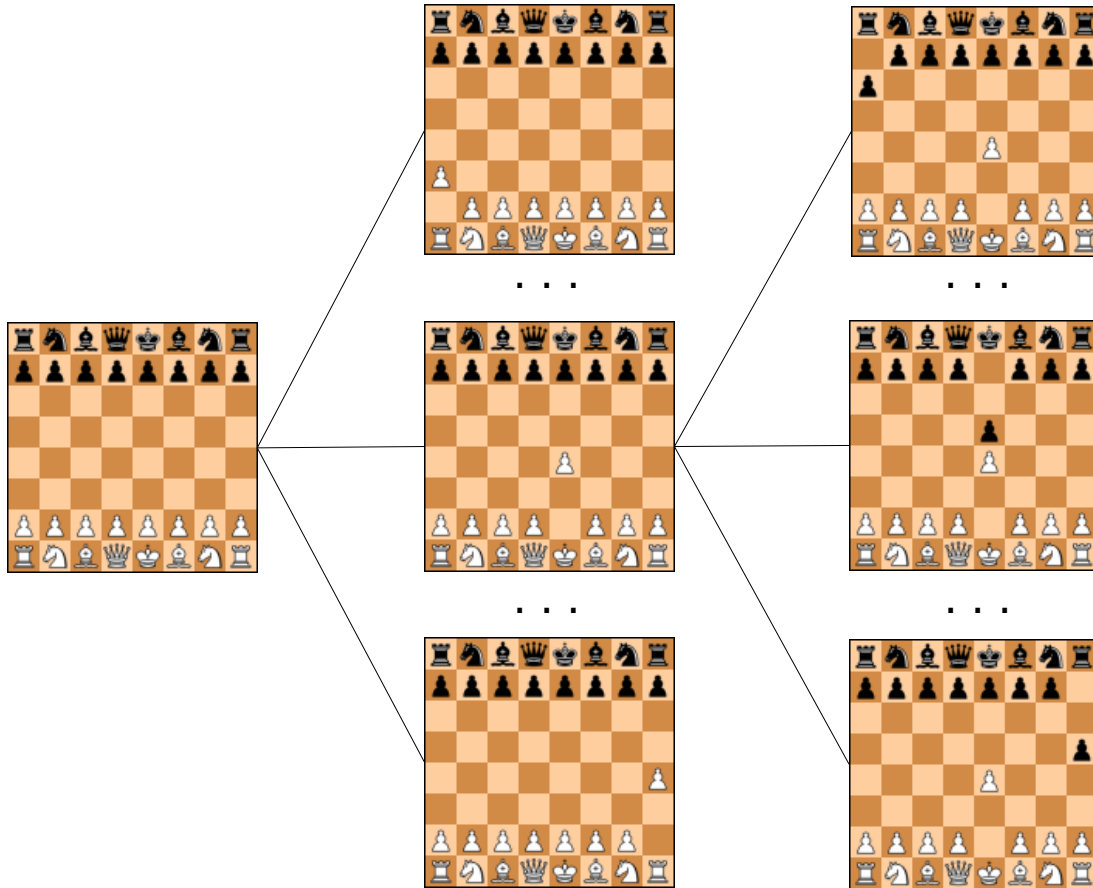




Playing Games

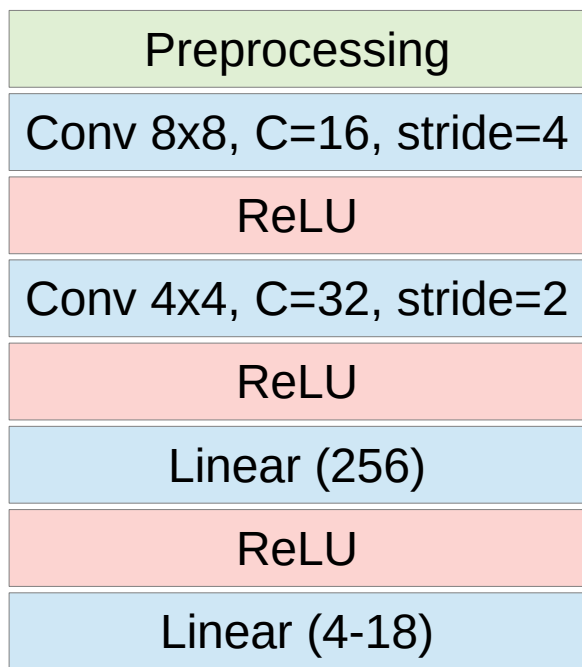
The Early Days: Chess



Exhaustive tree search with pruning (alpha-beta)

Handwritten evaluation: $V(s)$

Deep Learning: Atari Games



“Deep Q learning”

Learn to predict the long-term rewards for each state-action pair

$$V(s) = \mathbb{E}_{a \sim \pi(s)} Q(s, a)$$

Superhuman performance on three of the seven games they tested on.

