Welcome to Introduction to Robotics

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Introductions:
course staff and lab info

lab website:

http://coecsl.ece.illinois.edu/ece470/

Course Communication and Assistance

- Website: https://publish.illinois.edu/ece470-intro-robotics/
- Link to CampusWire on website
- Office Hours on website
  - Changes will be posted on CampusWire
- Homework Parties on Fridays TBD
  - Remember to be kind to your TAs

SCHEDULE – SPRING 2026

[Updated 1/12/26 – subject to change]

Important Information:

Subscribe to MediaSpace

Join PrairieLearn

Homework due Fridays at midnight

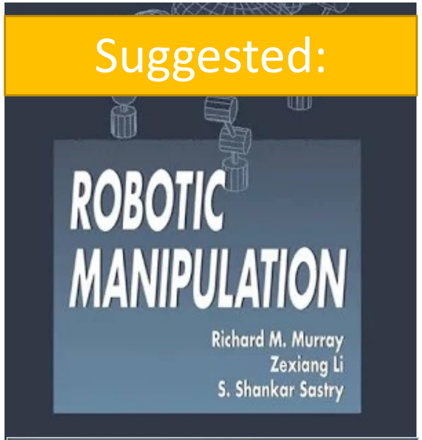
Week	Tues	Topic 1	Thurs	Topic 2	Side Notes
1	01.20	Intro + Review slides-empty slides-annotated	01.22	Mechanism Design Mod. Rob. Ch 2	Suggested Material: Matrix Cookbook Linear Algebra Done Right Gilbert Strang Lectures Spring 2023 Lectures: Linear Algebra Diff Eq
2	01.27	Rigid body motion	01.29	Transformations	
3	02.03	Screw Motions	02.05	Exponential Coordinates	
4	02.10	Review I	02.12	Exam I in CBTF	

Course Components

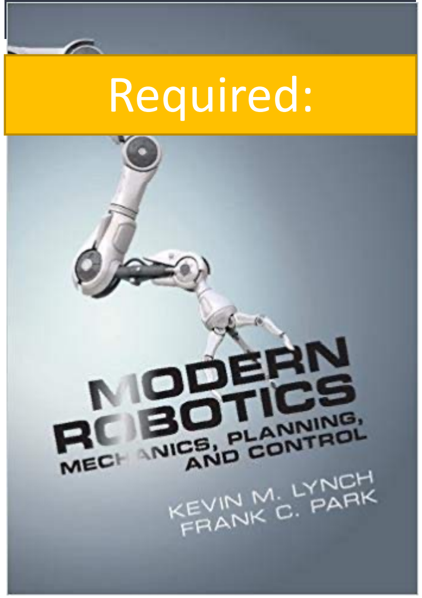
– 20% Homework
– 50% Exams (15-20% each)
– 20% Laboratory
– 10% Final Project

+ Extra Credit

Suggested:

