

**MATH FOR THE  
INDECISIVE:  
USING STATISTICS  
FOR CLIMATE  
DECISION-MAKING**

**Cecina Babich Morrow**



**WHO AM I?**





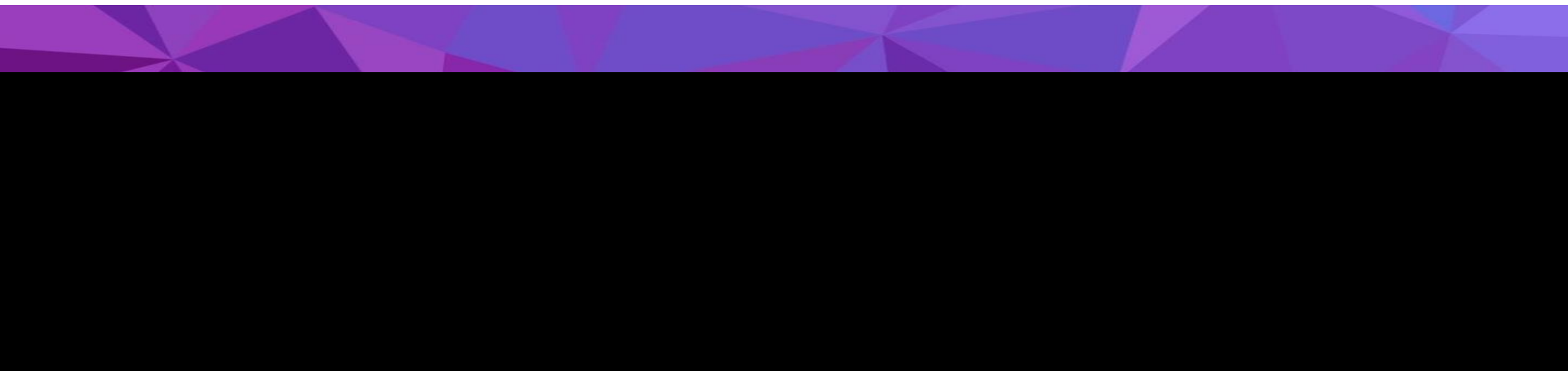
**WHO AM I?**



**WHO AM I?**

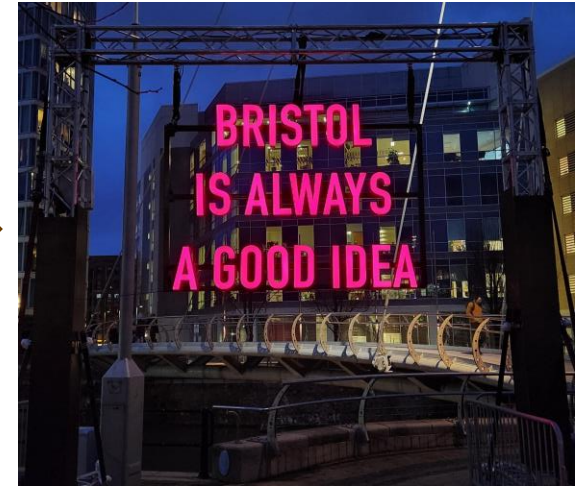


**WHO AM I?**

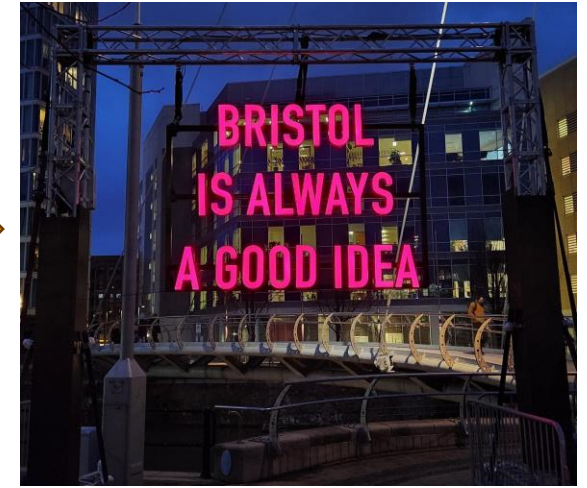




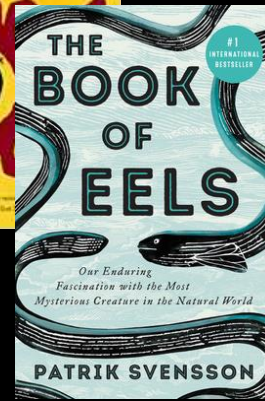
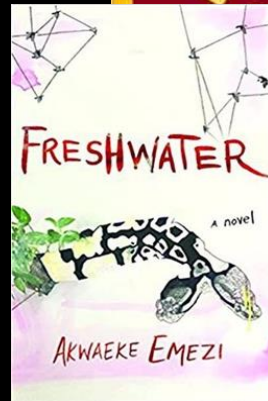
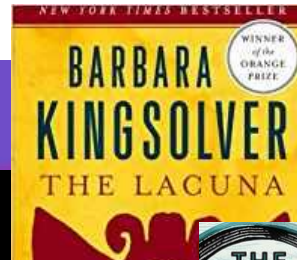
# WHO AM I?

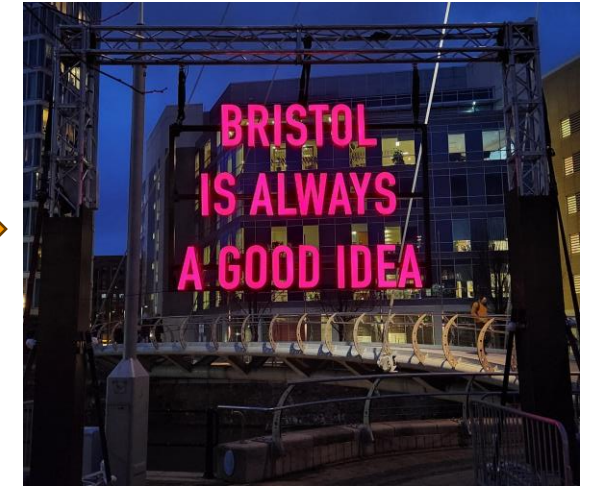


# WHO AM I?

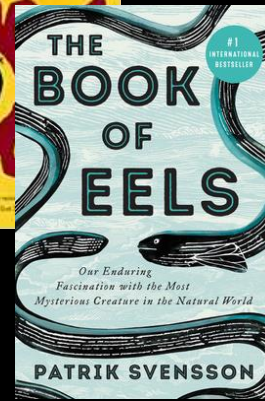
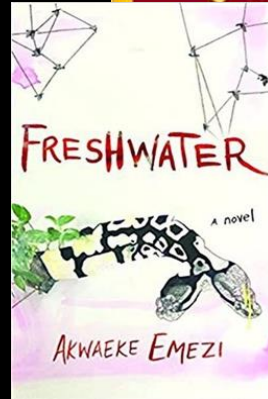
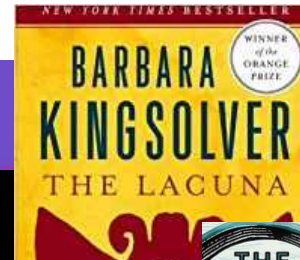


