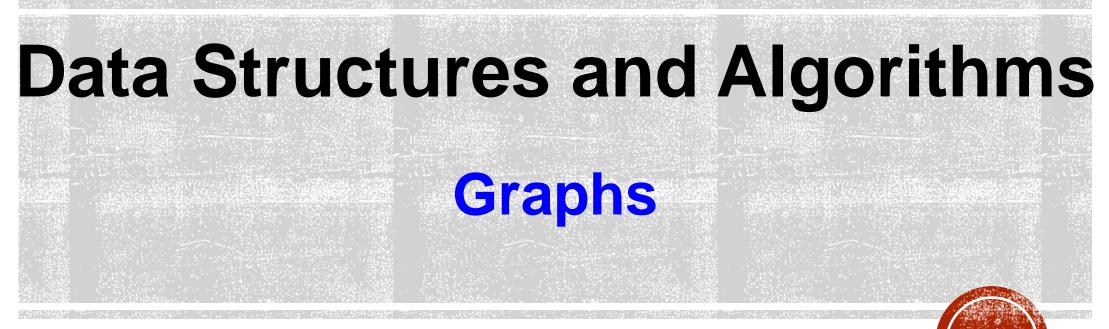


Indian Institute of Information Technology Allahabad



Dr. Shiv Ram Dubey

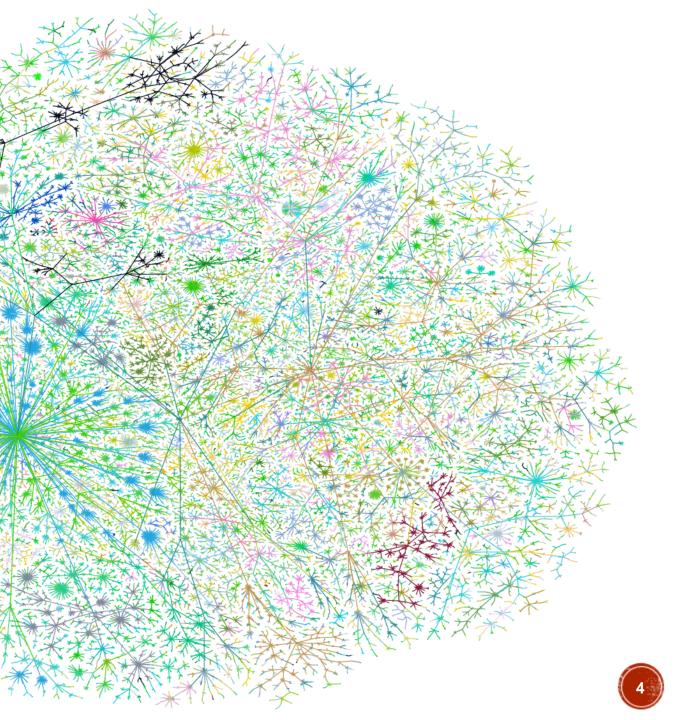
Assistant Professor Department of Information Technology Indian Institute of Information Technology, Allahabad

Email: srdubey@iiita.ac.in Web: https://profile.iiita.ac.in/srdubey/

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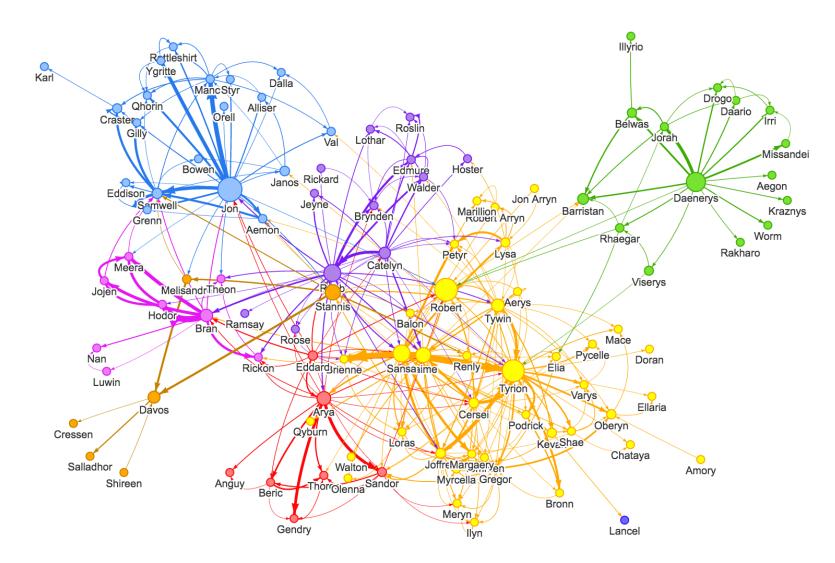
Graph of the internet (in 1999...it's a lot bigger now...)