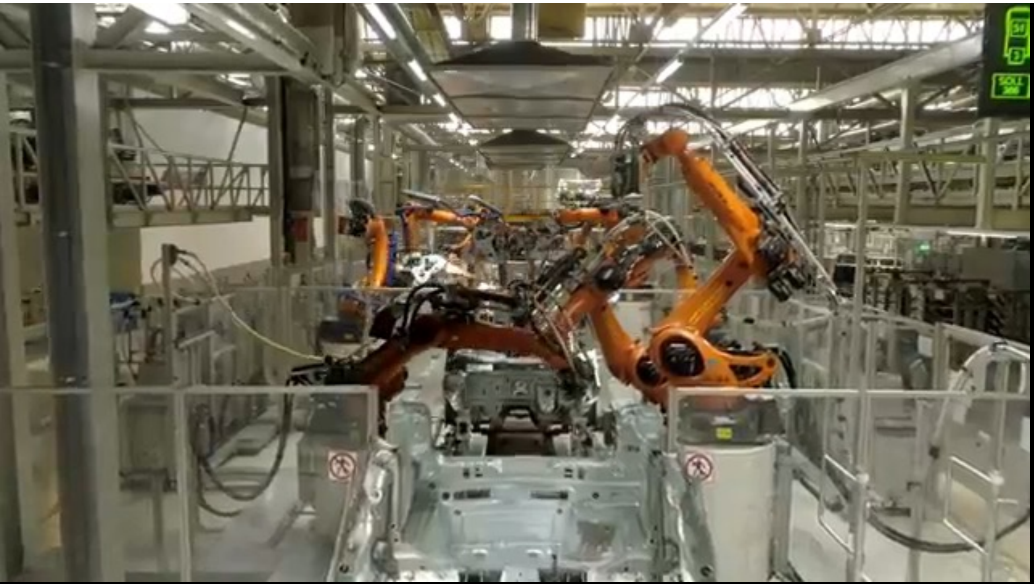


Required:



