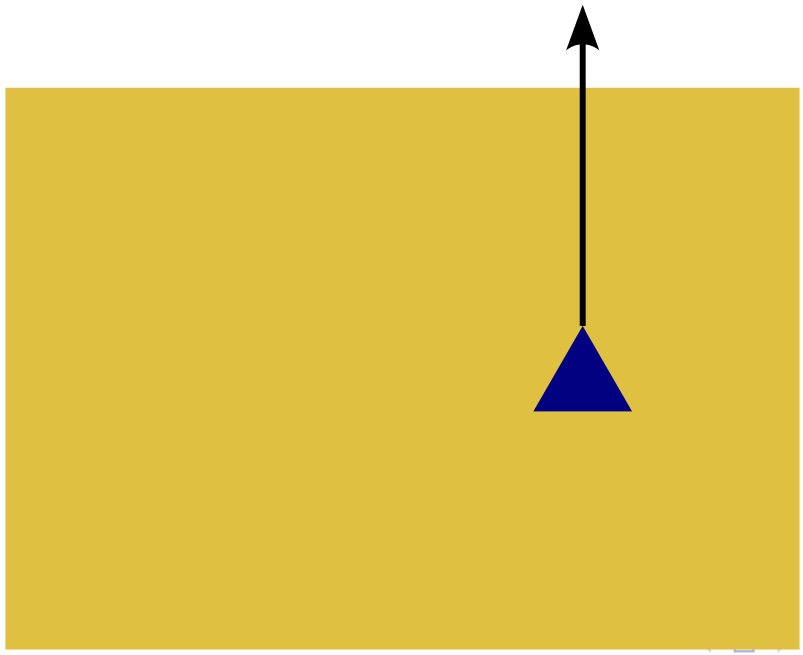


$$\ln\left(f\left(x\right)\right)$$

Formulas #1

A sensor in forward motion (triangle) gives me an image (rectangle). I know the latitude & longitude of the four corners.

1. Suppose the user clicks a point within the rectangle. How can I determine the point's latitude and longitude?
2. Repeat, but this time you know only the center's latitude and longitude, along with the width and height.



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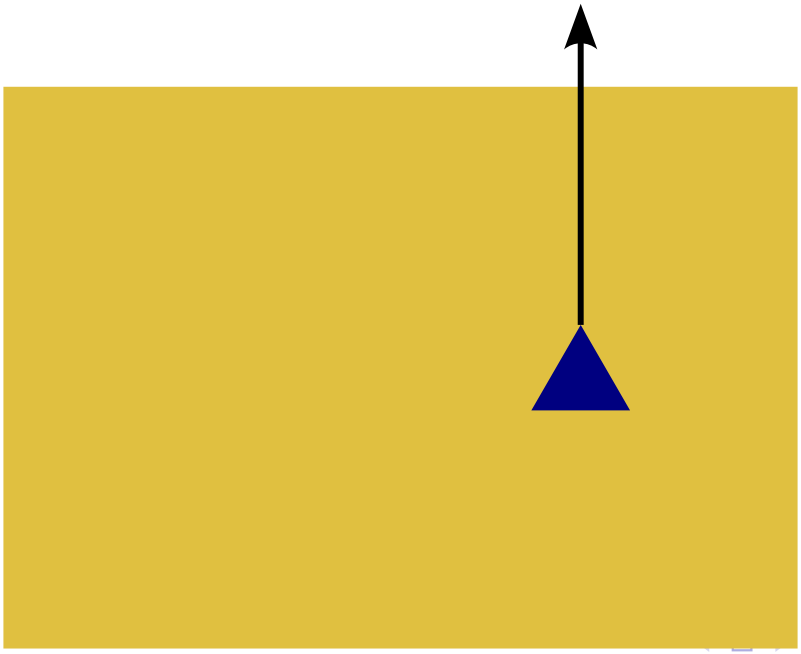

Formulas #2

three.js (link)

1. small portion of image through 1/2-size "window"
2. can specify *center's offset*
3. What offset would fix the window in the image's lower left corner? in the upper right?

