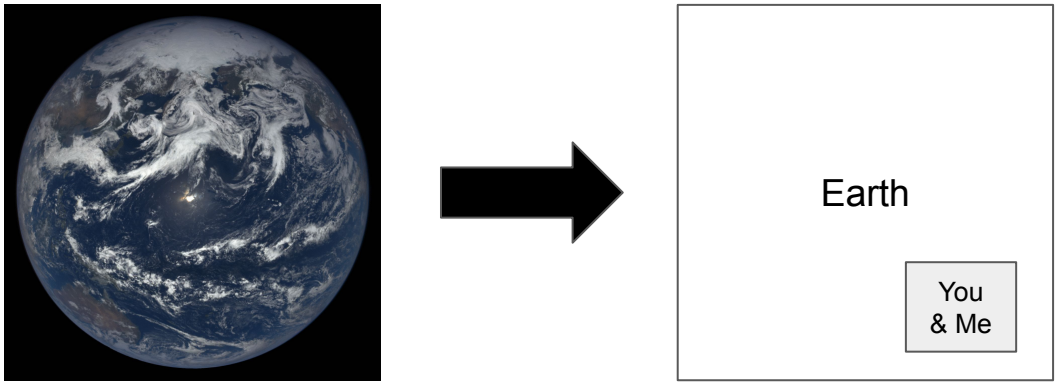
A Moment on Modeling



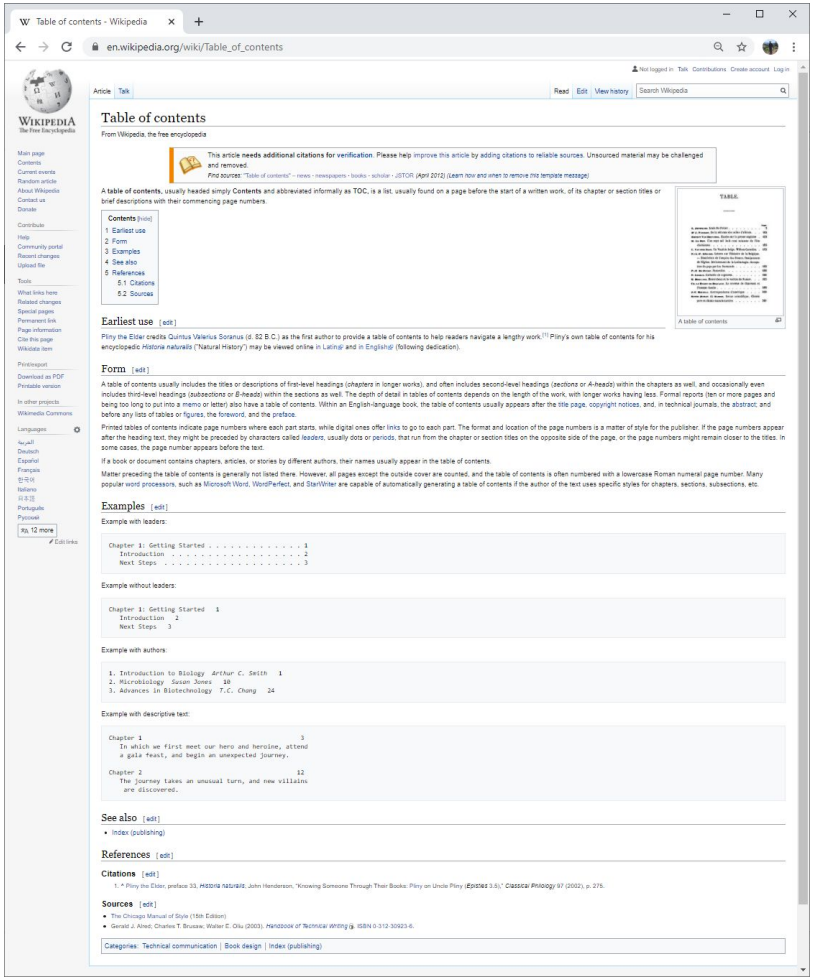
Prof. Charlie Kemp

https://charliekemp.com

Associate Professor
Biomedical Engineering
Georgia Tech

A Model for this Talk

- Models are wrong
- Models are useful
- Models are cheap
- Models are plentiful
- A Model Example



“All models are wrong, but some are useful.”

George E. P. Box

https://en.wikipedia.org/wiki/All_models_are_wrong

Models of the Natural World are Wrong

- Imperfect measurements
  - Uncertainty principle
  - Observer effect
- Imperfect predictions
  - Chaotic systems
  - Computational limits
  - Mathematical limits
- Extraordinary complexity
  - ~10^23 atoms in a 1 cm^3 of water
  - Even nothing is complex
    - “... even if all matter could be removed from a volume, it would still not be ‘empty’ due to vacuum fluctuations, dark energy, transiting gamma rays, cosmic rays, neutrinos, and other phenomena in quantum physics.” - https://en.wikipedia.org/wiki/Vacuum

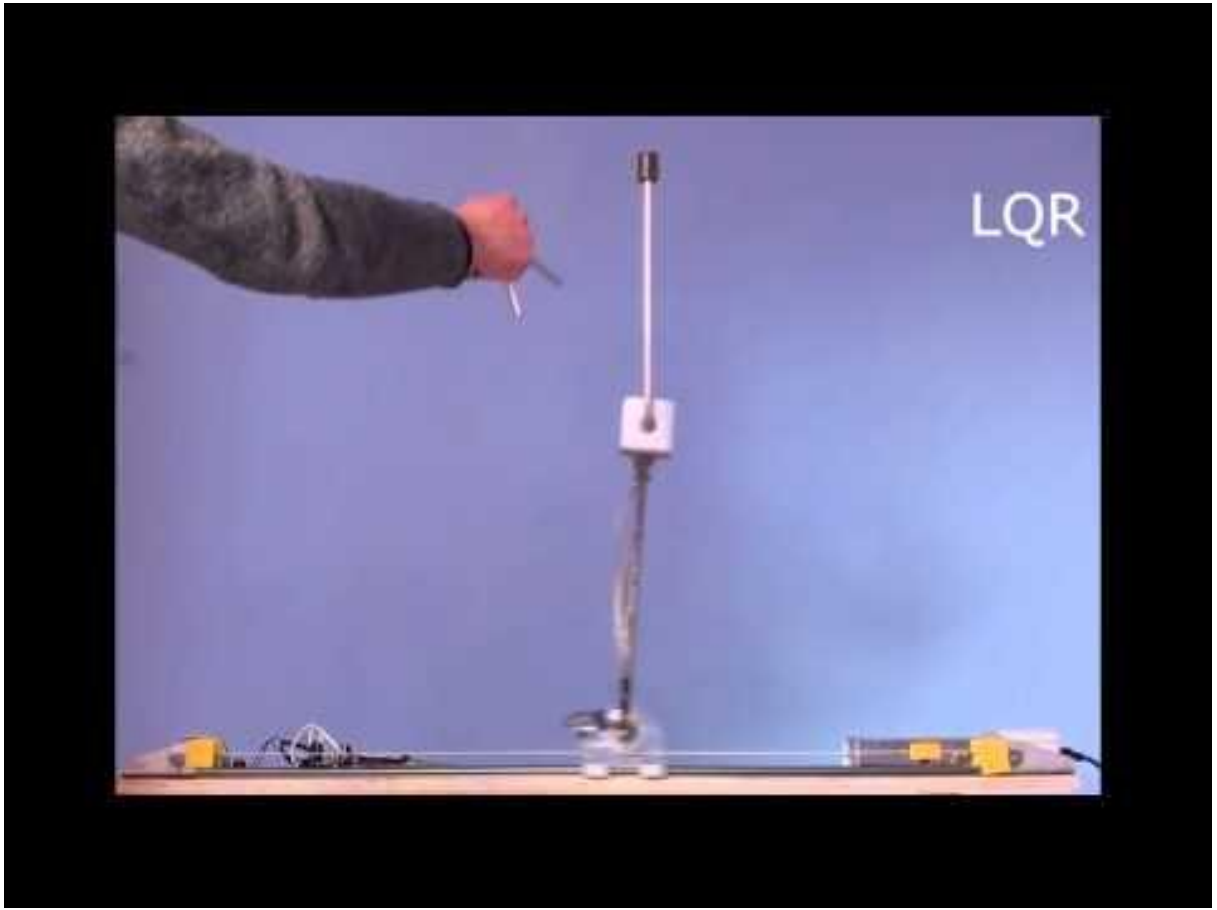
https://en.wikipedia.org/wiki/File:Double-compound-pendulum.gif

WARNING: Do not confuse a model with the real thing.

