Analysis of Latent Relationships in Semantic Graphs using DEDICOM

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National Nuclear Security Administration

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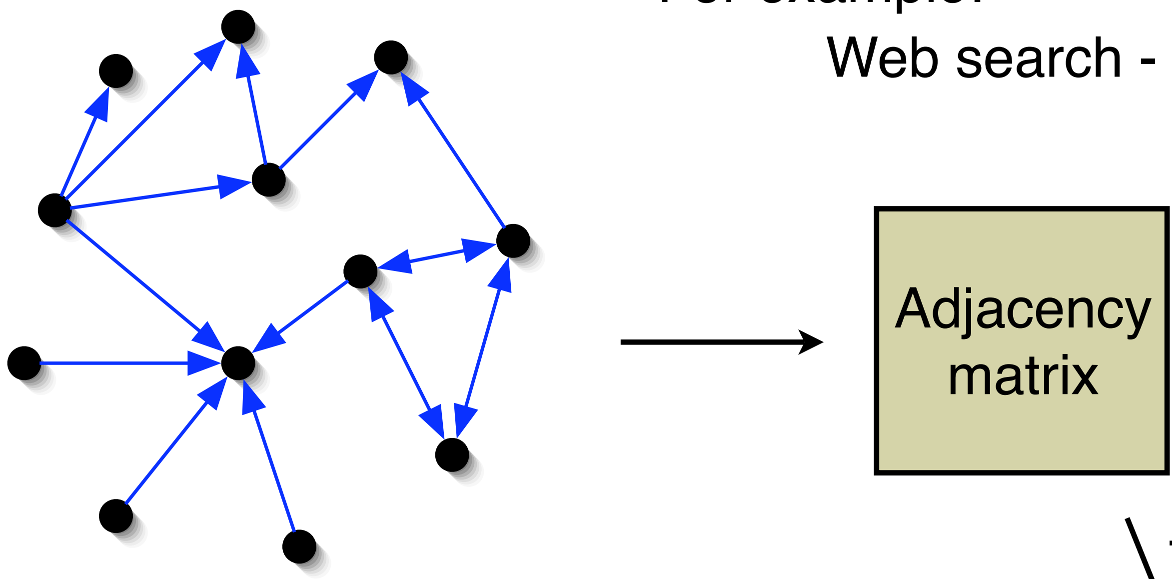
Common Graph Analysis Technique

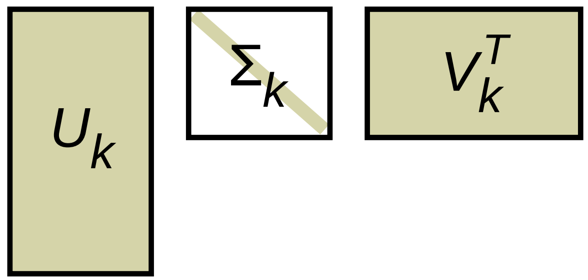
For example:

Web search - HITS (Kleinberg, 1998)



Truncated SVD

$$A_k = U_k \Sigma_k V_k^T = \sum_{i=1}^{k} \sigma_i u_i v_i^T$$



Best rank-*k* matrix filters out noise and captures “latent” information, which improves certain data mining tasks

But we may have ignored critical information by not considering edge metadata!

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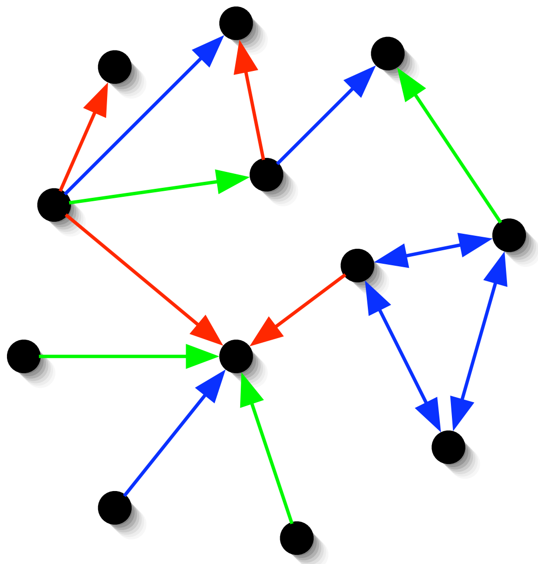
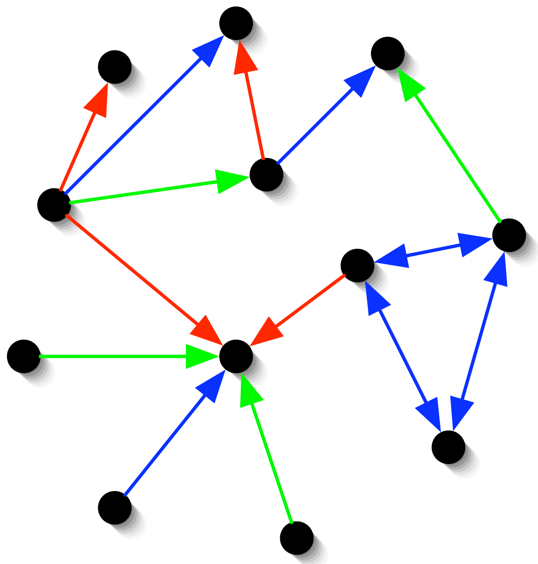
Semantic Graphs

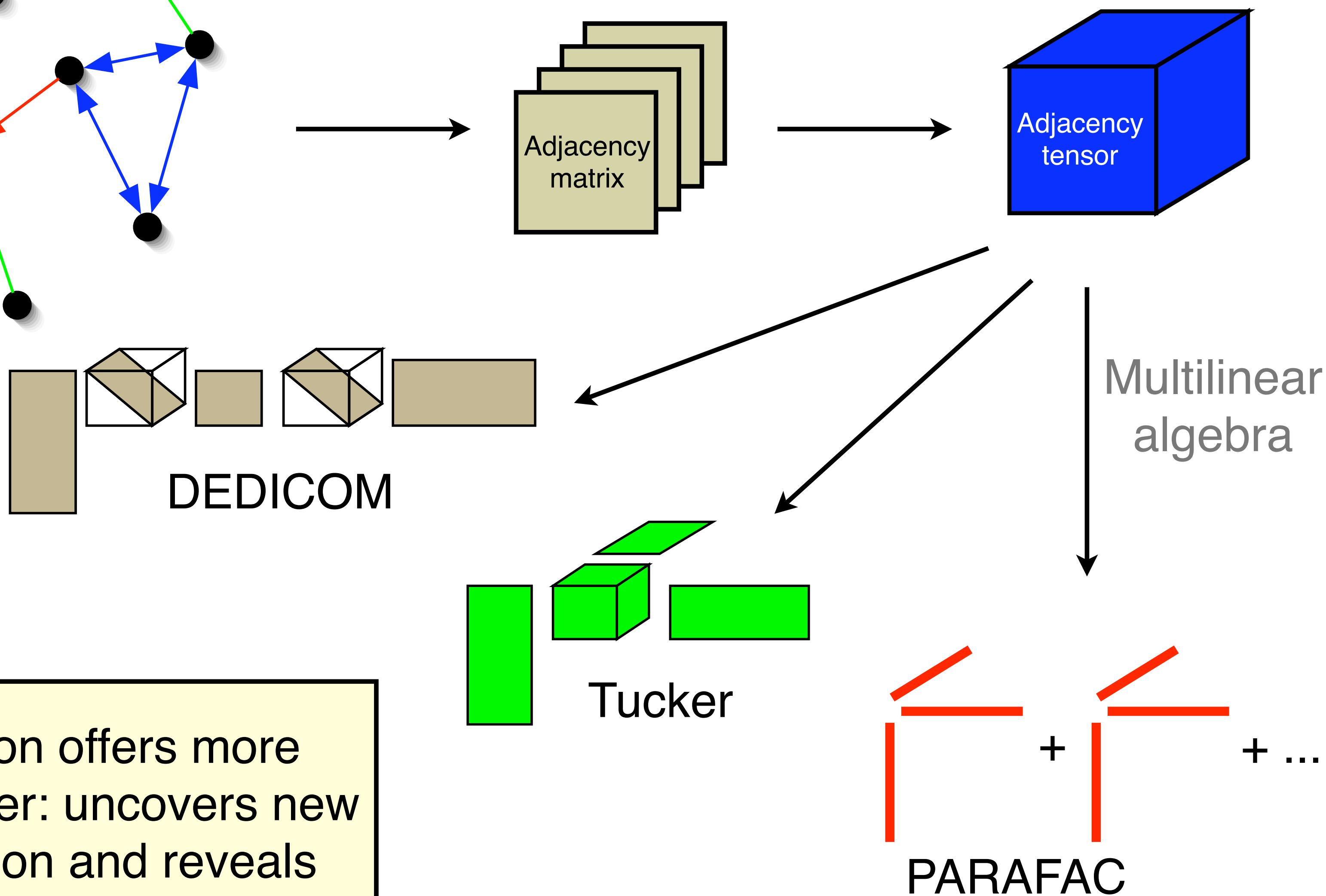


- Different types of edges
- Examples
  - WWW (anchor text)
  - Subway map [thanks Orly!]
  - Email communications (time stamp, to/cc)

