

# Theory of Computer Games

## 電腦對局理論

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# Goal

- Course name: Theory of Computer Games

## 電腦對局理論

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- 十三週年!!!
- Prerequisite: Computer Programming, **Linux/Unix**, C/C++, and Data Structure and Algorithms.
  - **Enjoy playing classical board games!**
  - **Heavy programming projects!**
- Goal: This course introduces techniques for computers to play various games which include Chinese chess and Go.
- Disclaimers:
  - **NOT** yet a course on game theory.
  - **NOT** yet a course on video games.
  - **NOT** yet a course on war game simulations.
- Web page:  
<http://www.iis.sinica.edu.tw/~tshsu/tcg/2019>

# About this course

- **Time and Place:** Every Thursday from 2:20pm to 5:20pm at Room 105 (NTU CSIE building).

	Sep		12	19	26	
	Oct	3	10	17	24	31
■ <b>Dates:</b>	Nov		7	14	21	28
	Dec	5	12	19	26	
	Jan	2		16		

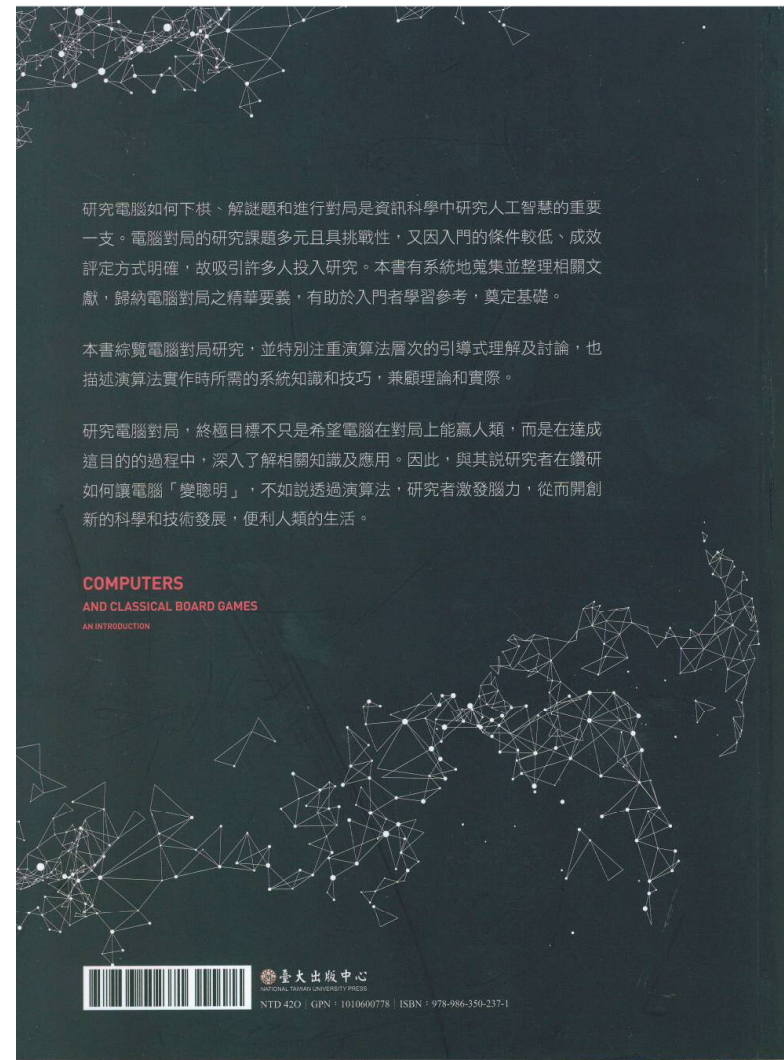
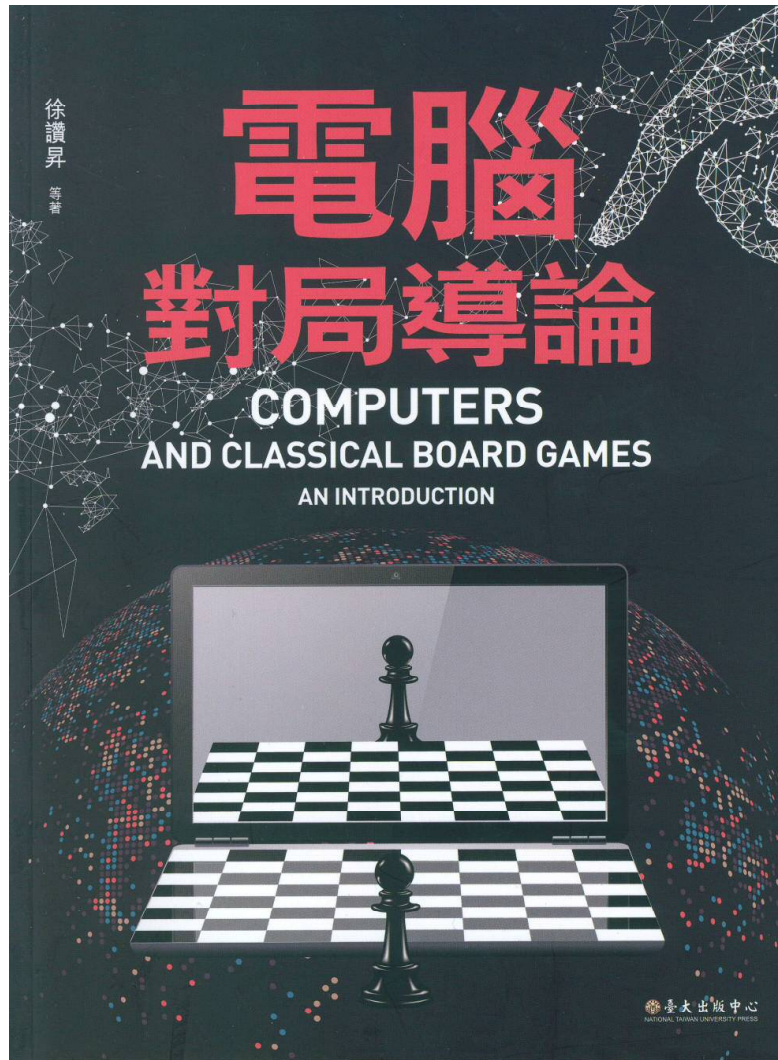
- **Format:**

