

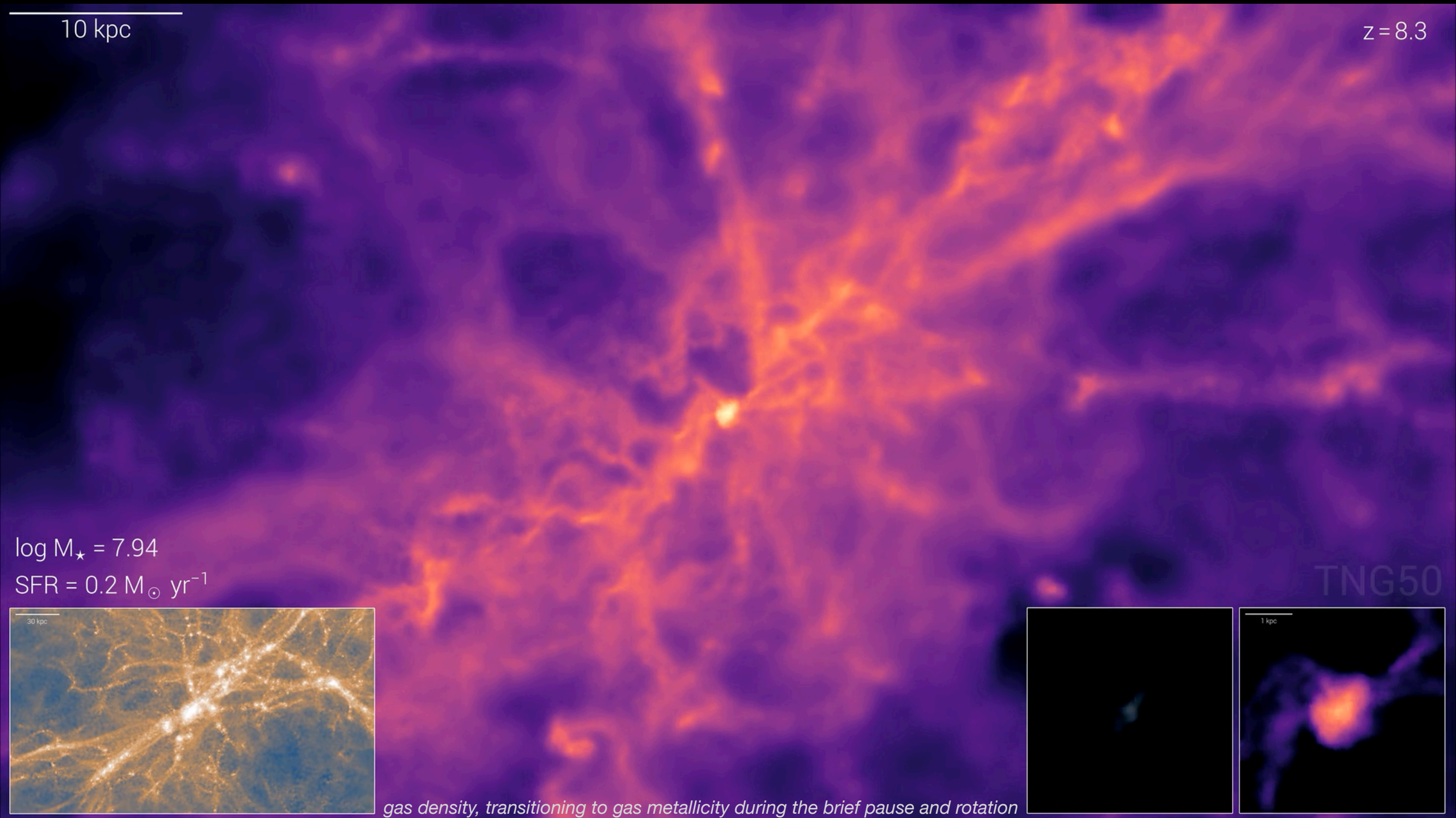
# The IllustrisTNG Project

*“The next generation of cosmological hydrodynamical simulations.”*

tng-project.org

10 kpc

$z = 8.3$



gas density, transitioning to gas metallicity during the brief pause and rotation

large-scale dark matter, then gas

small-scale stellar & gaseous distributions

# Prediction: Week 8

Introduction to Modern “Simulations” (Modern Predictions)

(Your final projects)

How to evaluate and appreciate **accuracy** and **uncertainty** in **Predictions**.

**Tuesday: Weather & Climate Prediction**

Special Guest: Prof. Marianna Linz, Assistant Professor of Environmental Science and Engineering and of Earth and Planetary Sciences, Harvard University

☆ Favorite ↗ Share ⋮

# Modern Prediction

This cluster includes expert interviews with researchers across an array of disciplines with the unifying topic of modern predictive systems. Learn about prediction efforts in Earth, Space, Health, Wealth, and the Future of the Future, accompanied by annotations and links to deepen your understanding.



## Introduction to Modern “Simulations” (Modern Predictions)

|   |                           |         |                   |                                |
|---|---------------------------|---------|-------------------|--------------------------------|
| 0 | Biological Sciences<br>+5 | English | Knowledge<br>None | LabXchange<br>Standard License |
|---|---------------------------|---------|-------------------|--------------------------------|



# ~What's to come?

| Week  | Topic                                       | Date            |                                             |                                                          | Date            |
|-------|---------------------------------------------|-----------------|---------------------------------------------|----------------------------------------------------------|-----------------|
| 8     | Intro to Modern Simulations                 | 3/18<br>(Thurs) | Where does Uncertainty come from?           | Weather & Climate:<br>Special guest: Prof. Marianna Linz | 3/23<br>(Tues)  |
| 9     | Modeling                                    | 3/25<br>(Thurs) | The Meaning of “Models”                     | Simulations                                              | 3/27<br>(Tues)  |
| 10    | The Future of Wealth & Health               | 4/1<br>(Thurs)  | Special AI & Health Event “at” Radcliffe    | Human Behavior, Decisions, Predictions                   | 4/6<br>(Tues)   |
| 11    | The Future of the Universe                  | 4/8<br>(Thurs)  | Simulating the Universe                     | The Search for Life                                      | 4/13<br>(Tues)  |
| 12    | Artificial Intelligence & Bayesian Thinking | 4/20<br>(Tues)  | Derek's Day                                 | Hypothesis-Free Prediction                               | 4/22<br>(Thurs) |
| “12a” | The Future of the Future                    | 4/27<br>(Tues)  | Final Discussions + featured student videos |                                                          | 4/29<br>(Thurs) |



# OF THE FUTURE



THEORY

## MODERN PREDICTION

edX

### John Snow & Cholera



Cholera Map

#### Health

- ▶ Epidemiology
- ▶ Personal Genomics
- ▶ Population Genetics

#### Wealth

- ▶ Climate & Wealth
- ▶ Behavioral Economics

edX

Without  
inclusion  
(tion)

Lost!

the  
tor

#### The Future of the Future

- ▶ AI, Derek's Day
- ▶ Philosophy
- ▶ Uncertainty

#### Earth

- ▶ Climate & Energy
- ▶ Climate Policy
- ▶ Tent Tarot
- ▶ Earthquakes

#### Space

- ▶ Futures  
of our Universe
- ▶ SETI

# “Modern Prediction” Interviews at PredictionX.org & LabXchange

Prediction & Philosophy

Agustin Rayo

Prediction in Astrophysics

Avi Loeb

Artificial Intelligence

Ben Shneiderman

Predicting Health, and Earthquakes

Brendan Meade and Susan Murphy

Prediction & Psychology

Dan Gilbert

The Future of Energy and the Earth

Dan Kammen

Behavioral Economics

David Laibson

Personal Genomics

George Church

Climate Change

Gina McCarthy

Population Genetics

Immaculata De Vivo and Peter Kraft

The Search for Extraterrestrial Intelligence

Jill Tarter

Epidemiology

Megan Murray

Philosophy & Prediction

Ned Hall

The Business of the Future of Energy and the Earth

Rebecca Henderson

Uncertainty in Science

Stuart Firestein

Your final projects:  
How to evaluate and appreciate **accuracy** and **uncertainty** in Predictions.

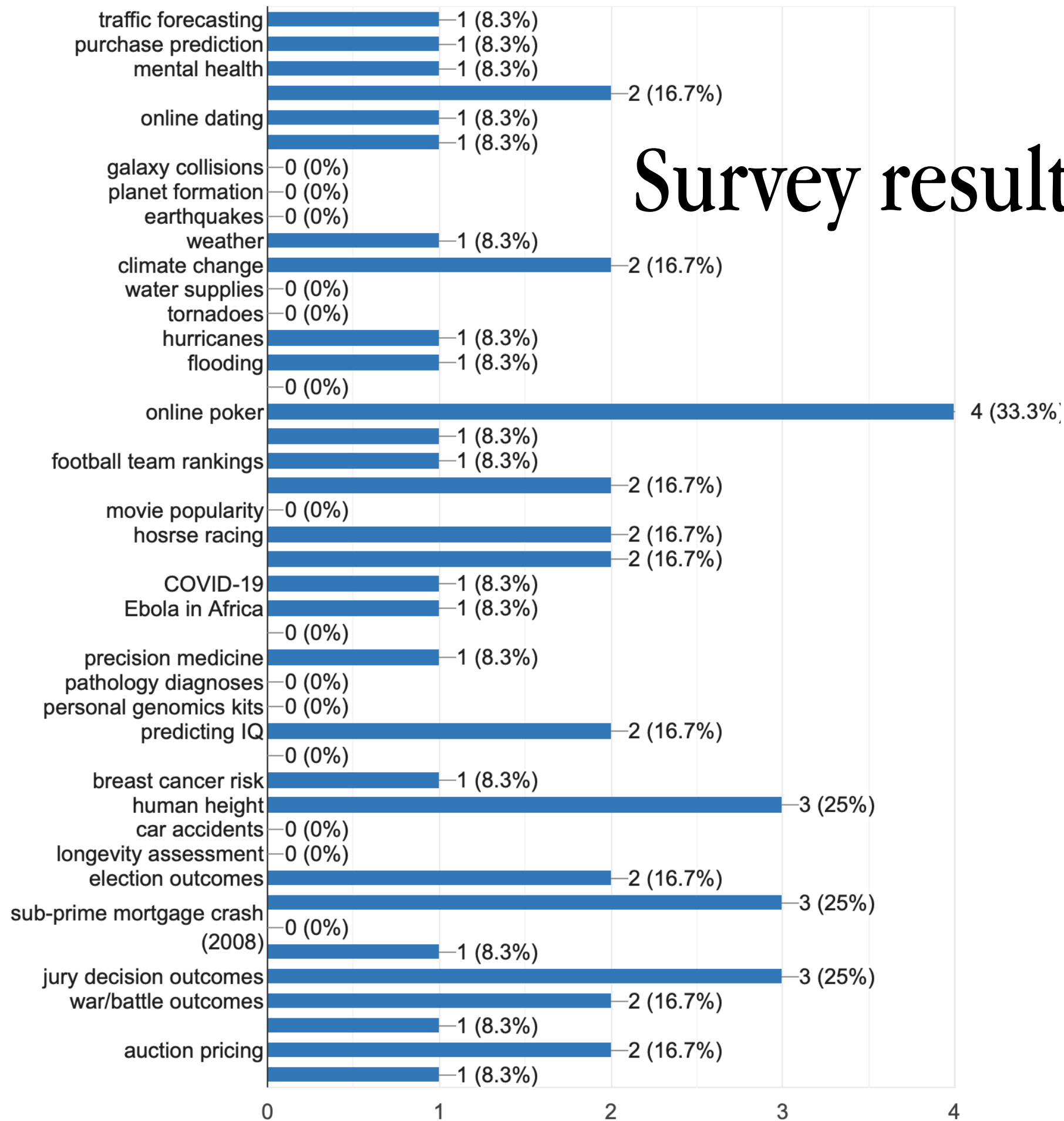
## The plan for final projects (link)

“Carry out a study a particular type of predictive system, with special attention to how **accurate** it *should* be, how **uncertainty** is measured, and how uncertainty about it is **communicated**. In particular, find a way to **study** its **accuracy** on your own, either with new analysis, or from the literature. In the end, you will create an **online video summary** (5 minutes long) of your findings, with accompanying text and graphics.”

