# Representing uncertainty

## in cases of very incomplete evidence

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# The plan

1. Start with a motivating example about uncertainty in climate models
2. Discuss why some think we shouldn’t use probability to represent it, and introduce contextualism about URs
3. Present a normative case for contextualism
4. ~~Apply the new picture to a second example about Covid-19~~
5. Reflect on what this means for Bayesian philosophy of science

1. A motivating example of high-stakes policy in the face of incomplete evidence

# Climate models

- Global climate models simulate the Earth's climate
- Involve scientific theory, observations from multiple sources, idealisations
- Common to make use of collections of such models, called ensembles

# Evidence from GCMs is significant…

1. Based on accepted physical principles which we have independent reason to believe govern the relevant domains
2. Can reproduce past and current climate, including its natural variability and its response to anthropogenic influences
3. Agrees remarkably well in predictions of climate change with various non-model-based methods, such as paleoclimate data

(Knutti et al., 2010)

# …but also partial and highly uncertain

1. GCMs disagree significantly over important variables (Stainforth, Allen, et al., 2007; Kaztav et al., 2021)
   - Most agreement at global scale, for high-level questions; much greater uncertainty at regional and local level
2. Our understanding of some important physical processes is limited, and the models are simplified and idealised (Parker 2010)
   - E.g., Parametrization of sub-grid processes
3. We’re projecting the behaviour of the system in a new state

# 2. How should we represent uncertainty?

# Uncertainty analysis and representation

- Theoretical picture: we expect discrepancies between model and reality due to
  A. Errors in data, parameter values
  B. Distorting effects of idealisations, simplifications
  C. Errors in the structure of the model
- Observation: GCM results vary
- We want to characterise this variation in terms of A-C and estimate missing effects of C
- Aim: tell users what to believe, how to act, on basis of results

# Some examples of uncertainty representation

Projected anomaly in annual mean global surface air temperature in 2050

…is 2°C

…is around 2°C

…is 2±0.5°C

…is 1.5-2.2°C

…is 1.5-2.2°C [95% interval], central estimate 2°C

…

# Probability as uncertainty representation

- Gold standard representation is probability
  - E.g., probability distribution function for a variable like GSAT, specifying the probability of each real world outcome
- PDFs are precise, numerical, facilitate comparison, come with well-developed statistical techniques
  - Favoured approach in most sciences, often called the “perfect” UR
- Also have a well-defined link to decision-making and decision-theoretic foundations (Bayesianism)

# Representing uncertainty vs belief

- An uncertainty representation is an explicit representation, it is constructed consciously, communicated, used in decision-making
- A belief representation is a theoretical device for investigating rationality, or a tool in the psychologist's lab
  - Represents an underlying attitude that is used in decision-making, but the formal structure of the representation is not accessible to the agent
- Note the link to decision-making—an UR needs a decision theory

# What's the target?

- Subjective uncertainty: a particular agent's uncertainty, so that UR=BR
  - SubUn of actual agents is clearly not what we want: can be based on partial understanding, incomplete evidence, might ignore disagreement
- Evidential uncertainty: the objective relation between the evidence and statements about the world we might believe
  - To a Bayesian, EvUn is a special case of SubUn—it is the SubUn an ideal agent ought to have, if they were in possession of all the evidence

# Critique of probability in climate science (1)

- Claim: PDFs based on models misrepresent the scientific uncertainty (e.g., Katzav et al. 2021)

1. Model ensembles are collections of “best guesses”
2. They are also “ensembles of opportunity”
3. So, they don’t attempt to span the space of possibilities scientists deem plausible
4. So, their distribution isn’t a representation of the scientific uncertainty