# WHO AM I?





# WHO AM I?



**WHAT DO I DO?**

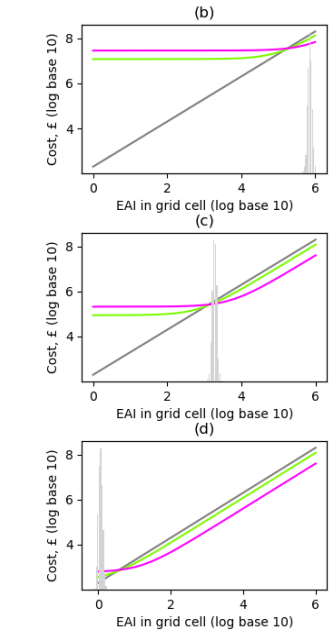
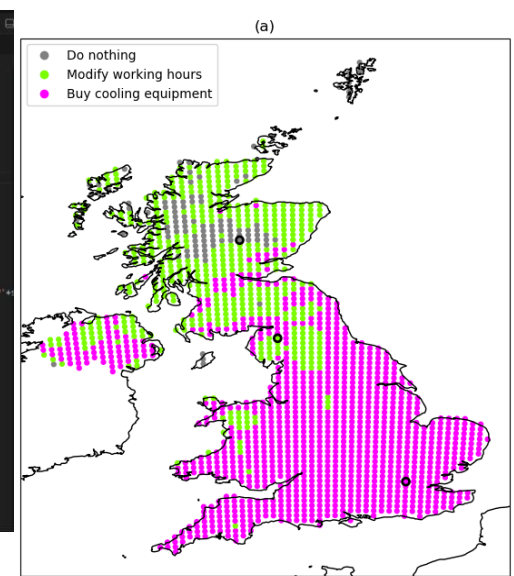
A decorative horizontal band at the bottom of the slide, featuring a complex geometric pattern of overlapping triangles in various shades of purple and magenta, set against a solid black background.



```
File Edit Selection View Go Run Terminal Help
bda_risk_dec_sensitivity

EXPLORER
  bda_risk_dec_sensitivity
  > vscode
  > code
  > __pycache__
  > ai_climate_health_poster.py
  > bda_risk_2024.yaml
  > bda_functions.py
  > default_dec_attr.py
  > ihc_sampling.py
  > onedec_cells.py
  > pawn_jmf_test.py
  > plotting_functions.py
  > python_plots.py
  > sensitivity_analysis.py
  > single_cell_viz.py
  > speed_test.py
  > write_decision_files.py
  > data
    > ChangeFactor
    > decision_files_200
    > decision_files_jit
    > ihc_samples
    > pawn_results
    > raw
    > UNCCP_BC
    > UNCCP_raw
    > UNCCPs
  > library
  > ml_hyp_samples_200.csv
  > README.md
  > README.txt
  > figures
  > diagram
  > dec-sens-main.nna
  > OUTLINE
  > TIMELINE

code
  bda_functions.py
  1 # File of functions to call
  2
  3 import numpy as np
  4 import pandas as pd
  5 from netCDF4 import Dataset
  6 import cftime
  7 import os
  8 from numba import jit
  9
 10 #####
 11 # BDA FUNCTIONS
 12 # Function to return the array of estimated annual impact (EAI)
 13 def get_EAI(input_data_path,
 14            data_source,
 15            warming_level,
 16            ssp,
 17            vdi,
 18            vdi2):
 19     # Load in GCM samples of EAI
 20     gamsamples_file = input_data_path+data_source+'GMSamples_expected_annual_impact_data_'+data_source+'_ML'+warming_level+'_SSP'+
 21     gamsamples = Dataset(gamsamples_file)
 22     EAI = np.array(gamsamples.variables['sin annual_impact'])
 23
 24     return EAI
 25
 26 # Function to return the array of number of people in each grid cell
 27 def get_Exp(input_data_path,
 28            ssp,
 29            ssp_year):
 30     # need the number of ppl in each grid cell to calculate the total cost as input is 'cost per person'
 31     exposure_netcdf = Dataset(input_data_path+'UNCCPs/employment_SSP'+ssp+'_12km_Physical.nc')
 32     units = getattr(exposure_netcdf['time'], 'units')
 33     calendar = getattr(exposure_netcdf['time'], 'calendar')
 34     dates = cftime.num2date(exposure_netcdf.variables['time'][:], units, calendar)
 35     year_to_index = [(k, timestep()) for year, v, k in enumerate(dates)]
 36     # pick out the right year (SSP year)
 37     index = year_to_index[int(ssp_year)]
 38     Exp = np.array(exposure_netcdf.variables['employment'][:][index])
 39
 40     return Exp
```

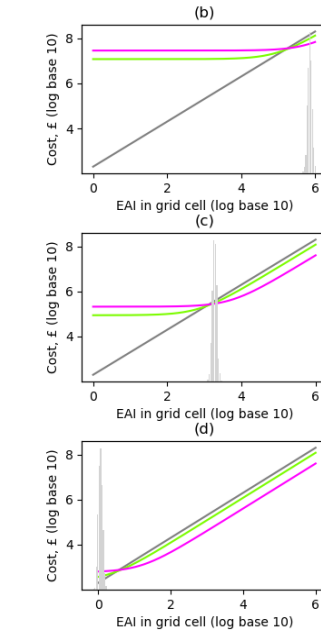
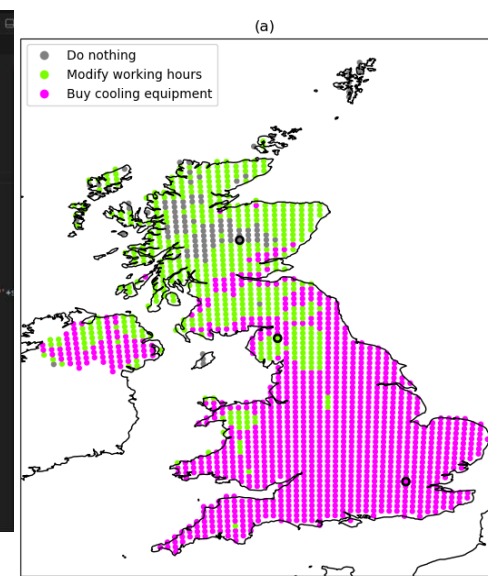


# WHAT DO I DO?



```

File Edit Selection View Go Run Terminal Help
bda_functions.py • pawm_jmf_test.py
code
  bda_functions.py
  code
    1 # File of functions to call
    2
    3 import numpy as np
    4 import pandas as pd
    5 from netCDF4 import Dataset
    6 import cftime
    7 import os
    8 from numba import jit
    9
    10 #####
    11 # BDA FUNCTIONS
    12 # Function to return the array of estimated annual impact (EAI)
    13 def get_EAI(input_data_path,
    14            data_source,
    15            warming_level,
    16            ssp,
    17            vdi,
    18            vdi2):
    19     # Load in GCM samples of EAI
    20     gamsamples_file = input_data_path+data_source+'GMSamples_expected_annual_impact_data_'+data_source+'_'+warming_level+'_'+ssp+'_'
    21     gamsamples = Dataset(gamsamples_file)
    22     EAI = np.array(gamsamples.variables['sin annual_impact'])
    23
    24     return EAI
    25
    26 # Function to return the array of number of people in each grid cell
    27 def get_Exp(input_data_path,
    28            ssp,
    29            ssp_year):
    30     # need the number of ppl in each grid cell to calculate the total cost as input is 'cost per person'
    31     exposure_netcdf = Dataset(input_data_path+'UNCSPPs/Employment_'+ssp+'_'+ssp_year+'.Physical.nc')
    32     units = getattr(exposure_netcdf['time'], 'units')
    33     calendar = getattr(exposure_netcdf['time'], 'calendar')
    34     dates = cftime.num2date(exposure_netcdf.variables['time'][:], units, calendar)
    35     year_to_index = {}
    36     for v, k in enumerate(dates):
    37         year_to_index[int(ssp_year)] = v
    38     Exp = np.array(exposure_netcdf.variables['employment'][:][year_to_index[ssp_year]])
    39
    40     return Exp
  
