New 01DROS
Seminar Course on Dynamic Decision Making

2017/2018

Course setup

- Elective course; **2+0z**; **2** credits.
- **Wednesdays, 15:30-17:30**, T-210
- Tatiana V. Guy, guy@utia.cas.cz; Miroslav Kárný, school@utia.cas.cz; ÚTIA
- Though 01DROS is complimentary to 01DRO1, attending 01DRO1 is not required
- recommended literature and other course materials will be available on the course webpage http://staff.utia.cas.cz/guy/DRO12.html
- Practical problems are presented in collaboration with:

DataSentics

FINEMATIC
computer-powered investments

01DROS Grading

- **2+0z**; **2** credits.

- Full attendance (2 absences max) and active participation.

01DROS - Course objectives:

How to develop DM methods theoretically and to apply them in practice.

- extend the topics learned in the lecture course 01DRO1
- describe actual topics and trends in DM, ML and AI
- read DM literature and literature in related fields (AI, ML, control)
- introduce a number of practical tasks, for e.g.
  - practical introduction into ML and business intelligence
  - searching potential employees in web data bases
  - taxi service
  - economic applications, futures trading
  - …

01DROS: Why should you attend the course?

You will ...

- get complementary information to 01DRO1 (those who attend 01DRO1)
- discuss papers from the main DM, AI, ML conferences
- listen homework presentations of your colleagues
- listen guests lectures
- learn about real applications and solutions used
- …

History Leading to Contemporary DM

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The Czech Academy of Sciences

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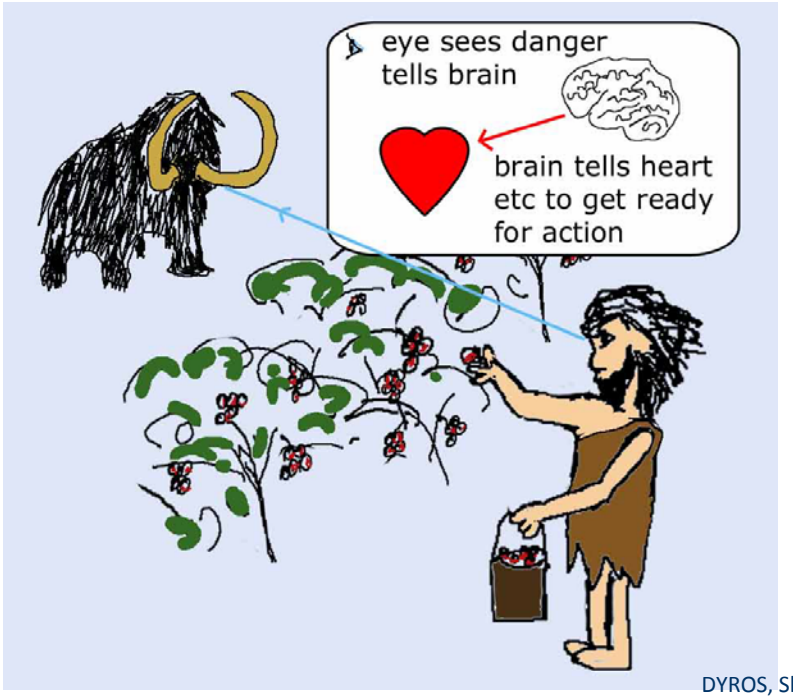
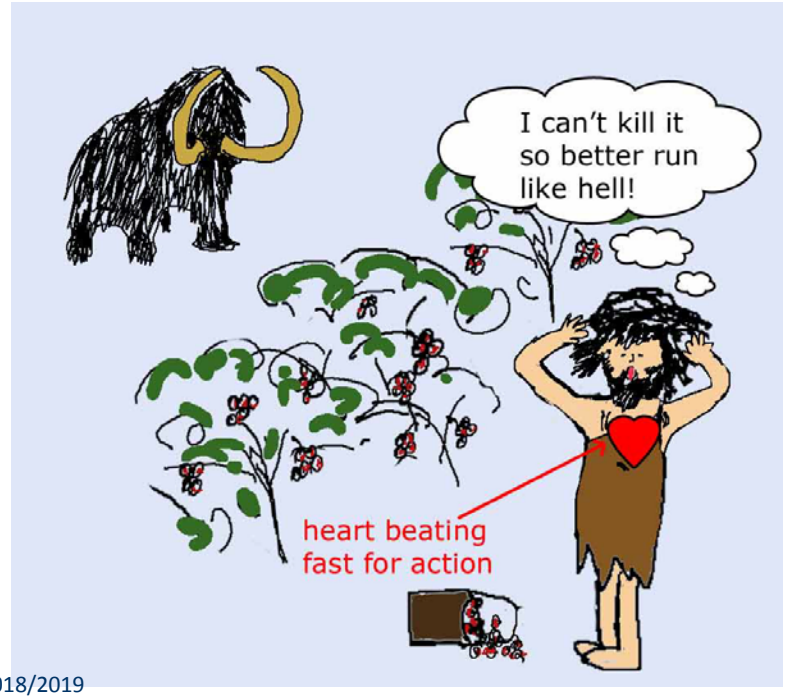
Towards Automated DM under Uncertainty