New Paradigm: "Multidimensional Data Mining"



Build an "adjacency tensor" such that there is an adjacency matrix for each edge type.



Third dimension offers more explanatory power: uncovers new latent information and reveals subtle relationships

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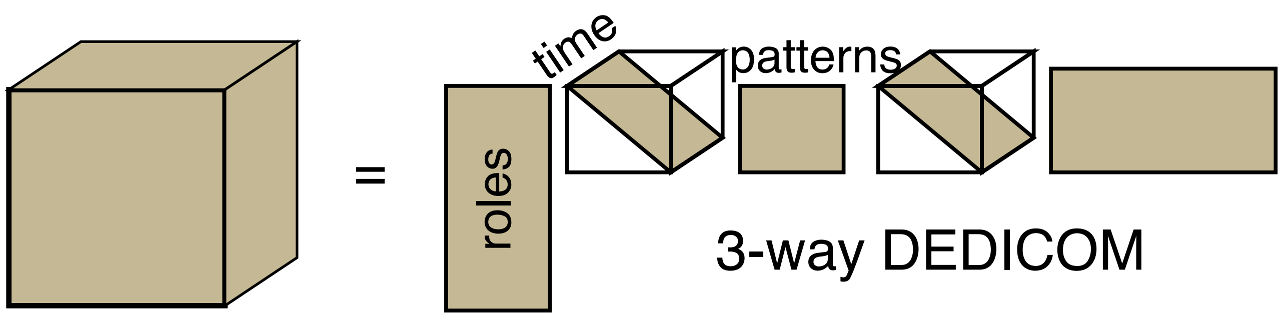
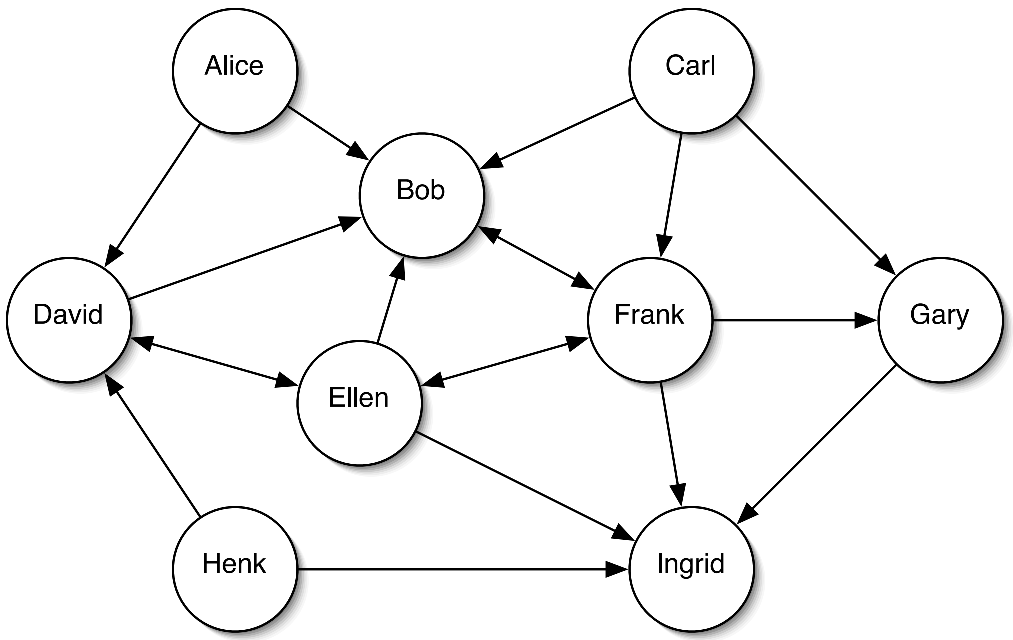
Objective

Use DEDICOM to analyze a semantic graph of email communications changing over time

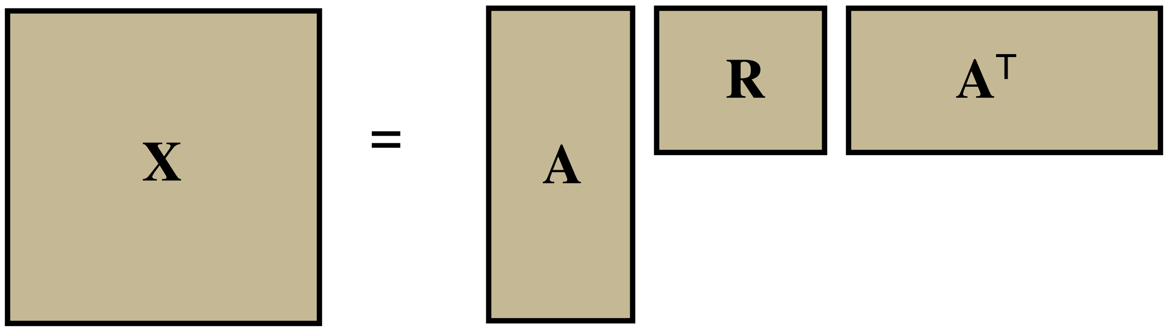




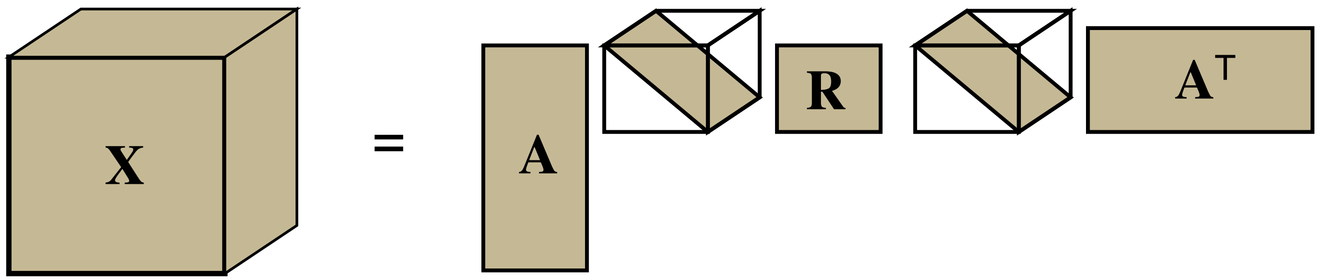
DEDICOM

- DEcomposition into DIrectional COMponents
- Introduced in 1978 by Harshman
- Past applications
  - Study asymmetries in telephone calls among cities
  - Marketing research
    - car switching: car owners and what they buy next
    - free associations of words
      - words to describe hair in advertising shampoo: “body” evokes “fullness” more often than “fullness” evokes “body”
  - Asymmetric measures of world trade (import/export)
- Variations
  - Three-way DEDICOM
  - Constrained DEDICOM

