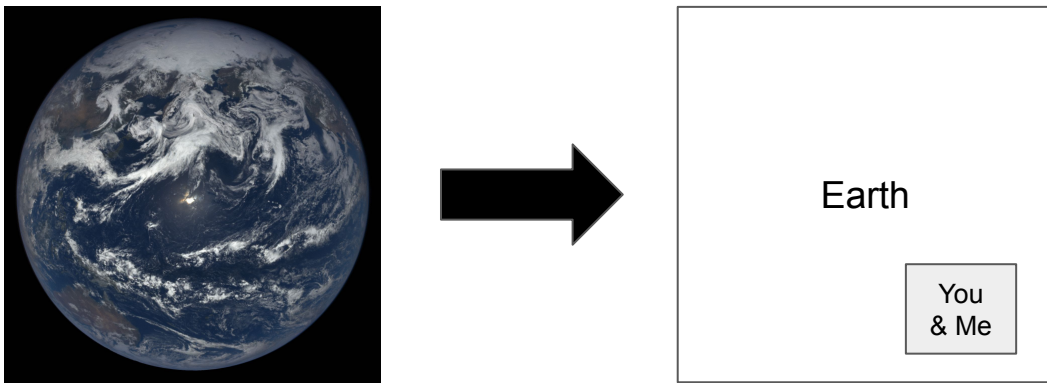


# A Moment on Modeling



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

The screenshot shows the Wikipedia page titled "Table of contents". The page includes a sidebar with navigation links, a main content area with a table of contents, and a section for examples. The table of contents lists sections such as "Earliest use", "Form", "Examples", and "References". The examples section provides various formats for tables of contents, including those with leaders, without leaders, with authors, and with descriptive text.

**Table of contents**

From Wikipedia, the free encyclopedia

This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed.  
Find sources: "Table of contents" – news – newspapers – books – scholar – JSTOR (April 2012) (Learn how and when to remove this template message)

A table of contents, usually headed simply **Contents** and abbreviated informally as **TOC**, is a list, usually found on a page before the start of a written work, of its chapter or section titles or brief descriptions with their commencing page numbers

**Contents** [hide]

- Earliest use
- Form
- Examples
- See also
- References
- Citation
  - Sources

**Earliest use** [edit]

Pliny the Elder credits Quintus Velleius Paterculus (d. 82 B.C.) as the first author to provide a table of contents to help readers navigate a lengthy work.<sup>[1]</sup> Pliny's own table of contents for his encyclopedia *Natural History* ("Natural History") may be viewed online in *Latin* and in *English* (following dedication).

**Form** [edit]

A table of contents usually includes the titles or descriptions of first-level headings (chapters in longer works), and often includes second-level headings (sections or A-heads) within the chapters as well, and occasionally even includes third-level headings (subsections or B-heads) within the sections as well. The depth of detail in tables of contents depends on the length of the work, with longer works having less. Formal reports (ten or more pages and being too long to put into a memo or letter) also have a table of contents. Within an English-language book, the table of contents usually appears after the title page, copyright notices, and, in technical journals, the abstract, and before any lists of tables or figures, the foreword, and the preface.

Printed tables of contents indicate page numbers where each part starts, while digital ones offer links to go to each part. The format and location of the page numbers is a matter of style for the publisher. If the page numbers appear after the heading text, they might be preceded by characters called *leaders*, usually dots or periods, that run from the chapter or section titles on the opposite side of the page, or the page numbers might remain closer to the titles. In some cases, the page number appears before the text.

If a book or document contains chapters, articles, or stories by different authors, their names usually appear in the table of contents.

Matter preceding the table of contents is generally not listed there. However, all pages except the outside cover are counted, and the table of contents is often numbered with a lowercase Roman numeral page number. Many popular word processors, such as Microsoft Word, WordPerfect, and StarWriter are capable of automatically generating a table of contents if the author of the text uses specific styles for chapters, sections, subsections, etc.

**Examples** [edit]

**Example with leaders**

Chapter 1: Getting Started	1
Introduction	2
Next Steps	3

**Example without leaders**

Chapter 1: Getting Started	1
Introduction	2
Next Steps	3

**Example with authors**

Chapter 1: Introduction to Biology	Arthur C. Seitz	1
2. Microbiology	Susan Jones	18
3. Advances in Biotechnology	T.C. Chang	24

**Example with descriptive text:**

Chapter 1	3
In which we first meet our hero and heroine, attend a gala feast, and begin an unexpected journey.	
Chapter 2	12
The journey takes an unusual turn, and new villains are discovered.	

**See also** [edit]

- Index (publishing)

**References** [edit]

**Citations** [edit]

<sup>[1]</sup> Pliny the Elder, *preface* 33, *MEDIEVAL* MEDIEVAL, John Henderson, "Crossing Someone Through Their Backs: Pliny on Unlucky Pliny" (*JPHS* 13.1), *Classical Philology* 97 (2002), p. 276.

**Sources** [edit]

- The Chicago Manual of Style (18th Edition).
- Gerard J. Auld, Charles T. Brusse, Walter C. Ols (2003), *Handbook of Technical Writing* (ISBN 0-312-30925-2).

Categories: Technical communication | Book design | Index (publishing)

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

George E. P. Box

[https://en.wikipedia.org/wiki/All\\_models\\_are\\_wrong](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
  - $\sim 10^{23}$  atoms in a 1 cm<sup>3</sup> 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>

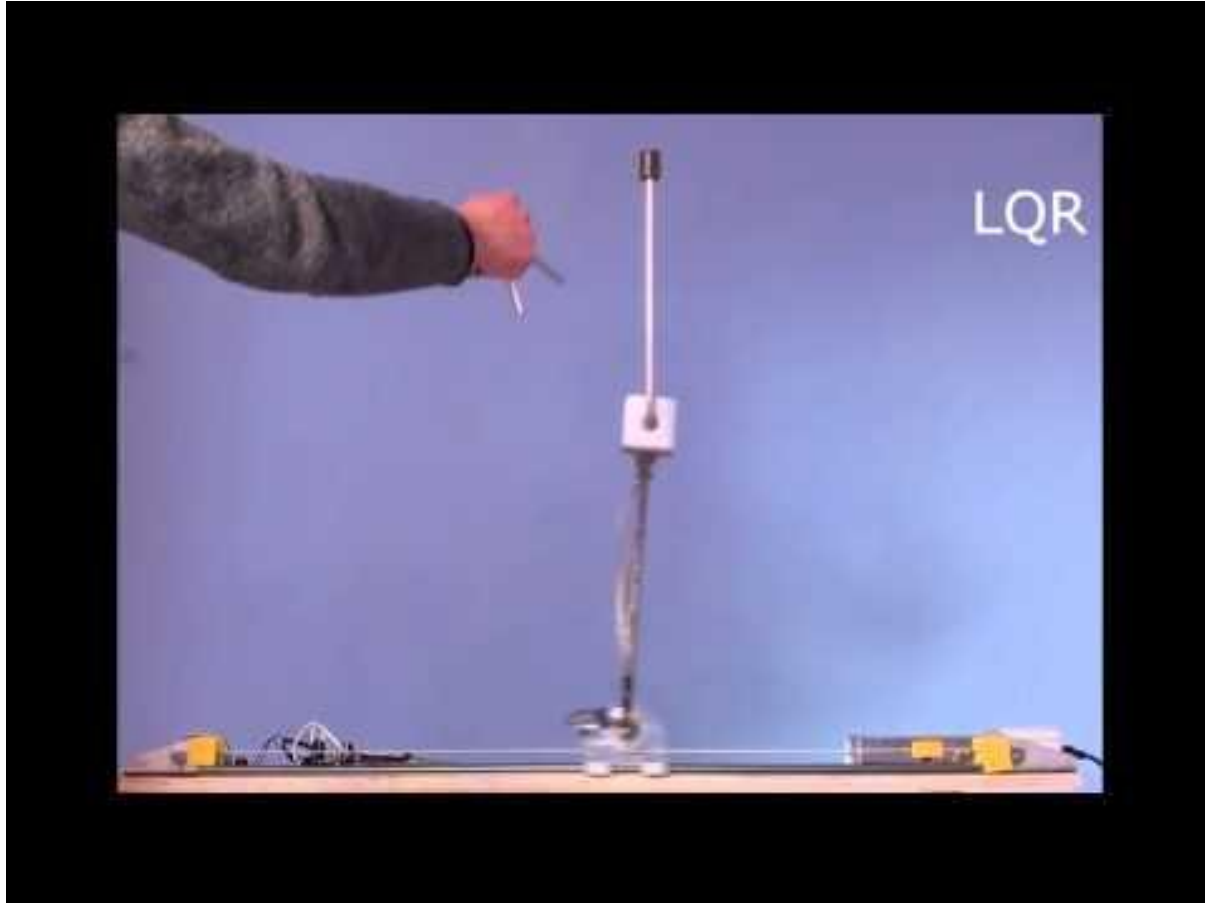


WARNING: Do not confuse a model with the real thing.



