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3-Day Intensive Course on

Info-Gap Theory and Its Applications in Engineering

Civil and Environmental Engineering
Tufts University
Boston, MA

Contents

Course Rationale Scientists, engineers, policy planners and analysts use measurements and science-based models to design systems, evaluate reliability, and make plans and policies. However, models may be simpler than reality, causal factors may be unknown, measurements may err or be incomplete, and systems may change over time in unknown ways. Probability is useful for modeling and managing some of these uncertainties. However some uncertainties are *info-gaps:* disparities between what *is known* and what *needs to be known* in order to make good decisions. For instance, we sometimes do not know the correct probability distribution or all of the relevant physical mechanisms such as non-linearities or time dependencies. This course studies info-gap theory for modeling and managing uncertainties in planning, design and decision problems. The course emphasizes the added value of an info-gap analysis as well as its limitations, and the integration of info-gap theory with probabilistic analysis.

Course Structure This course has three components. *Lectures* use simple examples to illustrate the info-gap method for analyzing risk and prioritizing choices when faced with deep uncertainty. *Exercises* help the participants to master the operational aspects of info-gap theory. The first two days are devoted to lectures and exercises. The third day is devoted to *mini-projects* that are formulated and implemented by the participants, in small groups, on topics of their choice such as versions of projects they work on elsewhere. This facilitates the internalization of the concepts and methods learned, their integration with other methods familiar to the participants, and their application to problems of interest to the participants. The mini-projects may evolve subsequently into thesis chapters or journal articles.

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The Instructor

Dr. Yakov Ben-Haim initiated and developed info-gap decision theory for modeling and managing deep uncertainty. Info-gap theory is applied in engineering, biological conservation, economics, project management, climate change management, national security, medicine, and other areas. He has been a visiting scholar in Australia, Austria, Canada, England, France, Germany, Italy, Japan, Korea, The Netherlands, Norway, and the US. He has lectured at universities, medical and technological research institutions and central banks around the world. He has published more than 120 articles and 6 books. He is a professor emeritus of mechanical engineering and held the Yitzhak Moda'i Chair in Technology and Economics at the Technion—Israel Institute of Technology.

The Participants Scientists, engineers, analysts and researchers involved in risk analysis, reliability assessment, planning and design in engineering, project management, and related areas.

Brief Outline

Day 1 26.2.2025

MORNING

09:00–09:50 *Lecture 1. Info-gap theory: Overview and examples.*

10:00–10:50 *Lecture 2. Info-gap robustness of a beam with uncertain load.*

10:50–11:20 Coffee break.

11:20–12:10 *Lecture 3. Probabilistic reliability with info-gap uncertainty.*

LUNCH 12:10–13:40

AFTERNOON

13:40–14:30 *Exercise 1. Trigger mechanism.*

14:40–15:30 *Exercise 2. Adaptive force balancing.*

15:30–16:00 Coffee break.

16:00–16:50 *Exercise 3. Cantilever.*

Day 2 27.2.2025

MORNING

09:00–09:50 *Lecture 4. Vibration suppression with uncertain load.*

10:00–10:50 *Lecture 5. Info-gap analysis of estimation and forecasting.*

10:50–11:20 Coffee break.

11:20–12:10 *Lecture 6. The optimizer's curse: An info-gap response.*

LUNCH 12:10–13:40

AFTERNOON

13:40–14:30 *Exercise 4. Allocation of scarce resource.*

14:40–15:30 *Exercise 5. Quantiles with asymmetric uncertainty.*

15:30–16:00 Coffee break.

16:00–16:50 *Exercise 6. Energy conservation by feedback.*

Day 3 28.2.2025

MORNING

09:00–09:30 *Brainstorm and define problems. Form small mini-project working groups.*

09:30–12:10 *Working groups formulate and implement robust info-gap solutions.*

LUNCH 12:10–13:40

AFTERNOON

13:40–16:00 *Working groups continue solution development.*

16:00–16:50 *Working groups present preliminary results.*

Detailed Outline

Day 1 26.2.2025

MORNING

09:00–09:50 *Lecture 1. Info-gap theory: Overview and examples.*[1]

- Examples of deep info-gaps.
- Principle of indifference.[2] Probability is powerful but not applicable in all situations. We illustrate this and discuss several paradoxes of probability.
- Applications of info-gap theory.

10:00–10:50 *Lecture 2. Info-gap robustness of a beam with uncertain load.*[3]

- Uncertain spatial distributions of load.[4]
- Info-gap models of uncertainty: uniform, envelope, Fourier ellipsoid.[5]

10:50–11:20 Coffee break.

