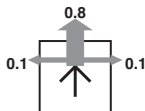
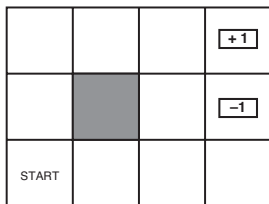


Value/Policy iteration

J. Kostlivá, Z. Straka, P. Švarný



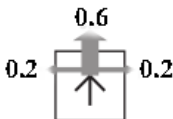
-10	<i>B</i>	30
-10	<i>A</i>	20

Máme:

- ▶ Stav: S , Akce: A
- ▶ Přejchodový model: $T(s, a, s') \equiv P(s'|s, a)$ pst, že ze stavu s při zvolení akce a skončím ve stavu s'
- ▶ Reward: $r(s)$, okamžitá odměna, immediate reward
- ▶ Hodnota/Value stavu: $V(s)$, očekávaný součet rewards při vykonání optimálních akcí
- ▶ Policy: π , strategie chování robota/agenta

Příklad

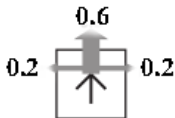
-40	30	-50
-40	A	-50
-40	B	-50



- ▶ kostičkový svět, čísla označují odměny
- ▶ červené stavy: terminální
- ▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$
- ▶ okamžitá odměna $r(A) = r(B) = -1$
- ▶ přechodový model: dle obrázku
- ▶ koeficient zapomínání/discount factor: $\gamma = 0.9$

Příklad

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

Úkol: nalézt optimální policy a hodnoty stavů A, B

A: $\pi(A) = \uparrow, \pi(B) = \leftarrow$

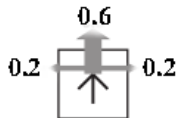
B: $\pi(A) = \rightarrow, \pi(B) = \leftarrow$

C: $\pi(A) = \leftarrow, \pi(B) = \uparrow$

D: $\pi(A) = \uparrow, \pi(B) = \uparrow$

Příklad

-40	30	-50
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▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

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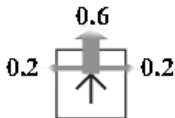
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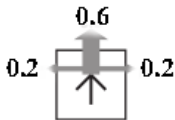
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▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

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Jak na to?

1. Spočítat hodnotu/value stavu $V(s)$:

A: $V(s) = \sum_{s'} p(s'|s, a)[r(s, a, s') + \gamma V(s')]$

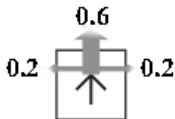
B: $V(s) = \sum_{s'} \gamma V(s')$

C: $V(s) = \max_a \sum_{s'} p(s'|s, a)[r(s, a, s') + \gamma V(s')]$

D: $V(s) = \sum_{s'} [r(s, a, s') + \gamma r(s')]$

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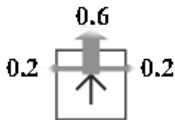
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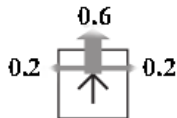
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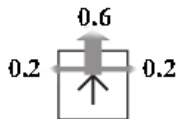
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2. Určit nejlepší strategii $\pi(s)$:
 - A: $\pi(s) = \arg \max_a \sum_{s'} [r(s, a, s') + \gamma r(s')]$
 - B: $\pi(s) = \sum_{s'} \gamma V(s')$
 - C: $\pi(s) = \max_a \sum_{s'} p(s'|s, a)[r(s, a, s') + \gamma V(s')]$
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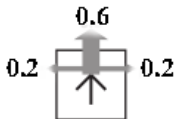
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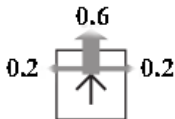
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Máme dvě metody:

- ▶ Value iteration
- ▶ Policy iteration

Příklad

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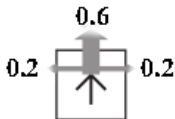
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Máme dvě metody:

- ▶ Value iteration
- ▶ Policy iteration

Různé varianty odměn

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► akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

