CHAPTER

1

CHAPMAN HALL/CRC

Risk Analysis in Engineering and Economics

INTRODUCTION

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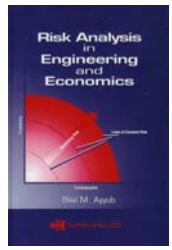

Risk Analysis for Engineering

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Societal Needs

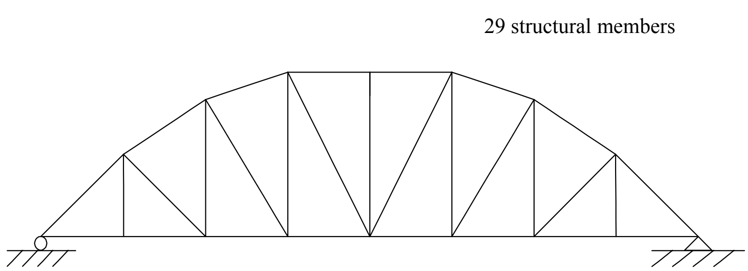
- Risk analysis is becoming very important tools for modern industrial societies.
- The abundance of information in these industrial societies does not necessarily gives certainty.
- In fact, these abundance of information can sometimes leads to errors in decision making, and hence to undesirable outcomes. Therefore, risk analysis is needed.

Risk Analysis

- Risk analysis should be performed using a systems framework that need to account for
  - uncertainties in modeling (system architecture),
  - Behavior (physical laws),
  - prediction models,
  - interaction among a system's components, and
  - impacts on the system and its surrounding environment.

Risk Analysis

- Example 1: Identification of Risk in a Truss Structural System



A Truss Structural System

Risk Analysis

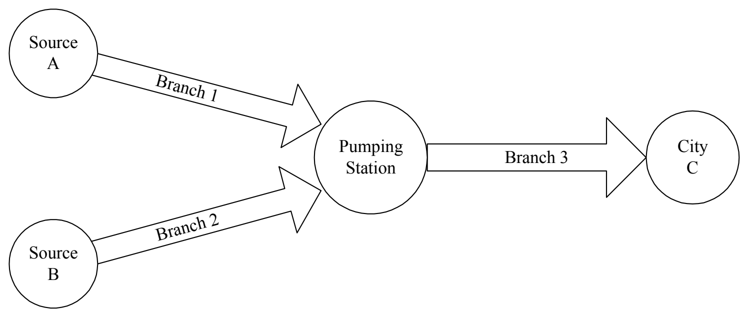
- Example 1 (cont'd): Identification of Risk in a Truss Structural System
  - The system can be thought as system in series.
  - If one of the truss 29 members fails, then the whole system fails to function and may collapse.
  - Therefore, the potential modes of failure can be identified and the associated risks must be assessed.

Risk Analysis

- Example 1 (cont'd): Identification of Risk in a Truss Structural System
  - A design could be enhanced to allow for partial failures instead of catastrophic failures and to introduce redundancy through the addition of some members to work as standby or load-sharing members to critical members in the structure.
  - Enhancements may include:
    - increasing design strength; and
    - reducing the failure likelihood and associated failure consequences to acceptable and safe levels.
  - Construction costs will increase – tradeoffs.

Risk Analysis

- Example 2: Identification of Risk in a Water Pipeline System



City Water Pipeline System

Risk Analysis

- Example 2 (cont'd): Identification of Risk in a Water Pipeline System
  - Assuming that either source alone is sufficient to supply the city with water, failure can happen in branch 1 or branch 2 or branch 3.
  - Designers and planners of the pipeline system, therefore, have to identify possible areas and sources of failure, and assess associated risks.

Risk Analysis

- Example 2 (cont'd): Identification of Risk in a Water Pipeline System
  - Example failure scenarios

Failures Possibilities and Their Impacts on Water Pipeline System

Source of Failure	Type of Failure	Impact on System or Consequences	
	Total or Partial [T] or [P]	Partial System Failure [P]	Total System Failure [T]
Failure of Branch 1 only	T	P	
Failure of Branch 2 only	T	P	
Failure of Branch 3 only	T		T
Failure of Branch 1 and 2 only	T		T
Failure of Branch 1 and 3 only	T		T
Failure of Branch 2 and 3 only	T		T
Failure of Branch 1, 2 and 3	T		T

