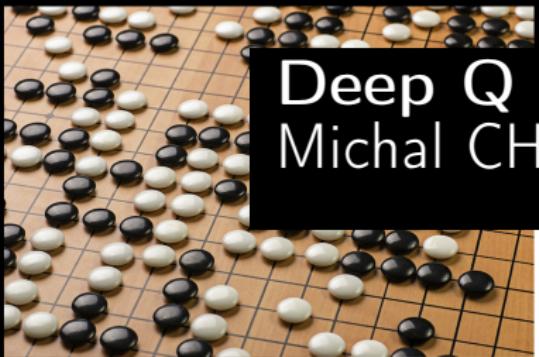


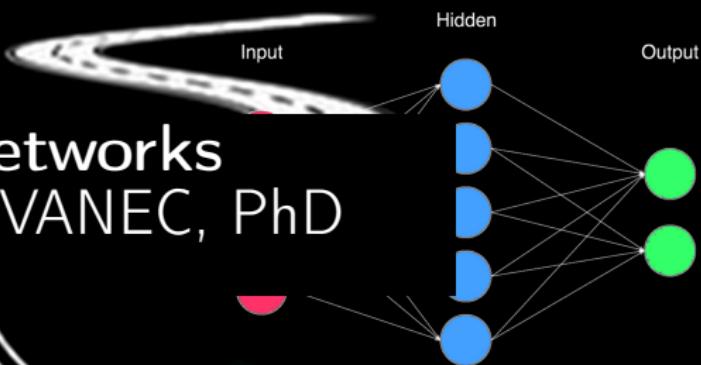
$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha [r_{t+1} + \lambda \max_a Q(s_{t+1}, a) - Q(s_t, a_t)]$$

(The New Action Value = The Old Value) + The Learning Rate  $\times$  (The New Information — the Old Information)



# Deep Q networks

Michal CHOVANEC, PhD



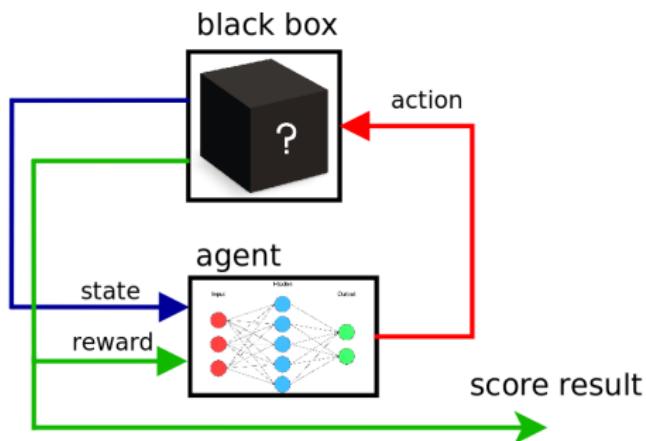
# Reinforcement learning

- learn from punishment and rewards
- learn to play a game with unknown rules



# Reinforcement learning

- obtain **state**
- choose **action**
- execute **action**
- obtain **reward**
- learn from **experiences**



