Knowledge of Go in the AI Age
AI时代的围棋知识

Lǐ Zhé (6p)

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Part I：小棋盘最优解问题
Optimal solutions for small boards

Part II: 围棋思维的结构
The structure of Go thinking

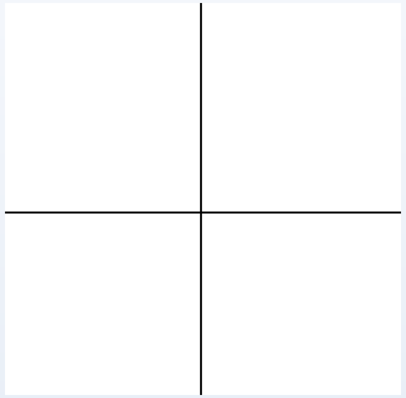
Part I：小棋盘最优解问题 Optimal solutions for small boards

1. 对于人和AI分别而言，多大的围棋盘可以算出最优解？让我们从最小的棋盘开始
2. 多少贴子/贴目是平衡的？
3. 最优解是唯一的吗？

1. For human being and AI respectively, what is the size of Go board where optimal solutions can be determined? Let us start with the smallest Go board.
2. What Komi is balanced?
3. Do we have one unique optimal solution?

一至三路小棋盘 1x1 to 3x3 small boards

1*1



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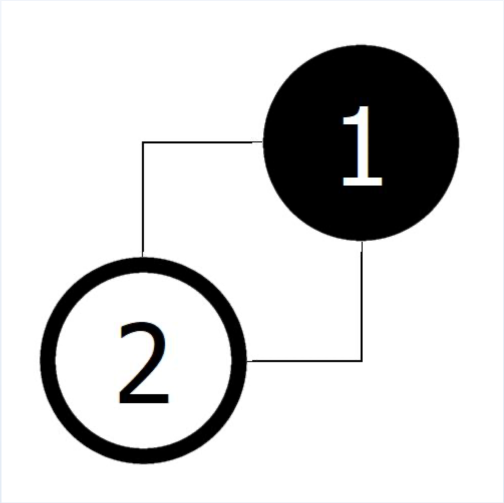
2*2



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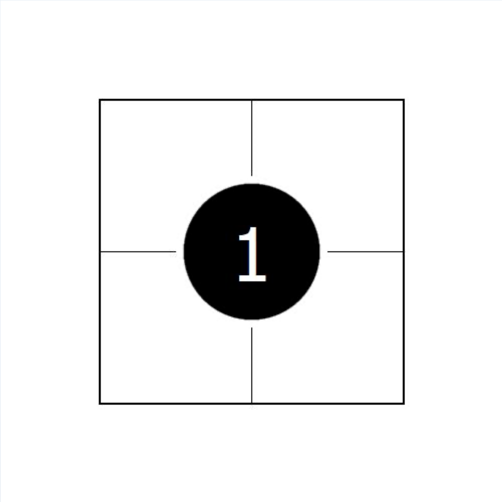
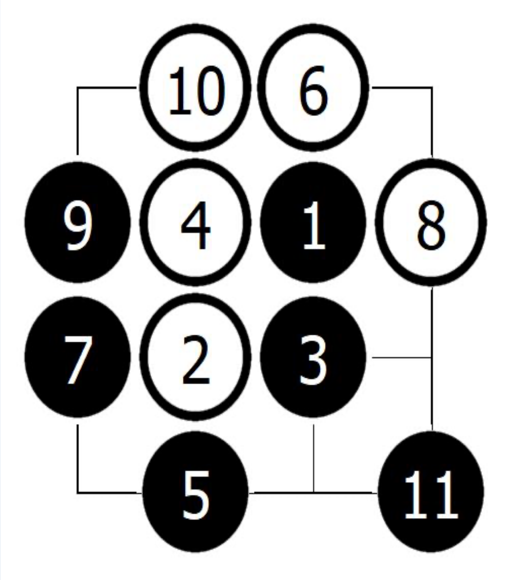
3*3



(All 9 and 8)

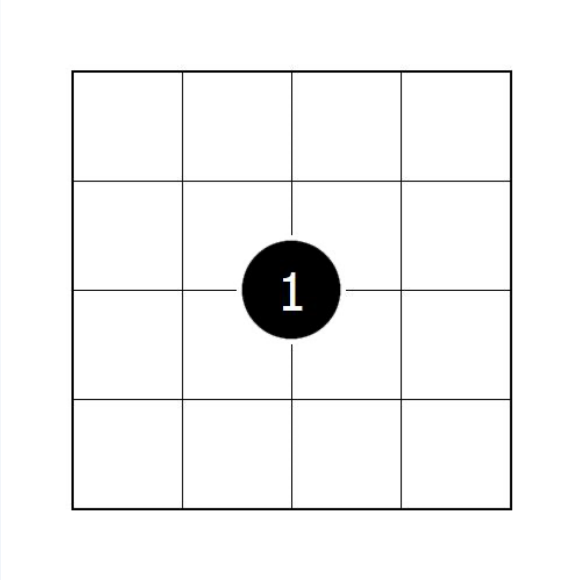
四至五路小棋盘 4x4 and 5x5 small boards

4*4



(2 and 0)

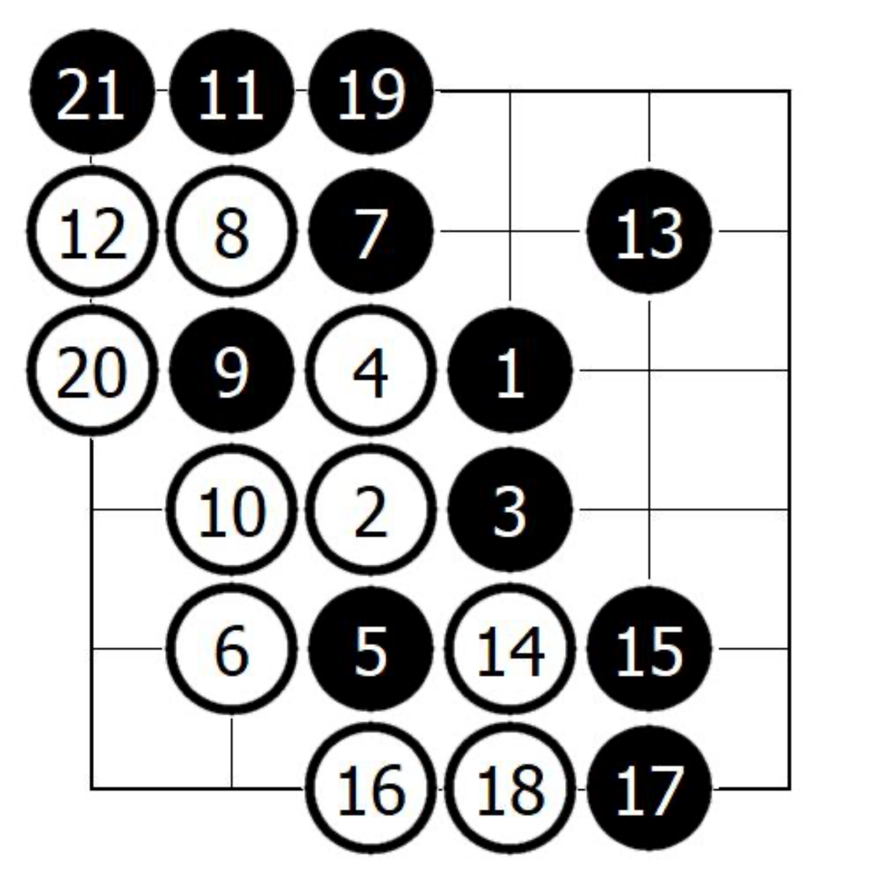
5*5



(All 25 and 24)

