Digital Image

(B4M33DZO, Summer 2024)

Lecture 11:

Image Segmentation 1

https://cw.fel.cvut.cz/wiki/courses/b4m33dzo/start

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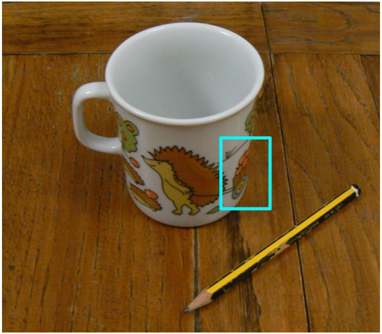
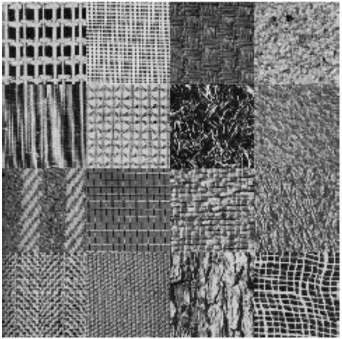
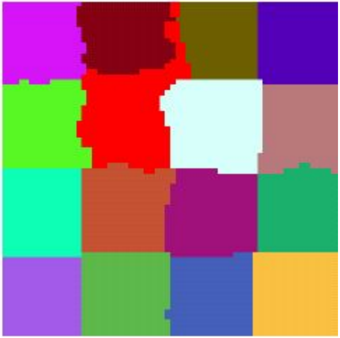
Segmentation

Segmentation



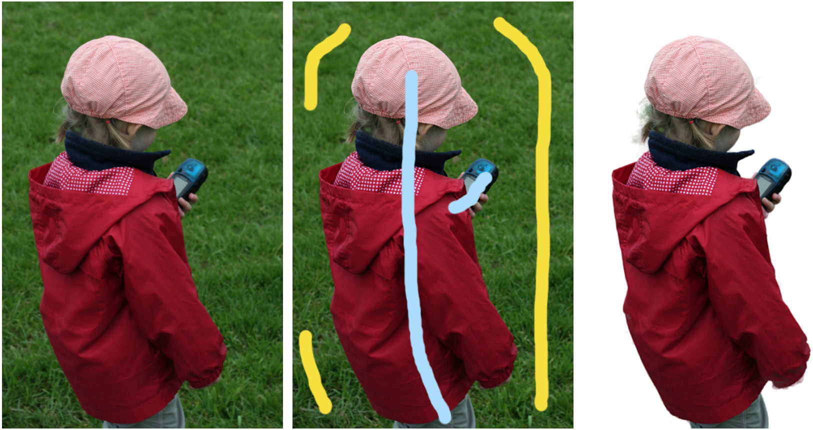
Texture Segmentation Example





User Assisted Segmentation

Interactive image segmentation:



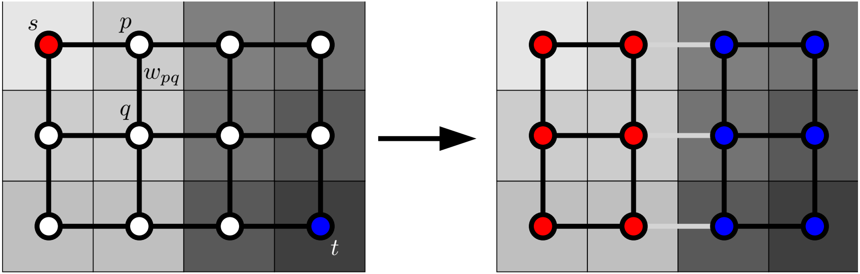
Extract part of the image using a set of user-specified constraints.

