Pattern Recognition with Hidden Markov Modells

Dynamic Programming at its Best

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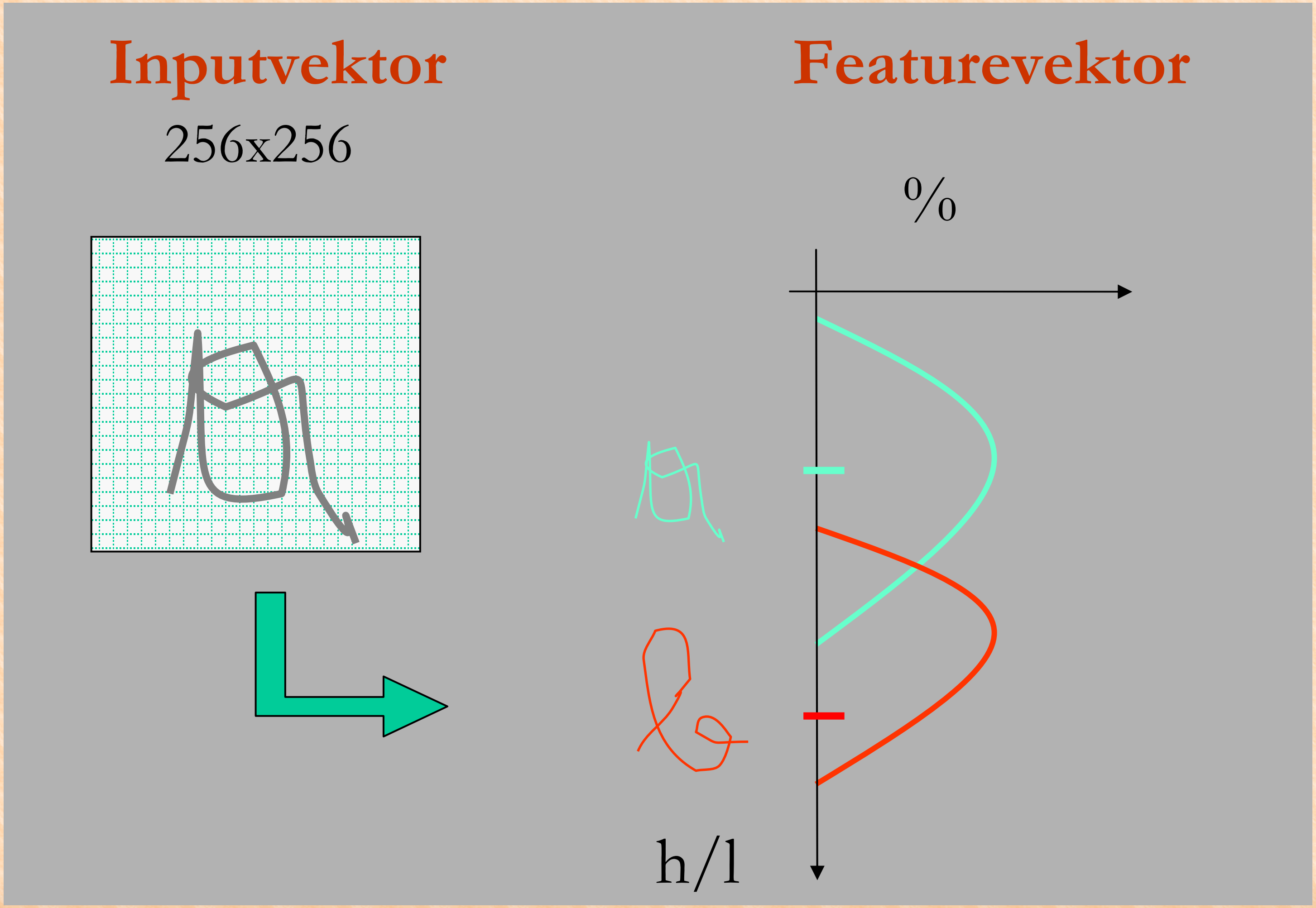
Stochastic Pattern Recognition