Risk Analysis

- Example 3: Identification of Risk in a Fire Escape System

Source of Risk as an Adverse Event	Escape Scenarios	Smoke Detector Working Successfully		Occupants Managed to Escape		Consequences in terms of Life Loss
		Yes	No	Yes	No	
Fire	Scenario 1	Yes		Yes		No Injury
initiated	Scenario 2	Yes			No	Death
in an	Scenario 3		No	Yes		Sever Injury
apartment	Scenario 4		No		No	Death

Risk Analysis

- Example 4: Risk Analysis in Project Management
  - In construction projects, managers and clients commonly pursue areas and sources of risks in all the phases of a project from feasibility to disposal or termination.
  - The methods can be applied by developing risk scenarios associated with failure states for all project phases by using methods that examine causes and effects.

Risk Analysis- Example 4

Source of Risk in the Project Stages	Failure State	Cause of Failure	Effect on the Project
1. Feasibility study	Delay	Feasibility stage is delayed due to complexities and uncertainties associated with the system.	The four stages of the project will be delayed causing problems to the client's financial and investment obligations.
2. Preliminary design	Approval not granted	The preliminary design is not approved for various reasons caused by the architect, engineer, project planner, or project manager.	The detailed design will not be ready for zoning and planning approval, and for the selection process of contractors causing delay accumulation in finishing the project leading to additional financial burdens on the client.
3. Detailed design	Delay	The detailed design performed by the architect/engineer is delayed.	The project management activities cannot be performed efficiently, and the contractor cannot start work properly causing delays in the execution of the project.
4. Execution and implementation	Delay or disruption	The execution and implementation stage is delayed or disrupted as a result of accidents.	The project will definitely not be finish on time and will be completed over budget causing serious financial problems to the client.
5. Disposal or termination	Delay	The termination stage is delayed or not scheduled.	The system will become unreliable and hazardous causing customer complaints and the increasing client's contractual obligation problems.

System Framework

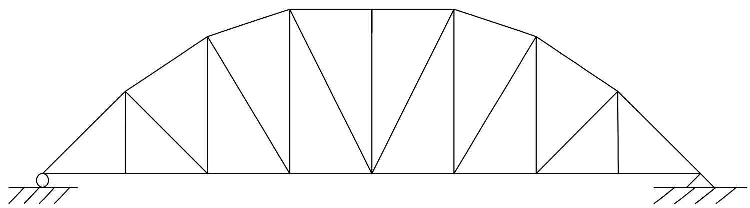
- A generalized systems formulation is needed for understanding:
  - the nature of a problem,
  - underlying physics,
  - Processes, and
  - activities.
- In a system formulation, an **image** or a **model** of an object that emphasizes some important and critical properties is defined.

System Framework (cont'd)

- System definition is usually the first step in an overall methodology formulated for achieving a set of objectives.
- Each level of knowledge that is obtained about an engineering problem defines a system to represent the project or the problem.

System Framework (cont'd)

- Example 5: System Boundary Identification for a Truss Structural System



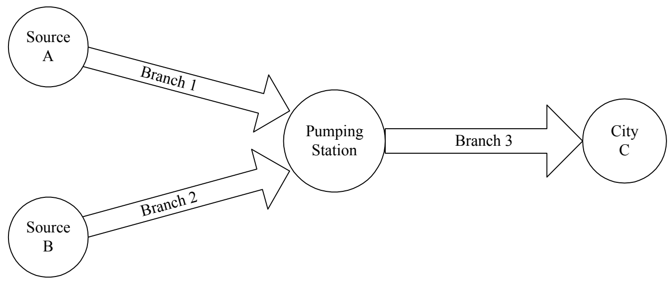
System boundaries can include:
- The twenty-nine members alone, or
- Including the supports, the roller and the pin, or
- Including the piers and foundation.

System Framework (cont'd)

- Example 5 (cont'd): System Boundary Identification for a Truss Structural System
  - Another extension of boundaries might require:
    - a group of similar trusses creating a hanger,
    - a roofing system for a factory, or
    - a multilane bridge.
  - In this case of multiple trusses, bracing members or roofing structure connected to the trusses need to be included.

System Framework (cont'd)

- Example 6: System Boundary Identification for a Water Pipeline System



- The system can be defined to consist of three long pipes.
- Some analyses might consider the shapes (layouts) of these pipes and whether they have different sizes or connected by intermediate valves and/or pumps.

