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
- 十六週年!!!
- 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/2022

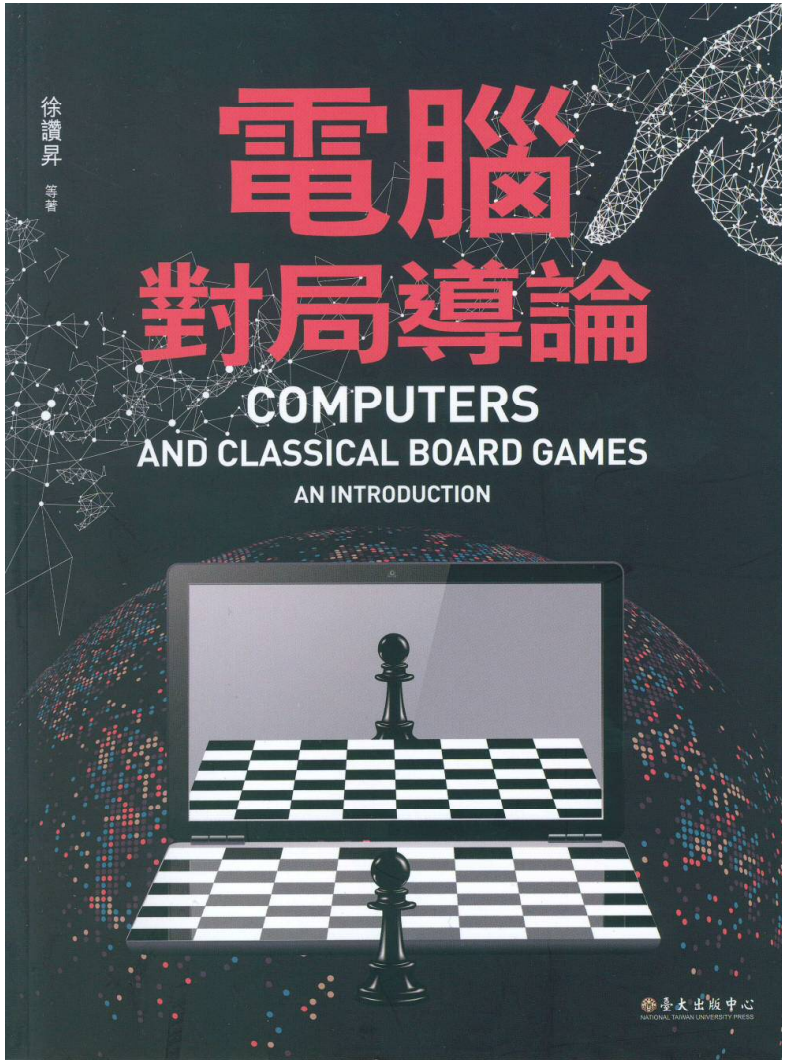
About this course

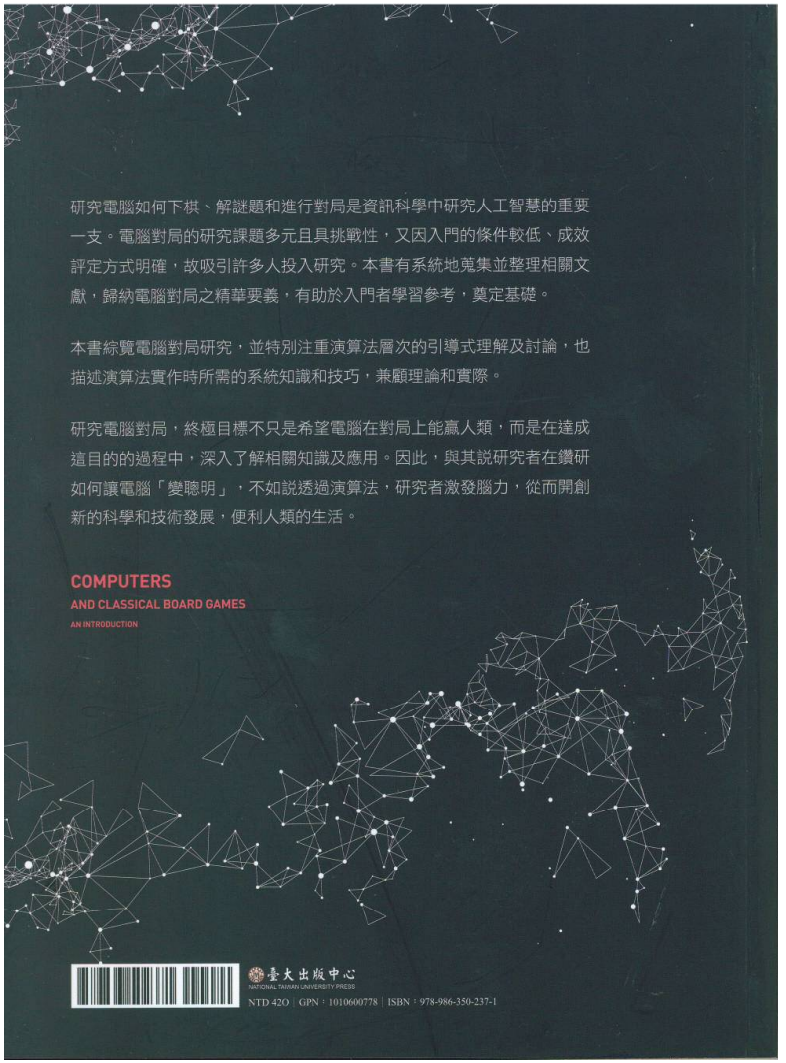
- **Time and Place:** Every Thursday from 2:20pm to 5:20pm at Room 105 (NTU CSIE building), **maybe** on-line due to COVID-19
- **Dates:**