- Sir Isaiah Berlin: „To understand is to perceive patterns"

- Patterns: recognizeable, obvious entities
- Input: raw data (image, signal,time series)
- Features: unique characteristics of patterns
- Model: assumptions on relationship btw. patterns & features

- Important: find set of features which
  - reduces amount/dimension of input data
  - still contains all information necessary to distinghuish patterns

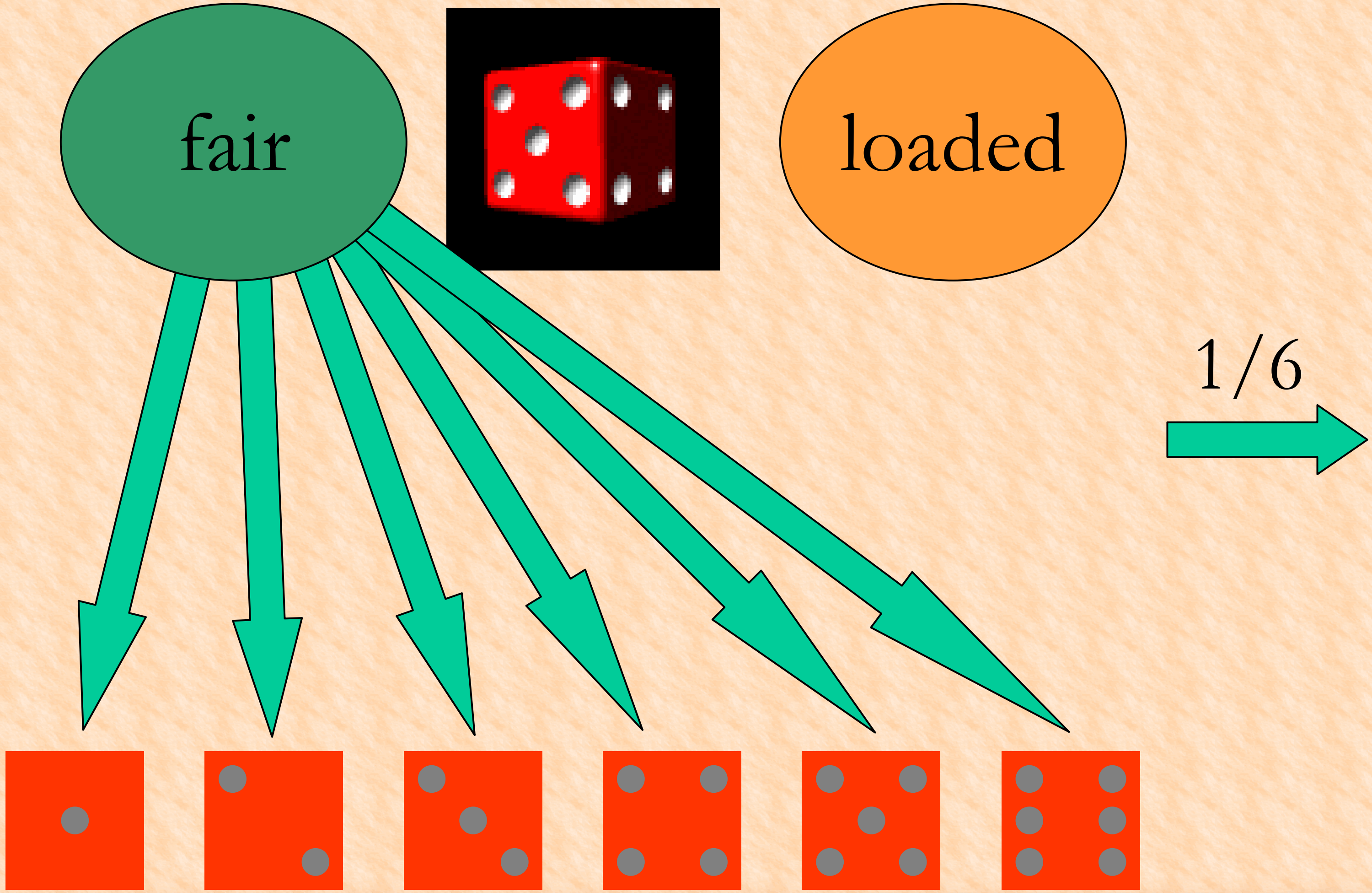
Example



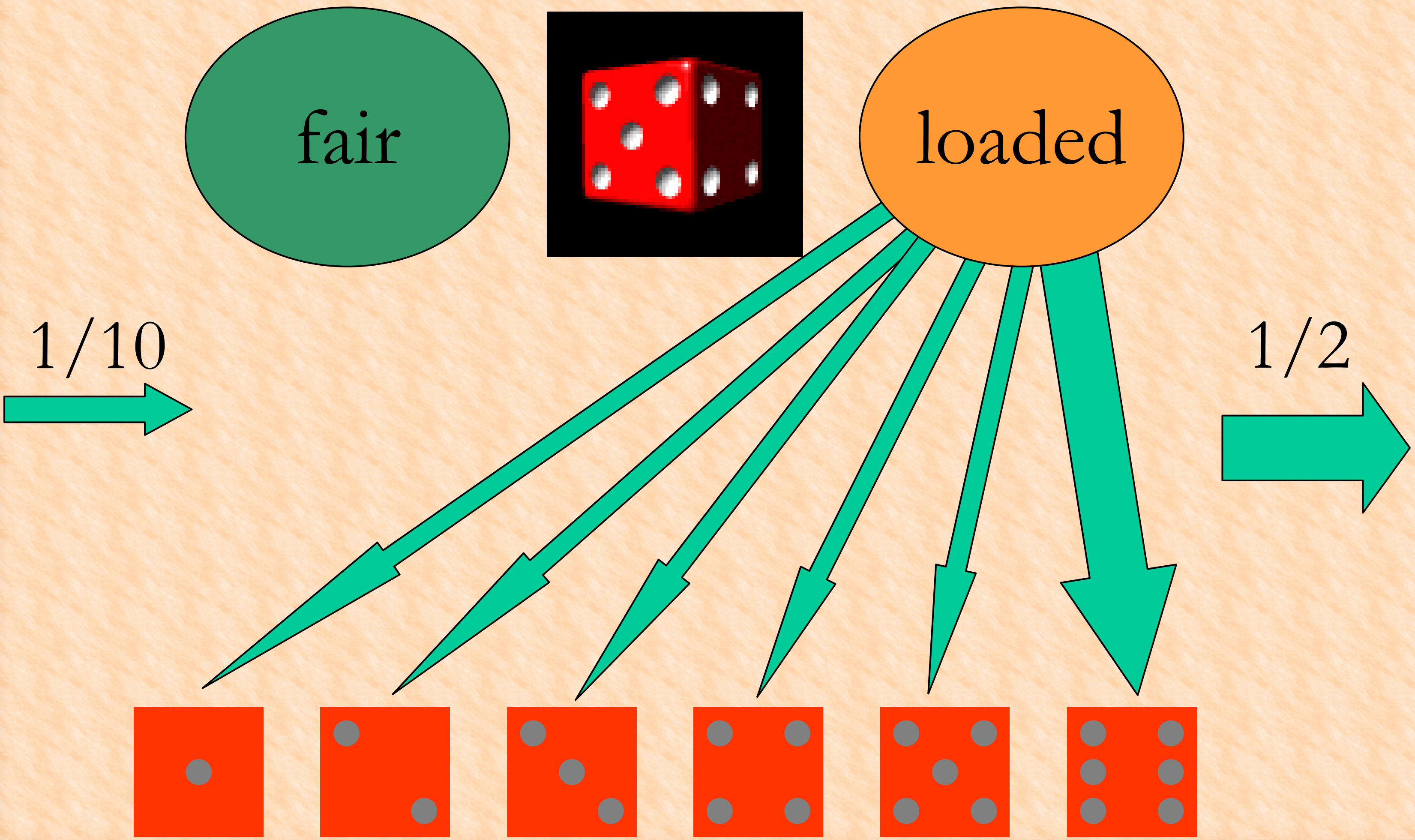
Stochastic Pattern Recognition

- HMMs: stochastic models for temporal/serial data
- i.e.:
  - model gives P[pattern | features]
  - features: series of natural numbers
- Applications
  - speech recognition
  - bioinformatics (gene hunting)
  - fault detection in machinery
  - DOS watchdogs
  - medical signal processing