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

# Some Models are Useful

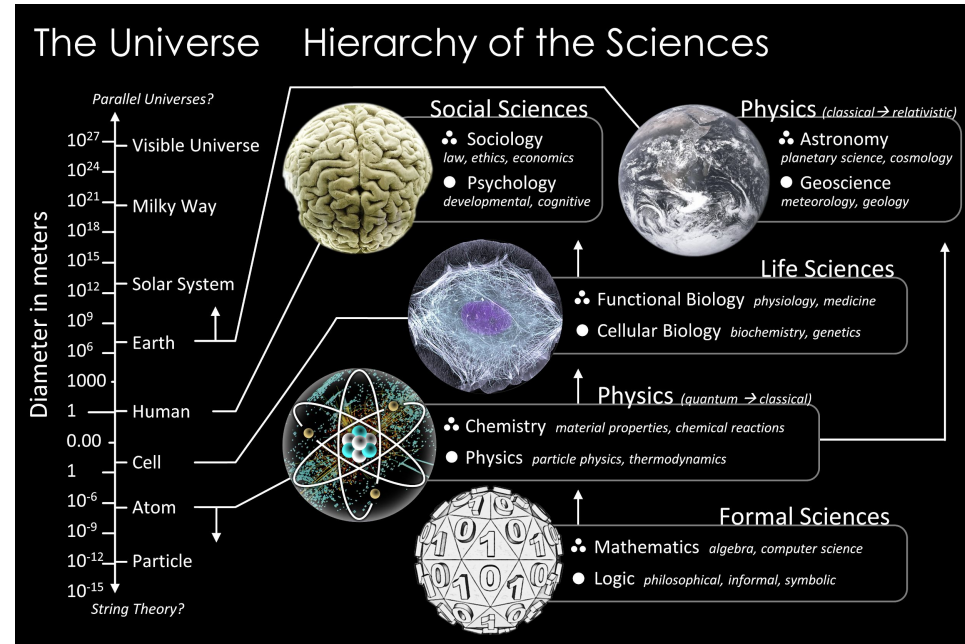


# Why are some models useful?

The natural world can be usefully

- Separated
- Approximated
- Idealized
- Abstracted

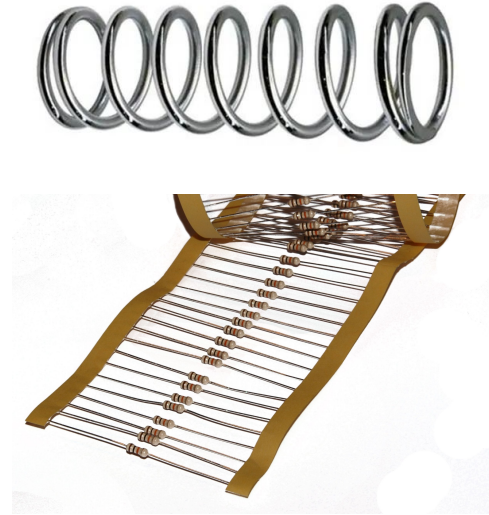
A model can focus on a particular aspect of the natural world to produce a useful result.



[https://en.wikipedia.org/wiki/Branches\\_of\\_science](https://en.wikipedia.org/wiki/Branches_of_science)

# Synthetic Systems can Simplify Modeling

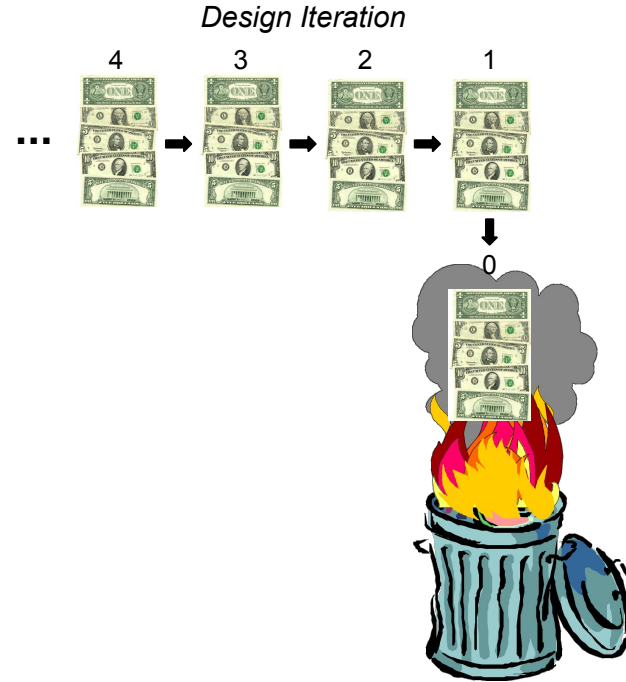
- Mass produced objects with little variation
- Components with simple behavior
  - [Linear spring](#)
  - [Linear resistor](#)
- LEGO like systems for engineers
  - Analog electronics
  - Fluids (plumbing)
  - ...
  - Digital systems
  - Synthetic biology
- Often only simplify half of the modeling problem,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





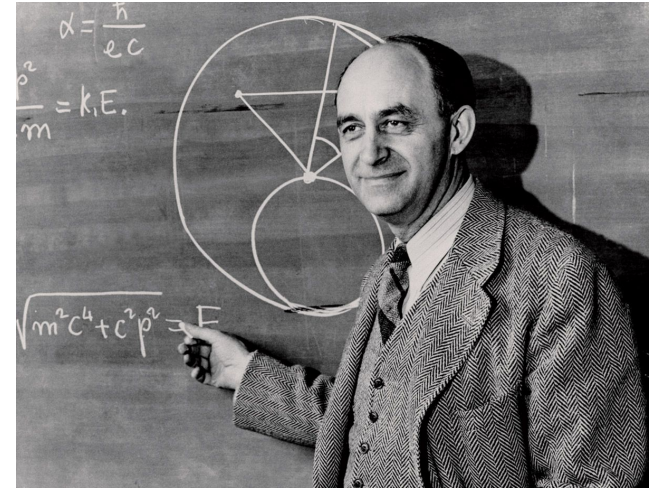
# Reality is Expensive - Models are Cheap

- 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



# Simple Models are Powerful

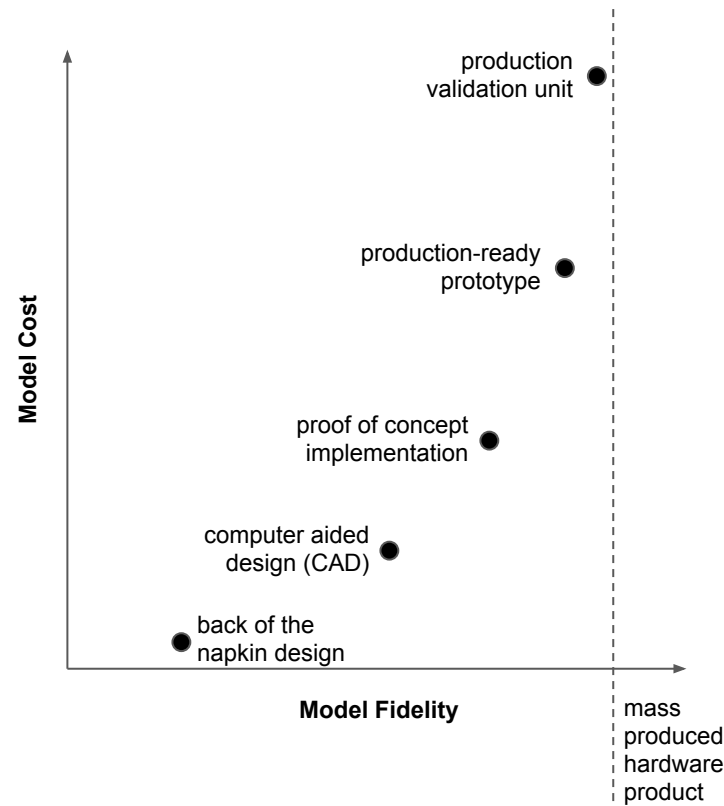
- Give intuition
- Quickly assess feasibility
- Find approximate answers
- Help identify what is important to model
- Stepping stone to more complex models
- Sanity check for more complex models
- Help with communication and collaboration
- **Impress your friends and co-workers!**



[https://en.wikipedia.org/wiki/Fermi\\_problem](https://en.wikipedia.org/wiki/Fermi_problem)

# 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



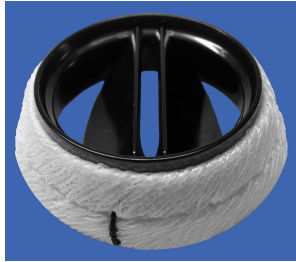
# Examples of Modeling Terminology in BME

- [in silico](#)
- [in vitro](#)
- [in vivo](#)
- [model organism](#)