Translation: "*This is not a pipe.*"

"The Treachery of Images ... is a 1929 painting by surrealist painter René Magritte." - https://en.wikipedia.org/wiki/The_Treachery_of_Images

Some Models are Useful



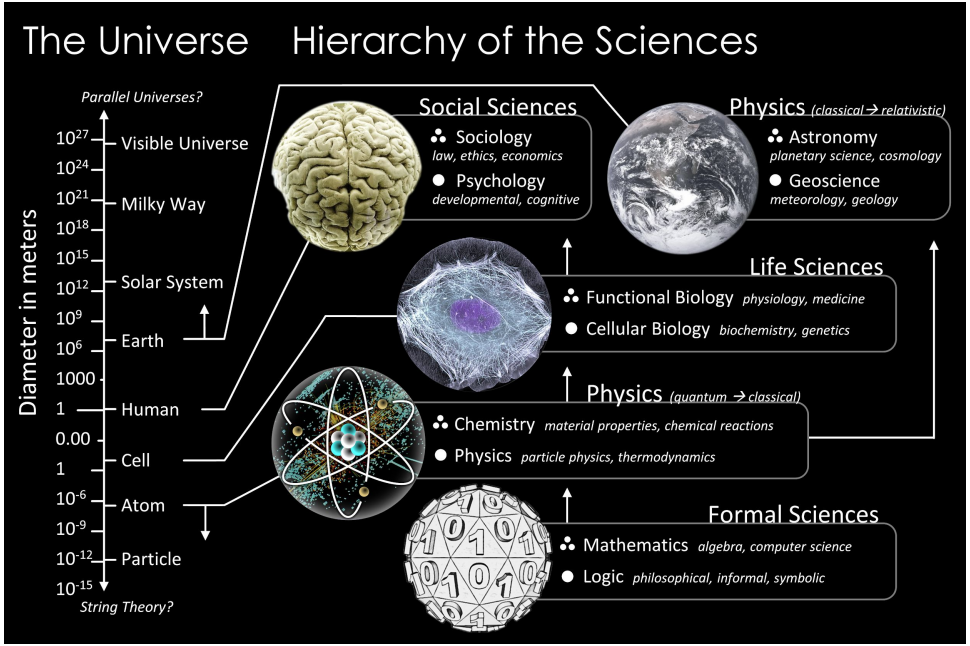
Control of Double Inverted Pendulum, WETI Gdańsk, Mar 13, 2014, https://youtu.be/JpNAhKT7yY4

Why are some models useful?

The natural world can be usefully

- Separated
- Approximated
- Idealized
- Abstracted

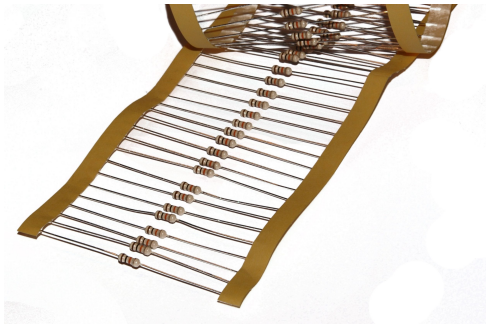
A model can focus on a particular aspect of the natural world to produce a useful result.



https://en.wikipedia.org/wiki/Branches_of_science

Synthetic Systems can Simplify Modeling

- Mass produced objects with little variation
- Components with simple behavior
  - Linear spring
  - Linear resistor
- LEGO like systems for engineers
  - Analog electronics
  - Fluids (plumbing)
  - ...
  - Digital systems
  - Synthetic biology
- Often only simplify half of the modeling problem, since synthetic systems interact with the natural world, especially in BME.



coil spring image: https://www.speedwaymotors.com/QA1-10-Inch-Coil-Over-Spring-2-1-2-Inch-I-D-,36862.html

Reality is Expensive - Models are Cheap

- Plan for iteration
- Building real things is costly
  - Costs time, money, effort, etc.
  - Manual Labor
  - Real components
  - Tooling for custom parts
  - Risks to real users
- Models can be fast & cheap
  - Pencil and paper
  - Thinking

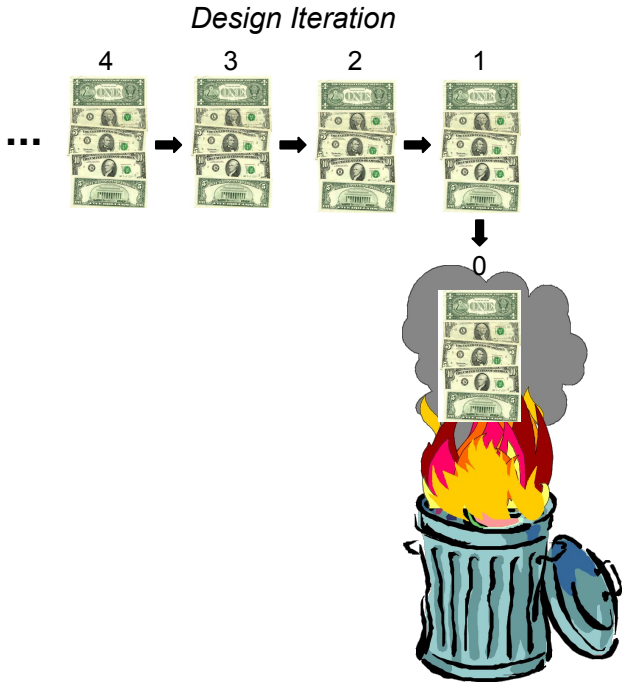
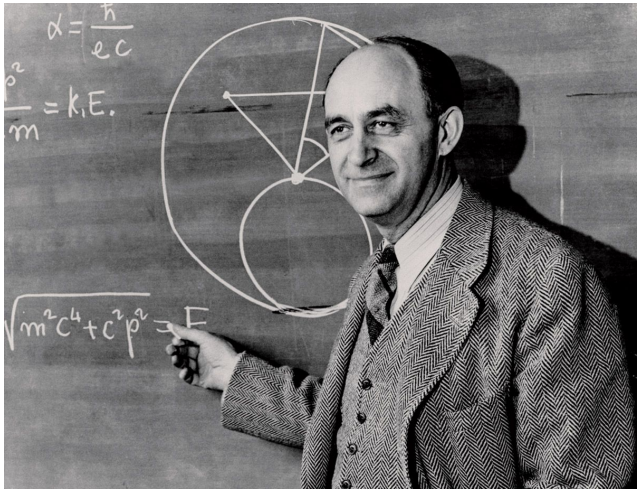


Image from: https://www.clipart.email/make-a-clipart/?image=7268829 https://upload.wikimedia.org/wikipedia/commons/6/63/USCurrency_Federal_Reserve.jpg

Simple Models are Powerful

- Give intuition
- Quickly assess feasibility
- Find approximate answers
- Help identify what is important to model
- Stepping stone to more complex models
- Sanity check for more complex models
- Help with communication and collaboration
- **Impress your friends and co-workers!**

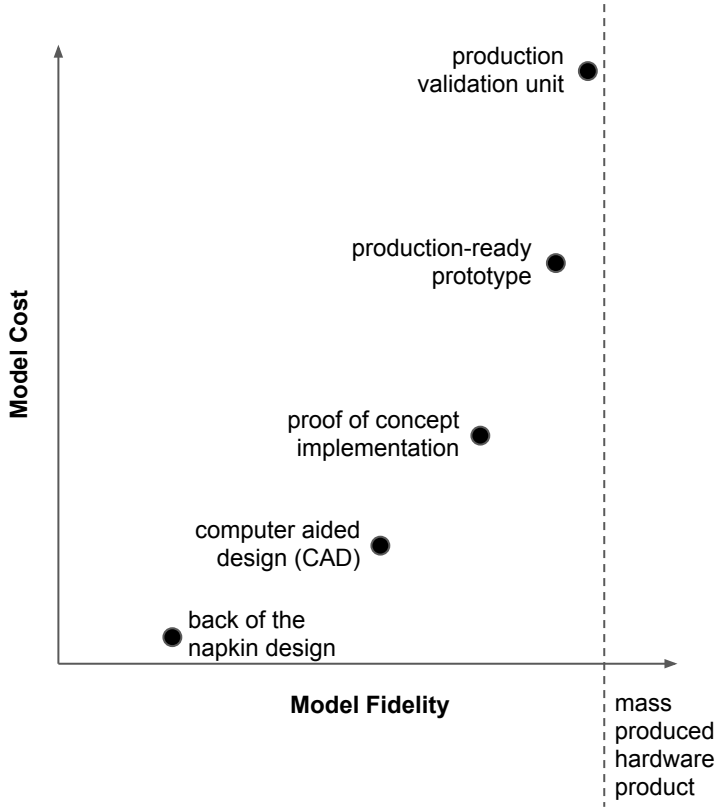


https://en.wikipedia.org/wiki/Fermi_problem

Photo: https://www.atomicheritage.org/profile/enrico-fermi

Models are Plentiful

- Model fidelity and the costs associated with using a model tend to increase together.
- Types of Models
  - Mathematical
  - Computational
  - Physical
- Example of mass produced hardware
  - A long road to product
  - Many models along the way

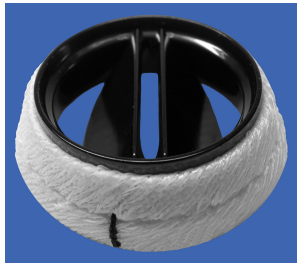


Examples of Modeling Terminology in BME

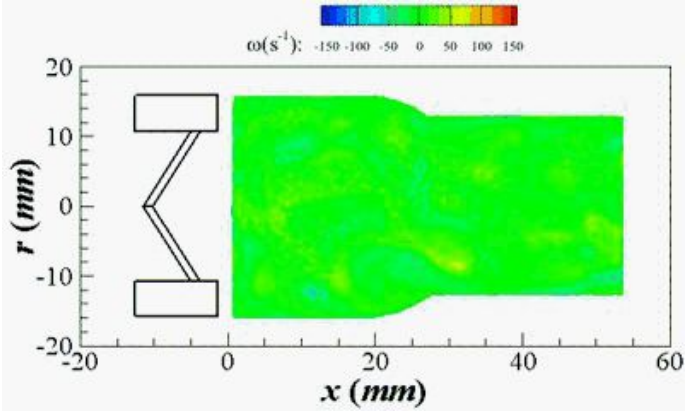
- in silico
- in vitro
- in vivo
- model organism

https://en.wikipedia.org/wiki/Model_organism

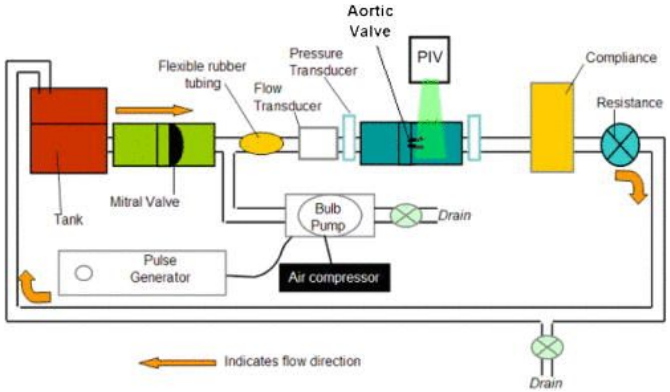
Prosthetic Heart Valve Research from Prof. Yoganathan's Lab