System Framework (cont'd)

- Example 7: System Boundary Identification for a Fire Escape System

Source of Risk as an Adverse Event	Escape Scenarios	Smoke Detector Working Successfully		Occupants Managed to Escape		Consequences in terms of Life Loss
		Yes	No	Yes	No	
Fire	Scenario 1	Yes		Yes		No Injury
initiated	Scenario 2	Yes			No	Death
in an	Scenario 3		No	Yes		Sever Injury
apartment	Scenario 4		No		No	Death

System Framework (cont'd)

- Example 7 (cont'd): System Boundary Identification for a Fire Escape System
  - Planners and designers may view the system boundary to only include the fire escape system from inside to outside the apartments.
  - Another perspective might be to consider other escape routes inside the building that are not designated as fire-escape routes, especially for those apartments in higher levels of the building (e.g., roof and adjacent structures).

System Framework (cont'd)

- Example 7 (cont'd): System Boundary Identification for a Fire Escape System
  - The system boundaries can be extended to include external escape routes.
  - Also, the system boundaries could extend beyond the location of the building to include communication links and response of fire and rescue units and personnel.

Knowledge and Ignorance

- **Knowledge:**
  - Knowledge can be viewed to consist of two types:
    - Nonpropositional
    - Propositional
  - The *nonpropositional* knowledge can be further broken down into:
    - know-how and concept knowledge
    - familiarity knowledge (commonly called object knowledge)

Knowledge and Ignorance (cont'd)

- **Knowledge (cont'd):**
  - The know-how and concept knowledge requires someone to know how to do a specific activity, function, procedure, etc., such as riding a bicycle.
  - The concept knowledge can be empirical in nature, e.g., large, hot, dark.
  - The object knowledge is based on a direct acquaintance with a person, place or thing, for example, Mr. Smith knows the President of the United States.

Knowledge and Ignorance (cont'd)

- **Knowledge (cont'd):**
  - Mr. Smith knows that the Rockies are in North America. This proposition can be expressed as

Mr. Smith knows that the Rockies are in North America

S knows *P*

Where

S is the subject, i.e., Mr. Smith; and

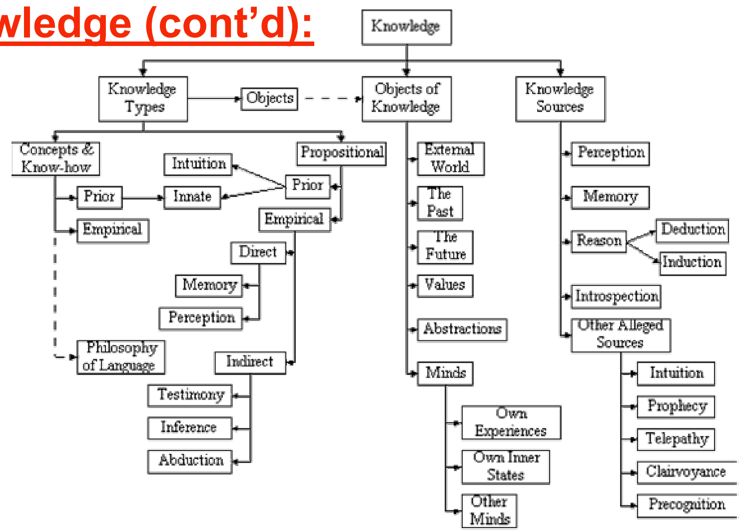
P is the proposition or claim that "the Rockies are in North America

Knowledge and Ignorance (cont'd)

- **Knowledge (cont'd):**
  - Epistemologists require the following three conditions for making a claim and in order to have a true proposition:
    - *S* must believe *P*,
    - *P* must be true, and
    - *S* must have a reason to believe *P*, i.e., *S* must be justified in believing *P*.
  - The justification in the third condition can take various forms; however, simplistically it can be taken as justification through rational reasoning or empirical evidence.

Knowledge and Ignorance (cont'd)

- **Knowledge (cont'd):**



Knowledge Types, Sources and Objects

Cognition and Cognitive Science

- **Cognition:** is defined as the mental processes of receiving and processing information for knowledge creation and behavioral actions.
- **Cognitive Science:** is the interdisciplinary study of mind and intelligence. Cognition science deals with
  - Philosophy
  - Psychology
  - Linguistics, etc.