六路棋盘 6x6 Go board

6x6



(4 and 3)

难度：A

平衡贴子数：2

平衡贴目数：3

最优解数量：最优解集合，不唯一且难以计数

Difficulty: A

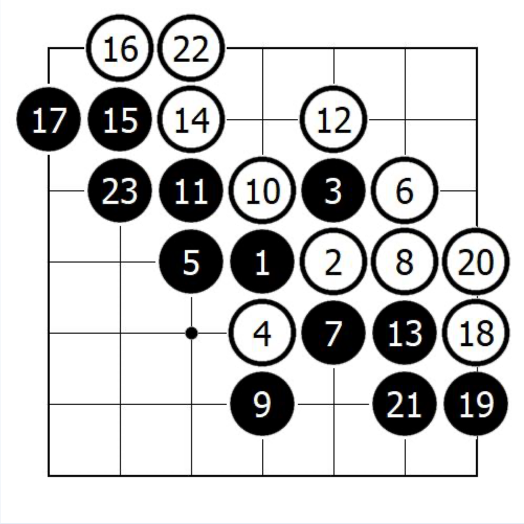
Balanced Komi (stones): 2

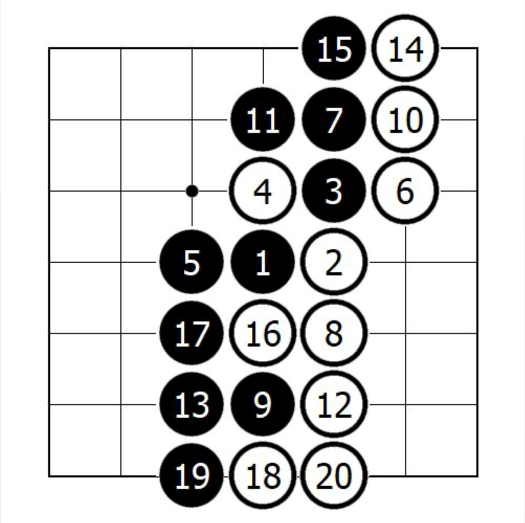
Balanced Komi (territory): 3

Number of optimal solutions: Set of optimal solutions, not unique and difficult to count

七路棋盘最优解（人类计算）Optimal solutions on 7x7 board (human calculation)

7x7



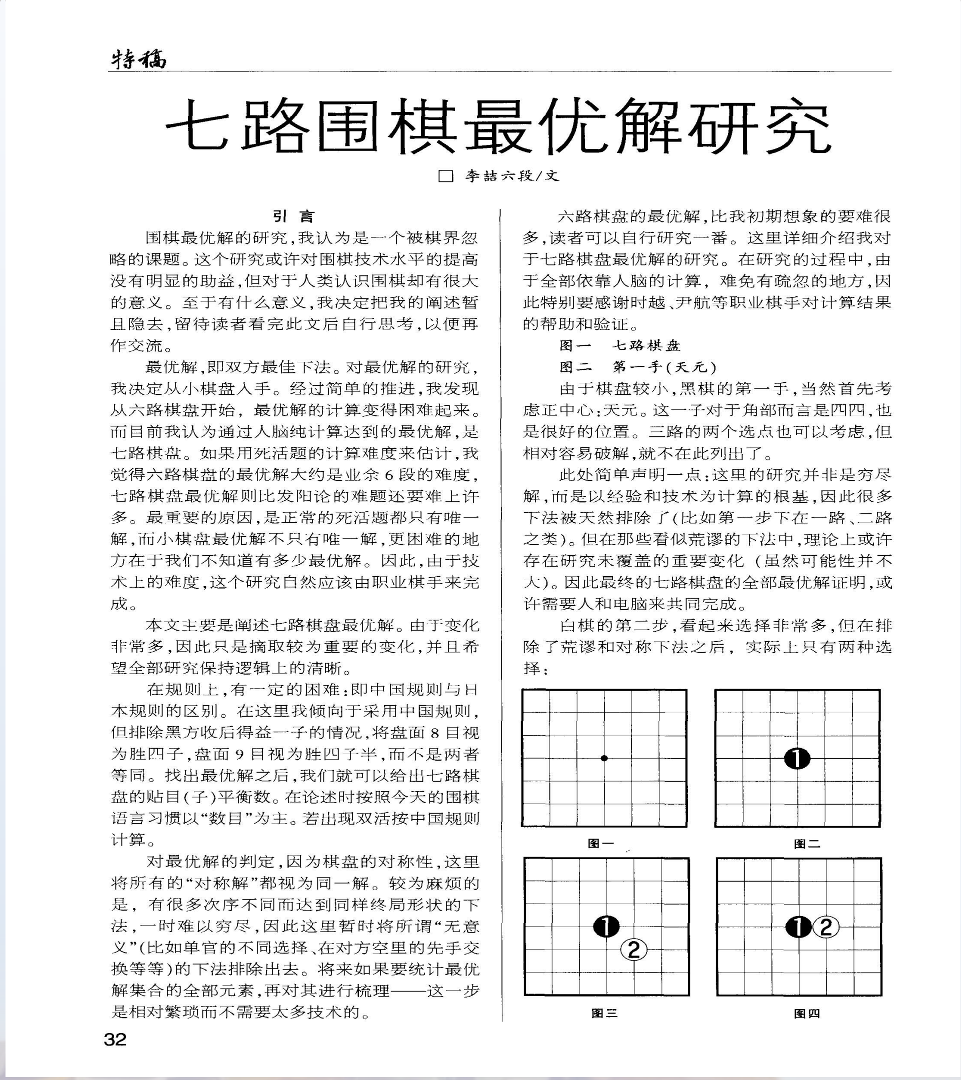


(9 and 9?)