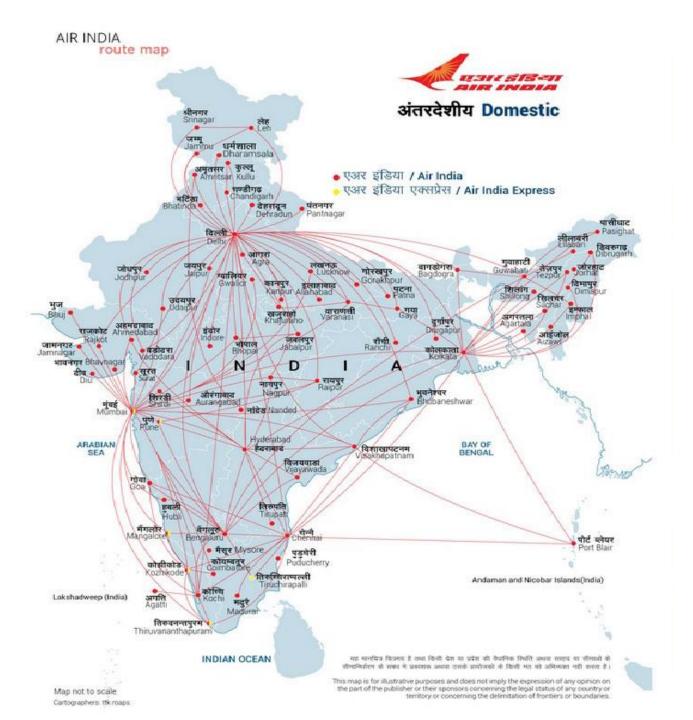


Davidson D 1984 Harding S 1987 Jaggar M M Sewingenstein L 1953 Rorty R 1989 Waker A 1983 Chodorow N 1978 Fanon Frantz Wretched Earth Wittgenstein L Philos Investigation Faderman Lillian 198 Spillers HU 1987 Shapin S 1985 Certeau MD 1984 Hartsock N 1983 Frye M 1983 Smith Barbara 1983 _ Daly M 1978 Latour Brugo 1993 Gilbert Sandra M 1979 Davis 6 1981 Hataway D J 1989 Shitow Apr 1983 Merchant C 1980 Butler J 1999 TOOKS B TOBY S 1991 Gillgen C 1982 Hartsock N C M 1983 Anderson B 1983 Scott JW 1991 Bourdieuer Ratignan © Begen Wendy 1985 Solvax CIP 1999 holistlette tentsol 1994 Benjamin W 1972 Rich A 199Keller EF 1985 Ruddick S 1980 Co. CRetricitutes LE908 Latour B 1987 Bourdieu Pierre 1984 Modia to Chinese and 1990 Benjamin Jessica 1988 Soot Joan Walach 1988 Rich A 1979 Showalter Elaine 1977 Fac Dollar Bashi2990 .richnote964 984 Scotl JW 1988 Sound G 1997 Annov 1999 Dinnerstein Dorothy 1976 Bubin G Bubipoks B 1984 Bounder E. 1 Sonise 1988 Benjamin Walter 1977 Dioperstein D 1976 LevisMacsic April Stephel J 1974 Marcus G 1986 Cixous H 1978 Butler J 1992 Speiman Figapett V 1988 Clifford J 1986 Chodorow Nancy 1978 Friedan Betty 1963 Riley D 1988 Flax J 1987 Goodman Nelson 1976 Nevlor Gloria 1983 · Seogwell ER IS Hooks B Hagicott D W 1971 Hanaway O 1995 Dub steps B 1992 Cases 7 1995 Mackanov, 1985 Frankerper, Russ 1999 1998 Manayayada 1991 Mackanov, 1985 Frankerper, Russ 1993 Goodman N 1978 Borde SF ballaut M Cillord Janes Plase H 1976 Kuhn T SEPOCAL HIRSHA HOVAGT Adams Con House 198 19 yerman Kaja 1988 Butler J 2000 Said EW 1989 Haraway Docemin M Hendh 1993 CT 1991 Mohanty C T 2003 Foucault Michel 1968 Irigerey L 1985 Fish S 1989 Grewal Inderpal 1994 Austin JL 19: Fouri Informatin Argent DE Lauratin T 1984 Kristeva J 1982 Fouriauti Micho 1997 (1983) Fouriauti Micho 1982 Fouriauti Micho 1997 Mohanty Chandra Talpade 1988 Bloom H 1973 Grosz Elizabeth , Sherayan Uma 1997 Plato Republic Fraser Nancy 1997 Young I M 1990 Bloom Harold 1975 Rorty Richard 1982 Rorty R 1979 Butler Judith 2000 Jardine A 1965 aciau Enesto 1985 Foucault M 1988 Feimer Shrsheea 1997999 Miler D A 1988 Chow Rev 1993 Rnapp S 1982 Harvey David 1989 Greenblatt S 1980 Foucault M 1977 Histh HapterGeoffrey H 1980 Said Edward W 1978 Foucault M 1984 Freud S Totem Taboo Fanon Frantz 1967 Frye Northrop 1957 Derrida J 1983 Lyotard. 1 #806ault M 1979 Lacan J 1977 Aristotle 1457 Chatter of Part Mangaguise 1992 Graft G 1979 Zizek Slavoj 1994 Freue Stand S CW128tion Its De Fish Stoplay id 8801980 Chow Rey 1991 Nandy Ashis 1983 Said E 1983. Bhabha H K 19 1 Said Edward 1993 Derrida J 1983 Athusser L Barthes Roland 1975 Caruth Cathy 1996 Derrica J 197Barrott M 1980 61 Lentricchia Zizek, Sevel 1989 Jorden Baleprvak G C 1999 Booth Wayne C 1961 Lagan J Tabin Lentricohia F. 1980 Aristotle Rhetoric Said E W 1973
Lacan Jacques 1990 gger M 1998
Deleuze G 1983 Solvak G 1990 DE Man Paul 1983 Derrida Jacques 1978 Derrida shte71 Guattari Felix 1994 Culler J 1981 Culler J 1982 Freud Sinte willions Presymond 1977 Coward R 1977 Jameson Fradri DE Man Paul 1984 Cullor J heltennal 751979 Appadural A 199 1982 Derrida J 1963 Louis 1970 Patton Paul 1994 Jameson Fredric 1991 Gadamer His detatari Felix 1987 Derrida Jacques 1996 REMan Paut 19 Perrica Jac. Dendry Pasta Pratt ML 1977 Deman P 19e Derrice Jacques 1981 Marx K Capital Foudault Michel Order Things Archaeo Gilroy P 1993 Deleuze Gilles 1990 DE Man Paul 1986 Levinas E 1969 Jameson Fredric 1979 Eagleton Terry 1976 Hebdige D 1929 Harvey D 1990 Agamben Giorgio 2000 Derrida Jacques 1988 Kant Immanuel Critique Judgment Derrichenide Jacones 1987 Celling Stronger Martin 1984 Kant I Critique Pure Reason Agamben Giorgio 1999 Cukdom Potentin Mikhail (1996) Cukdom Potentin (1990) Landston (1997) Benjamir W Illuminations Fukuyama E 1992 Marx K Grundrisse Heller-roazen Daniel 1998 Lacan Jac Prakov Brantz 1966 Agamber 1999 G 2005 Benjamin Walter 1996 Heidegger Martin 1962 Derrida J 2002 Benjamin Walley 1988ues 1992 Anamben Giorgio 1998 Derrida Jacques 1974 Schmitt C 1985 Gordon Colin 1980 Derrida Bactiger Jogques 1991 Derrida Jacques 2005 Irigaray L 1974 Nancy Jean-luc 1991 Buck-morss Susan 1989 Agamben G 1999 Foucault M Discipline Punish Derrida Jacques 1985 Derrida J 1967 Cavel S 1979 Cavell Stanley 1969

