Dr. Yakov Ben-Haim
Professor
Yitzhak Moda'i Chair in
Technology and Economics

Technion
Israel Institute of Technology
Faculty of Mechanical Engineering
Haifa 32000 Israel

yakov@technion.ac.il
http://info-gap.com
http://www.technion.ac.il/yakov
Tel: +972-4-829-3262 Fax: +972-4-829-5711

Joint Undergraduate-Graduate Course on

Info-Gap Analysis of Risk and Reliability

03 6057

Syllabus. Strategic decisions under uncertainty in analysis, design and certification of complex systems. Assessment and control of reliability and risk. Project management. Decision paradigms for information-gap uncertainty. Realizability with limited information. Balancing trade-offs between robustness, performance and opportunity. Evolution of preferences through analysis of uncertainty. Value judgments. Decisions with multiple criteria. Learning and the value of information. Decisions with hybrid uncertainties.

Audience. Persons involved in strategic decisions in a complex environment with severe uncertainty: engineers developing new and complex technologies, engineers in project management roles, systems engineers, systems analysts, project managers.

Related areas. Information theory, game theory, interactive decision making, conflict resolution, project management, analysis and design of systems.

Credits: 3.

Prerequisites. This course is based on concepts and methods drawn from the analysis of systems. Students with background in **systems analysis** will be able to master the course material: dynamic systems analysis, operational research, or economics. **Any one** of the following five courses serves as prerequisite:

03 4032. Linear systems, (enhanced).
09 4116. Production management 1.
09 4506. Micro-economics 3.
01 4004. Systems analysis.
01 4606. Construction management.

Grading. Course grade based upon:

Midterm exam, required, 54%.

Homework, required, 6%. Problems distributed regularly and discussed in the exercise session. Each adequate homework set is credited at 1 grade point, up to a total of 6 points towards a 100-point grade. That is, the highest possible grade without submission of any homework is 94. Homework is due one week after assignment unless otherwise indicated.

Project, required, 40%. Guidelines are presented below.

Time and place of lectures. Fall Semester 2009. Tuesdays, 14:30–17:30. Lady Davis Building (Mechanical Engineering Dept.) room 450.

Office hours. Sunday 13:00–14:00. Thursday 10:00–11:00. Lady Davis, room 363. Other times available by appointment.

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Outline of Lectures

1. (1 week) **Severe uncertainty.** Paradoxes of probability. Intuitive and quantitative discussion of types of uncertainty: information gaps, linguistic and probabilistic uncertainty. Hybrid uncertainty models.[1]

2. (1 week) **Preliminary example.** Design of a cantilever beam. Introductory discussion of the trade-off between performance (resistence to load) and robustness to load-uncertainty. Opportunity from uncertainty.[2]

3. (1 week) **Preliminary example.** Portfolio investment. Continued discussion of the trade-off between performance and robustness to uncertainty. Opportunity from uncertainty.[3]

4. (5 weeks) **Robustness and opportunity functions.** This is the heart of the course. By using examples from many disciplines, we develop paradigms for formulating and evaluating strategic decisions. Evolution of preferences through analysis of uncertainty. Examples from systems analysis and design, project management, technological reliability analysis, economics and public policy. Emphasis on generic tools, with examples from many topical areas.[4]

5. (2 week) **Hybrid uncertainties.** Decision paradigms with hybrid uncertainty models: combining info-gap and probabilistic models.[5]

6. (1 week) **Value judgments.** How safe is safe enough? How much reliability is needed? How good is our decision? Qualitative calibration of quantitative trade-offs. Analogical reasoning. Calibration by severity of consequences; by prior information.[6]

7. (1 week) **Value of information.** Assessing the value of information with respect to system goals, and exploiting this evaluation to optimize further information-gathering. Demand value of information in systems with generic (not necessarily monetary) reward.[7]

8. (1 week) **Robust-satisficing behavior.** Analysis of Ellsberg and Allais "paradoxes" of behavior under uncertainty. Examination of info-gap robust-satisficing resolutions.[8]

9. (1 week) **Learning under uncertainty.** We use info-gap theory to study the design and evaluation of learning strategies.[9]

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[1] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., sections 2.2, 2.5.
◦ Y. Ben-Haim, 2004, Uncertainty, probability and information-gaps, *Reliab. Eng. & System Safety,* 85: 249–266.
◦ Lecture Notes on Info-Gap Uncertainty (\risk\lectures\igunc.pdf), pp.2–11.