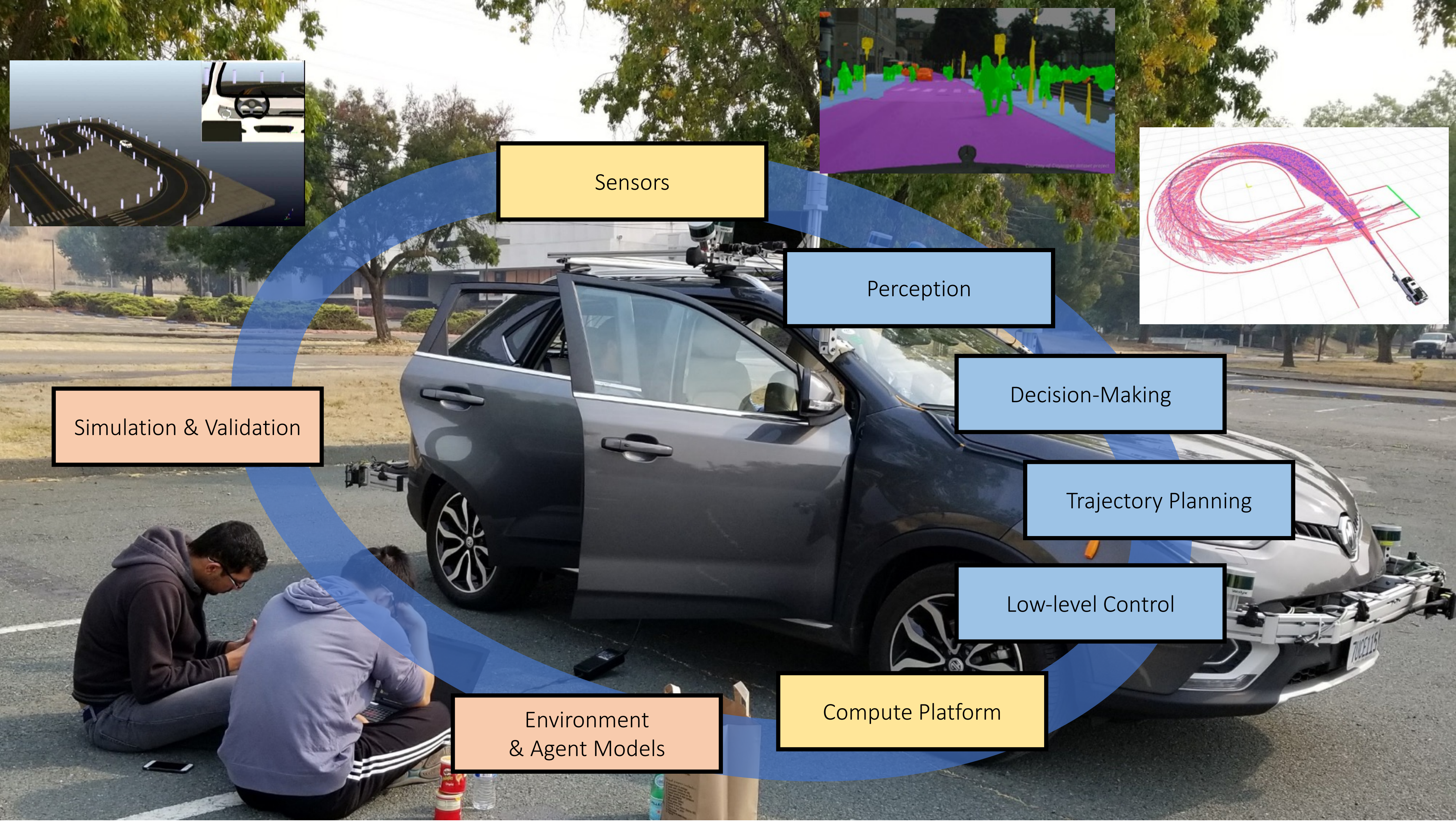
Course Components

- Almost weekly homework on PrairieLearn
  - Try logging on now!
  - HW1 is due next Friday!
  - No dropped assignments. Late assignments can be submitted for up to 50% credit one week late.
- Exams will be administered at the CBTF using PrairieLearn
  - Check out the CBTF orientation quiz

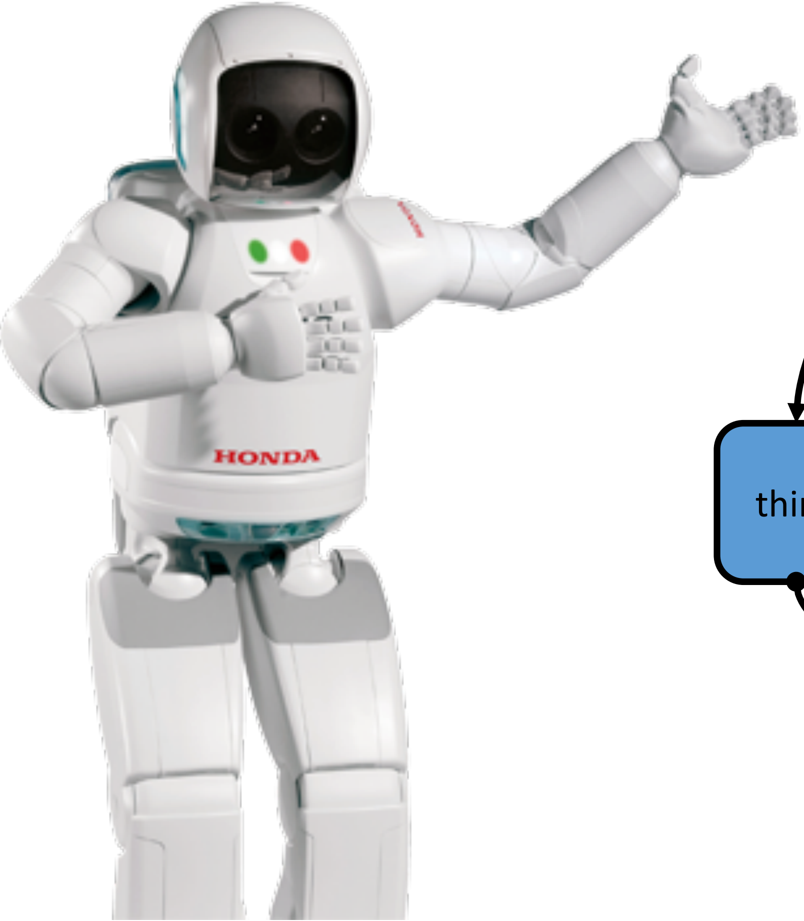


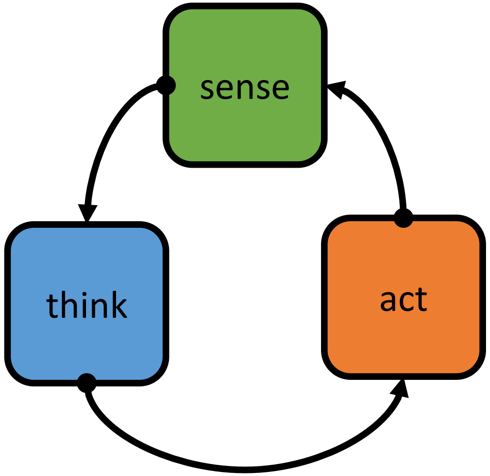
Let's dance
together !