Problem formulation

Find an optimal labelling x^* such that:

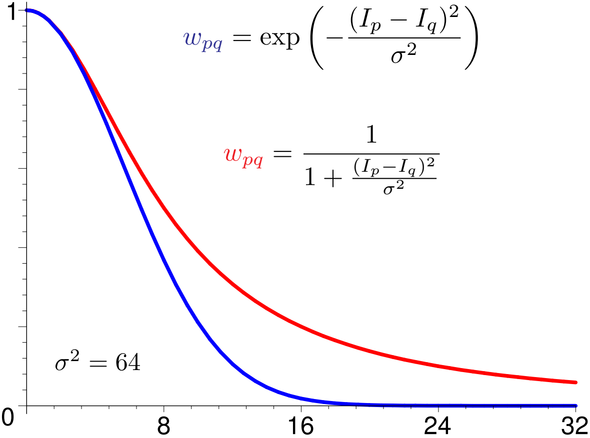
$$x^* = \arg\min_x \sum_{\{p,q\}\in\mathcal{N}} w_{pq} \left|x_p - x_q\right|^{\alpha}$$

subject to: $x_s = 0 \ \wedge \ x_t = 1$



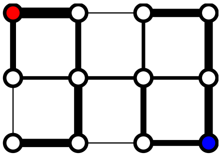
Edge weights

Salient edge $\Rightarrow$ lower energy:



Similarity metric

$$w_{pq} \left| x_p - x_q \right|^{\alpha}$$



α	algorithm	w_{pq}
1	min-cut	capacity
2	random walker	probability
∞	shortest path	$1/$length

Min-cut

Find an optimal labelling $x^* \in \{0,1\}$ such that:

$$x^* = \arg\min_x \sum_{\{p,q\}\in\mathcal{N}} w_{pq}\,|x_p - x_q|$$

subject to: $x_s = 0 \;\wedge\; x_t = 1$

---

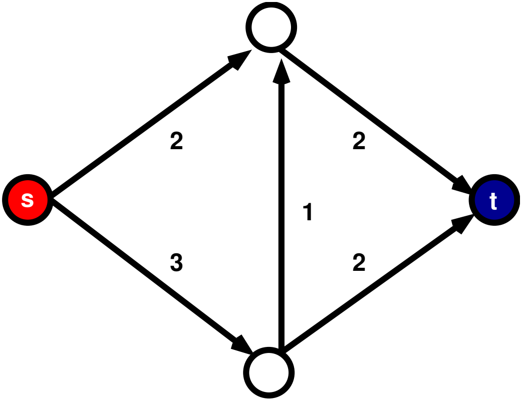
find a subset of edges with minimal total weight whose removal disconnects nodes s and t

$$\Updownarrow$$

find a maximum flow between nodes s and t in a pipe network with capacities equal to edge weights

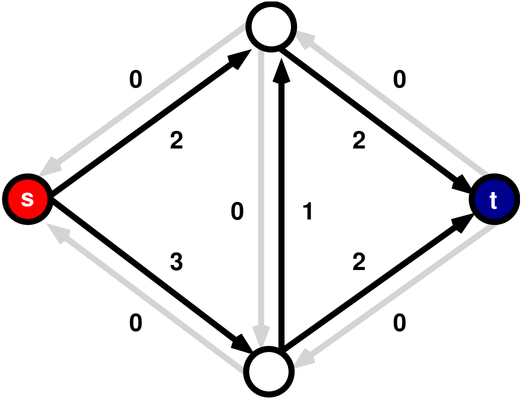
Max-flow

Find a maximum flow from source s to sink t:



[Ford-Fulkerson]

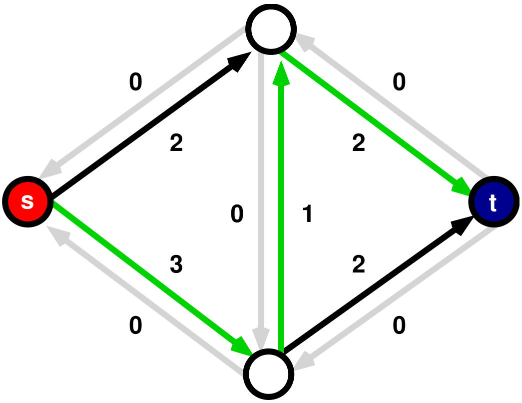
Residual network:



[Ford-Fulkerson]