# Critique of probability in climate science (2)

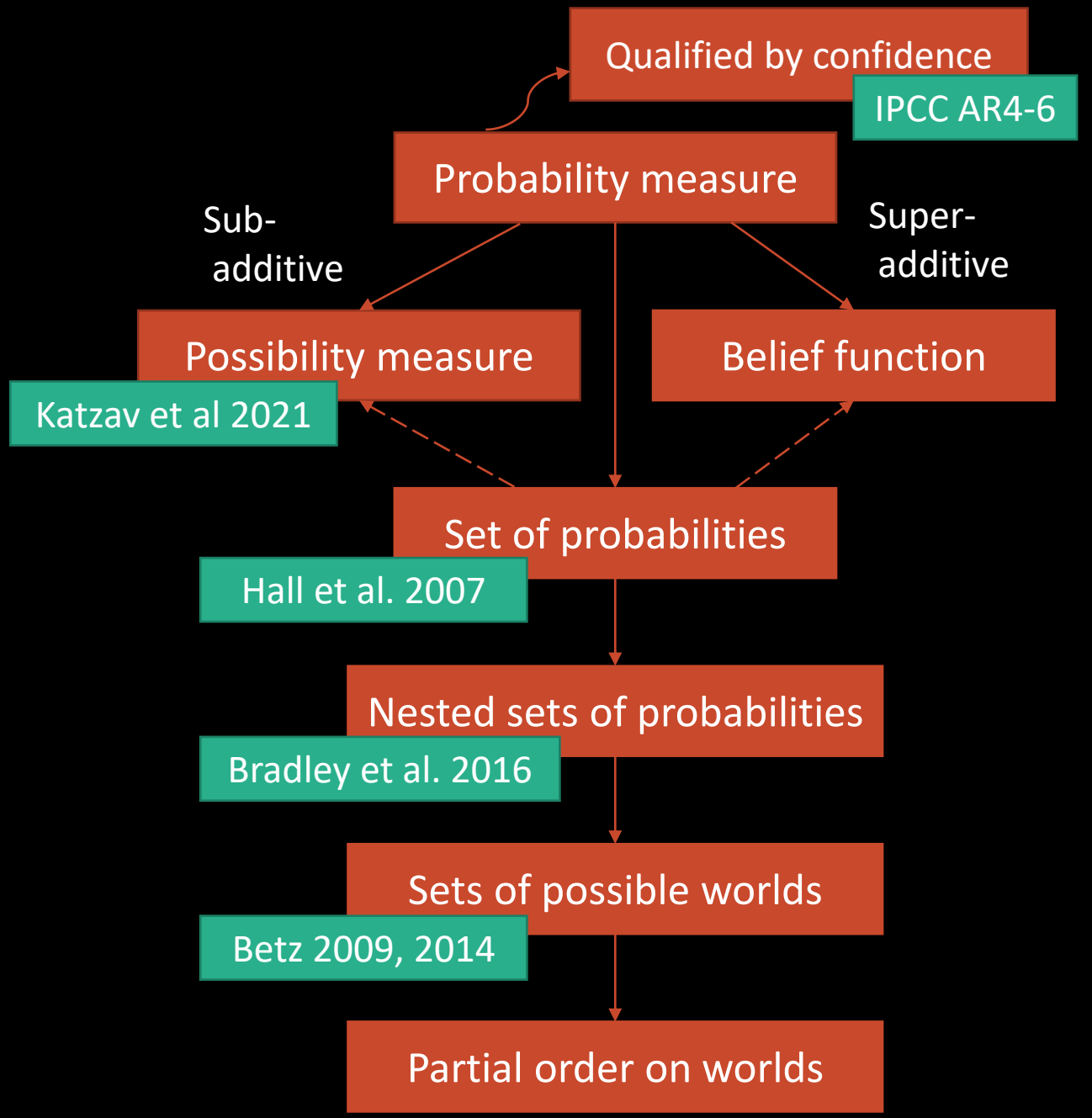
- Claim: GCMs are so uncertain, at the level of regional climate information especially, that they shouldn’t be regarded as providing quantifiable estimates (Stainforth et al. 2007)
  - This uncertainty manifests as extremely wide ranges for regional variables, e.g., Mediterranean average annual precipitation
  - Recall that these ranges are expected to be too narrow because of limited model diversity

# Anti-probabilist critique

- *These probabilities,* constructed PDFs from model results, aren't a representation of EvUn
- They aren't a representation of anyone's SubUn, either
- Open question: is there a PDF which would represent EvUn?
- Non-Bayesians say: it depends
- Bayesians are committed to saying yes
  - The right UR is always just the representation of the beliefs of the ideal scientist in that evidential situation

# What else is there?

- There is a whole landscape of mathematical URs
  - …and of course many informal ones
- In the climate case, various suggestions exist



# Example: Betz's possibilism

- Betz (2009, 2014) examines these arguments and concludes that, at best, climate models identify possibilities and verify that they are possible
  - No more: underdetermination, uncertainty, sampling issues
  - "Verify": show that these are possible in the sense of products of processes represented in the model (cf Katzav 2012, 2014)
- Proposed UR is very coarse:
  - Verified possibilities, verified impossibilities, possibilistic hypotheses