- Lectures.
- Presentations for homework projects (optional).
- Invited lectures: TBA.

- **Class materials**

- textbook: 電腦對局導論, 臺大出版中心, June 2017 ; ISBN: 978-986-350-237-1
- Class notes
- Collection of papers

# Textbook



勘誤表: <http://www.iis.sinica.edu.tw/~tshsu/tcg/errata20190906.pdf>

# 電腦對局導論

Computers and classical board games: An Introduction

2017年6月一版

勘誤表

July 16, 2019

頁碼/位置	內容	
	修改前	修改後
p.I 序一的第二段	預官退伍之後，讚昇出國到美國德州奧斯汀大學深造，專攻演算法研究。	預官退伍之後，讚昇出國到美國德州大學奧斯汀校區深造，專攻演算法研究。
p.I 序一的第三段	2005年8月，讚昇與我共同主辦第十屆國際電腦奧林匹亞大賽和CG2005電腦對局國際會議，開啓ICGA國際電腦對局學會在亞洲地區舉辦活動的新頁。	2005年8月，讚昇與我共同主辦第十屆國際電腦奧林匹亞大賽和CG2005電腦對局國際會議，開啓ICGA國際電腦對局學會在亞洲地區舉辦活動的新頁。
圖目錄之 2.4	混合雙佇列實作佇列之示意	混合雙佇列實作佇列之示意圖
圖目錄之 4.4	六貫棋性質證明：連接黑方棋子	六貫棋性質證明：連接各行中的黑方棋子
圖目錄之 5.7	位在中央的騎士	騎士的影響
圖目錄之 5.14	栓鏈的範例	栓鏈
圖目錄之 5.19	欠行局例	欠行
圖目錄之 7.4	斥候演算法搜尋的節點數比 Alpha-Beta 切捨演算法拜訪的節點數多的例子	斥候搜尋時 TEST 拜訪的節點數比 Alpha-Beta 切捨多的例子
圖目錄之 7.8	斥候演算法拜訪最少的節點數的例子	斥候演算法拜訪最少節點數的例子
演算法目錄之15	15 $F'(position\ p)$	15 $F'(position\ p, integer\ depth)$
演算法目錄之16	16 $G'(position\ p)$	16 $G'(position\ p, integer\ depth)$
演算法目錄之17	17 $F(position\ p)$	17 $F(position\ p, integer\ depth)$
演算法目錄之18	18 $F_2'(position\ p, value\ alpha, value\ beta)$	18 $F_1'(position\ p, value\ alpha, value\ beta)$
演算法目錄之19	19 $G_2'(position\ p, value\ alpha, value\ beta)$	19 $G_1'(position\ p, value\ alpha, value\ beta)$
演算法目錄之20	20 $F_2(position\ p, value\ alpha, value\ beta)$	20 $F_2(position\ p, value\ alpha, value\ beta, integer\ depth)$
演算法目錄之21	21 $F_2(position\ p, value\ alpha, value\ beta)$	21 $F_2(position\ p, value\ alpha, value\ beta, integer\ depth)$
演算法目錄之29	29 IDAS(position $p$ , integer $limit$ , integer $threshold$ )	29 IDAS(position $p$ , integer $limit$ , <u>value</u> $threshold$ )
演算法目錄之30	30 IDAS'(position $p$ , integer $limit$ , integer $threshold$ )	30 IDAS'(position $p$ , integer $limit$ , <u>value</u> $threshold$ )
演算法目錄之36	36 F4.4 (position $p$ , value $alpha$ , value $beta$ , integer $depth$ , Boolean <u>do_null</u> )	36 F4.4' (position $p$ , value $alpha$ , value $beta$ , integer $depth$ , Boolean <u>in_null</u> )
演算法目錄之37	37 F4.5' (position $p$ , value $alpha$ , value $beta$ , integer $depth$ , Boolean <u>do_lmr</u> )	37 F4.5' (position $p$ , value $alpha$ , value $beta$ , integer $depth$ , Boolean <u>in_lmr</u> )
演算法目錄之45	45 MCTS	45 MCTS