难度：SSS 超过任何一道死活题

Difficulty: SSS

more difficult than any life-and-death problems



特稿

七路围棋最优解研究

□ 李喆六段/文

引 言

围棋最优解的研究，我认为是一个被棋界忽略的课题。这个研究或许对围棋技术水平的提高没有明显的助益，但对于人类认识围棋却有很大的意义。至于有什么意义，我决定把我的阐述暂且隐去，留待读者看完此文后自行思考，以便再作交流。

最优解，即双方最佳下法。对最优解的研究，我决定从小棋盘入手。经过简单的推进，我发现从六路棋盘开始，最优解的计算变得困难起来。而目前我认为通过人脑纯计算达到的最优解，是七路棋盘。如果用死活题的计算难度来估计，我觉得六路棋盘的最优解大约是业余6段的难度，七路棋盘最优解则比发阳论的难题还要难上许多。最重要的原因，是正常的死活题都只有唯一解，而小棋盘最优解不只有唯一解，更困难的地方在于我们不知道有多少最优解。因此，由于技术上的难度，这个研究自然应该由职业棋手来完成。

本文主要是阐述七路棋盘最优解。由于变化非常多，因此只是摘取较为重要的变化，并且希望全部研究保持逻辑上的清晰。

在规则上，有一定的困难：即中国规则与日本规则的区别。在这里我倾向于采用中国规则，但排除黑方收后得益一子的情况，将盘面8目视为胜四子，盘面9目视为胜四子半，而不是两者等同。找出最优解之后，我们就可以给出七路棋盘的贴目（子）平衡数。在论述时按照今天的围棋语言习惯以“数目”为主。若出现双活按中国规则计算。

对最优解的判定，因为棋盘的对称性，这里将所有的“对称解”都视为同一解。较为麻烦的是，有很多次序不同而达到同样终局形状的下法，一时难以穷尽，因此这里暂时将所谓“无意义”（比如单官的不同选择、在对方空里的先手交换等等）的下法排除出去。将来如果要统计最优解集合的全部元素，再对其进行梳理——这一步是相对繁琐而不需要太多技术的。

六路棋盘的最优解，比我初期想象的要难很多，读者可以自行研究一番。这里详细介绍我对于七路棋盘最优解的研究。在研究的过程中，由于全部依靠人脑的计算，难免有疏忽的地方，因此特别要感谢时越、尹航等职业棋手对计算结果的帮助和验证。

图一　七路棋盘

图二　第一手（天元）

由于棋盘较小，黑棋的第一手，当然首先考虑正中心：天元。这一子对于角部而言是四四，也是很好的位置。三路的两个选点也可以考虑，但相对容易破解，就不在此列出了。

此处简单声明一点：这里的研究并非是穷尽解，而是以经验和技术为计算的根基，因此很多下法被天然排除了（比如第一步下在一路、二路之类）。但在那些看似荒谬的下法中，理论上或许存在研究未覆盖的重要变化（虽然可能性并不大）。因此最终的七路棋盘的全部最优解证明，或许需要人和电脑来共同完成。

白棋的第二步，看起来选择非常多，但在排除了荒谬和对称下法之后，实际上只有两种选择：

图一　图二

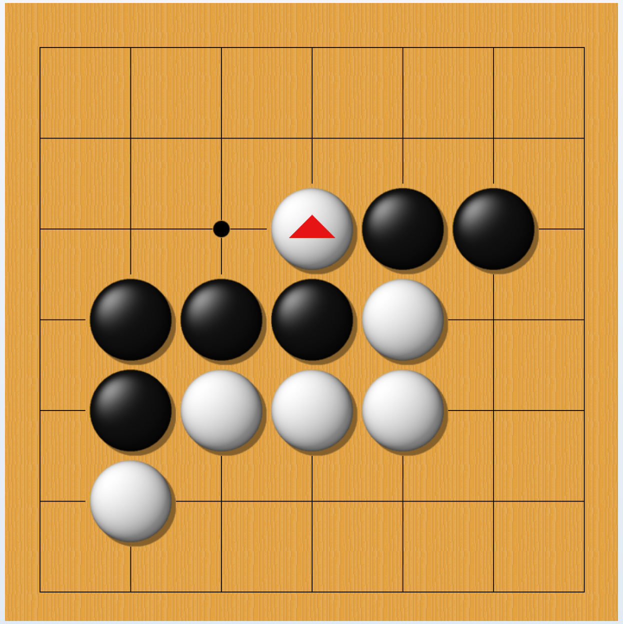
图三　图四

32

围棋天地 2015, 20

七路棋盘最优解（AI计算）Optimal solutions on 7x7 board (AI calculation)

AI发现的绝妙手！
AI disovered a brilliant Tesuji



Tromp-Taylor rules, komi 9
Japanese rules, komi 8 (Not 9)

Overview and Prior Work

Although not exhaustive, some of the notable prior published attempts to analyze or solve 7x7 appear to include:

- An American Go Journal article by James Davies with additional SGF here summarizing work by various pros and amateurs from the 1970s and 1980s.
- An academic paper Towards a solution of 7x7 Go with meta-MCTS by Chou et al. published in 2011 that applied computer techniques and discovered some new overlooked lines.
- An excellent article in Chinese published by a Chinese pro Li Zhe 6p around 2015 in collaboration with other pros, with some of the best overall summary of analysis up to that point in time.
- A later 2020 blog post by another individual in Chinese in response to the prior article, that applies some computer analysis and points out some minor improvements to the conclusions of that article, with a much broader analysis of a few variations.
- (Edit: 2021-08-07) - A smaller Chinese rules 7x7 book from Crazystone also from late 2020, which, although we were not aware it of prior to publishing the first version of our book, also independently discovers and confirms many of the same lines, including the most important new line for White under Japanese rules!

Much thanks and respect to the authors of these prior works! They were all fun and instructive to read, and they were hugely helpful to provide context for interpreting the results of KataGo's analysis, as well as for finding some of the most interesting variations to analyze and explore deeper. Our ability to comment on and understand the key moves owes much to the foundation provided by these past efforts.

Relative to some of these earlier 7x7 solution attempts, KataGo's opening books on this site do appear to include some new moves and discoveries! As of late 2021, we summarize some of the major highlights below.

Optimal Komi in Japanese Rules is Probably 8, Not 9!

This was actually discovered earlier in 2020 with KataGo's help, before these books, and many people contributed additional commentary and analysis at the time (for example this excellent video in Chinese and its followup), but is still worth re-emphasizing here. Prior analysis and solution attempts in the last several decades have all missed what seems to be a key tesuji for White, so for a long time the consensus of many solutions was that optimal play under Japanese rules gives B+9, but current analysis suggests it should be B+8.

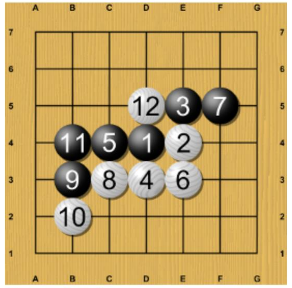


Diagram 1: Tesuji!.

The key new tesuji is White's probing cut at 12 here.