Max-flow

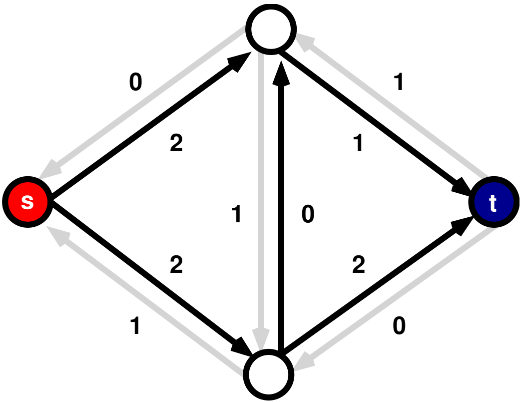
Find any path from node s to node t:



[Ford-Fulkerson]

Max-flow

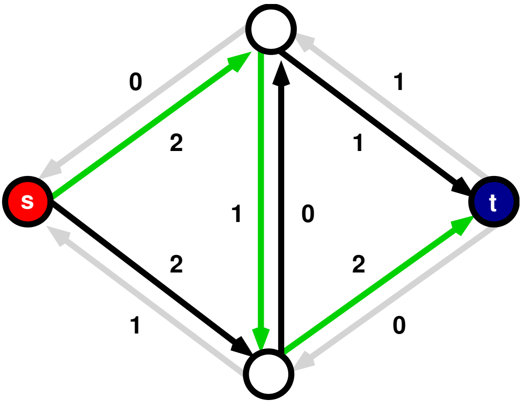
Update residual network according to path capacity:



[Ford-Fulkerson]

Max-flow

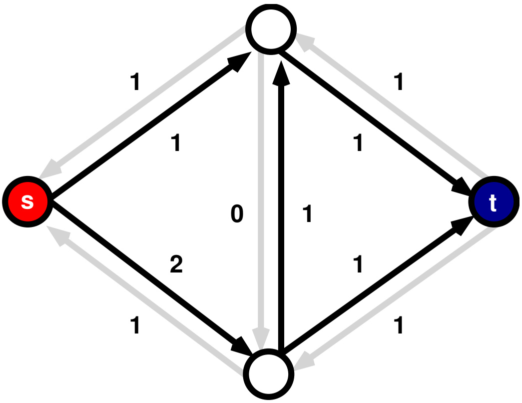
Find another path from node s to node t:



[Ford-Fulkerson]

Max-flow

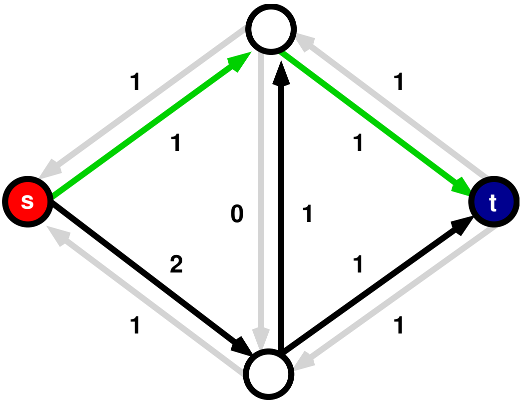
Update residual network according to path capacity:



[Ford-Fulkerson]

Max-flow

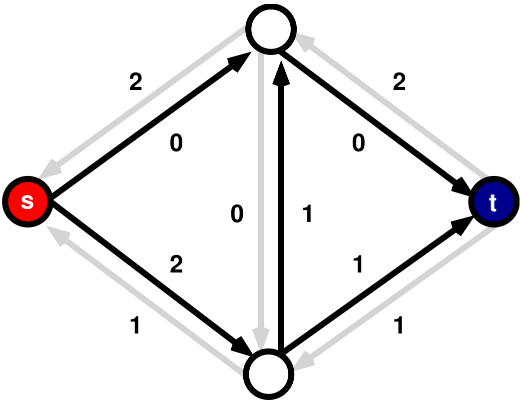
Find another path from node s to node t:



[Ford-Fulkerson]

