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Citation graph of literary theory academic papers

Game of Thrones Character Interaction Network







Immigration flows

Potato trade

World trade in fresh potatoes, flows over 0.1 m US\$ average 2005-2009





Graphical models



What eats what in the Atlantic ocean?



A simplified food web for the Northwest Atlantic. © IMMA

Neural connections in the brain



• There are a lot of graphs.

- We want to answer questions about them.
 - Efficient routing?
 - Community detection/clustering?
 - Signing up for classes without violating pre-req constraints
 - How to distribute fish in tanks so that none of them will fight.



- Has vertices and edges
 - V is the set of vertices
 - E is the set of edges
 - Formally, a graph is G = (V,E)



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- Example
 - V = {1,2,3,4}
 - $E = \{ \{1,3\}, \{2,4\}, \{3,4\}, \{2,3\} \}$
 - The **degree** of vertex 4 is 2.
 - There are 2 edges coming out.
 - Vertex 4's **neighbors** are 2 and 3



- Has vertices and edges
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 - E is the set of **DIRECTED** edges
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- Example
 - V = {1,2,3,4}
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- Has vertices and edges
 - V is the set of vertices
 - E is the set of **DIRECTED** edges
 - Formally, a graph is G = (V,E)

3 G = (V,E)

- Example
 - V = {1,2,3,4}
 - E = { (1,3), (2,4), (3,4), (4,3), (3,2) }
 - The **in-degree** of vertex 4 is 2.
 - The **out-degree** of vertex 4 is 1.
 - Vertex 4's incoming neighbors are 2,3
 - Vertex 4's outgoing neighbor is 3.

















• Option 1: adjacency matrix (directed graph) **Destination**





• Option 1: adjacency matrix (directed graph) Destination

















In either case

- Vertices can store other information
 - Attributes (name, IP address, ...)
 - helper info for algorithms that we will perform on the graph

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- Vertices can store other information
 - Attributes (name, IP address, ...)
 - helper info for algorithms that we will perform on the graph
- Want to be able to do the following operations:
 - Edge Membership: Is edge e in E?
 - Neighbor Query: What are the neighbors of vertex v?

Say there are n vertices and m edges.

 $\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$

3

2

Edge membership Is e = {v,w} in E?

Neighbor query Give me v's neighbors.

Space requirements

Say there are n vertices and m edges.	$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
Edge membership Is e = {v,w} in E?	O(1)	(2)
Neighbor query Give me v's neighbors.		
Space requirements		

Say there are n vertices	
and m edges.	

Edge membership Is e = {v,w} in E?

Neighbor query Give me v's neighbors.

Space requirements

O(deg(v)) or
O(deg(w))

3

2

3

 $\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$

O(1)

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O(1)	O(deg(v)) or O(deg(w))

O(n)

Say there are n vertices	
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Edge membership Is e = {v,w} in E?

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Space requirements

 $\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$ 3 3 O(deg(v)) or O(1)O(deg(w)) O(deg(v))O(n)

Say there are n vertices	
and m edges.	

Edge membership Is e = {v,w} in E?

Neighbor query Give me v's neighbors.

Space requirements

O(n²)

O(n) O(deg(v))

Say there are n vertices	
and m edges.	

Edge membership Is $e = \{v, w\}$ in E?

Neighbor query Give me v's neighbors.

Space requirements

 $\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$ O(deg(v)) or O(1)O(deg(w))

 $O(n^2)$

O(deg(v))O(n)

3

3

O(n + m)

Trade-offs		Generally better for sparse graphs
Say there are n vertices and m edges.	$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
Edge membership Is e = {v,w} in E?	O(1)	O(deg(v)) or O(deg(w))
Neighbor query Give me v's neighbors.	O(n)	O(deg(v))
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Edge membership Is e = {v,w} in E?	O(1)	O(deg(v)) or O(deg(w))
Neighbor query Give me v's neighbors.	O(n)	O(deg(v))
Space requirements	O(n²)	O(n + m) We'll assume this representation for the rest of the class

Acknowledgement

Stanford University

Thank You