Cognition and Cognitive Science

- Cognitive science claims that the human mind works by representing information and computation using empirical conjecture.
- **Limitations of Cognitive Science:**
  - ***Emotion:*** Cognition science neglects the important role of emotions in human thinking.
  - ***Consciousness:*** Cognition science ignores the importance of consciousness in human thinking.

Cognition and Cognitive Science

- ***Physical environments:*** Cognitive science disregards the significant role of physical environments on human thinking.
- ***Social factors:*** Humans deal with various dialectical processes in ways that cognitive science ignores.
- ***Dynamic nature:*** The mind is dynamic system, not a computational system.
- ***Quantum nature:*** Human thinking cannot be computational in the standard sense, so the brain must operate as a quantum computer.

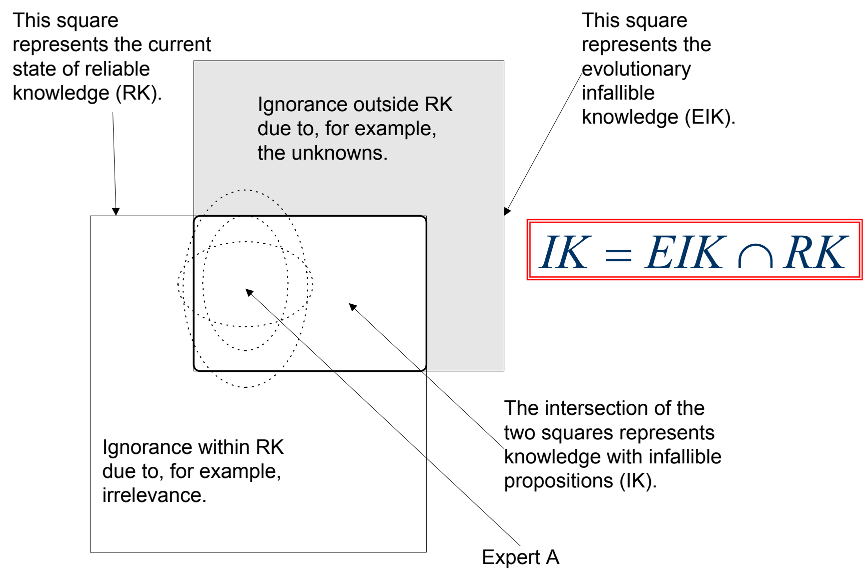
Quantum Knowledge

- **Reality is perceived as a continuum** in its composition of objects, concepts and propositions.
- **Knowledge is constructed in quanta** by humans to meet their cognitive abilities and limitations.
- **Quantum knowledge** leads to ignorance -- manifested in the form of blind ignorance, or **incompleteness** and/or **inconsistency**.
- **Uncertainty** (generally **ignorance**) needs to be **portray**ed in meaningful manner/forms/measures.

Human Knowledge and Ignorance

- In general, engineers, scientists, and even most humans tend to focus on what is *known* and not on the *unknowns*.
- Engineers and scientists tend to emphasize knowledge and information, and sometimes intentionally or unintentionally discard ignorance.
- Knowledge could be misleading in some situations.

Human Knowledge and Ignorance



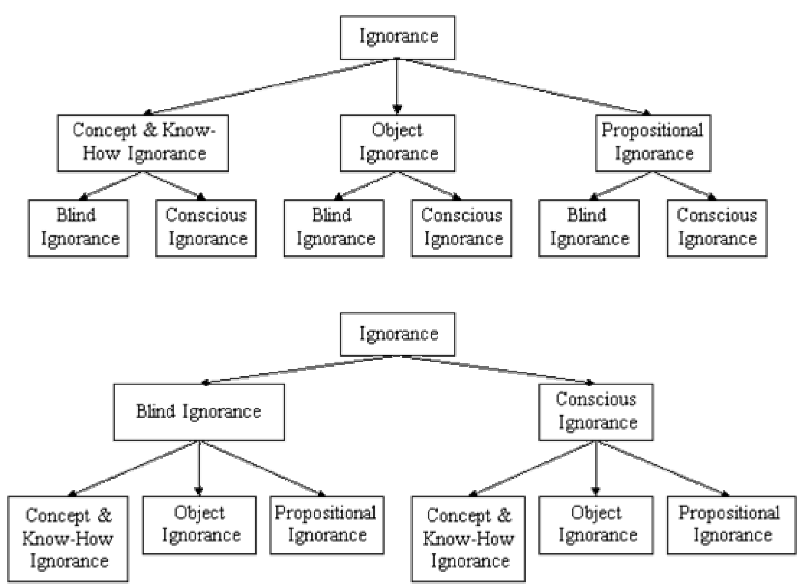
Human Knowledge and Ignorance

- Infallible knowledge (IK) can be defined as knowledge that can survive the dialectical processes of humans and societies and passes the test of time and use.
- This infallible knowledge can be schematically defined by the intersection ($\cap$) of the two squares.
- Two primary types of ignorance can be identified:

Human Knowledge and Ignorance

1. Ignorance within the knowledge base (RK) due to factors such as irrelevance.
2. Ignorance outside the knowledge base due to unknown
   - Objects
   - Interaction
   - Laws
   - Dynamics
   - Know-how

Classifying Ignorance



Classifying Ignorance (cont'd)

- Ignorance can be classified based on the following three knowledge sources:
  - *Know-how ignorance* can be related to the lack of, or having erroneous, know-how knowledge. Know-how knowledge requires someone to know how to do a specific activity, function, procedure, etc., such as riding a bicycle.
  - *Object ignorance* can be related to the lack of, or having erroneous, object knowledge.

Classifying Ignorance (cont'd)

Object knowledge is based on a direct acquaintance with a person, place, or thing; for example Mr. Smith knows the President of the United States.

- *Propositional ignorance* can be related to the lack of, or having erroneous, propositional knowledge. Propositional knowledge is based on propositions that can be either true or false; for example, Mr. Smith knows that Rockies are in North America.

Ignorance Hierarchy

- The following figures (A and B) express knowledge and ignorance in evolutionary terms as they are socially or factually constructed and negotiated.
- Ignorance can be viewed as having a hierarchical classification based on its sources and nature (see Figure C).

Ignorance Hierarchy (cont'd)

Knowledge, Information, Opinions, and Evolutionary Epistemology

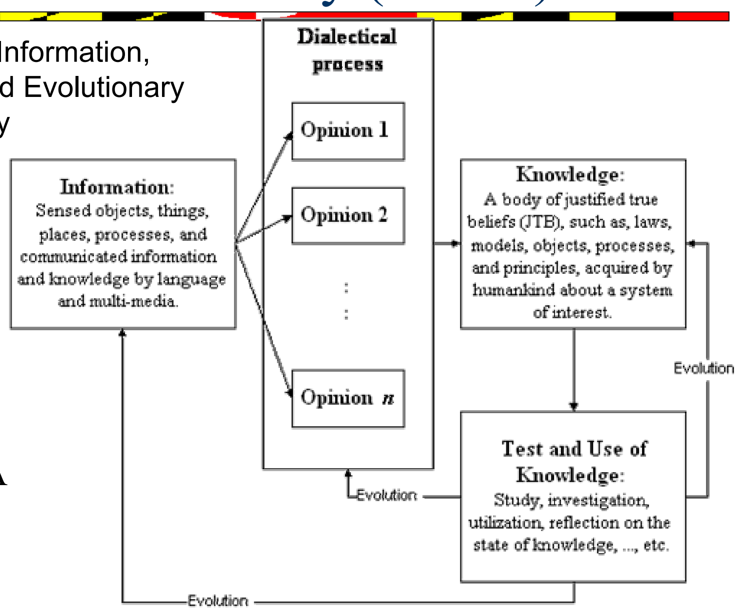
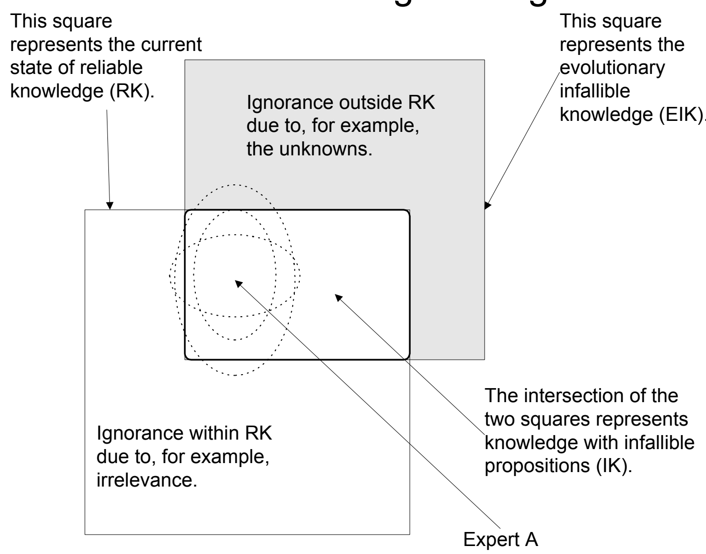