Max-flow

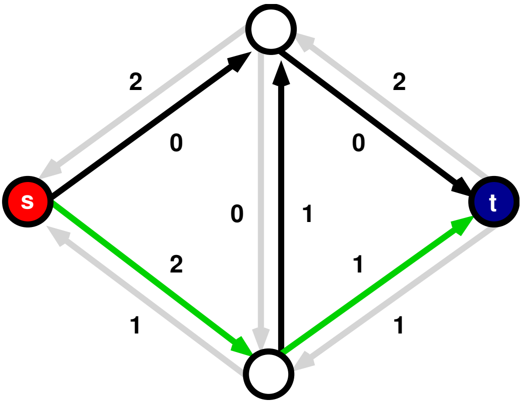
Update residual network according to path capacity:



[Ford-Fulkerson]

Max-flow

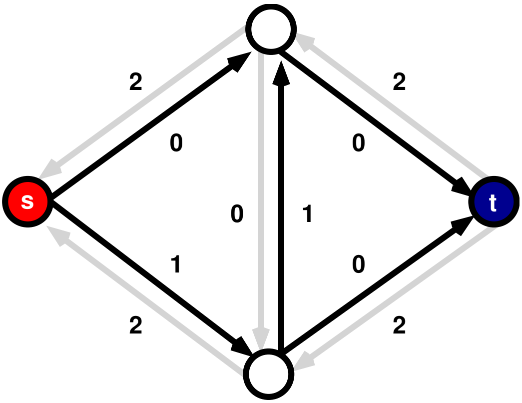
Find another path from node s to node t:



[Ford-Fulkerson]

Max-flow

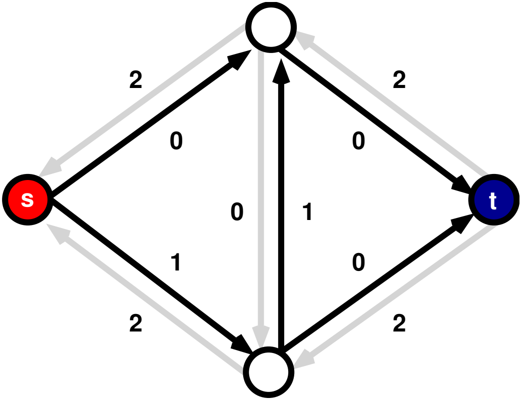
Update residual network according to path capacity:



[Ford-Fulkerson]

Max-flow

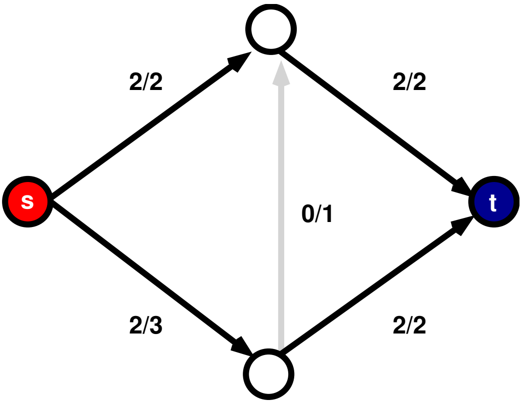
There is no other free path from node s to node t:



[Ford-Fulkerson]

Max-flow

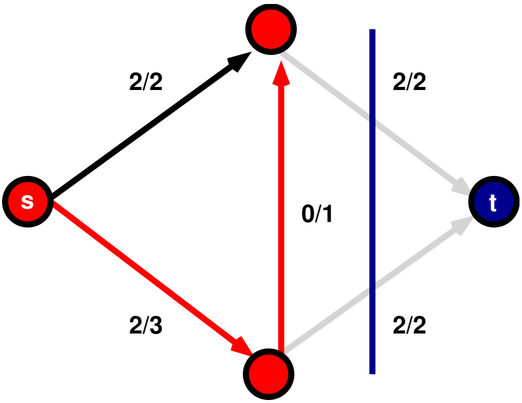
Maximum flow found:



[Ford-Fulkerson]