2021.8

[KataGo Opening Books - 7x7 Highlights and Discoveries (katagobooks.org)](katagobooks.org)

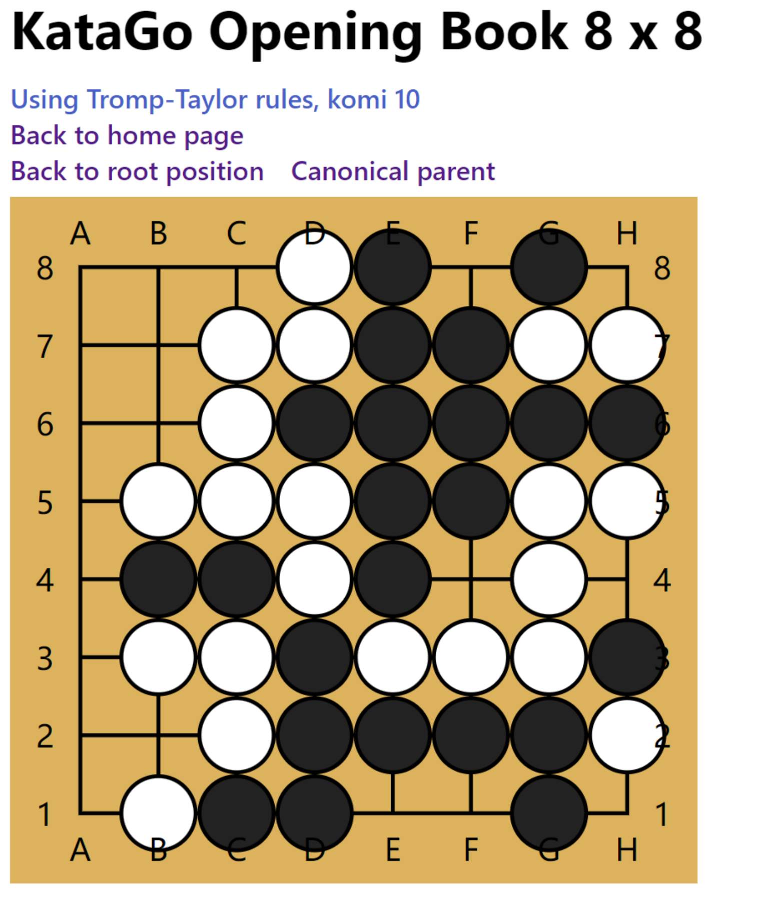
七路以上棋盘的最优解 Optimal solutions on boards bigger than 7x7

8x8: 人类棋手未完成计算
KataGo的计算结果是（10 and 9）
在7x7和8x8，目前还无法证明是否真的达到了最优解。
9x9：超出了人类棋手的计算能力
当前的AI也无法完成最优解计算

8x8: Human players could not solve the optimal solutions.
Results by KataGo: 10 and 9

7x7 and 8x8: We do not know whether we really reached the optimal solutions.

9x9：Beyond the calcuation power of human players.
Current AI also cannot find the optimal solutions.



多少贴子/贴目是平衡的？The number of balanced Komi (Chinese/Japanese rules)

2009年， Erik C.D. van der Werf 和 Mark H.M. Winands发表的论文中,给出了5*6以下的最优解结果。

观察这些数据, 可以发现关于平衡贴目的规律吗？

The paper by Erik C.D. van der Werf & Mark H.M. Winands (2009) demonstrates the optimal solutions for boards up to 5x6.

Can you discover any patterns by observing the table?

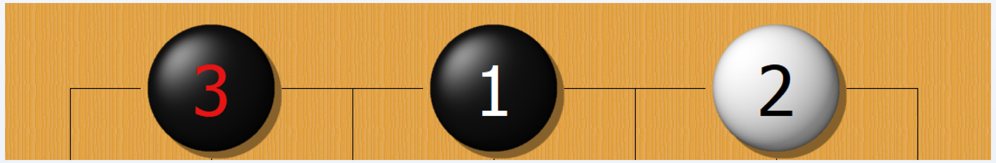
“Solving Go for Rectangular boards” June 2009
ICGA journal 32(2):77-88

Surface	Board	Result	Depth	Nodes	Time	First move	comments
30	3×10	≥6	29–	1.31T–	30.8(d)–	central	non-default [5]
30	5×6	4	27–38	214G–	4.5(d) –	central	non-default [6]
28	4×7	28	37	363G	10.6(d)	central	non-default [7]
27	3×9	5	29–30	289–294G	4.3(d)	centre	non-default
25	5×5	25	23	603M	14.3(m)	centre	
24	3×8	24	37	120G	1.86(d)	central	
24	4×6	8	29–34	3.13–13.2G	1.26–5.41(h)	central	
22	2×11	6	31–24	281G–18.3G	7.77(d)–12.2(h)	central	non-default
21	3×7	21	39	356M	7.87(m)	centre	
20	2×10	4	23–24	725–942M	14.1–25.9(m)	central	
20	4×5	20	21	20.3M	29.6(s)	central	
18	2×9	18	33	136M	2.76(m)	central	
18	3×6	18	17	2.74M	3.22(s)	central	
16	2×8	16	21	9.92M	10.2(s)	central	
16	4×4	2	21–23	695–826k	1.09–1.73(s)	central	
15	3×5	15	13	274k	276(ms)	centre	
14	2×7	14	15	705k	576(ms)	central	
12	1×12	2	53–48	1.07G–679M	18.7–11.5(m)	2,4	[8]
12	2×6	12	13	89.5k	66.2(ms)	central	
12	3×4	4	13–23	40.4–85.8k	41.4–86.4(ms)	central	
11	1×11	2	27–39	534k–9.11M	538(ms)–5.39(s)	2,4,6	
10	1×10	1	28–28	256–360k	224–272(ms)	2	
10	2×5	10	9	7.32k	5.55(ms)	central	
9	1×9	0	17–24	32.8–58.9k	23.7–43.3(ms)	2,4,5	
9	3×3	9	11	2.61k	2.13(ms)	centre	
8	1×8	3	15–30	10.6–57.1k	7.45–33.8(ms)	2	
8	2×4	8	9	2.05k	1.37(ms)	central	
7	1×7	2	9–22	1.97–5.84k	2.19–4.78(ms)	2,4	
6	1×6	1	9–18	1.09–2.12k	0.949–2.06(ms)	2	
6	2×3	0	16–25	1.57–5.88k	1.57–6.89(ms)	central	[9]
5	1×5	0	9–8	410–450	0.55–0.54(ms)	2,3	
4	1×4	4	7	131	0.327(ms)	central	
4	2×2	0	10–11	391–350	0.59–0.90(ms)	any	[10]
3	1×3	3	1	6	0.119(ms)	centre	
2	1×2	0	8–8	128–81	0.462(ms)	any	

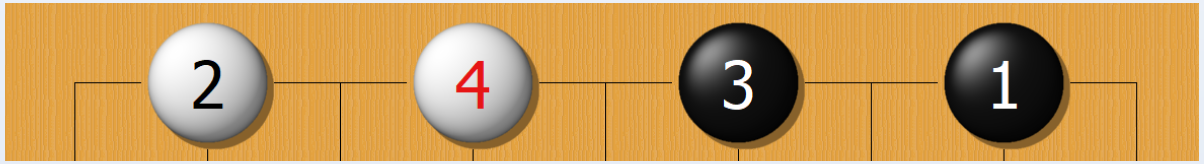
Table 1: Detailed results.