Figure A

Ignorance Hierarchy (cont'd)

Figure B. Human Knowledge and Ignorance



Ignorance Hierarchy (cont'd)

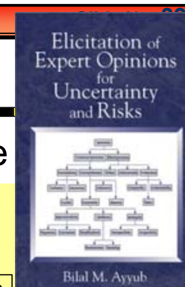
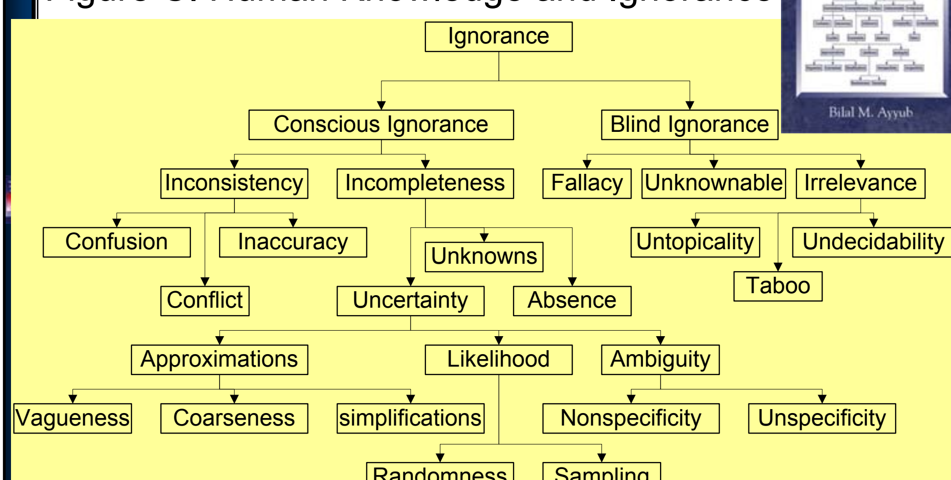
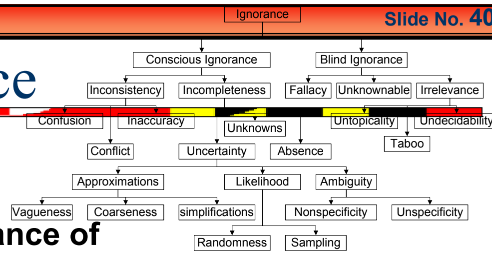


Figure C. Human Knowledge and Ignorance



Blind Ignorance

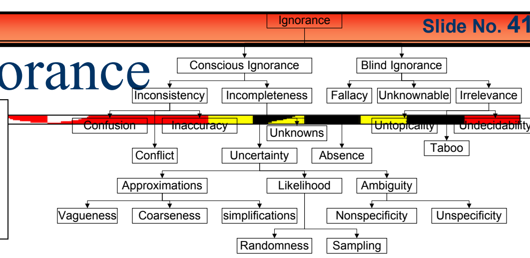


Blind Ignorance: Ignorance of self-ignorance or called meta-ignorance.

- **Fallacy**: erroneous belief due to misleading notions
- **Unknowable**: Knowledge that cannot be attained by humans based on current evolutionary progressions or limitations, or can only be attained through quantum leaps by humans .
- **Irrelevance: Ignoring something.**
  - ✓ **Untopicality:** attributed to intuitions of experts that are negotiated with others in terms of cognitive relevance.
  - ✓ **Taboo:** due to socially reinforced irrelevance.
  - ✓ **Undecidability:** deals with issues that are considered insoluble or solutions that are not verifiable.

Conscious Ignorance

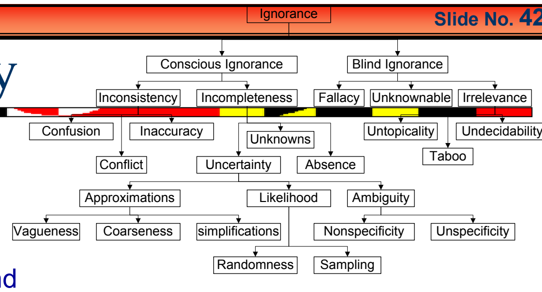
Kurt Gödel (1906-1978) showed that a logical agent could not be both consistent and complete; and could not prove itself complete without proving itself inconsistent and vise versa.