Bileaflet Heart Valve



Computational Model



Physical Model

Top gif from http://groups.bme.gatech.edu/groups/cfmg/group/home.htm
Bileaflet valve picture from https://en.wikipedia.org/wiki/Artificial_heart_valve#/media/File:Aortic_Karboniks-1_bileafter_prosthetic_heart_valve.jpg
Diagram from Dasi, L. P., et al. "Vorticity dynamics of a bileaflet mechanical heart valve in an axisymmetric aorta." Physics of Fluids (1994-present) 19.6 (2007): 067105.

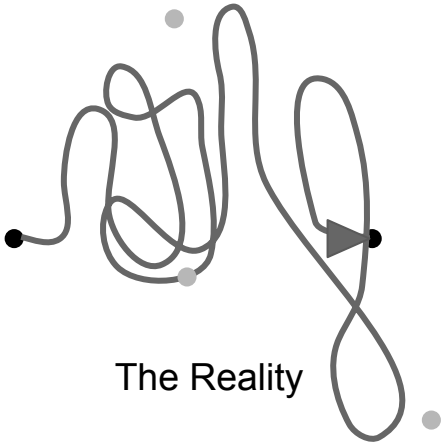
A Model Example

Problem Solving Trajectories

The Story We Tell

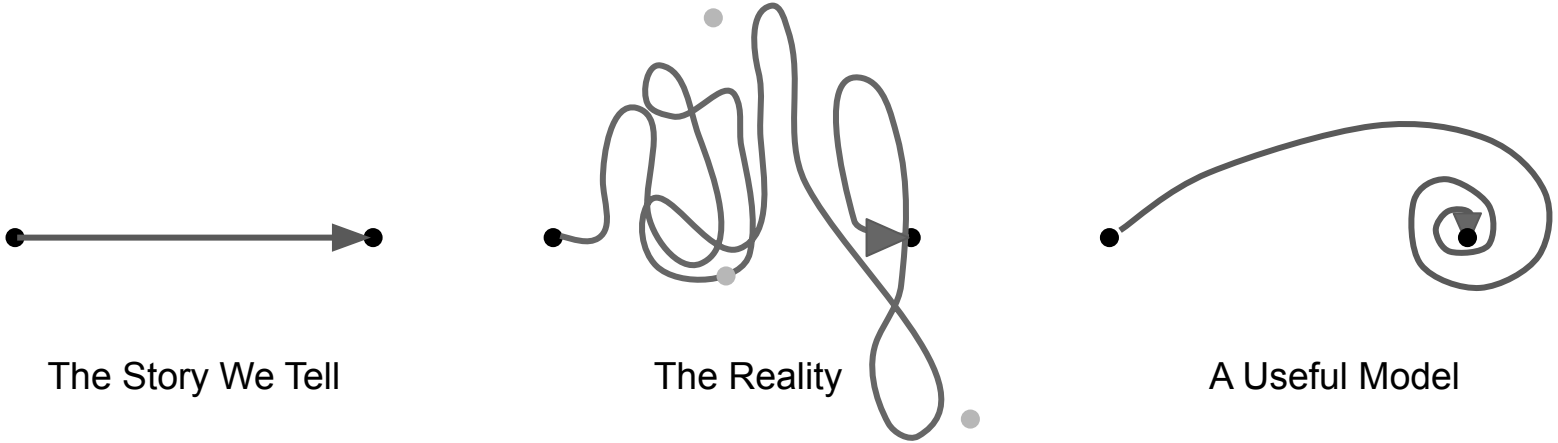
Problem Solving Trajectories

The Story We Tell



The Reality

Problem Solving Trajectories



The Story We Tell

The Reality

A Useful Model

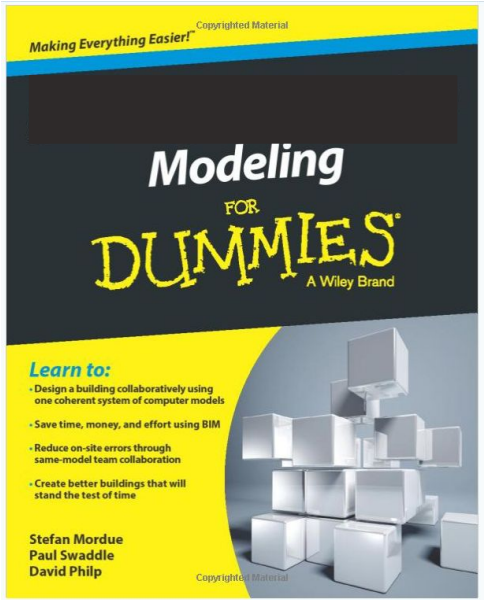
Most Models Won’t Work

- A model represents a narrow part of the world
- Pick the right tool for the right job
  - Can the model answer your question?
  - Do you have the required information?
  - Are the assumptions appropriate?
  - Is the answer reasonable?
  - **Be skeptical!**

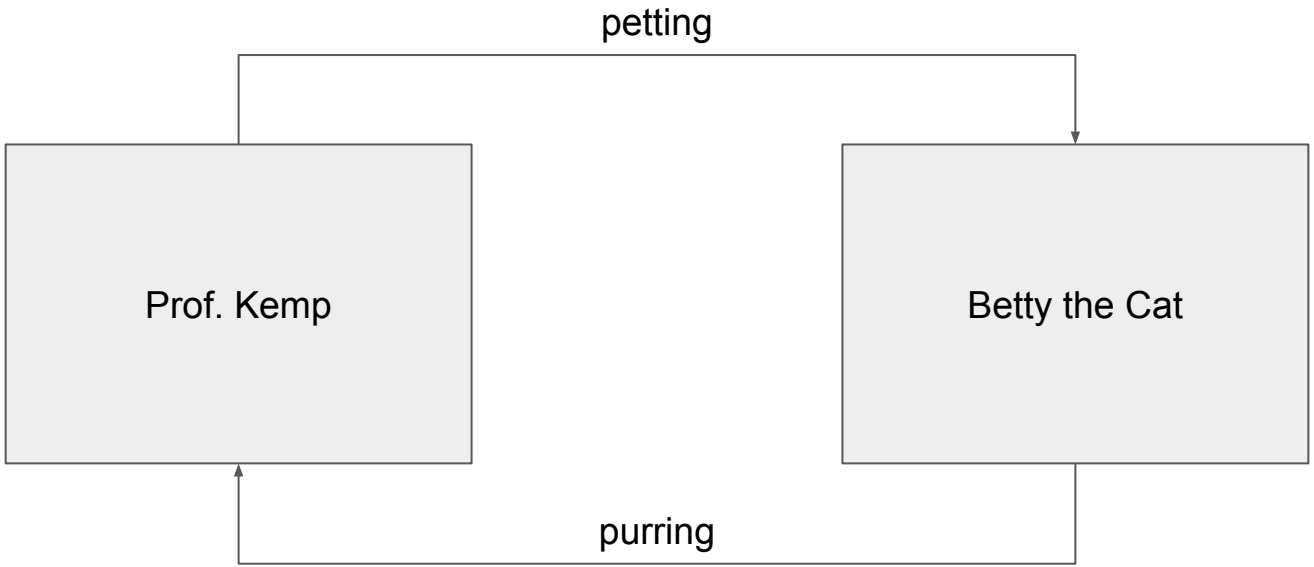
https://en.wikipedia.org/wiki/Spherical_cow