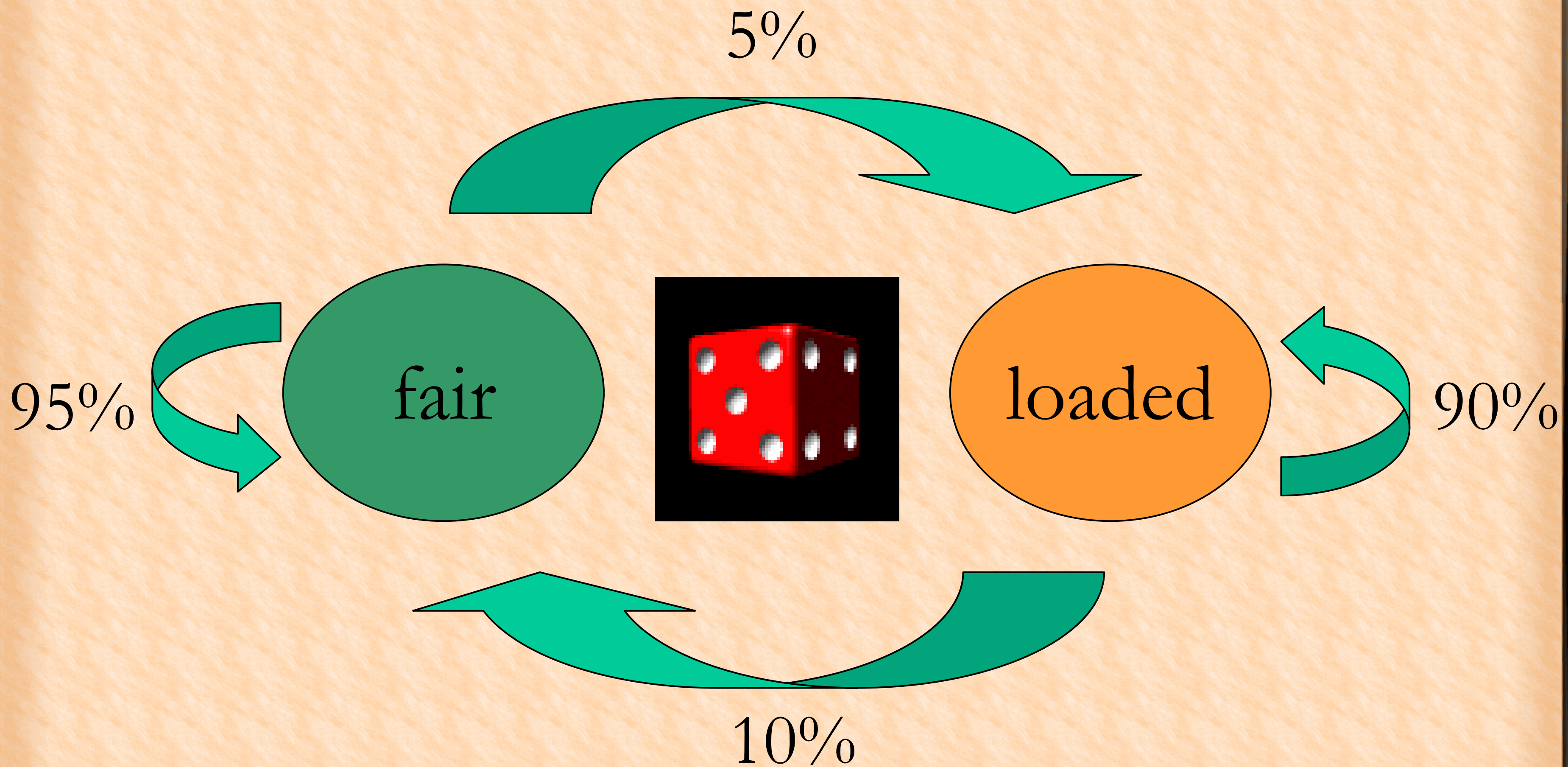
Example: The occasionally disshonest casino