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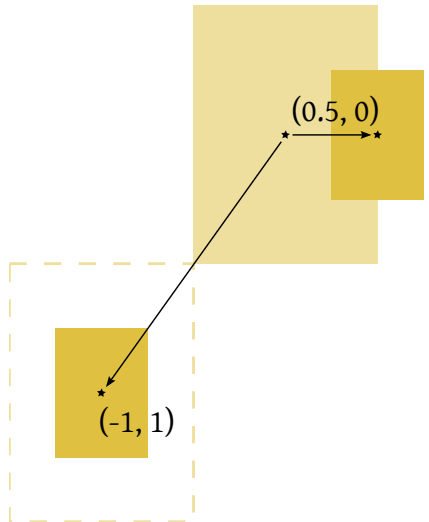

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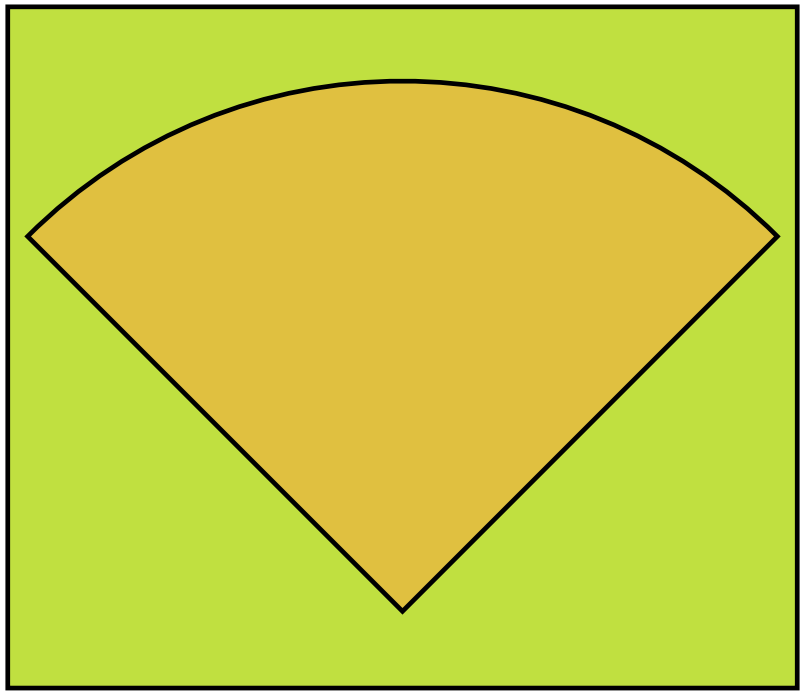

Given sector's radius, central angle, find dimensions of smallest circumscribing *rectangle*

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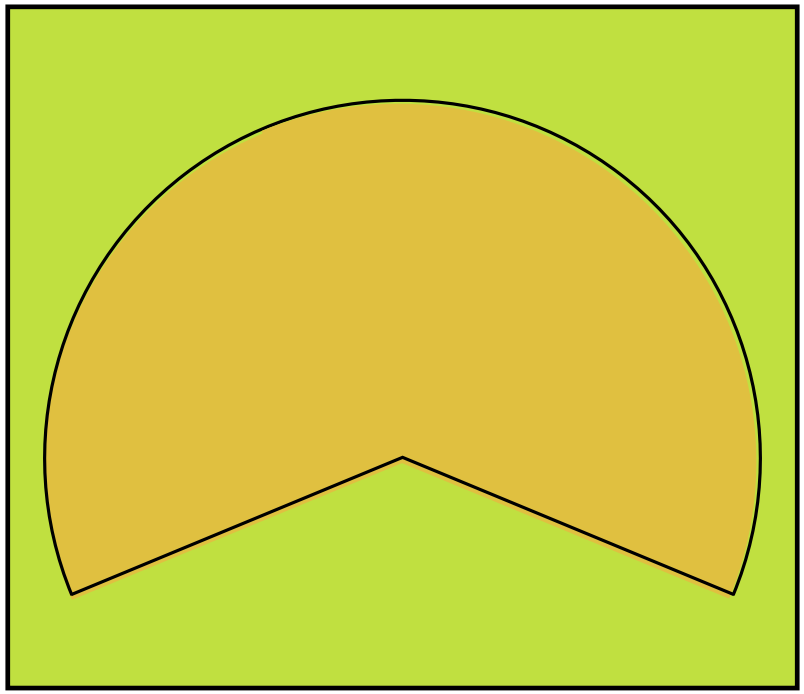