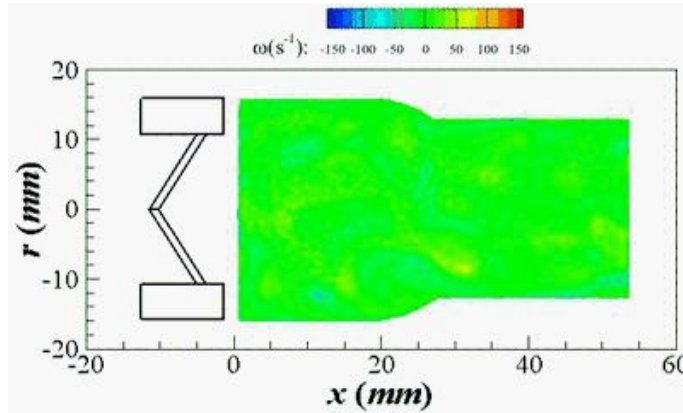


[https://en.wikipedia.org/wiki/Model\\_organism](https://en.wikipedia.org/wiki/Model_organism)

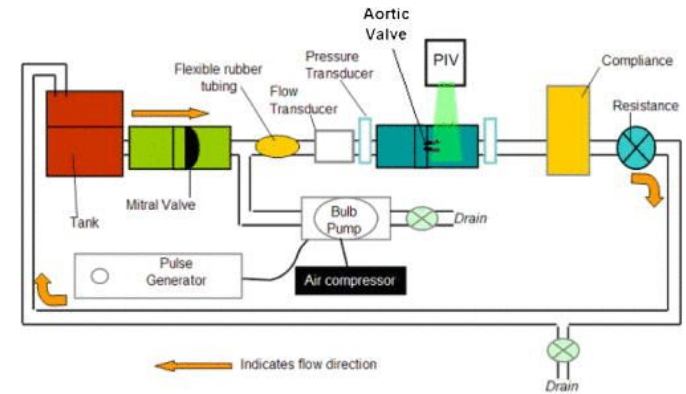
# Prosthetic Heart Valve Research from Prof. Yoganathan's Lab



**Bileaflet  
Heart Valve**



**Computational Model**



**Physical Model**

# A Model Example

# Problem Solving Trajectories

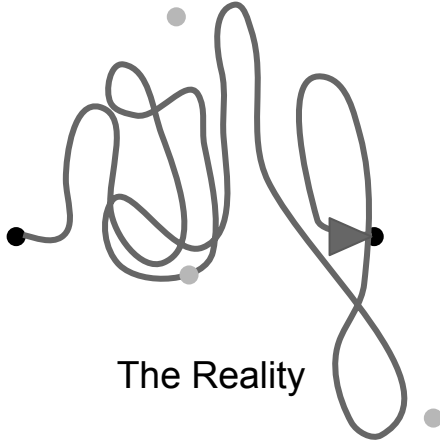


The Story We Tell

# Problem Solving Trajectories



The Story We Tell



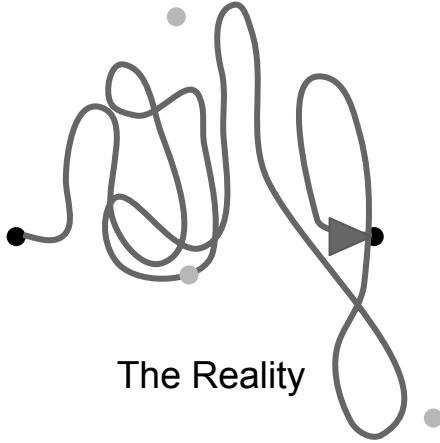
The Reality



# Problem Solving Trajectories



The Story We Tell



The Reality



A Useful Model

# Most Models Won't Work

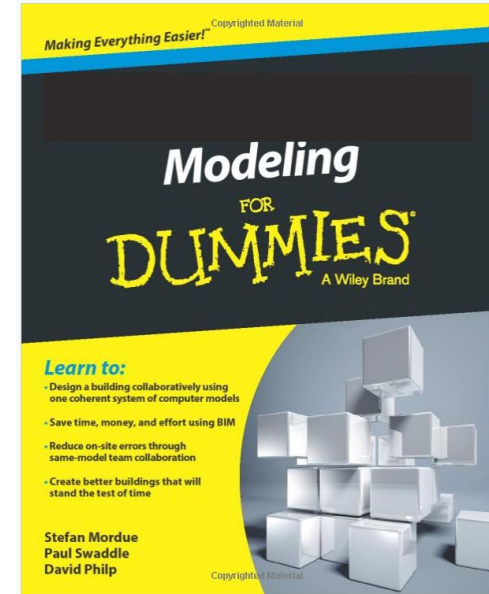
- A model represents a narrow part of the world
- Pick the right tool for the right job
  - Can the model answer your question?
  - Do you have the required information?
  - Are the assumptions appropriate?
  - Is the answer reasonable?
  - **Be skeptical!**



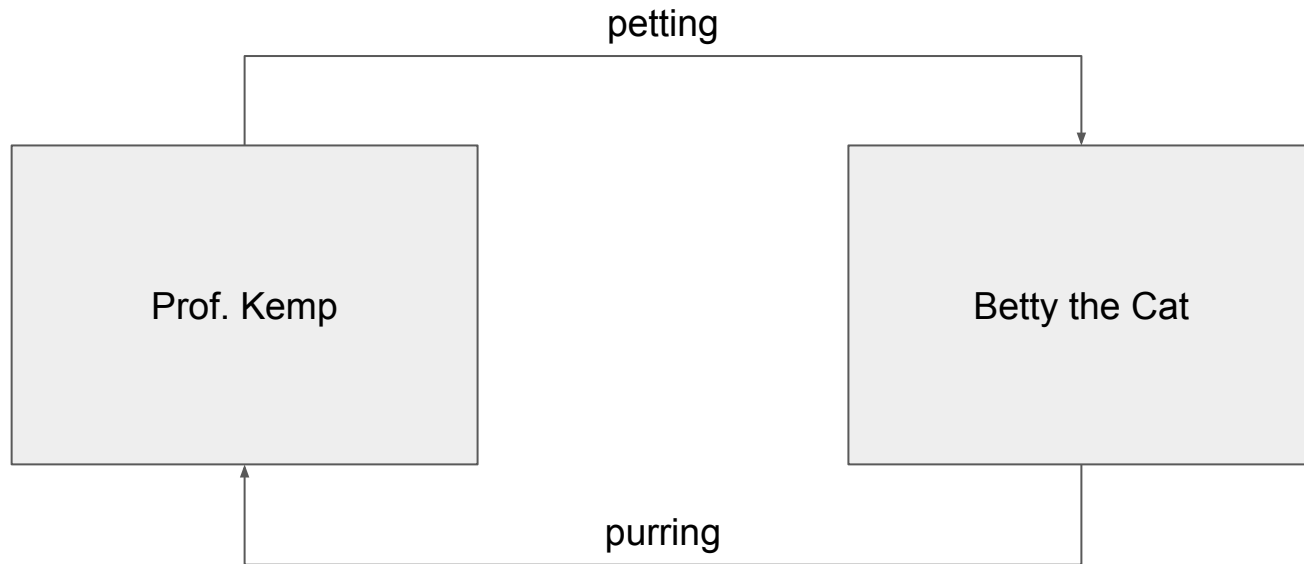
[https://en.wikipedia.org/wiki/Spherical\\_cow](https://en.wikipedia.org/wiki/Spherical_cow)