Sep		8	15	22	29
Oct	6	13	20	27	
Nov	3	10	17	24	
Dec	1	8	15	22	29
Jan	5				

- **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; **required!!**
  - Class notes
  - Collection of papers

Textbook





勘誤表: http://www.iis.sinica.edu.tw/~tshsu/tcg/errata20210824.pdf

電腦對局導論

Computers and classical board games: An Introduction

2017年 6月一版

勘誤表

August 23, 2021

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 F2′(position *p*, value *alpha*, value *beta*)	18 F1′(position *p*, value *alpha*, value *beta*)
演算法目錄之19	19 G2′(position *p*, value *alpha*, value *beta*)	19 G1′(position *p*, value *alpha*, value *beta*)
演算法目錄之20	20 F2(position *p*, value *alpha*, value *beta*)	20 F2(position *p*, value *alpha*, value *beta*, integer *depth*)
演算法目錄之21	21 F2(position *p*, value *alpha*, value *beta*)	21 F2(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*, value *threshold*)
演算法目錄之30	30 IDAS′(position *p*, integer *limit*, integer *threshold*)	30 IDAS′(position *p*, integer *limit*, value *threshold*)
演算法目錄之36	36 F4.4′(position *p*, value *alpha*, value *beta*, integer *depth*, Boolean *do_null*)	36 F4.4′(position *p*, value *alpha*, value *beta*, integer *depth*, Boolean *in_null*)
演算法目錄之37	37 F4.5′(position *p*, value *alpha*, value *beta*, integer *depth*, Boolean *do_lmr*)	37 F4.5′(position *p*, value *alpha*, value *beta*, integer *depth*, Boolean *in_lmr*)

Acknowledgements

- **Thanks to TA's and 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, 2018, 2019, 2020, and 2021.**
- **Special thanks to the following students.**
  - **Yuh-Jie Chen (class of 2008)**
  - **Jennya Chang (class of 2011)**
  - **Jessica Lin (class of 2011)**
- **TA of previous years**
  - 陳柏年
  - 陳冠伶
  - 許祐程
  - 張紘睿
  - 樂正
  - 鍾詠先
  - 陳約廷
  - 郭麗莎
  - 許嘉銘

Classroom rules

- **Wear a mask effectively.**
- **No drinking and eating.**
- **Maintain a proper social distance**
- **If you do not feel well, rest and do not mix with others.**
  - **Live broadcasting is available.**

Evaluation (1/3)

- **Homework (34%)**
  - **One homework project about single-player search (17%)**
    - *About A* and pattern database, single-person project, C/C++;Linux/Unix knowledge is* ***required****.*
    - *A generalized version of the tile-sliding game called* **Broken Sliding.**
    - *Your score is compared with the score of a good heuristic program playing on the same set of test data.*
    - *Implement a set of required techniques learned from the class and submit a written report.*
  - **One homework project about Monte-Carlo simulation (17%)**
    - *A single-person project, C/C++;Linux/Unix knowledge is* ***required****.*
    - *EWN Kari 2: EWN with larger 6x7 board, no capturing one's own pieces and no randomness.*
    - *Your program plays against a baseline program and other opponents. Your score is compared with the score of a good EWN kari 2 program playing on the same set of test data.*
    - *Implement a set of required techniques learned from the class and submit a written report.*