I've driven
7 million
miles.


Sensors
Perception
Decision-Making
Trajectory Planning
Low-level Control
Compute Platform
Environment
& Agent Models
Simulation & Validation

Topics in Intro to Robotics





1. Mechanism design
2. Rigid body motion & transformations
3. Screw theory
4. Forward Kinematics
5. Velocity Kinematics
6. Inverse Kinematics
7. Manipulation
8. Motion Planning
9. Fun topics!

Pick and Place

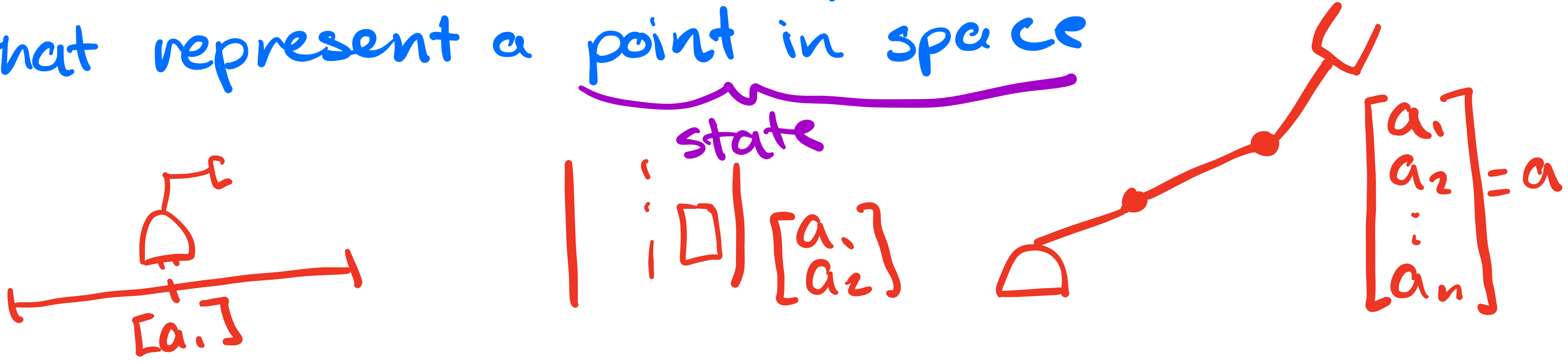
Video Credit: Keenan Wyrobek, Personal Robotics Lab, Stanford

Quick Math Review

Inspiration from Lukas Luft, Wolfram Burgard, and Roy Dong

Vectors

a vector is an array of numbers that represent a $\underbrace{\text{point in space}}_{\text{state}}$



recall: we can scale + add

- dot product : $a \cdot b = \sum_i a_i b_i = \|a\| \cdot \|b\| \cos\theta$
- cross product: $a \times b = \|a\| \cdot \|b\| \sin\theta \cdot \hat{n}$

$\rightarrow$ vector that is $\perp$ to both a + b

Matrices 1

collection of vec $\{a_1, a_2, \dots, a_n\}$

vector b is dependent from ↑ if

$$b = \sum k_i a_i$$

if there is no k_i, then b is linearly ind.

matrix: $A : \overset{\text{rows}}{n} \times \overset{\text{col}}{m}$

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1m} \\ a_{21} & a_{22} & & \vdots \\ \vdots & & \ddots & \\ a_{n1} & \dots & & a_{nm} \end{bmatrix}$$