On **Canvas** you will find a link to a Google Doc that provides:

1. Detailed **instructions**, with a step-by-step “rubric” for what we’d like you to include (history of the field, documentation of your research, controversies, future prospects, etc.), and point values.
2. Request to finalize your topic, in consultation with your TF.
3. Possible **themed**-sections or TF office hours, depending on your schedules.

Survey results (next slide)



Survey results ([link](#))



## Prediction X: Modern Simulations--THEMES/TAGS

#simulation\_or\_model (c.f. list )

#theoretical\_empirical (c.f. Rainbow diagram)

#framework\_model\_inputs (c.f. document)

#framework\_testing (c.f. document)

#biases (c.f. document)

#uncertainty (c.f. document, puck simulation (link), Take a Sweater)

#approximation (c.f. Ten questions) #Heuristic

#public\_reaction (c.f. document)

#predictability

(essay about predictability, determinism, randomness and uncertainty--use Clint's sand on shuffleboard analogy, includes

#convergence, #divergence, #feedback #chaos)

#unkown\_unknowns

#bayes\_theorem

#deterministic\_vs\_probabilistic (probabilistic vs. deterministic prediction...when is uncertainty small enough to call it "deterministic"?)

#machine\_learning (c.f. list)

#artificial\_intelligence(c.f. list, Derek's Day)

#prediction\_vs\_decision

#explanation\_vs\_prediction (c.f. rainbow diagram)

#technology\_theoretical\_computation\_and\_math (c.f. list)

#technology\_observational\_experimental\_devices\_and\_sensors (c.f. PtN)

#future\_of\_the\_future

#personal\_or\_societal

#samplesize

#resolution

#rainbow\_diagram

*These "tags," used on LabXchange  
will all make sense to you by the end  
of our course...*

*(video assignments to come + read  
Nate Silver's book, please!)*



# Breakouts

## Round 1

Consider & discuss  
sources of  
uncertainty for your  
Room's system

1

- ☐ traffic forecasting
- ☐ purchase prediction
- ☐ mental health
- ☐ advertising strategy/revenue
- ☐ online dating
- ☐ precision medicine
- ☐ pathology diagnoses
- ☐ personal genomics kits
- ☐ predicting IQ

2

- ☐ predicting travel risk (e.g. BlueDot)
- ☐ breast cancer risk
- ☐ human height
- ☐ car accidents
- ☐ longevity assessment
- ☐ election outcomes
- ☐ Dow Jones (index numbers)

3

- ☐ sub-prime mortgage crash (2008)
- ☐ insurance pricing
- ☐ jury decision outcomes
- ☐ war/battle outcomes
- ☐ airline schedules (arrival/departure delays)
- ☐ auction pricing

4

- ☐ prediction markets (politics)
- ☐ galaxy collisions
- ☐ planet formation
- ☐ earthquakes
- ☐ weather
- ☐ climate change
- ☐ water supplies
- ☐ tornadoes
- ☐ hurricanes
- ☐ flooding

5

- ☐ The Drake Equation (SETI)
- ☐ online poker
- ☐ baseball player ratings (moneyball)
- ☐ football team rankings
- ☐ March Madness (basketball)
- ☐ movie popularity

6

- ☐ horse racing
- ☐ music popularity (e.g. of a specific artist/genre)
- ☐ COVID-19
- ☐ Ebola in Africa
- ☐ "retrodict" Plague in Europe in the 1600s

# Factors Determining Uncertainty

Your final projects:  
How to evaluate and appreciate **accuracy** and **uncertainty** in Predictions.

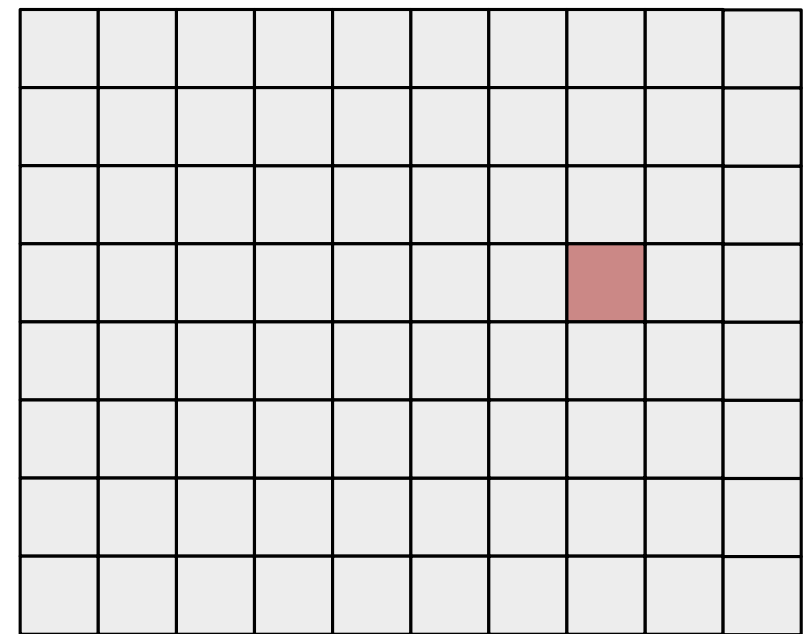
Where does *uncertainty* in Prediction come from?

Human Behavior



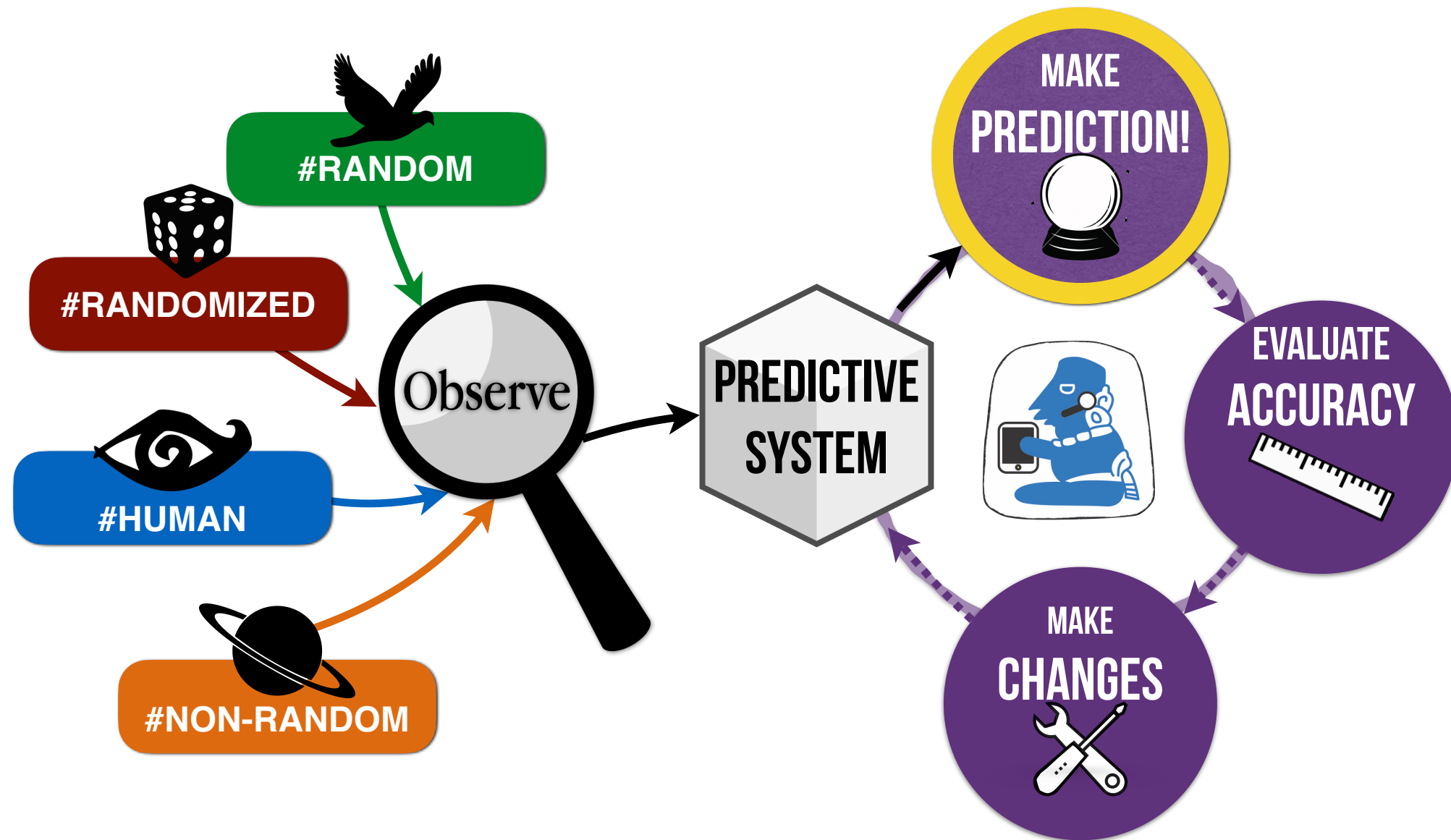
Models'