11:20–12:10 *Lecture 3. Probabilistic reliability with info-gap uncertainty.*[6]

LUNCH 12:10–13:40

AFTERNOON

13:40–14:30 *Exercise 1. Trigger mechanism.*[7]

14:40–15:30 *Exercise 2. Adaptive force balancing.*[8]

15:30–16:00 Coffee break.

16:00–16:50 *Exercise 3. Cantilever.*[9]

Day 2 27.2.2025

MORNING

09:00–09:50 *Lecture 4. Vibration suppression with uncertain load.*[10]

10:00–10:50 *Lecture 5. Info-gap analysis of estimation and forecasting.*[11]

10:50–11:20 Coffee break.

11:20–12:10 *Lecture 6. The optimizer's curse: An info-gap response.*[12]

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[1] **Lecture 1 slides:** tufts2025lec01-001.pdf

- Many simple examples of info-gap analyses are found in section 3.2 of: Yakov Ben-Haim, 2006, *Info-gap Decision Theory: Decisions Under Severe Uncertainty,* 2nd edition, Academic Press, London (henceforth *IGDT*).
- Qualitative non-technical discussion of info-gap decision theory and its applications is found in Yakov Ben-Haim, 2018, *Dilemmas of Wonderland: Decisions in the Age of Innovation,* Oxford University Press.

[2] *IGDT*, sections 2.2 and 2.3.

[3] **Lecture 2 slides:** tufts2025lec02-001.pdf

- Yakov Ben-Haim, 2005, Info-gap Decision Theory For Engineering Design. Or: Why 'Good' is Preferable to 'Best', appearing as chapter 11 in *Engineering Design Reliability Handbook,* Edited by Efstratios Nikolaidis, Dan M.Ghiocel and Surendra Singhal, CRC Press, Boca Raton.

[4] Yakov Ben-Haim, 1996, *Robust Reliability in the Mechanical Sciences,* Springer, sections 3.1, 3.2.

[5] - *IGDT*, section 2.5.

- Yakov Ben-Haim, *Info-Gap Economics: An Operational Introduction*, (hencefore *IGE*), chap. 7.

[6] **Lecture 3 notes:** tufts2025lec03-001.pdf.

- *IGDT*, section 3.2.3.

[7] **Exercise file** ps2p41.pdf. Based on ps2-02.tex #41.

[8] **Exercise file** ps2p55.pdf. Based on ps2-02.tex #55.

[9] **Exercise file** ps2p53.pdf. Do parts (a)–(d). Based on ps2-02.tex #53.

[10] **Lecture 4 notes:** tufts2025lec04-001.pdf

- *IGDT*, section 3.3.1.

[11] **Lecture 5 notes:** tufts2025lec05-001.pdf

- *IGDT*, section 3.2.13.
- *IGE*, chapter 6.
- Yakov Ben-Haim, 2009, Info-gap forecasting and the advantage of sub-optimal models, *European Journal of Operational Research,* 197: 203–213.

[12] **Lecture 6 notes:** tufts2025lec06-001.pdf.

LUNCH 12:10–13:40

AFTERNOON

13:40–14:30 *Exercise 4. Allocation of scarce resource.*[13]

14:40–15:30 *Exercise 5. Quantiles with asymmetric uncertainty.*[14]

15:30–16:00 Coffee break.

16:00–16:50 *Exercise 6. Energy conservation by feedback.*[15]

Day 3 28.2.2025

MORNING

09:00–09:50 *Brainstorm and define problems. Form small mini-project working groups.*

10:00–10:50 *Working groups formulate and implement robust info-gap solutions.*

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15:30–16:00 Coffee break.

16:00–16:50 *Working groups present preliminary results.*

Project Guidelines

1. Preliminary advice.
   (a) Keep it simple.
   (b) Write it up.
2. The story:
   (a) Problem statement.
   (b) Goals.
   (c) Uncertainties.
   (d) Decisions to be made:
      i. What must we decide about?
      ii. What are the options?
3. Math: Formulation.
   (a) System Model.
   (b) Performance requirements.
   (c) Uncertainty model.
   (d) Robustness definition (and perhaps opportuneness).
4. Math: Analysis.
   (a) Evaluate the robustness function (analytical or numerical).
   (b) Sketch or plot the robustness curves for alternative decisions.
5. Interpretation:
   (a) Interpret the robustness curves.
   (b) Make a decision, or start over.