```



# WHAT DO I DO?

## Computing information value



**Algorithm** Calculate  $\mathbb{E}_{\mathbf{X}}[u(\mathbf{X}, a_{opt|M})]$

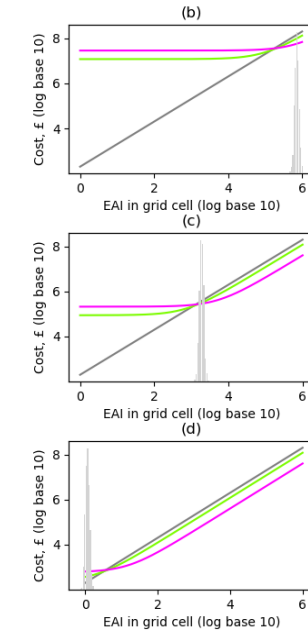
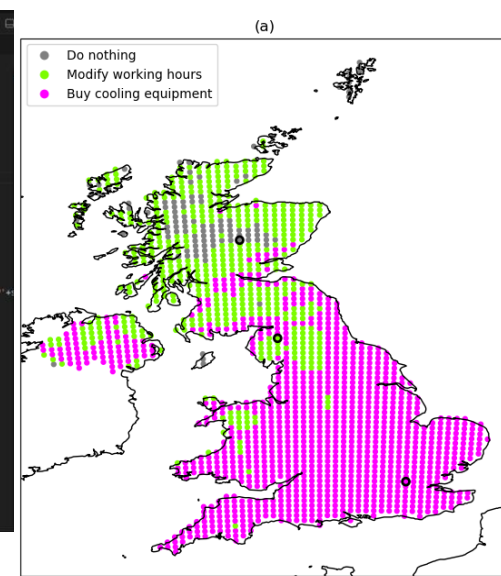
- 1: Take  $N$  samples of  $M \sim \mathcal{N}(7.5, 1)$
- 2: **for**  $m = 1$  to  $N$  **do**
- 3:   **for**  $a = 1$  to 3 **do**
- 4:     Take  $n$  samples of  $R_a$  and  $n$  samples of  $C_F$ .
- 5:     Calculate  $n$  values of  $Y_e(a)$  using  $M = m$  and the samples of  $R_a$  and  $C_F$ .
- 6:     Calculate  $\mathbb{E}_{\mathbf{X}_e|M}[Y_e(a)]$
- 7:     Calculate  $\mathbb{E}_{\mathbf{X}_e|M}[u(\mathbf{X}, a)] = -\mathbb{E}_{\mathbf{X}_e|M}[Y_e(a)] - c_a(a)$
- 8:   Find  $u(\mathbf{X}, a_{opt|M=m}) = \max_a \mathbb{E}_{\mathbf{X}_e|M} u(\mathbf{X}, a)$
- 9: Average the  $u(\mathbf{X}, a_{opt|M=m})$  over all  $m$  values to get  $\mathbb{E}_{\mathbf{X}}[u(\mathbf{X}, a_{opt|M})]$

Then  $V_M = \mathbb{E}_{\mathbf{X}}[u(\mathbf{X}, a_{opt|M})] - \mathbb{E}_{\mathbf{X}}[u(\mathbf{X}, a_{opt})]$



```

File Edit Selection View Go Run Terminal Help
bda_functions.py • pawn_jmf_test.py
code
bda_functions.py
code
1 # File of functions to call
2
3 import numpy as np
4 import pandas as pd
5 from netCDF4 import Dataset
6 import cftime
7 import os
8 from numba import jit
9
10 #####
11 # BDA FUNCTIONS
12 # Function to return the array of estimated annual impact (EAI)
13 def get_EAI(input_data_path,
14            data_source,
15            warming_level,
16            ssp,
17            v01,
18            v02):
19     # Load in GCM samples of EAI
20     gamsamples_file = input_data_path+data_source+'GMSamples_expected_annual_impact_data_'+data_source+'_'+warming_level+'_'+ssp+'.nc'
21     gamsamples = Dataset(gamsamples_file)
22     EAI = np.array(gamsamples.variables['sin annual_impact'])
23
24     return EAI
25
26 # Function to return the array of number of people in each grid cell
27 def get_Exp(input_data_path,
28            ssp,
29            ssp_year):
30     # need the number of ppl in each grid cell to calculate the total cost as input is 'cost per person'
31     exposure_netcdf = Dataset(input_data_path+'UNCSPPs/Employment_SSP'+ssp+'_12km_Physical.nc')
32     units = getattr(exposure_netcdf['time'], 'units')
33     calendar = getattr(exposure_netcdf['time'], 'calendar')
34     dates = cftime.num2date(exposure_netcdf.variables['time'][:], units, calendar)
35     year_to_index = {k: timeobj[0].year for v, k in enumerate(dates)}
36     # pick out the right year (SSP year)
37     index = year_to_index[int(ssp_year)]
38     Exp = np.array(exposure_netcdf.variables['employment'])[index]
39
40     return Exp
  
```



# WHAT DO I DO?

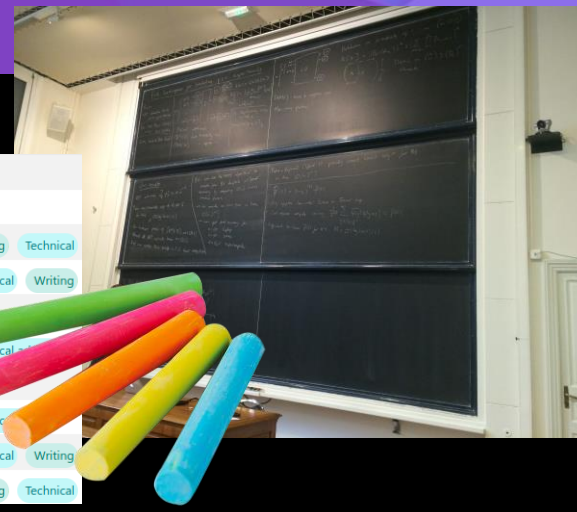
## Computing information value

**Algorithm** Calculate  $\mathbb{E}_X[u(\mathbf{X}, \alpha_{opt|M})]$

- 1: Take  $N$  samples of  $M \sim \mathcal{N}(7.5, 1)$
- 2: **for**  $m = 1$  to  $N$  **do**
- 3:   **for**  $\alpha = 1$  to 3 **do**
- 4:     Take  $n$  samples of  $R_\alpha$  and  $n$  samples of  $C_F$ .
- 5:     Calculate  $n$  values of  $Y_e(\alpha)$  using  $M = m$  and the samples of  $R_\alpha$  and  $C_F$ .
- 6:     Calculate  $\mathbb{E}_{X_e|M}[Y_e(\alpha)]$
- 7:     Calculate  $\mathbb{E}_{X_e|M}[u(\mathbf{X}, \alpha)] = -\mathbb{E}_{X_e|M}[Y_e(\alpha)] - c_\alpha(\alpha)$
- 8:     Find  $u(\mathbf{X}, \alpha_{opt|M=m}) = \max_\alpha \mathbb{E}_{X_e|M} u(\mathbf{X}, \alpha)$
- 9: Average the  $u(\mathbf{X}, \alpha_{opt|M=m})$  over all  $m$  values to get  $\mathbb{E}_X[u(\mathbf{X}, \alpha_{opt|M})]$

Then  $V_M = \mathbb{E}_X[u(\mathbf{X}, \alpha_{opt|M})] - \mathbb{E}_X[u(\mathbf{X}, \alpha_{opt})]$

Free Ask-JGI Helpdesk			
Fellowship grant application statistical analysis review.	Ka Kei Sum	23/2 - Clarified with cli	Experiment Statist
Ad hoc costed support (R help)	Zhujun Liu	23/02 zhujun&cecina s	Misc. Co. Visualisa Writing Technical
Probabilistic data linkage in Ugandan maternity data	Cecina Babich Mc	28/10: Cecina sent an e	Misc. Coding Technical Writing
Help Formatting Boxplot in R and Statistics of Results	Cecina Babich Mc	17/2: Cecina scheduled	
Possible support with figure for peer-reviewed manuscript?	Yining Yuan		Visualisation Technical
Bayesian statistics for archaeological chemistry	Cecina Babich Mc	13/2: Cecina met with J	Statistics
Research support - randomisation	Ka Kei Sum	Note: In the mailbox, th	Experimental design Technic
Fw: Support with website data extraction	Fahd Abdelazim	08/12 Fahd answer son	Web scraping Technical Writing
Data analysis for longitudinal model - type 1 diabetes	Cecina Babich Mc	28/10: meeting schedu	Statistics Writing Technical



**HOW DID I GET HERE?**

A decorative footer consisting of a horizontal band of purple and black geometric shapes, including triangles and polygons, creating a low-poly or mosaic effect.