1路棋盘的贴子猜想 Conjecture about komis on 1xn boards

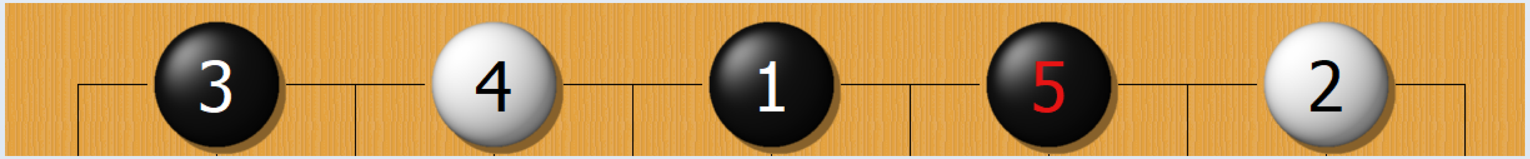
1x7　(2)



1x9　(0)



1x11　(2)



……

贴子猜想之一：
在 1 x (2n+3）棋盘上 (n>0),
n为偶数时，博弈值=2；
n为奇数时，博弈值=0

One conjecture:
On 1 x (2n+3）boards (n>0)
When n is an even number,
komi=2；
When n is an odd number,
komi=0

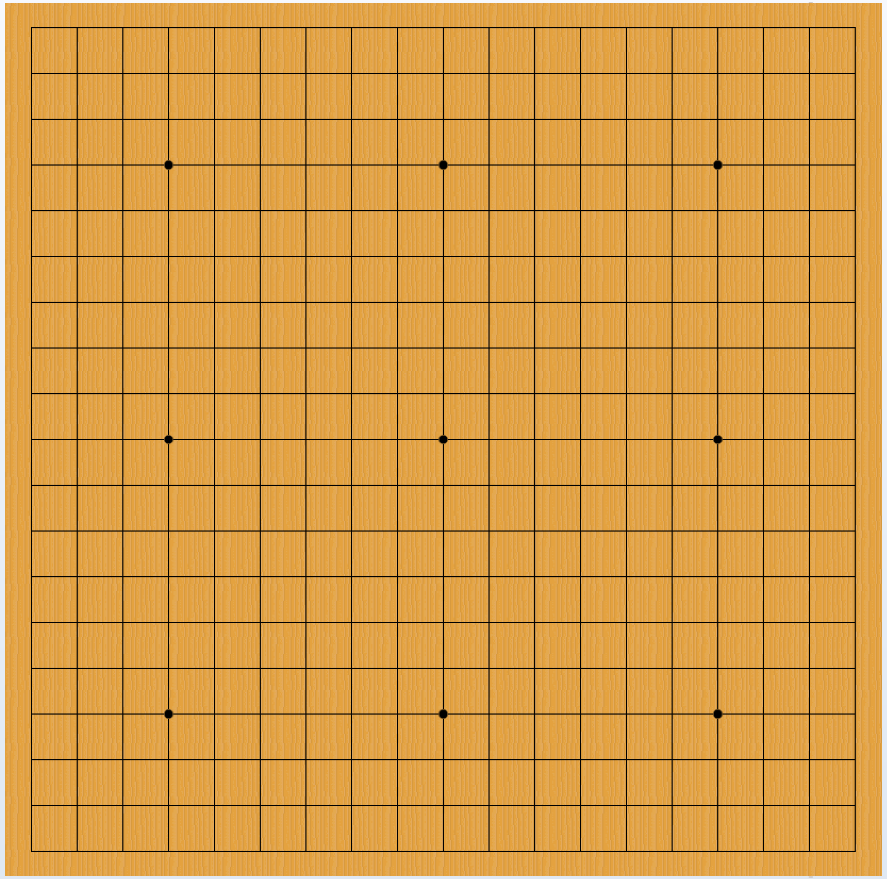
19*19棋盘的平衡贴子数 Balanced Komi on 19x19 board

Chinese rules ：7 (3.5 stones by black)（黑贴3子半）

Tromp-Taylor rules：7

Japanese rules：6 or 7？

有和棋才有平衡
Balance is only possible when Jigo exists.



围棋最优解的一些性质与延伸问题 (More questions on optimal solutions of Go)

1. 最优解不是唯一解，而是一个集合。
2. 在19*19棋盘上，最优解仍然千变万化，将有大量下法同处于最优解集合之中。
3. 这些同处于最优解集合的下法，有风格的差异吗？
4. 围棋的“风格”究竟是什么？

1. Optimal solutions do not have to be unique. Multiple optimal solutions are possible.
2. On 19x19 board, there are numerous optimal solutions. There will be a large amount of variations – a set of optimal solutions.
3. Are there any differences in style across those variants of optimal solutions?
4. What is exactly the “style” of Go playing?

Part II：围棋思维的结构 Structure of Go thinking

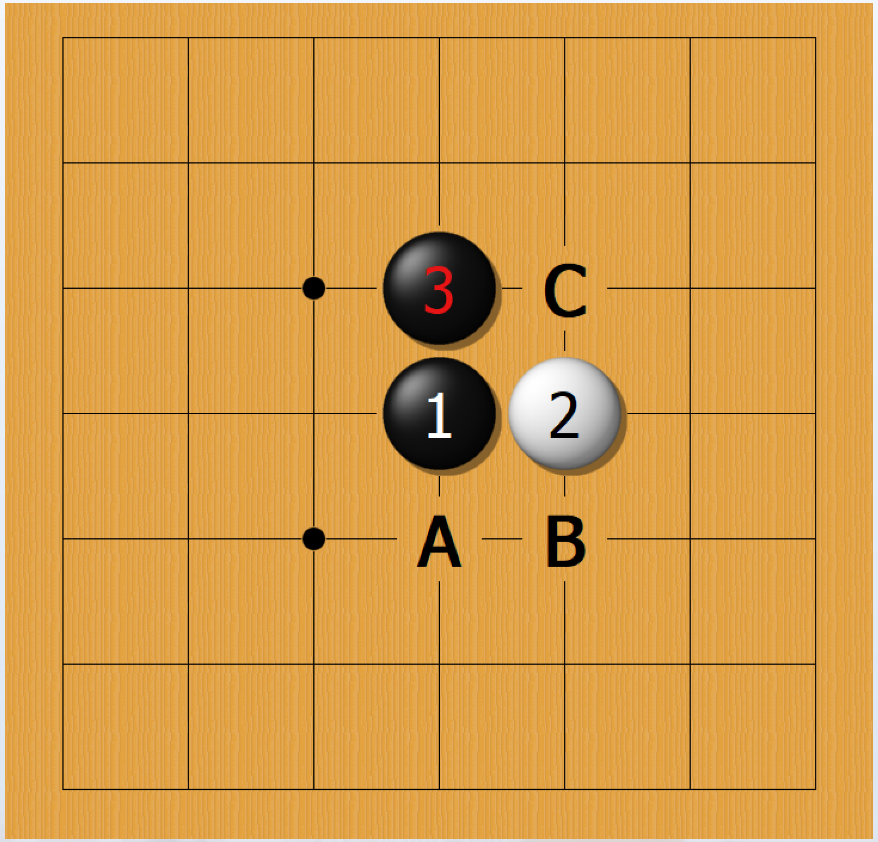
1. 计算小棋盘的最优解，与在19*19棋盘下棋的思维方式有什么区别？

2. 人类下棋的思维与AlphaGo下棋的算法在结构上是否有共通之处？

1. When calculating optimal solutions, what are the differences regarding the way of thinking between small boards and 19x19 board?
2. Are there any structural similarities of thinking by human Go players and the AlphaGo algorithms?

