Learning by Approximation

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Today two examples:

1. Approximation in least square sense
2. Approximative Q-learning

Least square approximation

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We have:

- given tuples $(x_i, f(x_i)) : (0, 2.1), (1, 3.6), (2, 4.9), (3, 6.6), \ldots$
- approximation of function $\hat{f}(x, \mathbf{w}) = w_1 x + w_0$

Task: determine/compute parameters w_0, w_1 with lowest error

How?:

A: minimize difference in coordinates

B: maximize error

C: minimize sum of squared errors

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How? - minimize sum of squared errors.

Define:

A: $\sum_i (f(x_i) - x_i)^2$

B: $\sum_i (\hat{f}(x_i, \mathbf{w}) - f(x_i))^2$

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Minimize sum of squared errors: $E = \sum_i (\hat{f}(x_i, \mathbf{w}) - f(x_i))^2$

How?:

A: find solution of $E = 0$

B: find maximum of E

C: find minimum of E

D: find solution $E = -\infty$

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How? Solve:

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B: $\partial E = 0$

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Derive by:

A: x

B: $\mathbf{w}$

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D: $f(x_i)$

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A: $\frac{\partial E}{\partial w_0} = 2 \sum_i (w_1 x_i - f(x_i))$

B: $\frac{\partial E}{\partial w_0} = 2 \sum_i (w_1 x_i + 1 - f(x_i))$

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Solve linear equation system.

Using given tuples (for simplicity let's use only first three tuples).

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Evaluate:

A: $\frac{\partial E}{\partial w_0} = w_1 - w_0 + 5$

B: $\frac{\partial E}{\partial w_0} = 2w_1 + w_0 - 4.2$

C: $\frac{\partial E}{\partial w_0} = 3w_1 + 3w_0 - 10.6$

D: $\frac{\partial E}{\partial w_0} = w_1 - 2w_0 - 3.1$

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C: $\frac{\partial E}{\partial w_0} = (w_1 \cdot 0 + w_0 - 2.1) + (w_1 \cdot 1 + w_0 - 3.6) + (w_1 \cdot 2 + w_0 - 4.9) = 3w_1 + 3w_0 - 10.6$

D: $\frac{\partial E}{\partial w_0} = w_1 - 2w_0 - 3.1$

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Evaluate:

A: $\frac{\partial E}{\partial w_1} = 5w_1 + 3w_0 - 13.4$

B: $\frac{\partial E}{\partial w_1} = 2w_1 + 6.2$

C: $\frac{\partial E}{\partial w_1} = w_1 + w_0 - 2.4$

D: $\frac{\partial E}{\partial w_1} = 2w_0 - 3.1$

Least square approximation

We have:

- given tuples $(x_i, f(x_i)) : (0, 2.1), (1, 3.6), (2, 4.9), (3, 6.6), \ldots$
- approximation of function $\hat{f}(x, \mathbf{w}) = w_1 x + w_0$

Task: determine/compute parameters w_0, w_1 with lowest error

Minimize sum of squared errors: $E = \sum_i (\hat{f}(x_i, \mathbf{w}) - f(x_i))^2$
Find minimum of E by derivation $\frac{\partial E}{\partial \mathbf{w}} = \frac{\partial}{\partial \mathbf{w}} \sum_i (w_1 x_i + w_0 - f(x_i))^2 = 0$

$$\frac{\partial E}{\partial w_0} = \sum_i (w_1 x_i + w_0 - f(x_i)) = 3w_1 + 3w_0 - 10.6 = 0$$

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Evaluate:

A: $\frac{\partial E}{\partial w_1} = (w_1 \cdot 0 + w_0 - 2.1) \cdot 0 + (w_1 \cdot 1 + w_0 - 3.6) \cdot 1 + (w_1 \cdot 2 + w_0 - 4.9) \cdot 2 = 5w_1 + 3w_0 - 13.4$

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$$-2w_1 + 2.8 = 0 \rightarrow w_1 = 1.4$$

$$w_0 = 1/3(10.6 - 3w_1) = \frac{6.4}{3} \approx 2.133$$

$\Rightarrow \hat{f}(x, \mathbf{w}) = 1.4x + 2.133$

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We have:

- an unknown grid world
- a few episodes the robot tried

Today:

- we approximate Q-function
- $\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$
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Episode 1	**Episode 2**	**Episode 3**
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each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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SGD briefly:

- Find $\mathbf{w}$ that minimize $\sum_t(\mathrm{trial}_t - \hat{q}(s_t, a_t, \mathbf{w}))^2$
- How to do it online?
- In every timestep t, modify $\mathbf{w}$ that value of $(\mathrm{trial}_t - \hat{q}(s_t, a_t, \mathbf{w}))^2$ will decrease.
- How?

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How?:

A: $\mathbf{w} \leftarrow \mathbf{w} + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}))\hat{q}(s_t, a_t, \mathbf{w}) + \alpha(\hat{q}(s_t, a_t, \mathbf{w}))$

B: $\hat{q}(s_t, a_t, \mathbf{w}) \leftarrow \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}))$

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A: $\mathrm{trial} = r_{t+1} + \gamma\hat{q}(s_{t+1}, a, \mathbf{w})$

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B: $w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))$

C: $w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$

D: $w_1^{t+1} = w_1^t + (\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
$A = \{0, 1\}$
$\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$

Task: compute Q-function - from each tuple refine w_0, w_1

- $\mathbf{w} \leftarrow \mathbf{w} + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}))\nabla\hat{q}(s_t, a_t, \mathbf{w})$
- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

Define w_1 update:

A: $w_1^{t+1} = w_1^t + \alpha(\hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$

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Approximative Q-learning

Episode 1	Episode 2	Episode 3
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$$w_1^{t+1} = w_1^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

Define w_0 update:

A: $w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))$

B: $w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$

C: $w_0^{t+1} = w_0^t + \alpha(\mathrm{trial})(1 - a_t)$

D: $w_0^{t+1} = w_0^t + (\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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Approximative Q-learning

Episode 1	Episode 2	Episode 3
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$$w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

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A: $w_0^{t+1} = w_0^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))$

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Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0,1,1,-2)$	$(0,0,-1,0)$	$(1,1,\mathit{exit},2)$
$(1,1,\mathit{exit},2)$	$(-1,0,\mathit{exit},-1)$	

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
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- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

Let's compute $\mathbf{w} = (w_1, w_0)$
For simplicity: $\gamma = 1, \alpha = 1$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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Let's compute $\mathbf{w} = (w_1, w_0)$

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Approximative Q-learning

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Let's compute $\mathbf{w} = (w_1, w_0)$

For simplicity: $\gamma = 1, \alpha = 1$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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  $$w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
  $$w_0^{t+1} = w_0^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$
- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

Initialize $\mathbf{w}$:

A: $\mathbf{w} = (w_1, w_0) = (1, 1)$

B: $\mathbf{w} = (w_1, w_0) = (0, 1)$

C: $\mathbf{w} = (w_1, w_0) = (0, 0)$

D: arbitrarily

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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Task: compute Q-function - from each tuple refine w_0, w_1

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$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- $\mathrm{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

Initialize $\mathbf{w}$:

A: $\mathbf{w} = (w_1, w_0) = (1, 1)$

B: $\mathbf{w} = (w_1, w_0) = (0, 1)$

C: $\mathbf{w} = (w_1, w_0) = (0, 0)$

D: arbitrarily (we choose $\mathbf{w} = (w_1, w_0) = (0, 0)$)

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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- $\mathrm{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2)$, $t = 1$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 1

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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$$w_0^{t+1} = w_0^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2)$, $t = 1$:

Compute:

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Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
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$$w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
$$w_0^{t+1} = w_0^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 1

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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- $\mathbf{w} \leftarrow \mathbf{w} + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}))\nabla\hat{q}(s_t, a_t, \mathbf{w})$

$$w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$:
Compute:

A: trial $= -2 + \max\{\hat{q}(s_{t+1} = 1, a = 0, \mathbf{w}^t), \hat{q}(s_{t+1} = 1, a = 1, \mathbf{w}^t)\} = -2 + \max\{0, 0\} = -2$