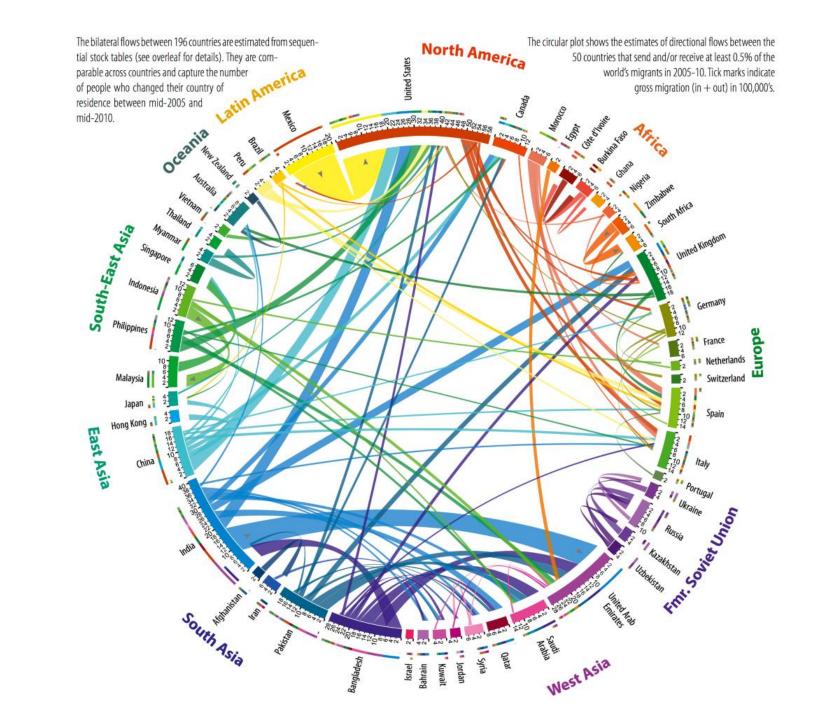
Citation graph of literary theory academic papers