小棋盘与大棋盘的思维差异 Different ways of thinking between small and big boards

A=9　B=8　C=11……



小棋盘计算思维：不需要借助文化性的概念，只要把每个选点所对应的后续双方最优变化及其数值算出，也就是只需要用数理和逻辑的方式。

Small board calculation: No need for cultural concepts. We only need to figure out the possible move and the following optimal variations with numerical calculation, i.e., we only need mathematical and logical methodologies.

小棋盘与大棋盘的思维差异 Different ways of thinking between small and big boards

19x19棋盘思维：在数理和逻辑之外，借助文化性的概念，用道理和分类概括的方式来认知围棋，产生出“厚薄”、“虚实”、“轻重”、“缓急”等等二元对立且无法量化的概念，用它们来定义和理解局面，并总结出相应的“策略”，如“围棋十决”。

这大概是由于人类还是太笨了，但围棋的文化属性也由此产生。

Thinking style on 19x19 board: In addition to mathematics and logic, we also borrow cultural concepts, and understand Go with rationale, categorization, and summary. We derive the dialectical and unquantifiable concepts such as thickness, influence, fast and slow etc. These concepts help us to define and understand the situation, and we summarize strategies accordingly, such as Ten Principles of Go.

Perhaps it is because human beings are not smart enough that we rely on these cultural aspects of Go playing.

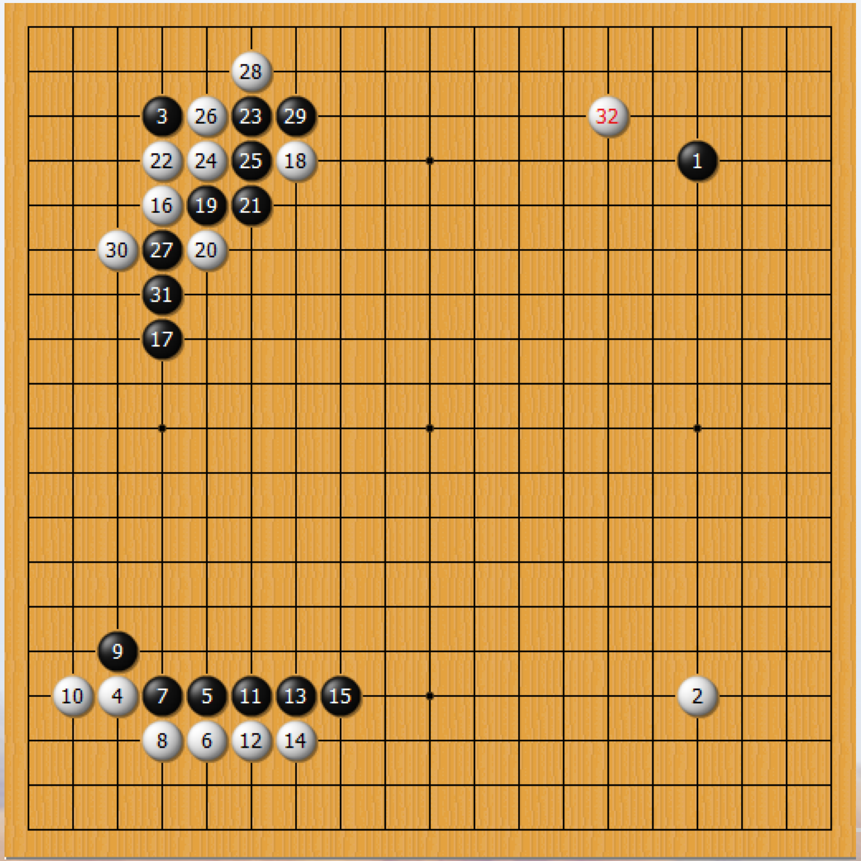
例：厚薄 Example: Thick vs. Thin

不同局面下厚势与实地的价值，哪个更大？被AlphaGo彻底淘汰的“妖刀”定式，以前并非没人怀疑过，但人类棋手对于厚薄的判断无法量化而不够精确

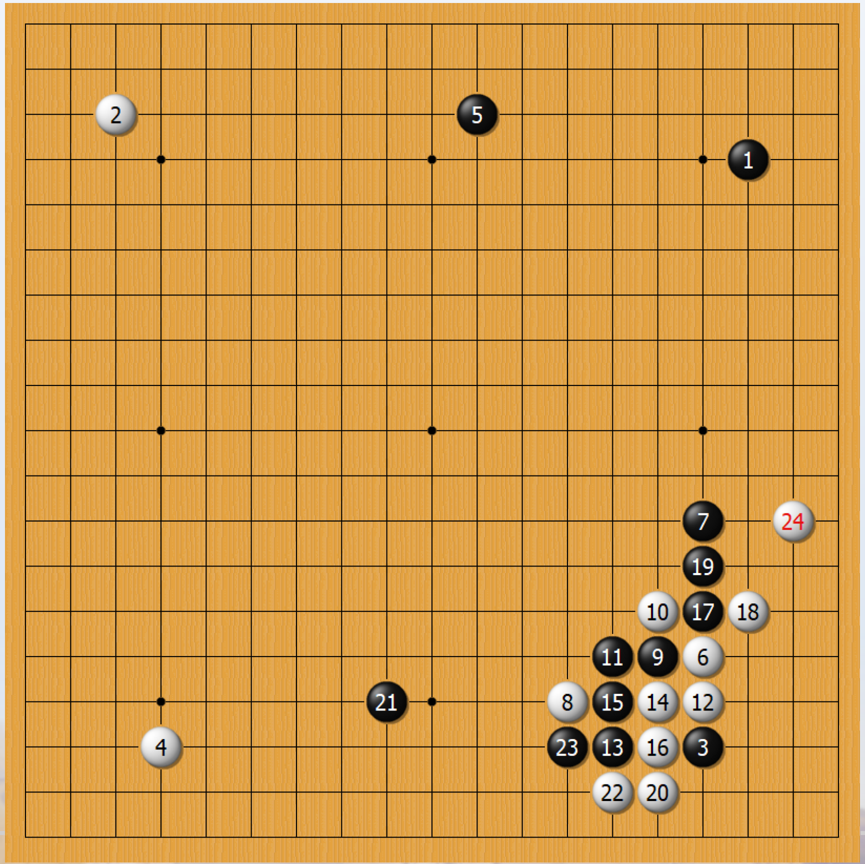
Which is more valuable in different positions: influence/thickness or territory?

