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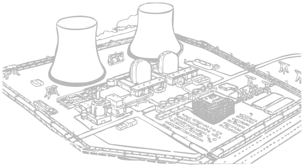

# Uncertainty in risk engineering: concepts


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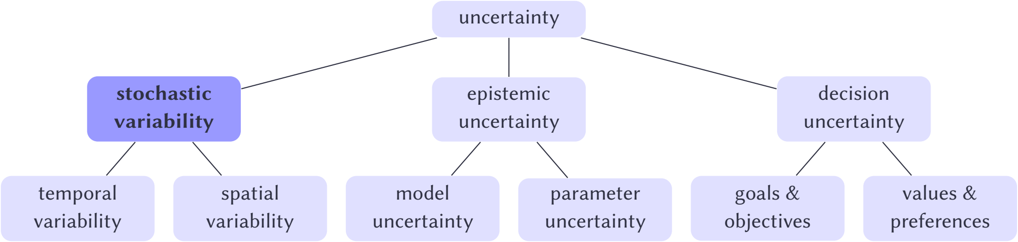
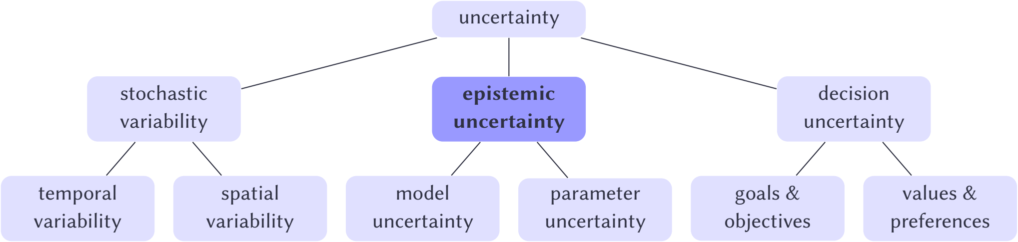
> *When using a mathematical model, careful attention must be given to uncertainties in the model.*
>
> *– Richard Feynman*

# Types of uncertainty



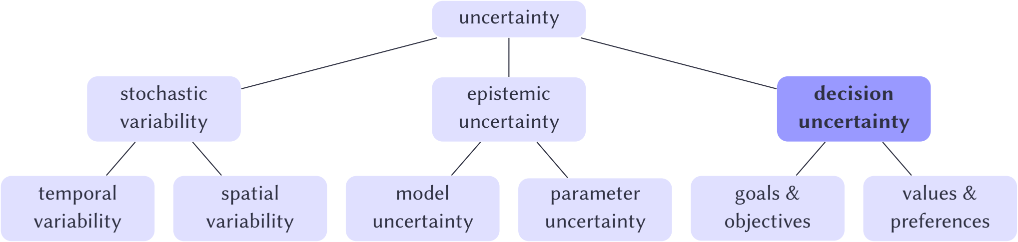

- **Stochastic (or aleatory) uncertainty**
  - related to the real variability of a population or a physical property
  - cannot be reduced
  - example: wind speed at Toulouse airport 100 days from now

# Types of uncertainty



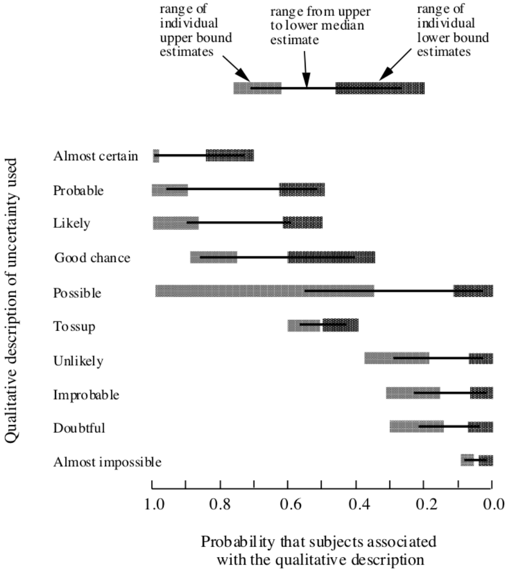

- **Epistemic uncertainty**
  - related to **lack of knowledge** or precision of a model parameter
  - model uncertainty: lack of confidence that the mathematical model is a "correct" formulation of the problem
  - parameter uncertainty: scientific knowledge insufficient to determine parameter exactly
  - in general, reducible with sufficient investment