collection of rows

$$\begin{bmatrix} a_{1*}^T \\ \vdots \\ a_{n*}^T \end{bmatrix}$$

collection of col

$[a_1 \dots a_m\}$

Matrices 2: Products

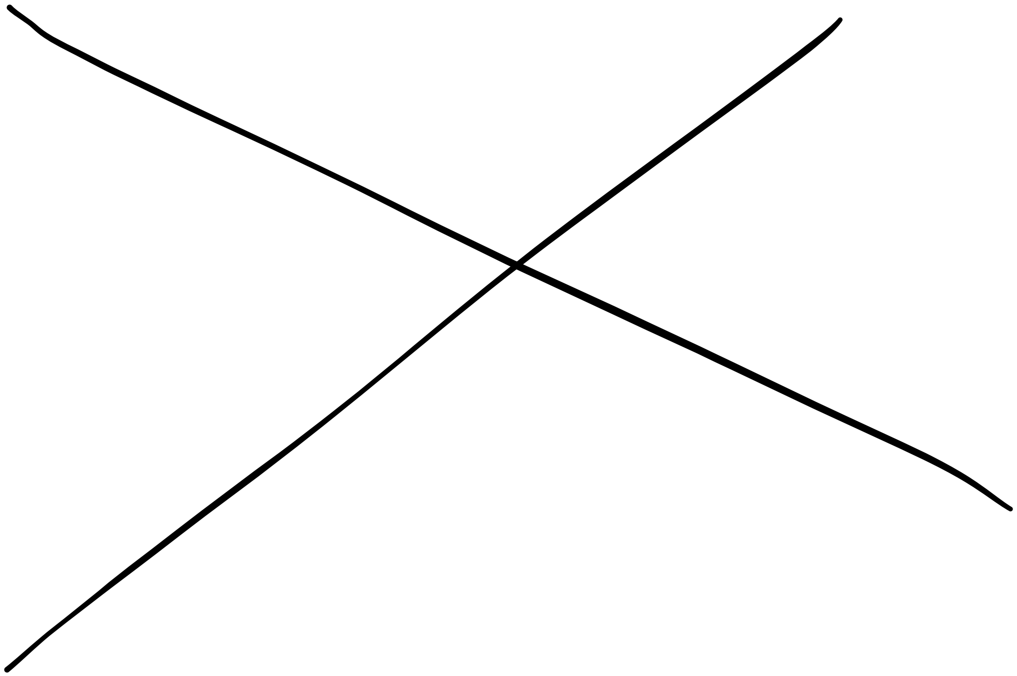
$$Ab = \begin{bmatrix} a_{1*}^T \\ \vdots \\ a_{n*}^T \end{bmatrix} b = \begin{bmatrix} a_{1*}^T b \\ \vdots \\ a_{n*}^T b \end{bmatrix} = \sum_k a_{*k} b_k$$

$$\underset{n\times p}{C} = \overset{n\times m}{A}\,\overset{m\times p}{B} = \begin{bmatrix} a_{1\cdot}^T b_{\cdot 1} & \cdots & a_{1\cdot}^T b_{\cdot m} \\ \vdots & \ddots & \vdots \\ a_{n\cdot}^T b_{\cdot 1} & \cdots & a_{n\cdot}^T b_{\cdot m} \end{bmatrix}$$

$$= \begin{bmatrix} \underbrace{A b_{\cdot 1}}_{c_1} & A b_{\cdot 2} & \cdots & \underbrace{A b_{\cdot p}}_{c_p} \end{bmatrix}$$

Matrices 2

Extra!



Matrix Operations and Rank

<u>Common Matrix Operations</u>

- Multiplication by a scalar
- Sum (commutative, associative)
- Multiplication by a vector
- Product (not commutative)
- Transposition
- Inversion (if square, full rank)

$A \cdot A^{-1} = I$

<u>Matrix Rank</u>

- Rank is determined by the maximum number of linearly independent rows (columns)
- If A is $m \times n$, then
  - $\text{rank}(A) \geq 0$
  - $\text{rank}(A) \leq \min(m, n)$
- $\text{rank}(A)$ can be computed by finding the rows that are linearly dependent, Gaussian elimination, and/or by counting the number of non-zero rows

Matrix Example

$$B : \begin{bmatrix} \hat{x} & \hat{y} & \hat{z} & p_b \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- sensor detect obj at p
- sensor pose relative to bot can be represented as a matrix B
- robot moves around
  → matrix A gives bot pose in world