Max-flow

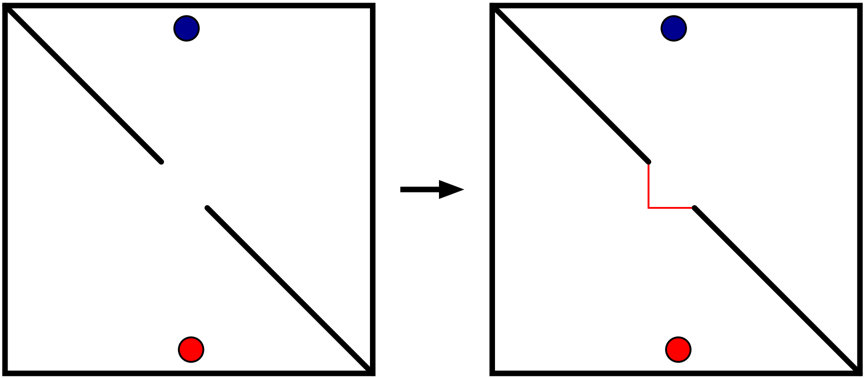
Corresponding minimal cut:



[Ford-Fulkerson]

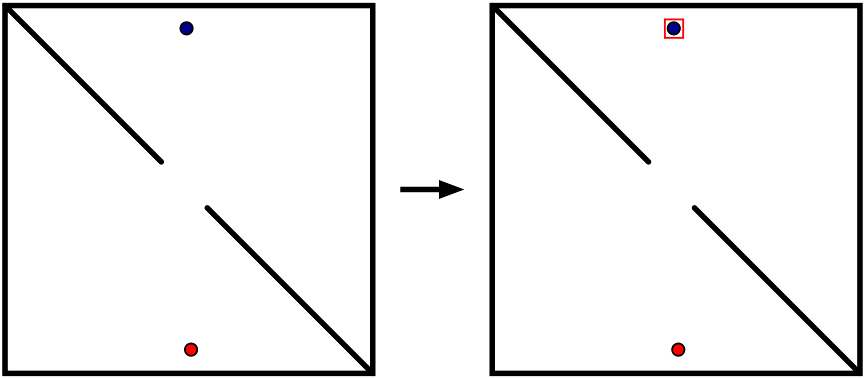
Min-cut

Metrication ($\alpha = 1$):



Min-cut

Shrinking bias ($\alpha = 1$):



Random walker

Find an optimal labelling $x^* \in \langle 0, 1 \rangle$ such that:

$$x^* = \arg\min_x \sum_{\{p,q\} \in \mathcal{N}} w_{pq} \left| x_p - x_q \right|^2$$

subject to: $x_s = 0 \ \wedge \ x_t = 1$

$$E = \sum_{\{p,q\} \in \mathcal{N}} w_{pq} \left| x_p - x_q \right|^2 \quad \Rightarrow \quad E' = 0$$

Laplace equation:

$$\boxed{\Delta x = 0}$$

$$w_{pq} = 1$$

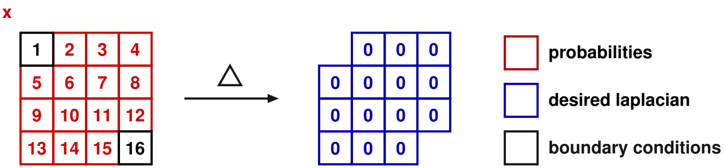
Laplace–Beltrami equation:

$$\boxed{\Delta_w x = 0}$$

$$w_{pq} \in \langle 0, 1 \rangle$$

Random walker

Linear system for Laplace equation:

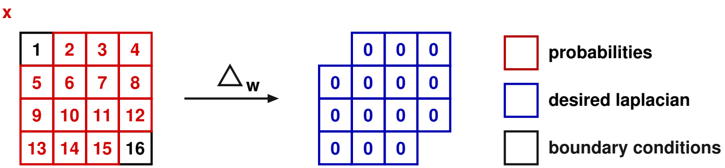


$$
\begin{array}{cccccccccccccc}
2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15
\end{array}
$$

$$
\begin{bmatrix}
-3 & 1 & & & 1 & & & & & & & & & \\
1 & -3 & 1 & & & 1 & & & & & & & & \\
 & 1 & -2 & & & & 1 & & & & & & & \\
 & & & -3 & 1 & & & 1 & & & & & & \\
1 & & & 1 & -4 & 1 & & & 1 & & & & & \\
 & 1 & & & 1 & -4 & 1 & & & 1 & & & & \\
 & & 1 & & & 1 & -3 & & & & 1 & & & \\
 & & & & & & \vdots & & & & & & &
\end{bmatrix}
\cdot
\begin{bmatrix} 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ \vdots \end{bmatrix}
=
\begin{bmatrix} 0 - 1 \\ 0 \\ 0 \\ 0 - 1 \\ 0 \\ 0 \\ 0 \\ \vdots \end{bmatrix}
$$

Random walker

Linear system for Laplace–Beltrami equation:

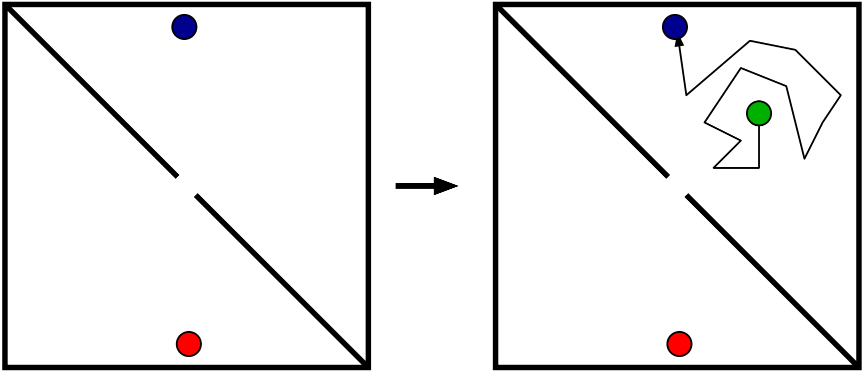


$$
\begin{array}{cccccccccccccc}
2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15
\end{array}
$$

$$
\begin{bmatrix}
-1 & 0.2 & & & 0.5 & & & & & & & & & \\
0.2 & -1 & 0.3 & & & 0.5 & & & & & & & & \\
 & 0.7 & -1 & & & & 0.3 & & & & & & & \\
 & & & -1 & 0.2 & & & 0.2 & & & & & & \\
0.1 & & & 0.2 & -1 & 0.3 & & & 0.4 & & & & & \\
 & 0.2 & & & 0.6 & -1 & 0.1 & & & 0.1 & & & & \\
 & & 0.2 & & & 0.5 & -1 & & & & 0.3 & & & \\
\vdots & & & & & & & & & & & & &
\end{bmatrix}
\cdot
\begin{bmatrix} 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ \vdots \end{bmatrix}
\begin{matrix} = \\ = \\ = \\ = \\ = \\ = \\ = \\ \end{matrix}
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \vdots \end{bmatrix}
\begin{matrix} - \boxed{1} * 0.3 \\ \\ \\ - \boxed{1} * 0.6 \\ \\ \\ \\ \\ \end{matrix}
$$

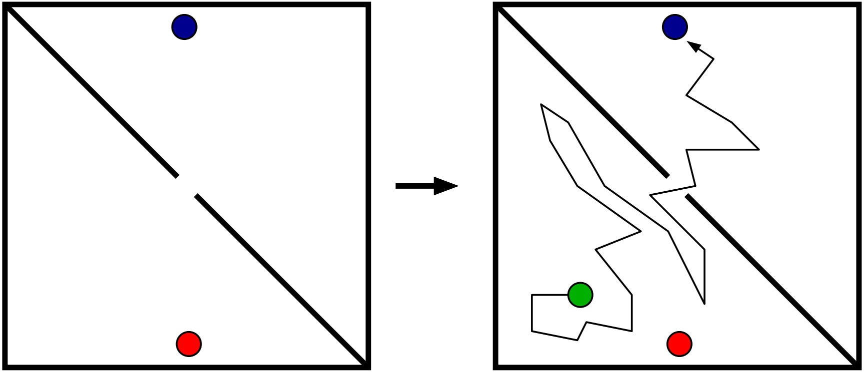
Random walker

What is the probability that random walker reaches blue seed first?