Evaluation (2/3)

- **Written mid-term exam (33%)**
- **Final coding project (33%)**
  - **An alpha-beta based computer game program for the original version of EWN.**
    - ▷ *A sample code with GUI will be provided.*
    - ▷ *The usage of this sample code is restricted for anything related to this course only.*
  - **The 16th NTU-TCG Cup.**
  - **The competition will be held during the 17th and 18th weeks of the semester in 2 or 3 non-consecutive days.**
  - **Submitted package: Code + documents.**
  - **Final written report: during the 18th week of the semester.**
    - ▷ *Document for the final project*
    - ▷ *Study notes.*
    - ▷ . . .
- **Class participation**
  - **Bonus for good participation**
  - **Students being recorded as not attending the classes will be penalized**
  - **More rules will be announced during the lectures**

Evaluation: Backup plans (3/3)

- **In case of unexpected circumstances due to COVID-19 or others.**
- **Possible options:**
  - **A written final exam.**
  - **Off-line competition.**
    - ▷ *Code submitted and then executed by TA.*
    - ▷ *Game logs are provided.*
    - ▷ *Multiple runs.*
- **For students that are falling behind during the semester, we will invite them to do extra work to make up the score.**

Lecturing format

- **Lecturing is entirely done in Mandarin**
- **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 (chapter 1): an A.I. oriented overview
- Programming tips (chapter 14.2.2)
- Single-player games (chapter 2 and chapter 3): lectures are skipped for chapter 2.1 – 2.2.5,
  - Basic techniques
  - Advanced techniques
- Homework I: announce at the 4th week and is due at the 7th week.
- Two-player perfect information games
  - Survey (chapter 4)
  - Introduction from Chess's point of view (chapter 5)
  - Alpha-beta and its extensions (chapters 6 and 7)
- Mid-term exam: 2:20pm–5:20pm Nov 3 (Thursday)
- Two-player perfect information games
  - Monte-Carlo based method (chapters 9 and 10)
- Homework II: announce at the 11th week and due at the 14th week.

Course at a glance (2/2)

- **Practical considerations**
  - **Transposition tables (ch. 8.1–8.3)**
  - **Advanced pruning techniques (ch 8.4–8.9)**
- **Searching chance nodes (ch 13.4)**
- **Advanced topics**
  - **Parallelization (ch. 11) (?)**
  - **Endgame (ch. 12) (?)**
  - **The graph-history interaction (GHI) problem (ch 13.2)**
  - **Opponent model(ch 13.3)**
- **Concluding remarks (ch 14)**
  - **Timing control**
  - **Software and hardware enhancements**
  - **Conclusion**
- **Final project: announce at the 14th week and due at the 18th week.**
  - **Live competition during Thursdays of the 17th and 18th weeks.**
- **Final report: 18th week.**

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+16]**
  - **...**

Single-player games

- **Games that can be played by one person [DH09]**
  - **combinatorial games such as 15-puzzle or Sukodu**
  - **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+12]**
  - **Original ideas [Bru93]**
  - **Best first game tree growing**
  - **UCT**
  - **Pruning techniques**
    - ▷ *Online knowledge [BH04] [YYK+06]*
    - ▷ *Offline knowledge [ST09] [HCL10a]*
    - ▷ *Deep learning [SHM+16]*
- **Searching chance nodes**
- **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)

- **Bit board**
- **Multi-player game tree search and pruning**
- **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)*
    - ▷ *2018 at New Taipei City, Taiwan (21th)*
    - ▷ *2019 at Macau, China (22th), co-located with IJCAI*
    - ▷ *2020 (23th) is on-lined due to COVID-19.*
    - ▷ *2021 (24th) is on-lined due to COVID-19.*

Resources (2/6)

- **TCGA web site**
  - Taiwan Computer Games Association
  - Since 2011.
  - http://tcga.ndhu.edu.tw
  - Annual May/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)*
    - *2021 (online) (17th)*
- **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 (10th; New Taipei City, Taiwan)**, 2020 (cancelled)*

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, August 20th, 2017.**
  - **2018 (7th), Sweden**
  - **Not sure about it after 2018**

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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