DEDICOM Models & Algorithms



- Generalized Takane method (Takane, 1985; Kiers et al., 1990)
- New algorithm

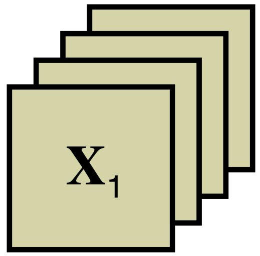


- Kiers' method (Kiers, 1993)
- New algorithm

All are "alternating" algorithms

Mathematical Notation

- Scalars a
- Vectors $\mathbf{a}$
- Matrices $\mathbf{A}$
- Tensors (3-way array) $\boldsymbol{\mathcal{D}}$ $\boldsymbol{\mathcal{X}}$
  - frontal slices of $\boldsymbol{\mathcal{X}}$: $\mathbf{X}_i$



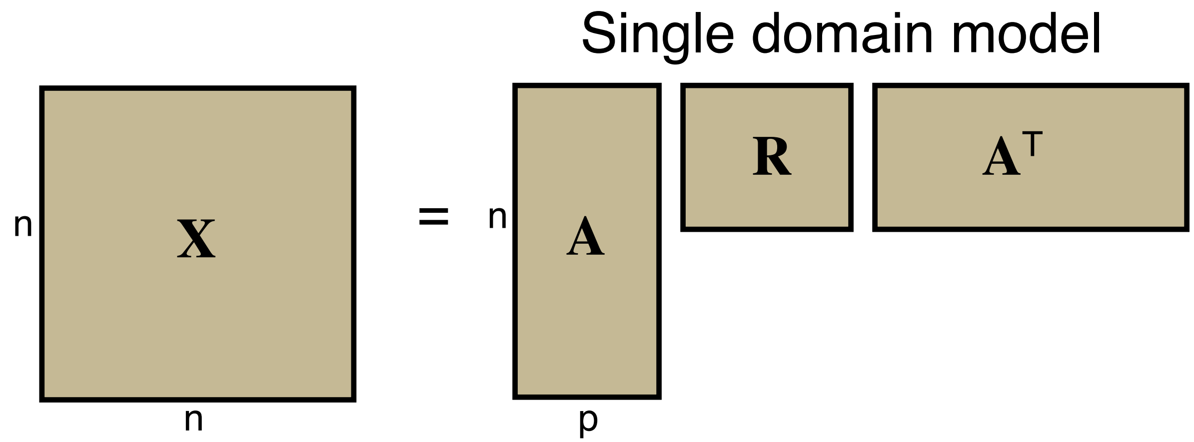
- Special symbols
  - Kronecker product

$$\mathbf{A} \otimes \mathbf{B} = \begin{bmatrix} a_{11}\mathbf{B} & \dots & a_{1n}\mathbf{B} \\ \vdots & \ddots & \vdots \\ a_{m1}\mathbf{B} & \dots & a_{mn}\mathbf{B} \end{bmatrix}$$

  - Hadamard product (elementwise)

$$\mathbf{A} * \mathbf{B} = \begin{bmatrix} a_{11}b_{11} & \dots & a_{1n}b_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1}b_{m1} & \dots & a_{mn}b_{mn} \end{bmatrix}$$

Two-way DEDICOM



$$\mathbf{X} = \mathbf{A}\mathbf{R}\mathbf{A}^T + \mathbf{E}$$

$$\mathbf{X} \approx \mathbf{A}\mathbf{R}\mathbf{A}^T$$

$$\min_{\mathbf{A},\mathbf{R}} \left\| \mathbf{X} - \mathbf{A}\mathbf{R}\mathbf{A}^T \right\|_F^2$$

s.t. $\mathbf{A}$ orthogonal

- $\mathbf{A}$ (n x p) is an orthogonal matrix of loadings or weights
- $\mathbf{R}$ (p x p) is a dense matrix that captures asymmetric relationships

- Decomposition is not unique
  - $\mathbf{A}$ can be transformed with no loss of fit to the data
  - Nonsingular transformation $\mathbf{Q}$:

$$\mathbf{A}\mathbf{R}\mathbf{A}^T = (\mathbf{A}\mathbf{Q})(\mathbf{Q}^{-1}\mathbf{R}\mathbf{Q}^{-T})(\mathbf{A}\mathbf{Q})^T$$

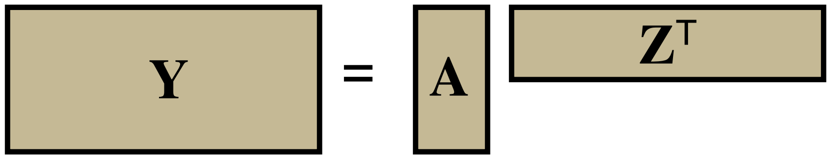
  - Usually “fix” $\mathbf{A}$ with some standard rotation (e.g., VARIMAX)

New Algorithm

Solving for $\mathbf{A}$:

Stack data and model "side by side" in a single equation

$$\begin{aligned}\begin{pmatrix}\mathbf{X} & \mathbf{X}^T\end{pmatrix} &= \begin{pmatrix}\mathbf{ARA}^T & \mathbf{AR}^T\mathbf{A}^T\end{pmatrix} \\ &= \mathbf{A}\left(\begin{pmatrix}\mathbf{R} & \mathbf{R}^T\end{pmatrix}\begin{pmatrix}\mathbf{A}^T & 0 \\ 0 & \mathbf{A}^T\end{pmatrix}\right)\end{aligned}$$



...and solve least-squares problem: $\min_{\mathbf{A}} \left\| \mathbf{Y} - \mathbf{AZ}^T \right\|_F^2$

$$\mathbf{A}_{new} \leftarrow \begin{pmatrix}\mathbf{X} & \mathbf{X}^T\end{pmatrix}\left(\begin{pmatrix}\mathbf{R} & \mathbf{R}^T\end{pmatrix}\begin{pmatrix}\mathbf{A}^T & 0 \\ 0 & \mathbf{A}^T\end{pmatrix}\right)^{\dagger}$$

or

$$\mathbf{A}_{new} = \left(\mathbf{XAR}^T + \mathbf{X}^T\mathbf{AR}\right)\left(\mathbf{R}(\mathbf{A}^T\mathbf{A})\mathbf{R}^T + \mathbf{R}^T(\mathbf{A}^T\mathbf{A})\mathbf{R}\right)^{-1}.$$

Solving for $\mathbf{R}$:

$$\mathbf{R}_{new} = \mathbf{A}^{\dagger}\mathbf{X}(\mathbf{A}^T)^{\dagger}$$

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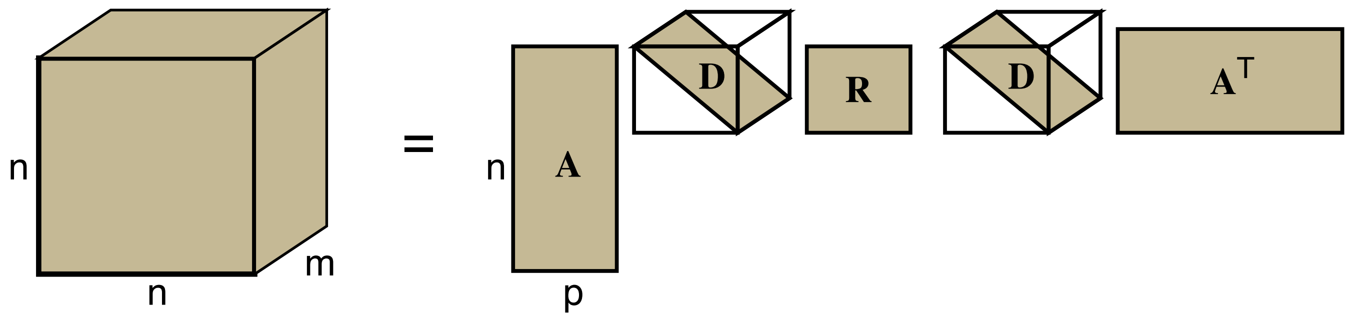
Three-way DEDICOM



$$\mathbf{X}_i = \mathbf{A}\mathbf{D}_i\mathbf{R}\mathbf{D}_i\mathbf{A}^T + \mathbf{E}_i \quad \text{for } i = 1, \ldots, m,$$

$$\min_{\mathbf{A},\mathbf{R},\mathcal{D}} \sum_{i=1}^{m} \left\| \mathbf{X}_i - \mathbf{A}\mathbf{D}_i\mathbf{R}\mathbf{D}_i\mathbf{A}^T \right\|_F^2$$