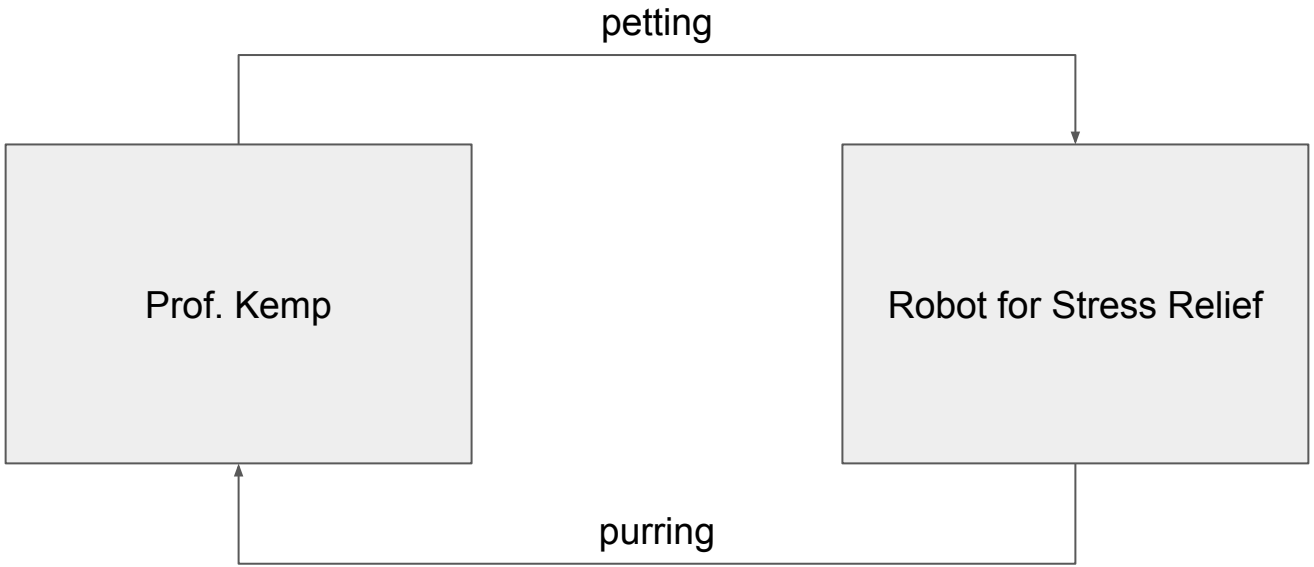
A Simple Model of Modeling

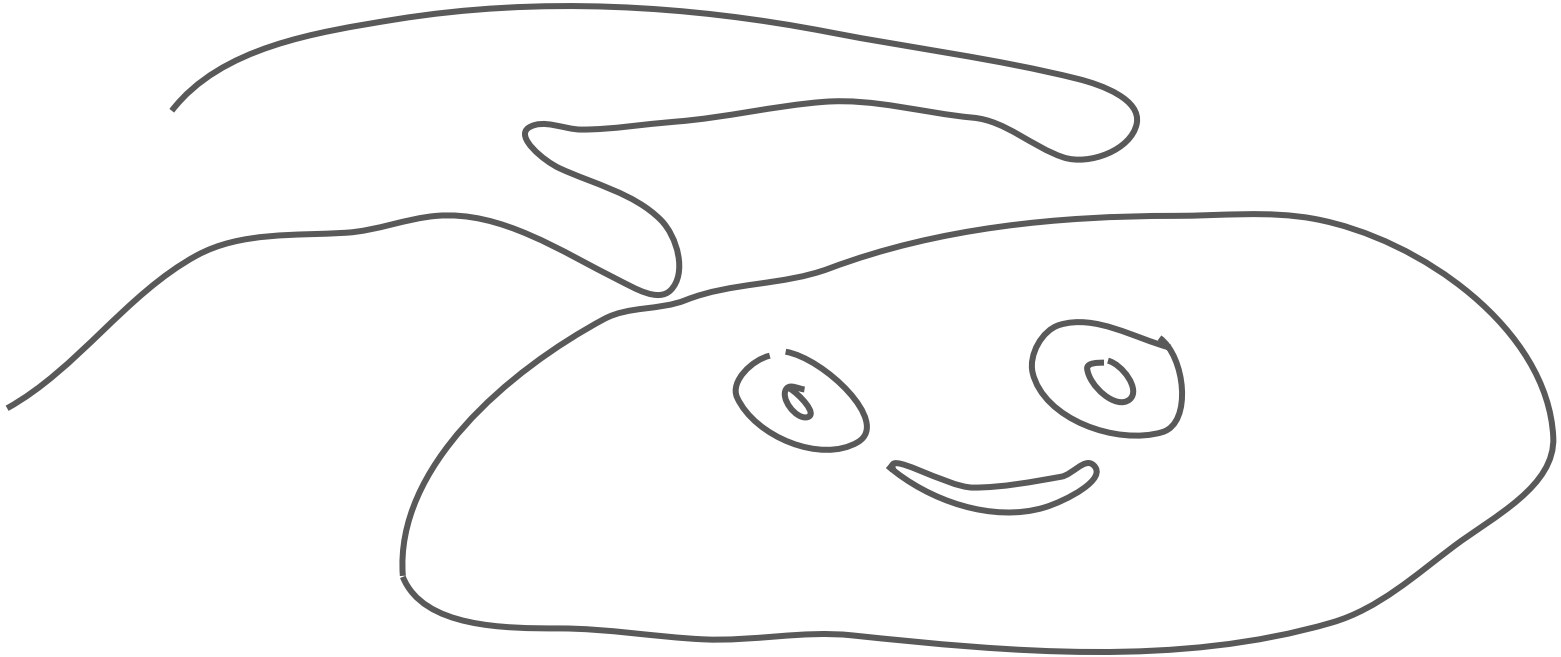
1. Draw pictures and diagrams of the system.
2. Come up with an important question.
3. Guess the answer to your question.
4. Use simple models to answer your question.
5. **Iterate through models**, increasing complexity as needed.

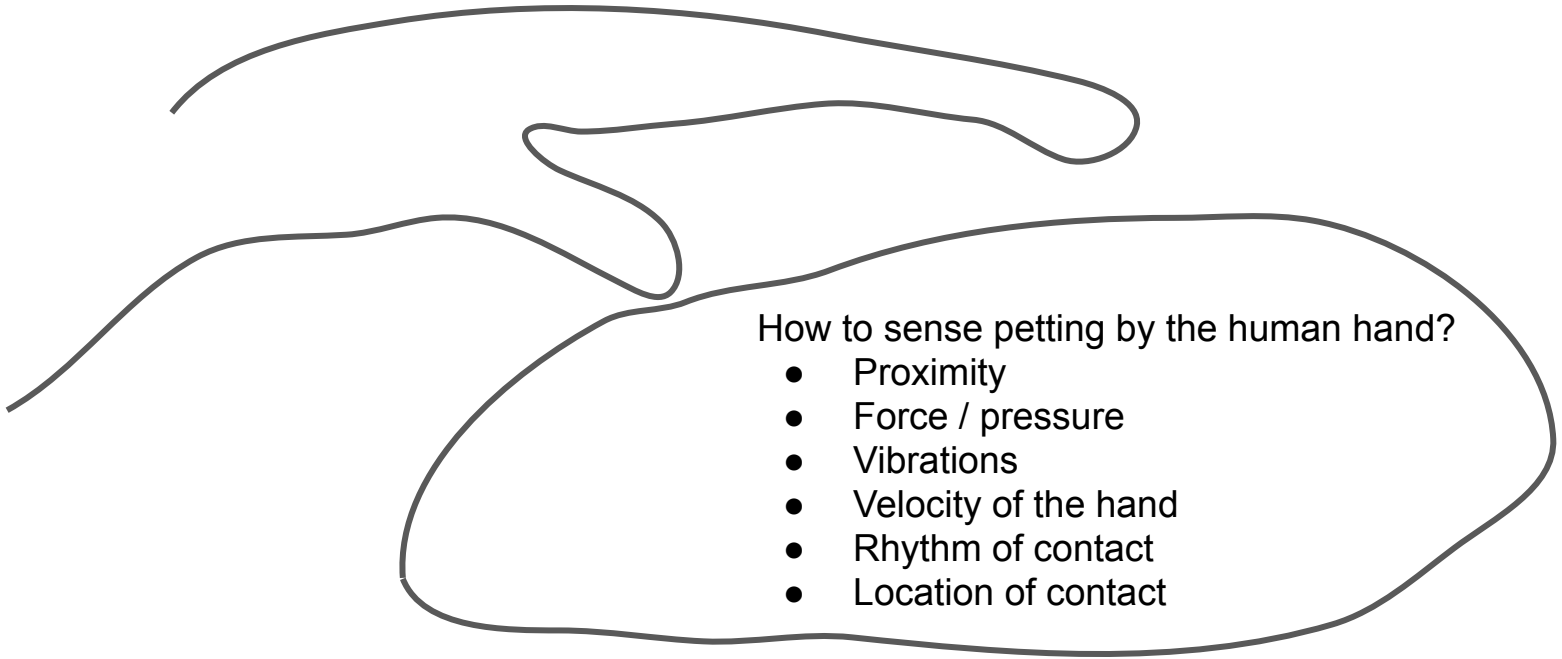


https://www.amazon.com/Building-Information-Modeling-Dummies-Stefan/


petting
Prof. Kemp
Betty the Cat
purring

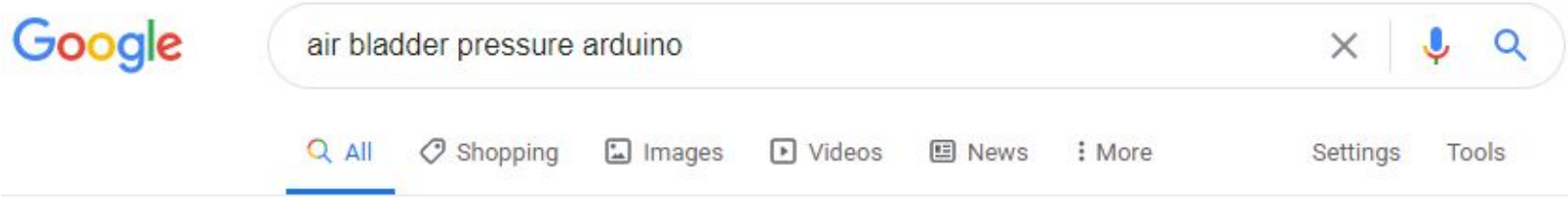

petting
Prof. Kemp
Robot for Stress Relief
purring




How to sense petting by the human hand?
Proximity
Force / pressure
Vibrations
Velocity of the hand
Rhythm of contact
Location of contact