B: trial=0

C: trial = -1

D: trial = 1

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
$A = \{0, 1\}$
$\gamma = 1,\ \alpha = 1$
$\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$

Task: compute Q-function - from each tuple refine w_0, w_1

- $\mathbf{w} \leftarrow \mathbf{w} + \alpha(\mathrm{diff})\nabla\hat{q}(s_t, a_t, \mathbf{w})$; $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$

$$w_1^{t+1} = w_1^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2)$, $t = 1$: trial = -2
Compute $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 1

C: diff = -1

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0,1,1,-2)$ $(1,1,exit,2)$	$(0,0,-1,0)$ $(-1,0,exit,-1)$	$(1,1,exit,2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$: trial = -2
Compute $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 1

C: diff = -1

D: diff $= -2 - 0 = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
$A = \{0, 1\}$
$\gamma = 1,\ \alpha = 1$
$\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$

Task: compute Q-function - from each tuple refine w_0, w_1

- $\mathbf{w} \leftarrow \mathbf{w} + \alpha(\mathrm{diff})\nabla\hat{q}(s_t, a_t, \mathbf{w}); \mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$
$$w_1^{t+1} = w_1^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$
- $\mathrm{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$: trial = -2, diff = -2
Compute :

A: $w_1^{t+1} = 2$

B: $w_1^{t+1} = 0$

C: $w_1^{t+1} = 1$

D: $w_1^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
$A = \{0, 1\}$
$\gamma = 1, \ \alpha = 1$
$\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$

Task: compute Q-function - from each tuple refine w_0, w_1

- $\mathbf{w} \leftarrow \mathbf{w} + \alpha(\mathrm{diff})\nabla\hat{q}(s_t, a_t, \mathbf{w})$; $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$

$$w_1^{t+1} = w_1^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- $\mathrm{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$: trial = -2, diff = -2
Compute :

A: $w_1^{t+1} = 2$

B: $w_1^{t+1} = w_1^t + [\mathrm{diff}]s_t a_t = 0 + (-2) \cdot 1 \cdot 0 = 0$

C: $w_1^{t+1} = 1$

D: $w_1^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0,1,1,-2)$ $(1,1,exit,2)$	$(0,0,-1,0)$ $(-1,0,exit,-1)$	$(1,1,exit,2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$: trial = -2, diff = -2 $\Rightarrow w_1^{t+1} = 0$

Compute :

A: $w_0^{t+1} = 2$

B: $w_0^{t+1} = 1$

C: $w_0^{t+1} = 0$

D: $w_0^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
$(1, 1, exit, 2)$	$(-1, 0, exit, -1)$	

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$: trial = -2, diff = -2 $\Rightarrow w_1^{t+1} = 0$
Compute :

A: $w_0^{t+1} = 2$

B: $w_0^{t+1} = 1$

C: $w_0^{t+1} = 0$

D: $w_0^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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$t = 0$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 0, a_t = 1, s_{t+1} = 1, r_{t+1} = -2), t = 1$: trial = -2, diff = -2 $\Rightarrow w_1^{t+1} = 0$
Compute :

A: $w_0^{t+1} = 2$

B: $w_0^{t+1} = 1$

C: $w_0^{t+1} = w_0^t + [\mathrm{diff}](1 - a_t) = 0 + -2(1-1) = 0$

D: $w_0^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 2$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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Approximative Q-learning

Episode 1	Episode 2	Episode 3
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$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2), t = 2$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2), t = 2$:
Compute:

A: trial = -2

B: trial=0

C: trial = -1

D: trial $= 2 + \max\{0, 0\} = 2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0,1,1,-2)$	$(0,0,-1,0)$	$(1,1,exit,2)$
$(1,1,exit,2)$	$(-1,0,exit,-1)$	

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 2$: trial $= 2$
Compute $\text{diff} = \text{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 2

C: diff = -1

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 2$: trial $= 2$
Compute $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 2 − 0 = 2

C: diff = -1

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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$$w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
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- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 2$: trial $= 2$, diff $= 2$
Compute :