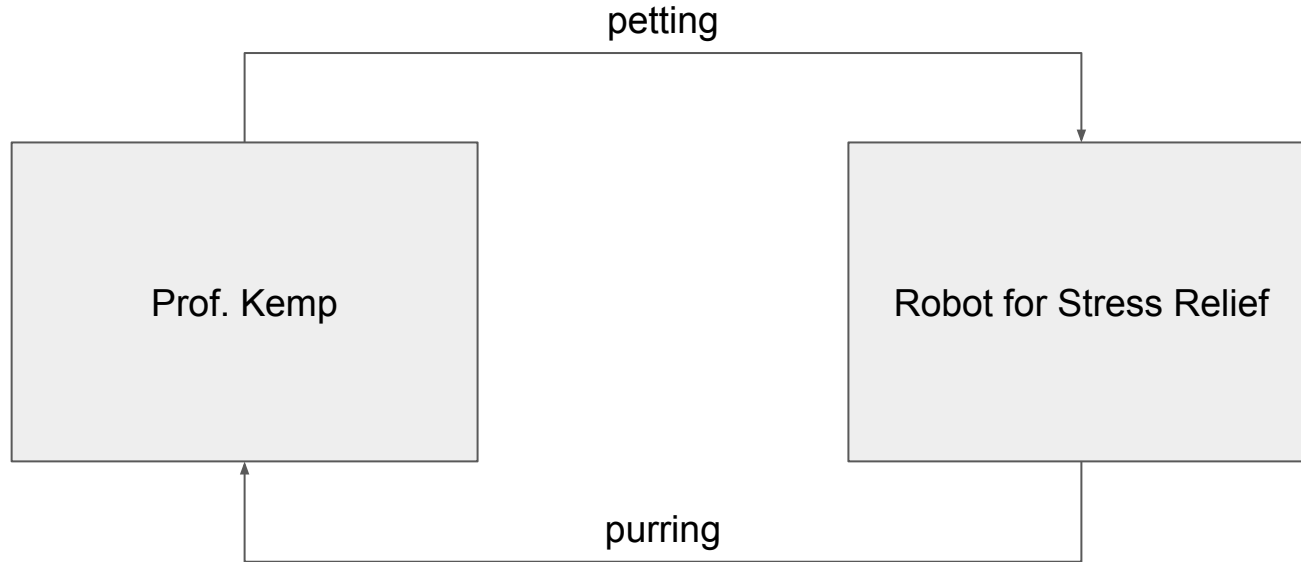
# A Simple Model of Modeling

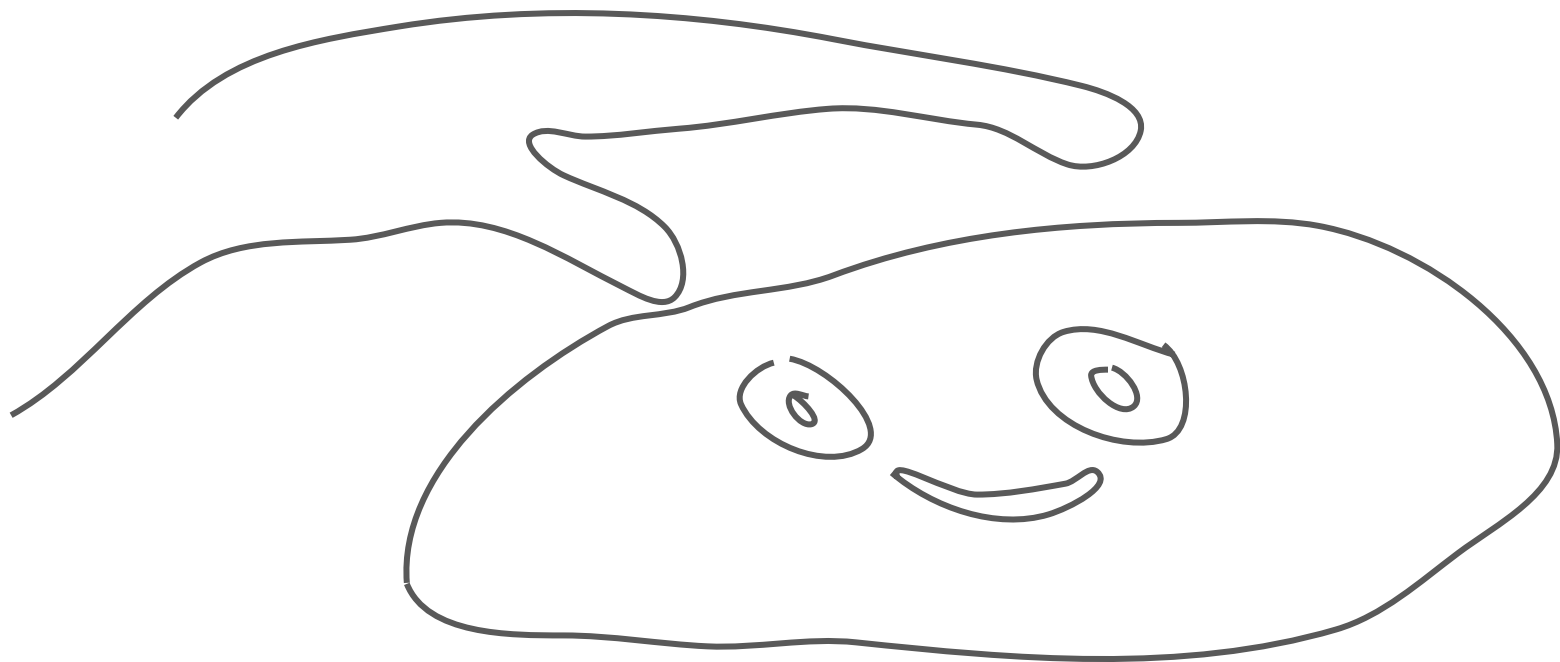
1. Draw pictures and diagrams of the system.
2. Come up with an important question.
3. Guess the answer to your question.
4. Use simple models to answer your question.
5. **Iterate through models**, increasing complexity as needed.

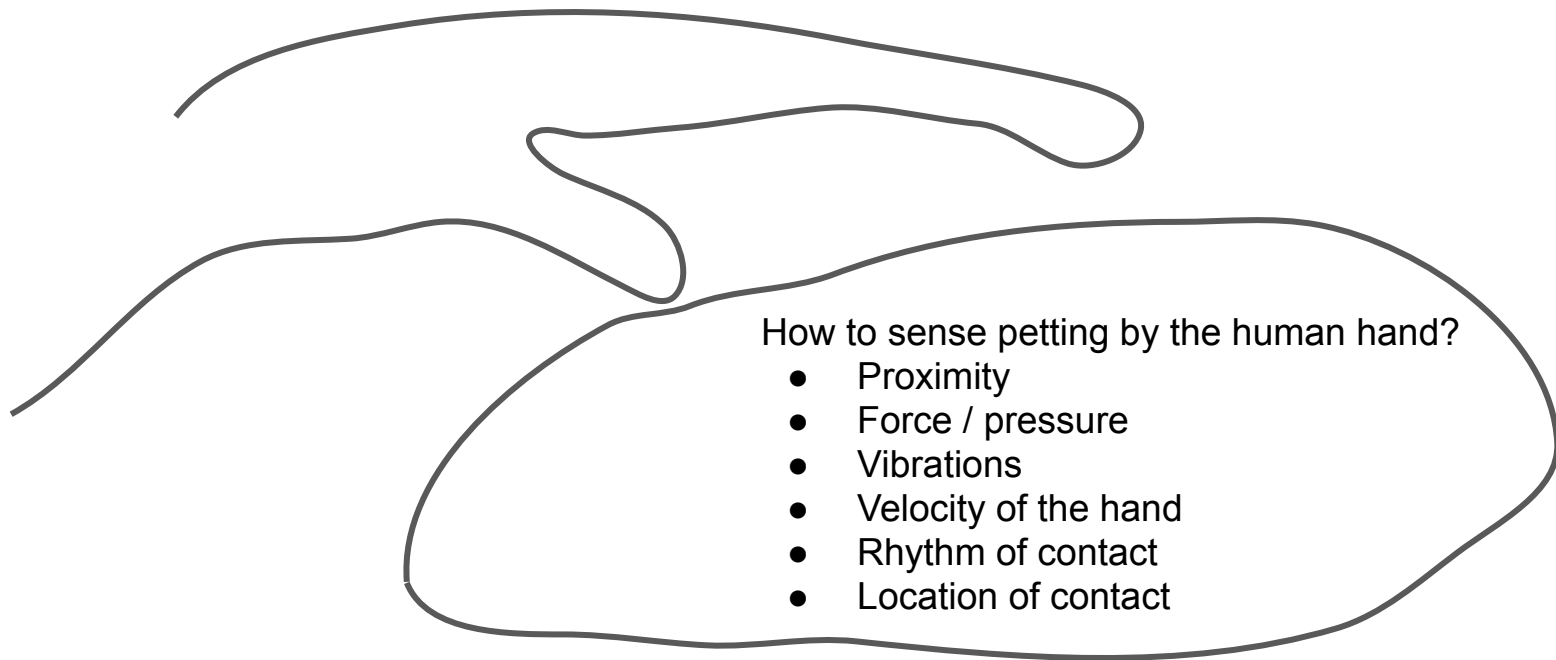












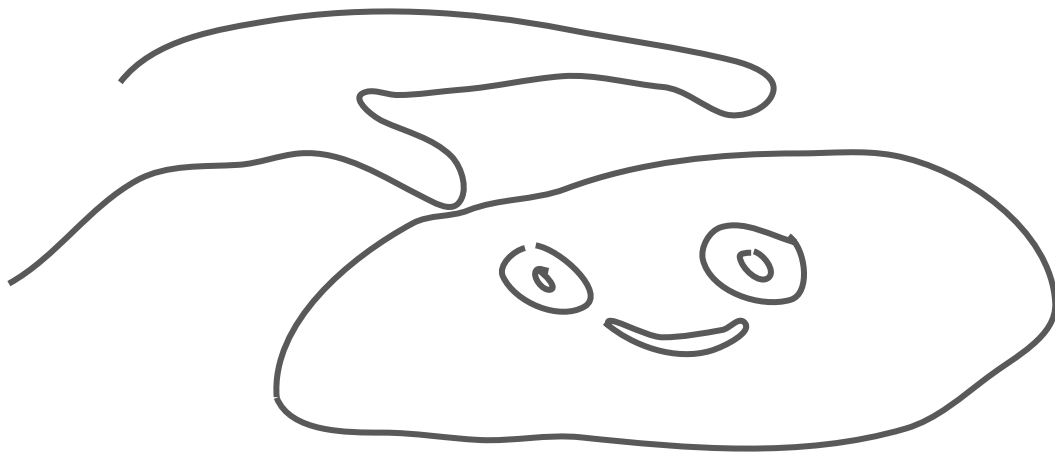
How to sense petting by the human hand?