phoenixzoo  
ARIZONA CENTER for NATURE CONSERVATION



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**R M B L**

science. **OUTSIDE.**

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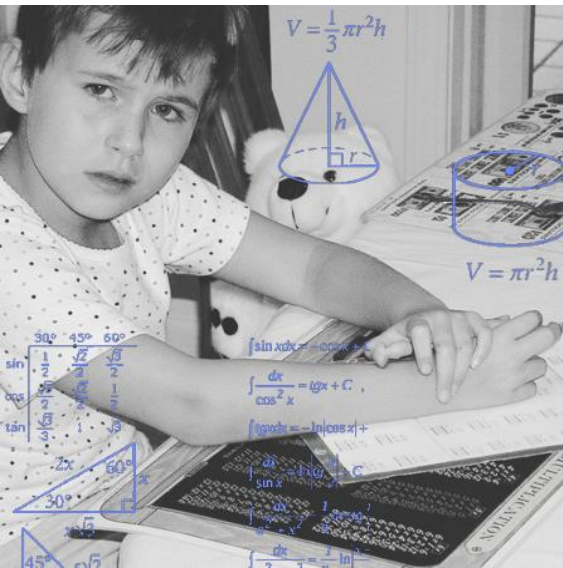


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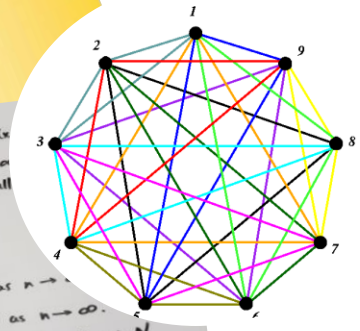
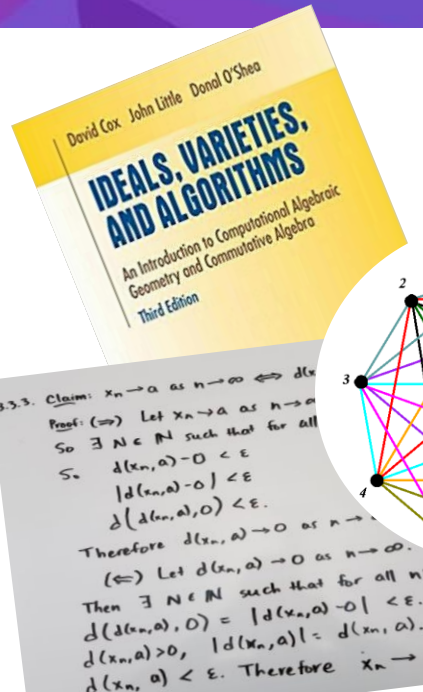
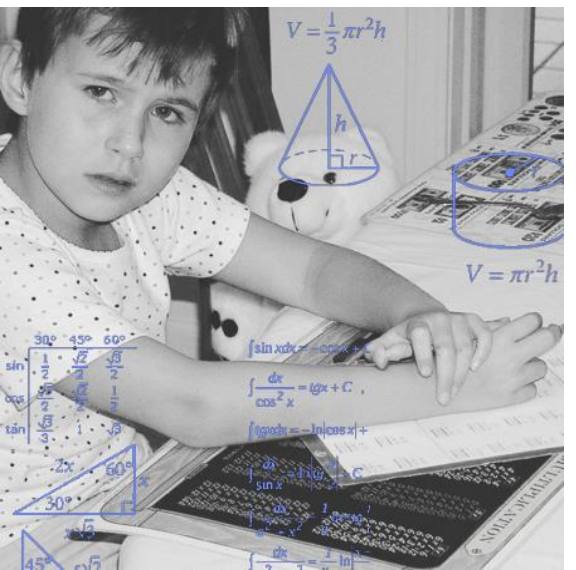


R M B L

science. OUTSIDE.

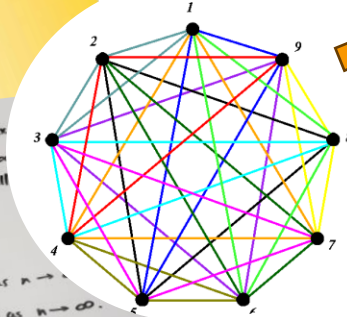
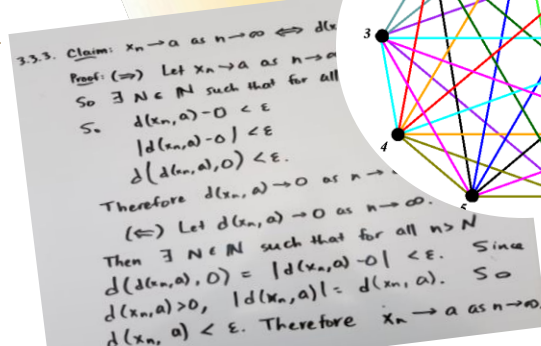
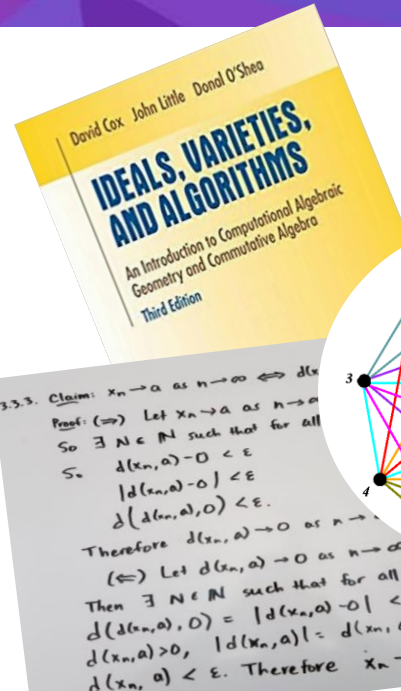
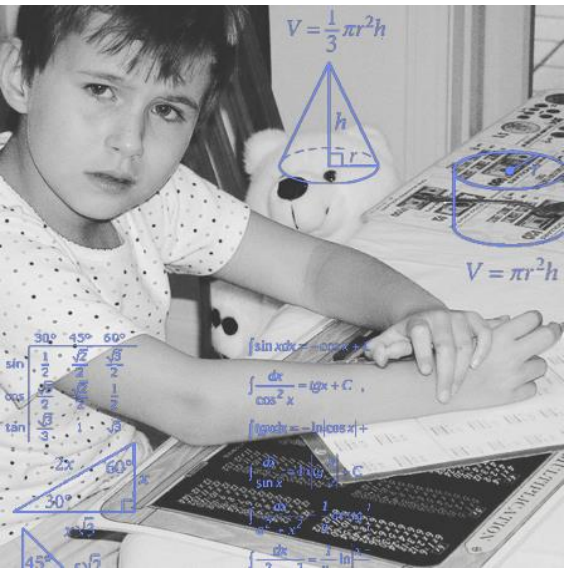
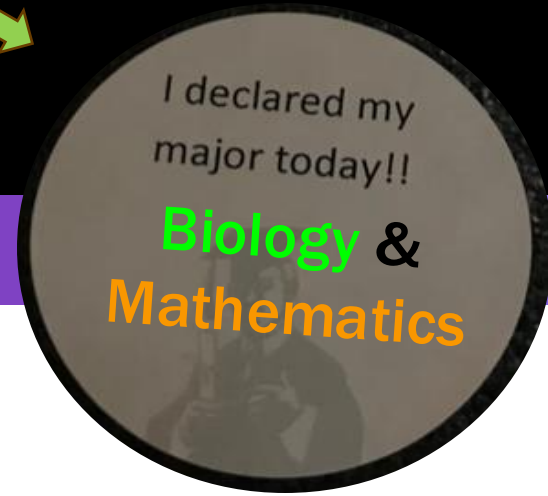
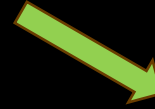