# Acknowledgements

- Thanks to the students of this course for providing constructive feedbacks on the slides.
  - Classes of 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018.
- Special thanks to the following persons.
  - Yuh-Jie Chen (class of 2008)
  - Jenny Chang (class of 2011)
  - Jessica Lin (class of 2011)
  - 許祐程 (TA of the 2012 class)

# Evaluation (1/3)

- **Homework (30%)**
  - **One homework project about single-agent search (15%)**
    - ▷ *About single agent search, single-person project, Linux/Unix knowledge is **required**.*
    - ▷ *Implement different techniques learned from the class and compare the results.*
  - **One homework project about Monte-Carlo simulation (15%)**
    - ▷ *A 2-player game with a strong Monte Carlo flavor, single-person project, Linux/Unix knowledge is **required**.*
    - ▷ *Your program against TA's program, and against all other students.*
- **Written exam: midterm exam (30%)**

# Evaluation (2/3)

- **Final project (40%)**
  - An alpha-beta based computer game program for Chinese Dark Chess.
    - ▷ *A sample code with GUI will be provided.*
    - ▷ *The usage of this sample code is restricted for anything related to this course only.*
  - The 13th NTU-TCG Cup.
  - A whole day tournament, attendance is **required!!**
  - Submitted package: Code + documents.
- **Class participation (bonus)**



# Evaluation (3/3)

- **Presentation/Report of a research paper on game tree search.**
  - **If we have more than 16 students, then**
    - ▷ *Bonus for selected students who are obviously falling behind.*
  - If we have less than 17 students, then**
    - ▷ *This is required for each student.*
    - ▷ *This will be 10% of your score in which case the two programming homework each take 10%.*
  - **If time allows, give an in-class presentation.**
    - ▷ *Discussion before presentation.*
    - ▷ *30-minute talk.*
    - ▷ *≤ 30 slides in PDF format.*
    - ▷ *10–15 minutes of Q & A.*
    - ▷ *Each student asks  $\geq 1$  non-trivial question.*
    - ▷ *Submit your revised set of slides one week later.*
  - **If time does not allow, submit a written report.**
    - ▷ *Pick a paper related to the course.*
    - ▷ *Write a report with at least 1000 words in PDF format.*
    - ▷ *Summary of results in the paper.*
    - ▷ *Comments about this paper, its strength, weakness and potential improvements.*