Sense Petting by a Human Hand

- Proximity
  - < ~1cm to surface, thick fur
  - Capacitive sensing
- Force / pressure
  - < ~2 N = 0.2 kg * 10 m/s^2 = ma
  - Force sensitive resistors
  - Air pressure
- Vibrations
  - ? (depends on surface?)
  - Accelerometers
  - Contact microphone
- Other properties
  - Velocity of the hand
    - ~0.1 m/s
  - Rhythm of contact
    - ~1Hz
  - Location of contact
    - Top surface of the robot
    - All surfaces other than the face?



http://pneuduino.org/toolkit/

https://softroboticstoolkit.com/pds/design

https://softroboticstoolkit.com/pds/design/sensor

https://softroboticstoolkit.com/pds

soft robotics toolkit

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Gripper for SDM fingers

- *Pneumatic Deformation Sensors*
- Background
- Design
- Fabrication
- Testing
- Downloads
- Corresponding Author

Contributor

Aidan Leitch

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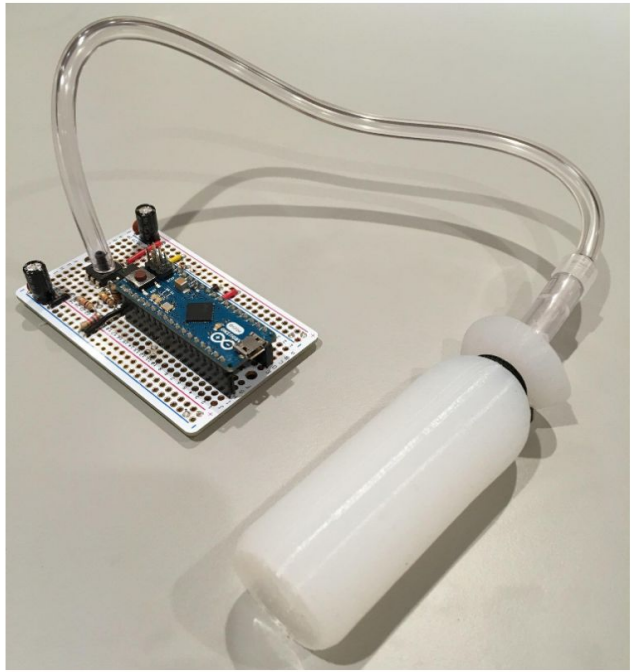
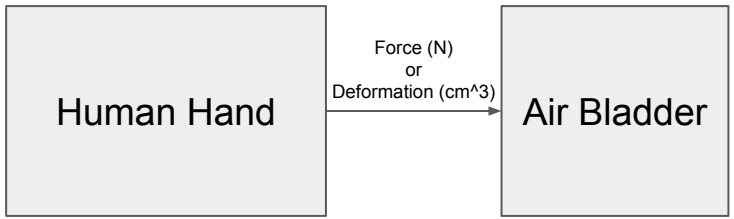
Pneumatic Deformation Sensors

Pneumatic Deformation Sensors (PDS's) are a new type of soft sensor designed for use with soft robots. The sensors are intended to provide feedback on how they deform, hence them being deformation sensors. They can be fitted and utilized in many soft robotic actuators, such as the actuators on the Soft Robotics Toolkit.



Sense Petting with an Air Bladder

Sense Petting with an Air Bladder



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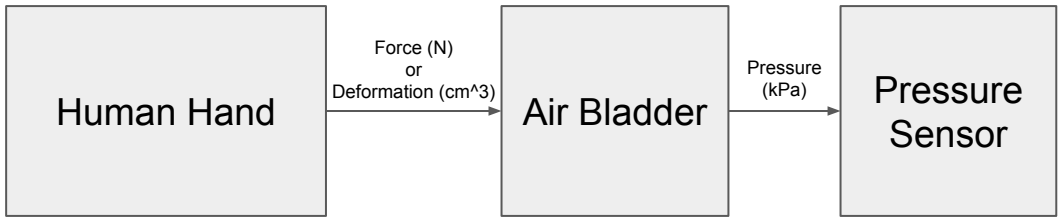

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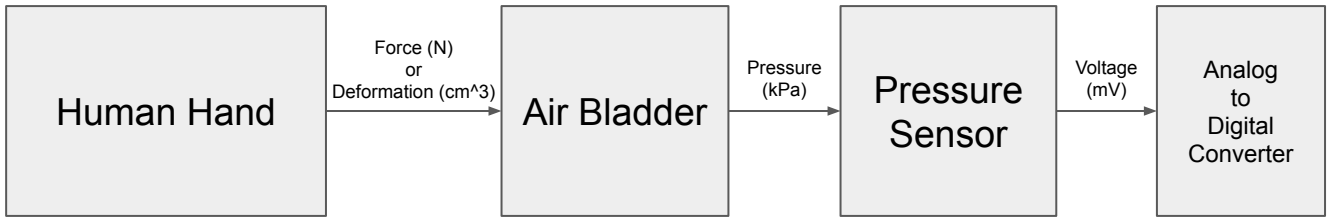

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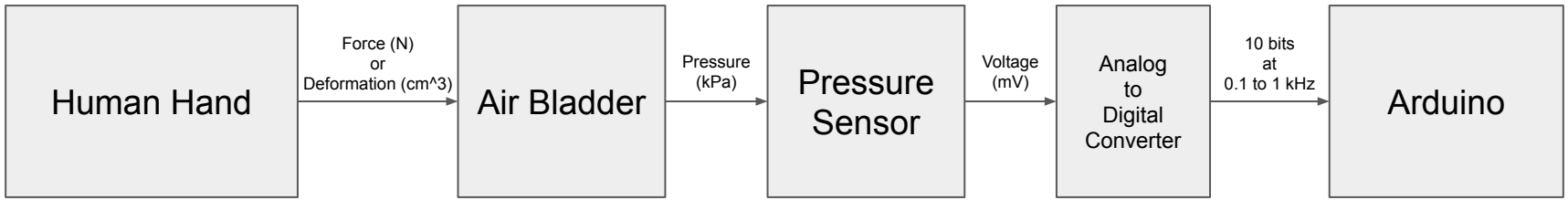

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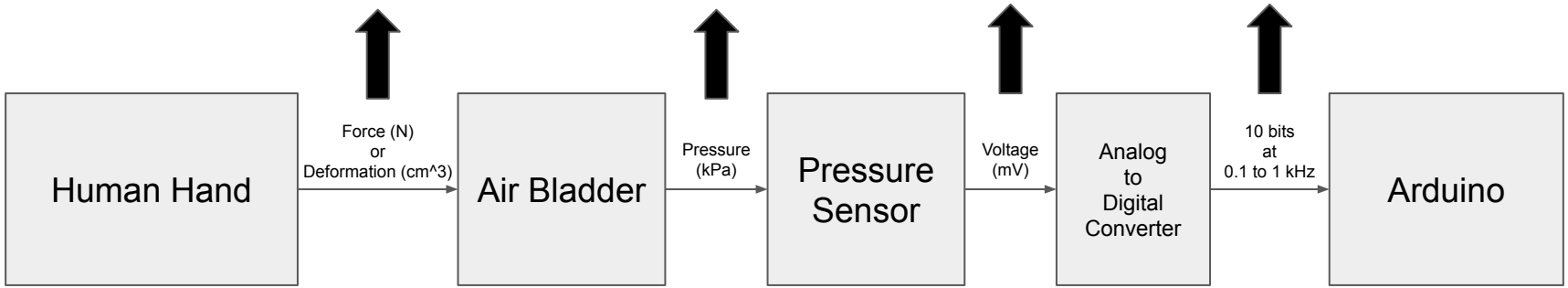

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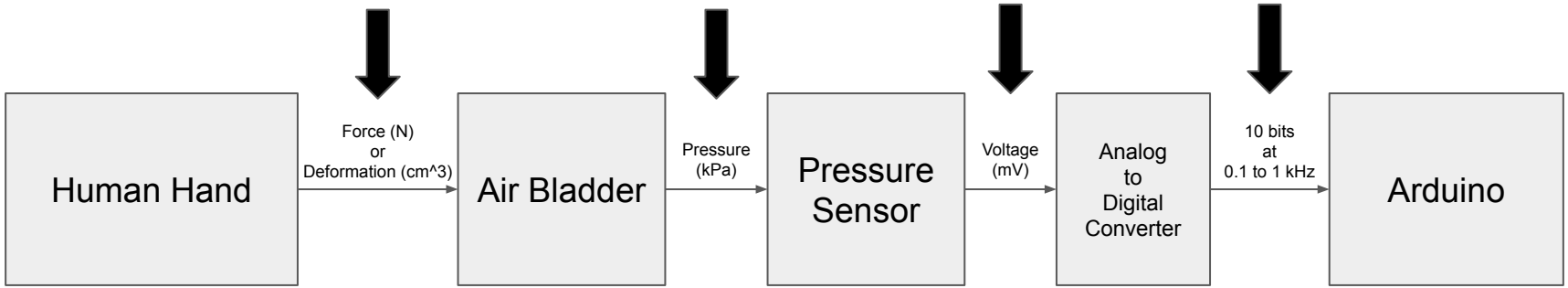