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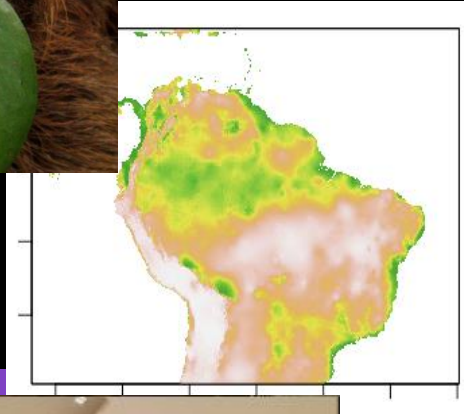
3.3.3. Claim:  $x_n \rightarrow a$  as  $n \rightarrow \infty \iff d(x_n, a) \rightarrow 0$  as  $n \rightarrow \infty$ .  
Proof: ( $\implies$ ) Let  $x_n \rightarrow a$  as  $n \rightarrow \infty$ .  
So  $\exists N \in \mathbb{N}$  such that for all  $n > N$ ,  
So  $|d(x_n, a) - 0| < \epsilon$   
 $|d(x_n, a) - 0| < \epsilon$   
 $d(d(x_n, a), 0) < \epsilon$ .  
Therefore  $d(x_n, a) \rightarrow 0$  as  $n \rightarrow \infty$ .  
( $\impliedby$ ) Let  $d(x_n, a) \rightarrow 0$  as  $n \rightarrow \infty$ .  
Then  $\exists N \in \mathbb{N}$  such that for all  $n > N$   
 $d(d(x_n, a), 0) = |d(x_n, a) - 0| < \epsilon$ . Since  
 $d(x_n, a) > 0$ ,  $|d(x_n, a) - 0| = d(x_n, a)$ . So  
 $d(x_n, a) < \epsilon$ . Therefore  $x_n \rightarrow a$  as  $n \rightarrow \infty$ .

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I declared my  
major today!!

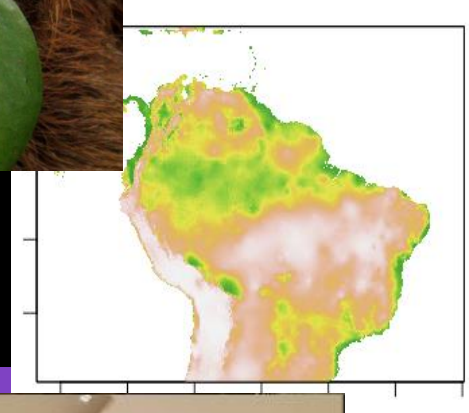
**Biology &  
Mathematics**



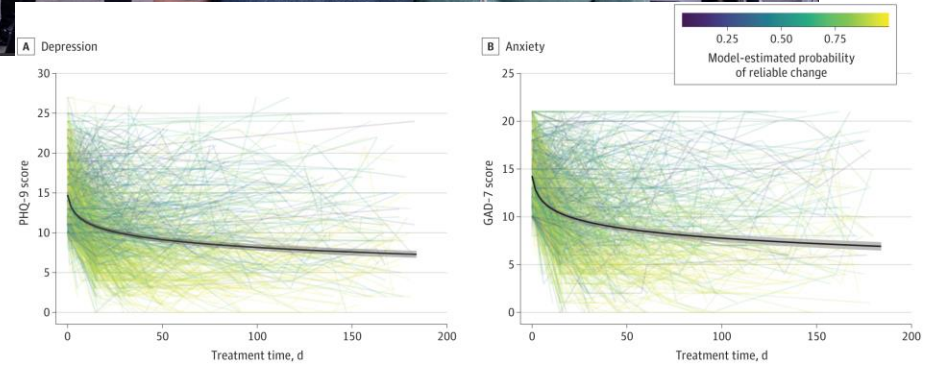
I declared my  
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**Biology &  
Mathematics**



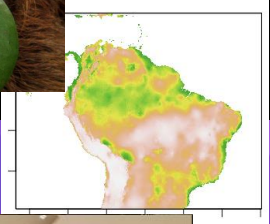


I declared my major today!!  
**Biology & Mathematics**

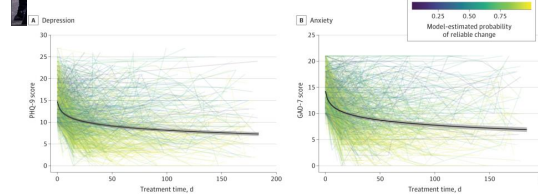
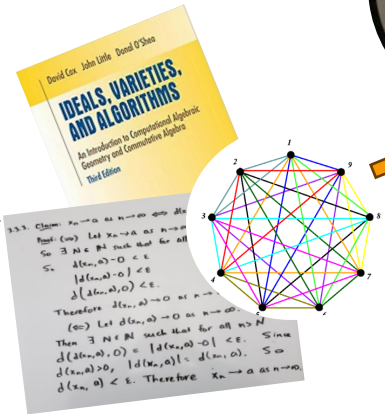
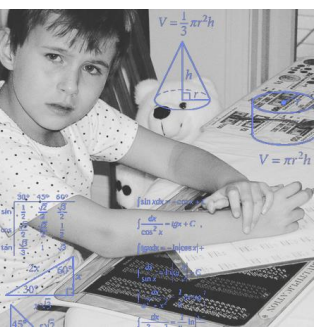




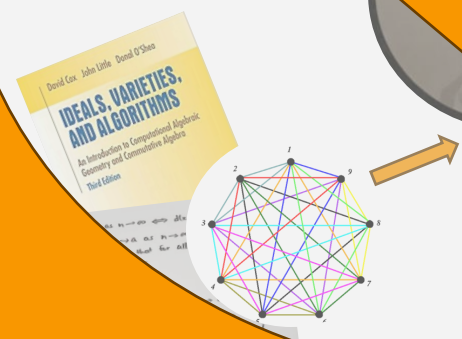
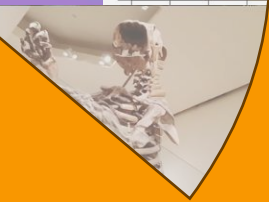
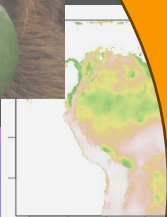
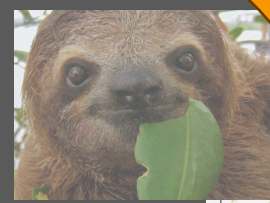
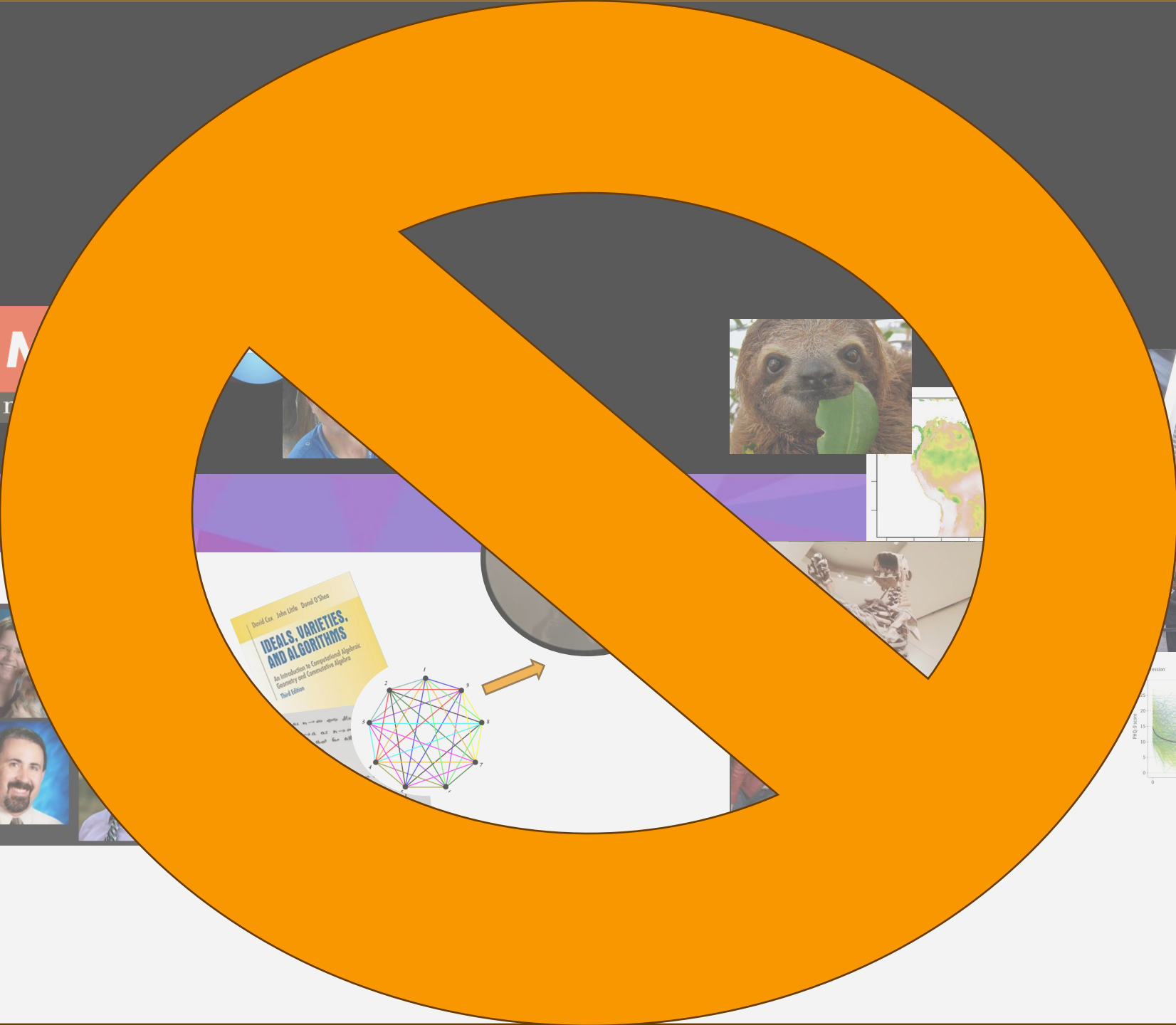
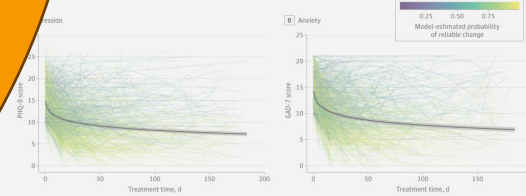
**R M B L**  
science. **OUTSIDE.**