# Q learning (1989)

$$Q(s, a) = R + \gamma \max_{a'} Q(s', a')$$

where

$s$  is state

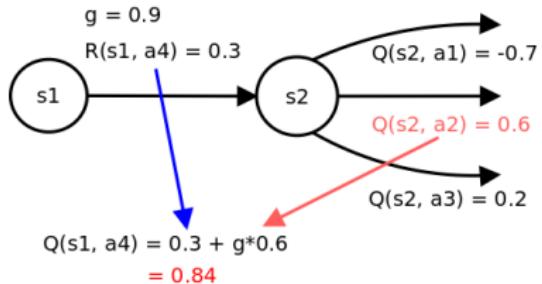
$a$  is action

$s'$  is next state

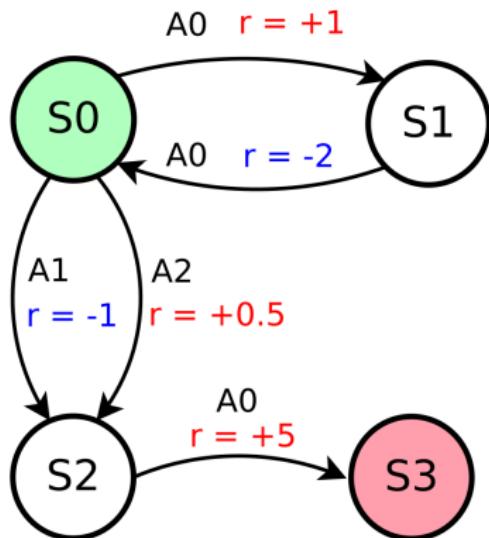
$a'$  is best action in next state

$R(s, a)$  is reward

$\gamma \in \langle 0, 1 \rangle$  is discount factor

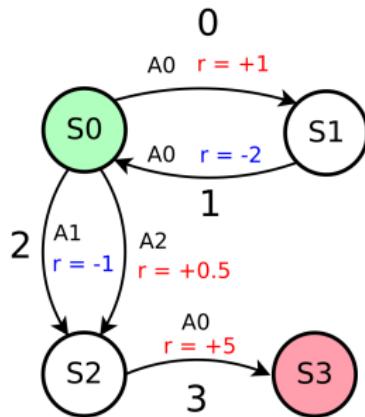


## Q learning - example



S	reward			Q(s,a)		
	A0	A1	A2	A0	A1	A2
0	1	-1	0.5	0	0	0
1	-2	x	x	0	0	0
2	5	x	x	0	0	0
3	x	x	x	0	0	0

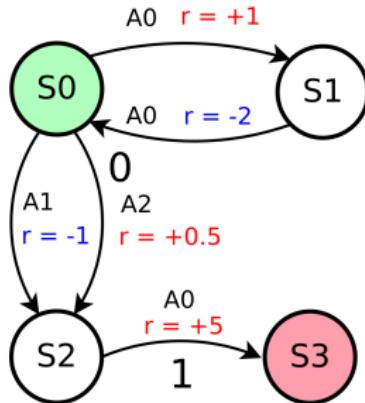
# Q learning - example



S	reward			Q(s,a)		
	A0	A1	A2	A0	A1	A2
0	1	-1	0.5	2.035	3.5	0
1	-2	x	x	1.15	0	0
2	5	x	x	5	0	0
3	x	x	x	0	0	0

state	S0	S1	S0	S2	S3
action	A0	A0	A1	A0	
reward	+1	-2	-1	+5	
Q	$1 + 0.9 * 1.15 =$ 2.035	$-2 + 0.9 * 3.5 =$ 1.15	$-1 + 0.9 * 5 =$ 3.5	5	

# Q learning - example



S	reward			Q(s,a)		
	A0	A1	A2	A0	A1	A2
0	1	-1	0.5	<b>2.035</b>	<b>3.5</b>	<b>5</b>
1	-2	x	x	<b>1.15</b>	0	0
2	5	x	x	<b>5</b>	0	0
3	x	x	x	0	0	0

state	S0	S2	S3
action	A2	A0	
reward	0.5	+5	
Q	$0.5 + 0.9 \cdot 5 = 5$	5	

# Deep Q network - DQN (2013)

Approximate  $Q(s, a)$  using deep neural network as  $\hat{Q}(s, a; w)$ ,  
where  $w$  are learnable network parameters

$$Q(s, a) = R + \gamma \max_{\alpha'} Q(s', \alpha')$$

$$\hat{Q}(s, a; w) = R + \gamma \max_{\alpha'} \hat{Q}(s', \alpha'; w)$$

error to minimize

$$E = R + \gamma \max_{\alpha'} \hat{Q}(s', \alpha'; w) - \begin{array}{l} \hat{Q}(s, a; w) \\ \text{predicted value} \end{array}$$

target value

weights gradient

$$\Delta w = \eta E \nabla_w \hat{Q}(s, a, w)$$

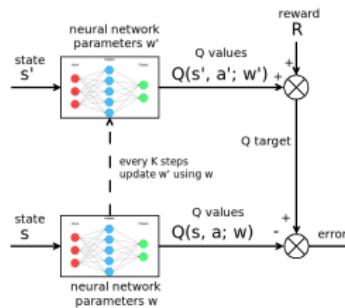
# Deep Q network - DQN

- **correlated states** : experience replay buffer
- **unstable training** :  
non-stationary target value  $\hat{Q}(s, a; w)$ , depends on  $w$
- **solution - fix  $w$**  :  
using temporary network with  $w'$  weights.