A subjective sketch of its *history* and *ideas*

DM as a “profit” oriented choice among options is old as mankind





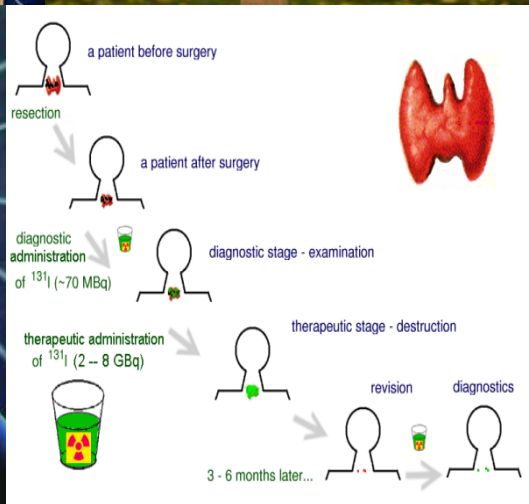
Helmsmen

DM as a “profit” oriented choice among options is old as mankind

Environment sensing, thinking & acting agents

Varia

DM as a “profit” oriented choice among options is old as mankind



What is Common?

An *action* is *available* and its use is *purposeful*

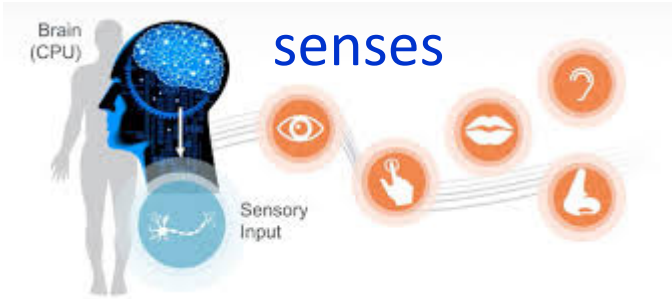
- **Agent** interacts with a world part and it:
- ✓ is influenced by this environment via sensors
- ✓ sends actions via actuators
- ✓ "computes", it thinks in order to process its knowledge and aims
- **Environment** responses are uncertain due to its changes or agent's knowledge lack ⇒ beliefs into responses a part of DM
- **Human** is the **weakest link** in the decision process

Need to *Get Rid* of *Human* ⇒ Need for Automation

Environment evolves

Agent acts

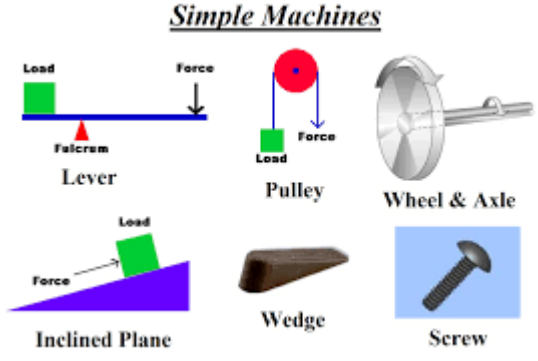
Agent processes knowledge & aims

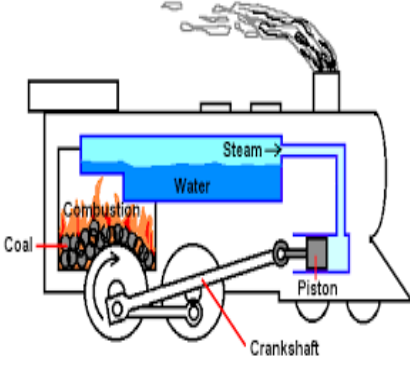


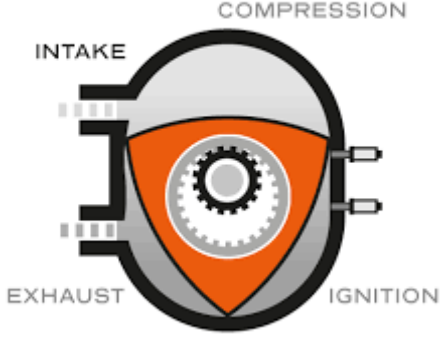
computes

How to Get Rid of Human?