- Proximity
- Force / pressure
- Vibrations
- Velocity of the hand
- Rhythm of contact
- Location of contact



# Sense Petting by a Human Hand

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





air bladder pressure arduino



All



Shopping



Images



Videos



News



More

Settings

Tools

<http://pneuduino.org/toolkit/>

<https://softroboticstoolkit.com/pds/design>

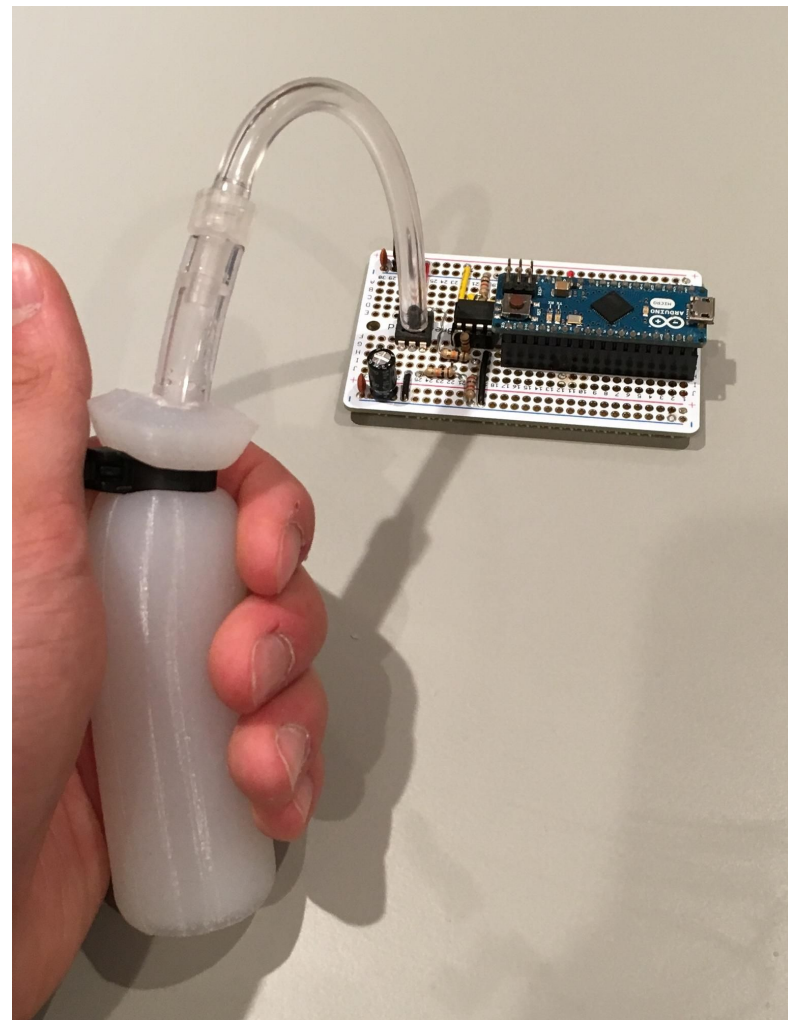
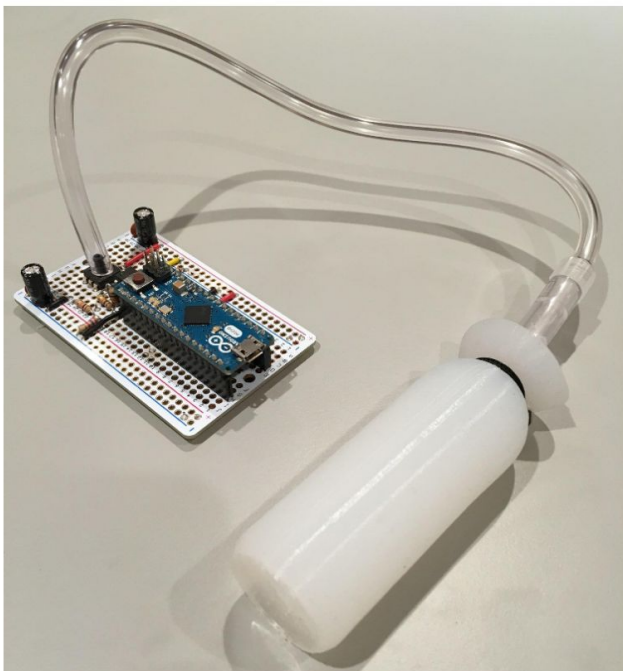
<https://softroboticstoolkit.com/pds/design/sensor>

<https://softroboticstoolkit.com/pds>


**Pneumatic Deformation  
Sensors**[Background](#)[Design](#)[Fabrication](#)[Testing](#)[Downloads](#)[Corresponding Author](#)**Contributor**[Aidan Leitch](#)

## 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.

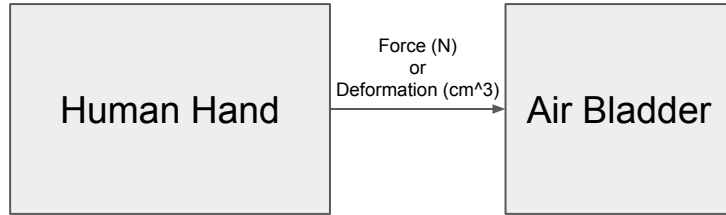


# Sense Petting with an Air Bladder

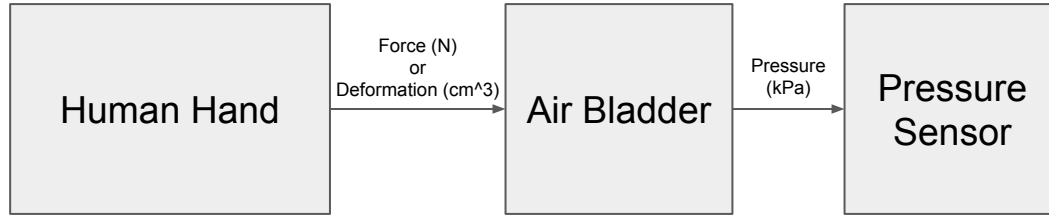


Human Hand

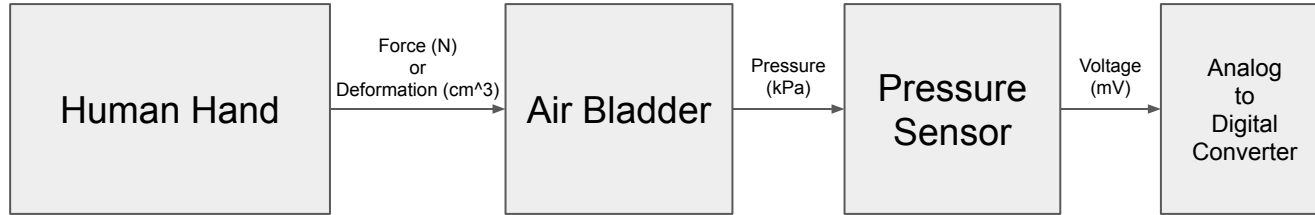
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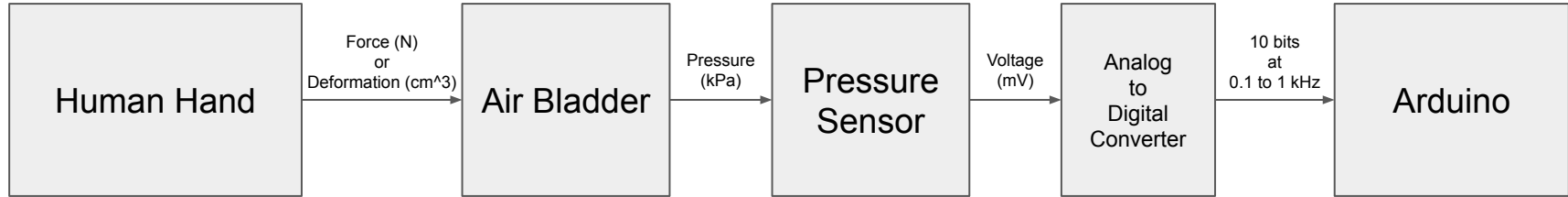
# Sense Petting with an Air Bladder