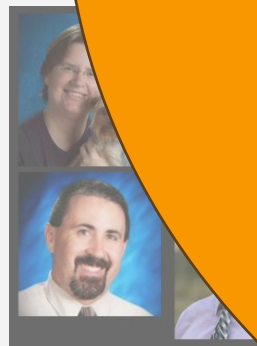
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**Biology & Mathematics**



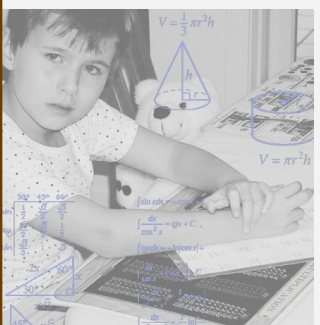
Spring Health 



R M  
scien



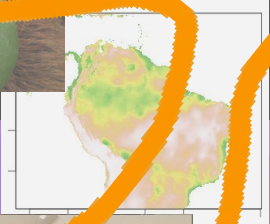
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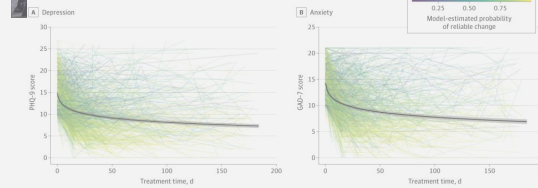
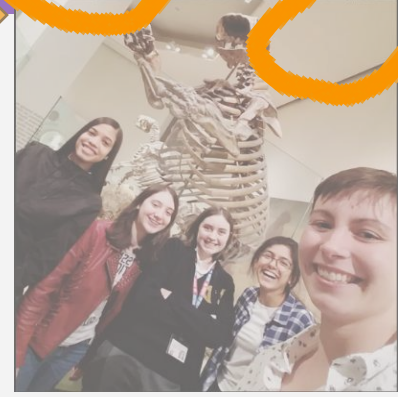
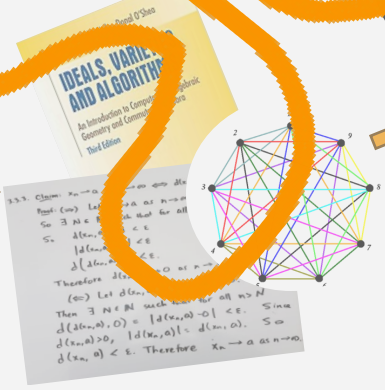
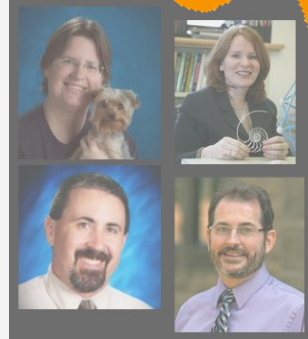
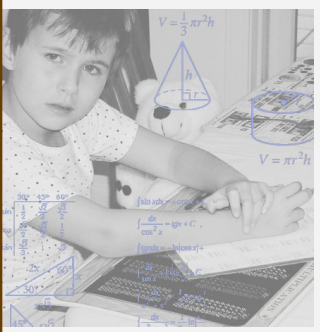
phoenixzoo  
ARIZONA CENTER FOR NATURE CONSERVATION



**R M B L**  
science. OUTSIDE.



I declare  
this for today!!  
**Math & Mathematics**



**WHAT DO I RESEARCH?**

A decorative horizontal band at the bottom of the slide, featuring a complex geometric pattern of overlapping triangles in various shades of purple and magenta, set against a solid black background.

# CLIMATE ADAPTATION DECISION- MAKING

## WEATHER

[Home](#) | [Weather Warnings](#) | [Flood Warnings](#) | [Monthly Outlook](#) | [Coast and Sea](#) | [Help](#)

**Double record-breaking year for UK as 2025 confirmed as warmest and sunniest on record**

**England enters fourth heatwave as temperatures reach 33.4C**

EEA report 01/2026

**Overheated and underprepared:  
Europeans' experience of living with  
climate change**

Report (PDF) | Published 04 Feb 2026

“Every fraction of a degree of warming will cause more hospital admissions and heat deaths, putting more strain on the NHS.”

**Professor Antonio Gasparri**  
Lead of the EHM Lab, LSHTM

# CLIMATE ADAPTATION DECISION-MAKING

11 December 2025

UK social homes are unprepared for rising heat as policy fails to keep pace, new research warns

Europe, Physical Risk, UK

## Employers told to invest in climate adaptations as workers feel the heat

By [Florence Jones](#)



CLIMATE ACTION AND WASTE REDUCTION

## What is climate change adaptation and why is it a priority at COP27?

Oct 28, 2022

## Women and Extreme Heat: Simple Adaptations Make a Big Difference

CEO of World Neighbours Dr. Kate Schecter explains how extreme heat undermines women's livelihoods and what can be done to adapt



by [Kate Schecter - CEO of World Neighbors](#) — December 23, 2025 in [Climate Change](#), [Health](#), [Society](#)

Comment | Published: 29 January 2026

## Climate change adaptation must consider older people

[Liming Yao](#), [Shiqi Tan](#), [Chengwei Lv](#), [Nan Wang](#), [Yoshikuni Yoshida](#) & [Yin Long](#) 

[Nature Human Behaviour](#) (2026) | [Cite this article](#)