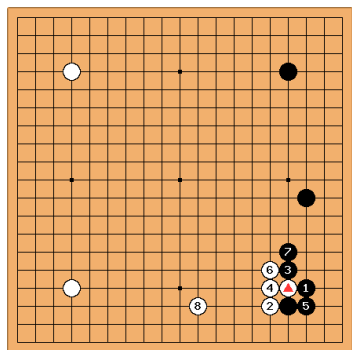
Deep Learning + Search: Go

- Two network outputs: policy and value

π

V

- Monte Carlo Tree Search



Sample rollouts

$$a_i \sim \pi(s_i)$$

Evaluate the resulting position

$$V(s_N)$$

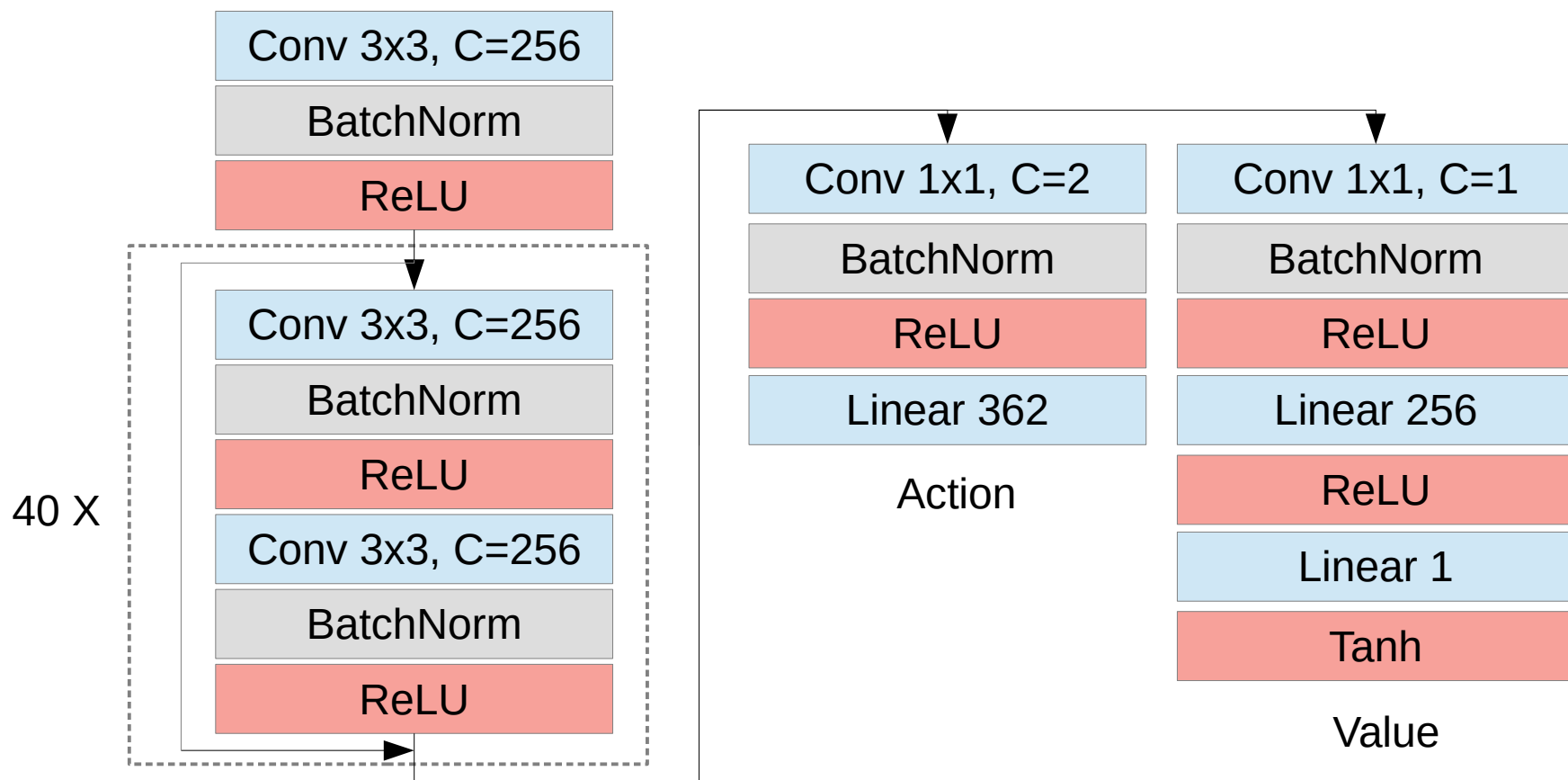
AlphaGo¹: Initially trained by imitation learning
Later trained by self-play