# Sense Petting with an Air Bladder

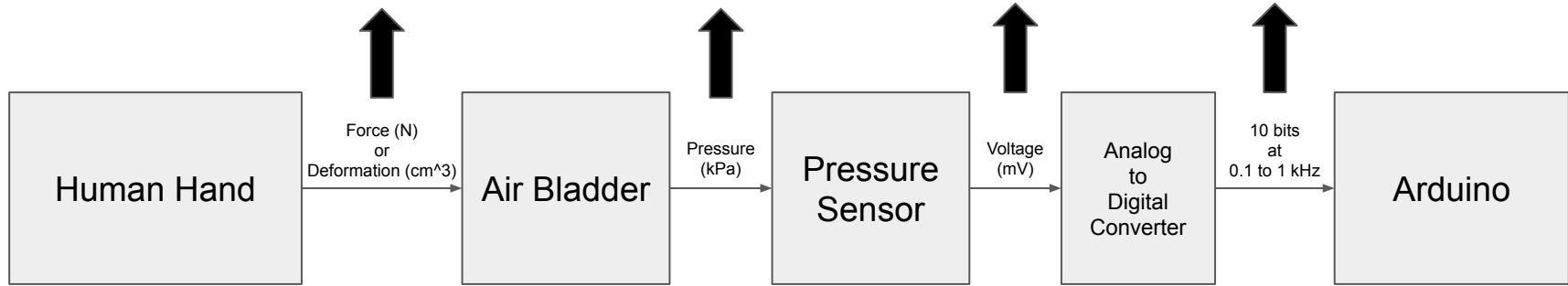


# Sense Petting with an Air Bladder

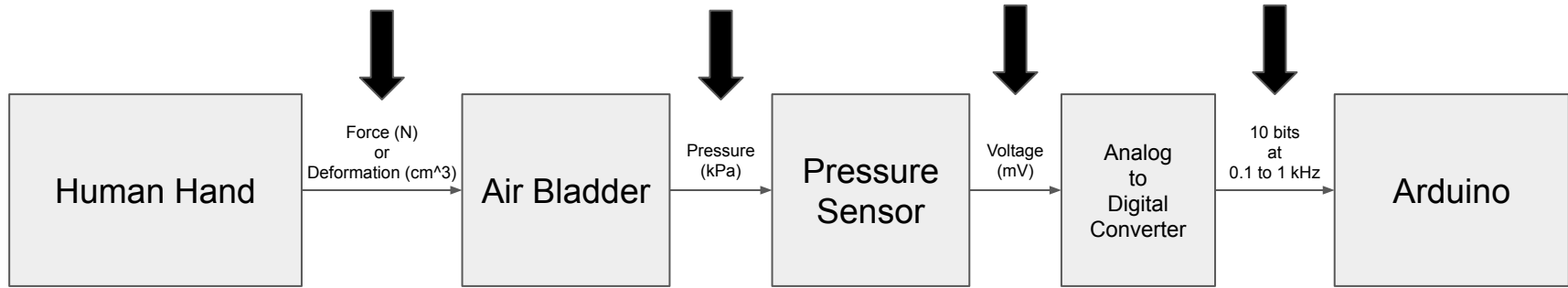




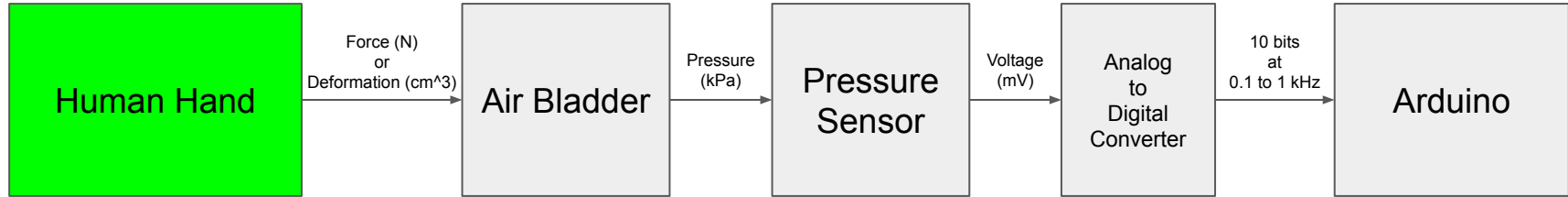
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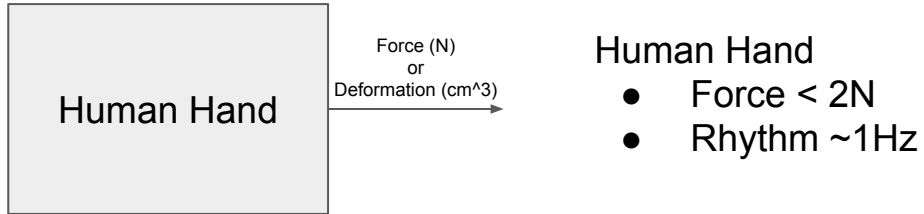
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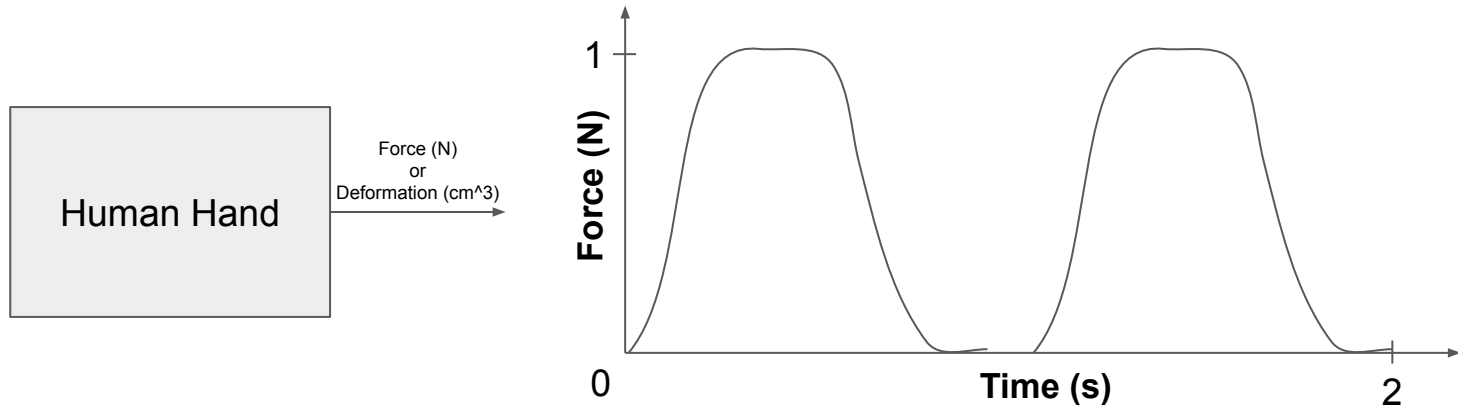
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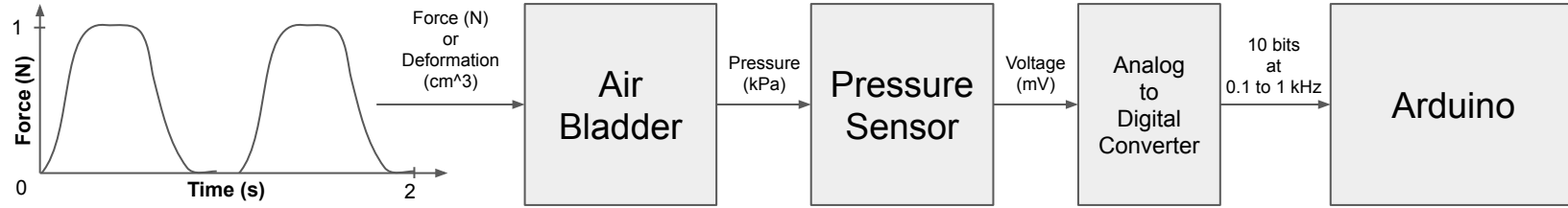
# Sense Petting with an Air Bladder



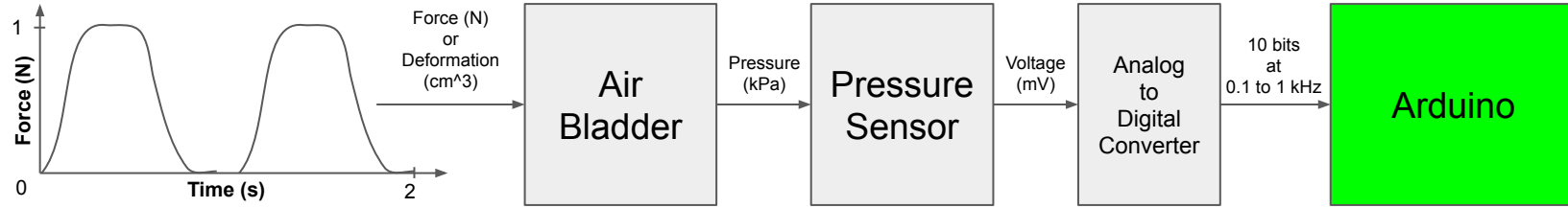
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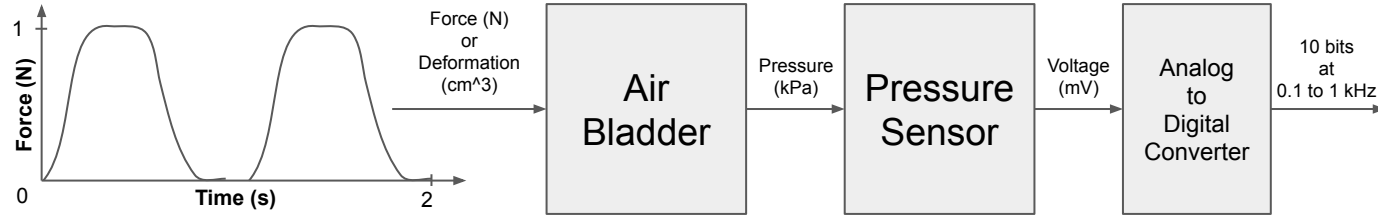
# Sense Petting with an Air Bladder