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Co když máme jinou variantu MDP? Mějme $r(s)$ místo $r(s, a, s')$. Pak se

$V(s) = \max_a \sum_{s'} p(s'|s, a)[r(s, a, s') + \gamma V(s')]$ změní na:

A: $V(s) = \sum_{s'} [V(s') + \gamma r(s')]$

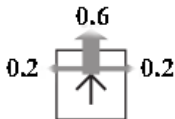
B: $V(s) = r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V(s')$

C: $V(s) = \sum_{s'} p(s'|s, a)[r(s) + \gamma V(s')]$

D: $V(s) = \max_{a \in A(s)} \sum_{s'} \gamma (V(s') + r(s'))$

Různé varianty odměn

-40	30	-50
-40	$r(A) = -1$	-50
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► akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

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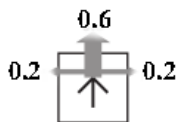
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Příklad - Value Iteration

-40	30	-50
-40	$r(A) = -1$	-50
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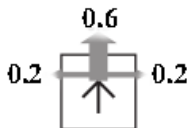
- ▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$
- ▶ $\gamma = 0.9$

Použít **Bellman update** $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Iterovat dokud se hodnoty $V(s)$ mění, o více než dané ϵ

Příklad - Value Iteration

-40	30	-50
-40	$r(A) = -1$	-50
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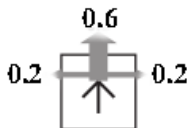
$t = 0: V(A) = 0, V(B) = 0$

$$t = 1: V(A) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot 0 = -24 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 30 + 0.2 \cdot 0 = -18 \\ (\uparrow) \quad 0.6 \cdot 30 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = 0 \\ (\downarrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -18 \end{array} \right\} = -1 \quad (\uparrow)$$

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Příklad - Value Iteration

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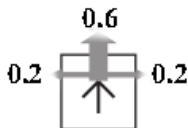
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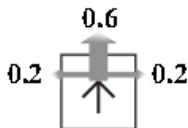
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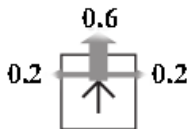
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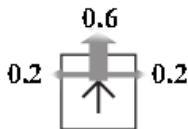
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$$V(B) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 0 + 0.2 \cdot 0 = -30 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 0 + 0.2 \cdot 0 = -24 \\ (\uparrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18 \\ (\downarrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -18 \end{array} \right\} = -17.2 \quad (\uparrow)/(\downarrow)$$

Příklad - Value Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

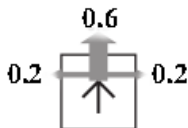
$t = 0$: $V(A) = 0, V(B) = 0$

$$t = 1: \quad V(A) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot 0 = -24 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 30 + 0.2 \cdot 0 = -18 \\ (\uparrow) \quad 0.6 \cdot 30 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = 0 \\ (\downarrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -18 \end{array} \right\} = -1 \quad (\uparrow)$$

$$V(B) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 0 + 0.2 \cdot 0 = -30 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 0 + 0.2 \cdot 0 = -24 \\ (\uparrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18 \\ (\downarrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -18 \end{array} \right\} = -17.2 \quad (\uparrow)/(\downarrow)$$

Příklad - Value Iteration

-40	30	-50
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▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

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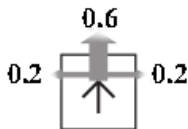
$t = 0$: $V(A) = 0, V(B) = 0$

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$$V(B) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 0 + 0.2 \cdot 0 = -30 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 0 + 0.2 \cdot 0 = -24 \\ (\uparrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18 \\ (\downarrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -18 \end{array} \right\} = -17.2 \quad (\uparrow)/(\downarrow)$$

Příklad - Value Iteration

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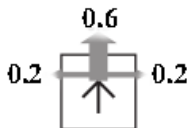
$t = 0$: $V(A) = 0, V(B) = 0$

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Příklad - Value Iteration

-40	30	-50
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▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

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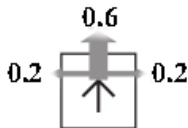
$t = 0$: $V(A) = 0, V(B) = 0$