- $\mathbf{A}$ (n x p) is a matrix of loadings or weights (not necessarily orthogonal)
- $\mathbf{R}$ (p x p) is a dense matrix that captures asymmetric relationships
- $\mathbf{D}$ (p x p x m) is a tensor with diagonal frontal slices giving the weights of the columns of $\mathbf{A}$ for each slice in third mode

- *Unique* solution with enough slices of $\mathbf{X}$ with sufficient variation
  - i.e., no rotation of $\mathbf{A}$ possible
  - greater confidence in interpretation of results

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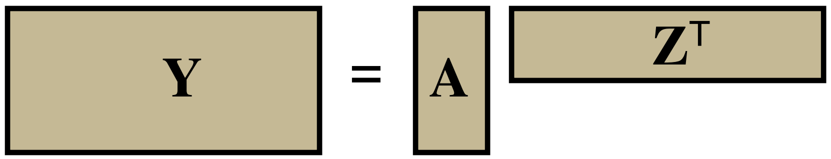
New Algorithm - Updating A

$$\min_{\mathbf{A},\mathbf{R},\mathcal{D}} \sum_{i=1}^{m} \| \mathbf{X}_i - \mathbf{A}\mathbf{D}_i\mathbf{R}\mathbf{D}_i\mathbf{A}^T \|_F^2$$

Solving for $\mathbf{A}$:

$$\left(\mathbf{X}_1 \quad \mathbf{X}_1^T \quad \cdots \quad \mathbf{X}_m \quad \mathbf{X}_m^T\right) = \mathbf{A}\left(\mathbf{D}_1\mathbf{R}\mathbf{D}_1 \quad \mathbf{D}_1\mathbf{R}^T\mathbf{D}_1 \quad \cdots \quad \mathbf{D}_m\mathbf{R}\mathbf{D}_m \quad \mathbf{D}_m\mathbf{R}^T\mathbf{D}_m\right)\left(\mathbf{I}_{2m} \otimes \mathbf{A}^T\right)$$



$$\mathbf{A} = \mathbf{Y}\mathbf{Z}(\mathbf{Z}^T\mathbf{Z})^{-1}$$

$$\mathbf{A} = \left[\sum_{i=1}^{m}\left(\mathbf{X}_i\mathbf{A}\mathbf{D}_i\mathbf{R}^T\mathbf{D}_i + \mathbf{X}_i^T\mathbf{A}\mathbf{D}_i\mathbf{R}\mathbf{D}_i\right)\right]\left[\sum_{i=1}^{m}(\mathbf{B}_i + \mathbf{C}_i)\right]^{-1}$$

$$\text{where} \quad \mathbf{B}_i \equiv \mathbf{D}_i\mathbf{R}\mathbf{D}_i(\mathbf{A}^T\mathbf{A})\mathbf{D}_i\mathbf{R}^T\mathbf{D}_i,$$
$$\mathbf{C}_i \equiv \mathbf{D}_i\mathbf{R}^T\mathbf{D}_i(\mathbf{A}^T\mathbf{A})\mathbf{D}_i\mathbf{R}\mathbf{D}_i.$$

New Algorithm - Updating D

$$\min_{\mathbf{D}_i} \| \mathbf{X}_i - \mathbf{A}\mathbf{D}_i\mathbf{R}\mathbf{D}_i\mathbf{A}^T \|_F^2$$

Solving for $\mathbf{D}$:

Use Newton's method to solve the optimization problem for $d = \text{diag}(\mathbf{D}_i)$

$$d_{new} = d - H^{-1}g$$

Gradient: $g_k = -\sum_{i,j} \left[2(\mathbf{X} - \mathbf{ADRDA}^T) * (\mathbf{AD}\mathbf{r}_k\mathbf{a}_k^T + \mathbf{a}_k\mathbf{r}_{k,:}\mathbf{DA}^T) \right]_{i,j}$

Hessian: $h_{st} = -2\sum_{i,j} \left[(\mathbf{X} - \mathbf{ADRDA}^T) * (\mathbf{a}_s r_{st}\mathbf{a}_t^T + \mathbf{a}_t r_{ts}\mathbf{a}_s^T) - (\mathbf{AD}\mathbf{r}_s\mathbf{a}_s^T + \mathbf{a}_s\mathbf{r}_{s:}\mathbf{DA}^T) * (\mathbf{AD}\mathbf{r}_t\mathbf{a}_t^T + \mathbf{a}_t\mathbf{r}_{t:}\mathbf{DA}^T) \right]_{i,j}$

Use compression

QR factorization: $\mathbf{A} = \mathbf{Q}\tilde{\mathbf{A}},$

$$\min_{\mathbf{D}_i} \left\| \mathbf{Q}^T\mathbf{X}_i\mathbf{Q} - \tilde{\mathbf{A}}\mathbf{D}_i\mathbf{R}\mathbf{D}_i\tilde{\mathbf{A}}^T \right\|_F^2$$

Smaller problem (p x p)

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Our Algorithm - Updating R

$$\min_{\mathbf{R}} \sum_{i=1}^{m} \| \mathbf{X}_i - \mathbf{A}\mathbf{D}_i\mathbf{R}\ \mathbf{D}_i\mathbf{A}^T \|_F^2$$

Solving for $\mathbf{R}$:

Use the approach in (Kiers, 1993)

$$\text{minimize:}\ \ f(\mathbf{R}) = \left\| \begin{pmatrix} \text{Vec}(\mathbf{X}_1) \\ \vdots \\ \text{Vec}(\mathbf{X}_m) \end{pmatrix} - \begin{pmatrix} \mathbf{A}\mathbf{D}_1 \otimes \mathbf{A}\mathbf{D}_1 \\ \vdots \\ \mathbf{A}\mathbf{D}_m \otimes \mathbf{A}\ \mathbf{D}_m \end{pmatrix} \text{Vec}(\mathbf{R}) \right\|$$

$$\text{Vec}(\mathbf{R}) = \left(\sum_{i=1}^{m} (\mathbf{D}_i\mathbf{A}^T\mathbf{A}\mathbf{D}_i) \otimes (\mathbf{D}_i\mathbf{A}^T\mathbf{A}\mathbf{D}_i) \right)^{-1} \sum_{i=1}^{m} \text{Vec}(\mathbf{D}_i\mathbf{A}^T\mathbf{X}_i\mathbf{A}\mathbf{D}_i)$$

Algorithm Costs

Updating $\mathbf{A}$ is most expensive part

Dominant costs:

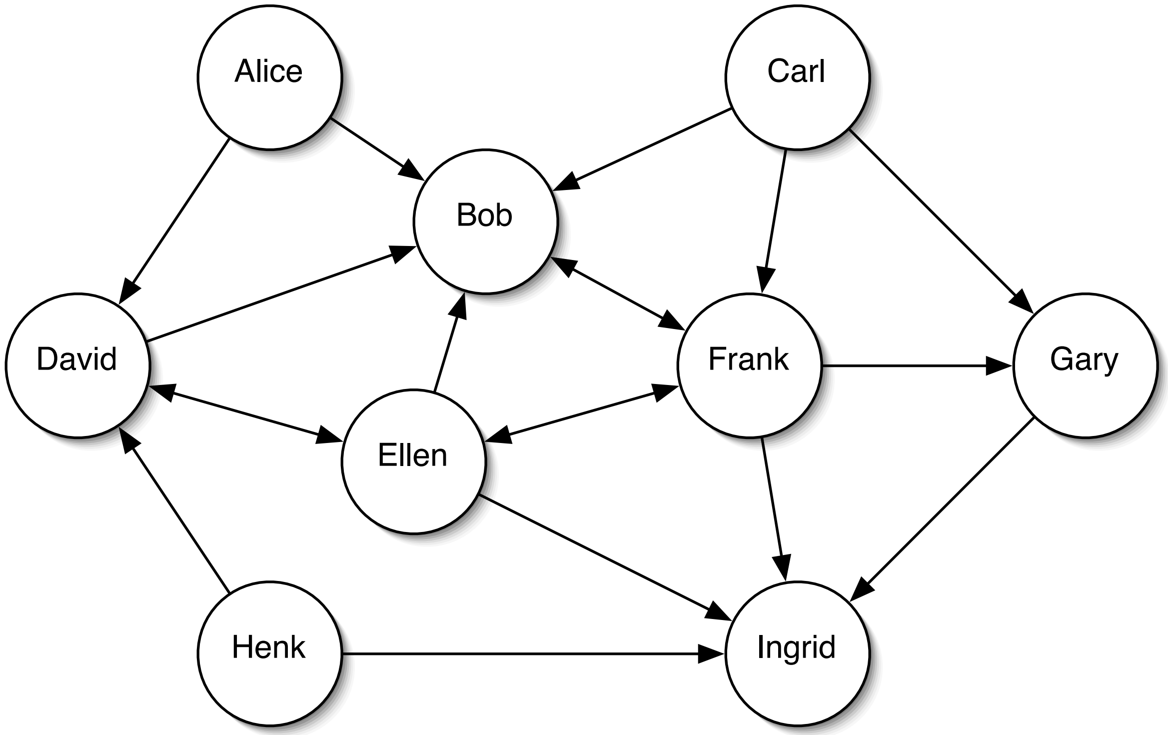
linear in nnz of $\mathbf{X}_i$:

- $\mathbf{Q}^T\mathbf{X}_i\mathbf{Q}$
- $\mathbf{X}_i\mathbf{A}\mathbf{R}^T$
- $\mathbf{X}_i^T\mathbf{A}\mathbf{R}$

$\mathcal{O}(p^2n)$:

- $\mathbf{A}^T\mathbf{A}$
- QR factorization of $\mathbf{A}$

Application: Enron Email Analysis



- Links consist of email communications
- What can we learn about this network strictly from their communication patterns? (Social network analysis)

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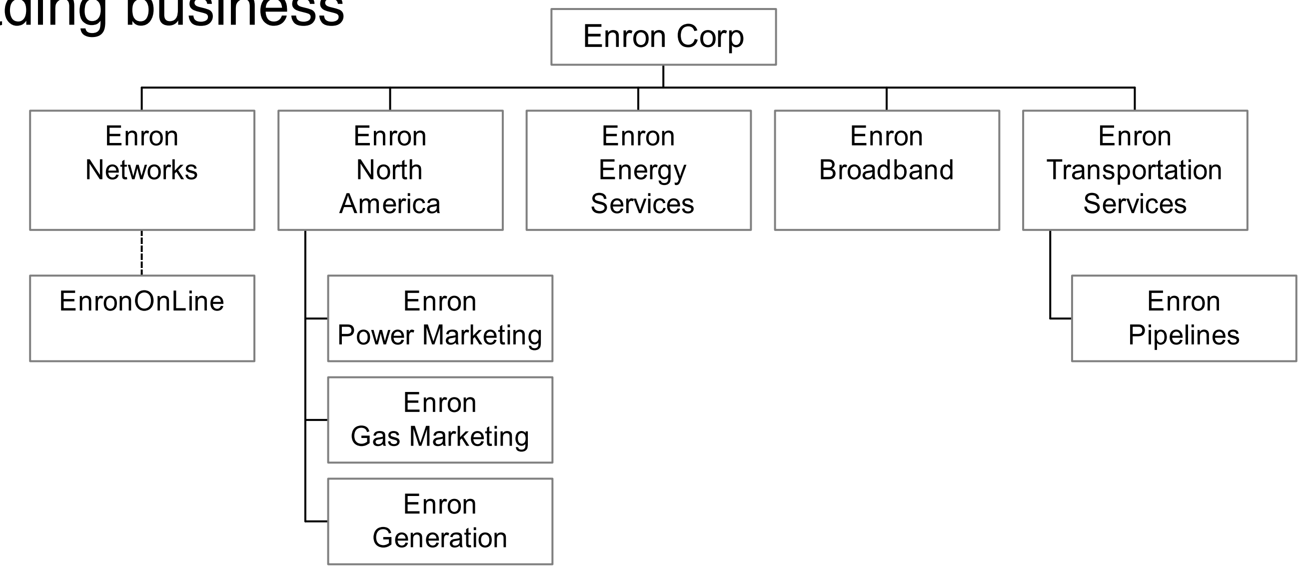
Enron Corp.

- U.S. corporation involved with creating energy markets
  - 7th largest by revenue
- EnronOnline: e-trading business
  - natural gas
  - electric power



- Investigations
  - U.S. Federal Energy Regulatory Commission (FERC)
    - energy market manipulation
    - involved energy traders
  - U.S. Securities and Exchange Commission (SEC)
    - accounting fraud
    - insider trading

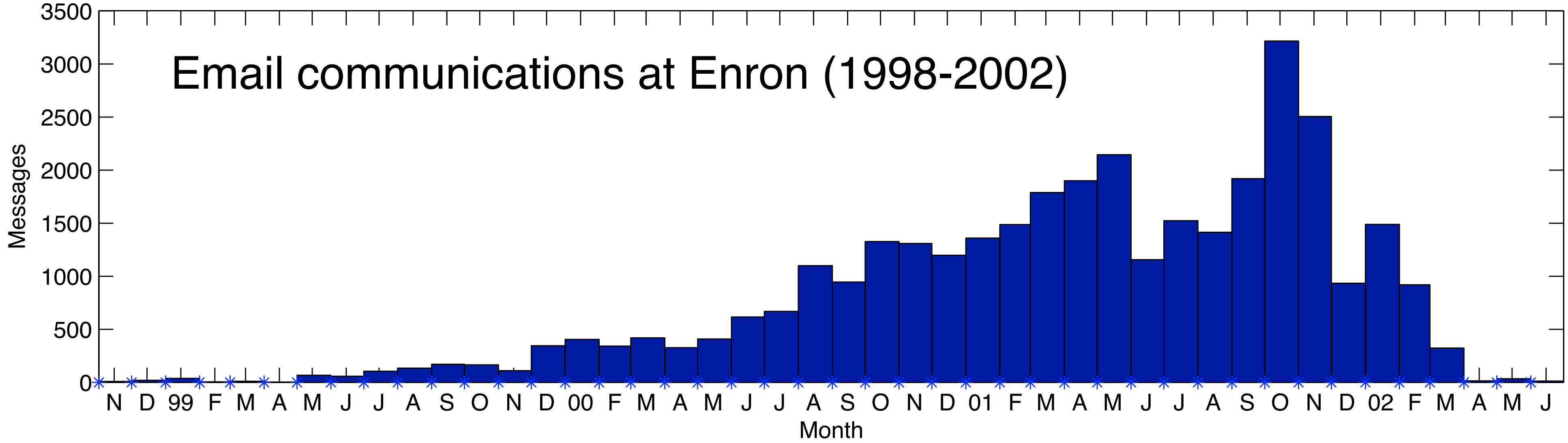
Enron Email Data

- FERC collected email of ~150 employees as evidence
  - Included emails saved in inbox, sent items, deleted items, and all other folders

- Released to the public in 2002 by FERC as part of their investigation
  - To/from, date, subject, body
  - Attachments and some names/emails removed
  - Approx. 500,000 email messages

Smaller Enron Data Set

We used a smaller data set prepared by Priebe et al.
34,427 emails among 184 employees over 44 months



- Limited information on the 184 employees
- No org chart

DEDICOM Experiment

- Aggregate communications
  - Sparse matrix of size 184 x 184 (3007 nonzeros)