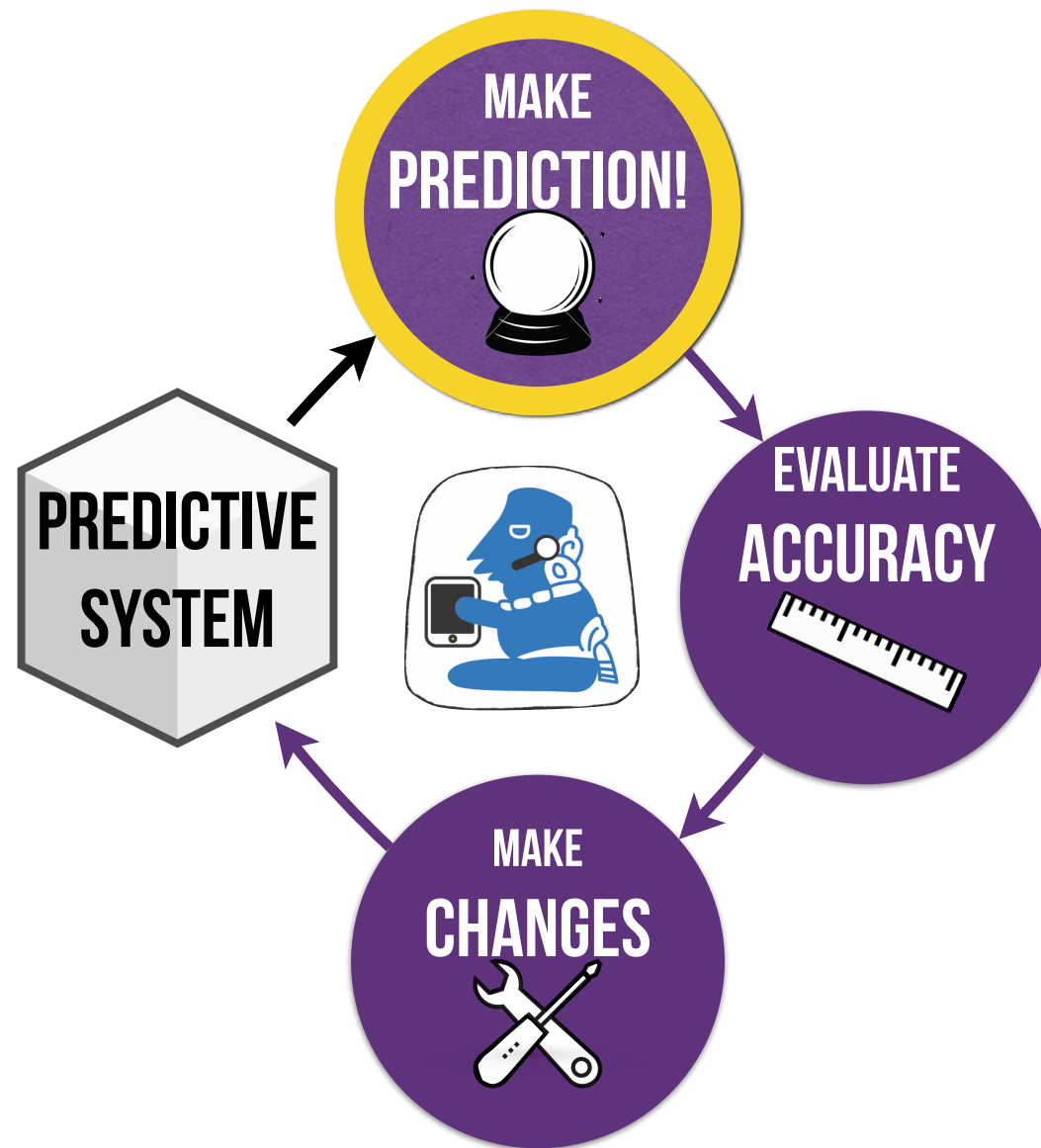
Resolution, Appropriateness, Inputs

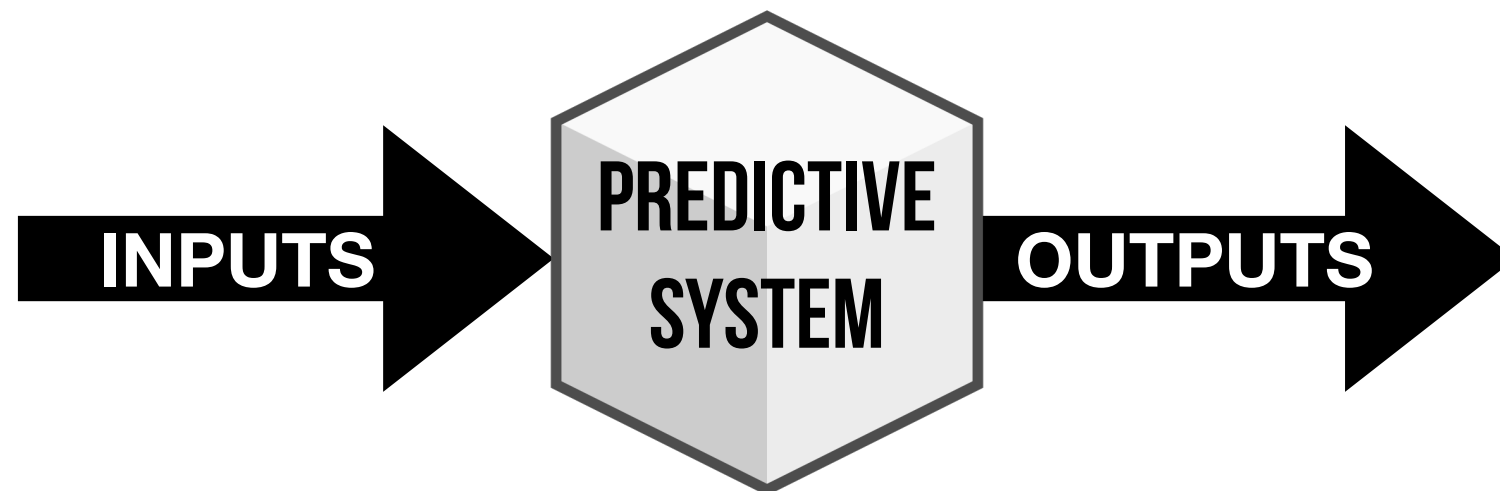




# “MODERN SIMULATIONS” & the Framework





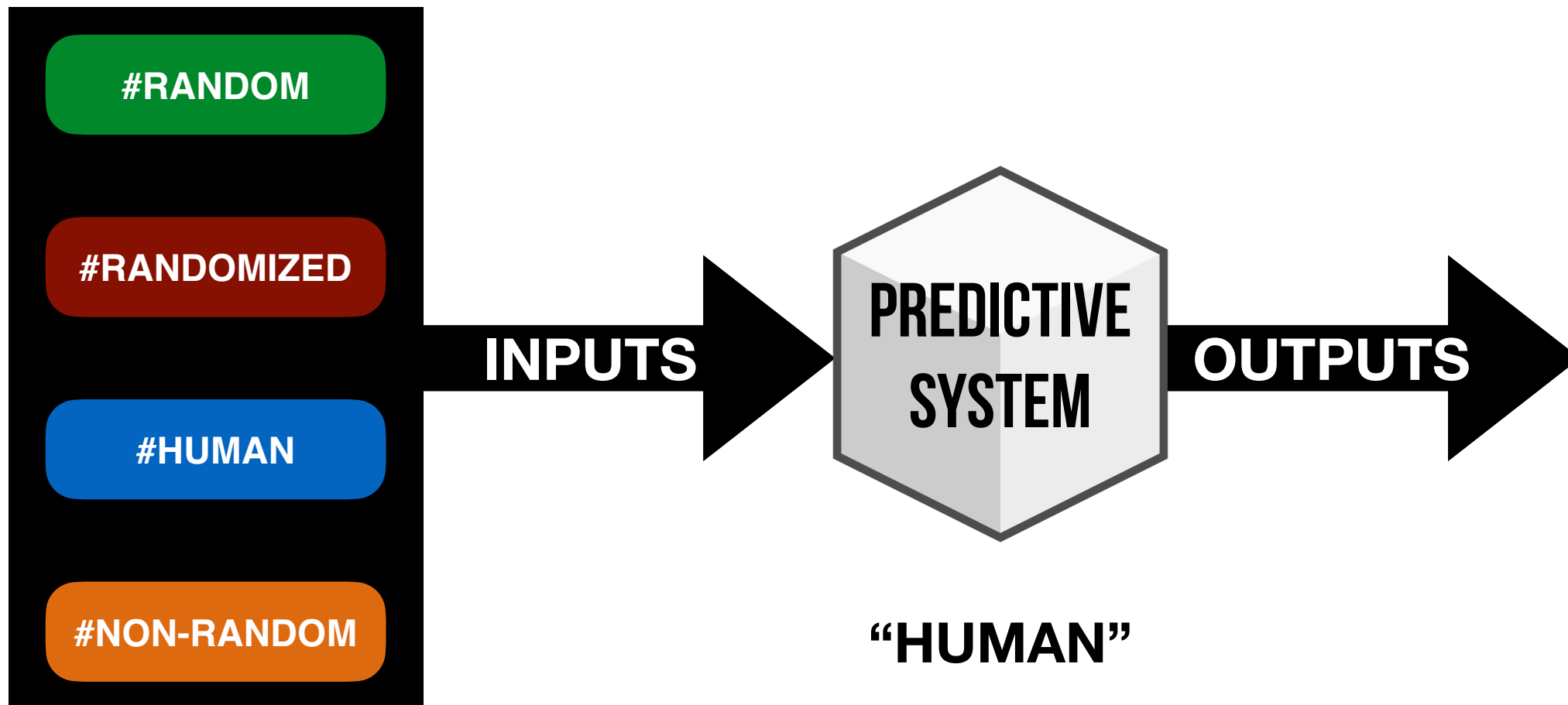


**“HUMAN”**

**STATISTICAL**

**SIMULATION**

**COMBINATIONS**



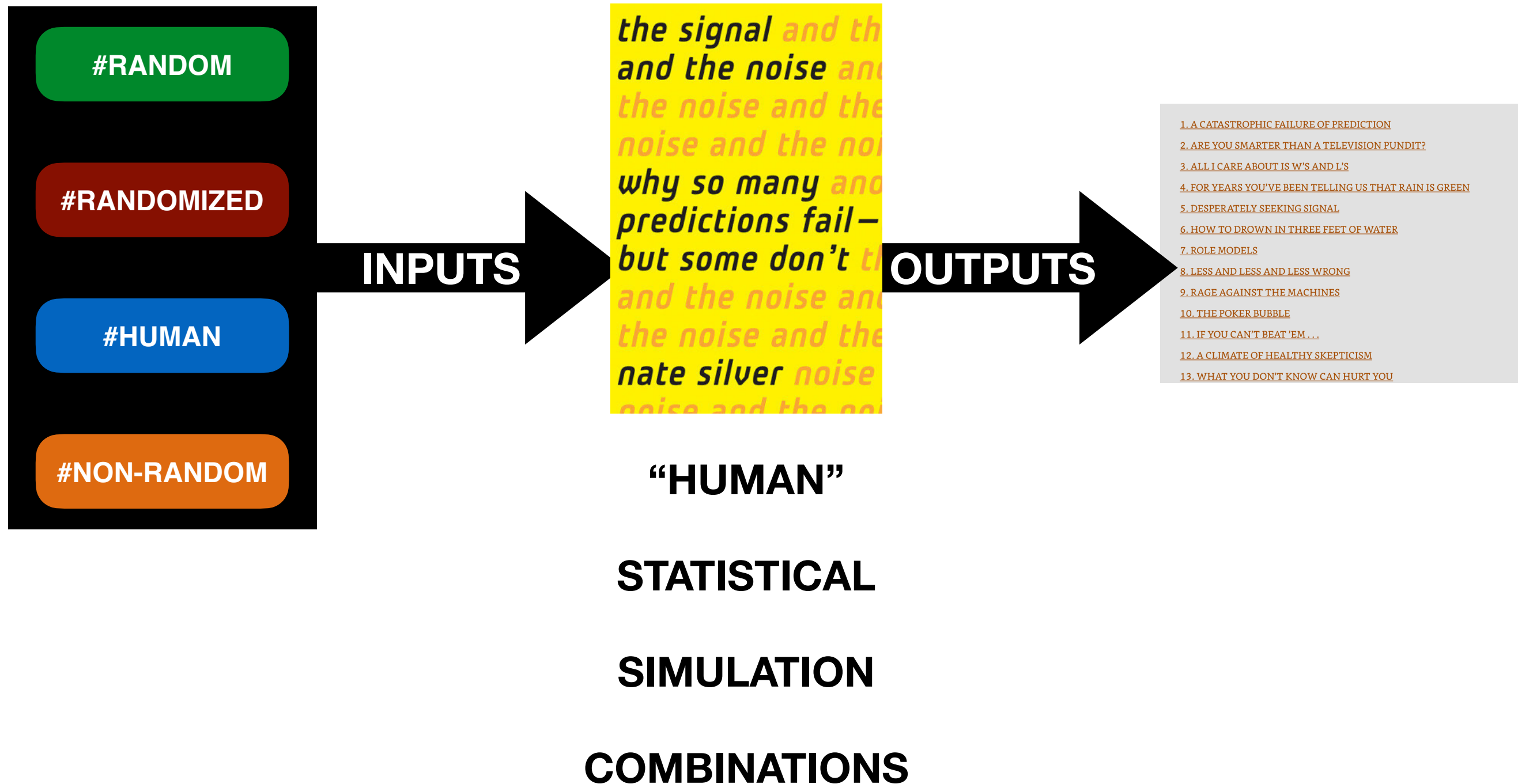
**“HUMAN”**

**STATISTICAL**

**SIMULATION**

**COMBINATIONS**

A variety of such examples are presented in *The Signal and the Noise*, by Nate Silver





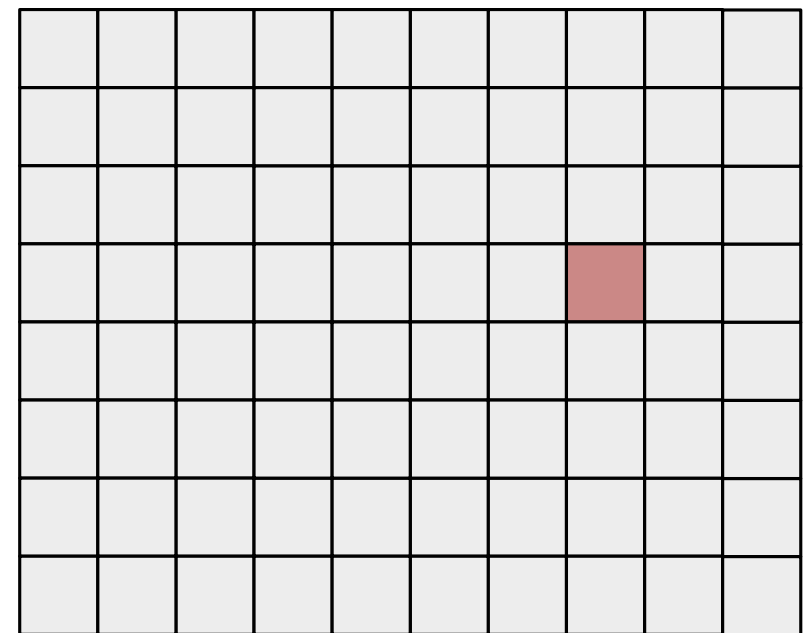
# Where does *uncertainty* in Prediction come from?

