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3-Day Intensive Course on

Info-Gap Theory and Its Applications in Engineering

14–16 September 2016
Université de Franche-Comté
Besançon, France

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 four components. *Lectures* use simple examples to illustrate the info-gap method for analyzing risk and prioritizing choices when faced with severe uncertainty. *Exercises* help the participants to master the operational aspects of info-gap theory. A *computer tutorial session* focusses on problems that require numerical solutions. The first two days are devoted to lectures, exercises and a computer lab. 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 Instructors

Dr. Yakov Ben-Haim initiated and developed info-gap decision theory for modeling and managing severe 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, 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 100 articles and 5 books. He is a professor of mechanical engineering and holds the Yitzhak Moda'i Chair in Technology and Economics at the Technion—Israel Institute of Technology.

Dr. Scott Cogan is a senior research fellow in the CNRS and is currently leader of the Model Validation and Uncertainty Quantification group at the Department of Applied Mechanics in the FEMTO-ST Institute in Besançon. He has published numerous articles and has participated in the direction of over two dozen PhD students. He has been actively involved in nearly forty industry-funded projects in engineering analysis and design and has developed three licensed software platforms for model calibration, validation and uncertainty quantification.

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

Brief Outline

Day 1 Wednesday, 14 September 2016

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 Thursday, 15 September 2016

MORNING

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

10:00–10:50 *Lecture 5. Estimation with info-gap uncertainties.*

10:50–11:20 Coffee break.

11:20–12:10 *Lecture 6. Safety factors and info-gap robustness.*

LUNCH 12:10–13:40

AFTERNOON

13:40–15:30 *Computer lab:* tutorial session with problems that require numerical solutions.

15:30–16:00 Coffee break.

16:00–16:50 *Computer lab:* continuation.

Day 3 Friday, 16 September 2016

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.*

10:50–11:20 Coffee break.

11:20–12:10 *Working groups continue solution development.*

LUNCH 12:10–13:40

AFTERNOON

13:40–15:30 *Working groups continue solution development.*

15:30–16:00 Coffee break.

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

Detailed Outline

Day 1 Wednesday, September 2016

MORNING

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

- Examples of severe 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 Thursday, September 2016

MORNING

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

10:00–10:50 *Lecture 5. Estimation with info-gap uncertainties.*[11]

10:50–11:20 Coffee break.

11:20–12:10 *Lecture 6. Safety factors and info-gap robustness.*[12]

LUNCH 12:10–13:40

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[1] **Lecture 1 notes:** besancon2016lec01-001.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*).

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

[3] **Lecture 2 notes:** besancon2016lec02-002.pdf

[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:** besancon2016lec03-001.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:** besancon2016lec04-001.pdf

- *IGDT*, section 3.3.1.

[11] **Lecture 5 notes:** besancon2016lec05-001.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:** besancon2016lec06-001.pdf.

- Yakov Ben-Haim, 2005, Info-gap decision theory for engineering design. Or: Why 'good' is preferable to 'best', in *Engineering Design Reliability Handbook,* Edited by E. Nikolaides, D. Ghiocel and Surendra Singhal, CRC Press.

AFTERNOON

13:40–15:30 *Computer lab:* tutorial session with problems that require numerical solutions.

15:30–16:00 Coffee break.

16:00–16:50 *Computer lab:* continuation.

Day 3 Friday, September 2016

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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11:20–12:10 *Working groups continue solution development.*

LUNCH 12:10–13:40

AFTERNOON

13:40–15:30 *Working groups continue solution development.*

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. English (or French): 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. English (or French): Interpretation.
   (a) Interpret the robustness curves.
   (b) Make a decision, or start over.

Selected Sources: Info-gap theory and applications

Books:

1. Yakov Ben-Haim, 2006, *Info-gap Decision Theory: Decisions Under Severe Uncertainty,* 2nd edition, Academic Press, London.
2. Yakov Ben-Haim, 2010, *Info-Gap Economics: An Operational Introduction,* Palgrave.

Foundations of info-gap theory:

3. Yakov Ben-Haim, 2012, Doing Our Best: Optimization and the Management of Risk, *Risk Analysis,* 32(8): 1326–1332.
4. Yakov Ben-Haim, 2012, Why risk analysis is difficult, and some thoughts on how to proceed, *Risk Analysis,* 32(10): 1638–1646.
5. Barry Schwartz, Yakov Ben-Haim, and Cliff Dacso, 2011, What Makes a Good Decision? Robust Satisficing as a Normative Standard of Rational Behaviour, *The Journal for the Theory of Social Behaviour,* 41(2): 209–227.

Engineering design:

6. 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.
7. David Hambling, 5 Sept. 2012, Self-Defense for the Self-Driving Car, *Popular Mechanics,* Online version:

   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

8. M.Pasquali, C.J.Stull and C.R.Farrar, 2015, Info-gap robustness of an input signal optimization algorithm for damage detection, *Mechanical Systems and Signal Processing,* 50–51: 1–10.

Environmental protection:

9. Jim W. Hall, Robert J. Lempert, Klaus Keller, Andrew Hackbarth, Christophe Mijere, and David J. McInerney, 2012, Robust Climate Policies Under Uncertainty: A Comparison of Robust Decision Making and Info-Gap Methods, *Risk Analysis,* 32(10): 1657–1672.
10. 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.
11. 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.

Public policy:

12. Yakov Ben-Haim, Craig Osteen and L. Joe Moffitt, 2013, Policy Dilemma of Innovation: An Info-Gap Approach, *Ecological Economics,* 85: 130–138.

Security:

13. Yakov Ben-Haim, Policy neutrality and uncertainty: An info-gap perspective, *Intelligence and National Security,* to appear.
14. Yakov Ben-Haim, Uncertainty and deterrence, *Air and Space Power Journal — A&F,* to appear.
15. Yakov Ben-Haim, 2015, Dealing with uncertainty in strategic decision-making, *Parameters,* US Army War College Quarterly, 45(3) Autumn 2015.
16. Yakov Ben-Haim, 2014, Strategy selection: An info-gap methodology, *Defense & Security Analysis,* 30(2): 106–119.
17. Lior Davidovitch and Yakov Ben-Haim, 2008, Is your profiling strategy robust? *Law, Probability and Risk,* 10: 59–76.

Medicine:

18. Yakov Ben-Haim, Nicola M. Zetola and Clifford Dacso, 2012, Info-Gap Management of Public Health Policy for TB with HIV-Prevalence, *BMC Public Health,* 12: 1091.

    DOI: 10.1186/1471-2458-12-1091, URL: http://www.biomedcentral.com/1471-2458/12/1091

Info-gap statistics:

19. Yakov Ben-Haim, Miriam Zacksenhouse, Ronit Eshel, Raphael Levi, Avi Fuerst and Wayne Bentley, 2014, Failure detection with likelihood ratio tests and uncertain probabilities: An info-gap application, *Mechanical Systems and Signal Processing,* vol. 48, pp.1–14
20. Yakov Ben-Haim, 2011, Interpreting null results from measurements with uncertain correlations: An info-gap approach, *Risk Analysis,* 31(1): 78–85.

More references, background material, links: http://info-gap.com