Game of Thrones Character Interaction Network







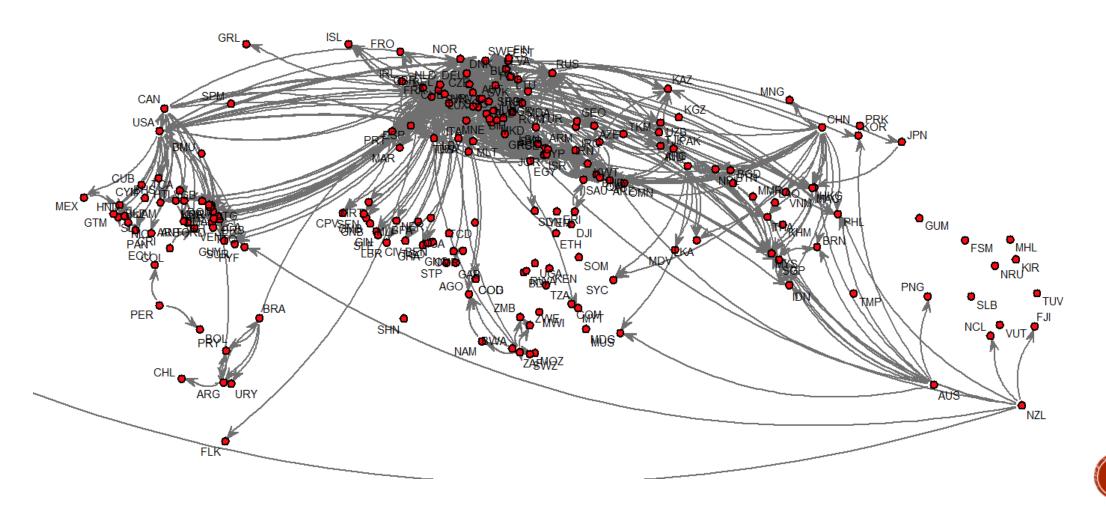


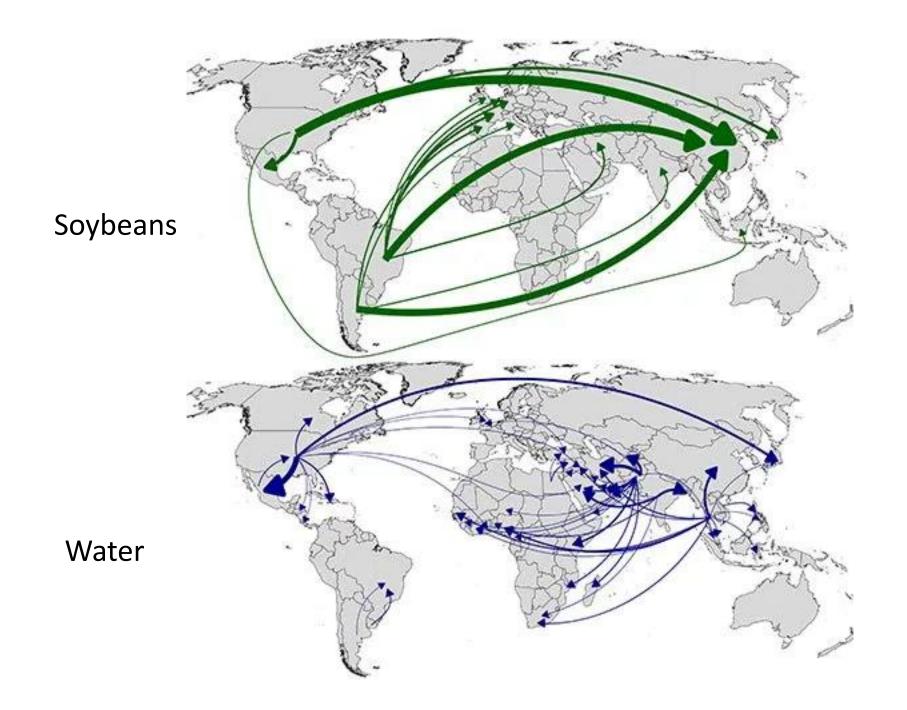
8)