The "Demon Blade" Joseki, which was never questioned before, was completely eliminated by AlphaGo.

Human judgment on thickness and influence is not quantifiable and hence not precise enough.



陈耀烨 VS AlphaGo 2017.1



古力 VS 李喆 2008.5

厚薄的知识论 Epistemology of thickness

AI下棋没有“轻重”、“厚薄”这样的二元概念，AI既不需要也很难接受并运用这些概念知识

但是人类棋手长久以来形成了这样的经验知识和概念，这些概念被用来帮助我们理解形势。

这是由于人类计算量的限度和AI不同，方法也不同。即便有了AI，人类可能还是需要这些概念来认知棋局

There are no binary concepts such as "weight" or "thickness" in AI Go. AIs do not need and at the same time have difficulties in absorbing and applying such conceptual knowledge.

But human players have developed such empirical knowledge and concepts over time, and these concepts are used to help us understand the situation.

This is due to the fact that the limits of human computation are different from the AI. The methods are also different. Even with AI, humans may still need these concepts to understand the game of Go.

人类棋手对弈的思维过程

可概括为主要三个要素/步骤：

棋感 —— 计算 —— 判断

It can be summarized in three main elements/steps: :

Go intuition —— Computation —— Judgment

棋感

棋感是一种“剪枝”方法，使计算资源投入于主干，使决策树的生长更优，这是人和AI共通的技艺。但，剪枝也有可能剪掉更优的选点。

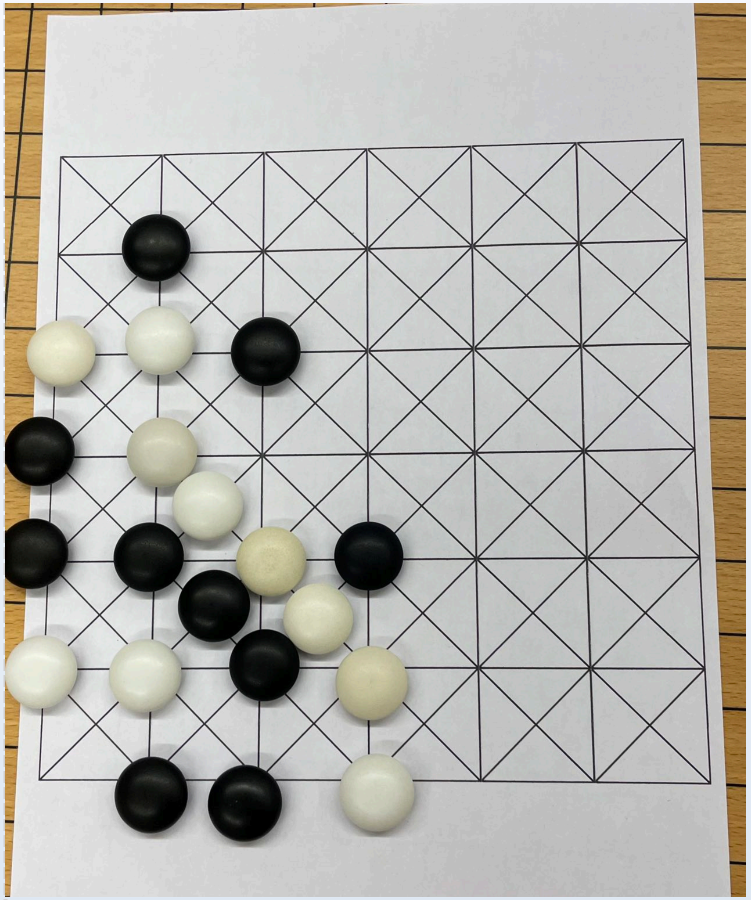
棋感的来源
1. 个体经验：实践（对局）+反馈（复盘）
2. 集体经验：棋形感（做题）+全局感（打谱）

Go intuition is a method of "pruning", so that computational resources are invested in the main stem. The decision tree grows more efficiently. This is a skill common to both humans and AIs. However, pruning also has the potential to cut out better choices.

Sources of Go intuition
1. Individual experience: practice (playing games) + feedback (game reviews)
2. Collective experience:
intuition on shapes (Tsumego problems) + intuition on whole board judgment (studying Kifus)

Translated with DeepL

如果没有棋感？What if intuition is missing?



8-Liberty-Go

还是围棋规则，还是需要计算，但没有了棋感
所有人都很困惑，所有人都变成新手
It's still following the rules of Go, and it still requires calculation, but the intuition is missing:
Everyone is confused. Everyone is a novice!

计算 Computation

跟随棋感，换位思考，设想双方可能性较大的下法

计算出多个变化分支，like策略树

判断各变化分支的优劣，得出选点优劣，做出决策——计算与判断往往是连续的

Follow the intuition, think from the perspective of opponents, and envision the more probable moves for both sides.

Calculate multiple branches of variations, like a strategy tree.

Judge the strengths and weaknesses of each branch of the variation, compare the chosen points, and make a decision - calculations and judgments tend to be continuous.

判断 Judgment

量化判断
Quantitative judgment

死活性质 Life and death
目数大小 counting points
一手棋的价值 value of each move
子效比较 efficiency of each move
......

（逻辑推演、数字）
(logical deduction, numerics)

非量化判断
Qualitative judgment

厚薄 (thick and thin)
虚实、地势 (influence and territory
轻重、缓急 (light vs. heavy, slow vs. fast)
棋形优劣 (good vs. bad shape)
......

（经验归纳、道理）
(generalization from experience, rationale)