177 Accesses | 2 Altmetric | [Metrics](#)

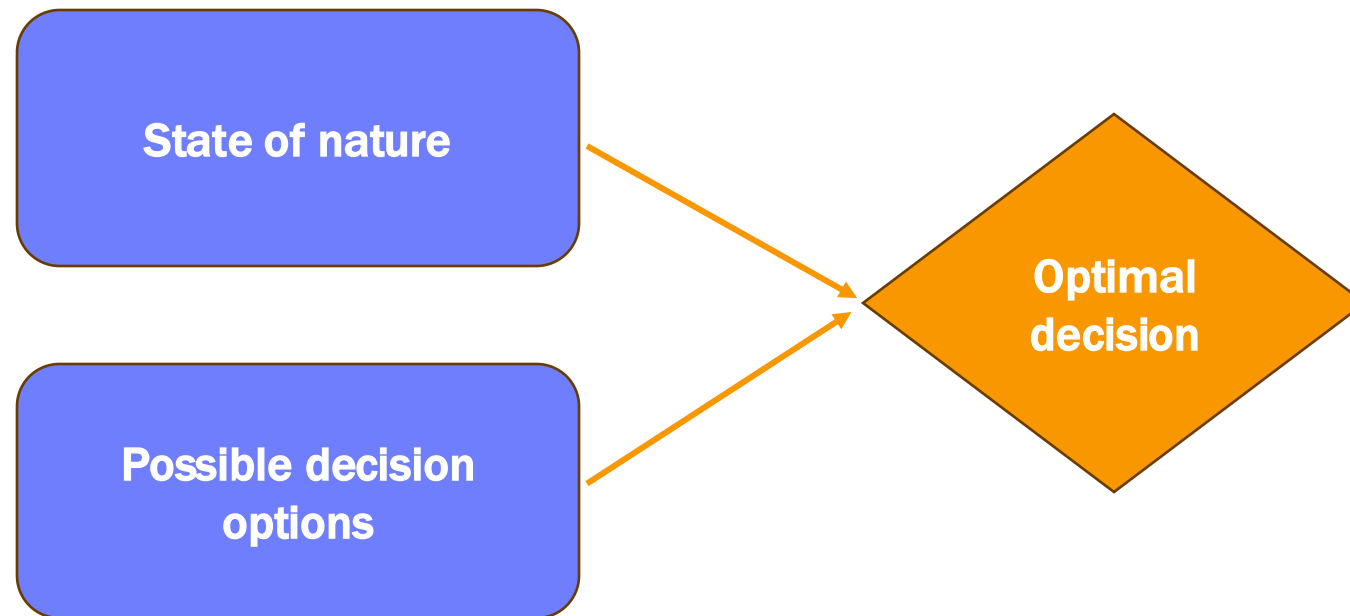
Older adults face higher risks from climate change. We propose an age-sensitive climate adaptation framework, which emphasizes non-digital communication, financial assistance and community-based strategies for older populations.

# BAYESIAN DECISION ANALYSIS

How can we make decisions *under uncertainty*?

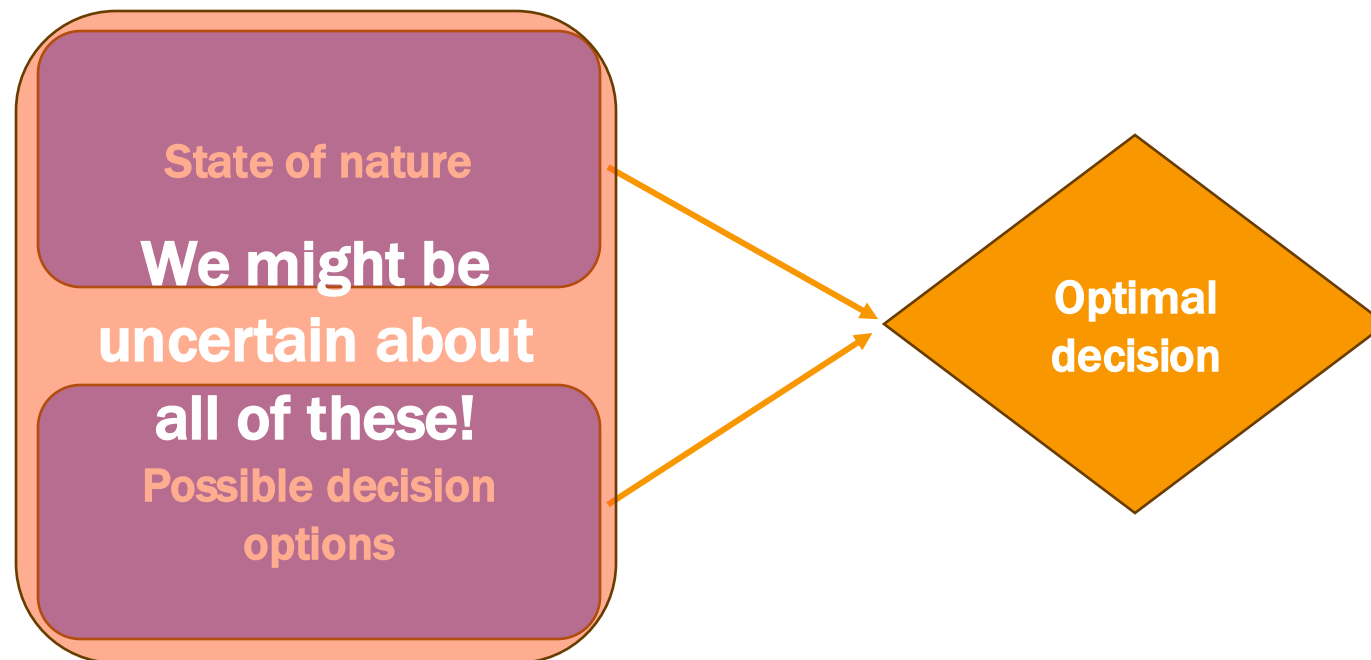
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How can we make decisions *under uncertainty*?



# A BRITISH DECISION

State of nature: will it rain tomorrow?

Decision options: wear a raincoat OR don't wear a raincoat

# A BRITISH DECISION

**State of nature: will it rain tomorrow?**

**Weather forecast: 67% chance of rain tomorrow**

**Decision options: wear a raincoat OR don't wear a raincoat**

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Weather forecast: 67% chance of rain tomorrow

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What is the *utility* of each of our decisions, given a particular state of nature?

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	It rains tomorrow	It doesn't rain tomorrow
Wear a raincoat		
Don't wear a raincoat		

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Weather forecast: 67% chance of rain tomorrow

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OR don't wear a raincoat**

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	<b>It rains tomorrow</b>	<b>It doesn't rain tomorrow</b>
<b>Wear a raincoat</b>	+ 5 (stay dry!)	-2 (too hot)
<b>Don't wear a raincoat</b>	-10 (got rained on)	+10 (comfortable)

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Weather forecast: 67% chance of rain tomorrow

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	It rains tomorrow	It doesn't rain tomorrow
Wear a raincoat	+ 5 (stay dry!)	-2 (too hot)
Don't wear a raincoat	-10 (got rained on)	+10 (comfortable)

**What do you want to do?**

# A BRITISH DECISION

	It rains tomorrow	It doesn't rain tomorrow
Wear a raincoat	+ 5 (stay dry!)	-2 (too hot)
Don't wear a raincoat	-10 (got rained on)	+10 (comfortable)



Pick your decision



Roll your dice:

1, 2, 3, or 4: it rains  
5 or 6: it doesn't rain



What is your utility?

# THE BAYES OPTIMAL BRITISH DECISION

## *Bayes optimal decision*

Select the decision that maximises expected utility:

Bayes decision under utility  $U$

Select the decision  $d^*$  such that

$$d^* = \arg \max_d \sum_{\theta \in \Theta} U(\theta, d) p(\theta) = \arg \max_d \bar{U}(d)$$

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Weather possibilities

Utility of a particular decision given a particular weather

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Bayes decision under utility  $U$

Select the decision  $d^*$  such that

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Raincoat:  $E[U(\text{raincoat})] =$

$$\begin{aligned} & U(\text{rain, raincoat}) \times P(\text{rain}) + \\ & U(\text{no rain, raincoat}) \times P(\text{no rain}) \\ & = \end{aligned}$$

No raincoat:  $E[U(\text{no raincoat})] =$

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# A MORE COMPLICATED BRITISH DECISION

But what if the parameters of our decision change?