# High-level approach: contextualism

- In computer science, logic, other bits of statistics the approach is contextualist
- Katzav, Betz, Stainforth all agree: it could have been the case that probability was the right UR
- Method: analyse the evidential situation, and select an UR which matches this situation
- There is no one-size-fits-all solution (contrary to statistical practice and Bayesianism)

# 3. The normative case for contextualism

# Elevating contextualism to a normative claim

- Contextualism about UR is often found is descriptive exercises and engineering projects
  - Local practical concerns dominate
  - No commitment to have UR match with an epistemology
- Aim: provide a normative case for contextualism about URs
- Method: draw on arguments in epistemology about the importance of evidence
- (while keeping in mind potential gap between UR and BR)

# One broad strategy is “evidentialist”

- Evidentialism: a belief is justified just in case it is supported by an agent’s evidence
- The “wise man… proportions his belief to the evidence” (Hume in the *Enquiry*)
  - Incorporate all available evidence, don’t ignore any
  - Do not go beyond what is supported by the evidence
- UR-version: overly specific URs are unjustified because unsupported by the evidence

# Sturgeon's Fitting Character Thesis

- Consider drawing a ball from an urn. You are told

| | |
|---|---|
| a. 85/100 balls are red | Credence 0.85 |
| b. 80-to-90 balls are red | 80-90% confident |
| c. A slim majority of balls are red | $Con_c(Red)>0.5$ |
| d. A solid majority of balls are red | $Con_d(Red)>Con_C(Red)$ |

- Sturgeon's (2020) claim: the nature of your attitude should fit the character of the evidence
  - Notice different structure in (a)-(d), dictated by the evidence

# Sturgeon, contd.

- Ordinary cases don’t involve explicitly numerical evidence
- Often warrant high confidence without any specific number
- (Note additional motivation: psychological realism)

# Why should an UR fit the evidence structurally?

- As in the case of “real” evidentialism in epistemology, there are two broad justificatory strategies
- Epistemic: criticism of Bayesianism
- Ethical: role-specific obligations on the scientist qua advisor

# Unwarranted precision leads to unwarranted comparisons

- Consider a case of very incomplete evidence, in which we use a probability UR
  - (C) SMHI's projects that under RCP4.5, Stockholm's change in average temperature during 2071-2100 will be +2.7-4.7°C
  - 10-90$^{th}$ percentile range for model outputs ~ 80% confidence
- Such a representation facilitates precise comparisons with other probabilistically quantified events (Joyce 2011)
  - One pair in Texas Hold Em > C > Total from 4 die rolls is above 12
  - Committed to extremely specific comparisons, and if the UR is to guide decisions, to make trade-offs on this basis

# Ethics of (degree of) belief

- Clifford (1877): “it is wrong always, everywhere, and for anyone to believe anything upon insufficient evidence”
  - Implausible as a general analysis of belief
- But, classic “good cases” for ethics-based evidentialism involve high stakes, decisions on behalf of others
  - E.g., health policy official forming beliefs about the efficacy of vaccine trials
  - URs may not be beliefs, but they act “in the place of” beliefs in distributed policy decision-making, in just these contexts