[2] ◦ Lecture Notes on Performance vs. Robustness of a Cantilever (\risk\lectures\beam_op.pdf).

[3] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., section 3.2.7.
◦ Lecture Notes on Robustness and Opportuneness (\risk\lectures\ro.pdf) section 12.

[4] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 3.
◦ Lecture Notes on Robustness and Opportuneness (\risk\lectures\ro.pdf) various sections.

[5] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 10.
◦ Lecture Notes on Hybrid Uncertainties (\risk\lectures\hybunc.pdf) various sections.

[6] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 4.
◦ Lecture Notes on Value Judgements (\risk\lectures\vjud.pdf) various sections.

[7] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 7.

[8] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 11.
◦ Lecture Notes on Robust-Satisficing Behavior (\risk\lectures\rsb01.pdf) various sections.

[9] ◦ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapters 7 and 8.
◦ Lecture Notes on Info-Gap Learning (\risk\lectures\lrn.pdf) various sections.

Books

The main text is:

Yakov Ben-Haim, 2006, *Info-Gap Decision Theory: Decisions Under Severe Uncertainty,* 2nd edition, Academic Press.

Supplementary material includes:

1. David E. Bell, Howard Raiffa and Amos Tversky, eds., 1988, *Decision Making: Descriptive, Normative, and Prescriptive Interactions,* Cambridge University Press.
2. Yakov Ben-Haim, 1996, *Robust Reliability in the Mechanical Sciences,* Springer-Verlag, Berlin.
3. Yacov Y. Haimes, 1998, *Risk Modeling, Assessment, and Management,* John Wiley.
4. Ralph Keeney, 1992, *Value Focussed Thinking,* Harvard University Press.
5. Ralph L. Keeney and Howard Raiffa, 1993, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs,* Cambridge University Press.
6. M. Granger Morgan and Max Henrion, 1990, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* With a chapter by Mitchell Small. Cambridge University Press.

Project Guidelines

1. The project is devoted to the **risk assessment** or **reliability analysis** of a **complex system.** It will contain the following elements:
   (a) **Statement of the problem:** safety analysis, mission-dependability assessment, design optimization, project management and risk assessment, etc.
   (b) Mathematical **model of the system.** The system may be a specific technological device or it may be a project or network of sub-units or tasks.
   (c) Mathematical formulation of **failure criteria.**
   (d) Mathematical **uncertainty model** with info-gap (and possibly probabilistic) components.
   (e) Mathematical derivation of the **risk** or **reliability** of the **system,** together with numerical analysis where needed to complete the assessment of the reliability. This step explicitly combines the previous three steps.
   (f) Application of the reliability derived in step 1e to **resolution of the problem** identified in step 1a.
2. The project will be submitted in two stages.
   (a) Stage 1: Project **definition and outline** of items 1a–1d above. A printed outline of about 1 page length is due by about the 8th week of the semester.
   (b) Stage 2: **Final report.** Printed, with text not exceeding 10 pages (not counting tables or graphs). Due by the end of the exam period.
3. Each student must submit his own project. **No team submissions.**
4. **Expected depth and complexity:** more than the typical homework problem; much less than a realistic full scale analysis.
5. **Advice and suggestions** can be obtained by consulting with the instructor.
6. **Grading.** The project makes up 40% of the final grade. The project grade will be one of four: 100 (excellent), 85 (good), 70 (pass), 40 (fail).