A: $w_1^{t+1} = 2$

B: $w_1^{t+1} = 0$

C: $w_1^{t+1} = 1$

D: $w_1^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 2$: trial $= 2$, diff $= 2$
Compute :

A: $w_1^{t+1} = 0 + 2 \cdot 1 \cdot 1 = 2$

B: $w_1^{t+1} = 0$

C: $w_1^{t+1} = 1$

D: $w_1^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2), t = 1$: trial $= 2$, diff $= 2 \Rightarrow w_1^{t+1} = 2$

Compute :

A: $w_0^{t+1} = 2$

B: $w_0^{t+1} = 1$

C: $w_0^{t+1} = 0$

D: $w_0^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 1$: trial $= 2$, diff $= 2 \Rightarrow w_1^{t+1} = 2$

Compute :

A: $w_0^{t+1} = 2$

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C: $w_0^{t+1} = 0$

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Approximative Q-learning

Episode 1	Episode 2	Episode 3
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- $\mathbf{w} \leftarrow \mathbf{w} + \alpha(\mathrm{diff})\nabla\hat{q}(s_t, a_t, \mathbf{w}); \mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$

$$w_1^{t+1} = w_1^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 1$ $\mathbf{w} = (w_1, w_0) = (0, 0)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2), t = 2$: trial $= 2$, diff $= 2 \Rightarrow w_1^{t+1} = 2$
Compute :

A: $w_0^{t+1} = 2$

B: $w_0^{t+1} = 1$

C: $w_0^{t+1} = 0 + 2(1-1) = 0$

D: $w_0^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
$(1, 1, exit, 2)$	$(-1, 0, exit, -1)$	

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
$A = \{0, 1\}$
$\gamma = 1,\ \alpha = 1$
$\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$

Task: compute Q-function - from each tuple refine w_0, w_1

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$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 2$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = 0, a_t = 0, s_{t+1} = -1, r_{t+1} = 0)$, $t = 3$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 2$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = 0, a_t = 0, s_{t+1} = -1, r_{t+1} = 0)$, $t = 3$:

Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0,1,1,-2)$	$(0,0,-1,0)$	$(1,1,exit,2)$
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each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
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- $\mathrm{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 2$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = 0, a_t = 0, s_{t+1} = -1, r_{t+1} = 0)$, $t = 3$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 2$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = 0, a_t = 0, s_{t+1} = -1, r_{t+1} = 0)$, $t = 3$:
Compute:

A: trial = -2

B: trial$=0 + \max\{(2 \cdot (-1) \cdot 0 + 0(1 - 0)), (2(-1)1 + 0(1 - 1))\} = 0 + \max\{-2, 0\} = 0$

C: trial = -1

D: trial= 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
$(1, 1, exit, 2)$	$(-1, 0, exit, -1)$	

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 2$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = 0, a_t = 0, s_{t+1} = -1, r_{t+1} = 0)$, $t = 3$: trial $= 0$
Compute $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 2

C: diff = -1

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 2$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = 0, a_t = 0, s_{t+1} = -1, r_{t+1} = 0)$, $t = 3$: trial $= 0$
Compute $\text{diff} = \text{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff $= 0 - (2 \cdot 0 \cdot 0 + 0(1 - 0)) = 0$

B: diff = 2

C: diff = -1

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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$t = 2$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = 0, a_t = 0, s_{t+1} = -1, r_{t+1} = 0)$, $t = 3$: trial $= 0$, diff $= 0$
Since [diff]$= 0$:

$\Rightarrow$ no change in (w_1, w_0)

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1)$, $t = 4$:

Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
$(1, 1, exit, 2)$	$(-1, 0, exit, -1)$	

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1), t = 4$:

Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

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$$w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
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- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1), t = 4$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0,1,1,-2)$	$(0,0,-1,0)$	$(1,1,exit,2)$
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- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1)$, $t = 4$:
Compute:

A: trial = -2

B: trial=0

C: $\text{trial} = -1 + 0 = -1$

D: trial = 2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
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$$w_0^{t+1} = w_0^t + \alpha(\mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))(1 - a_t)$$

- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1)$, $t = 4$: trial $= -1$
Compute $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 2