Immigration flows

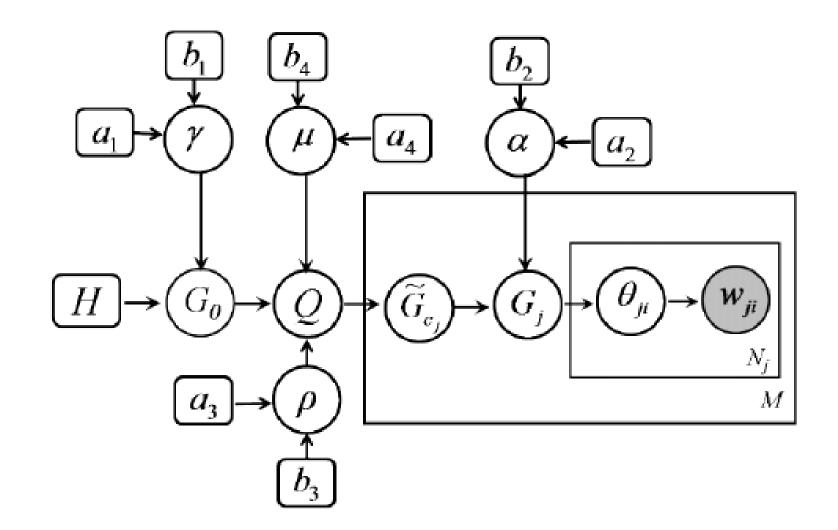
Potato trade

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

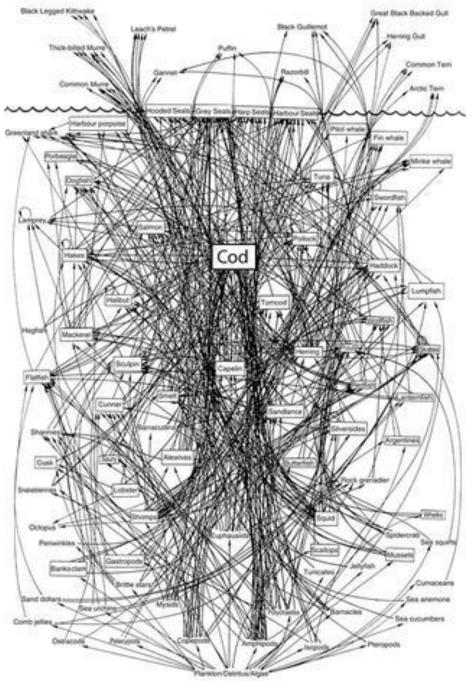




Graphical models



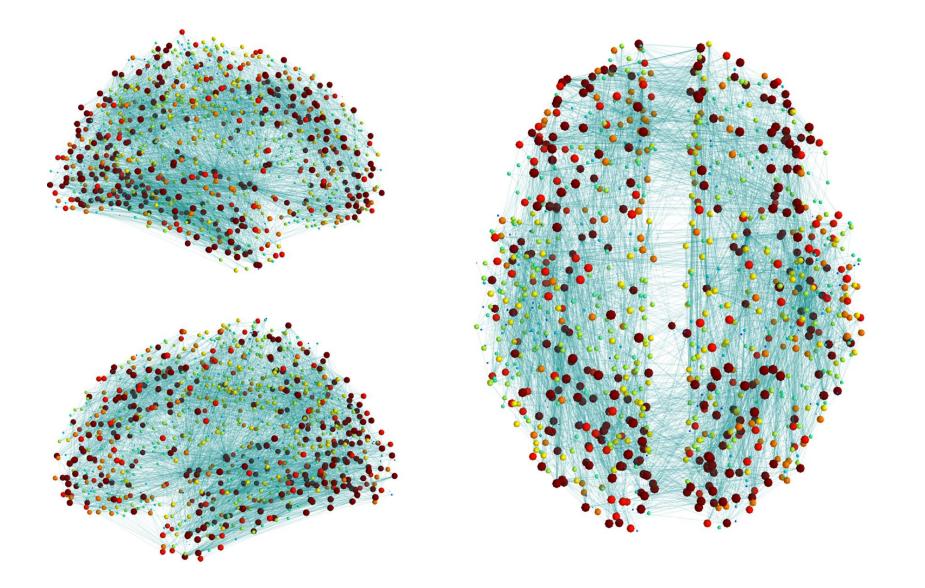




What eats what in the Atlantic ocean?

A simplified food web for the Northwest Atlantic. © IMMA

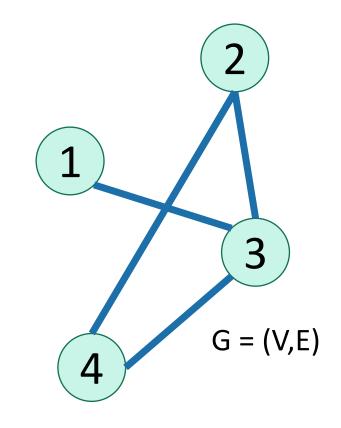
Neural connections in the brain



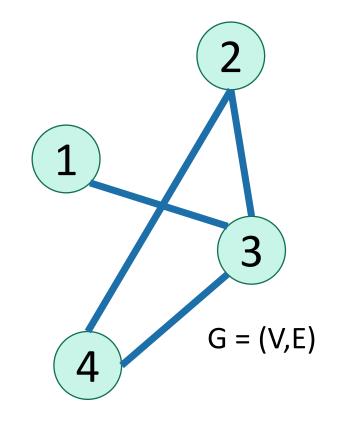
• There are a lot of graphs.

- 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.

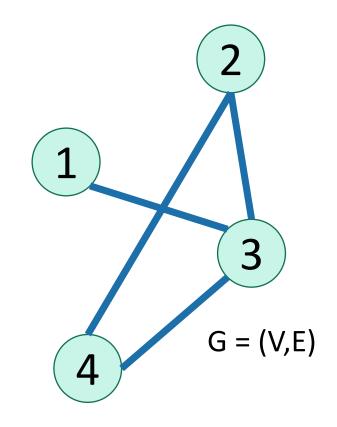




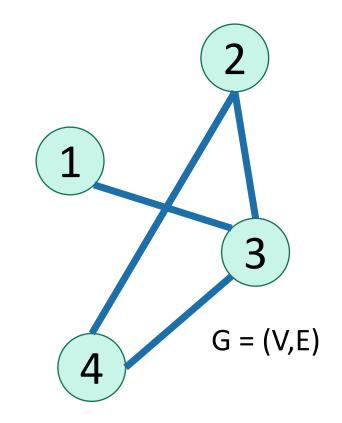
- Has vertices and edges
 - V is the set of vertices
 - E is the set of edges
 - Formally, a graph is G = (V,E)



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- Example
 - V = {1,2,3,4}
 - E = { {1,3}, {2,4}, {3,4}, {2,3} }