## DQN equation

$$\hat{Q}(s, a; w) = R + \gamma \max_{\alpha'} \hat{Q}(s', \alpha'; w')$$

$$E = R + \gamma \max_{\alpha'} \hat{Q}(s', \alpha'; w') - \hat{Q}(s, a; w)$$



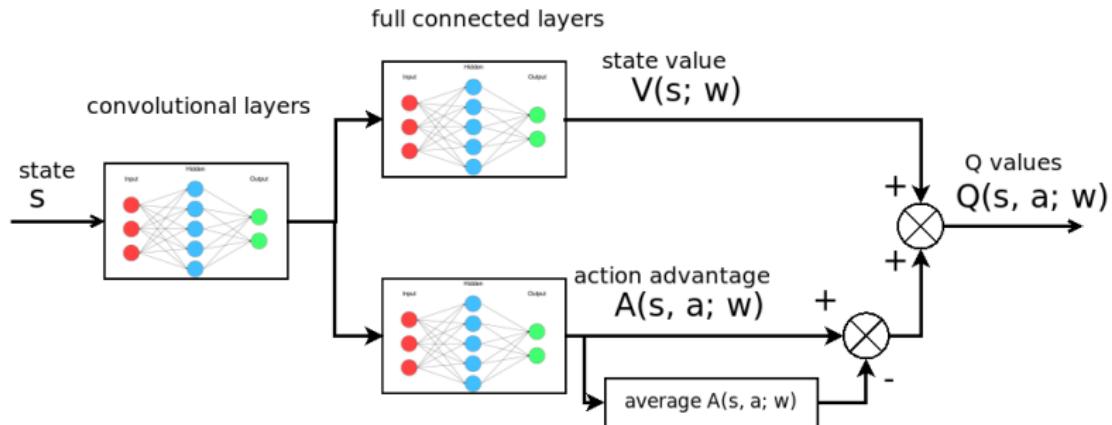
# Dueling deep Q network - DDQN (2016)

$$\hat{Q}(s, a; w) = \hat{V}(s; w) + \hat{A}(s, a; w)$$

value for being in state s      advantage of taking action a at state s

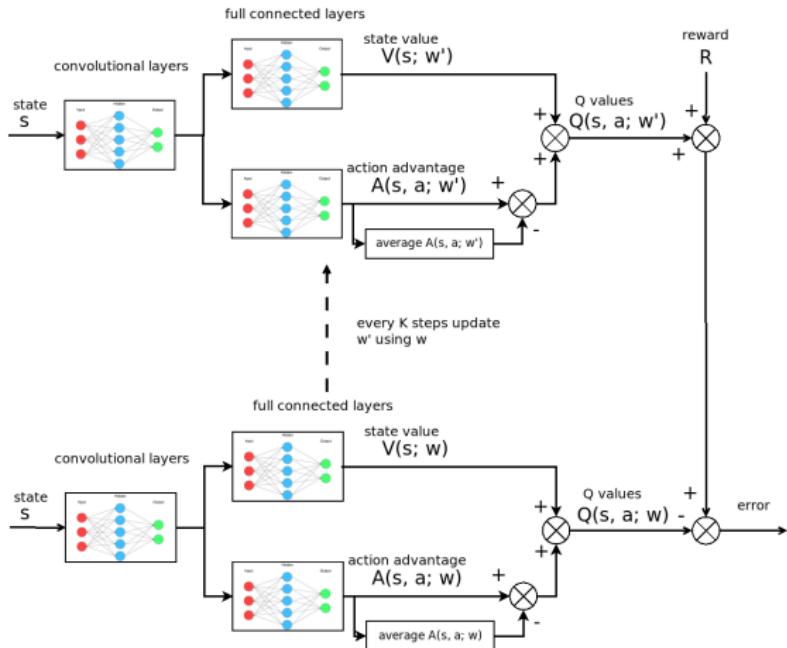
to avoid identifiability we subtract average value of A truth all actions

$$\hat{Q}(s, a; w) = \hat{V}(s; w) + \hat{A}(s, a; w) - \frac{1}{N_{\alpha'}} \sum_{\alpha'} \hat{A}(s, \alpha'; w)$$