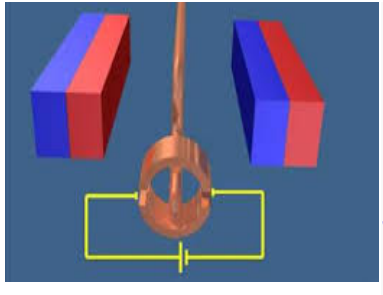
Actuators *convert* & *amplify* virtual actions into physical actions

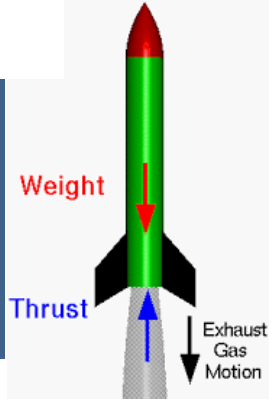






electric motor

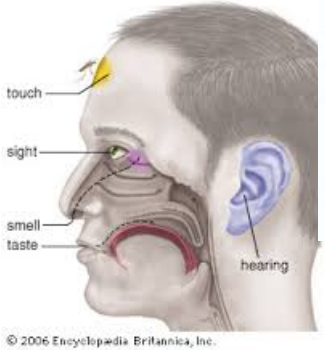


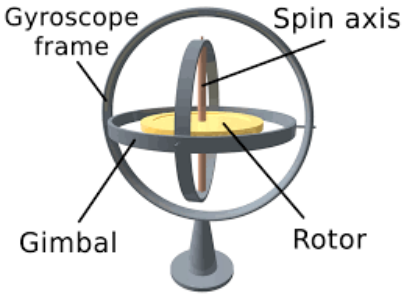


linear motor

How to Get Rid of Human?

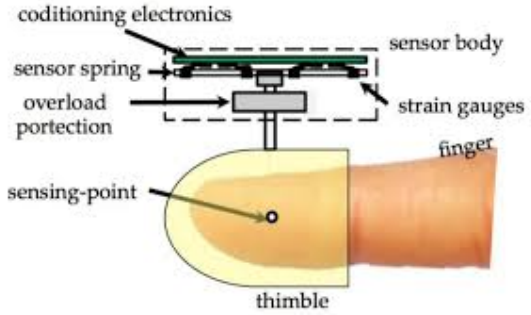
Sensors map the environment evolution to agent's "computer"





Sensors map to perceptible domain

Sensors allow machine to machine information flow

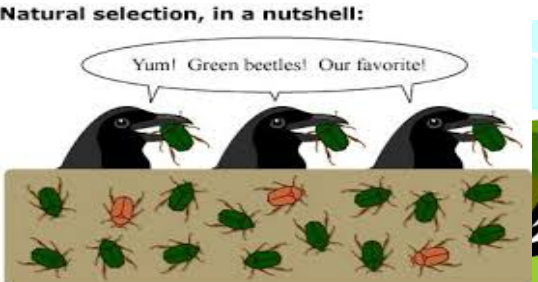


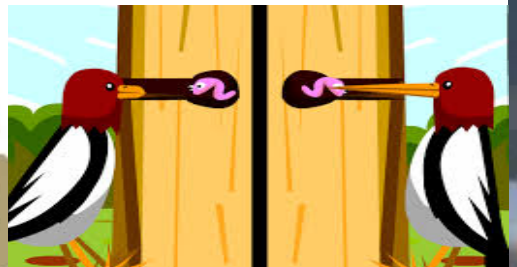
How to Get Rid of Human?

