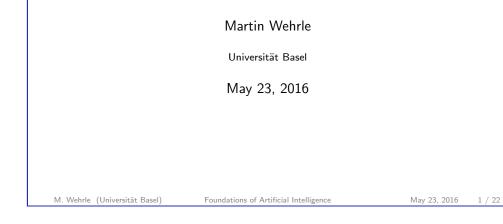
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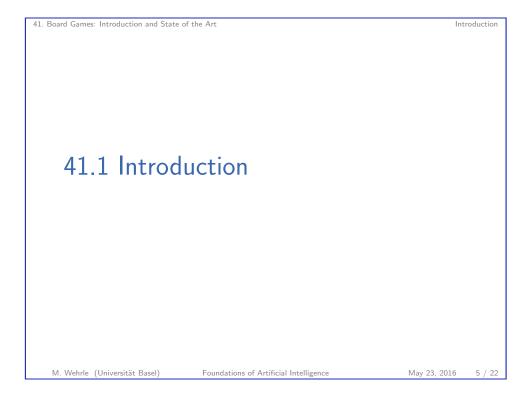




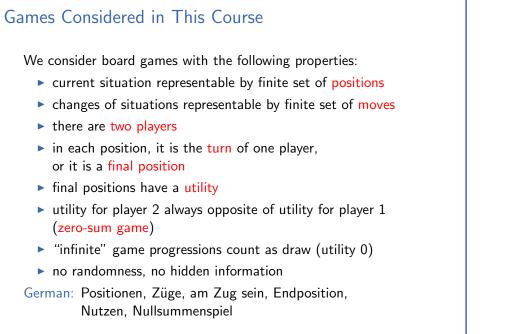
Foundations of Art May 23, 2016 — 41. Board (	ificial Intelligence Games: Introduction and State of the	Art	
41.1 Introduction	n		
41.2 State of the	e Art		
41.3 Summary			
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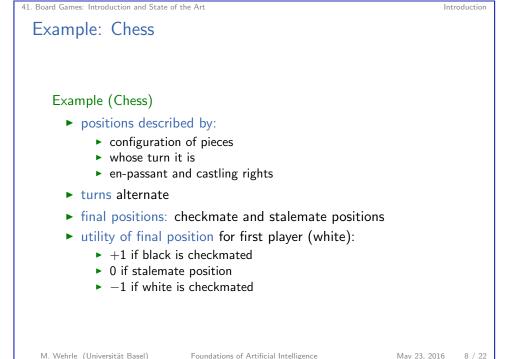


41. Board Games: Introduction and State of the Art



Board games are or	ne of the oldest areas of Al	
(Shannon 1950; Tu		
abstract class	of problems, easy to formalize	
obviously "inte	elligence" is needed (really?)	
	telligent machine capable of pl lectronic computers	aying chess
	elen's "Schachtürke" (1769), edo's "El Ajedrecista" (1912)	
German: Brettspiel	e	
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41. Board Games: Introduction and State of the Art



Introduction

6 / 22

## Other Game Classes

important classes of games that we do not consider:

- with randomness (e.g., backgammon)
- ▶ with more than two players (e.g., chinese checkers)
- with hidden information (e.g., bridge)
- with simultaneous moves (e.g., rock-paper-scissors)
- ▶ without zero-sum property ("games" from game theory → auctions, elections, economic markets, politics, ...)
- ...and many further generalizations

Many of these can be handled with similar/generalized algorithms.

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## Formalization

Board games are given as state spaces  $S = \langle S, A, cost, T, s_0, S_{\star} \rangle$  with two extensions:

- ▶ player function *player* : S \ S<sub>\*</sub> → {1,2} indicates whose turn it is
- utility function  $u: S_{\star} \to \mathbb{R}$  indicates utility of final position for player 1

### other differences:

action costs cost not needed

We do not go into more detail here as we have previously seen sufficiently many similar definitions.