# Dueling deep Q network - DDQN

$$\hat{Q}(s, a; w) = \hat{V}(s; w) + \hat{A}(s, a; w) - \frac{1}{N_{\alpha'}} \sum_{\alpha'} \hat{A}(s, \alpha'; w)$$



## Dueling deep Q network - DDQN

using DQN equation

$$\hat{Q}(s, a; w) = R + \gamma \max_{\alpha'} \hat{Q}(s', \alpha'; w')$$

we obtain dueling deep Q network equation

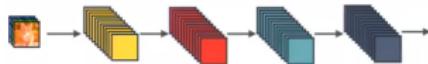
$$\hat{Q}(s, a; w) = R + \gamma \left( \hat{V}(s'; w') + \max_{\alpha'} \hat{A}(s', \alpha'; w') - \frac{1}{N_{\alpha'}} \sum_{\alpha'} \hat{A}(s', \alpha'; w') \right)$$

and finally the weights update rule

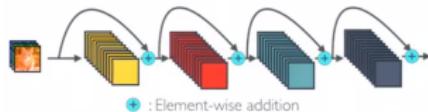
$$\Delta w = \eta \left( R + \gamma \left( \hat{V}(s'; w') + \max_{\alpha'} \hat{A}(s', \alpha'; w') - \frac{1}{N_{\alpha'}} \sum_{\alpha'} \hat{A}(s', \alpha'; w') \right) - \hat{Q}(s, a; w) \right) \nabla_w \hat{Q}(s, a; w)$$

# DenseNet

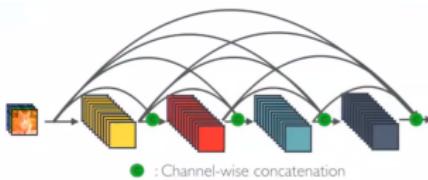
- CNN



- ResNET

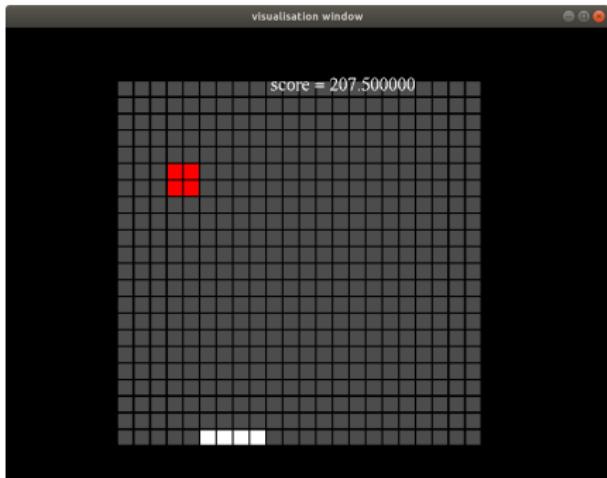


- DenseNet



layer type	input dimensions	kernel dimensions	output dimensions
dense convolution	256x256x4	3x3x8	256x256x12
dense convolution	256x256x12	3x3x8	256x256x20
dense convolution	256x256x20	3x3x8	256x256x28
dense convolution	256x256x28	3x3x8	256x256x36
convolution	256x256x36	1x1x16	256x256x16
pooling	256x256x16	2x2	128x128x16