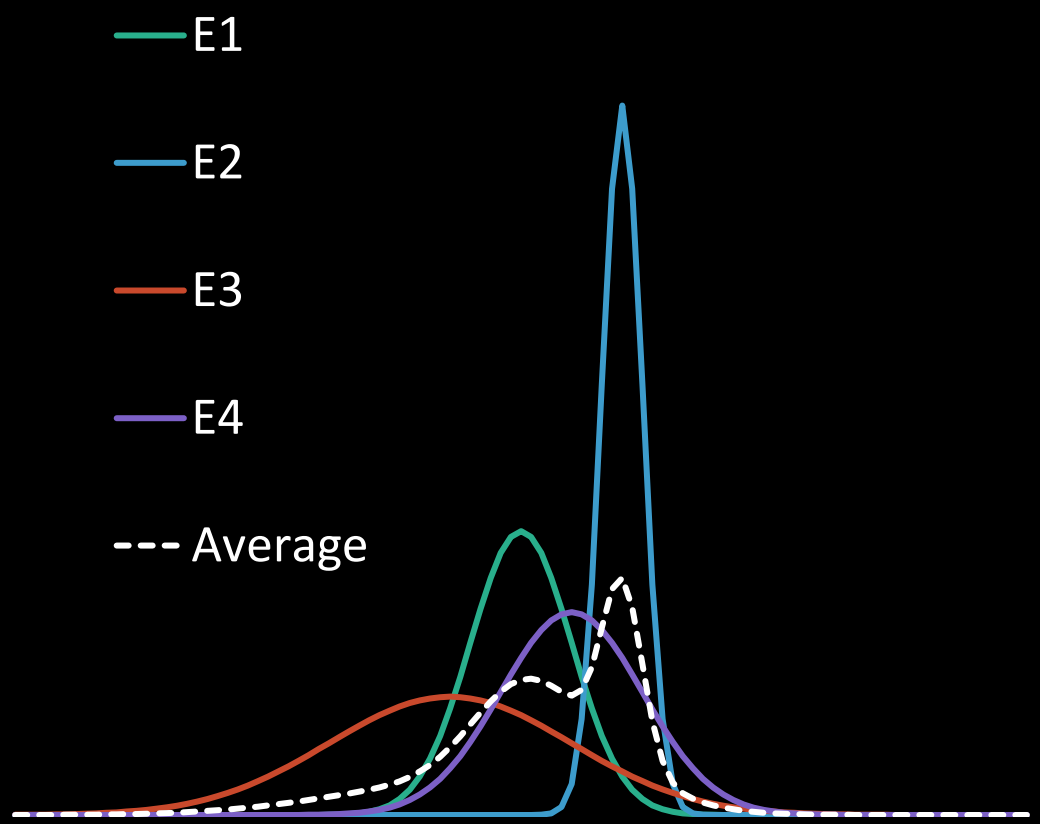
# Role-specific duties

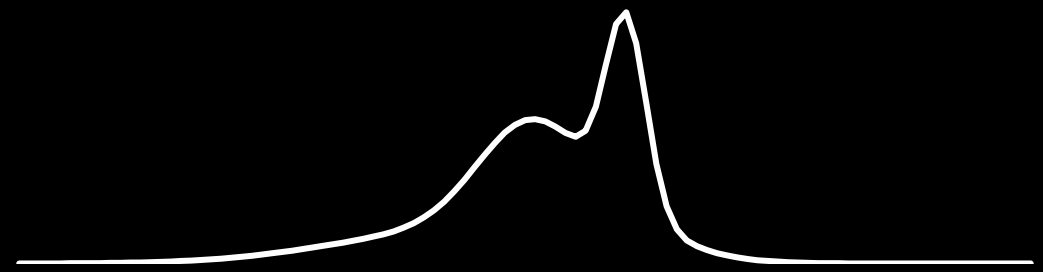
- What is the role of the science advisor?
- Provide scientific input to a policy decision, presumed to be democratic
  - Policymaker provides the values (caveat: up to value-ladenness)
  - Scientist provides information to facilitate a good decision
- What makes for a good decision, in terms of info?
  - Accuracy, salience, cognitive feasibility
  - More broadly: not misleading through omission or framing