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$$V(B) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 0 + 0.2 \cdot 0 = -30 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 0 + 0.2 \cdot 0 = -24 \\ (\uparrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18 \\ (\downarrow) \quad 0.6 \cdot 0 + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -18 \end{array} \right\} = -17.2 \quad (\uparrow)/(\downarrow)$$

Příklad - Value Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



► akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

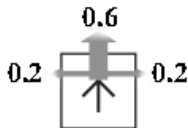
► $\gamma = 0.9$

► $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$$\begin{aligned}
 t = 2: \quad V(A) &= -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot (-17.2) = -27.44 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 30 + 0.2 \cdot (-17.2) = -21.44 \\ (\uparrow) \quad 0.6 \cdot 30 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = 0 \\ (\downarrow) \quad 0.6 \cdot (-17.2) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.32 \end{array} \right\} = -1 \quad (\uparrow) \\
 V(B) &= -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot (-1) + 0.2 \cdot (-17.2) = -33.64 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot (-1) + 0.2 \cdot (-17.2) = -27.64 \\ (\uparrow) \quad 0.6 \cdot (-1) + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18.6 \\ (\downarrow) \quad 0.6 \cdot (-17.2) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.32 \end{array} \right\} = -17.74 \quad (\uparrow) \\
 t = 3: \quad V(A) &= -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot (-17.74) = -27.548 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 30 + 0.2 \cdot (-17.74) = -21.548 \\ (\uparrow) \quad 0.6 \cdot 30 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = 0 \\ (\downarrow) \quad 0.6 \cdot (-17.74) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.64 \end{array} \right\} = -1 \quad (\uparrow) \\
 V(B) &= -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot (-1) + 0.2 \cdot (-17.74) = -33.748 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot (-1) + 0.2 \cdot (-17.74) = -27.748 \\ (\uparrow) \quad 0.6 \cdot (-1) + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18.6 \\ (\downarrow) \quad 0.6 \cdot (-17.74) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.64 \end{array} \right\} = -17.74 \quad (\uparrow)
 \end{aligned}$$

Příklad - Value Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$$t = 2: \quad V(A) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot (-17.2) = -27.44 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 30 + 0.2 \cdot (-17.2) = -21.44 \\ (\uparrow) \quad 0.6 \cdot 30 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = 0 \\ (\downarrow) \quad 0.6 \cdot (-17.2) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.32 \end{array} \right\} = -1 \quad (\uparrow)$$

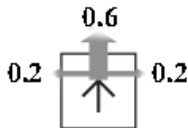
$$V(B) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot (-1) + 0.2 \cdot (-17.2) = -33.64 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot (-1) + 0.2 \cdot (-17.2) = -27.64 \\ (\uparrow) \quad 0.6 \cdot (-1) + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18.6 \\ (\downarrow) \quad 0.6 \cdot (-17.2) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.32 \end{array} \right\} = -17.74 \quad (\uparrow)$$

$$t = 3: \quad V(A) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot (-17.74) = -27.548 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot 30 + 0.2 \cdot (-17.74) = -21.548 \\ (\uparrow) \quad 0.6 \cdot 30 + 0.2 \cdot (-40) + 0.2 \cdot (-50) = 0 \\ (\downarrow) \quad 0.6 \cdot (-17.74) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.64 \end{array} \right\} = -1 \quad (\uparrow)$$

$$V(B) = -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot (-1) + 0.2 \cdot (-17.74) = -33.748 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot (-1) + 0.2 \cdot (-17.74) = -27.748 \\ (\uparrow) \quad 0.6 \cdot (-1) + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18.6 \\ (\downarrow) \quad 0.6 \cdot (-17.74) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.64 \end{array} \right\} = -17.74 \quad (\uparrow)$$

Příklad - Value Iteration

-40	30	-50
-40	$r(A) = -1$	-50
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▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