# Types of uncertainty



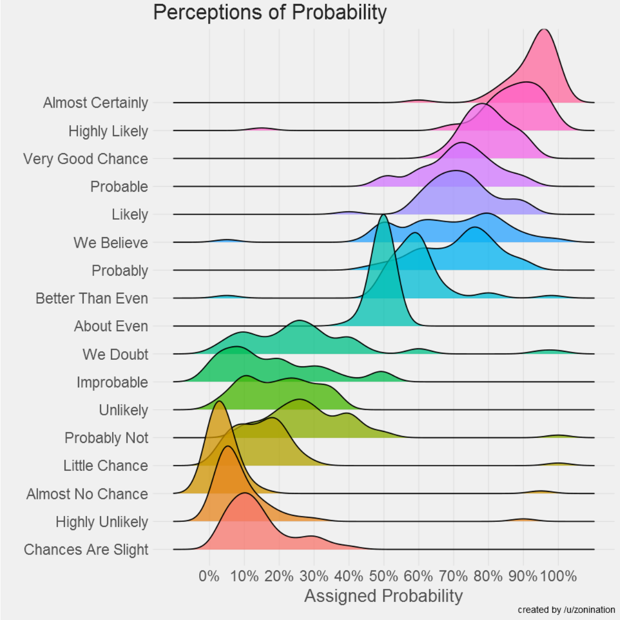

- **Decision uncertainty**
  - presence of ambiguity or controversy about how to quantify or compare social objectives
  - which risk metrics, which acceptance criteria?
  - how to aggregate the utilities of individuals?
  - how to discount delayed benefits against short-term benefits?

# Epistemic uncertainty and linguistic imprecision




*Communication relies on shared context, but terms used for discussing likelihood are very subjective and "fuzzy"*

# Epistemic uncertainty and linguistic imprecision




Source: github.com/zonination/perceptions

# Illustration of linguistic imprecision

Forecast from US National Intelligence Estimate 29-51 *Probability of an Invasion of Yugoslavia* (1951):

> *Although it is impossible to determine which course the Kremlin is likely to adopt, we believe that the extent of Satellite military and propaganda preparations indicates that an attack on Yugoslavia in 1951 should be considered a serious possibility.*

Authors of the report were asked "what odds they had had in mind when they agreed to that wording". Their answers ranged from 1:4 to 4:1.

Image: Podgarić monument, former Yugoslavia

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# Uncertainty does not only concern the future

Bank of England projection of various macroeconomic indicators use “fan charts” to illustrate the level of uncertainty in their predictions (probability mass in each colored band is 30%, 10% probability that outcomes lie outside of the colored area).

Note that there is also uncertainty about data concerning the past.

Projection of the level of GDP (wide bands)[(a)(b)(c)]

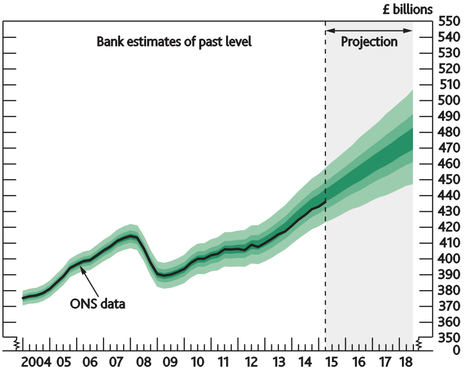


Figure source: bankofengland.co.uk

# Treatment of uncertainty

*He who knows and knows he knows,*
*He is wise — follow him;*

*He who knows not and knows he knows not,*
*He is a child — teach him;*

*He who knows and knows not he knows,*
*He is asleep — wake him;*

*He who knows not and knows not he knows not,*
*He is a fool — shun him.*

Ancient arabic proverb

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# Types of uncertainty

> *As we know, there are known knowns. There are things we know we know. We also know there are known unknowns. That is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know, we don't know.*
>
> *– Donald Rumsfeld, February 2002, US DoD news briefing*

Image source: US DoD, public domain

# Goal of uncertainty modelling

Aims of quantitative uncertainty assessments:

- **understand** the influence of uncertainties
  - help prioritize any additional measurement, modeling or R&D efforts
- to **qualify** or accredit a model or a method of measurement
  - *"this is of sufficient quality for this purpose"*
- to **influence design**: compare relative performance and optimize the choice of a maintenance policy, an operation or the design of the system
- **compliance**: to demonstrate the system's compliance with explicit criteria or regulatory thresholds
  - examples: nuclear or environmental licensing, aeronautical certification…

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# Five levels of integration of uncertainty in risk assessment