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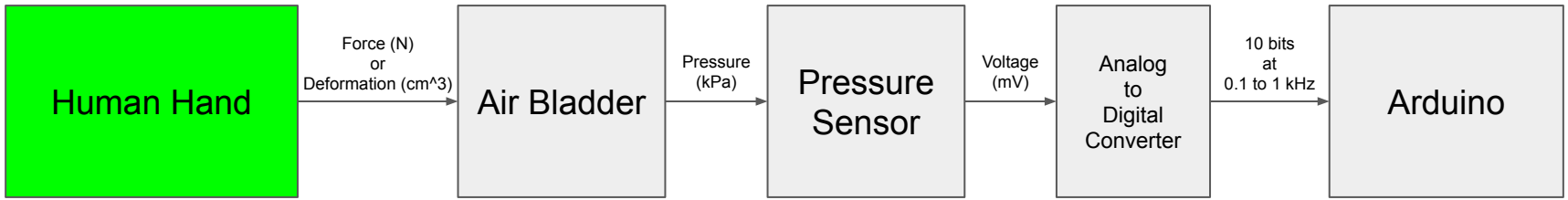

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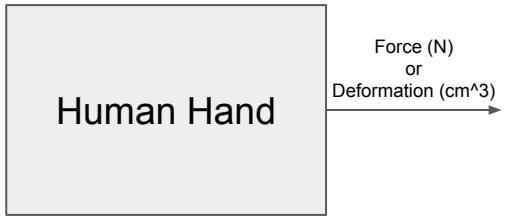
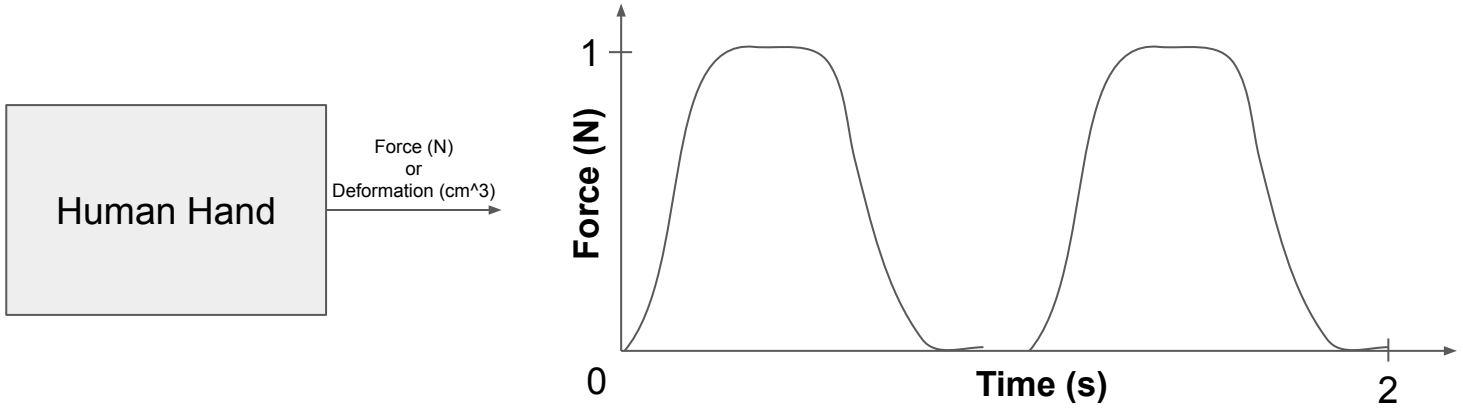


Human Hand

- Force < 2N
- Rhythm ~1Hz

Sense Petting with an Air Bladder



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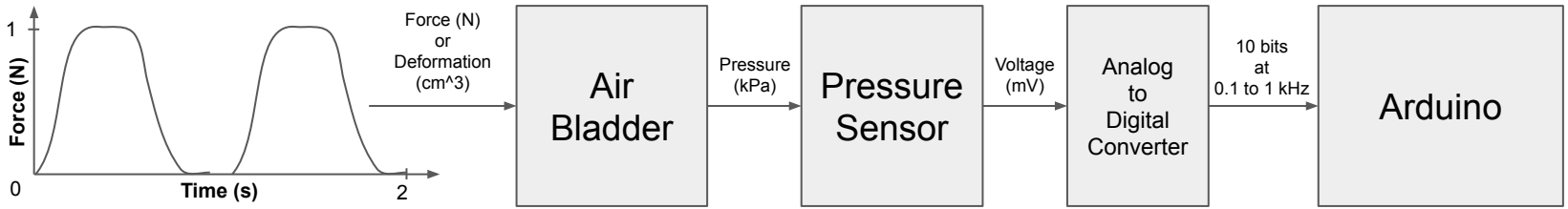

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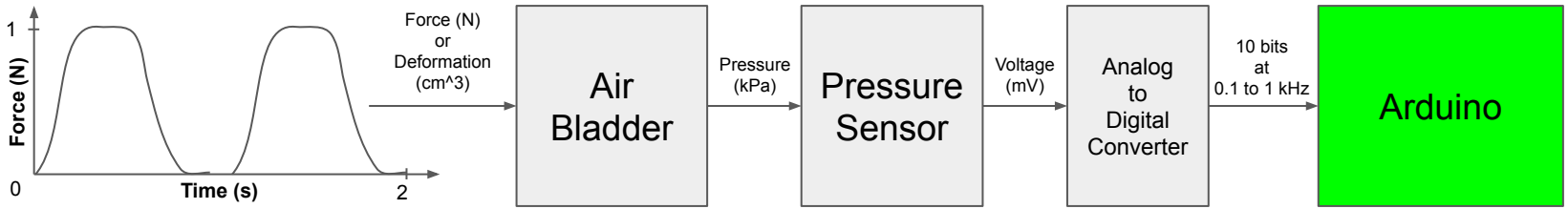

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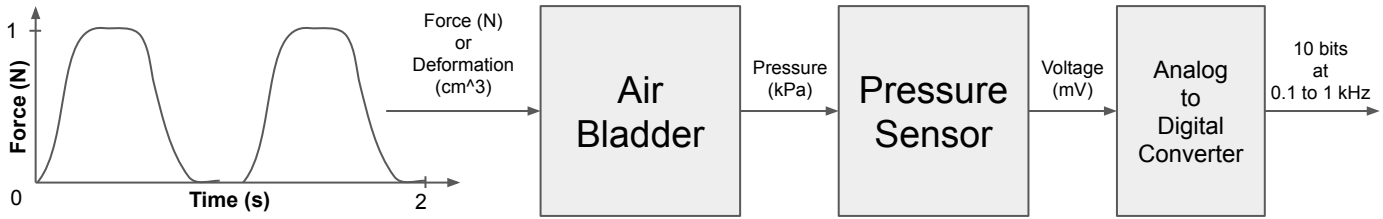

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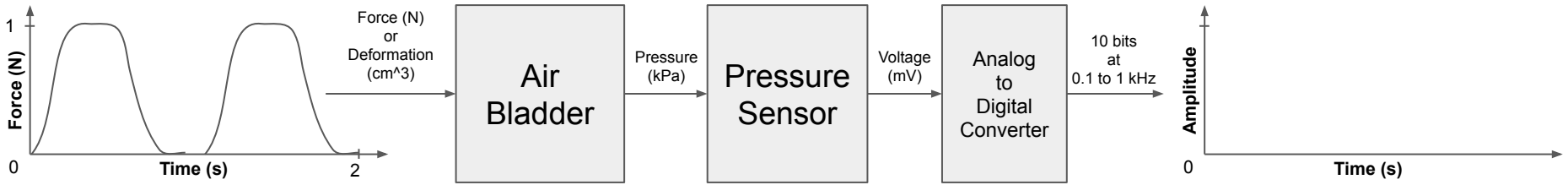

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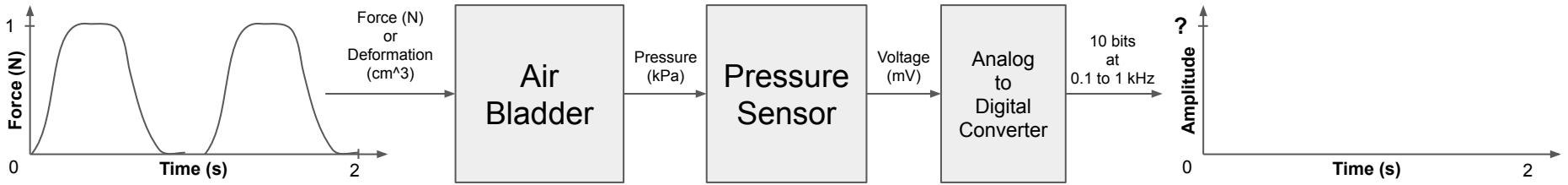

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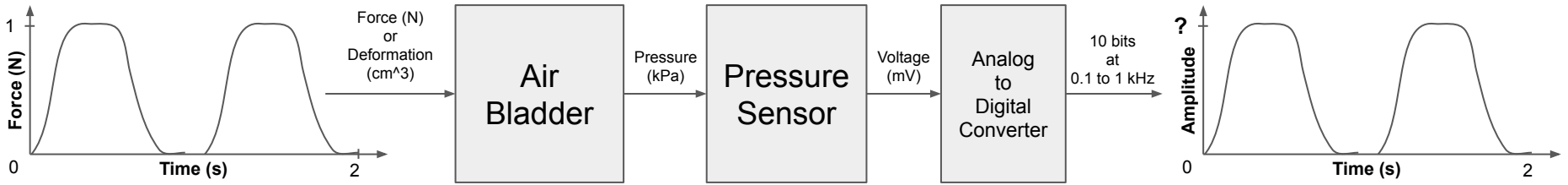