Computing is mapping: knowledge & aims → action

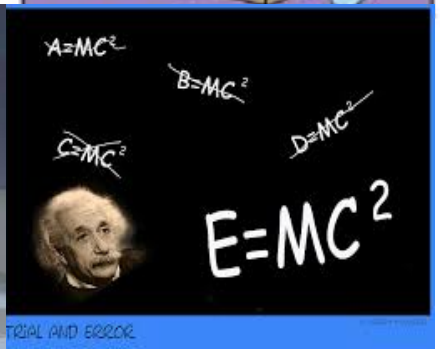
Historical tool & method

… drive selection & evolution





Examples

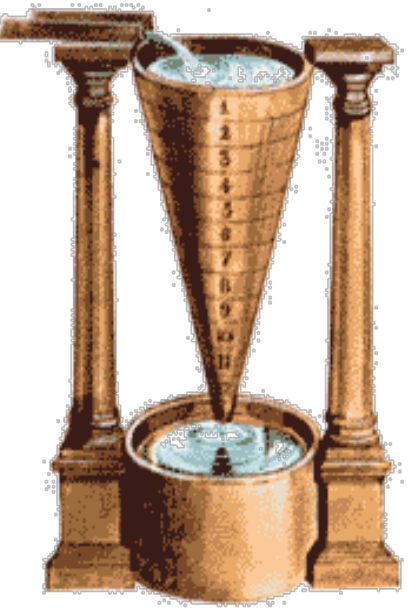


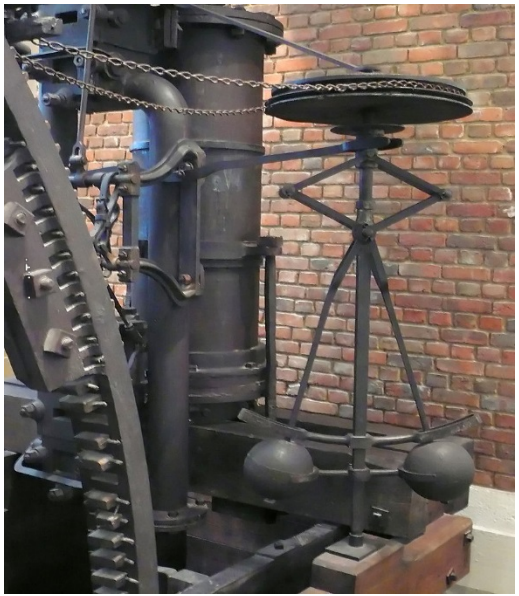
Theories Supporting “Computing”
They stand on the shoulders of giants

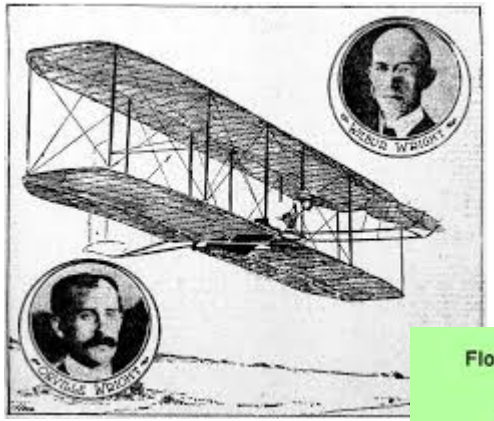
- Control
- Cybernetics
- Models of uncertainty
- Game theory
- Expected utility theory
- Turing machines
- Artificial intelligence