# Lecturing format

- **For each topic**
  - **The first and most influential papers are introduced.**
  - **A list of recent and latest papers is provided for further readings and/or topics for presentations.**

# Course at a glance (1/2)

- Introduction: an A.I. oriented overview
- Single-player games
  - Basic techniques
  - Advanced techniques
- **Homework 1: October**
- Two-player perfect information games
  - Survey
  - Introduction from Chess's point of view
  - Alpha-beta and its extensions
- **Midterm exam: November**

# Course at a glance (2/2)

- Two-player perfect information games
  - Monte-Carlo based method
- **Homework 2: December**
- **Practical considerations**
  - Memorizing knowledge
    - ▷ *Transposition tables*
    - ▷ *Endgame databases*
  - Advanced pruning techniques
  - Parallelization (?)
  - The graph-history interaction (GHI) problem
  - Opponent model (?)
  - Timing control
  - Hardware enhancements (?)
- **Conclusion**
- **Final project: January**

# Introduction and an A.I. oriented overview

- **Relations between computer games and Artificial Intelligence.**
  - Why we study computer games?
  - Why we play or study games?
- **History [SvdH02] [Sha50a]**
  - The Turk, a chess playing “machine” at 1780’s [LN82]
  - The endgame playing machine at 1910’s [McC04]
  - C. E. Shannon (1950) [Sha50b] and A. Samuel (1960) [Sam60]
- **Games that machines have beaten human champions [SvdH02] [Sch00]**
  - Chess [CHH02]
  - Othello [Bur97]
  - Checker [SLLB96]
  - Go [SHM<sup>+</sup>16]
  - ...

# Single-player games

- **Games that can be played by one person [DH09]**
  - combinatorial games such as 15-puzzle or Sudoku
  - other solitaire
- **Classical approaches [Kor85] [KF02] [CS98]**
  - Brute-force, BFS, DFS and its variations including DFID
  - Bi-directional search
  - A\*
  - IDA\*
  - IDA\* with databases
- **Disk-based approach [KS05]**

# Two-player perfect information games (1/2)

- A survey of current status [vdHUvR02]
- The original Computer Chess paper by C.E. Shannon [Sha50a] in 1950.
- Classical approaches
  - ▷ *Alpha-beta search and its analysis* [KM75]
  - ▷ *Scout and Negascout* [Pea80] [Rei83] [Fis83]
  - ▷ *MTD( $f$ ): Best-first fixed-depth search* [PSPdB96] [Pea80] if time allowed
- Enhancements to the classical approaches
  - ▷ *Aspiration search*
  - ▷ *Quiescence search* [Bea90]
  - ▷ *Move ordering and other techniques* [Sch89] [AN77] [Hsu91]
  - ▷ *Further pruning techniques* [SP96] including null move pruning and late move reduction
  - ▷ *Proof-number search* [AvdMvdH94] if time allowed

# Two-player perfect information games (2/2)

- **Monte-Carlo game tree search [BPW<sup>+</sup>12]**
  - Original ideas [Bru93]
  - Best first game tree growing
  - UCT
  - Pruning techniques
    - ▷ *Online knowledge [BH04] [YYK<sup>+</sup>06]*
    - ▷ *Offline knowledge [ST09] [HCL10a]*
    - ▷ *Deep learning [SHM<sup>+</sup>16]*
- **Case study:**
  - Computer Chinese chess [YCYH04]
  - Computer Chinese dark chess [CSH10] if time allowed



# Practical considerations (1/2)

- **Transposition tables**
  - Recording prior-search results to avoid researching
  - Design of a good hash function
    - ▷ *Zobrist's hash function [Zob70]*
- **Open-game [Hya99] [Bur99] and endgame databases [Tho86] [Tho96] [WLH06]**
  - Off-line collecting of knowledge
  - Computation done in advance
- **Parallelization**
  - Parallel alpha-beta based game tree search [Bro96] [FMM94] [HM02] [HSN89] [Hya97] [Man01]
  - Parallel Monte-Carlo game tree search [CJ08] [CWvdH08]
- **The graph-history interaction (GHI) problem [Cam85] [BvdHU98] [WHH05]**
  - The value of a position depends on the path leading to it.
    - ▷ *Position value is dynamic and static.*