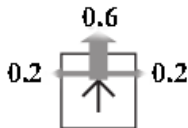
▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$$\begin{aligned}
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 \end{aligned}$$

Příklad - Value Iteration

-40	30	-50
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▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

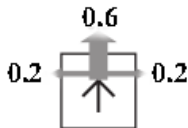
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Příklad - Value Iteration

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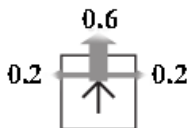
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 V(B) &= -1 + 0.9 \cdot \max \left\{ \begin{array}{l} (\rightarrow) \quad 0.6 \cdot (-50) + 0.2 \cdot (-1) + 0.2 \cdot (-17.2) = -33.64 \\ (\leftarrow) \quad 0.6 \cdot (-40) + 0.2 \cdot (-1) + 0.2 \cdot (-17.2) = -27.64 \\ (\uparrow) \quad 0.6 \cdot (-1) + 0.2 \cdot (-40) + 0.2 \cdot (-50) = -18.6 \\ (\downarrow) \quad 0.6 \cdot (-17.2) + 0.2 \cdot (-50) + 0.2 \cdot (-40) = -28.32 \end{array} \right\} = -17.74 \quad (\uparrow) \\
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 \end{aligned}$$

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 1 iterace:

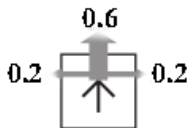
A: 1 krok

B: 2 kroky

C: 3 kroky

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 1 iterace:

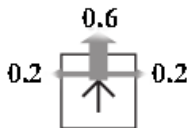
A: 1 krok

B: 2 kroky

C: 3 kroky

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 1 iterace:

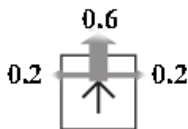
A: 1 krok

B: 2 kroky

C: 3 kroky

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 1 iterace: 2 kroky

1. Policy Evaluation:

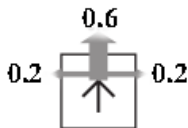
A: Počítám policy

B: Počítám hodnoty stavů

C: Počítám obojí

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 1 iterace: 2 kroky

1. Policy Evaluation:

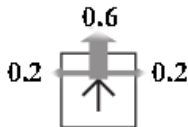
A: Počítám policy

B: Počítám hodnoty stavů

C: Počítám obojí

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 1 iterace: 2 kroky

1. Policy Evaluation:

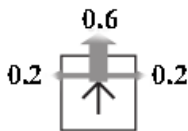
A: Počítám policy

B: Počítám hodnoty stavů

C: Počítám obojí

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 2 kroky:

1. Policy evaluation:

- ▶ $V_{k+1}^{\pi_i}(s) \leftarrow \sum_{s'} p(s'|s, \pi_i(s)) [r(s, \pi_i(s), s') + \gamma V_k^{\pi_i}(s')]$
- ▶ iteračně nebo analyticky

2. Policy refinement:

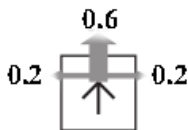
A: Počítám policy

B: Počítám hodnoty stavů

C: Počítám obojí

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 2 kroky:

1. Policy evaluation:

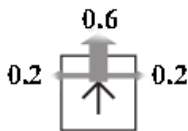
- ▶ $V_{k+1}^{\pi_i}(s) \leftarrow \sum_{s'} p(s'|s, \pi_i(s)) [r(s, \pi_i(s), s') + \gamma V_k^{\pi_i}(s')]$
- ▶ iteračně nebo analyticky

2. Policy refinement:

- A: Počítám policy
- B: Počítám hodnoty stavů
- C: Počítám obojí

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 2 kroky:

1. Policy evaluation:

- ▶ $V_{k+1}^{\pi_i}(s) \leftarrow \sum_{s'} p(s'|s, \pi_i(s)) [r(s, \pi_i(s), s') + \gamma V_k^{\pi_i}(s')]$
- ▶ iteračně nebo analyticky

2. Policy refinement:

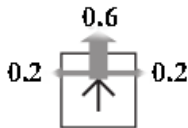
A: Počítám policy

B: Počítám hodnoty stavů

C: Počítám obojí

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Policy iteration - 2 kroky:

1. Policy evaluation:

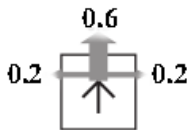
- ▶ $V_{k+1}^{\pi_i}(s) \leftarrow \sum_{s'} p(s'|s, \pi_i(s)) [r(s, \pi_i(s), s') + \gamma V_k^{\pi_i}(s')]$
- ▶ iteračně nebo analyticky

2. Policy refinement:

$$\pi_{i+1}(s) = \arg \max_a \sum_{s'} p(s'|s, a) [r(s, a, s') + \gamma V_k^{\pi_i}(s')]$$

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$t = 0$: $\pi(A) = \rightarrow, \pi(B) = \leftarrow$

$$t = 1: \text{PE: } \begin{aligned} V(A) &= -1 + 0.9 \cdot \{0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot V(B)\} \\ V(B) &= -1 + 0.9 \cdot \{0.6 \cdot (-40) + 0.2 \cdot V(A) + 0.2 \cdot V(B)\} \end{aligned}$$

$$V(A) = -22.6 + 0.18 \cdot V(B)$$

$$V(B) = -1 + 0.9 \cdot \{-24 + 0.2 \cdot (-22.6 + 0.18 \cdot V(B)) + 0.2 \cdot V(B)\} =$$

$$= -26.668 + 0.2124 \cdot V(B)$$

$$V(B) = \frac{-26.668}{0.7876} = -33.86$$

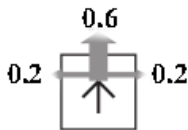
$$V(A) = -28.69$$

$$PR: \pi(A) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -28.69 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -23.29 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (30) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -1 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\uparrow)$$

$$\pi(B) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -39.26 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -33.86 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (-28.69) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -32.69 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\leftarrow)$$

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$t = 0$: $\pi(A) = \rightarrow, \pi(B) = \leftarrow$

$t = 1$: PE: $V(A) = -1 + 0.9 \cdot \{0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot V(B)\}$
 $V(B) = -1 + 0.9 \cdot \{0.6 \cdot (-40) + 0.2 \cdot V(A) + 0.2 \cdot V(B)\}$

$$V(A) = -22.6 + 0.18 \cdot V(B)$$

$$V(B) = -1 + 0.9 \cdot \{-24 + 0.2 \cdot (-22.6 + 0.18 \cdot V(B)) + 0.2 \cdot V(B)\} =$$

$$= -26.668 + 0.2124 \cdot V(B)$$

$$V(B) = \frac{-26.668}{0.7876} = -33.86$$

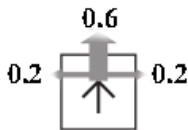
$$V(A) = -28.69$$

$$PR: \pi(A) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -28.69 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -23.29 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (30) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -1 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\uparrow)$$

$$\pi(B) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -39.26 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -33.86 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (-28.69) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -32.69 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\leftarrow)$$

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$t = 0$: $\pi(A) = \rightarrow, \pi(B) = \leftarrow$

$t = 1$: PE: $V(A) = -1 + 0.9 \cdot \{0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot V(B)\}$
 $V(B) = -1 + 0.9 \cdot \{0.6 \cdot (-40) + 0.2 \cdot V(A) + 0.2 \cdot V(B)\}$

$$V(A) = -22.6 + 0.18 \cdot V(B)$$

$$V(B) = -1 + 0.9 \cdot \{-24 + 0.2 \cdot (-22.6 + 0.18 \cdot V(B)) + 0.2 \cdot V(B)\} =$$

$$= -26.668 + 0.2124 \cdot V(B)$$

$$V(B) = \frac{-26.668}{0.7876} = -33.86$$

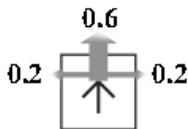
$$V(A) = -28.69$$

$$PR: \pi(A) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -28.69 \\ (\leftarrow) -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -23.29 \\ (\uparrow) -1 + 0.9\{0.6 \cdot (30) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -1 \\ (\downarrow) -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\uparrow)$$

$$\pi(B) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -39.26 \\ (\leftarrow) -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -33.86 \\ (\uparrow) -1 + 0.9\{0.6 \cdot (-28.69) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -32.69 \\ (\downarrow) -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\leftarrow)$$