# Experiments



## Network hyperparameters

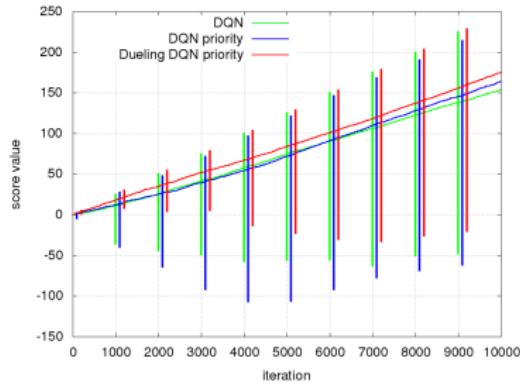
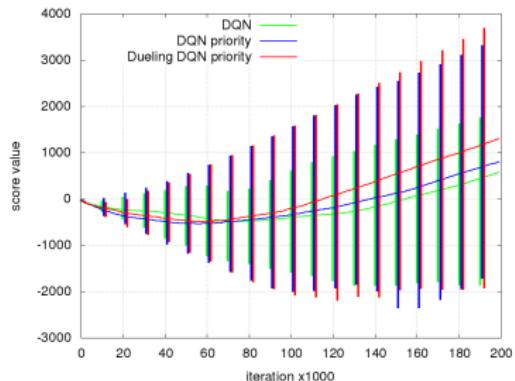
- init weights : XAVIER
- learning rate : 0.0005
- L1 regularization : 0.0000001
- L2 regularization : 0.0000001
- dropout : 0.2
- minibatch size : 32

## RL hyperparameters

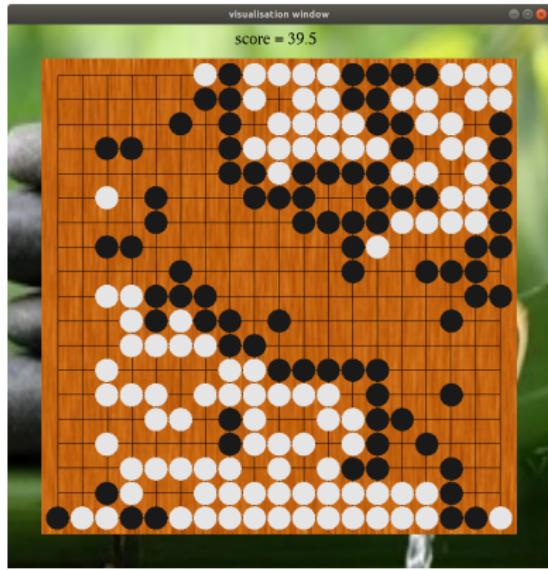
- experience buffer size : 1024
- gamma : 0.95
- epsilon training : 0.1
- epsilon testing : 0.05

layer type	input dimensions	kernel dimensions
dense convolution	22x22x1	3x3x8
dense convolution	22x22x9	3x3x8
dense convolution	22x22x17	3x3x8
dense convolution	22x22x25	3x3x8
convolution	22x22x33	3x3x32
full connected	22x22x32	actions_count

# Results



# Playing GO (October 2017)

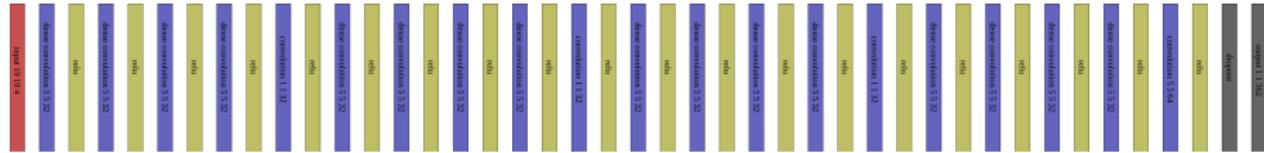


- **supervised training** - train game using Masters games
- **reinforcement learning** - let play two networks against each other

## Network architecture

we need to go much deeper for GO

- **20 convolutional layers**  
4 blocks with 4 dense conv + 1 conv layer
  - **input**  
4 matrices  $19 \times 19$ : black stones, white stones, empty fields, active player
  - **output**  
recommended moves  $19 \times 19 + 1$  for pass = 362 outputs