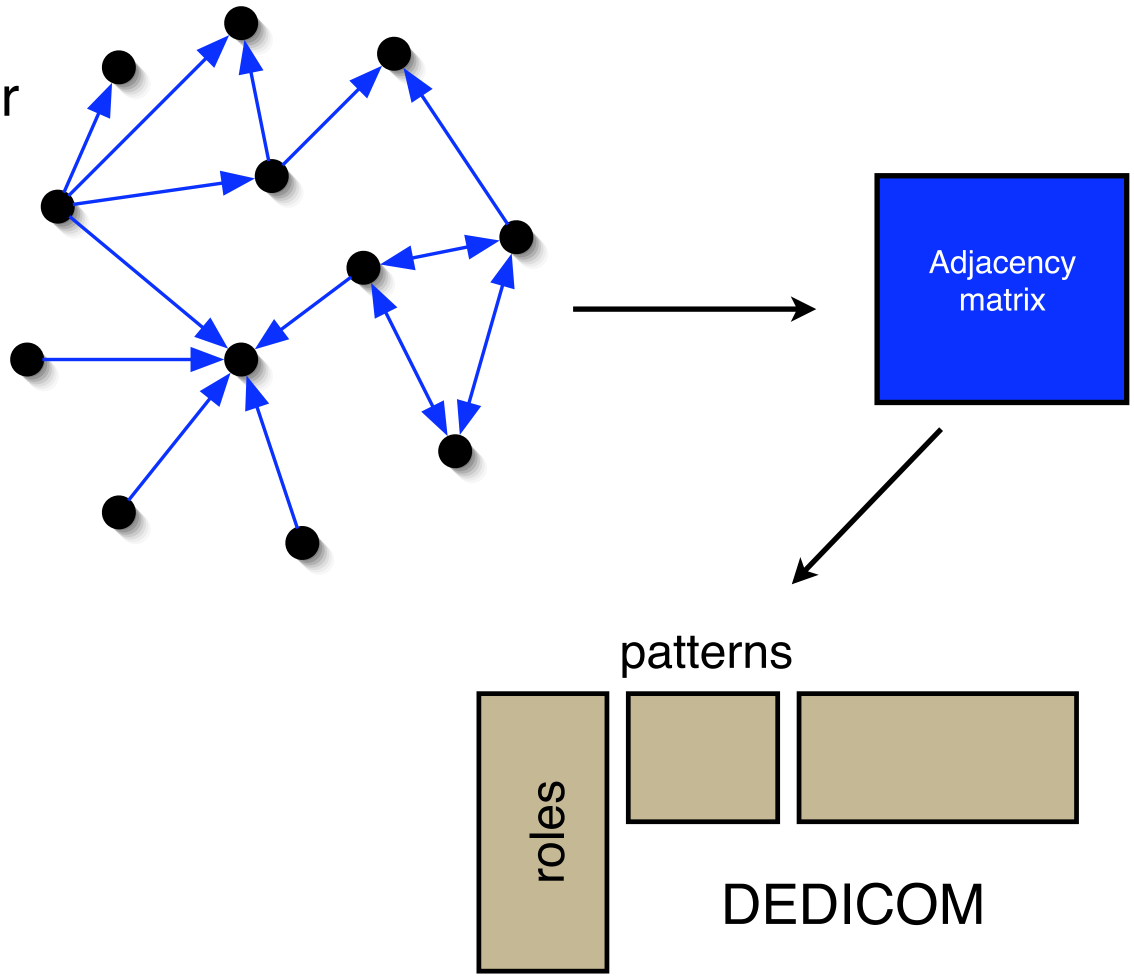
- Time series of communication graphs
  - Sparse tensor of size 184 x 184 x 44 (9838 nonzeros)

- Weighted adjacency matrix
  - scaling: x number of messages scaled by log(x)+1
  - other common choices give similar results

- Models:
  - SVD
  - 2-way DEDICOM
  - 3-way DEDICOM

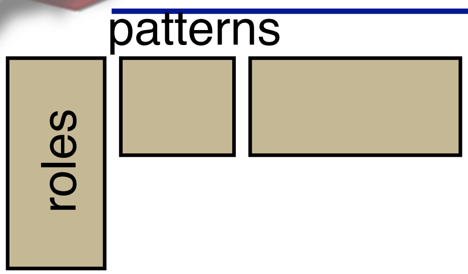
Social Network Analysis

Communication graph among employees over all times



- Description of employees by their roles
- Aggregate communication patterns among roles

DEDICOM Results



Executives Legal Pipeline

	Employee	DEDICOM Solution 1	DEDICOM Solution 2	DEDICOM Solution 3
Execs	J. Lavorato - CEO, Enron America	**0.41**	0.07	0.04
	L. Kitchen - President, Enron Online	**0.26**	**0.21**	0.04
	M. Grigsby - Director, West Desk Gas Trading	**0.22**	-0.01	-0.01
	D. Delainey - CEO, ENA and Enron Energy Services	**0.20**	0.06	0.06
	G. Whalley - President,	**0.17**	0.05	0.04
	L. Taylor - Executive Assistant to Greg Whalley,	**0.17**	0.06	0.03
Legal	T. Jones - Employee, Financial Trading Group (ENA Legal)	**-0.12**	**0.38**	-0.02
	M. Taylor - Manager, Financial Trading Group ENA Legal	-0.10	**0.35**	-0.01
	S. Shackleton - Employee, ENA Legal	**-0.13**	**0.31**	-0.02
	S. Panus - Senior Legal Specialist, ENA Legal	**-0.11**	**0.26**	-0.02
	M. Heard - Senior Legal Specialist, ENA Legal	-0.10	**0.24**	-0.02
	E. Sager - VP and Asst Legal Counsel, ENA Legal	-0.01	**0.24**	0.02
Pipeline	S. Corman - VP, Regulatory Affairs	-0.04	-0.01	**0.33**
	K. Watson - Employee, Transwestern Pipeline Company (ETS)	-0.08	-0.03	**0.32**
	L. Donoho - Employee, Transwestern Pipeline Company (ETS)	-0.08	-0.03	**0.30**
	D. Fossum - VP, Transwestern Pipeline Company (ETS)?	-0.06	-0.00	**0.30**
	M. Lokay - Admin. Asst., Transwestern Pipeline Company (ETS)	-0.07	-0.02	**0.28**
	K. Hyatt - Director, Asset Development TW Pipeline Co. (ETS)	-0.06	-0.02	**0.25**
	R. Hayslett - VP, Also CFO and Treasurer	-0.04	-0.01	**0.23**
	R matrix	70.3	11.6	6.7
		15.4	68.2	5.0
		9.9	6.7	59.5