AlphaGo Zero²: Trained entirely by self-play

1 David Silver, et al. "Mastering the Game of Go with Deep Neural Networks and Tree Search." Nature. Jan. 27, 2016

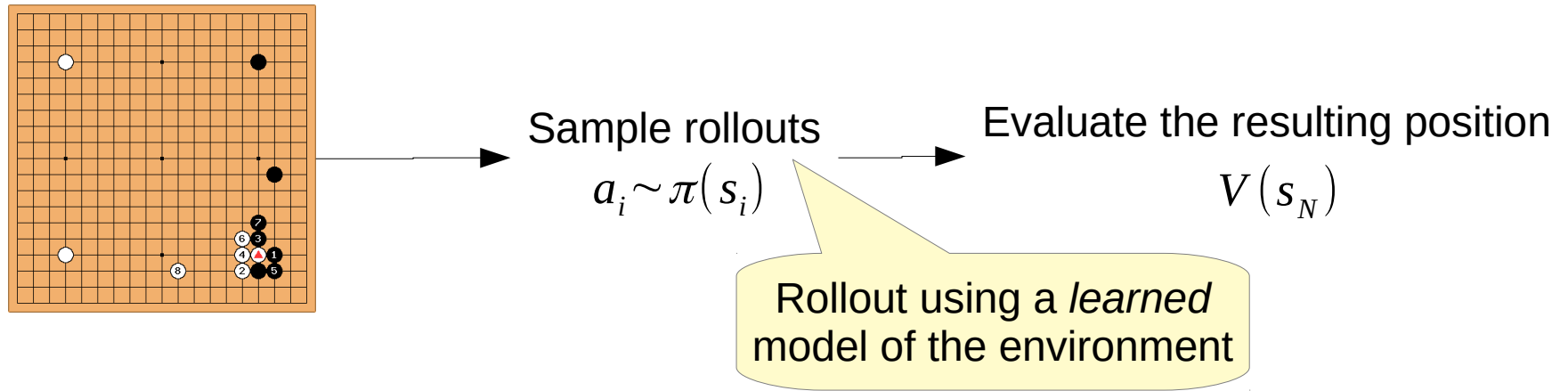
2 David Silver, et al. "Mastering the Game of Go without Human Knowledge." Nature. Oct. 18, 2017

AlphaGoZero Architecture



Generalization: AlphaZero and MuZero

- AlphaZero: Same architecture for Chess, Shogi, and Go.
- MuZero: No prior knowledge of the game rules.

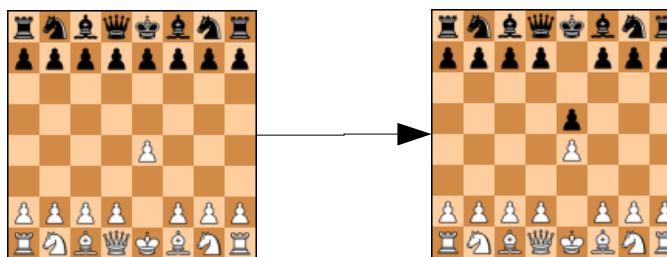
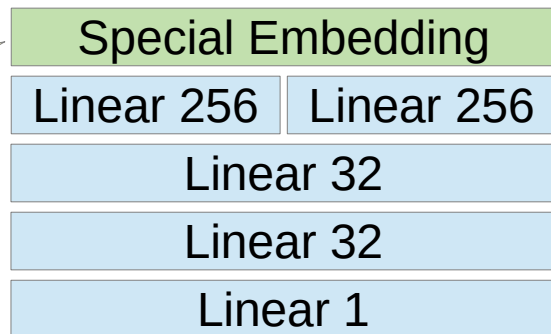