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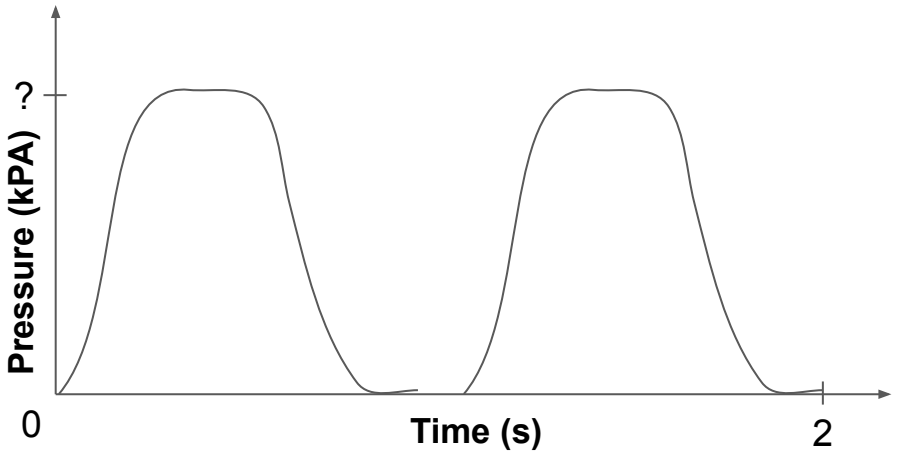

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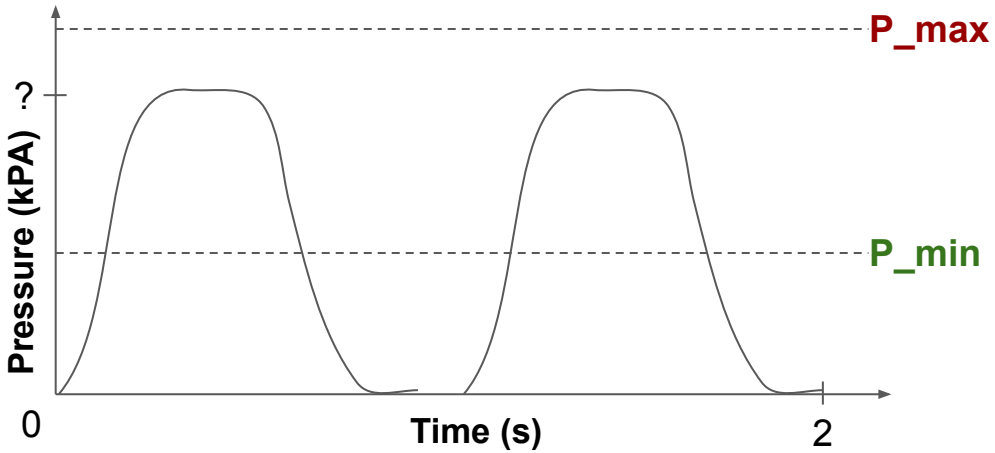

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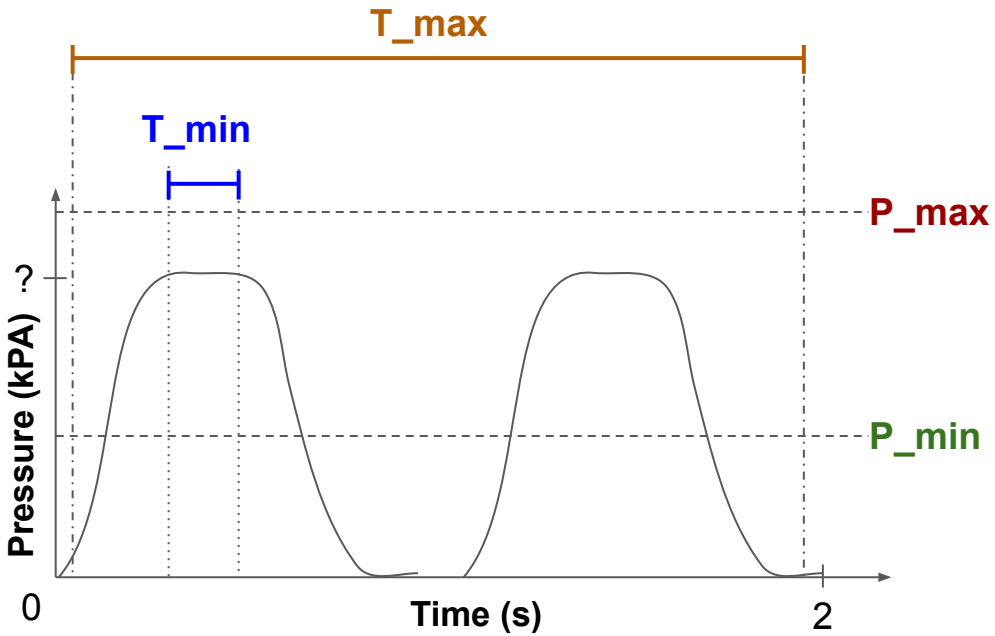

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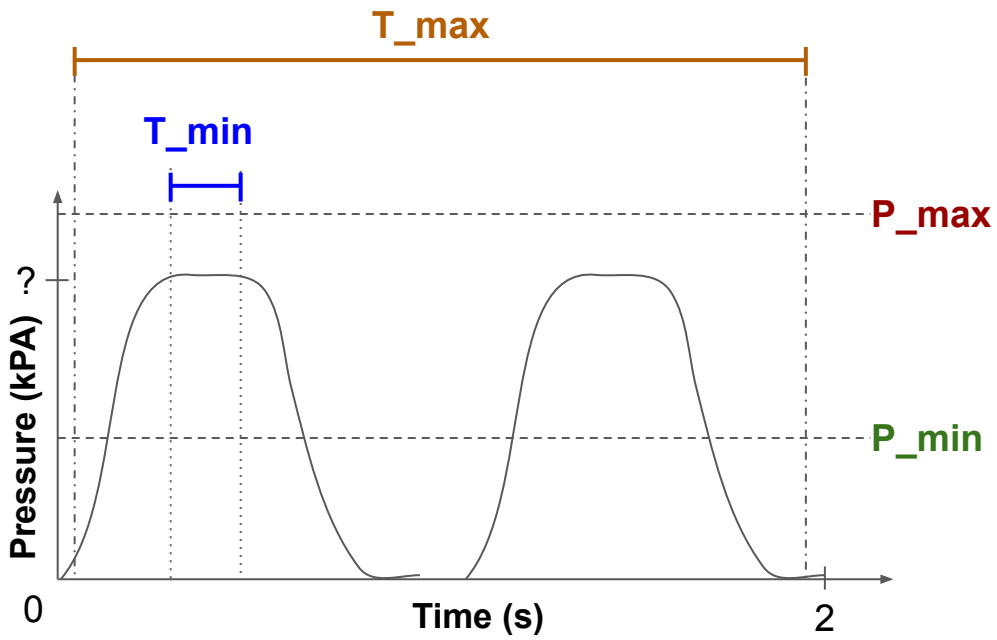
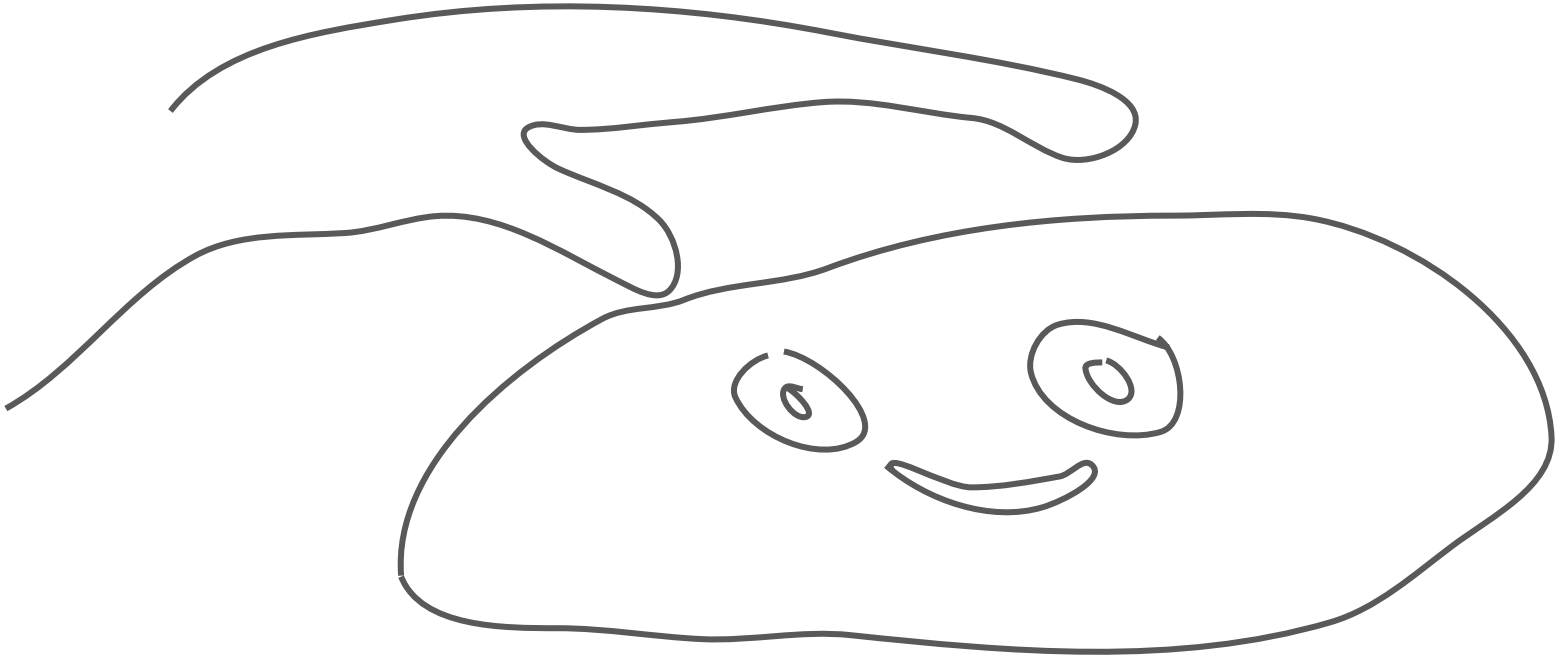
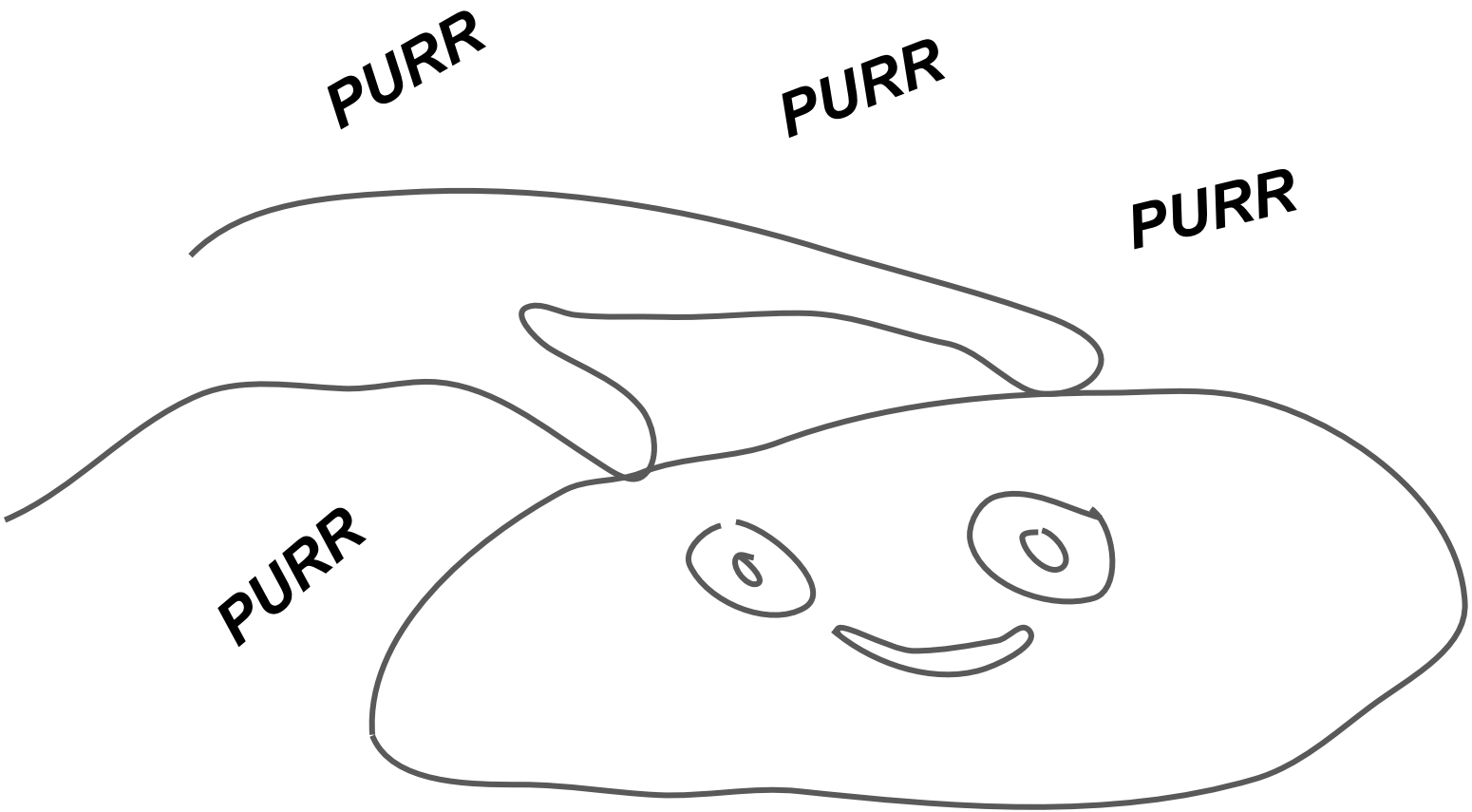