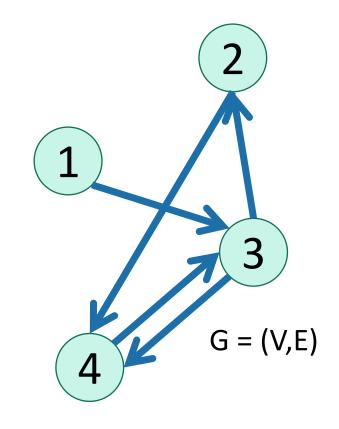


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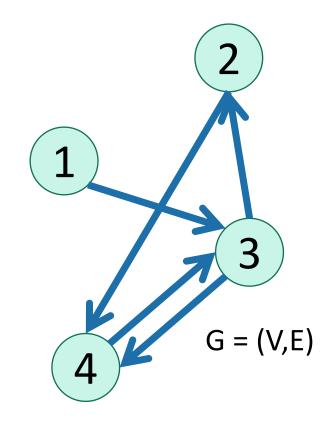
- The **degree** of vertex 4 is 2.
 - There are 2 edges coming out.
- Vertex 4's neighbors are 2 and 3



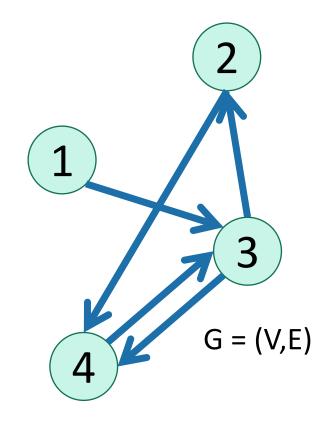




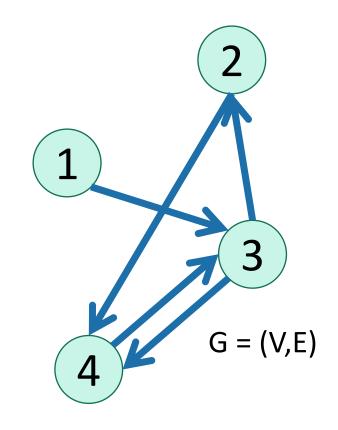
- Has vertices and edges
 - V is the set of vertices
 - E is the set of **DIRECTED** edges
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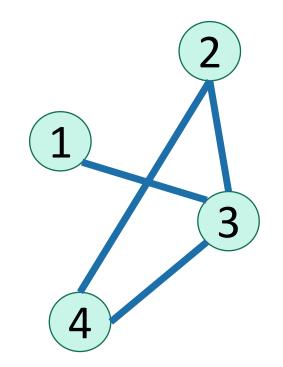
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- Example
 - V = {1,2,3,4}
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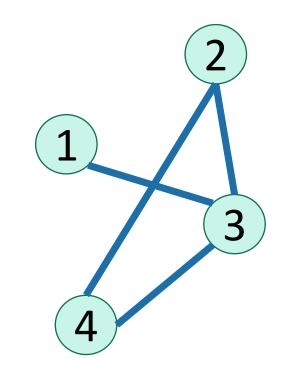


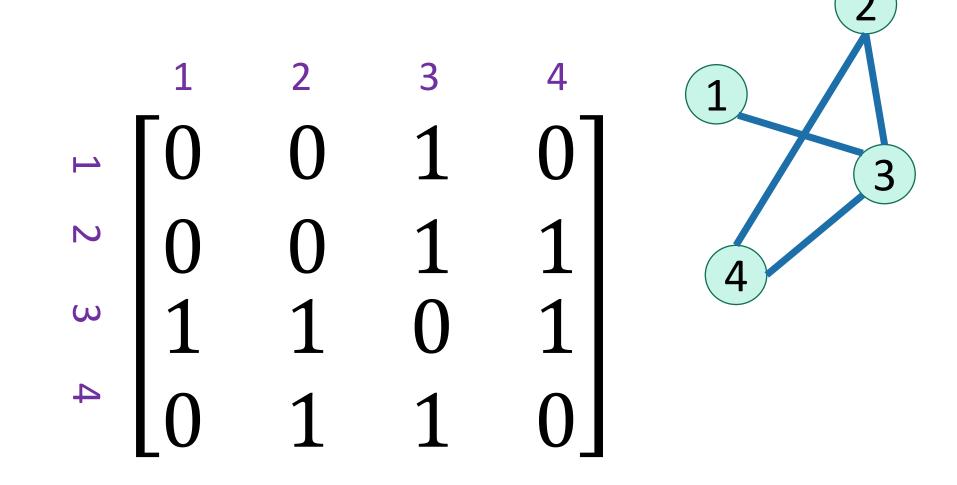
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- Example
 - V = {1,2,3,4}
 - E = { (1,3), (2,4), (3,4), (4,3), (3,2) }