“Model-based reinforcement learning”

NNUE: Shogi and Chess

Deep networks are slow to run on CPU

Allows efficient computation of adjacent positions



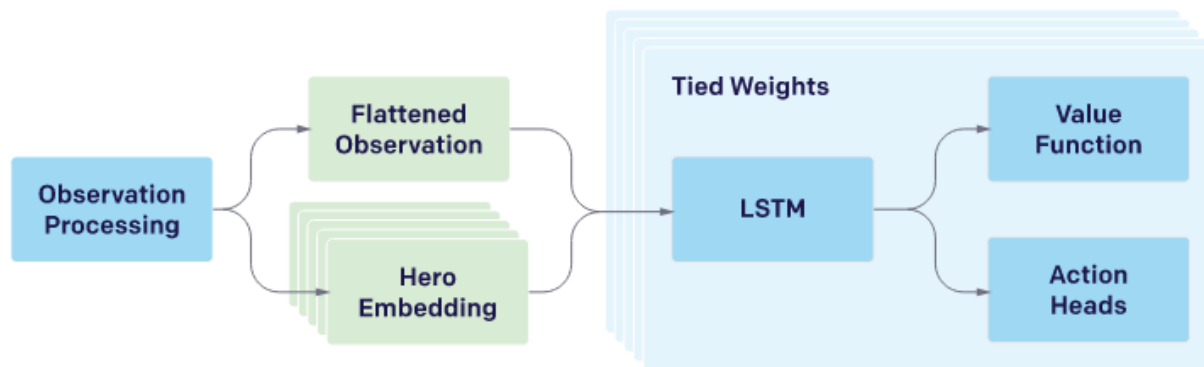
Most activations are unchanged

~500x more nodes per second than Leela Chess Zero

Video Games

- Partial observability, complex rules
- High-dimensional state and action spaces
- Real-time constraints
- Cooperation

Dota 2: OpenAI 5



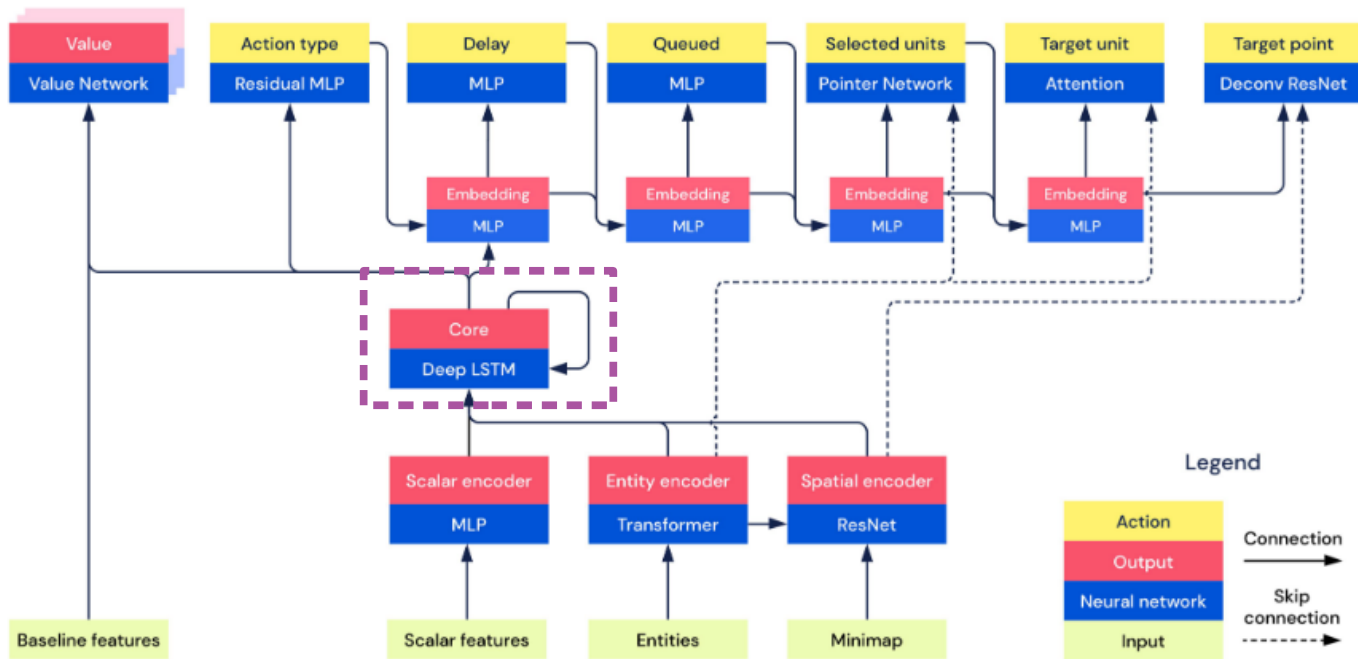
(+ some handwritten logic)