Conscious Ignorance: A recognized self-ignorance through reflection.

- **Inconsistency**
  - ✓ Confusion (Wrongful substitutions)
  - ✓ Conflict (Contradictory assignments or substitutions)
  - ✓ Inaccuracy (Bias and distortion in degree)
- **Incompleteness**
  - ✓ Unknowns (The difference between the *becoming* knowledge state and *current* knowledge state)
  - ✓ Absence (Incompleteness in kind)
  - ✓ Uncertainty (inherent deficiencies with acquired knowledge)
    - Ambiguity, Likelihood, Approximations

Uncertainty



- **Ambiguity**
  - ✓ includes unspecificity and nonspecificity as a result of outcomes or assignments that are incompletely or improperly defined, respectively.
- **Vagueness**
  - ✓ is due to uncertainties of memberships to sets and boundaries of sets.
- **Coarseness & Simplification**
  - ✓ Forms of approximations
- **Likelihood**
  - ✓ can be due to physical randomness, statistical or modeling uncertainty
  - ✓ Statistical uncertainty arises from using samples to characterize populations.
  - ✓ Modeling uncertainty arises from using analytical models to predict system behavior.

Ignorance Hierarchy (cont’d)

Table A. Taxonomy of Ignorance

Term	Meaning
1. Blind ignorance	Ignorance of self-ignorance or called meta-ignorance.
1.1. Unknowable	Knowledge that cannot be attained by humans based on current evolutionary progressions, or cannot be attained at all due to human limitations, or can only be attained through quantum leaps by humans.
1.2. Irrelevance	Ignoring something.
1.2.1. Untopicality	Intuitions of experts that could not be negotiated with others in terms of cognitive relevance.
1.2.2. Taboo	Socially reinforced irrelevance. Issues that people must not know, deal with, inquire about, or investigate.
1.2.3. Undecidability	Issues that cannot be designated true or false because they are considered insoluble, or solutions that are not verifiable, or ignoratio elenchi.
1.3. Fallacy	Erroneous belief due to misleading notions.

Ignorance Hierarchy (cont'd)

Table A. (*cont'd*) Taxonomy of Ignorance

2. Conscious ignorance	A recognized self-ignorance through reflection.
2.1. Inconsistency	Inconsistency in knowledge can be attributed to distorted information as a result of inaccuracy, conflict, contradiction, and/or confusion.
2.1.1. Confusion	Wrongful substitutions.
2.1.2. Conflict	Conflicting or contradictory assignments or substitutions.
2.1.3. Inaccuracy	Bias and distortion in degree.
2.2. Incompleteness	Incomplete knowledge due to absence or uncertainty.
2.2.1. Absence	Incompleteness in kind.
2.2.2. Unknowns	The difference between the *becoming* knowledge state and *current* knowledge state
2.2.3. Uncertainty	Knowledge incompleteness due to inherent deficiencies with acquired knowledge.
2.2.3.1. Ambiguity	The possibility of having multi-outcomes for processes or systems.
a) Unspecificity	Outcomes or assignments that are not completely defined.
b) Nonspecificity	Outcomes or assignments that are improperly defined.

Ignorance Hierarchy (cont'd)

Table A. (*cont'd*) Taxonomy of Ignorance

2.2.3.2. Approximations	A process that involves the use of vague semantics in language, approximate reasoning, and dealing with complexity by emphasizing relevance.
a) Vagueness	Non-crispness of belonging and non-belonging of elements to a set or a notion of interest.
b) Coarseness	Approximating a crisp set by subsets of an underlying partition of the set's universe that would bound the set of interest.
c) Simplifications	Assumptions needed to make problems and solutions tractable.
2.2.3.3. Likelihood	Defined by its components of randomness, statistical and modeling.
a) Randomness	Non-predictability of outcomes.
b) Sampling	Samples versus populations.