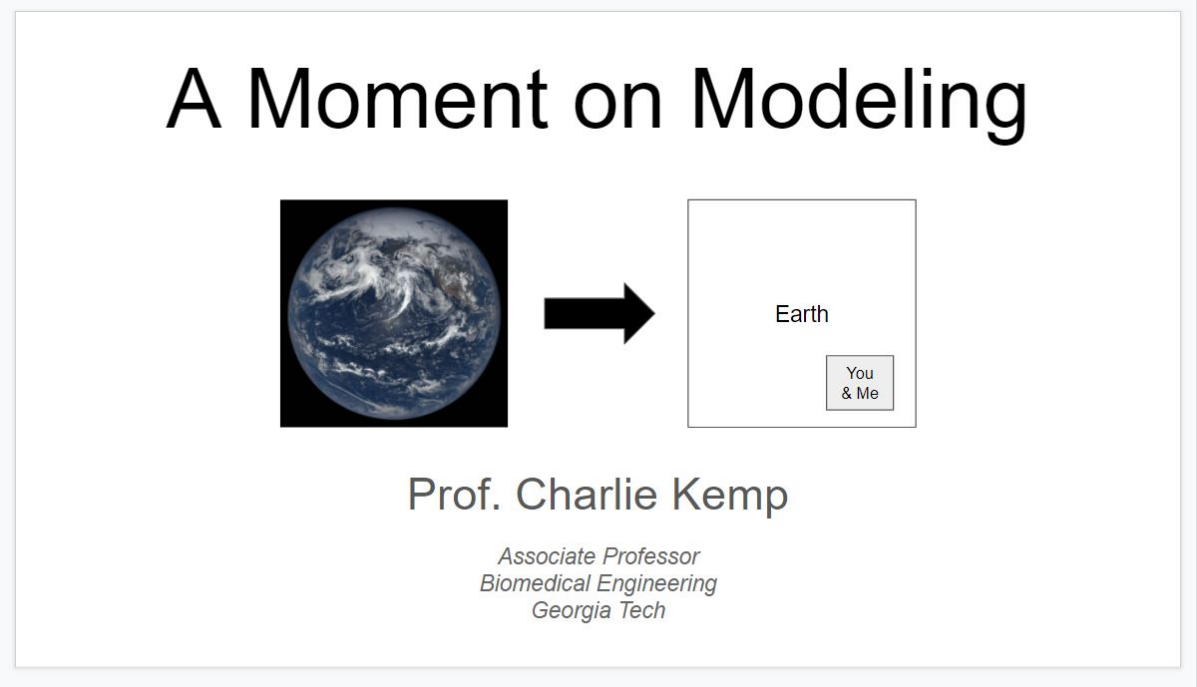

```
petting = False
stroke = 0
Reset timer
While not petting
     P = New pressure reading
     If P_min < P < P_max
          Start timer
     Else
          Stop timer
          If T_min < timer < T_max
               stroke = stroke + 1
          Reset timer
     If stroke >= 2
          petting = True
Make purring sound
Repeat
```




PURR
PURR
PURR
PURR

Recapitulation

- Models are wrong
- Models are useful
- Models are cheap
- Models are plentiful
- A Model Example



The natural world is complex… really really complex

You'll never perfectly model the natural world. Embrace imperfection.

"The uncertainty principle implies that it is in general not possible to predict the value of a quantity with arbitrary certainty, even if all initial conditions are specified." - https://en.wikipedia.org/wiki/Uncertainty_principle

"Physicists have found that even passive observation of quantum phenomena (by changing the test apparatus and passively 'ruling out' all but one possibility), can actually change the measured result." - https://en.wikipedia.org/wiki/Observer_effect_(physics)

"In chaotic systems, the uncertainty in a forecast increases exponentially with elapsed time." https://en.wikipedia.org/wiki/Chaos_theory

"According to modern understanding, even if all matter could be removed from a volume, it would still not be "empty" due to vacuum fluctuations, dark energy, transiting gamma rays, cosmic rays, neutrinos, and other phenomena in quantum physics." - https://en.wikipedia.org/wiki/Vacuum

"In computability theory, an undecidable problem is a type of computational problem that requires a yes/no answer, but where there cannot possibly be any computer program that always gives the correct answer; that is, any possible program would sometimes give the wrong answer or run forever without giving any answer." - https://en.wikipedia.org/wiki/List_of_undecidable_problems

"Although a solution to an NP-complete problem can be verified "quickly", there is no known way to find a solution quickly. That is, the time required to solve the problem using any currently known algorithm increases rapidly as the size of the problem grows." - https://en.wikipedia.org/wiki/NP-completeness

"Gödel's incompleteness theorems are two theorems of mathematical logic that demonstrate the inherent limitations of every formal axiomatic system capable of modelling basic arithmetic." - https://en.wikipedia.org/wiki/G%C3%B6del%27s_incompleteness_theorems

"Although the Standard Model is believed to be theoretically self-consistent and has demonstrated huge successes in providing experimental predictions, it leaves some phenomena unexplained and falls short of being a complete theory of fundamental interactions." - https://en.wikipedia.org/wiki/Standard_Model