# Practical considerations (2/2)

- **Opponent model [CM96]**
  - How to take advantage of knowing the playing style of your opponent.
- **Timing and resource usage control [Hya84] [HGN85] [MS93]**
  - Using time wisely
    - ▷ *Use too little time in the opening may be fatal.*
    - ▷ *Use too much time in opening may be fatal, too.*
    - ▷ *Knowledge from real tournament environments [vV09].*
    - ▷ *For Monte-Carlo type of search [HCL10b].*
- **Hardware enhancements [DL04]**

# Other games – if time allowed

- **Games with imperfect information and stochastic behaviors [FBM98]**
  - Backgammon
  - Bridge
- **Multi-player games [Stu06]**
  - Poker
  - Majon

# Concluding remarks

- Search chance nodes
- How to put everything together?
- How to test your implementation?
- How to measure the strength?

# Resources (1/6)

## ■ ICGA web site

- <http://ticc.uvt.nl/icga/>
- Formally as ICCA (International Computer Chess Association)
  - ▷ *Between 1977 and 2001.*
- International Computer Games Association
  - ▷ *Since 2002.*
- Host of Computer Olympiad
  - ▷ *International competition of games played by computers*
  - ▷ *1989 at London, United Kingdom (1st)*
  - ▷ *...*
  - ▷ *2004 at Ramat-Gan, Israel (9th)*
  - ▷ *2005 at Taipei, Taiwan (10th)*
  - ▷ *...*
  - ▷ *2011 at Tilburg, the Netherlands (16th)*
  - ▷ *2013 at Yokohama, Japan (17th)*
  - ▷ *2015–2017 at Leiden, the Netherlands (18–20th)*
  - ▷ *2019 at Macau, China (21th), co-located with IJCAI*

# Resources (2/6)

- **TCGA web site**
  - Taiwan Computer Games Association
  - Since 2011.
  - <http://tcga.ndhu.edu.tw>
  - Annual June conference and tournaments
- **TAAI game tournaments**
  - Taiwan AI Association
    - ▷ <http://www.taai.org.tw/TAAI/>
  - Annual conference since 2001
  - Annual November game tournament since 2009

# Resources (3/6)

## ■ Proceedings of IJCAI

- International Joint Conference on Artificial Intelligence
- Covers all areas of A.I.
- Computer games occupy only a small session now
- Since 1969, odd numbered of years

## ■ Proceedings of AAAI

- Association for the Advancement of A.I.
- Covers all areas of A.I.
- Computer games occupy only a small session now
- Since 1980

# Resources (4/6)

## ■ Proceedings of the ACG conference

- Advances in Computer Games International Conference
- Every (if possible) odd numbered of year

▷ ...

▷ 1999 at Paderborn Germany (9th)

▷ 2003 at Graz, Austria (10th)

▷ 2005 at Taipei, Taiwan (11th)

▷ 2009 at Pamplona, Spain (12th)

▷ 2011 at Tilburg, the Netherlands (13th)

▷ 2015, 2017 at Leiden, the Netherlands (14th, 15th)

▷ 2019 at Macau, China (16th)

## ■ Proceedings of the CG conference

- Computers and Games International Conference
- Since 1998, **almost** even numbered of years

▷ 1998 (1st), 2000, 2002, 2004, 2006, 2008, 2010 (7th), 2013 (8th), 2016 (9th), 2018 (New Taipei City, Taiwan)



# Resources (5/6)

- **Proceedings of IEEE CIG**
  - Computational Intelligence and Games International Conference
  - Since 2005, every year.
  - Video game, classical games, ...
- **Proceedings of the Computer Games Workshop (CGW)**
  - Since 2012, every year.
  - Classical games, 2017 with IJCAI at Melbourne, Sunday August 20th, 2017.

# Resources (6/6)

- **Artificial Intelligence**
  - Flagship journal
  - Since 1970
- **ICGA journal**
  - Quarterly publication since 1977
- **The A.I. magazine**
  - Journal for AAAI
  - Since 1980
- **IEEE Transactions on Computational Intelligence and A.I. in Games**
  - An IEEE journal
  - Quarterly publication since 2009
  - Since, 2017, IEEE Transactions on Games.

# Collection of papers

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