○ Smith, James E. and Robert L. Winkler, 2006, The optimizer's curse: Skepticism and postdecision surprise in decision analysis, *Management Science,* Vol. 52, No. 3, pp.311–322.

○ Thaler, Richard H., 1992, *The Winner's Curse: Paradoxes and Anomalies of Economic Life,* Princeton University Press.

[13] **Exercise file** ps2p94.pdf. Do parts (a), (b). Based on ps2-02.tex #94.

[14] **Exercise file** ps2p87.pdf. Based on ps2-02.tex #87.

[15] **Exercise file** ps2p101.pdf. Based on ps2-02.tex #101.

Selected Sources: Info-gap theory and applications

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2. Yakov Ben-Haim, 2010, *Info-Gap Economics: An Operational Introduction,* Palgrave.
3. Yakov Ben-Haim, 2018, *The Dilemmas of* Wonderland*: Decisions in the Age of Innovation,* University of Oxford Press.

Engineering design:

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5. Xiong Wu, Nailiang Li, Mingkang He, Xiuli Wang, Song Ma and Jingjing Cao, 2021, Risk-constrained day-ahead scheduling for gravity energy storage system and wind turbine based on IGDT, *Renewable Energy,* Available online 27 December 2021.
6. Jun Liu, Chong Chen, Zhenling Liu, Kittisak Jermsittiparsert, Noradin Ghadimi, 2020, An IGDT-based risk-involved optimal bidding strategy for hydrogen storage-based intelligent parking lot of electric vehicles, *Journal of Energy Storage,* 27 (2020) 101057.
7. Deping Ke, Feifan Shen, C. Y. Chung, Chen Zhang, Jian Xu, and Yuanzhang Sun, 2018, Application of information gap decision theory to the design of robust wide-area power system stabilizers considering uncertainties of wind power, *IEEE Transactions on Sustainable Energy,* vol. 9, no. 2, April 2018, pp.805–817.
8. Korteling, B., Dessai, S., Kapelan, Z., 2012, Using information-gap decision theory for water resources planning under severe uncertainty, *Water Resources Management,* 27(4): 1149–1172.
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   http://www.popularmechanics.com/military/a8093/self-defense-for-the-self-driving-car-12410682/
   Selection from article: http://tx.technion.ac.il/~yakov/IGT/hambling2012selection.html
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11. Yakov Ben-Haim, 2019, Info-gap decision theory, in V.A.W.J. Marchau, W.E. Walker, P. Bloemen, and S.W. Popper (eds.), *Decision Making Under Deep Uncertainty: From Theory to Practice,* Springer.
12. Yakov Ben-Haim, 2019, Assessing 'beyond a reasonable doubt' without probability: An info-gap perspective, *Law, Probability and Risk,* appearing online, https://doi.org/10.1093/lpr/mgy021.
13. Yakov Ben-Haim and Mike Smithson, 2018, Data-Based Prediction under Uncertainty: A Dual Approach. *Journal of Mathematical Psychology,* 87: 11–30.
14. Yakov Ben-Haim, 2017, Does a better model yield a better argument? An info-gap analysis, Proceedings of the Royal Society, A, 5 April 2017.
15. Yakov Ben-Haim, 2014, Order and indeterminism: An info-gap perspective, appearing in Error and Uncertainty in Scientific Practice, Marcel Boumans, Giora Hon and Arthur Petersen, eds., Pickering & Chatto Publishers, London, pp.157–175.

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17. Yakov Ben-Haim, 2012, Why risk analysis is difficult, and some thoughts on how to proceed, *Risk Analysis*, 32(10): 1638–1646.
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20. Dylan R. Harp and Velimir V. Vesselinov, 2013, Contaminant remediation decision analysis using information gap theory, *Stochastic Environmental Research and Risk Assessment*, 27(1): 159–168.
21. Yemshanov, Denys, Frank H. Koch, Yakov Ben-Haim and William D. Smith, 2010, Detection capacity, information gaps and the design of surveillance programs for invasive forest pests, *Journal of Environmental Management*, 91: 2535–2546.

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26. Yakov Ben-Haim, 2020, Quantitative analysis for interpreting diagnostic tests for Covid-19: Rev. Thomas Bayes can help. 42nd Annual Meeting of the Society for Medical Decision Making, October 2020.
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30. Yakov Ben-Haim, 2011, Interpreting null results from measurements with uncertain correlations: An info-gap approach, *Risk Analysis*, 31(1): 78–85.

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Public policy:

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More references and background material on many info-gap applications: http://info-gap.technion.ac.il