# Network architecture

layer type	input size	kernel size	output size
dense convolution	19x19x4	5x5x32	19x19x36
dense convolution	19x19x36	5x5x32	19x19x68
dense convolution	19x19x68	5x5x32	19x19x100
dense convolution	19x19x100	5x5x32	19x19x132
convolution	19x19x132	1x1x32	19x19x32
dense convolution	19x19x32	5x5x32	19x19x64
dense convolution	19x19x64	5x5x32	19x19x96
dense convolution	19x19x96	5x5x32	19x19x128
dense convolution	19x19x128	5x5x32	19x19x160
convolution	19x19x160	1x1x32	19x19x32
dense convolution	19x19x32	5x5x32	19x19x64
dense convolution	19x19x64	5x5x32	19x19x96
dense convolution	19x19x96	5x5x32	19x19x128
dense convolution	19x19x128	5x5x32	19x19x160
convolution	19x19x160	1x1x32	19x19x32
dense convolution	19x19x32	5x5x32	19x19x64
dense convolution	19x19x64	5x5x32	19x19x96
dense convolution	19x19x96	5x5x32	19x19x128
dense convolution	19x19x128	5x5x32	19x19x160
convolution	19x19x160	5x5x64	19x19x64
full connected	19x19x64	19x19x362	362

# Supervised results

74	5	6	6	13	12	26	25	23	19	21	20	19	22	14	12	12	15	82
12	26	43	37	31	35	32	33	35	30	30	35	35	36	31	30	43	26	7
25	39	50	73	42	50	34	35	37	43	34	32	38	50	48	58	48	52	15
15	29	55	82	43	46	41	41	41	31	38	37	38	44	35	55	48	40	16
28	37	62	50	47	43	43	50	51	50	47	46	46	45	44	56	49	48	20
31	34	64	53	44	43	44	48	43	50	46	47	43	44	44	52	54	43	17
35	35	45	43	44	44	48	49	45	45	51	51	44	42	46	49	36	47	21
31	34	46	46	49	45	51	46	50	53	48	48	47	46	50	45	42	49	27
29	33	41	41	48	49	46	50	50	52	47	50	48	46	47	41	46	49	25
27	41	39	34	48	47	48	49	49	54	50	51	48	49	52	35	49	45	29
31	37	42	42	47	49	47	47	49	48	49	50	48	47	47	40	43	45	34
28	39	44	46	45	46	45	49	51	49	51	45	46	43	46	41	44	49	22
29	38	38	45	50	44	48	50	45	43	50	49	51	50	41	49	43	49	20
31	34	73	49	40	41	42	45	42	45	47	47	47	45	48	53	53	49	25
32	30	57	52	44	41	42	44	47	50	51	46	46	43	47	52	49	40	18
24	34	64	77	47	53	41	45	43	30	45	46	41	48	40	61	71	39	8
24	51	56	65	46	58	45	42	41	46	38	35	38	45	63	76	51	52	9
32	26	52	47	44	46	47	39	40	44	43	42	43	37	45	44	46	46	18
77	3	4	3	7	13	13	17	29	34	19	25	20	23	13	9	8	13	66
															100			

# Usefull links

-  **CHRISTOPHER J.C.H. WATKINS : Q-learning**  
<http://www.gatsby.ucl.ac.uk/~dayan/papers/cjch.pdf>
-  **Richard S. Sutton : Reinforcement Learning: An Introduction**  
<https://www.amazon.com/Reinforcement-Learning-Introduction-Adaptive-Computation/dp/0262193981>
-  **Google DeepMind : Playing Atari with Deep Reinforcement Learning**  
<https://arxiv.org/pdf/1312.5602.pdf>
-  **Google DeepMind : Dueling Network Architectures for Deep Reinforcement Learning**  
<https://arxiv.org/pdf/1511.06581.pdf>
-  **Google DeepMind :Mastering the Game of Go without Human Knowledge**  
[https://deepmind.com/documents/119/agz\\_unformatted\\_nature.pdf](https://deepmind.com/documents/119/agz_unformatted_nature.pdf)
-  **Andrej Karpathy : Pong from pixels**  
<http://karpathy.github.io/2016/05/31/r1/>
-  **Maxim Lapan : Deep reinforcement learning**  
<https://www.amazon.com/Practical-Reinforcement-Learning-Maxim-Lapan/dp/1788834240>
-  **Mohit Sewak : Practical Convolutional Neural Networks**  
<https://www.amazon.com/Practical-Convolutional-Neural-Networks-Implement/dp/1788392302>
-  **Densely Connected Convolutional Networks**  
<https://arxiv.org/pdf/1608.06993.pdf>

# Q&A



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github <https://github.com/michalnand>