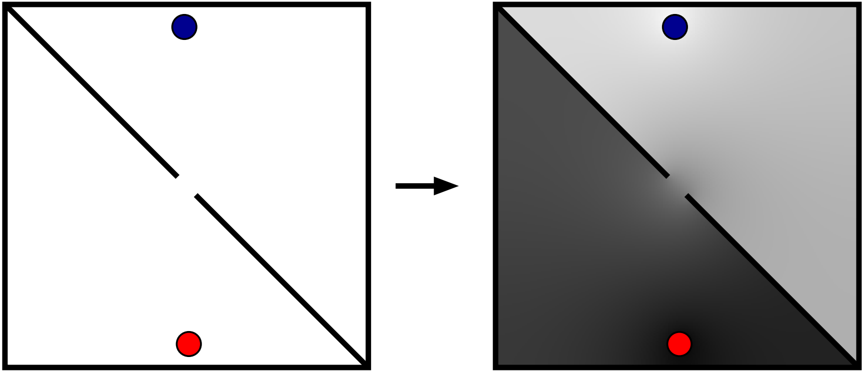
Random walker

What is the probability that random walker reaches blue seed first?



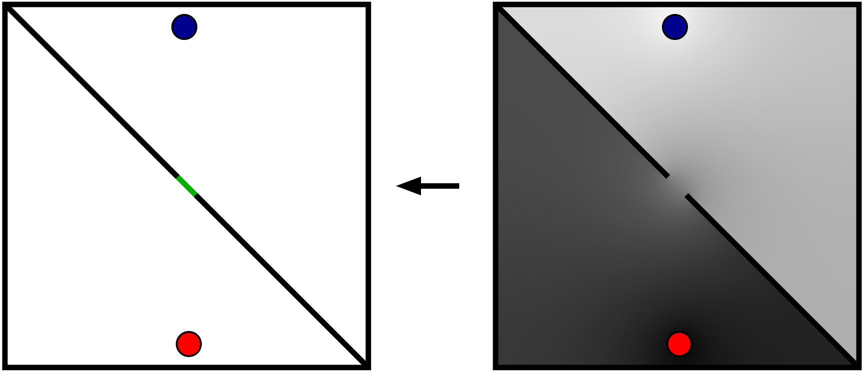
Random walker

What is the probability that random walker reaches blue seed first?



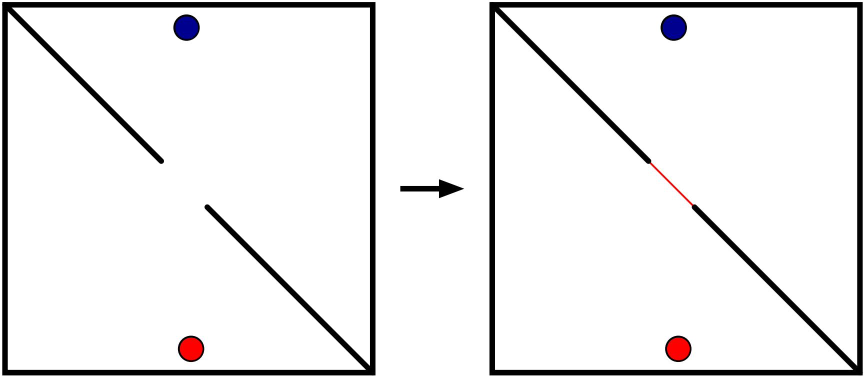
Random walker

The boundary between segments has probability $= \frac{1}{2}$:



Random walker

Better closure ($\alpha = 2$):



Random walker

Proximity bias ($\alpha = 2$):