Trained with self-play and reward shaping.

Defeated top 1v1 players in August 2017.

Won 5v5 match against the world champions in April 2019.

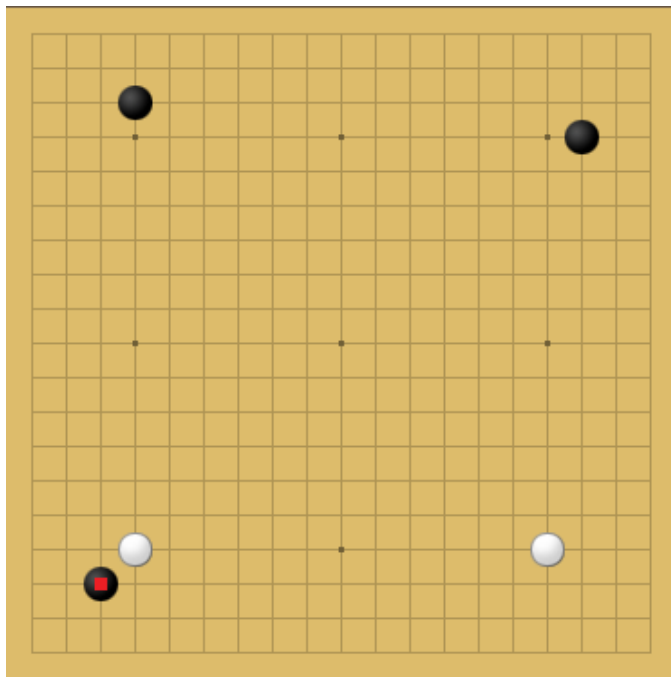
StarCraft II: AlphaStar



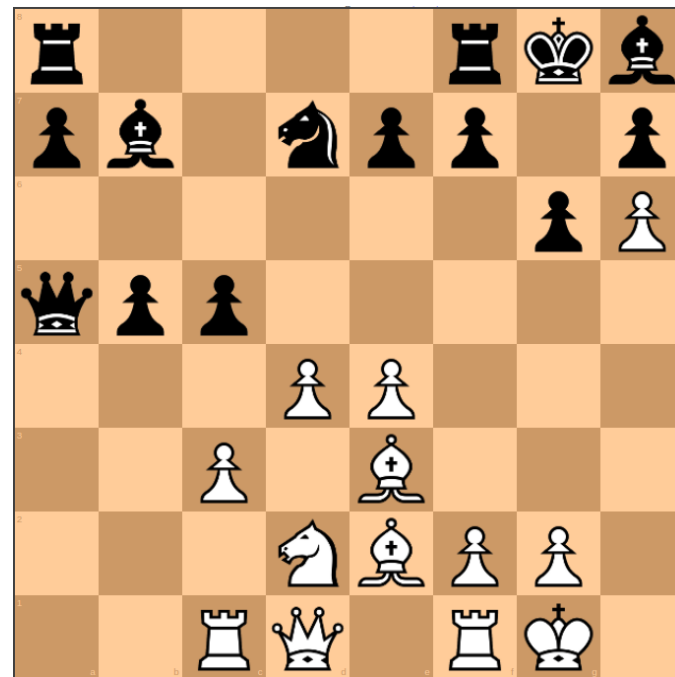
Combination of imitation learning and self-play

Rating higher than 99.8% of human players in blind league play

Feedback to Human Play



Ichiriki Ryo (9p) vs Byun Sangil (9p)
14th Chunlan Cup World Weiqi Championship
Round of 24



Magnus Carlsen vs. Shakhriyar Mamedyarov
Norway Chess 2019
Round 4