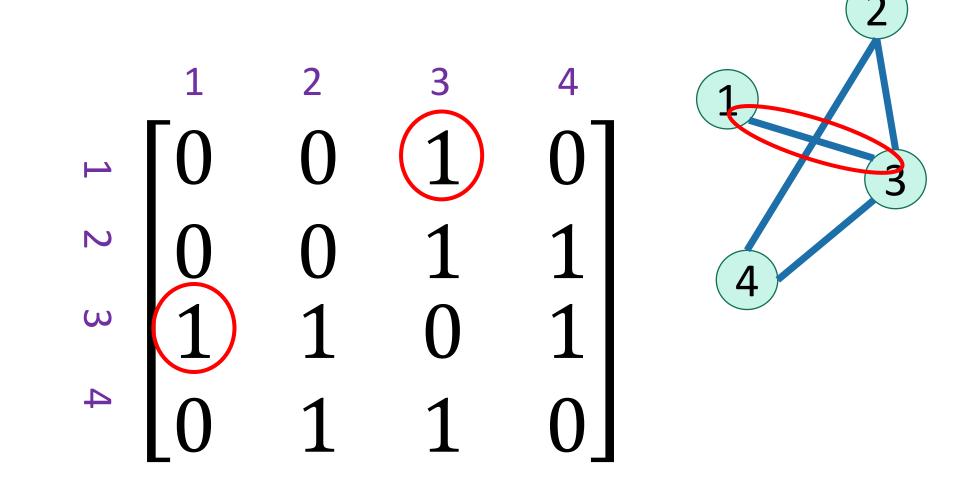


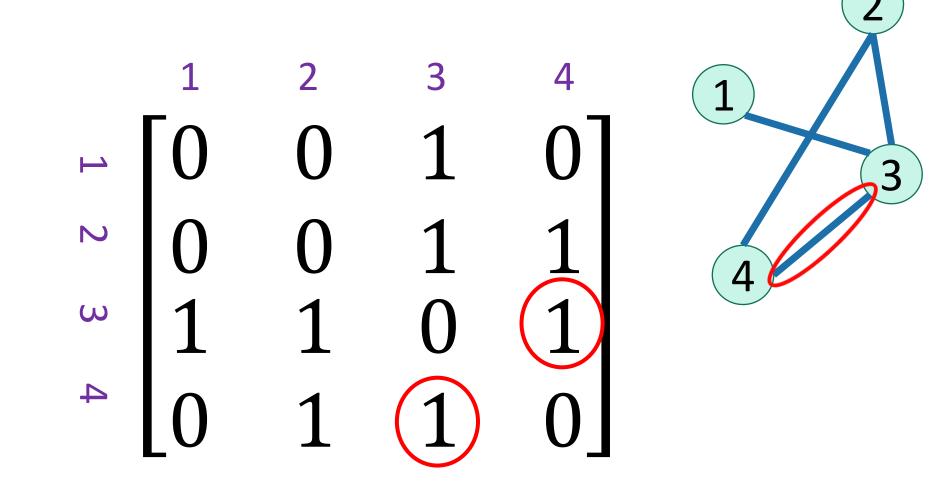
- The **in-degree** of vertex 4 is 2.
- The **out-degree** of vertex 4 is 1.
- Vertex 4's incoming neighbors are 2,3
- Vertex 4's outgoing neighbor is 3.