、

全局形势判断 Whole board judgment
决策 Decision

人类思维与AlphaGo算法的结构对比

棋感 —— 计算 —— 判断

Go intuition —— Computation —— Judgment

策略网络
Policy Network

蒙特卡洛树搜索
Monte Carlo Tree Search

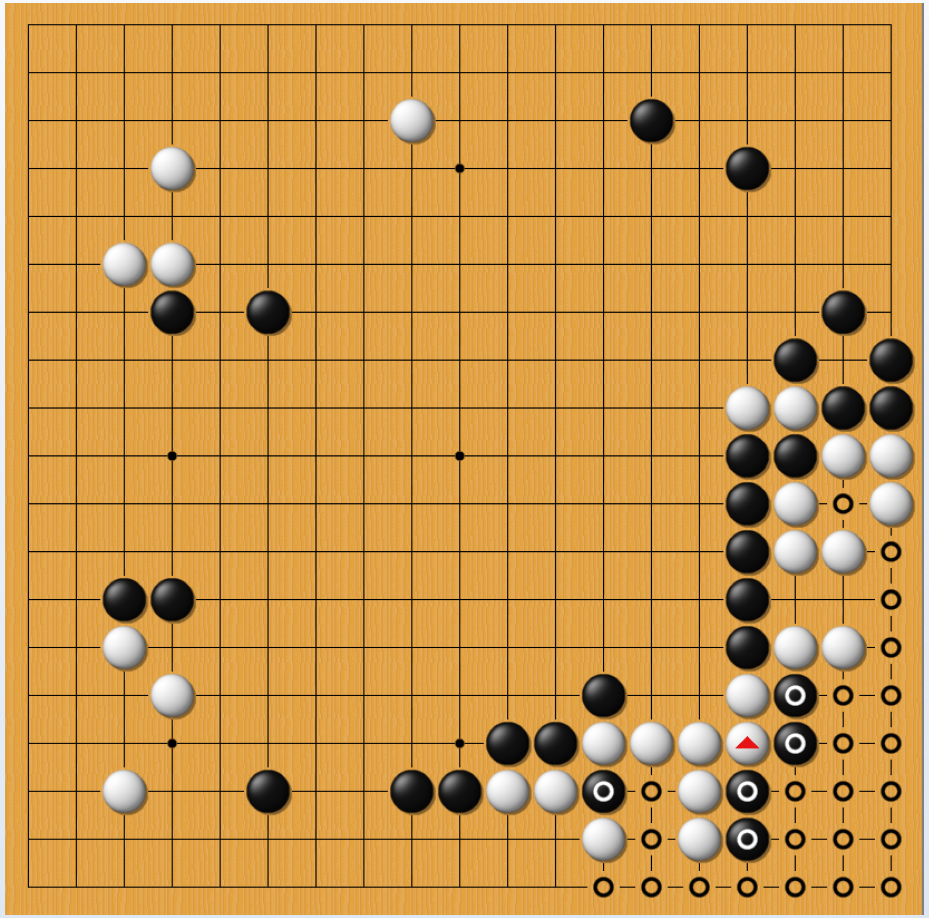
价值网络
Value Network

例：外势与实地的判断 Example: judgment about influence and territory

在地势均衡的局面下，人类棋手与AI的判断差异往往并不大。在地势对抗的局面下，判断差距容易体现出来。
如右图局面的形势判断
人类棋手：感觉白好，因为白实地多、效率高、黑外势不厚、中腹不好围空……（可以说出无数理由）
AI：黑胜率70%
人类棋手：Why？
AI：……

When both players have similar influence and territory, the differences between human players and AI judgment are often small. When players have different degrees of influence and territory, the differences tend to be bigger.

Human player: I feel that White is better because White has more territory and is more efficient, Black's influence is not thick, and it is difficult to have territory in the center (and other countless reasons).
AI: Black win rate is 70%.
Human player: Why?
AI: ...



DeepZenGo VS 孔杰+CGI 2017

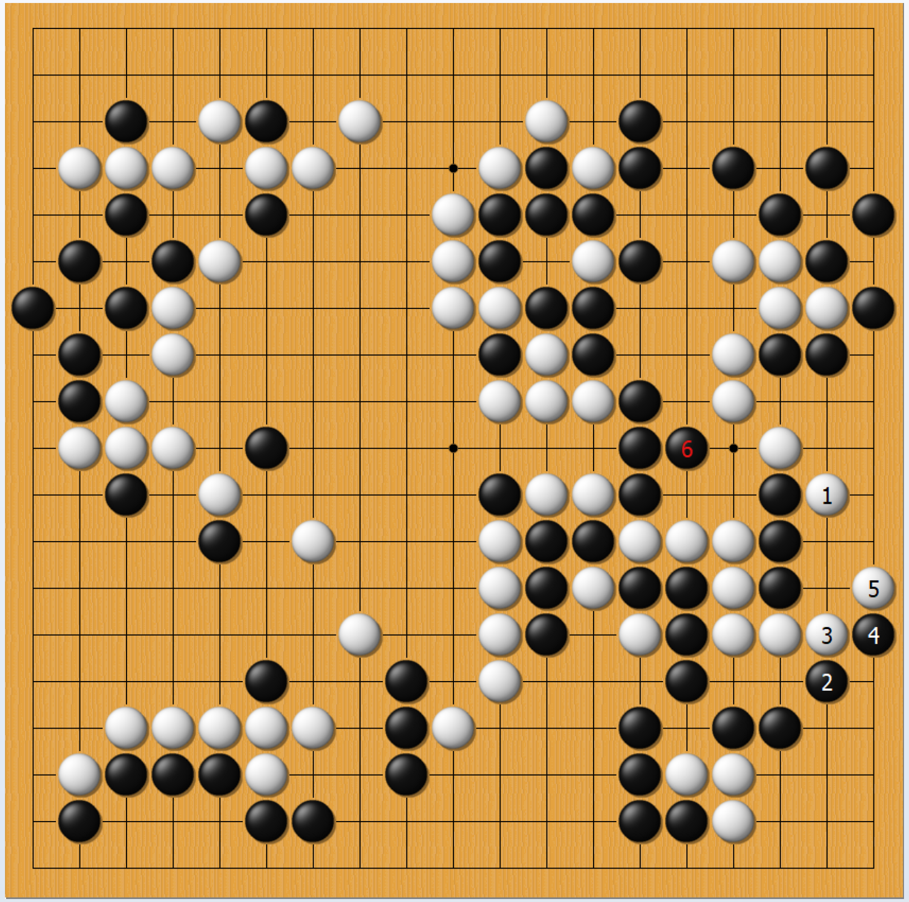
差距 Difference

右图：
AI：白1，白92% 😊
人类：黑2，白棋死了 😏
AI：……😑
在一些极端的局面下，人类逻辑计算的准确性仍有可能超过AI。人类棋手与AI在棋上最重要的技术差距，在于人类无法用量化的方式进行判断的部分。

AI: white 1, white win rate 92% 😊
Human: black 2, white is dead 😏
AI: ……😑

In some extreme positions, it is still possible for the accuracy of human logical calculations to outperform AI.

The most important technical gap between human players and AI in Go lies in the parts of the game that humans cannot judge in a quantifiable way.



李喆 VS 神算子　2018.1

人类棋手未来可能的进步方向 Possible future progress for human Go players

棋感：长期用AI训练可以积累出比以前更好的棋感。
计算：人的理性有限，计算力很难显著突破。
判断：1. 经验——借助AI胜率进行大量的局面判断练习，提高全局判断的准确度
2. 理论——在AI的帮助下，创造出比“厚薄”、“轻重”等更有效的概念

Go intuition: long-term training with AI can accumulate a better intuition than before.
Computation: Human rationality is limited, and it is difficult to make a significant breakthrough in computation power.
judgment:
1. Experience – practice a lot of positional judgment with the help of AI's win rate to improve the accuracy of global judgment.
2. Theory – with the help of AI, create more effective concepts than "thickness", "weight" and so on.

Thank you for your attention!

Now it is time for

Q&A