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$t = 0$: $\pi(A) = \rightarrow, \pi(B) = \leftarrow$

$$t = 1: \text{PE: } \begin{aligned} V(A) &= -1 + 0.9 \cdot \{0.6 \cdot (-50) + 0.2 \cdot 30 + 0.2 \cdot V(B)\} \\ V(B) &= -1 + 0.9 \cdot \{0.6 \cdot (-40) + 0.2 \cdot V(A) + 0.2 \cdot V(B)\} \end{aligned}$$

$$V(A) = -22.6 + 0.18 \cdot V(B)$$

$$V(B) = -1 + 0.9 \cdot \{-24 + 0.2 \cdot (-22.6 + 0.18 \cdot V(B)) + 0.2 \cdot V(B)\} =$$

$$= -26.668 + 0.2124 \cdot V(B)$$

$$V(B) = \frac{-26.668}{0.7876} = -33.86$$

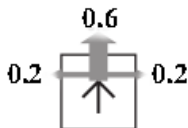
$$V(A) = -28.69$$

$$PR: \pi(A) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -28.69 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (30) + 0.2 \cdot (-33.86)\} = -23.29 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (30) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -1 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\uparrow)$$

$$\pi(B) = \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -39.26 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (-28.69) + 0.2 \cdot (-33.86)\} = -33.86 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (-28.69) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -32.69 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-33.86) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -35.48 \end{array} \right\} = (\uparrow)$$

Příklad - Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

$$t = 2: \quad PE: \quad \begin{aligned} V(A) &= -1 + 0.9 \cdot \{0.6 \cdot (30) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} \\ V(B) &= -1 + 0.9 \cdot \{0.6 \cdot V(A) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} \end{aligned}$$

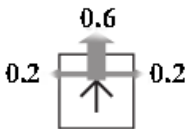
$$V(A) = -1$$

$$V(B) = -1 + 0.9 \cdot \{-0.6 - 18\} = -17.74$$

$$PR: \quad \begin{aligned} \pi(A) &= \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (30) + 0.2 \cdot (-17.74)\} = -25.79 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (30) + 0.2 \cdot (-17.74)\} = -20.39 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (30) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -1 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-17.74) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -26.78 \end{array} \right\} = (\uparrow) \\ \pi(B) &= \arg \max_a \left\{ \begin{array}{l} (\rightarrow) \quad -1 + 0.9\{0.6 \cdot (-50) + 0.2 \cdot (-1) + 0.2 \cdot (-17.74)\} = -31.37 \\ (\leftarrow) \quad -1 + 0.9\{0.6 \cdot (-40) + 0.2 \cdot (-1) + 0.2 \cdot (-17.74)\} = -25.97 \\ (\uparrow) \quad -1 + 0.9\{0.6 \cdot (-1) + 0.2 \cdot (-40) + 0.2 \cdot (-50)\} = -17.74 \\ (\downarrow) \quad -1 + 0.9\{0.6 \cdot (-17.74) + 0.2 \cdot (-50) + 0.2 \cdot (-40)\} = -26.78 \end{array} \right\} = (\uparrow) \end{aligned}$$

Příklad - Srovnání Value/Policy Iteration

-40	30	-50
-40	$r(A) = -1$	-50
-40	$r(B) = -1$	-50



▶ akce: $\{\leftarrow, \rightarrow, \uparrow, \downarrow\}$

▶ $\gamma = 0.9$

▶ $V_{k+1}(s) \leftarrow r(s) + \gamma \max_{a \in A(s)} \sum_{s'} p(s'|s, a) V_k(s')$

Výsledná policy:

A: Může být jiná

B: Musí být shodná

C: Neměla by být jiná