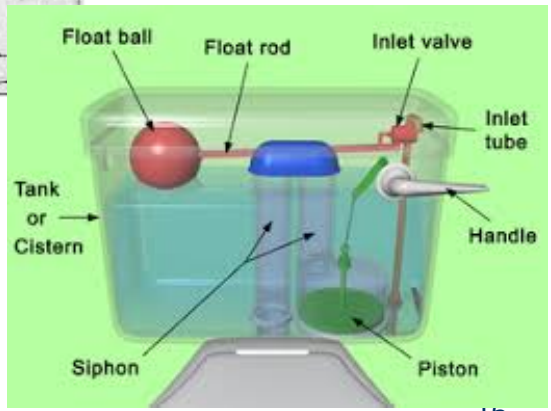
Hardware Based Control

Clepsydra -500 Boulton-Watt engine 1788 Wright Brothers 1903 …

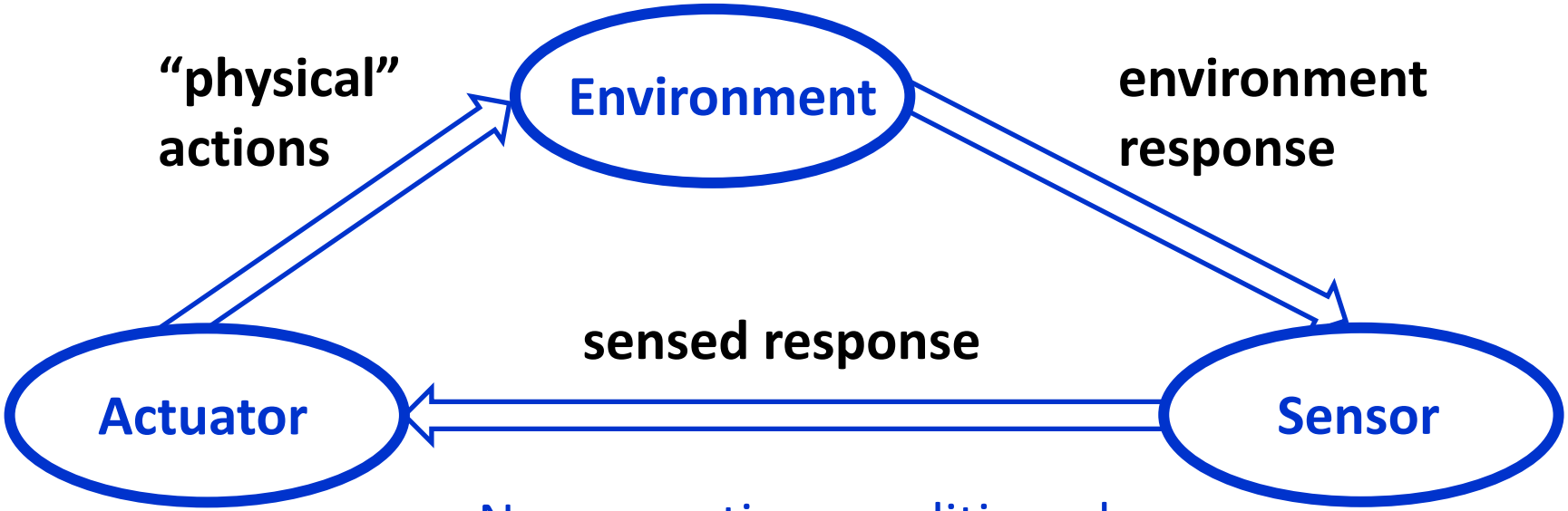








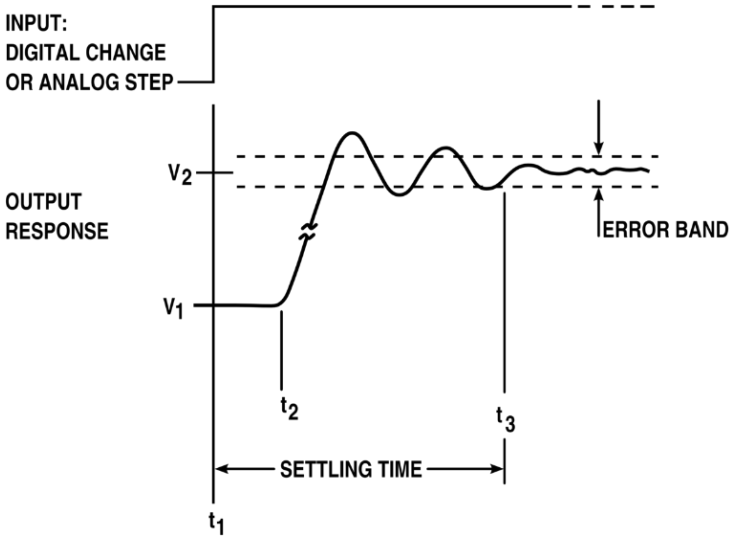
Hardware Realization of Feedback

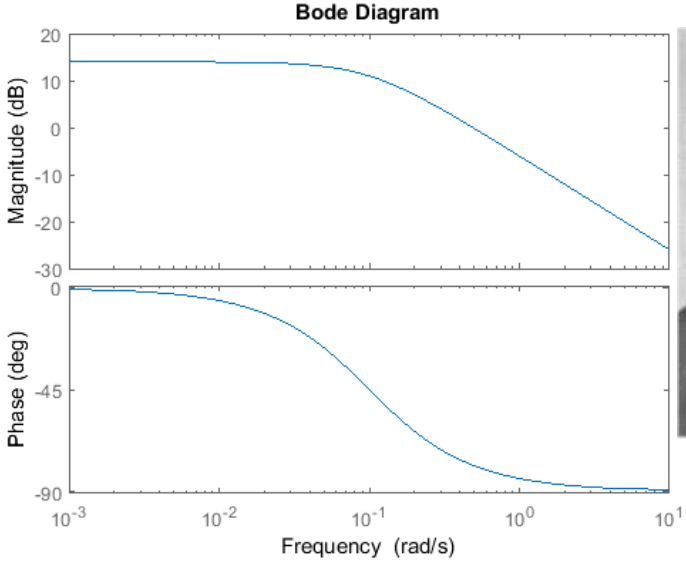


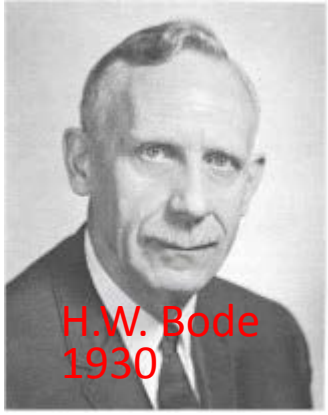
No computing-conditioned transformation !

