Checkers Solved

Schaeffer et al. 2007

Artificial Intelligence for Games

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Fabian Jäger
Overview

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History

• 1950 start with Arthur Samuel’s pioneering work in machine learning
• 1963 first win of a checker program
• 1989 start of the search for a champion challenging program
• 1992 peak, over 200 processors were devoted simultaneously
• 1994 defeat of a world champion (Chinook), but not solved yet
Definition Of Solving

3 States of Solving:

1. **ultra weakly**: Outcome known for starting position
2. **weakly**: Outcome and Strategy known for the starting position
3. **strong**: Outcome and Strategy known for the every position
Checkers

Rules:
- Kings can move one field, but backwards, too
- 8x8 field, but only on black played
- 2 types of figures

=> $5 \times (10^{20})$ positions

Restriction:
- Forced-Capture
Solving Methods

Perfect play from both players

max
min
max
or
and
or
-1 3 5 8 -6 -4 2 4
Solving Methods

3 Components:
1. Database
2. Proof-tree manager
3. Proof-tree solver
   1. Alpha-Beta
   2. Depth first proof number (Df-Pn)
Database

- 1989-1996 8 piece
- In 2001 only 1 month for 8 piece
- 2001-2005 10 pieces

For 1 piece: \((32+28)\times2=120\)

<table>
<thead>
<tr>
<th>Pieces</th>
<th>Number of positions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>6,972</td>
</tr>
<tr>
<td>3</td>
<td>261,224</td>
</tr>
<tr>
<td>4</td>
<td>7,092,774</td>
</tr>
<tr>
<td>5</td>
<td>148,688,232</td>
</tr>
<tr>
<td>6</td>
<td>2,503,611,964</td>
</tr>
<tr>
<td>7</td>
<td>34,779,531,480</td>
</tr>
<tr>
<td>8</td>
<td>406,309,208,481</td>
</tr>
<tr>
<td>9</td>
<td>4,048,627,642,976</td>
</tr>
<tr>
<td>10</td>
<td>34,778,882,769,216</td>
</tr>
<tr>
<td>Total 1–10</td>
<td>39,271,258,813,439</td>
</tr>
</tbody>
</table>

forced-capture => fast reduction to 10
=> much smaller game tree
Proof-tree manager

Maintains a tree of the proof in progress
Identifies positions which are interested

1. Several hundred at a time

Proof number Search

1. Disprove value := minimum number of leaf nodes needed for disproof

2. Prove value := minimum number of leaf nodes needed for the proof
Proof number

Rules

1. Or: sum up child disproof numbers
2. And: sum up child proof numbers
Alpha-Beta-Pruning

Thresholds for pruning trees
1. Alpha := lower threshold
2. Beta := upper threshold
3. initialized with +/- „infinity“

\[ b^d \Rightarrow b^{(d/2)} \]
Depth-First Proofing Number

• Similar to Alpha-Beta
• Creates threshold for disproof/proof number
• Follows best children until a proof is found

=> if no proof is found a heuristics value is calculated (Chinook)
Iteration

• Most iterate on search depth
• Manager uses threshold $t$:
  • scores $\leq -t$ are losses
  • scores $\geq t$ are wins
  • increase $t$
Results

Only 19 starting positions have to be considered:
1. 300 three-move openings, more than 100 are duplicates
2. rest can be proven to be irrelevant by an alpha-beta search

=> Checkers only solved weakly!
=> if one side makes a losing mistake, the proof tree may not necessarily show how to win
=> it’s a draw!

<table>
<thead>
<tr>
<th>No.</th>
<th>Opening</th>
<th>Proof</th>
<th>Searches</th>
<th>Max ply</th>
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<tbody>
<tr>
<td>1</td>
<td>09:13 22:17 13 22</td>
<td>Drawn</td>
<td>736,984</td>
<td>56</td>
</tr>
<tr>
<td>3</td>
<td>09:13 22:18 10:09</td>
<td>Drawn</td>
<td>715,280</td>
<td>103</td>
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<tr>
<td>4</td>
<td>09:13 23:18 05:09</td>
<td>Drawn</td>
<td>673,948</td>
<td>119</td>
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<tr>
<td>5</td>
<td>09:13 22:18 13:18</td>
<td>Drawn</td>
<td>564,138</td>
<td>85</td>
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<tr>
<td>6</td>
<td>09:13 22:18 11:15</td>
<td>Drawn</td>
<td>554,250</td>
<td>53</td>
</tr>
<tr>
<td>7</td>
<td>09:13 24:20 11:15</td>
<td>Drawn</td>
<td>3,058,328</td>
<td>59</td>
</tr>
<tr>
<td>8</td>
<td>09:13 24:20 05:09</td>
<td>Drawn</td>
<td>3,202,533</td>
<td>77</td>
</tr>
<tr>
<td>9</td>
<td>09:13 24:20 11:15</td>
<td>Lose</td>
<td>2,296,790</td>
<td>58</td>
</tr>
<tr>
<td>10</td>
<td>10:14 23:18 14:23</td>
<td>Drawn</td>
<td>453,603</td>
<td>60</td>
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<tr>
<td>12</td>
<td>10:15 23:18 16:23</td>
<td>Drawn</td>
<td>2,969,641</td>
<td>69</td>
</tr>
<tr>
<td>13</td>
<td>12:16 24:19 09:13</td>
<td>Loss</td>
<td>205,385</td>
<td>44</td>
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<tr>
<td>14</td>
<td>12:16 24:19 09:14</td>
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<td>61,279</td>
<td>45</td>
</tr>
<tr>
<td>15</td>
<td>12:16 24:19 10:14</td>
<td>Drawn</td>
<td>21,328</td>
<td>31</td>
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<tr>
<td>16</td>
<td>12:16 24:19 10:14</td>
<td>Drawn</td>
<td>31,473</td>
<td>35</td>
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<tr>
<td>17</td>
<td>12:16 24:19 11:15</td>
<td>Drawn</td>
<td>23,803</td>
<td>34</td>
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<tr>
<td>18</td>
<td>12:16 24:19 15:20</td>
<td>Drawn</td>
<td>283,353</td>
<td>49</td>
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<tr>
<td>19</td>
<td>12:16 24:19 03:12</td>
<td>Drawn</td>
<td>266,924</td>
<td>49</td>
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<tr>
<td>Overall</td>
<td>Drawn</td>
<td>Total</td>
<td>15,123,711</td>
<td>Max 154</td>
</tr>
</tbody>
</table>
Results

• search effort: $10^{14}$ (with only alpha beta $10^{24}$)
• 10 pieces database is 237 Gb large (154 positions per byte)
• 50 computers simultaneously for search tree for 3 years
Conclusion

Correctness:

• many potential sources of errors (algorithm bugs, data transmission errors)
• computations have been independently verified
• outcome manually checked
• Chance of error propagation is small
Sources

• Checkers Is Solved, Schaeffer et al. 2007
• An Analysis of Alpha-Beta, Priming Donald E. Knuth and Ronald W. Moore
• Searching for Solutions in Games and Artificial Intelligence, L. Allis
• Parallel Depth First Proof Number Search, Tomoyuki Kaneko
• Proof-Number Search and its Variants, H. Jaap van den Herik and Mark H.M. Winands