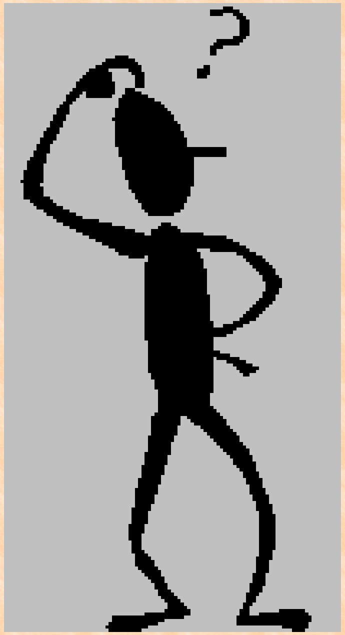
Example: The occasionally disshonest casino



Example: The occasionally disshonest casino



Pattern Recognition Problem



- given a list of dice rolls (outcomes)
- decide:
  - when was fair dice used
  - when loaded one
- “decoding” problem

let the dice roll ... (300 times)

4324504012120222054501120034242505343351314205211322104225234111423113415141013015520535150554555553
0000000000000000000000000000000011100000000000000000000000000000000000000000000111111111111111111110
0000000000000000000000000000000000000000000000000000000000000000000000000000000001111111111111111110

1202320120103250151340555141051540355323340251155344141234043341404413211004155502251501452053550552
0000000000000100000001111000011111111110000000110000000000000000000000000000011111111111100111111111
0000000000000000000000000000000000000000000000000000000000000000000000000000011111111111111111111111

3535545552250152525003250153332114013155253235135345555205543520240543554153050530004402241145455055
1111111110111111110000000000000000000000111111111111111111000000001111111110000000000000000000111111
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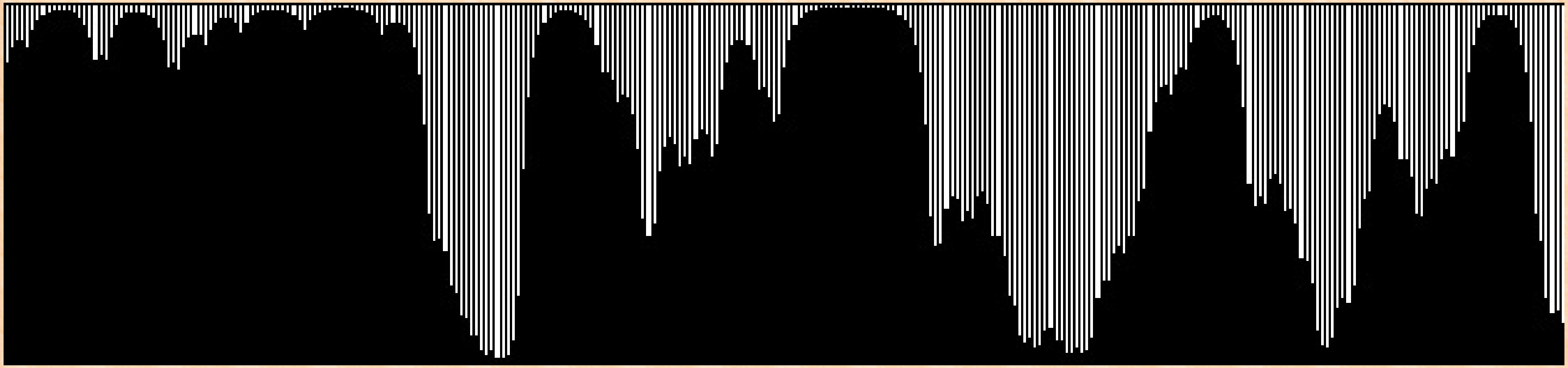
Stochastic Model Generates Probabilities

- solid bars: probability of fair dice
- white rectangles: probability of loaded dice
- decision rule: pattern with highest probability is „recognized“



A little bit of history...