Experiment-Based Analysis of Control Systems

Motivated by physics



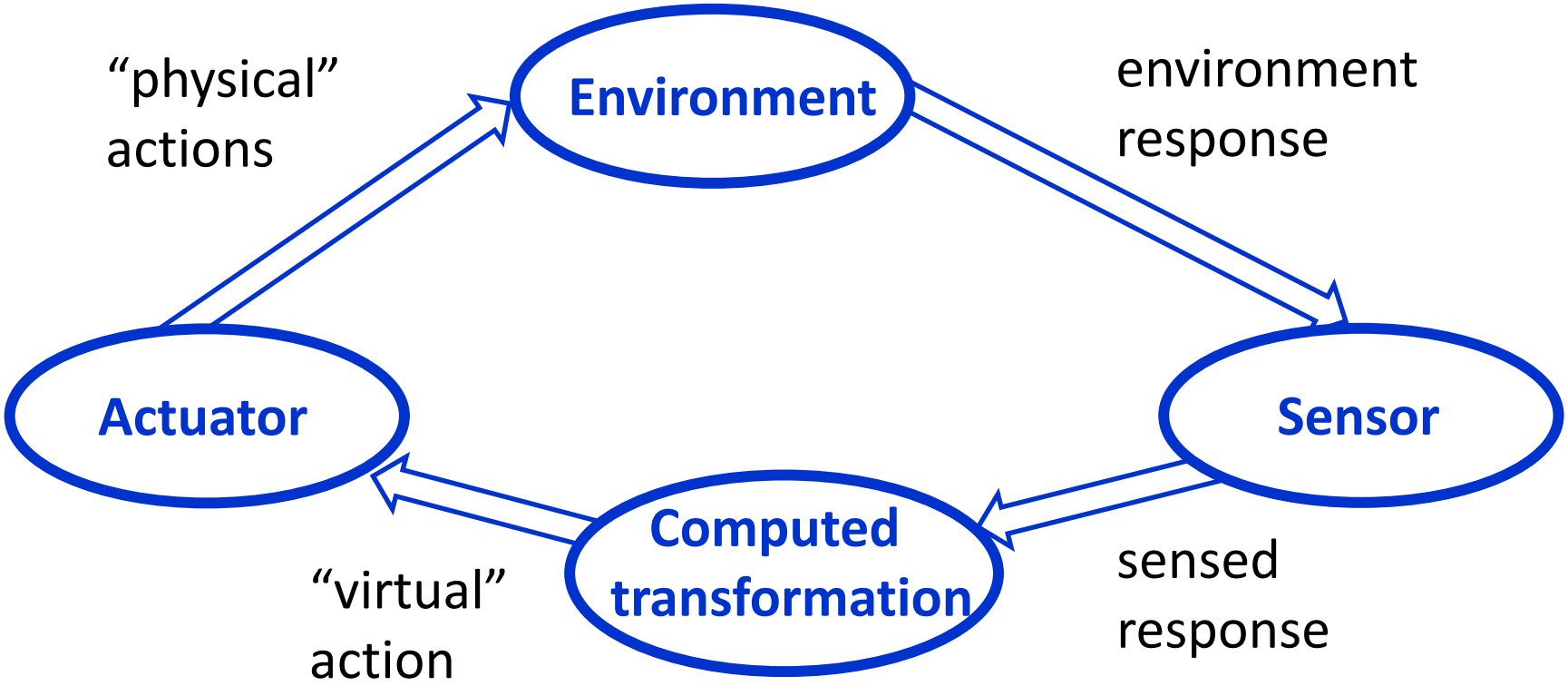




Analysis serves to *prediction of the work* of subparts' *interconnections as* closed-loop *stability by Nyquist plot*

A nice example of usefulness of analysis in complex domain

Realization of Feedback with *Computing*



Systematically Made by *Deterministic* Control Theory

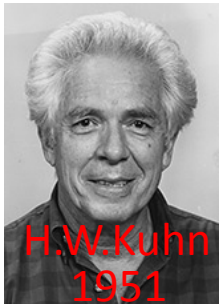
Analysis

† Operators modelling a state evolution as an action function

† State-space realization, stability, reachability, controllability, chaos …

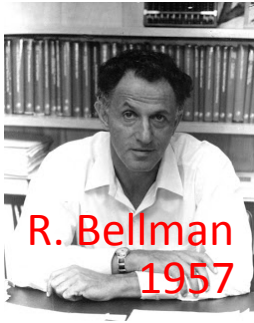
Design treated as optimization via

† non-linear programming … KKT conditions



† maximum principle …
Hamilton- Jacobi eqn.