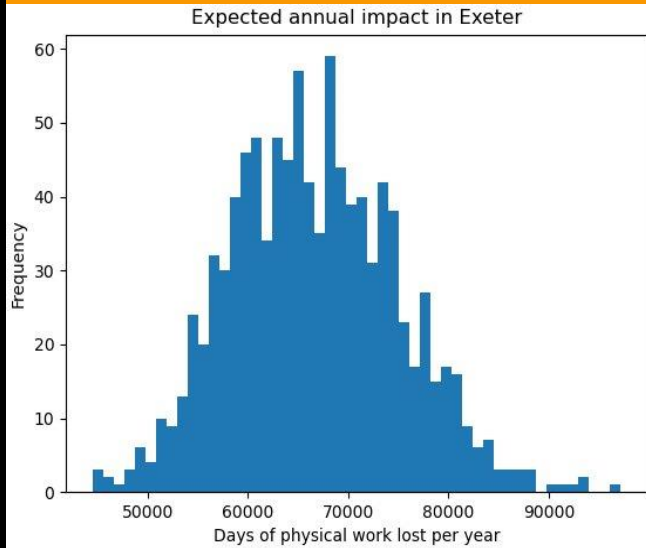
- What if the probability of rain is only 50%? 30%?
- What if our utilities are different?
- What if we are deciding between multiple jacket options?
- ...

# MY RESEARCH

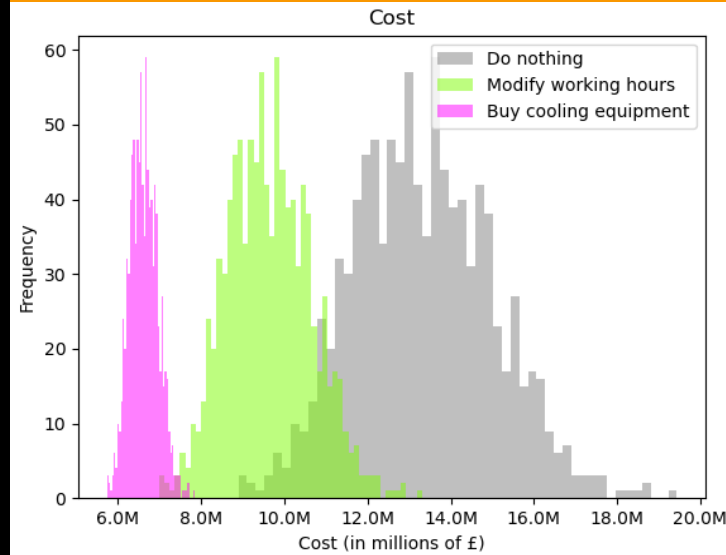
- **How do we make climate adaptation decisions?**
- **How can we account for uncertainty in climate information?**
- **How can we account for uncertainty in decision information?**
- **What makes a decision robust?**
- **How can we make decisions over time?**

# AN EXAMPLE DECISION

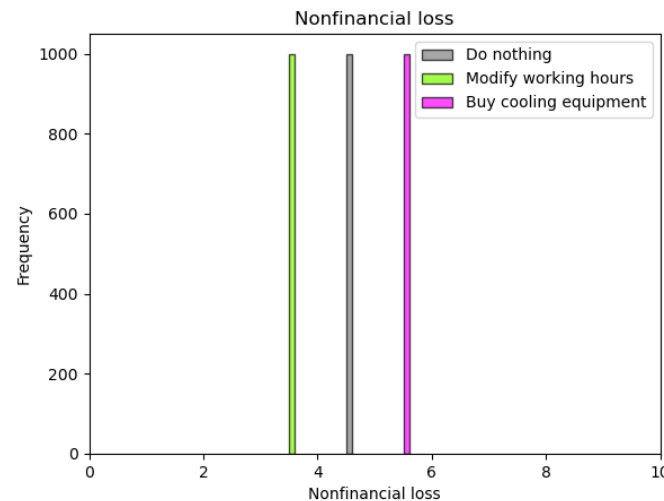
## Risk



## Financial loss



## Non-financial loss



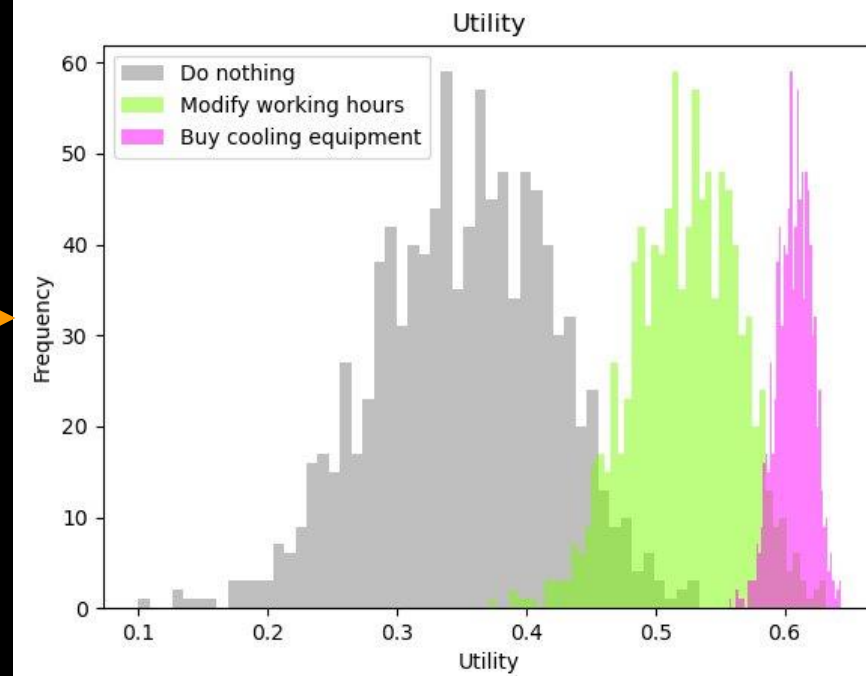
## $\mathcal{D}$ : decisions

$d_1$  : do nothing

$d_2$  : modify working hours

$d_3$  : buy cooling equipment

## Utility



# DECISION UNCERTAINTY

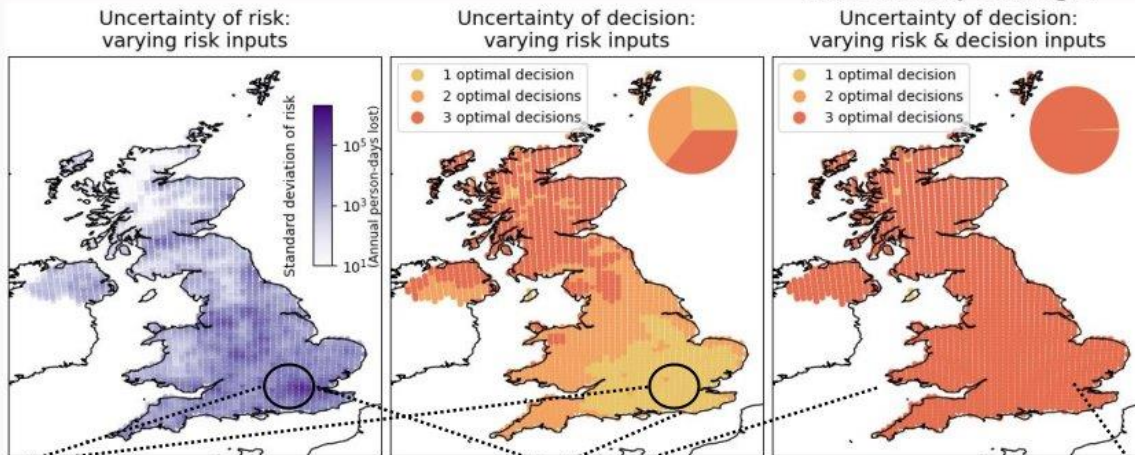
Varying all risk-related inputs, how uncertain is...

Also varying decision-related inputs...

the predicted risk?

the optimal decision?

how does decision uncertainty change?



Greatest uncertainty in risk, but only **one optimal decision**

Now **any decision** could be optimal in most locations

How sensitive is the optimal decision to...