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# Terminology Compared to State-Space Search

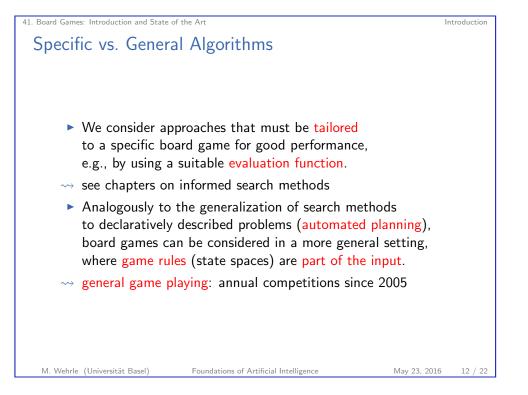
Many concepts for board games are similar to state-space search. Terminology differs, but is often in close correspondence:

- ▶ state ~→ position
- ► goal state ~→ final position
- $\blacktriangleright$  action  $\rightsquigarrow$  move
- ► search tree ~→ game tree

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May 23, 2016 10 / 22



May 23, 2016

9 / 22

Introduction

Introduction



# Why are Board Games Difficult?

As in classical search problems, the number of positions of (interesting) board games is huge:

- Chess: roughly 10<sup>40</sup> reachable positions; game with 50 moves/player and branching factor 35: tree size roughly 35<sup>100</sup> ≈ 10<sup>154</sup>
- Go: more than  $10^{100}$  positions; game with roughly 300 moves and branching factor 200: tree size roughly  $200^{300} \approx 10^{690}$

In addition, it is not sufficient to find a solution path:

- ▶ We need a strategy reacting to all possible opponent moves.
- Usually, such a strategy is implemented as an algorithm that provides the next move on the fly (i.e., not precomputed).

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Foundations of Artificial Intelligence May 23, 2016

41.2 State of the Art

# Algorithms for Board Games

properties of good algorithms for board games:

- look ahead as far as possible (deep search)
- consider only interesting parts of the game tree (selective search, analogously to heuristic search algorithms)
- evaluate current position as accurately as possible (evaluation functions, analogously to heuristics)

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May 23, 2016 14 / 22

State of the Art

Introductio



some well-known board games:

- ► Chess, Go: ~ next slides
- Othello: Logistello defeated human world champion in 1997; best computer players significantly stronger than best humans
- Checkers: Chinook official world champion (since 1994); proved in 2007 that it cannot be defeated and perfect game play results in a draw (game "solved")
  German: Schach, Go, Othello/Reversi, Dame

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Introduction

13 / 22

State of the Art

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#### 41. Board Games: Introduction and State of the Art

#### State of the Art

17 / 22

State of the Art

## **Computer Chess**

World champion Garri Kasparov was defeated by Deep Blue in 1997 (6 matches, result 3.5–2.5).

- specialized chess hardware (30 cores with 16 chips each)
- ▶ alpha-beta search (~→ Chapter 43) with extensions
- database of opening moves from millions of chess games

Nowadays, chess programs on standard PCs are stronger than human world champions.

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Computer Chess: Another Quote John McCarthy (1997) In 1965, the Russian mathematician Alexander Kronrod said, "Chess is the Drosophila of artificial intelligence." However, computer chess has developed much as genetics might have if the geneticists had concentrated their efforts starting in 1910 on breeding racing Drosophilae. We would have some science, but mainly we would have very fast fruit flies. 41. Board Games: Introduction and State of the Art

## Computer Chess: Quotes

### Claude Shannon (1949)

The chess machine is an ideal one to start with, since

- the problem is sharply defined both in allowed operations (the moves) and in the ultimate goal (checkmate),
- it is neither so simple as to be trivial nor too difficult for satisfactory solution,
- chess is generally considered to require "thinking" for skillful play, [...]
- the discrete structure of chess fits well into the digital nature of modern computers.

## Alexander Kronrod (1965)

Chess is the drosophila of Artificial Intelligence.

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May 23, 2016 18 / 22

State of the Art

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State of the Art

# Computer Go

## Computer Go

- ▶ The best Go programs use Monte-Carlo techniques (UCT).
- Until recently (autumn 2015), Zen, Mogo, Crazystone played on the level of strong amateurs (1 kyu/1 dan).
- Until then, Go has been considered as one of the "last" games that are too complex for computers.
- In October 2015, Google's AlphaGo defeated the European Champion Fan Hui (2p dan) with 5:0.
- In March 2016, AlphaGo defeated world-class player Lee Sedol (9p dan) with 4:1. The prize for the winner was 1 million US dollars.
- → We will discuss AlphaGo and its underlying techniques in more detail later in the course.