ABp give obj location in world frame

Jacobian Matrices

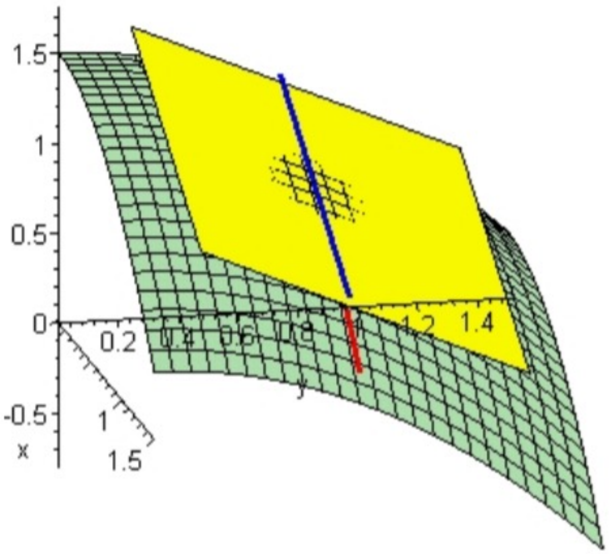
$$f(x) = \begin{bmatrix} f_1(x) \\ \vdots \\ f_m(x) \end{bmatrix}$$

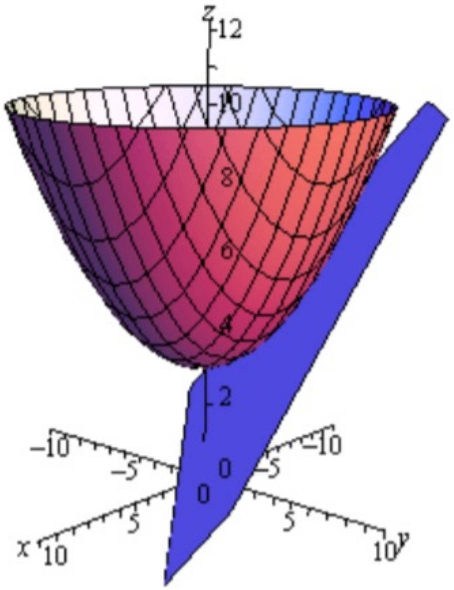
Jacobian is defined as:

$$F_x = \begin{bmatrix} \partial f_1/\partial x_1 & \cdots & \partial f_1/\partial x_n \\ \partial f_2/\partial x_1 & \cdot & \vdots \\ \vdots & \ddots & \\ \partial f_m/\partial x_1 & \cdots & \partial f_m/\partial x_n \end{bmatrix}$$

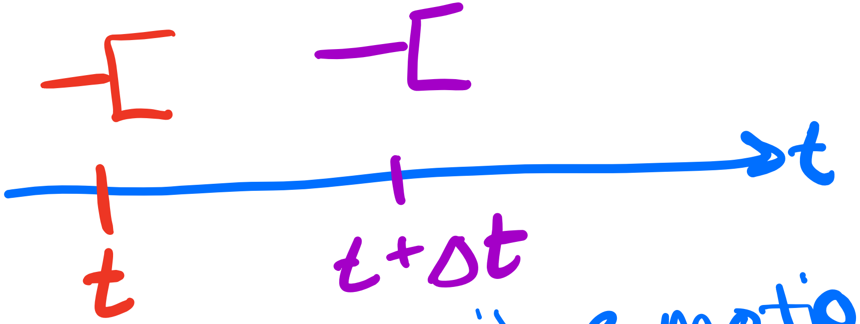
Jacobian Matrix

Gives the orientation of the **tangent plane**
to the vector-valued function at a given point





Motions as Differential Equations



$x(t+\Delta t) = x(t) + v\cdot\Delta t$

we can describe motion as diff eq:

$dx/dt = \dot{x}(t) = f(x(t)) = \dot{x} = f(x)$

what does it mean when we say a fn $x(\cdot)$ satisfies a diff eq?

① take fn $x(\cdot)$ ② differentiate: $\dot{x}$

③ plug in $f(x)$ ④ match?

Exponentials 1

① $x(t) = \exp(at) = e^{at}$

Does it satisfy $\dot{x} = ax$?