## Human Behavior

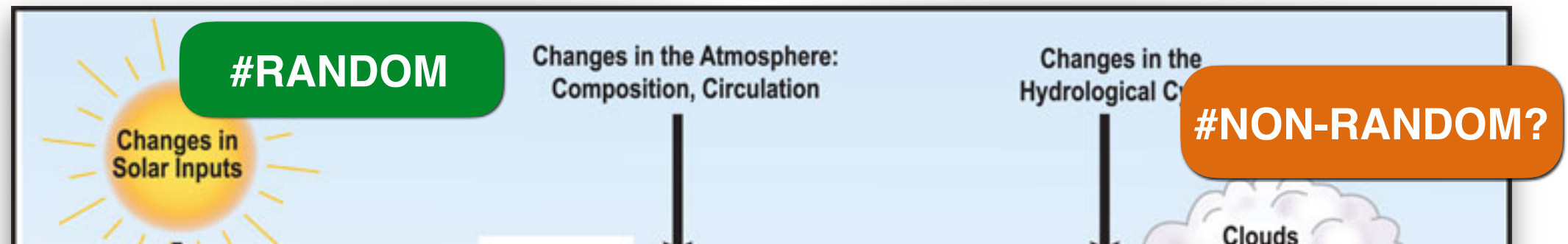


## Models'

Resolution, Appropriateness, Inputs

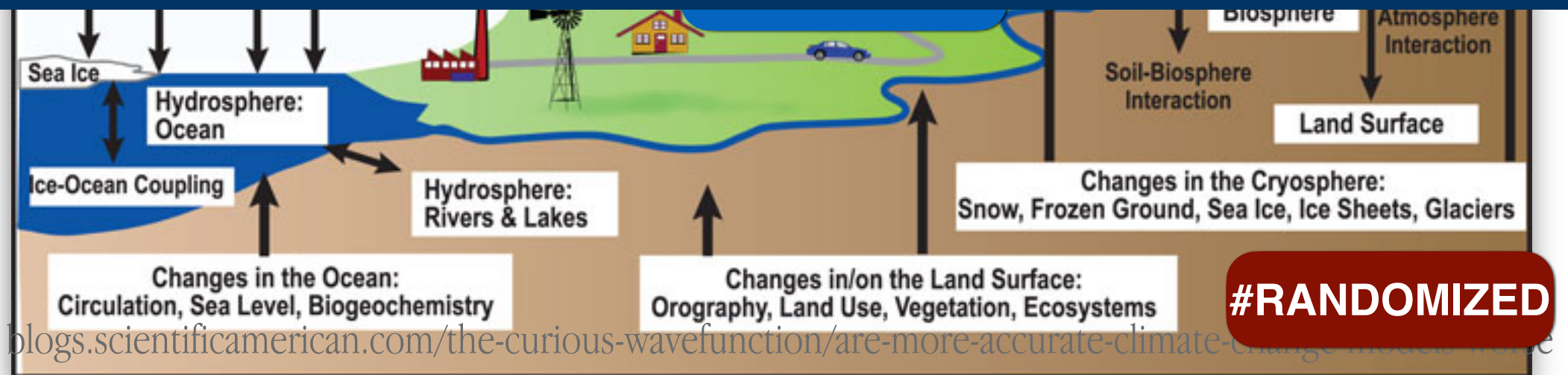


# Climate Change Simulation & the Framework



## Tuesday: Weather & Climate Prediction

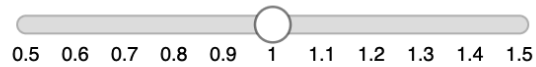
Special Guest: Prof. Marianna Linz, Assistant Professor of Environmental Science and Engineering and of Earth and Planetary Sciences, Harvard University



# Let's try something simpler...

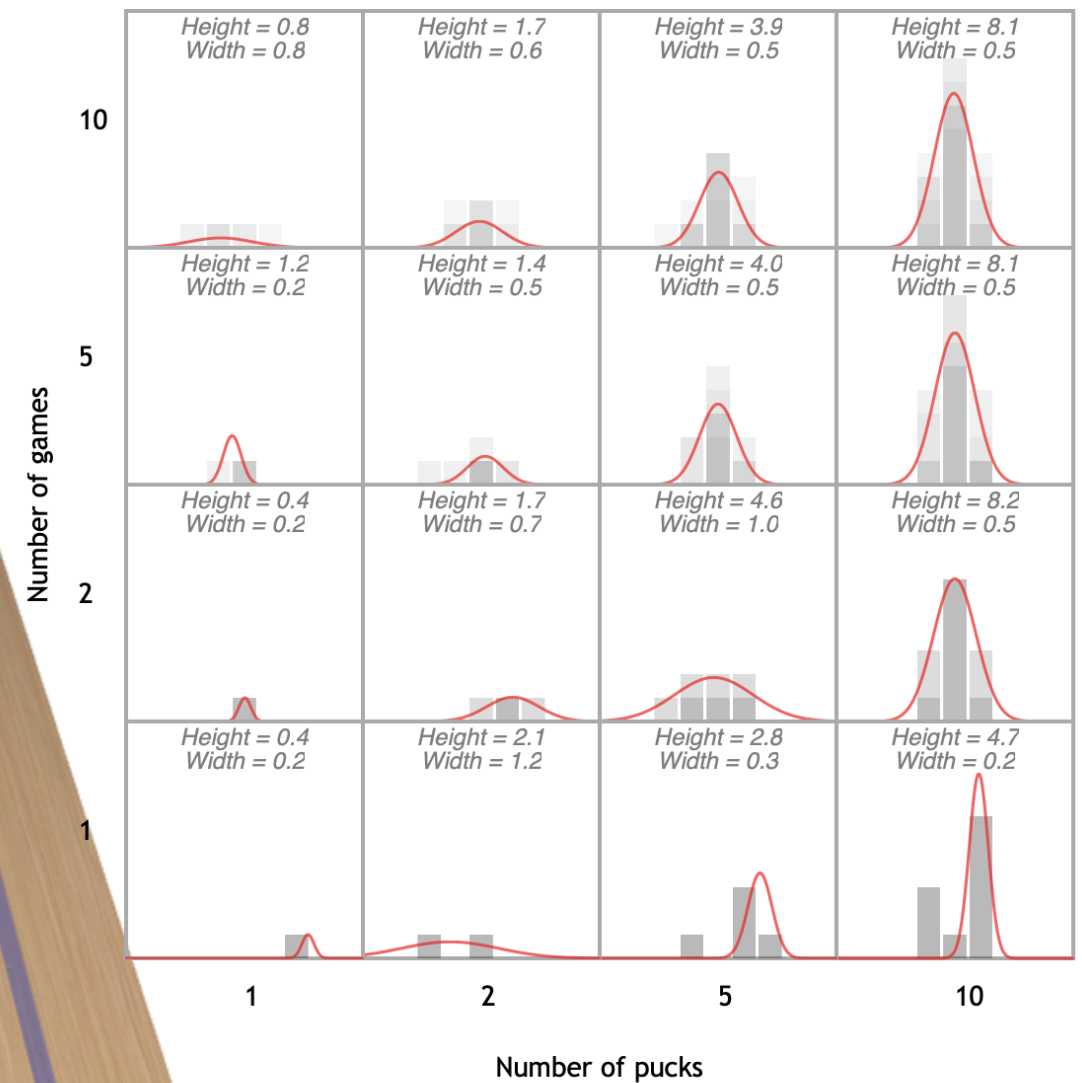
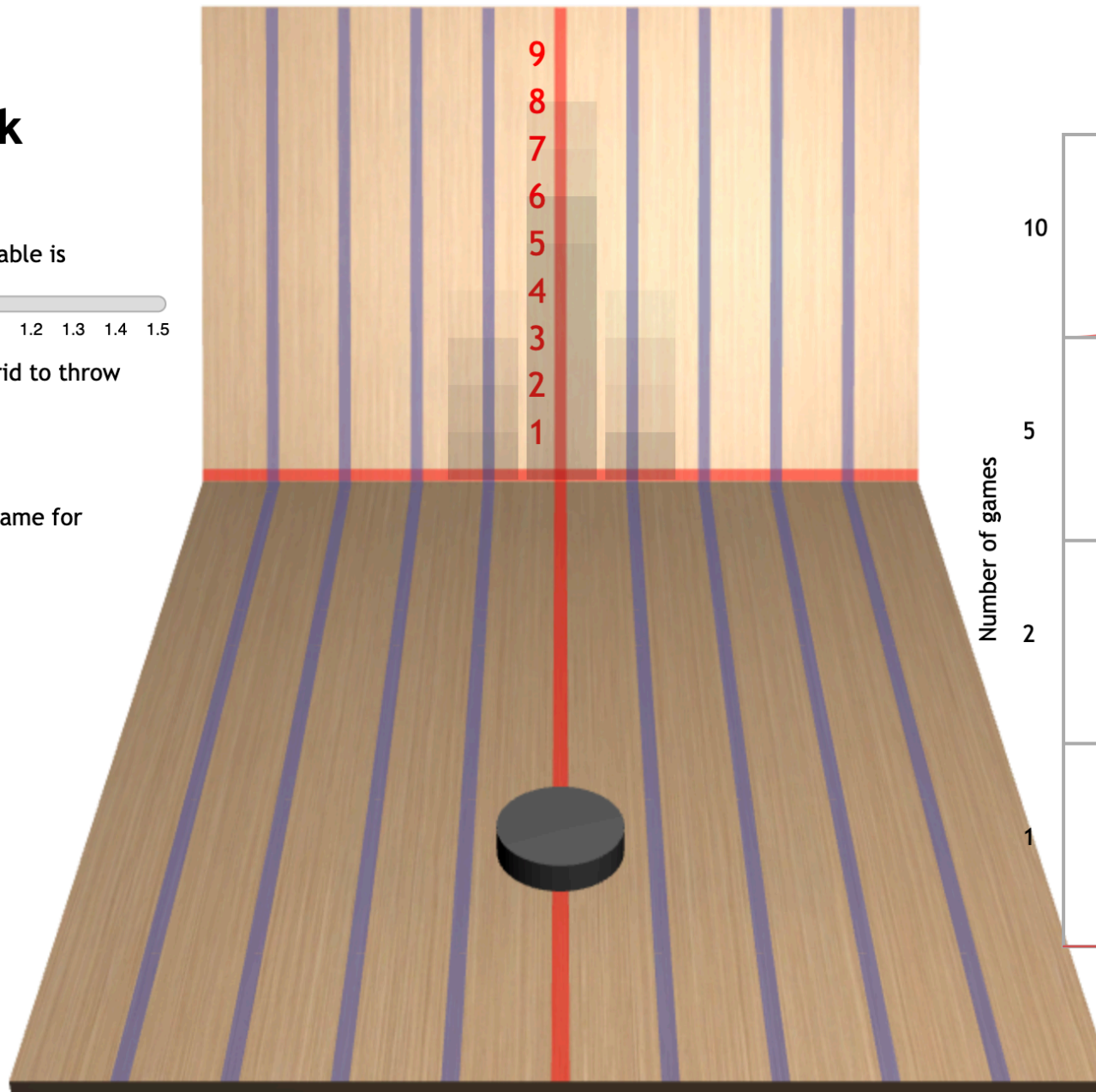
## Slide-the-puck