Mathematical Models for Ignorance Types

- Example Applications of Theories to Model and Analyze Ignorance types

	Ignorance Type						
Theory	Confusion & Conflict	Inaccuracy	Ambiguity	Randomness & Sampling	Vagueness	Coarseness	Simplification
Classical sets			Modeling				
Probability		Forecasting		Quality control			Modeling
Statistics				Sampling			
Bayesian							
Fuzzy sets					Control		
Rough sets						Classification	Modeling
Evidence	Diagnostic						
Possibility		Forecasting			Control		
Monotone measure							
Interval probabilities		Risk Analysis					
Interval analysis		Validation					

Information Uncertainty in Engineering Systems

- Abstraction and Modeling of Engineering Systems
- Ignorance and Uncertainty in Abstracted Aspects of a System
- Ignorance and Uncertainty in Non-abstracted Aspects of a System
- Ignorance due to Unknown Aspects of a System

Information Uncertainty in Engineering Systems (cont'd)

- Abstraction and Modeling of Engineering Systems
  - *Safety Factors (SF):* deterministic approach
  - *Partial Safety Factors (PSF):* Probabilistic
  - Uncertainty traditionally classified into:
    - Objective
    - Subjective
  - ***Objective types*** are based on physical, statistical, modeling sources of uncertainty.

Information Uncertainty in Engineering Systems (cont'd)

- ***Subjective types*** are based on *lack of knowledge* and *expert-based* assessment of engineering variables and parameters.
- Engineers and scientists use information for the purpose of system analysis and design.
- Data in this case, is classified, sorted, and analyzed, and used to predict system behavior.
- However, it can be difficult to classify, sort, and analyze uncertainty to assess our predictions.

Information Uncertainty in Engineering Systems (cont'd)

- Ignorance and Uncertainty in Abstracted Aspects of a System
  - Engineers have dealt with
    - Ambiguity
    - Likelihood
  - They deal with *ambiguity* and *likelihood* when using the theories of probability, statistics, and Bayesian methods to predict system behavior and design.

Information Uncertainty in Engineering Systems (cont'd)

- Ignorance and Uncertainty in Abstracted Aspects of a System
  - Probabilistic methods include:
    - Reliability methods
    - Probabilistic engineering methods
    - Stochastic finite-element methods
    - Reliability-based design formats
      - Developed for this purpose, however, a realization was reached of the presence of the approximations types of uncertainty.

Information Uncertainty in Engineering Systems (cont'd)

- Ignorance and Uncertainty in Non-abstracted Aspects of a System
  - The *abstracted aspects* of a system and their uncertainty models can be developed to account for the *non-abstracted aspects* of the system to some extent.
  - The accounting process is incomplete; a source of uncertainty exists due to non-abstracted aspects of the system.
  - The ignorance categories and uncertainty types in this case are more difficult to deal with.

Information Uncertainty in Engineering Systems (cont'd)

- Ignorance due to Unknown Aspects of a System
  - Some engineering system failures have occurred because of failure modes that were not accounted for in the design stages of these systems.
  - Not accounting for failure modes can be due to
    - Blind ignorance, negligence, and errors, and
    - A general state of knowledge about a system that is incomplete.

Information Uncertainty in Engineering Systems (cont'd)

- Example 8: Human Knowledge and Ignorance in Fire Escape Systems

Source of Risk as an Adverse Event	Escape Scenarios	Smoke Detector Working Successfully		Occupants Managed to Escape		Consequences in terms of Life Loss
		Yes	No	Yes	No	
Fire	Scenario 1	Yes		Yes		No Injury
initiated	Scenario 2	Yes			No	Death
in an	Scenario 3		No	Yes		Sever Injury
apartment	Scenario 4		No		No	Death

Information Uncertainty in Engineering Systems (cont'd)

- Example 8 (cont'd)
  - System definition can include the occupants.
  - The behavior of the occupants in case of fire is uncertain.
  - If the locations of the escape routes are known to the occupants of an apartment, then catastrophic consequences might result due in part to this lack of knowledge.
  - The result of risk analysis in this case are greatly affected by assumption made about the occupants.

Information Uncertainty in Engineering Systems (cont'd)

- Example 9: Human Knowledge and Ignorance in Project Management Systems
  - Risk analysis in project management, human knowledge and ignorance can be a primary source for delaying a completion of a project or causing its budget to be overrun.
  - Incompetent project managers or unqualified contractors can cause series drawbacks to a project and affect the investment of a client.

Information Uncertainty in Engineering Systems (cont'd)

  - Lack of knowledge or experience in managing a project from technical and economical dimensions can cause delays and budget overruns.
  - Risk analysis requires constructing models that account for any lack of knowledge and represent uncertainties associated with the model structures and their inputs properly.
  - These models should include experience of personnel that are assigned to execute the project in assessing the risks.

Homework Assignment #1

Problems
- 1.2
- 1.6
- 1.8