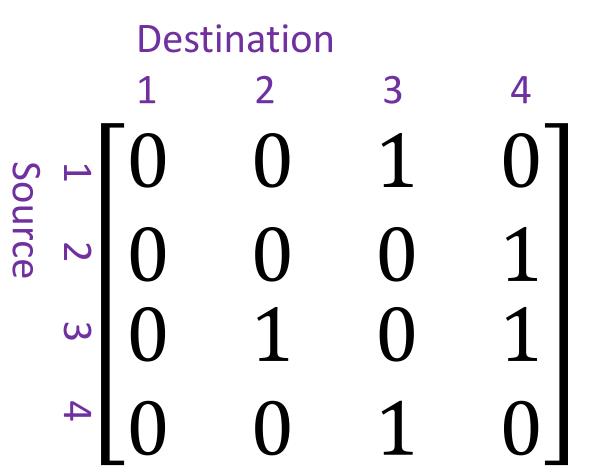


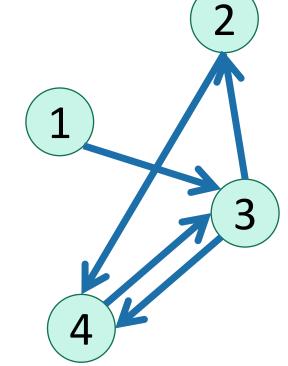


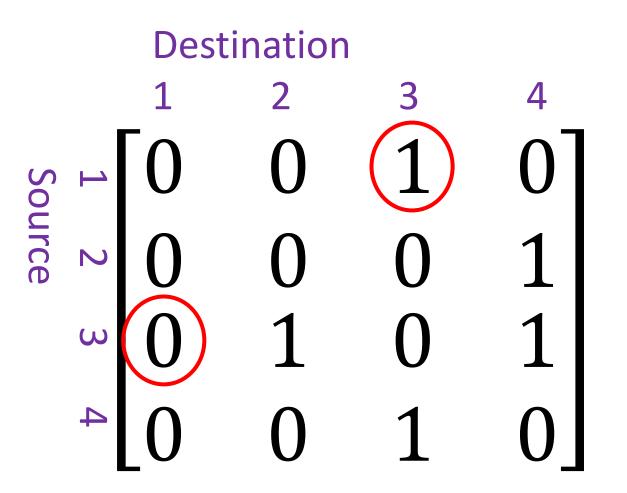


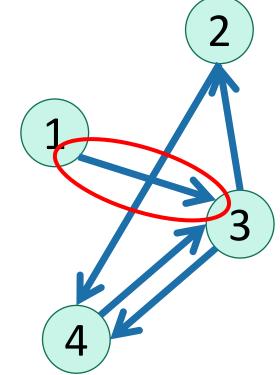




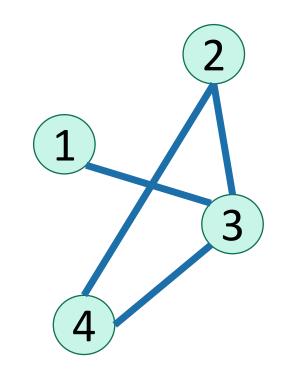




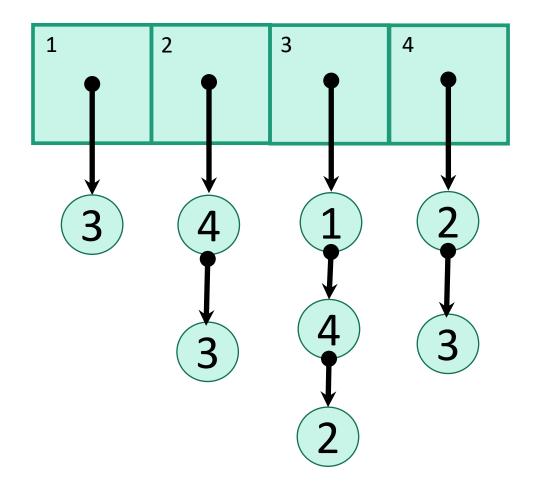


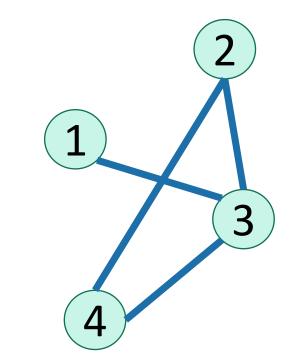


• Option 2: adjacency lists.

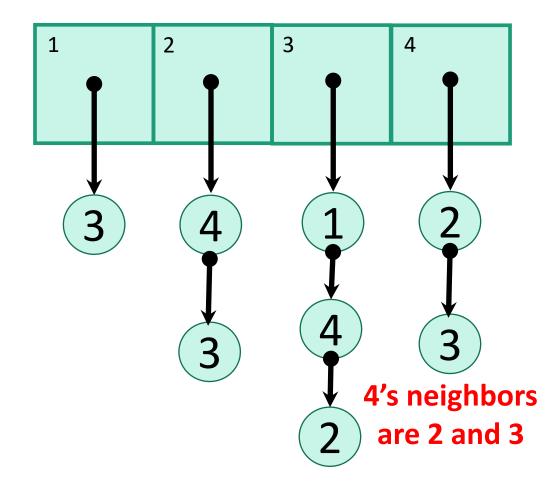


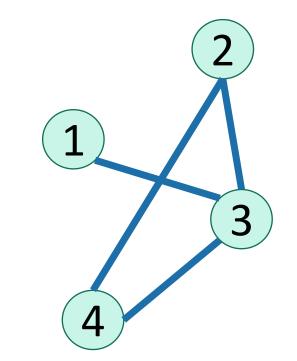
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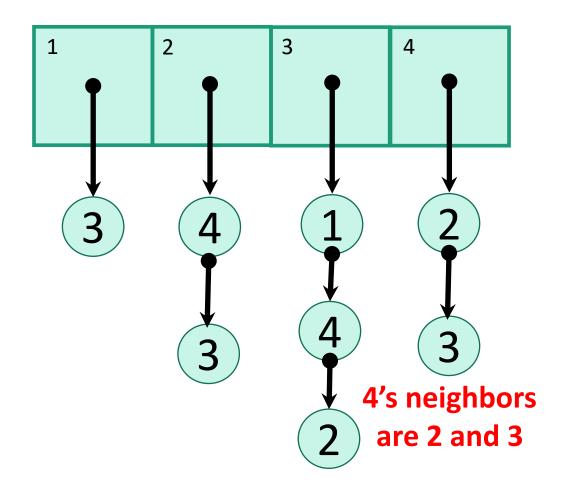


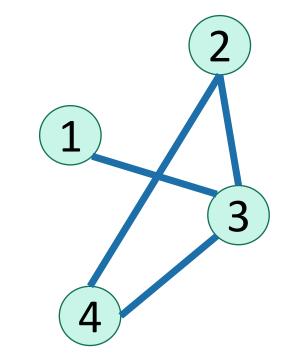
• Option 2: adjacency lists.





• Option 2: adjacency lists.





How would you modify this for directed graphs?

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

36)

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.		
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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.		
Space requirements		

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Space requirements		

40

Say there are n vertices and m edges.	$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
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Space requirements	O(n²)	O(n + m)

Generally better for **sparse** graphs

Say there are n vertices and m edges.	$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
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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