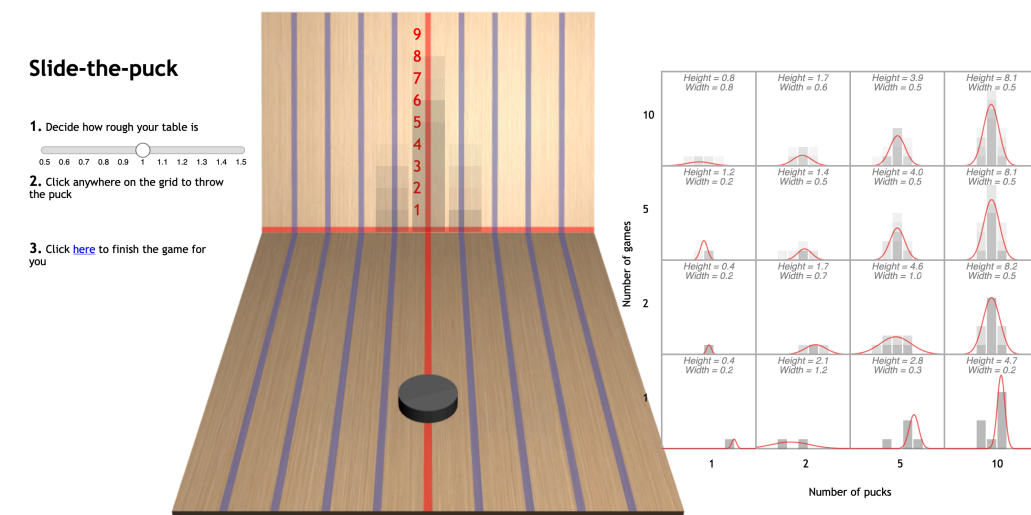
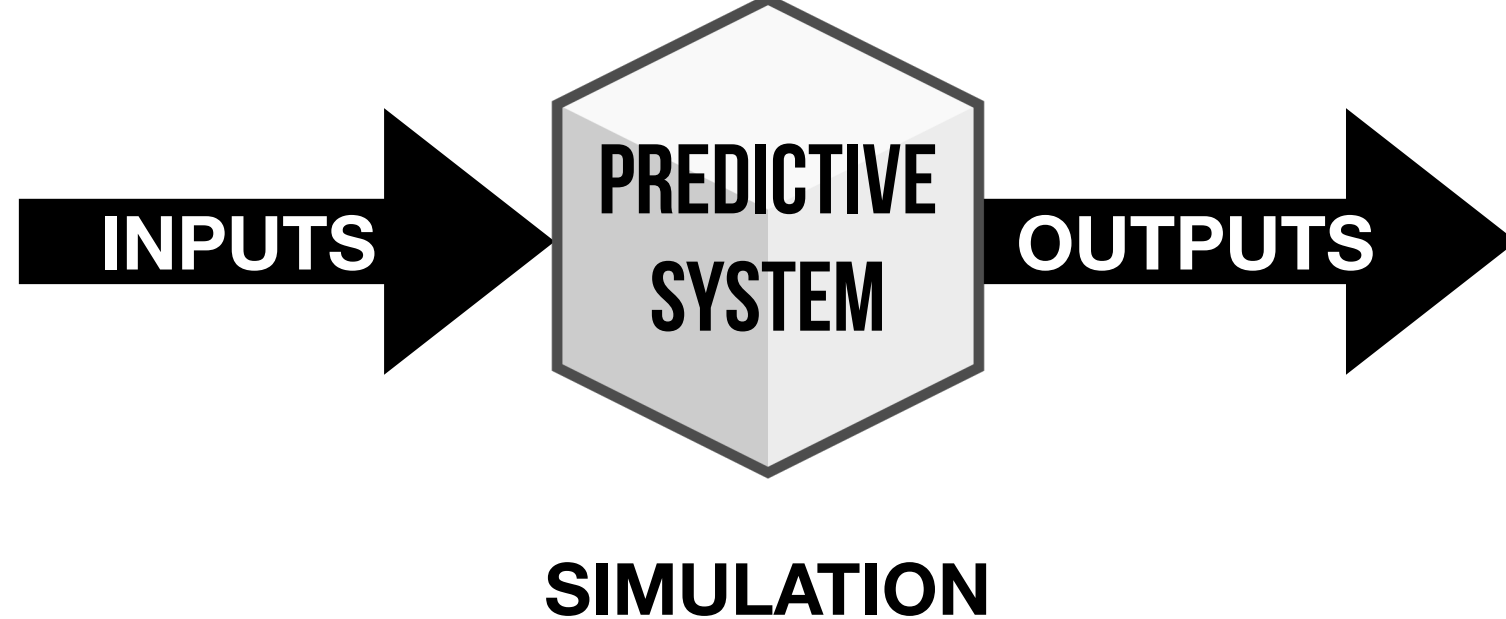
1. Decide how rough your table is



2. Click anywhere on the grid to throw the puck

3. Click [here](#) to finish the game for you





## ***What comes into play in this SIMULATION?***

The model in this “predictive system” is **#NON-RANDOM** Newtonian physics, with friction.

The puck is launched with in a **#RANDOMIZED** direction (**input**) whose **mean** is straight ahead (along the red line).

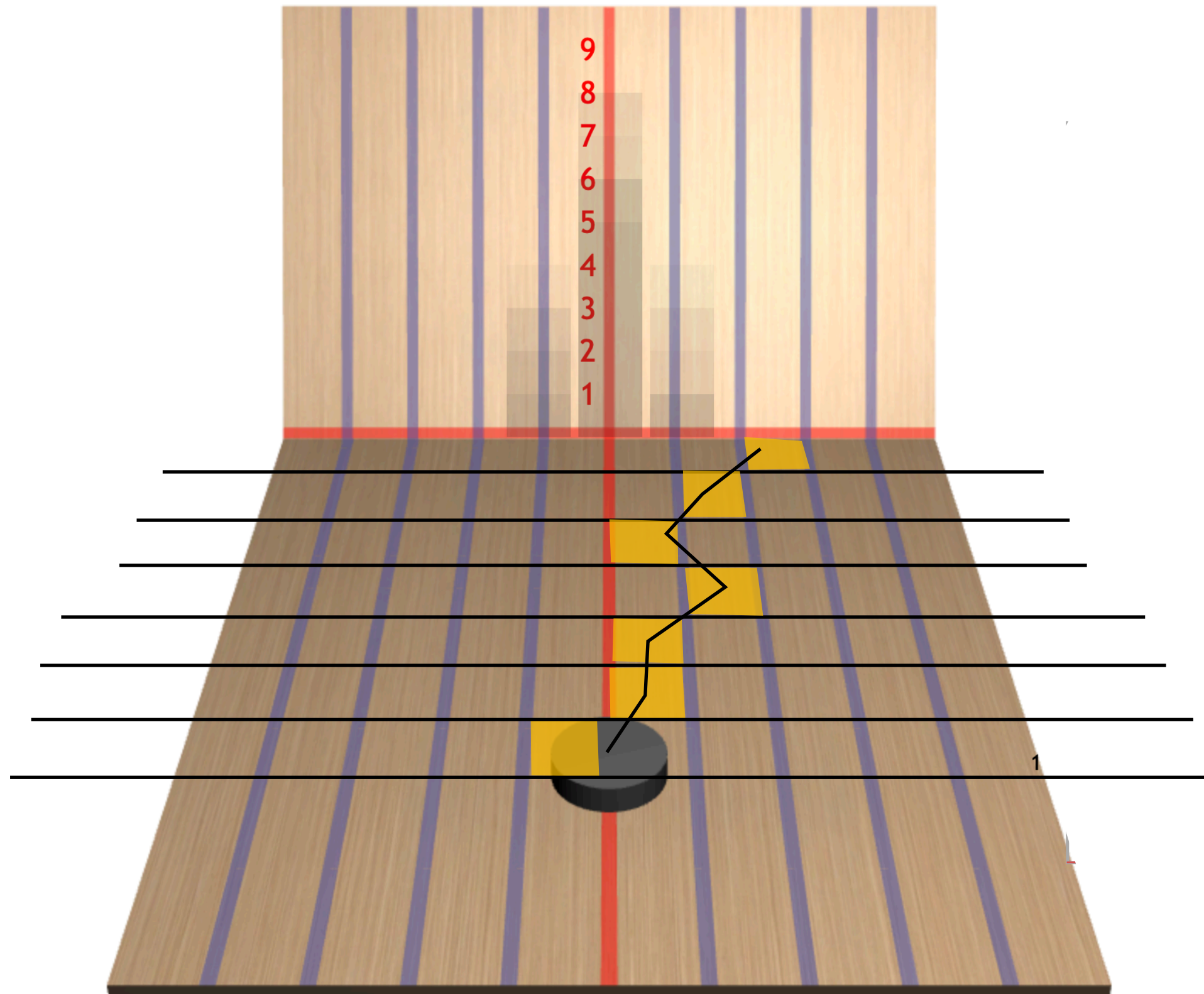
At each “**time-step**,” the puck’s direction is given a **#RANDOMIZED** directional offset, within a small range centered on “straight ahead.” The range is determined by the “roughness” of the table. Perfectly smooth=exactly straight ahead.

The path of the puck looks jerky when you play because the **time** and/or **spatial resolution** of the situation is low (not very good).

The **distribution** of final positions (**outputs**) shows a range of positions (“**uncertainty**” around prediction of exactly straight ahead) effected by **inputs** (in this case table roughness), and settles to reliable values with more and more **trials**.



The path of the puck looks jerky when you play because the **time** and/or **spatial resolution** of the situation is low (not very good).



# Breakouts

## Round 2

Consider & discuss  
sources of  
uncertainty for your  
Room's system

Notes at

<https://tinyurl.com/gened-uncertain>

1

- ☐ traffic forecasting
- ☐ purchase prediction
- ☐ mental health
- ☐ advertising strategy/revenue
- ☐ online dating
- ☐ precision medicine
- ☐ pathology diagnoses
- ☐ personal genomics kits
- ☐ predicting IQ

2

- ☐ predicting travel risk (e.g. BlueDot)
- ☐ breast cancer risk
- ☐ human height
- ☐ car accidents
- ☐ longevity assessment
- ☐ election outcomes
- ☐ Dow Jones (index numbers)
- ☐ sub-prime mortgage crash (2008)

3

- ☐ insurance pricing
- ☐ jury decision outcomes
- ☐ war/battle outcomes
- ☐ airline schedules (arrival/departure delays)
- ☐ auction pricing

- ☐ prediction markets (politics)

- ☐ galaxy collisions

- ☐ planet formation

- ☐ earthquakes

- ☐ weather

- ☐ climate change

4

- ☐ water supplies

- ☐ tornadoes

- ☐ hurricanes

- ☐ flooding

- ☐ The Drake Equation (SETI)

5

- ☐ online poker

- ☐ baseball player ratings (moneyball)

- ☐ football team rankings

- ☐ March Madness (basketball)

- ☐ movie popularity

- ☐ horse racing

6

- ☐ music popularity (e.g. of a specific artist/genre)