0. Hazard identification
1. Worst case approach
2. Quasi worst case
3. Best estimates
4. Probabilistic risk analysis

Adapted from *Uncertainties in global climate change estimates*, E. Paté-Cornell, *Climatic Change*, 1996:33:145-149

# Integration level 0

- ▷ Undertake **hazard identification**
- ▷ Example: product is carcinogenic (yes/no)
- ▷ Suitable approach where no numerical tradeoff required:
  - hazard is clearly defined and solution is simple and inexpensive
  - hazard is poorly known and would have catastrophic impact, so benefits of available solutions would dwarf the costs in any case

# Integration level 1

- **Worst-case** approach
- Example: *"What is the maximum number of potential victims in a specified event?"*
- Suitable approach when the worst case is clear and there is a reasonable solution to address the worst case
- Typical approach used for **emergency planning**
- **Problem**: no matter how conservative you are concerning parameters, someone can still highlight an "even worse" case which would require even more safety investment

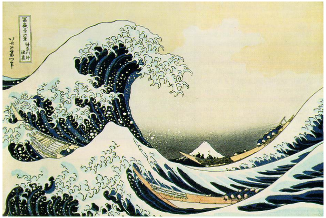
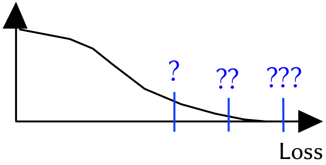


Image: *The Great Wave off Kanagawa*, K. Hokusai, ≈ 1825, public domain

# Integration level 2

- Quasi worst-case and plausible upper bounds
  - insurance industry is concerned with *maximum forseeable loss*
- Example: *"What is the "maximal probable flood" or the "maximum credible earthquake" in this area?"*
- Fundamentally, we are truncating the probability distribution of the potential loss distribution
- Problems:
  - how to be coherent between "maximum probable flood" & "maximum credible earthquake"?
  - difficult to assess resulting level of safety
  - can't guarantee that people in different locations are treated fairly

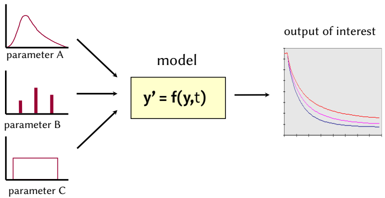


# Integration level 3

- **Best estimates**, using point values at the median of the parameters' probability distributions
- Example: *"What is the 'most credible' estimate of the probability of an accident or of losses in an accident in a chemical plant?"*
- **Problem**: a low probability outcome (even with hugely undesirable consequences) will be ignored in this approach

# Integration level 4

- **Probabilistic risk analysis** based on mean probabilities or future frequencies of events
  - estimate probability distribution of each input parameter
  - propagate uncertainty through model to obtain distribution of outputs of interest
  - stochastic "Monte Carlo" methods
- Example: *"What is the probability of exceeding specified levels of losses in different degrees of failure of a particular dam?"*




*See slides on Monte Carlo methods at risk-engineering.org*

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# Risk measures

- A quantity used for the inference of the outputs of interest under uncertainty is called a *quantity of interest*, or *performance measure* or *risk measure* in finance and economics
- Some examples:
  - percentages of error/uncertainty on the variables of interest (*i.e.* coefficient of variation)
  - confidence intervals on the variables of interest
  - quantile of the variable of interest (such as the *value at risk* in finance), possibly conditional on penalized inputs
  - probabilities of exceedance of a safety threshold or of an event of interest
  - expected value (cost, utility, fatalities…) of the consequences

*See slides on risk metrics at risk-engineering.org*

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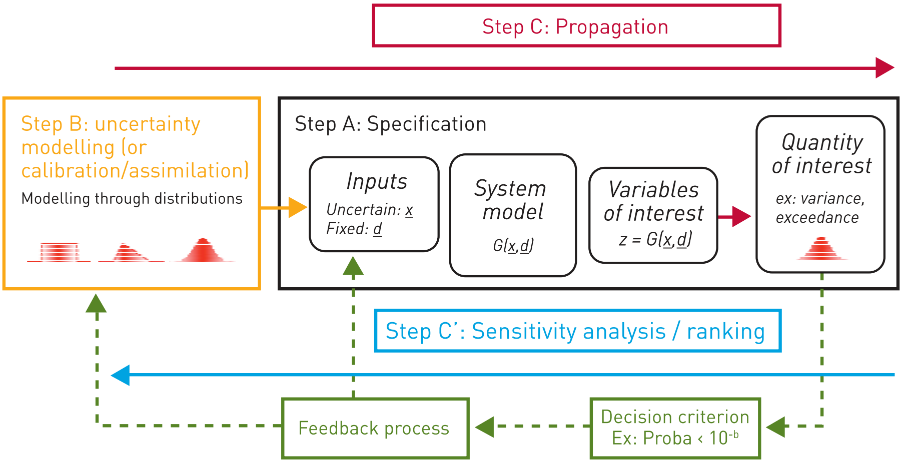
# Framework for uncertainty modelling