Identify shared characteristics to label group

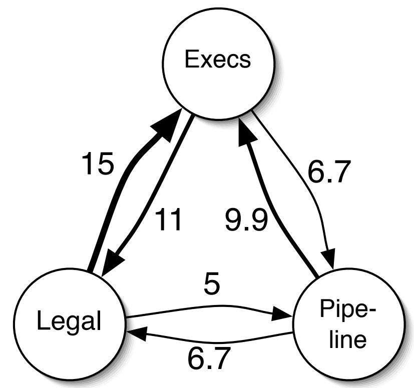
Executives

Legal

Pipeline employees

Some employees have dual roles

Pattern of communications in $\mathbf{R}$ matrix



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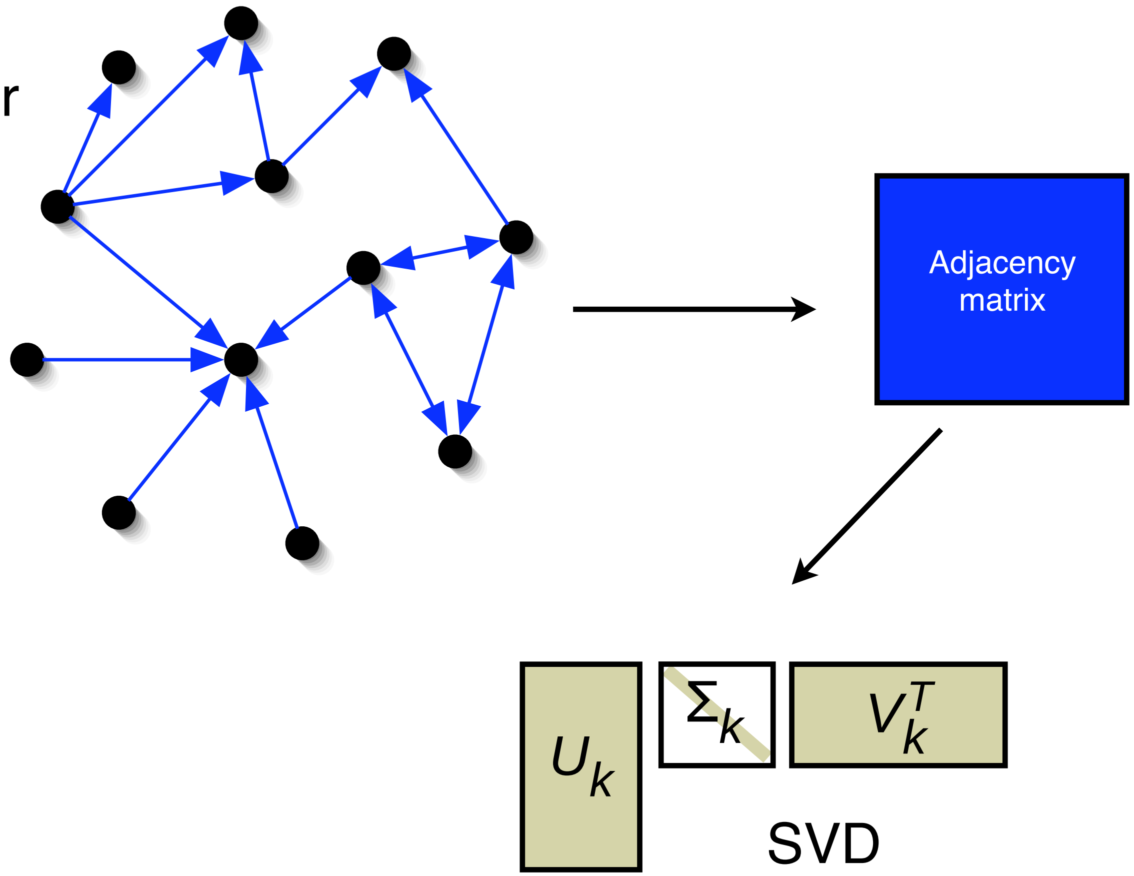
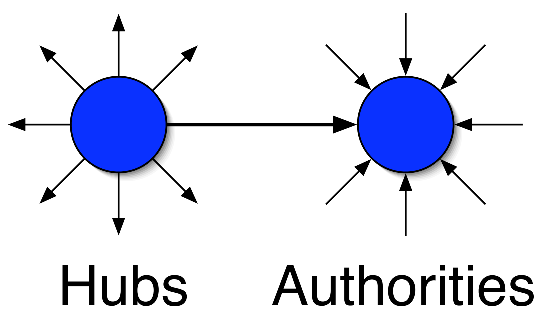
Social Network Analysis

Communication graph among employees over all times



- “Hubs” and “authorities” for different roles



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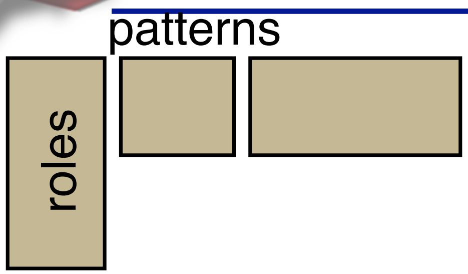
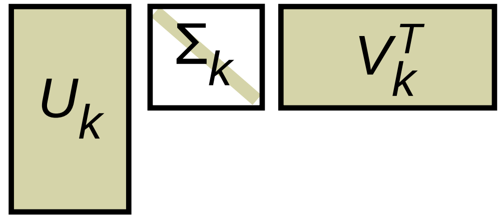
DEDICOM & SVD Results





Executives Legal Pipeline

		DEDICOM Solution			U (hubs)			V (authorities)		
	Employee	1	2	3	1	2	3	1	2	3
Execs	J. Lavorato - CEO, Enron America	**0.41**	0.07	0.04	**0.30**	-0.07	**-0.21**	**0.31**	-0.09	-0.07
Execs	L. Kitchen - President, Enron Online	**0.26**	**0.21**	0.04	**0.31**	0.07	-0.05	**0.29**	0.02	0.04
Execs	M. Grigsby - Director, West Desk Gas Trading	**0.22**	-0.01	-0.01	**0.16**	-0.09	**-0.33**	**0.14**	-0.06	**-0.20**
Execs	D. Delainey - CEO, ENA and Enron Energy Services	**0.20**	0.06	0.06	**0.20**	-0.05	-0.00	**0.20**	-0.05	0.03
Execs	G. Whalley - President,	**0.17**	0.05	0.04	0.08	-0.02	-0.02	**0.24**	-0.07	0.02
Execs	L. Taylor - Executive Assistant to Greg Whalley,	**0.17**	0.06	0.03	**0.24**	-0.05	-0.08	0.09	-0.01	-0.02
Legal	T. Jones - Employee, Financial Trading Group (ENA Legal)	**-0.12**	**0.38**	-0.02	**0.17**	**0.36**	**0.13**	0.10	**0.24**	**0.10**
Legal	M. Taylor - Manager, Financial Trading Group ENA Legal	-0.10	**0.35**	-0.01	**0.13**	**0.27**	**0.13**	**0.13**	**0.26**	**0.12**
Legal	S. Shackleton - Employee, ENA Legal	**-0.13**	**0.31**	-0.02	0.08	**0.26**	**0.10**	0.08	**0.26**	**0.10**
Legal	S. Panus - Senior Legal Specialist, ENA Legal	**-0.11**	**0.26**	-0.02	0.09	**0.27**	0.10	0.05	**0.20**	0.08
Legal	M. Heard - Senior Legal Specialist, ENA Legal	-0.10	**0.24**	-0.02	0.06	**0.20**	0.09	0.08	**0.22**	0.09
Legal	E. Sager - VP and Asst Legal Counsel, ENA Legal	-0.01	**0.24**	0.02	**0.12**	**0.13**	0.10	**0.15**	**0.21**	**0.12**
Pipeline	S. Corman - VP, Regulatory Affairs	-0.04	-0.01	**0.33**	0.08	**-0.18**	**0.22**	0.07	**-0.18**	**0.21**
Pipeline	K. Watson - Employee, Transwestern Pipeline Company (ETS)	-0.08	-0.03	**0.32**	0.03	**-0.16**	**0.19**	0.04	**-0.18**	**0.22**
Pipeline	L. Donoho - Employee, Transwestern Pipeline Company (ETS)	-0.08	-0.03	**0.30**	0.03	**-0.16**	**0.18**	0.03	**-0.17**	**0.20**
Pipeline	D. Fossum - VP, Transwestern Pipeline Company (ETS)?	-0.06	-0.00	**0.30**	0.07	**-0.18**	**0.23**	0.05	**-0.13**	**0.16**
Pipeline	M. Lokay - Admin. Asst., Transwestern Pipeline Company (ETS)	-0.07	-0.02	**0.28**	0.03	**-0.14**	**0.17**	0.04	**-0.17**	**0.20**
Pipeline	K. Hyatt - Director, Asset Development TW Pipeline Co. (ETS)	-0.06	-0.02	**0.25**	0.03	**-0.13**	**0.17**	0.04	**-0.14**	**0.17**
Pipeline	R. Hayslett - VP, Also CFO and Treasurer	-0.04	-0.01	**0.23**	0.04	**-0.13**	**0.16**	0.05	**-0.14**	**0.16**
	R matrix / singular values	70.3	11.6	6.7	86.3			86.3		
		15.4	68.2	5.0		54.1			54.1	
		9.9	6.7	59.5			52.6			52.6

SVD: Hubs and Authorities in U and V

- Roles more difficult to identify in singular vectors
- No patterns of communication