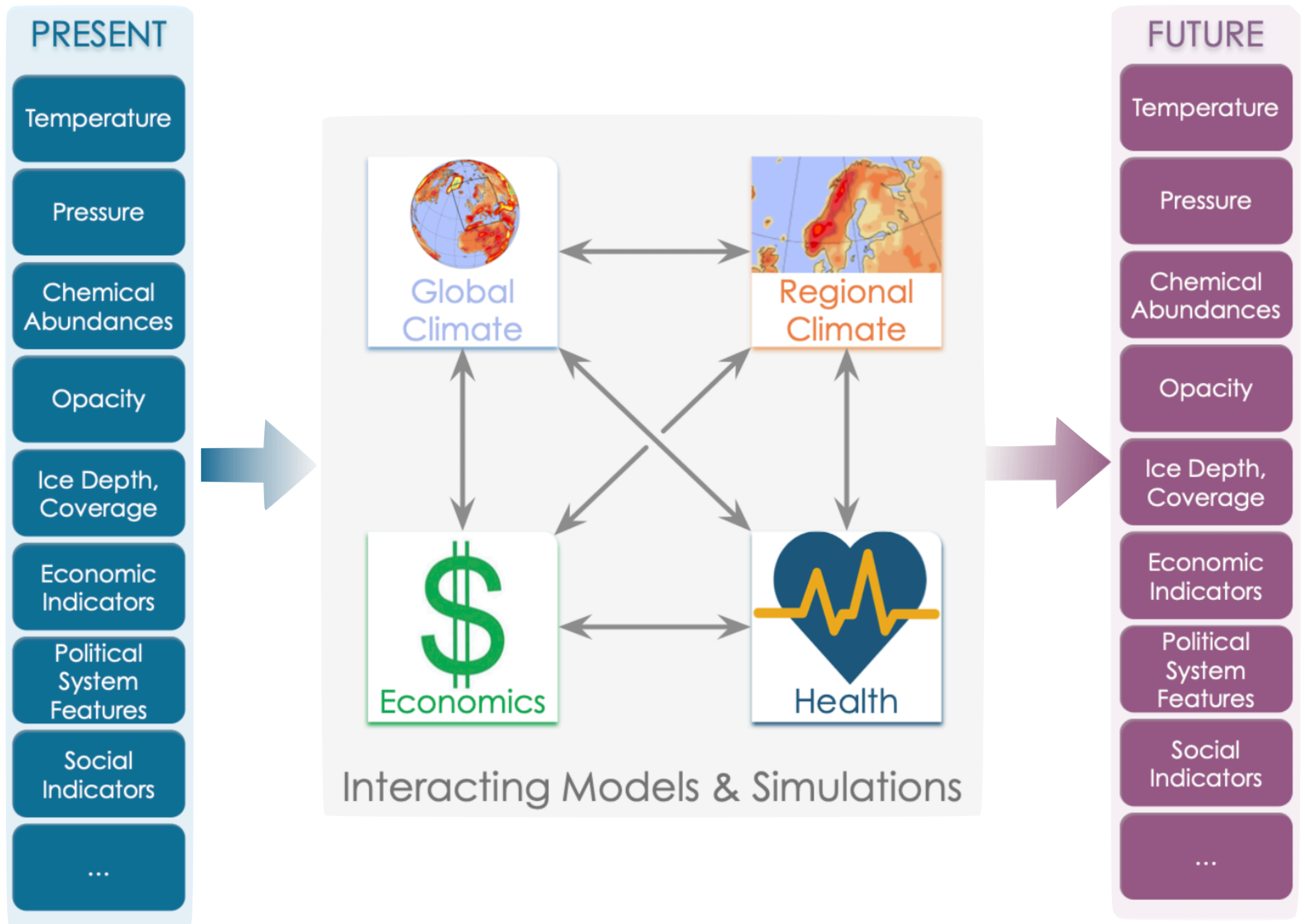
- ☐ COVID-19

- ☐ Ebola in Africa

- ☐ "retrodict" Plague in Europe in the 1600s



# Where we will be in 5 weeks...





# Fine points & questions for future discussions

“Simulation” vs. “Numerical Experiment”

Simulation: goal is reality

Numerical Experiment: A “what if” question, about one parameter or idea.

What to do about critical inputs you can't have

(e.g. underground activity in earthquake forecasting, true # of COVID-19 infections, aspects of human behavior)?

Is a more complicated system always better?

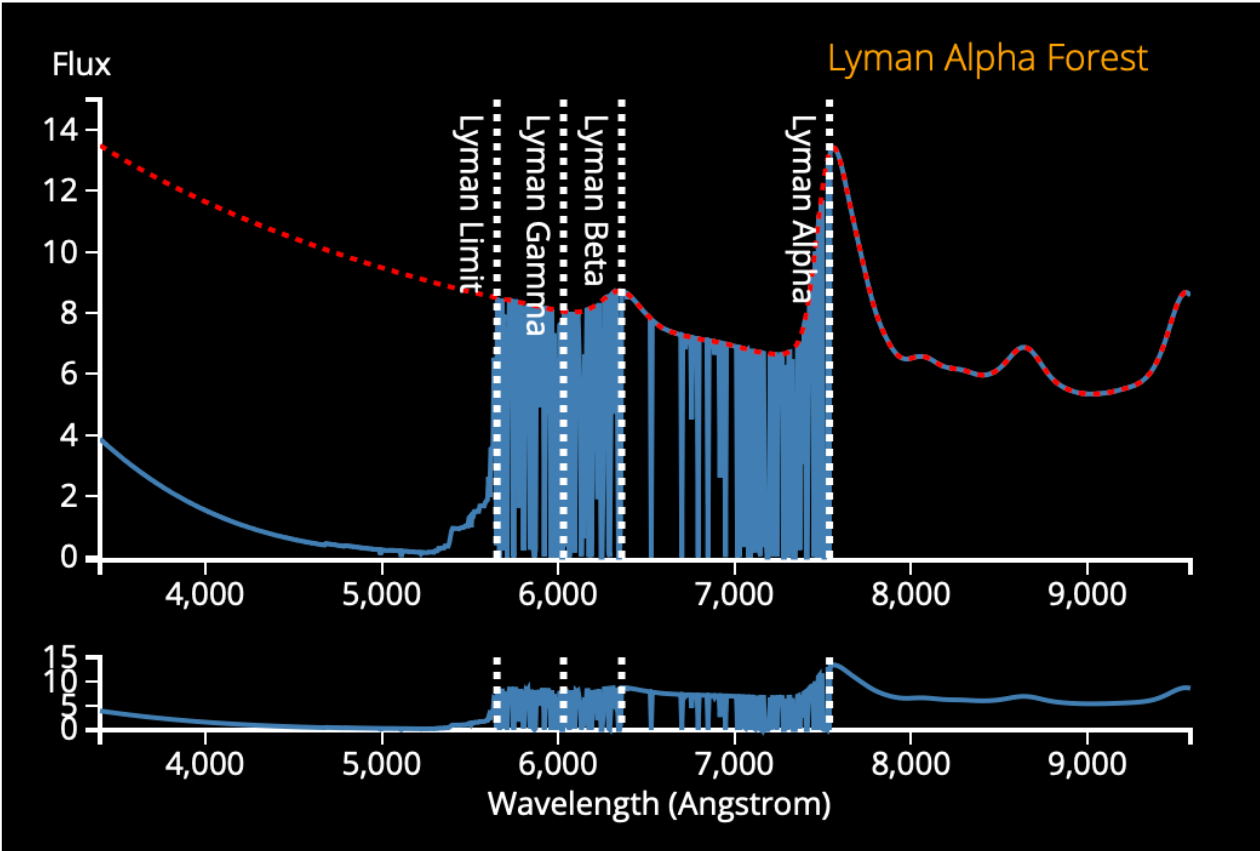
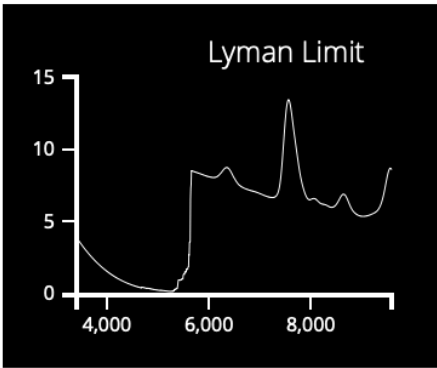
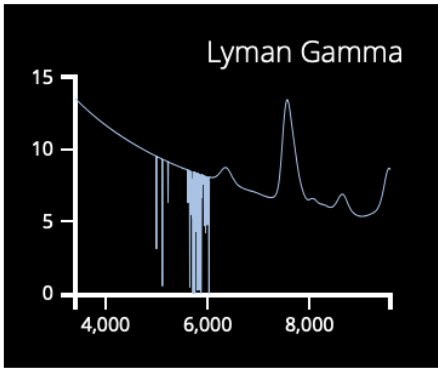
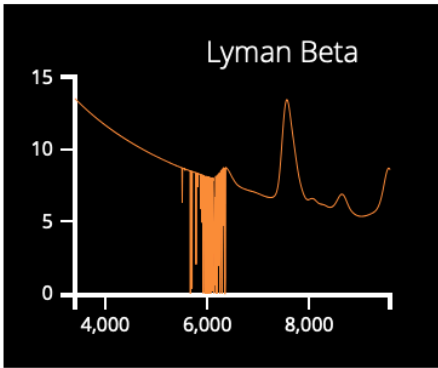
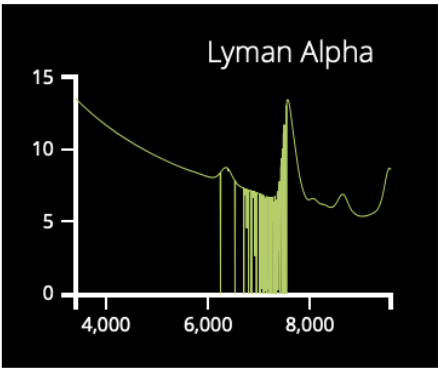
(Note Marianna Linz' simple global temperature model...)

SimCity 2000 vs. The Sims...



**extra materials...**





- ☐ Remove plot labels
- ☒ Lyman-alpha
- ☒ Lyman-beta
- ☒ Lyman-gamma
- ☒ Lyman-limit
- ☐ Continuum subtracted
- ☒ Quasar mode
- ☒ Quasar Spectrum

Animate



Total column density

7.9e17 atoms/cm<sup>2</sup>



Redshift index,  $\beta$

20.1



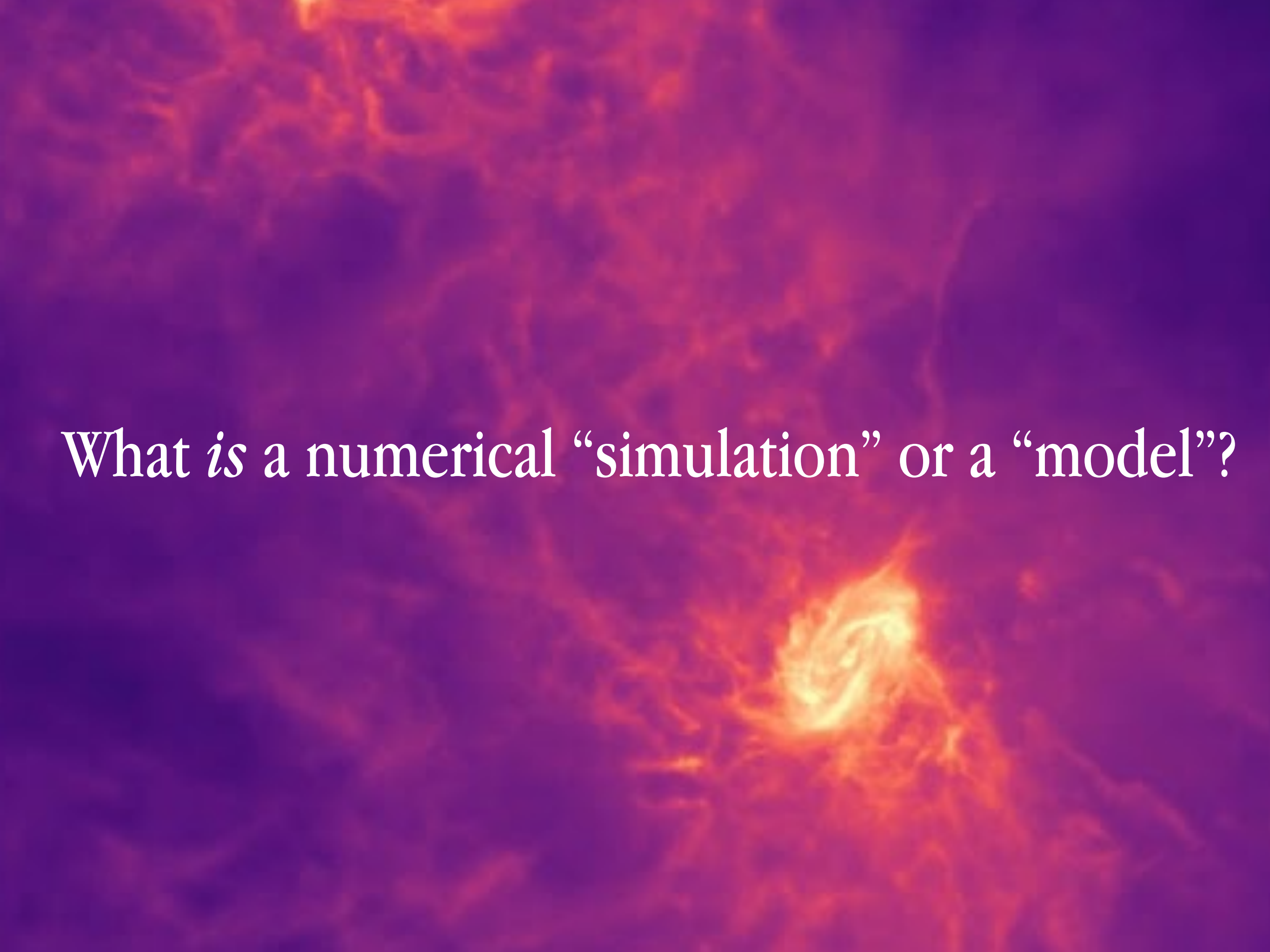
Column density index,  $\alpha$

1.3



Quasar redshift

5.2

A Cosmic Microwave Background (CMB) fluctuation map showing temperature variations across the sky. The background is a deep purple, with intricate, filamentary structures of red, orange, and yellow. These structures represent density fluctuations in the early universe. A prominent, bright yellow-orange region is visible in the lower right quadrant, indicating a higher temperature. The overall pattern is complex and non-uniform, characteristic of the CMB's anisotropy.