# Role-specific duties

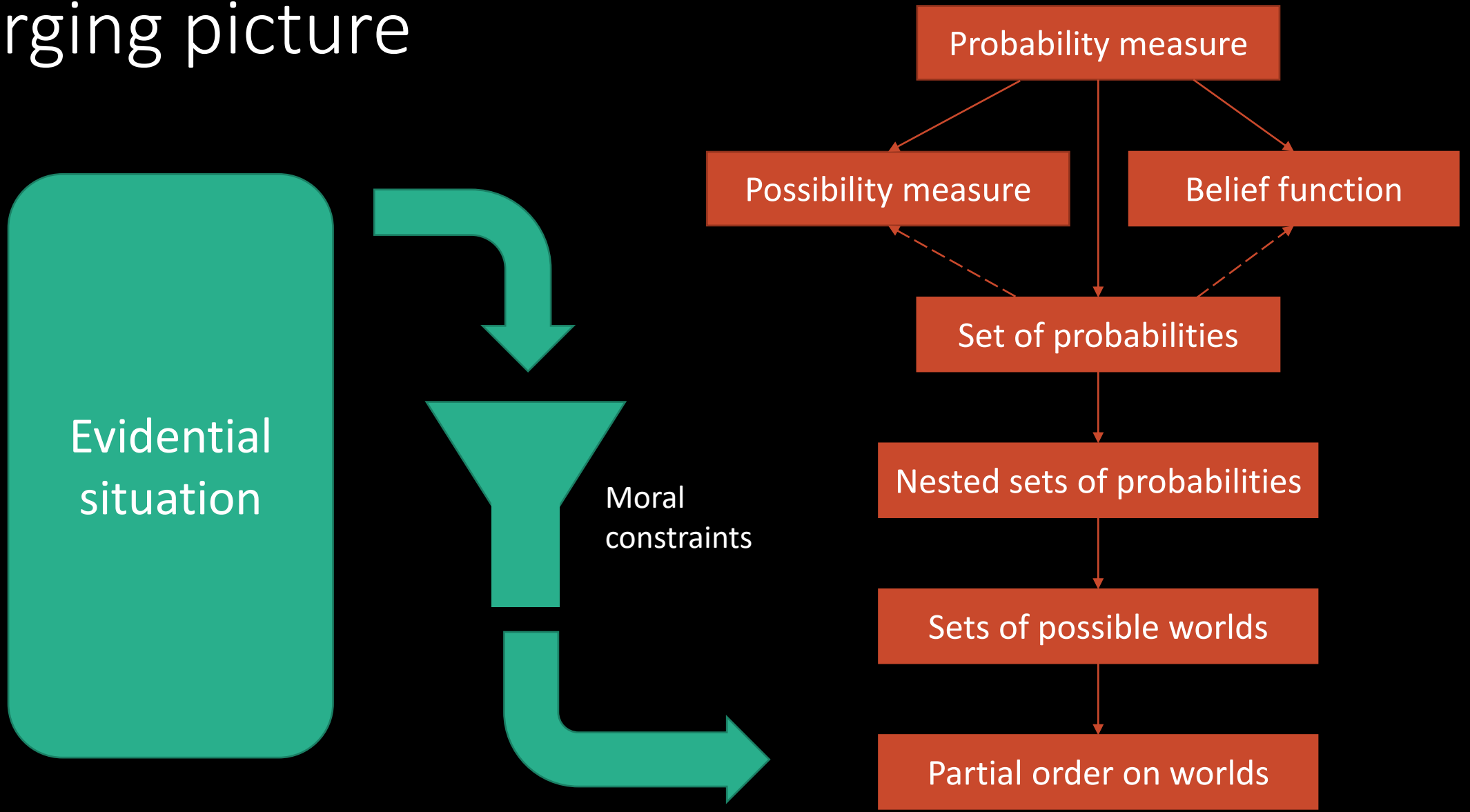
- Obligation claim: Qua information provider, scientists have a role-specific obligation to transparently and accurately characterise the evidential situation to the policymaker
  - This obligation derives from the position of trust they are in relative to non-expert policymakers
- Contextualism about UR: excessive precision—i.e., always using probabilities—constitutes a violation of this obligation
  - E.g., by encouraging unjustified comparisons/trade-offs which risk harm, harm which is culpable given that the scientist knows this and could do otherwise

# Contrast two cases



# Emerging picture



# 5. Back to Bayesianism

# Defusing Bayesian worries

- Why do we want to be Bayesians, anyway?
- Good reasons!
  - Dutch book arguments: exploitability is practically irrational
  - Accuracy arguments: probabilism is epistemically optimal
- Practical rationality: other URs can be paired with decision theories which aren't exploitable. So if we take this seriously, we can make adjustments elsewhere to avoid irrationality
- Epistemic rationality: one view is that evidential considerations must supplement accuracy considerations (Joyce 2011), so that there is no problem. Also note that in the advisory context, with partial deference to scientists, there is no guarantee of accuracy optimality

# Broader epistemic motivation: coherence

- The classic justification for probabilism is coherentist
- Recall problematic comparisons of the regional climate projection and various bets
- The justification the Bayesian can offer for such fine-grained comparisons is simply the coherence of the overall attitude set
- But non-probabilistic URs also have coherence conditions: e.g., sets of possibilities can be more or less coherent. If something like the Fitting Character Thesis is right, they beat Bayesianism on the evidentialist front

# Confidence vs confirmation

- Major use of Bayesianism in philosophy of science is as a theory of confirmation
- There is room for separating these out
  - What UR is best for representing confidence in science advising situations?
  - What is the best theory of confirmation, for an idealised analysis of scientific inference?
- Some of these arguments may apply, but if you're a confirmation theorist you needn't necessarily be worried

# Conclusion

- In high stakes policy situations involving incomplete evidence, there should be no default presumption in favour of probability as an UR
- Instead, one should choose the UR that fits with the evidential context
- This is supported on broad epistemic grounds and moral grounds specific to the role of the scientist as advisor