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three.js (link)

- (relatively) easy to draw three-dimensional graphics in browser
- will rotate images
- *but...*
  - sometimes we want to a plane to "clip" an object
  - three.js will *not* rotate a clipping plane
  - we have to rotate it ourselves

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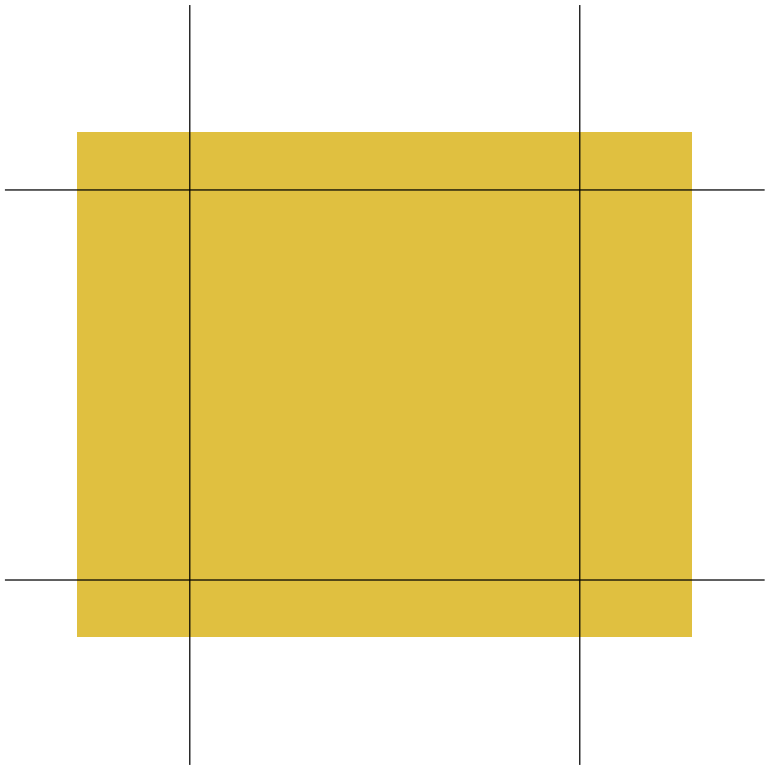

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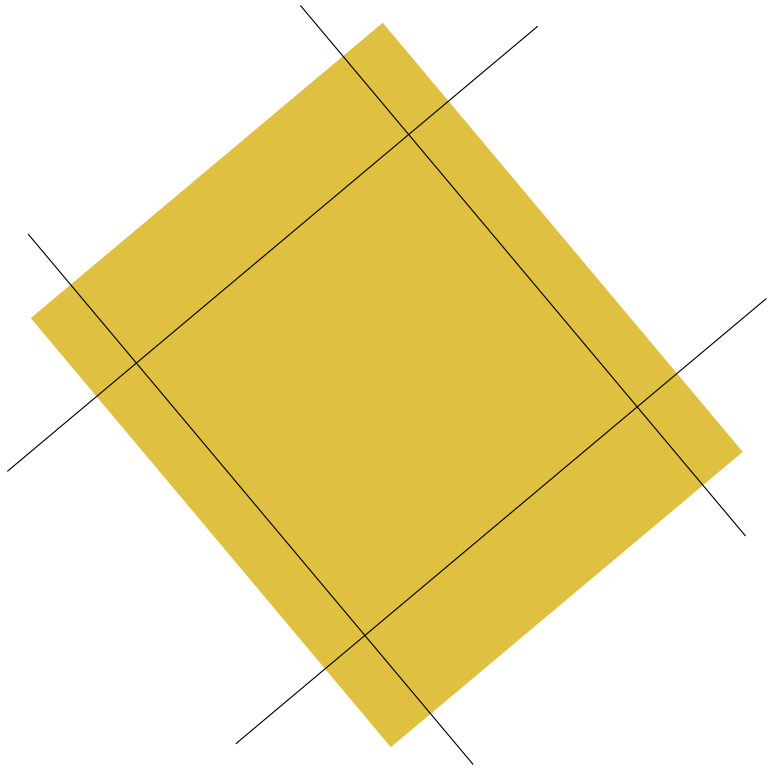