What *is* a numerical “simulation” or a “model”?



**Words or phrases you heard in class recently  
that were MOST unfamiliar or confusing to  
you...**

Inputs

Processes

Outputs

What's a Simulation?

→ tube top demo ←

"nature of stuff"

Inputs

"what happens"

Processes

"new version of stuff"

Outputs

individually random,  
predictable en masse  
(because the physics  
is simple)

Evaluation

direction of puck  
roughness of surface  
→ distance to wall "d"  
speed of puck "s"

Friction  
Newton's 1st Law  
"object in motion"  
"cons of momentum"

position where  
puck  
hits  
wall.

leave  
subtleties  
for  
discussion

- density fluctuations at  $t > 0$  of Universe
- ratio of DM/BM
- assumptions about dark energy
- temperature (motions at " $t > 0$ ")

- gravity
- magnetic fields
- thermal processes / Chemistry / particle physics

(CMB anisotropy)

- large-scale structure
  - in DM
  - in BM
- galaxies (#, positions, types, distributions)
- intergalactic structures - connect to Y Tim
- structure w/in galaxies

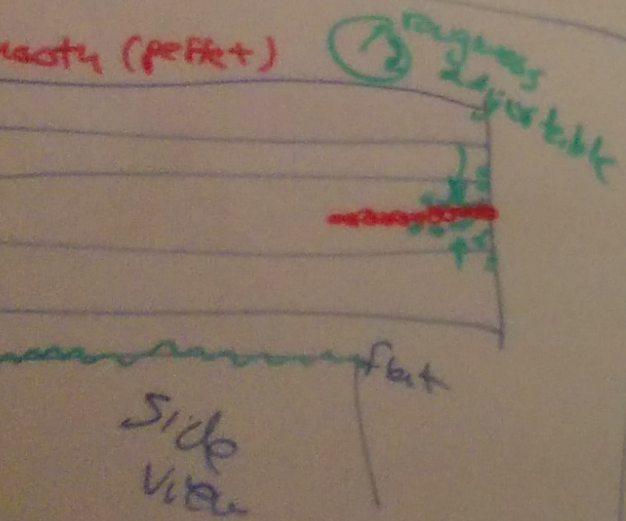
Shapley-Cox

How?



# The Origins & Future of the Universe

s of the Universe over time



Empirical

Theoretical

Ultimate Modern Simulation

What's a Simulation? (Physics & Computing)  
Of What? (Astronomy)

What is a simulation in this case?

stuff ← predict how that stuff will change (move, heat up, cool off, change color, etc.)

Difference empirical & theoretical

Need to know

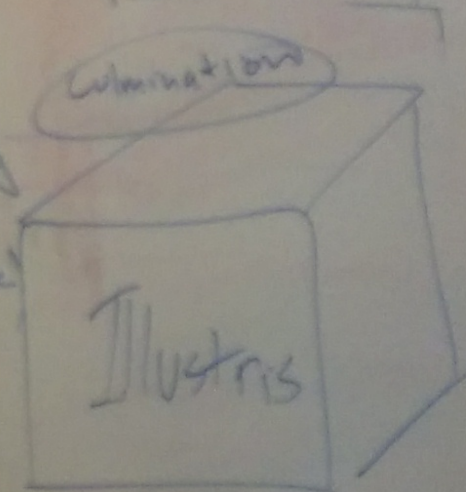
Sources of info

How to eval

Don't get scammed

Skepticism/Legitimacy

"Paradigm shifts" at first, idea seems crazy but then it makes testable predictions



Humans want to know their origin

Observations

Simulations (p)

Can you predict current Universe?

Finite & not

not

not



random,  
en masse  
(the physics  
simple)

Uncertainty that be reduced vs. not  
D. between empirical & theoretical

Humans want to  
know their  
origin & fate.

Need to know

Sources of info

Observations

Simulations (Physics)

How to eval

can you predict current

Universe from past

Finite of speed

of light +

makes possible

Don't get scammed

Skepticism/Legitimacy

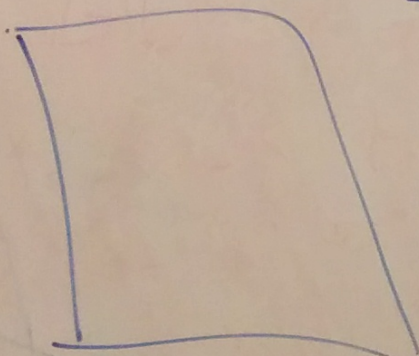
"Paradigm shifts"  
at first idea seems  
crazy but then  
it makes testable  
predictions

+ other "predictions"  
tests e.g.  
astrology

Ultimate  
Modern  
Simulation

What's a Simulation? (Physics & Computing)  
Of What? (Astronomy)

Shapley-Curtis



modern  
observations

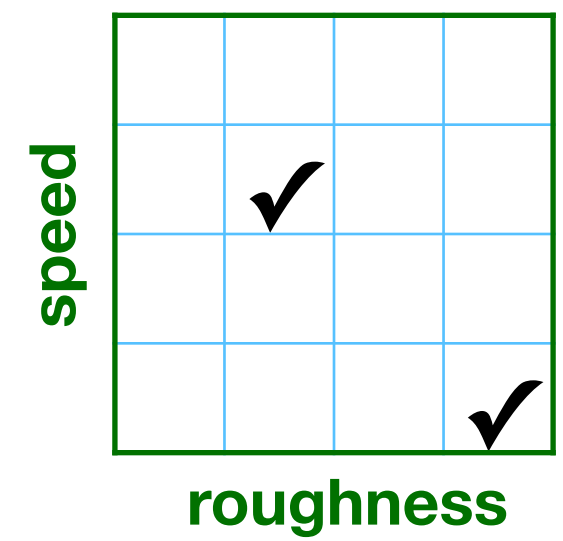
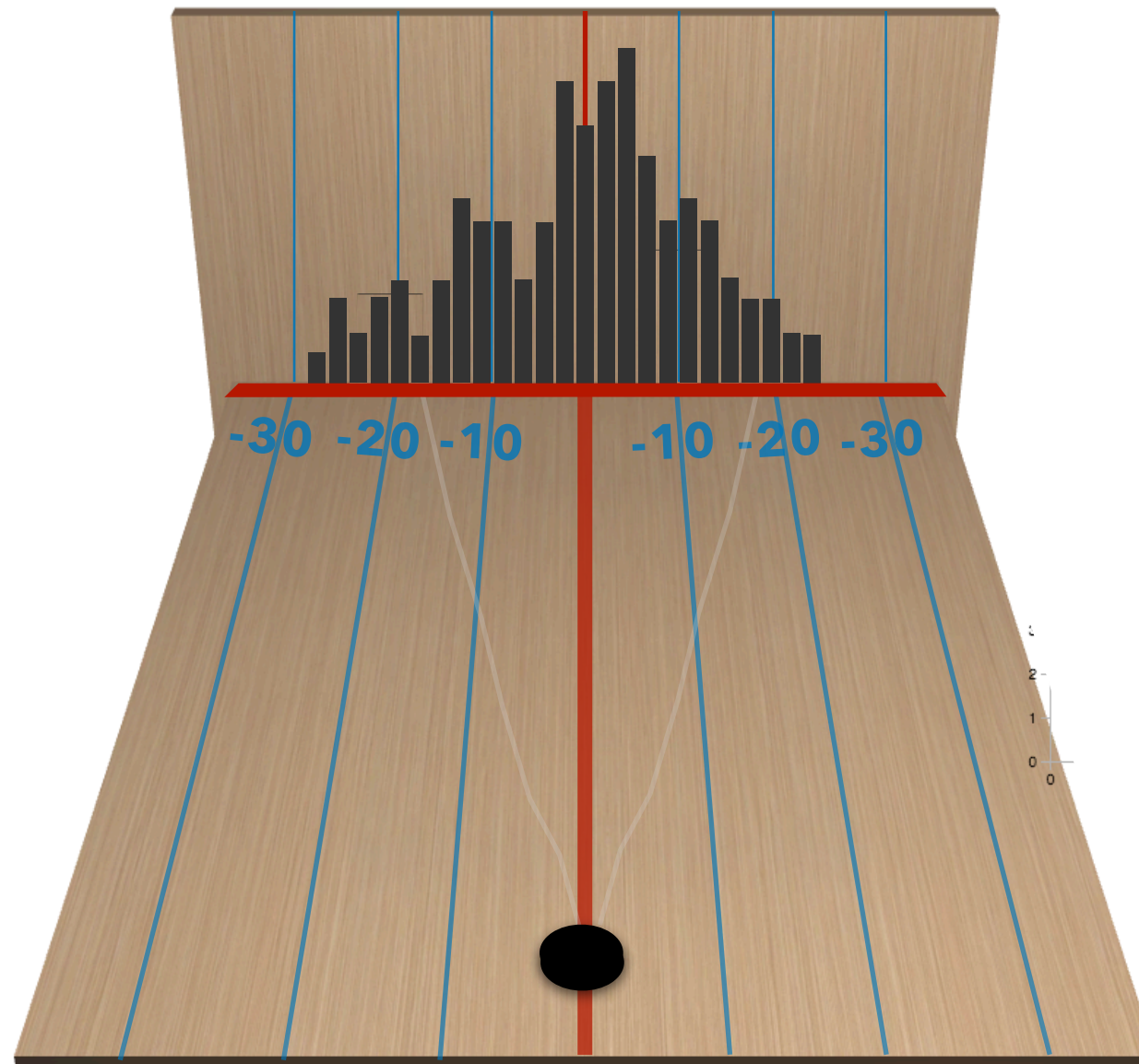
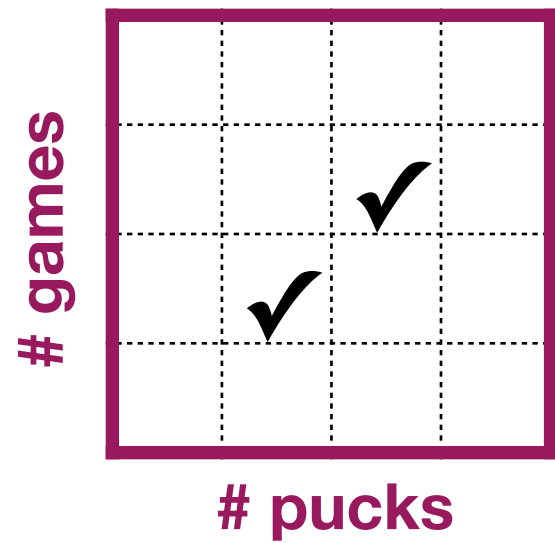
What is a simulation in this  
case?

stuff ← predict how that stuff  
will change (move, heat up, cool  
off, change color, etc.)