Andrei Andreyevich Markov

Born: 14 June 1856
Ryazan, Russia

Died: 20 July 1922
Petrograd, Russia

A little bit of history...

Markov is particularly remembered for his study of Markov chains, sequences of random variables in which the future variable is determined by the present variable but is independent of the way in which the present state arose from its predecessors.

Example: upper part of our model: coin choosing

A little bit of history...

Markov is particularly remembere[...] Markov
chains, sequences of random va[...]
variable is determined by the p[...]endent
of the way in which the prese[...]
predecessors.

easy: independent coin flips (multiply probs.)

hard: arbitrary dependence between events (common distribution)

compromise: future depends on present but not on past

Example: upper part of our model: coin choosing

A little bit of history...

Thomas Bayes

Born: 1702
London, England

Died: 17 April 1761,
Kent, England

A little bit of history...

Bayes set out his theory of probability in *Essay towards solving a problem in the doctrine of chances* in 1764.

Bayes's conclusions were accepted by Laplace in a 1781 memoir, rediscovered by Condorcet, and remained unchallenged until Boole questioned them in the *Laws of Thought*.

Since then Bayes' techniques have been subject to controversy.

HMMs are Markov Chains

- States cannot be observed directly
- Instead: at each instance a dice (selection depends on state) is rolled, only the outcome thereof can be observed
- State is „hidden“: hidden markov model
- Mathematically: subclass of markov models, nothing new...

HMMs are Markov Chains

- 1966-77: Baum et. al.: basic theory
- 1975ff: speech recognition using HMMs
- 1985ff: good tutorials (L. R. Rabiner, …)
  application to other areas, esp. Bioinformatics
- why HMMs?
  - rich math. structure => wide of range applications
  - „work well in practice“ (Rabiner, 1988)

The 3 classical problems

- Evaluation Problem:
  - Given observation, compute probability under given HMM
  - Used in Bioinformatics: model selection
  - forward algorithm
- Decoding Problem:
  - Given observation, compute most probable path in given HMM
  - Used in Speech Recognition: find series of phonems
  - Viterby algorithm, forward-backward algorithm
- Training Problem:
  - Given a lot of observations, find suitable HMM
  - EM Algorithm, ...

Forward Algorithm

- Problem: complexity of computation: $O(\#S^n)$

$$P[B] = \sum_{\substack{\text{all paths } A \\ \text{of length } n}} P[B \cap A]$$

- Forward Algorithm solves this in $O(n \, \#S^2)$
- exploits Markov property

Viterby & Forward-Backward Algorithm

- 2 conditions for optimality:

$$A^* = \underset{A \text{ path of length } n}{\operatorname{argmax}} P[B \cap A] \quad \text{Viterby}$$

$$A_i^* = \underset{a \in S}{\operatorname{argmax}} P[a_i = a \mid B] \quad \text{F.B.}$$

Remarks

- Viterby
  - also linear in observation length n
  - backtracking
  - global optimal solution
- Forward Backward
  - also linear in observation length n
  - no backtracking needed
  - local optimal solutions, resulting path has smaller prob. than Viterby

Bioinformatics revisited

- PFAM collection of proteins online:
  - http://pfam.wustl.edu/cgi-bin/getdesc?name=Globin
  - http://www.rcsb.org/pdb/
  - http://pfam.wustl.edu/hmmsearch.shtml

- try it out:
  - >1BZZ:A HEMOGLOBIN ALPHA CHAIN

    MLSPADKTNVKAAWGKVGAHAGEYGAEALERMFLSFPTTKTYFPHFDLSHGSAQVKGHGK
    KVADALTNAVAHVDDMPNALSALSDLHAHKLRVDPVNFKLLSHCLLVTLAAHLPAEFTPA
    VHASLDKFLASVSTVLTSKYR

Links & References

- Tutorial: Rabiner (pdf on www)
- further links...: www.stefan.wegenkittl.com

Danke für die Einladung!