C: diff = -1

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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$\gamma = 1,\ \alpha = 1$
$\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$

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$$w_1^{t+1} = w_1^t + \alpha(\text{trial} - \hat{q}(s_t, a_t, \mathbf{w}^t))s_t a_t$$
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- trial $= r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1)$, $t = 4$: trial $= -1$
Compute $\text{diff} = \text{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 2

C: diff $= -1 - 0 = -1$

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
$(1, 1, exit, 2)$	$(-1, 0, exit, -1)$	

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

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- $\mathrm{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1)$, $t = 4$: trial $= -1$, diff $= -1$
Compute :

A: $w_1^{t+1} = 2$

B: $w_1^{t+1} = 0$

C: $w_1^{t+1} = 1$

D: $w_1^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
$(1, 1, exit, 2)$	$(-1, 0, exit, -1)$	

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$\hat{q}(s, a, \mathbf{w}) = asw_1 + (1 - a)w_0$

Task: compute Q-function - from each tuple refine w_0, w_1

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- $\text{trial} = r_{t+1} + \gamma \max_a \hat{q}(s_{t+1}, a, \mathbf{w})$

$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1)$, $t = 4$: trial $= -1$, diff $= -1$
Compute :

A: $w_1^{t+1} = 2 + (-1) \cdot (-1) \cdot 0 = 2$

B: $w_1^{t+1} = 0$

C: $w_1^{t+1} = 1$

D: $w_1^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$ $(1, 1, exit, 2)$	$(0, 0, -1, 0)$ $(-1, 0, exit, -1)$	$(1, 1, exit, 2)$

each field in the table is an n-tuple $(s_t, a_t, s_{t+1}, r_{t+1})$

$S = \{-1, 0, 1\}$
$A = \{0, 1\}$
$\gamma = 1,\ \alpha = 1$
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$t = 3$ $\mathbf{w} = (w_1, w_0) = (2, 0)$

Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1), t = 4$: trial $= -1$, diff $= -1 \Rightarrow w_1^{t+1} = 2$

Compute :

A: $w_0^{t+1} = 2$

B: $w_0^{t+1} = -1$

C: $w_0^{t+1} = 0$

D: $w_0^{t+1} = -2$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
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Approximative Q-learning

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Transition $(s_t = -1, a_t = 0, s_{t+1} = exit, r_{t+1} = -1)$, $t = 4$: trial $= -1$, diff $= -1 \Rightarrow w_1^{t+1} = 2$
Compute :

A: $w_0^{t+1} = 2$

B: $w_0^{t+1} = 0 + (-1) \cdot (1 - 0) = -1$

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Approximative Q-learning

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$t = 4$ $\mathbf{w} = (w_1, w_0) = (2, -1)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 5$:
Compute:

A: trial = -2

B: trial = 0

C: trial = -1

D: trial = 2

Approximative Q-learning

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Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 5$: trial $= 2$
Compute $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff = 0

B: diff = 2

C: diff = -1

D: diff = -2

Approximative Q-learning

Episode 1	Episode 2	Episode 3
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$t = 4$ $\mathbf{w} = (w_1, w_0) = (2, -1)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 5$: trial $= 2$
Compute $\mathrm{diff} = \mathrm{trial} - \hat{q}(s_t, a_t, \mathbf{w})$:

A: diff $= 2 - (2 \cdot 1 \cdot 1 + (-1)(1 - 1)) = 2 - 2 = 0$

B: diff $= 2 - 0 = 2$

C: diff $=$ -1

D: diff $=$ -2

Approximative Q-learning

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$t = 4$ $\mathbf{w} = (w_1, w_0) = (2, -1)$

Transition $(s_t = 1, a_t = 1, s_{t+1} = exit, r_{t+1} = 2)$, $t = 5$: trial $= 2$, diff $= 0$
Since [diff]$= 0$:
$\Rightarrow$ no change in (w_1, w_0)

Final solution: $\mathbf{w} = (w_1, w_0) = (2, -1)$

Approximative Q-learning

Episode 1	Episode 2	Episode 3
$(0, 1, 1, -2)$	$(0, 0, -1, 0)$	$(1, 1, exit, 2)$
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