Culmination

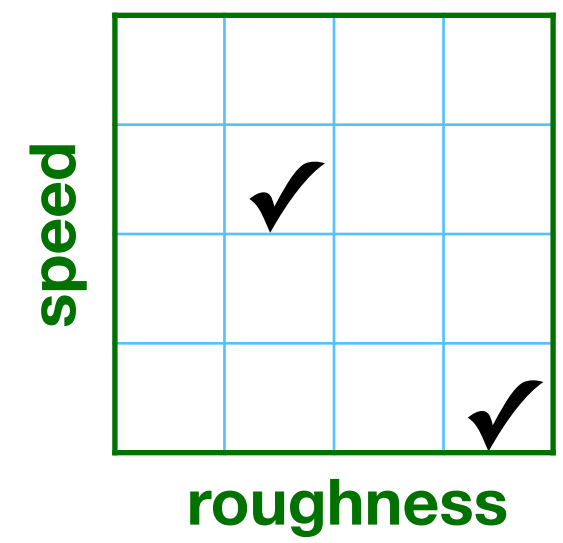
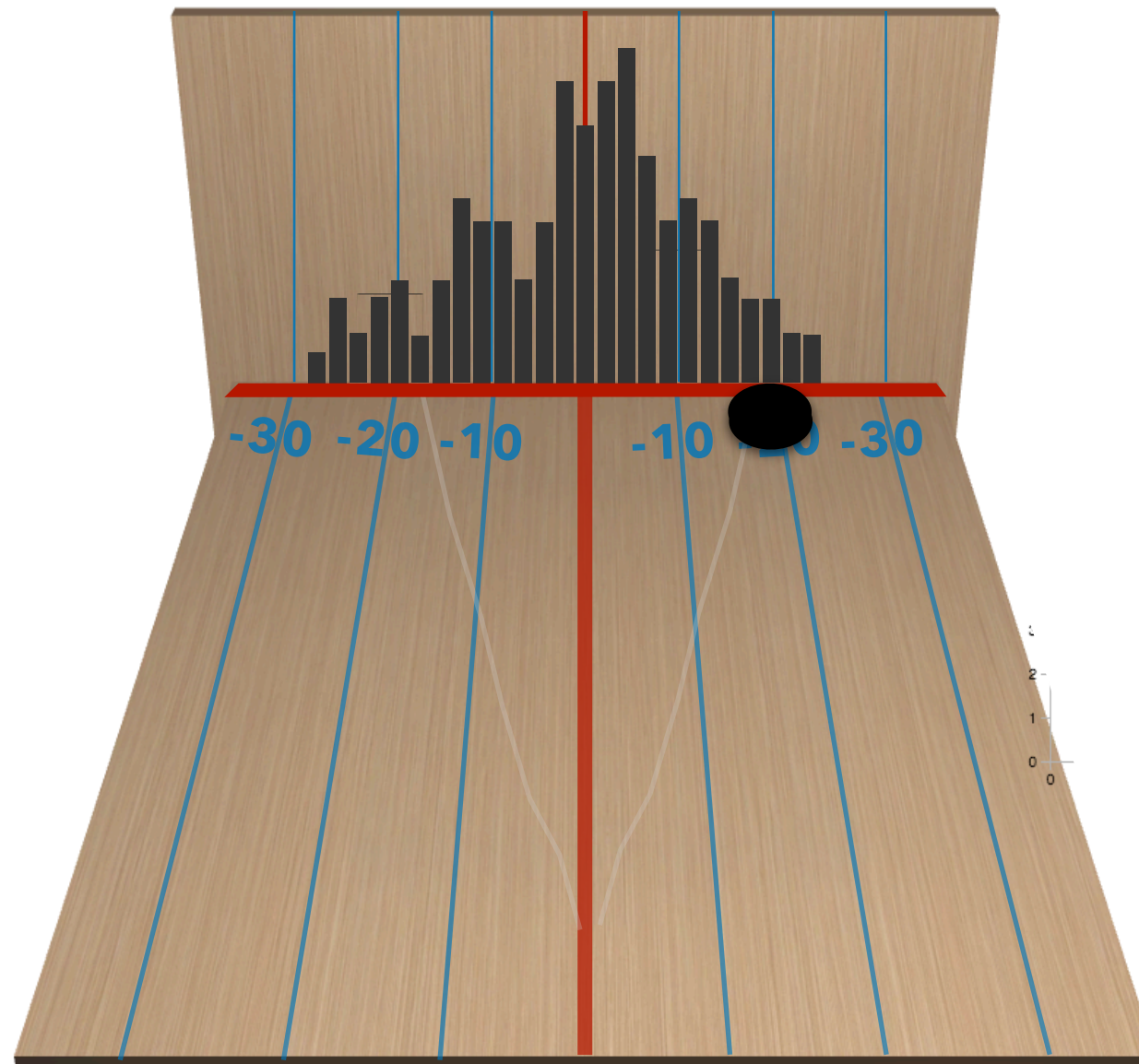
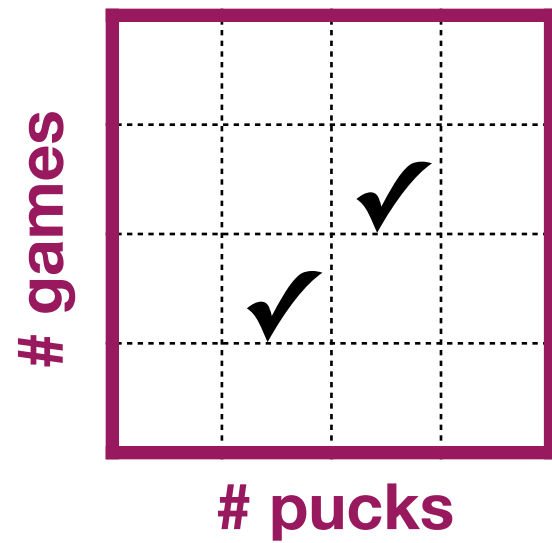
Illustris



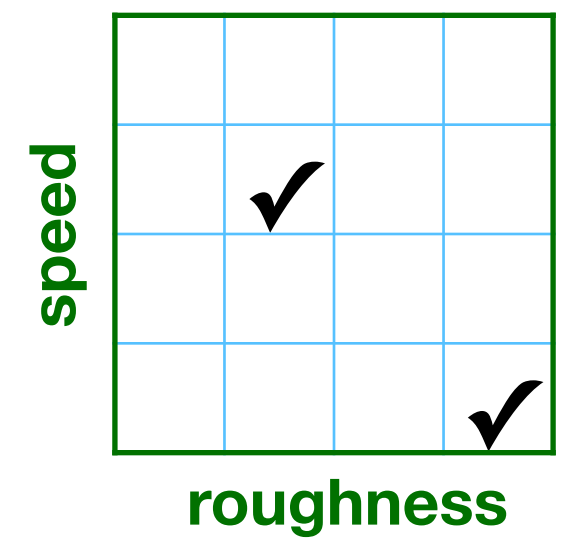
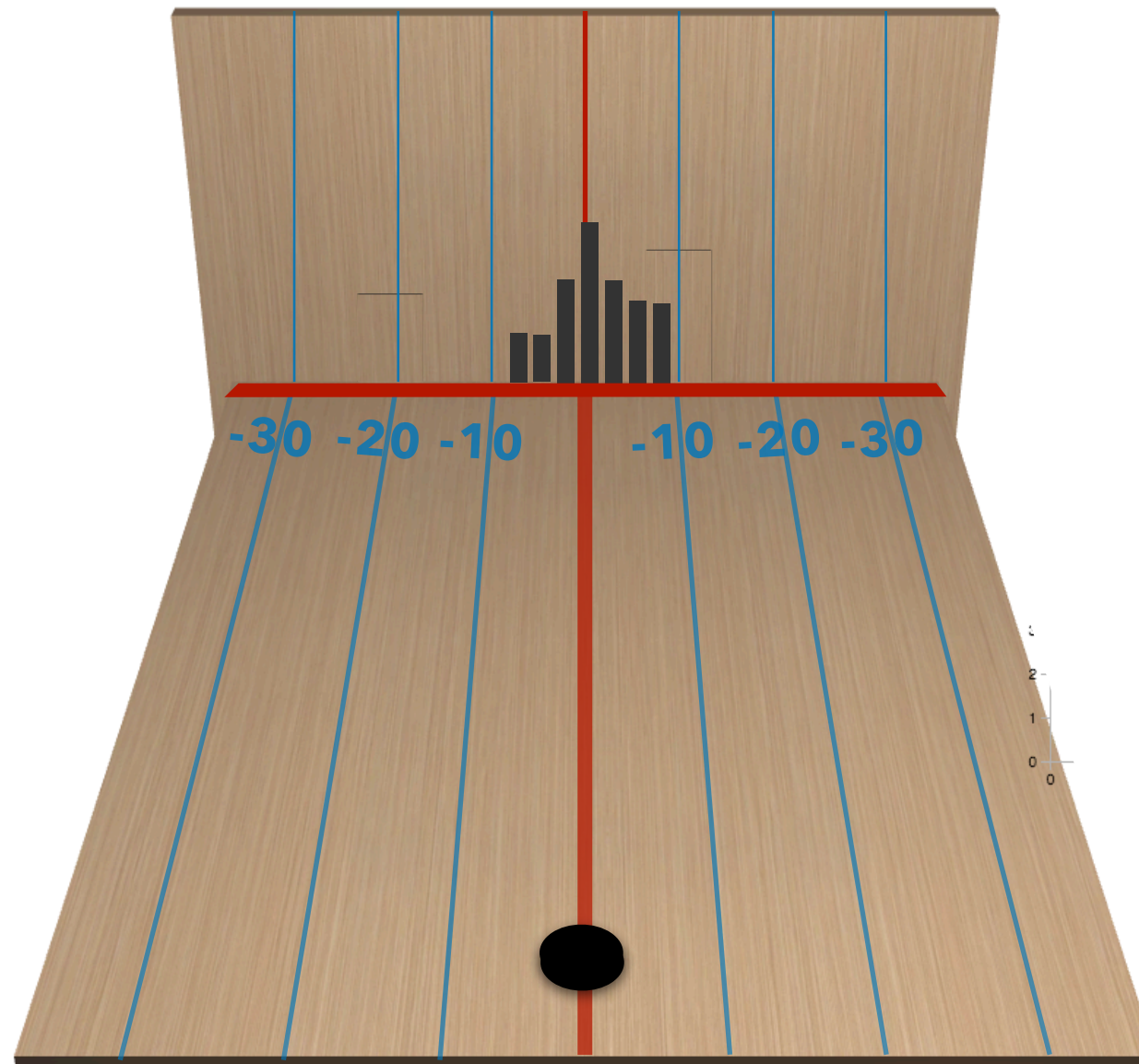
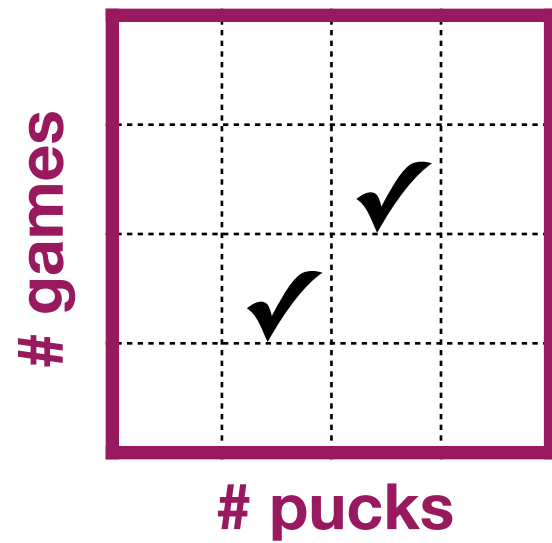


movie slider becomes “#players”





movie slider becomes “#players”



movie slider becomes “#players”