# Is continual resolving really almighty? 

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## Outline

- continual resolving recapitulation
- PAWS domain

■ CR and PAWS

- should everyone use CR
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## Is continual resolving really almighty?

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$\square$ Heads-up no-limit Texas hold'em: $10^{160} \rightarrow 10^{14}$

- $10^{146} \times$ reduction of the size of the game


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$\square$ Heads-up no-limit Texas hold'em: $10^{160} \rightarrow 10^{14}$

- $10^{146} \times$ reduction of the size of the game

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## PAWS Problem

| $\left[\begin{array}{c}\text { [17. } 17] \\ 0\end{array}\right.$ | $\left[\begin{array}{c}\text { [17, 18] } \\ 0\end{array}\right.$ | $\left[\begin{array}{c}17,19] \\ 0\end{array}\right.$ | $\left[\begin{array}{c}\text { [17, } 20] \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[17,21]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[17,22]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[17,23]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[17,24]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}117.25] \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[17,26]} \\ 0\end{array}\right.$ | ${ }_{\text {[17, } 27]}$ |
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| $\left[\begin{array}{c}18,17] \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[18,18]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}\text { [18, 19] } \\ 0\end{array}\right.$ | $\begin{aligned} & {[18,20]} \\ & 45674.43 \end{aligned}$ | $\left[\begin{array}{c}{[18,21]} \\ 0\end{array}\right.$ | $\begin{gathered} {[18,22]} \\ 0 \end{gathered}$ | $\left[\begin{array}{c}{[18,23]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[18,24]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[18,25]} \\ 0\end{array}\right.$ | $\begin{gathered} {[18,26]} \\ 0 \end{gathered}$ | $\left[\begin{array}{c}\text { [18, 27] } \\ 0\end{array}\right.$ |
| $\begin{gathered} {[19,17]} \\ 0 \end{gathered}$ | $\begin{gathered} {[19,18]} \\ 0 \end{gathered}$ | $\begin{gathered} {[19,19]} \\ 27093.188 \end{gathered}$ | $\left[\begin{array}{c} 19,20] \\ 0 \end{array}\right.$ | $\begin{gathered} {[19,21]} \\ 0 \end{gathered}$ | $\begin{aligned} & {[19,22]} \\ & 49578.441 \end{aligned}$ | $\underset{0}{[19,23]}$ | $\begin{aligned} & {[19,24]} \\ & 65040.983 \end{aligned}$ | ${ }_{40007.654}^{[19.25]}$ | $\begin{gathered} {[19,26]} \\ 0 \end{gathered}$ | $\begin{gathered} {[19,27]} \\ 0 \end{gathered}$ |
| $\left[\begin{array}{c}{[20,17]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[20,18]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}\text { [20, 19] } \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[20,20]} \\ 0\end{array}\right.$ | $[20,21]$ 0 | $\begin{gathered} {[20,22]} \\ 0 \end{gathered}$ | $\left[\begin{array}{c}{[20,23]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[20,24]} \\ 0\end{array}\right.$ | $\begin{aligned} & {[20.25]} \\ & 51151.326 \end{aligned}$ | $[20,26]$ 0 | $\left[\begin{array}{c}{[20,27]} \\ 0\end{array}\right.$ |
| $\left[\begin{array}{c}\text { [21, 17] } \\ 0\end{array}\right.$ | ${ }^{[21.18]}$ 4613.754 | $\begin{aligned} & {[21,19]} \\ & 34789.209 \end{aligned}$ | $\begin{aligned} & {[21,20]} \\ & 36087548 \end{aligned}$ | $\left[\begin{array}{c}{[21,21]} \\ 0\end{array}\right.$ | $\begin{gathered} {[21,22]} \\ 0 \\ \text { base } \end{gathered}$ | $\left[\begin{array}{c}{[21,23]} \\ 0\end{array}\right.$ | $\begin{aligned} & {[21,24]} \\ & 34990.466 \end{aligned}$ | $\begin{aligned} & {[21,25]} \\ & 61964.373 \end{aligned}$ | $\begin{aligned} & {[21,26]} \\ & 48798.449 \end{aligned}$ | ${ }_{\text {[21, } 27]}$ |