# Sense Petting with an Air Bladder

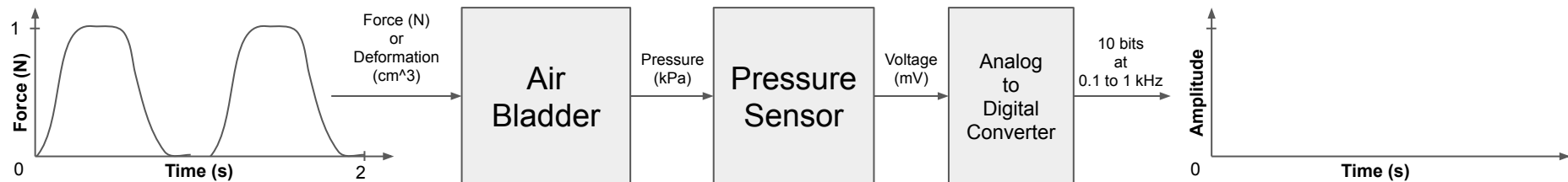


# Sense Petting with an Air Bladder

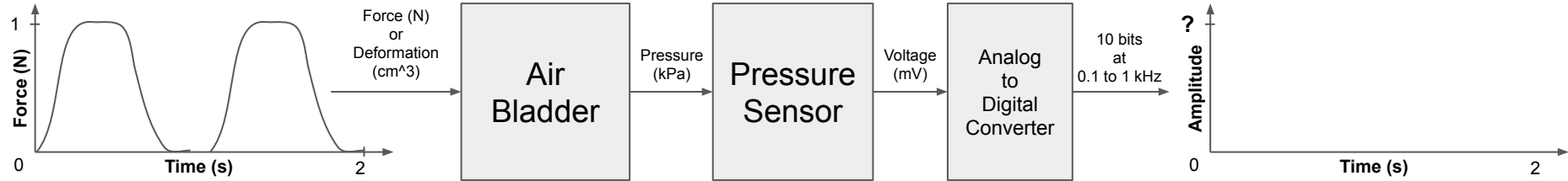




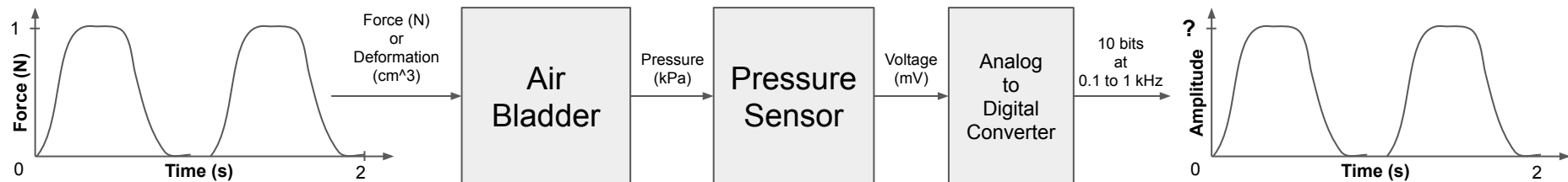
# Sense Petting with an Air Bladder



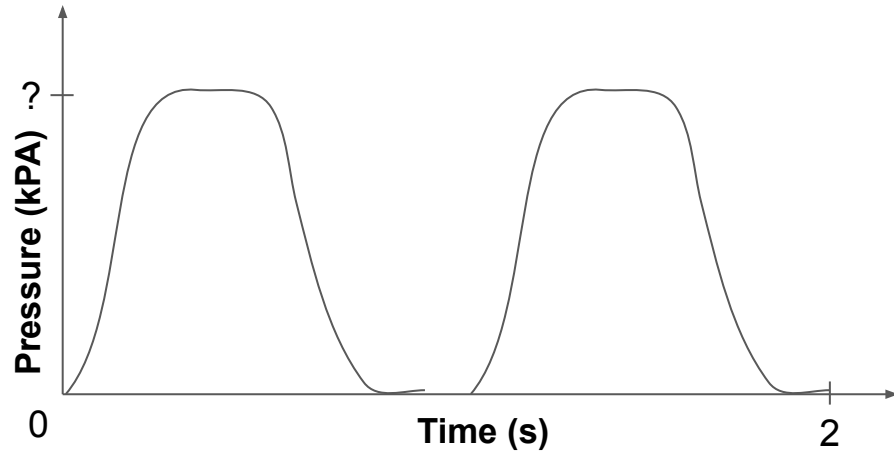
# Sense Petting with an Air Bladder



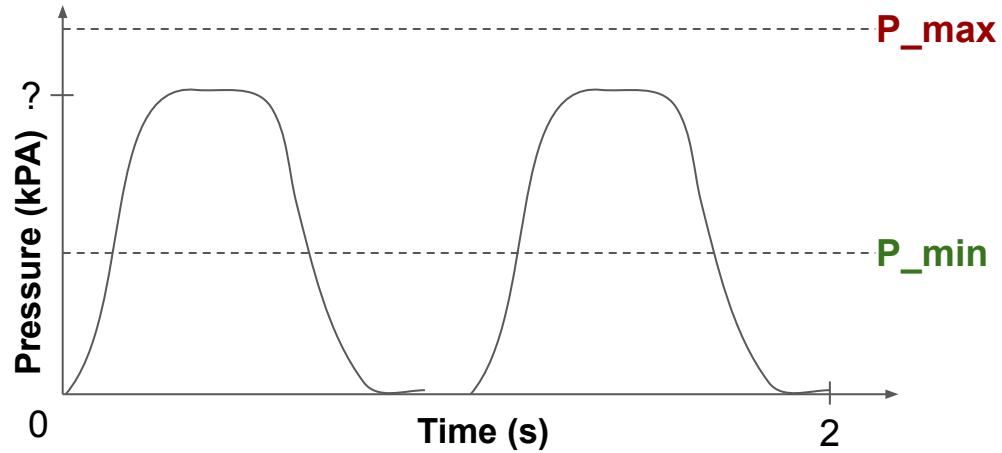
# Sense Petting with an Air Bladder



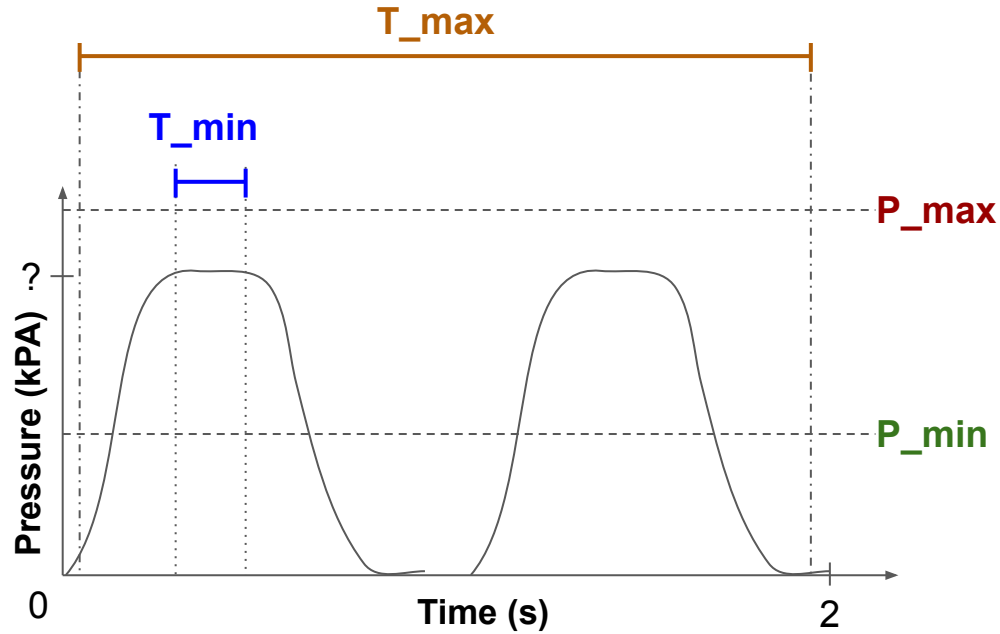
# Sense Petting with an Air Bladder



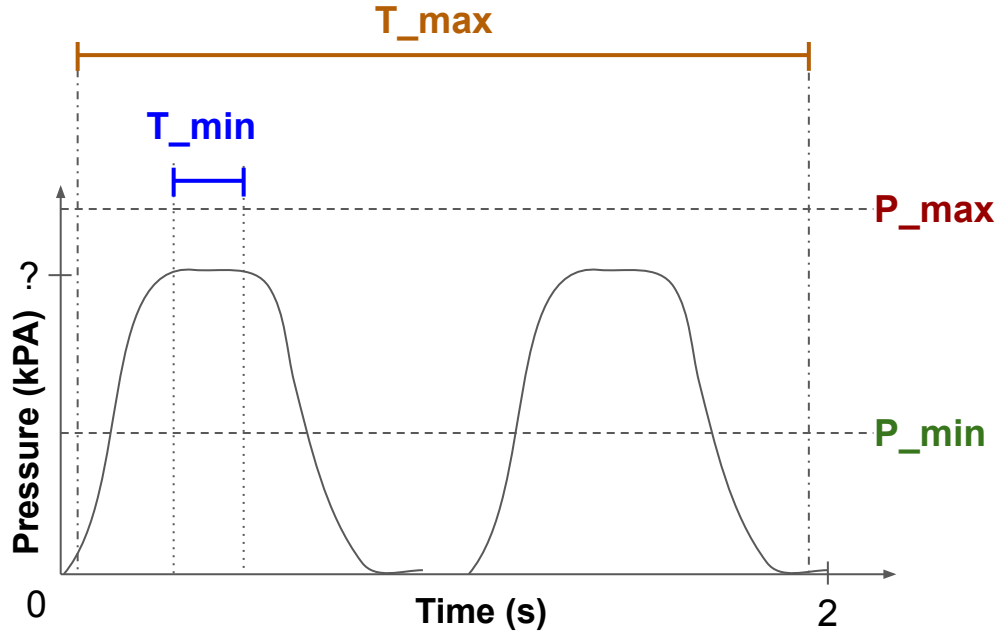
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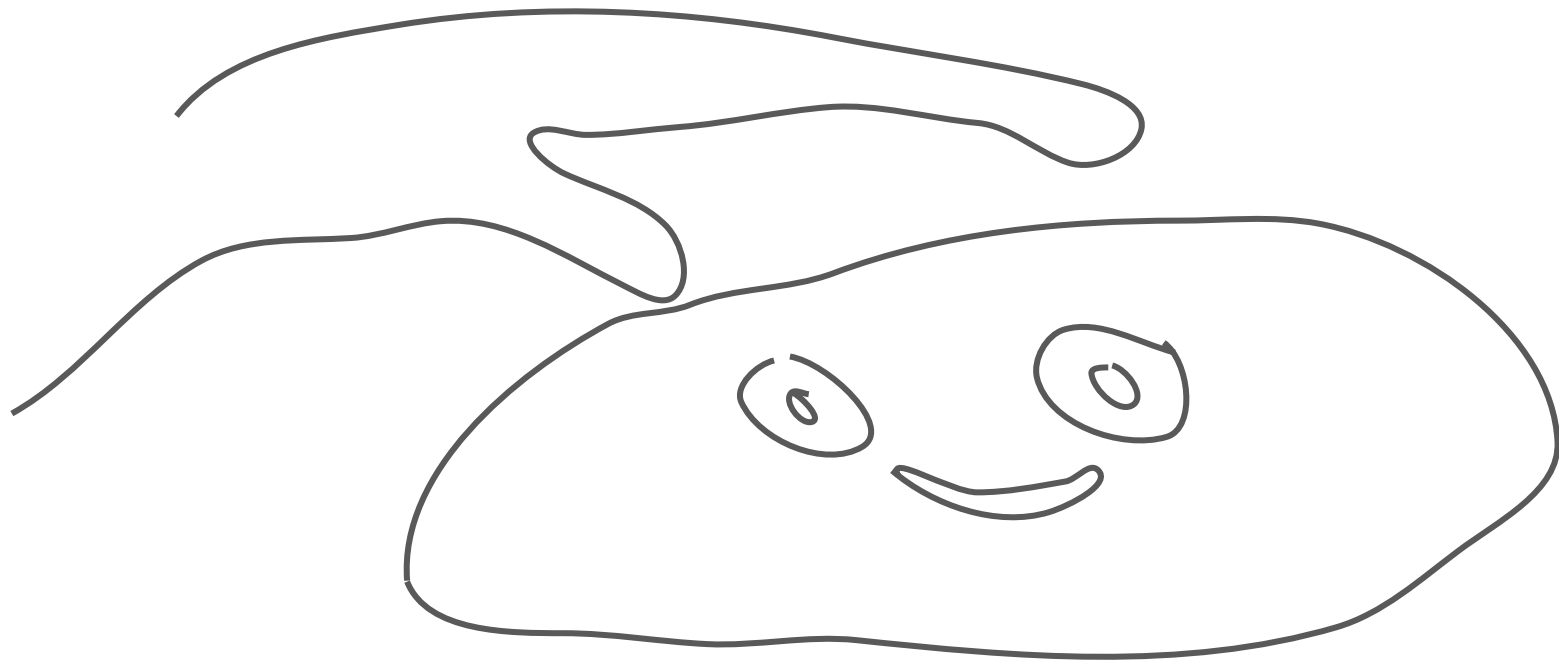
# Sense Petting with an Air Bladder



# Sense Petting with an Air Bladder



```
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  $T_{min} < \text{timer} < T_{max}$ 