Outline

Searching

- Web sites
  - LinkedIn, Indeed, ...
    - Connect w/people in field, specialty, company
  - USAJobs
  - Company websites: link to "Careers"
- Networking
  - People
    - "Headhunters": internal / external
    - The 3 F's: Friends, Family, Faculty!
    - Contacts listed in advertisements
    - Employees referrals **"3× more effective"**
  - Organizations
    - Professional societies
    - University career center

Applying

- Cover letter: strongly recommended, sets you apart
- CV or Resume?

	Resume	CV
Audience	Industry	Academia
Contains	Job-related highlights	Everything work-related
Length	1-2 pp	As long as necessary
Highlight	Portfolio	Depends on institution

- **Do**
  - Spell-check!
  - Answer how you address the job needs
  - Have someone else read it
  - Customize for each employer
- **Don't**
  - Lie / inflate credentials
  - Rely on AI
  - Forget to change names of institutions

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Interview

- Before
  - Research the company
  - Know its mission, slogans, main talking points
- Answer
  - What attracts you to this position?
  - How can *you* contribute to our mission?
  - Specifics about Resume & CV
- Ask
  - Typical day?
  - New position? Replacing recent departure / retiree?
  - What do you expect to see from me in 6 weeks / months?
  - *[Question that shows you researched the company]*?
- Afterwards
  - Reach out **once** and **thank** them for opportunity
  - Answer anything you promised in a follow-up
  - Offer to answer other questions

Interview

- Before
  - Research the company
  - Know its mission, slogans, main talking points
- Answer
  - What attracts you to this position?
  - How can *you* contribute to our mission?
  - Specifics about Resume & CV
- Ask
  - Typical day?
  - New position? Replacing recent departure / retiree?
  - What do you expect to see from me in 6 weeks / months?
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BS #1

- Student evaluation
- 1st day of internship
- Talk to prospective high school students

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- Talk to prospective high school students
  USM forced me to work w/4 programming languages... **and that was a good thing**

BS #2

The biggest characteristic I portrayed was eagerness to learn skills, grow professionally, and impact the output of the department in a positive way. ... All I had was my mathematics bachelor's and a fancy sounding thesis, but it was enough to sit down with [...] Acoustics and portray that *while I may not understand ocean acoustics now, I am very eager to understand soon.* ... Pretty sure my eagerness got me my position.

BS #2

You get as much out of those resources [Indeed] as you put in. I went full bore shotgun style anyone and everyone, and considered my options based on who responded quickest and what the best 5-year plan for me was.

BS #2

Everyone I've talked to on site is always extremely busy with too many things to do. It's not unheard of for emails to go weeks without a reply WITHIN THE DEPARTMENT, let alone from an outside email address. After the position is found, there will still be a process of getting a response, and they should not be discouraged by the amount of time replies take.

BS #3

Computing Taylor series expansions or LaPlace transforms is not a part of my day-to-day routine. However, you will absolutely use the skills such rigourous exercises taught you. Just as a football player does not actually lift weights or do footing drills in the middle of a football game, he uses the strength and agility such training developed within him.

BS #3

The ultimate value of a Math degree is that it trains you to think and reason. Employers look at a Mathematics BS as a certificate that says "this person knows how to think". Employers know this...Dr. John Sample at NRL knew this when he hired me.

BS #3

Proofs train you to argue why something is true. ...some of the most relevant industries for these skills are software development, research, and even law (proofs teach you how to reason and argue...Supreme Court decisions often read like a proof)

BS #3

linear/abstract algebra are especially good training for working in the software world where you frequently encounter "elements" that need "operations" done on them...both forward and "inverse". abstraction in general is a big concept in computer science