| $\left[\begin{array}{c}{[22,17]} \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[22,18]} \\ 0\end{array}\right.$ | $\begin{gathered} {[22,19]} \\ 31887.188 \end{gathered}$ | $\begin{gathered} {[22.20]} \\ 34007.866 \end{gathered}$ | $\left[\begin{array}{c}\text { [22, 21] } \\ 0\end{array}\right.$ | $\left[\begin{array}{c}\text { [22,22] } \\ 0\end{array}\right.$ | $\left[\begin{array}{c}{[22,23]} \\ 0\end{array}\right.$ | $\begin{aligned} & {[22,24]} \\ & 40449.729 \end{aligned}$ | $\left[\begin{array}{c}{[22,25]} \\ 0\end{array}\right.$ | $\left[{ }^{[22,26]}\right.$ | $\left[{ }^{[22,27]}\right.$ |
| $\begin{gathered} {[23,17]} \\ 0 \end{gathered}$ | $\begin{gathered} {[23,18]} \\ 0 \end{gathered}$ | $\begin{gathered} {[23,19]} \\ 0 \end{gathered}$ | $\begin{gathered} {[23.20]} \\ 0 \end{gathered}$ | $\begin{gathered} {[23,21]} \\ 0 \end{gathered}$ | $\underset{0}{[23,22]}$ | $\begin{aligned} & {[23.231} \\ & 42169.577 \end{aligned}$ | $\begin{aligned} & {[23,24]} \\ & 35476.933 \end{aligned}$ | $\begin{gathered} {[23,25 \mid} \\ 0 \end{gathered}$ | $\begin{gathered} {[23,26]} \\ 0 \end{gathered}$ | $\begin{gathered} {[23,27]} \\ 0 \end{gathered}$ |
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| $\begin{gathered} {[25,17]} \\ 0 \end{gathered}$ | $\begin{gathered} {[25,18]} \\ 0 \end{gathered}$ | $\begin{gathered} {[25,19]} \\ 0 \end{gathered}$ | $\left[\begin{array}{c} {[25,20]} \\ 0 \end{array}\right.$ | $\begin{gathered} {[25,21]} \\ 493446.414 \end{gathered}$ | $\begin{gathered} {[25,22]} \\ 0 \end{gathered}$ | $\begin{gathered} {[25,23]} \\ 0 \end{gathered}$ | $\begin{gathered} {[25,24]} \\ 0 \end{gathered}$ | $\underset{0}{[25,25]}$ | $\begin{gathered} {[25,26]} \\ 0 \end{gathered}$ | $\begin{gathered} {[25,27]} \\ 0 \end{gathered}$ |
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## Is continual resolving really almighty?

■ use DeepStack ideas on different domains than poker
■ replace neural network with handmade heuristics

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Single attack
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Single attack


Multiple attacks

## Should everyone use continual resolving?

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Well, not really

## Heuristics producing strategies

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Poker:
PAWS:

## Heuristics producing strategies

Poker:
■ large game tree

PAWS:
■ large game tree

## Heuristics producing strategies

Poker:

- large game tree

■ too complex strategies

PAWS:
■ large game tree

## Heuristics producing strategies

Poker:<br>■ large game tree<br>■ too complex strategies

PAWS:
■ large game tree
■ not so complex strategies

## Improvement during on-line play

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CTU
CZECH TEGHNICAL UNIVERSITY in pracue

## Improvement during on-line play



## Improvement during on-line play



## Improvement during on-line play


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CTU
CZECH TECHNICAL university
in pracue

## Improvement during on-line play



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[1] Fang, Fei, et al. - Deploying PAWS: Field Optimization of the Protection Assistant for Wildlife Security. AAAI (2016)
[2] Moravčík et al. — Deepstack: Expert-level artificial intelligence in heads-up no-limit poker. Science, 356(6337):508-513 (2017)

## Thank You!