            stroke = stroke + 1
        Reset timer
    If stroke  $\geq 2$ 
        petting = True
Make purring sound
Repeat
```



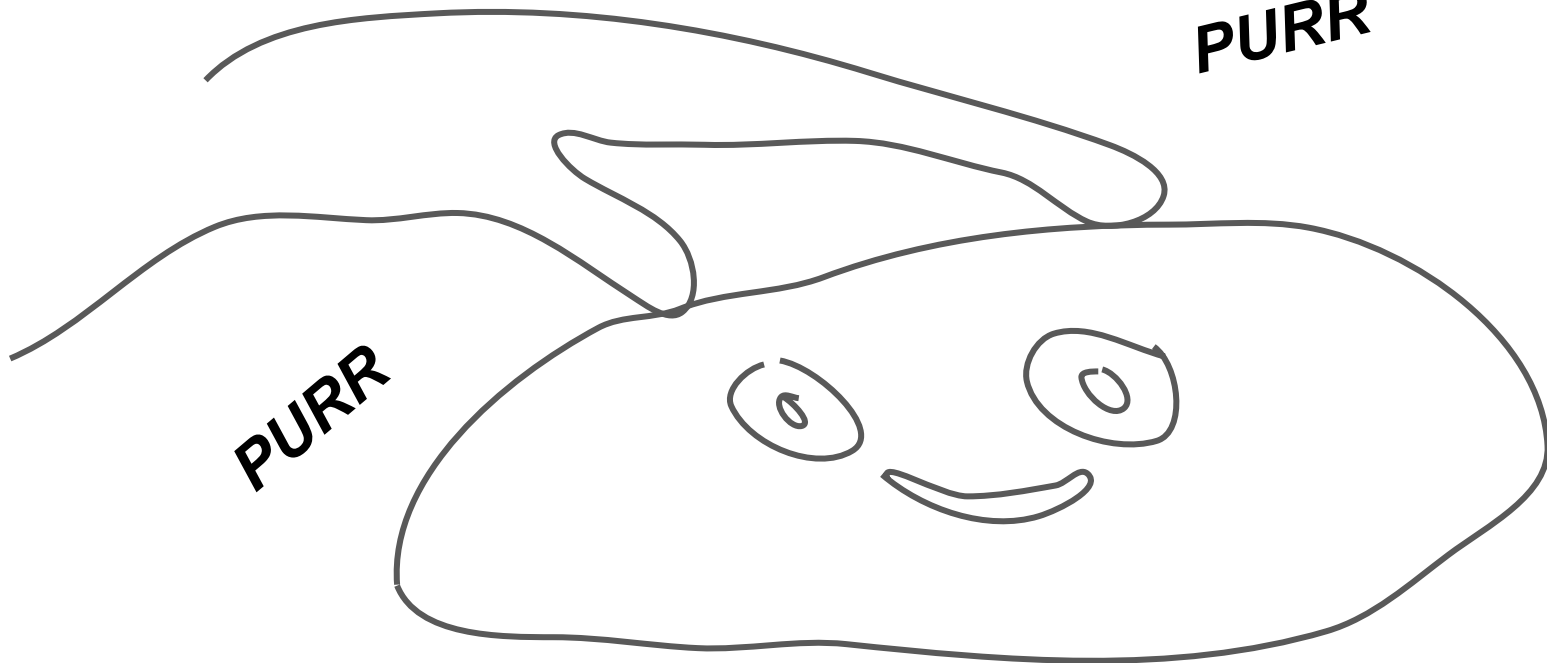


PURR

PURR

PURR

PURR

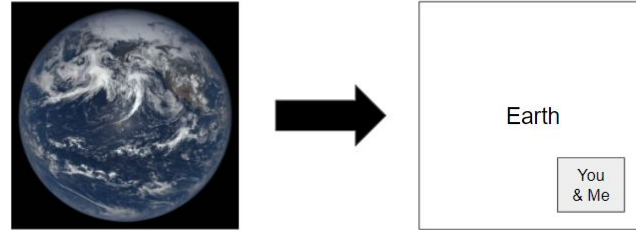




# Recapitulation

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

## A Moment on Modeling



Prof. Charlie Kemp

*Associate Professor  
Biomedical Engineering  
Georgia Tech*

# 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](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\\_\(physics\)](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](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](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](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](https://en.wikipedia.org/wiki/Standard_Model)