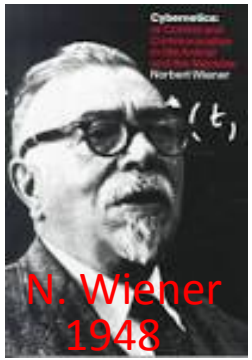
† dynamic programming



– Quite complex knowledge demanding

– No explicit model of uncertainties: robustness too pessimistic

Cybernetics as science how to steer, navigate or govern



N. Wiener 1948

Abstract unified view on control *and* communication in

- ✓ the animal and the machine
- ✓ society and its substructures

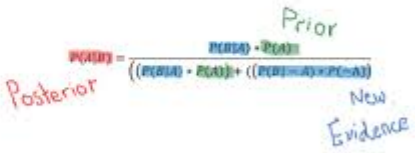
† "*Agents*" everywhere

† *Feedback* and *system*-theory view

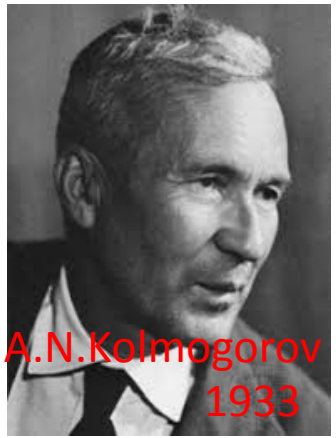
† Incorporation of *uncertainties* into control problem ⇒ stochastic control, *dynamic decision making* under *uncertainty*

- Computational complexity aspects insufficiently covered
- Forbidden in the East block is now believed to origin there

Models of Uncertainties



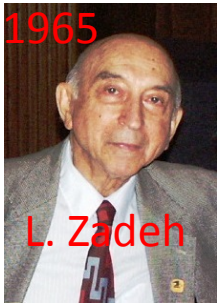
Modify prior *belief* into **A** (God exists) by a perceivable evidence **B** (a miracle appeared) into posterior belief !



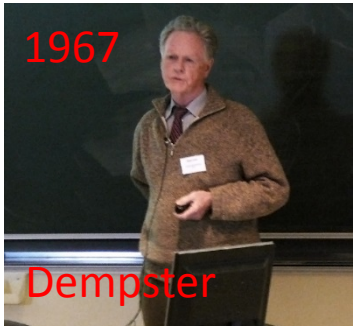
Probability is non-negative σ additive *measure* on Boolean σ algebra of subsets of a set having measure 1

- Extremely rich
- Bayes rule a trivial theorem
- Interpretation via computational complexity
- Subcase of quantum probability on non-Boolean events

Some Competing Uncertainty Models



- **Fuzzy logic** replaces set indicator by membership degree $\in$ [0,1] combined via the product *t*-norm, which replaces truth tables of classical logic



- **Dempster–Shafer theory** handles imprecise probabilities
- **Interval-valued** description of uncertainties
- **Information-gap, Rough sets** …

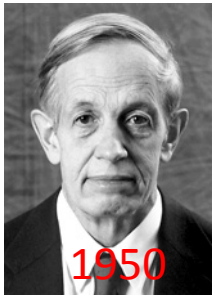
None of attempts led to DM unreducible to that based on probability

Game Theory

Agents' interaction: competitive, cooperative, forming coalition

Origins: observable in Talmud or in Darwin's work

Core: specification & analysis of equilibria



V. Pareto's Improvement for one deteriorates other's

J. F. Nash's No agent can do better unilaterally

Modern mathematical version origins in 2nd World War, 1994, Neumann, Morgenstern, Theory of Games & Economic Behavior

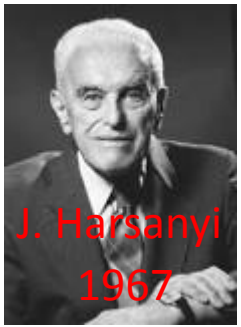
Game Theory is

† Interesting still developing mathematical domain
† Strong for analysis of interactions and equilibria
† Clarifying differences caused by information sharing scenarios
– Complex in a vast majority of real-life problems
– Poorly supporting design of agents' acting

Development in this respects led to:

- Bayesian agents model other agent as environment
- K-level games deal with obsolete model of co-agent

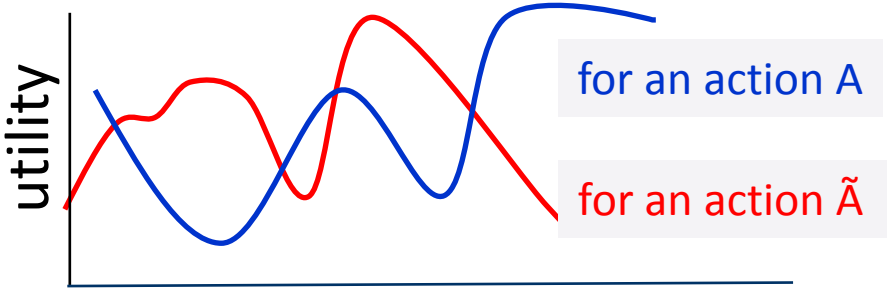
… and became a rich subversion of expected utility theory


J. Harsanyi 1967

Expected Utility Theory

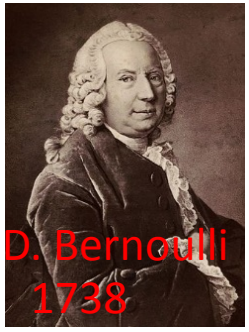
How to act if uncertainty

makes actions' utility incomparable?