Generic conceptual framework for uncertainty modelling, from *Quantifying uncertainty in an industrial approach: an emerging consensus in an old epistemological debate*, E. de Rocquigny, 2009, journals.openedition.org/sapiens/782

# Uncertainty in risk analysis

- It can be tempting for risk analysts to **under-emphasize the degree of uncertainty** present in a risk analysis of a complex system
  - engineers are trained to deal with "hard facts" and not with judgments ("mechanical objectivity", writes J. Downer)
  - experts concerned that laypeople may overreact to information on uncertainty in risk estimations
  - the authority of engineers and regulators is (seen to be) undermined by "admission" of uncertainty
  - there is often political pressure to de-emphasize the presence of uncertainty, to avoid challenges to policy decisions
- Professional ethics and the long-term credibility of technical risk assessment require uncertainties to be assessed, presented to stakeholders, and integrated in decision-making

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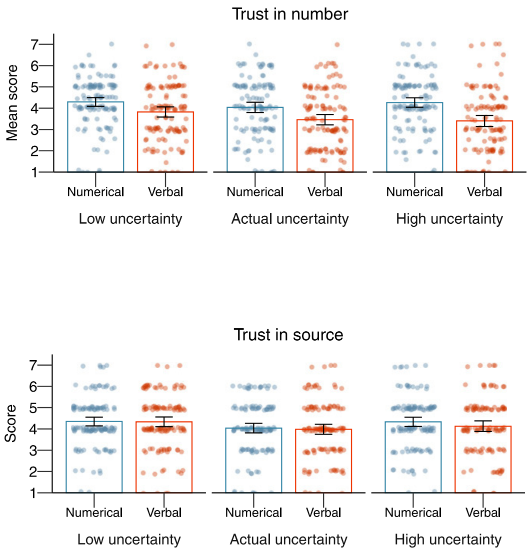


A recent study on the link between the inclusion of information on uncertainty and the level of public trust suggests that explicit communication of epistemic uncertainty leads only to a small decrease in trust in numbers and perceived trustworthiness of the source.

Source: van der Bles et al 2020, *The effects of communicating uncertainty on public trust in facts and numbers*, PNAS, DOI: 10.1073/pnas.1913678117

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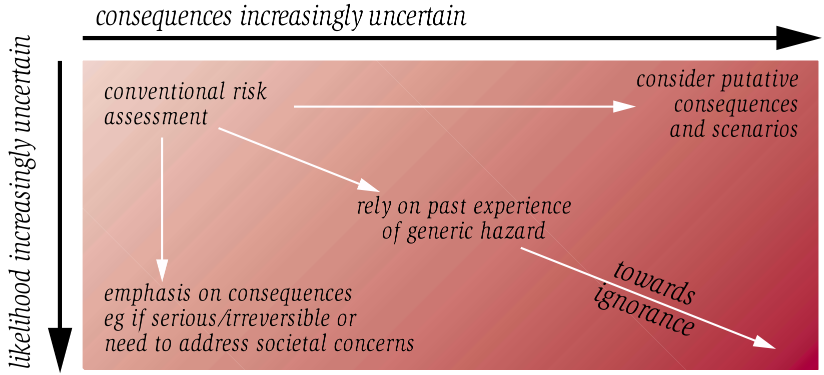
# Uncertainty and decision-making




Source: *Reducing risk, protecting people: HSE's decision-making process*, UK Health and Safety Executive, 2001, hse.gov.uk/risk/theory/r2p2.pdf

Statue “Politicians discussing global warming” by I. Cordal, Berlin

# Further reading

- Slides on *Sensitivity analysis* from `risk-engineering.org`
- Book *Uncertainty in Industrial Practice — A guide to quantitative uncertainty management*, Wiley, 2008, ISBN: 978-0-470-99447-4
- *Literature review of methods for representing uncertainty*, Industrial Safety Cahiers number 2013-03, available from `foncsi.org/en/`

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