② $\dot{x} = a e^{at}$

③ $f(x(t)) = a\,x(t) = a e^{at}$

④ ✓

$\dot{x} = Ax$

Exponentials 2

Given an initial condition $x(0)$ ① & a diff eq ② $\dot{x} = f(x)$, there is exactly 1 fn that satisfies both (1 & 2)

x_0

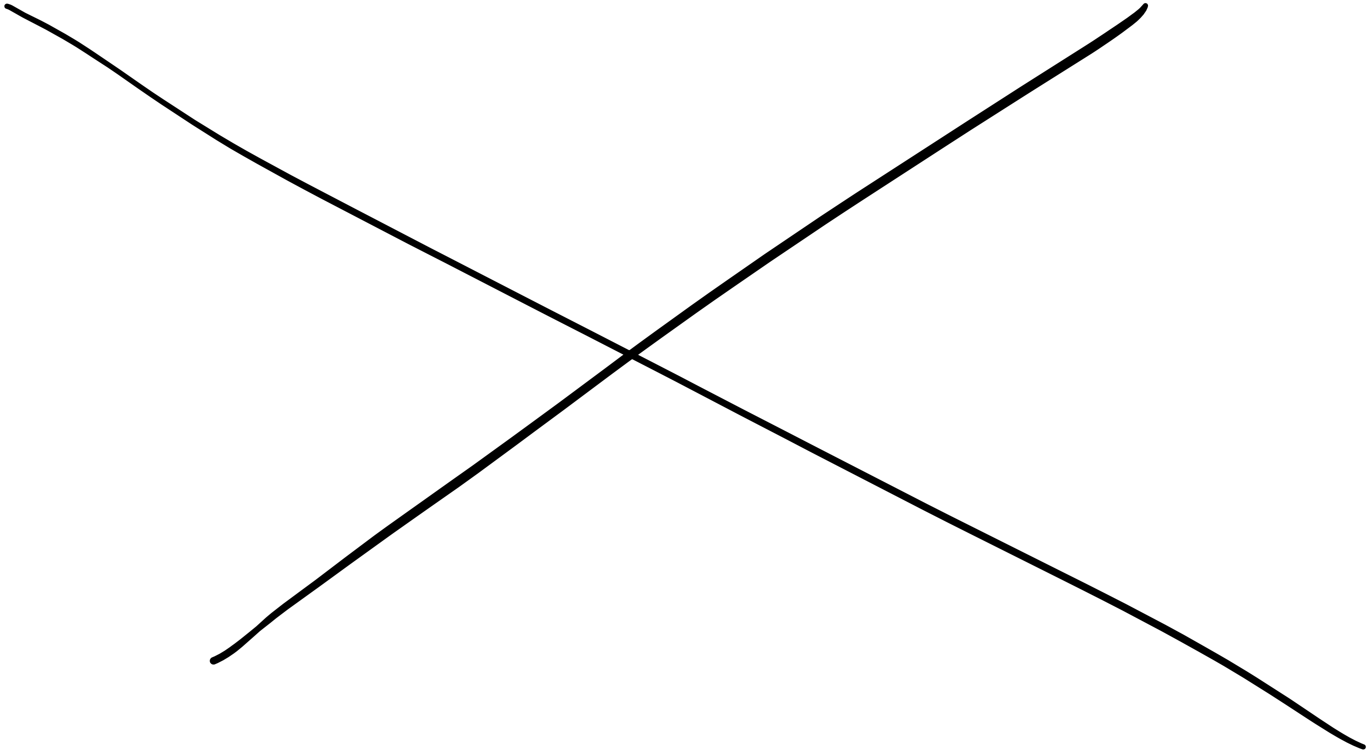
ex) $\dot{x} = ax$, $x(0) = c$

$\rightarrow x(t) = ce^{at}$

recall: integral form:

$$x(t) = x(0) + \int_0^t f(x(s))\,ds$$

Extra!



review materials for linear algebra

- The Matrix Cookbook
- Linear Algebra Done Right
- Textbooks on Linear Algebra by Gilbert Strang

Summary

- Introduced course content
- Reviewed Vector and Matrix representations and operations
- The **Jacobian** contains the partial derivatives for a vector valued function
- Quick refresher on differential equations
  - Matrix exponentials will be very useful matrix operations!