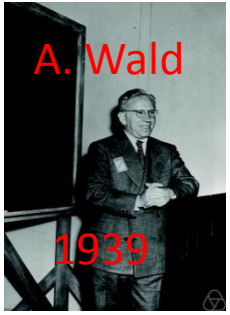
uncertain factors:
unknown, fuzzy, random …

- Assign beliefs to uncertain factors
- Maximize expected utility


D. Bernoulli
1738

expected profit optimization unreasonable

utility ≠ profit: think of 1M$ for you and B. Gates

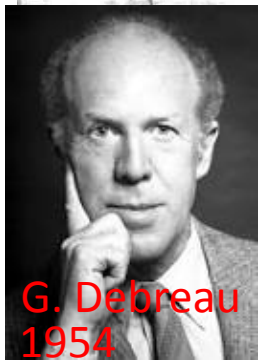

A. Wald
1939

maximization over decision functions: knowledge → action

Expected Utility Theory


L.J. Savage
1954

Appealing axioms interpret probabilities in expected utility as subjective beliefs

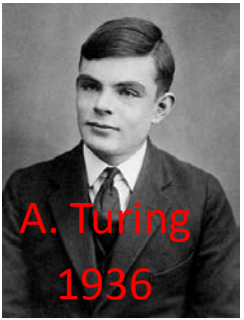

G. Debreau
1954

Utility numerically represents a preference ordering ◄
It exists iff topology ◄ intervals not richer than of < intervals

† Axiomatic, unifying, appealing
† Deductive, adaptive & explorative union of DM & learning

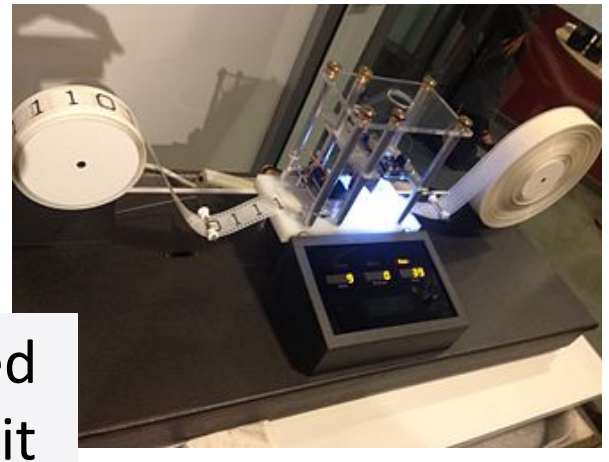
- A closed world of uncertainties: no zooming & extensions as people
- Lack of universal deductive rules how to create/learn utilities
- Computation aspects neglected

Turing machines
Computing theories relevant to DM



Church-Turing hypothesis:

Anything what can be computed using a finite amount rules is equivalent to



† Majority of contemporary computation is based on von Neumann architecture stemming from it

† It forms basis of computational complexity theory ⇒ complexity based probability theory

– Direct & Gödel results depressingly limit extent of computable tasks

Artificial Intelligence

Ambition to get rid of human completely (as science1956)

It still bears influence of its fathers' domains

A. Newell information language processing

H. Simon economy

J. McCarthy computer sciences

M. Minsky Cognitive science

2005

M. Hutter

⇒ bag of subdomains and tricks gradually moving to UAI, close to dynamic DM under uncertainty with computer sciences

Success?

No Human is Back Even More

- **Complexity enforces** parallel processing and task division similar to human brain and mankind

⇒ unsolved DM tasks with multiple agents having different knowledge, language, abilities, resources, beliefs and aims

⇒ cooperation, competition, knowledge and resources sharing

- **Even one agent** has many aims (profit, pleasure)

& DM tasks: a fraction is optimally addressed

- **A human is and will be always present, at least in the methodology choice …**

1982
D. Kahneman

Omitted?
Almost everything!

- Topics covered by 01DRO1
- Military aspects
- Contemporary state of the mentioned theories
- Adaptive systems
- …
- **A range of contributors, especially, women**

K.J. Astrom

Take Home Message

- Dynamic DM under uncertainty is the fascinating domain needing the **best brains** at all levels

✓ conceptual

✓ theoretical

✓ algorithmic

✓ advanced real-life applications

- A deeper understanding of **principles of dynamic DM** guarantees you will be **always employable** in the changing labor market

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