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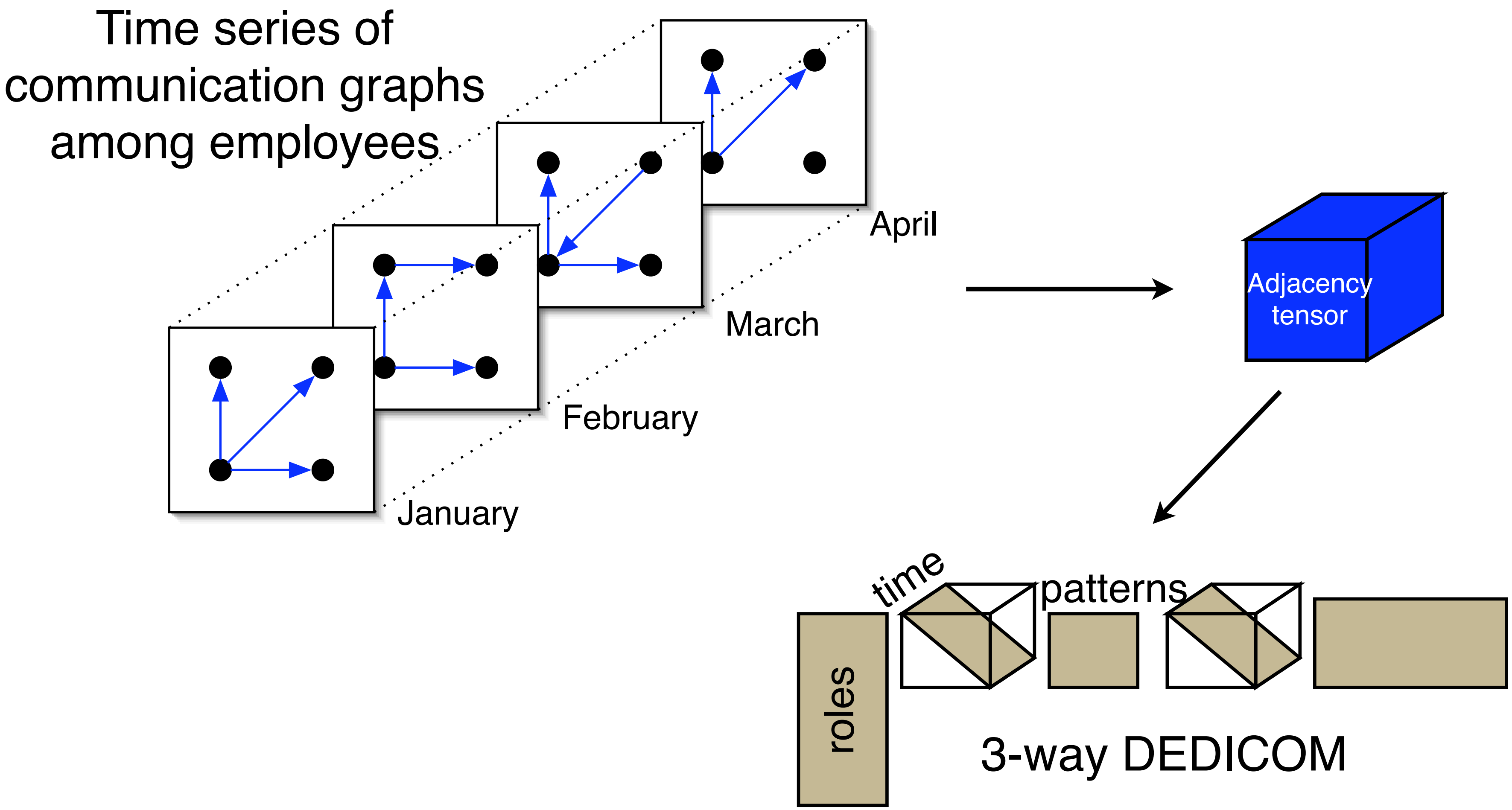
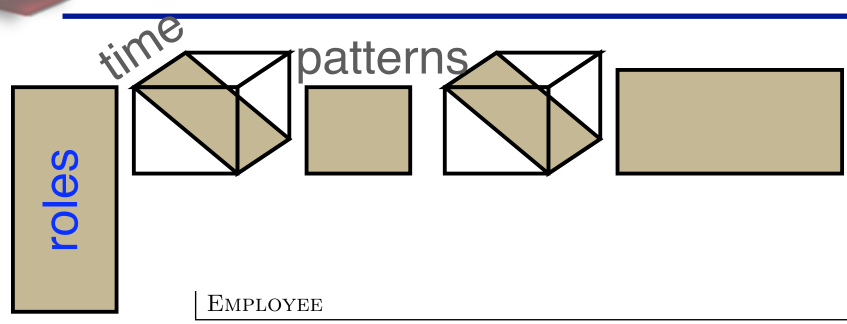
Temporal Social Network Analysis



- Unique description of employees by their roles
- Aggregate communication patterns among roles
- Behavior over time

Roles of Employees

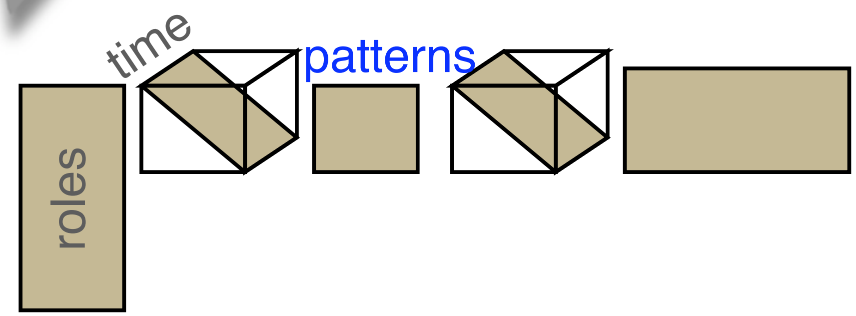


Legal | Gov't affairs | Trade execs | Pipeline

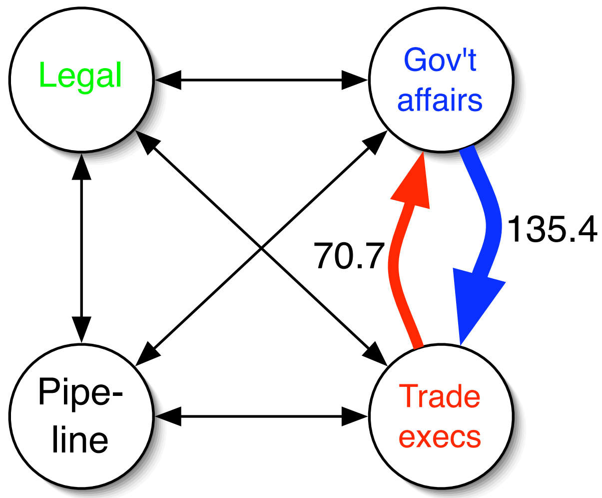
Group	Employee	1	2	3	4
Legal	T. Jones - Employee, Financial Trading Group (ENA Legal)	**0.64**	-0.01	0.02	-0.00
	S. Shackleton - Employee, ENA Legal	**0.45**	-0.00	-0.01	-0.00
	M. Taylor - Manager, Financial Trading Group ENA Legal	**0.37**	0.01	0.02	-0.00
	S. Bailey - Legal Assistant, ENA Legal	**0.26**	-0.00	-0.01	-0.00
	S. Panus - Senior Legal Specialist, ENA Legal	**0.26**	-0.00	-0.00	-0.00
	M. Heard - Senior Legal Specialist, ENA Legal	**0.23**	-0.00	0.00	-0.00
	J. Hodge - Asst General Counsel, ENA Legal	**0.13**	0.03	0.01	-0.00
	L. Kitchen - President, Enron Online	**0.11**	**-0.09**	**0.53**	0.00
	S. Dickson - Employee, ENA Legal	**0.09**	-0.00	0.00	-0.00
	E. Sager - VP and Asst Legal Counsel, ENA Legal	**0.08**	0.02	**0.07**	-0.00
Gov't affairs	J. Dasovich - Employee, Government Relationship Executive	-0.01	**0.58**	0.06	0.01
	J. Steffes - VP, Government Affairs	0.00	**0.53**	**-0.06**	-0.01
	R. Shapiro - VP, Regulatory Affairs	-0.00	**0.40**	**0.10**	-0.00
	S. Kean - VP, Chief of Staff	-0.00	**0.37**	-0.04	-0.00
	R. Sanders - VP, Enron Wholesale Services	0.03	**0.16**	-0.01	-0.00
	D. Delainey - CEO, ENA and Enron Energy Services	0.01	**0.09**	**0.09**	-0.00
	S. Corman - VP, Regulatory Affairs	-0.00	**0.08**	-0.00	**0.20**
	M. Carson - Employee, Corporate and Environmental Policy	-0.00	**0.08**	-0.02	-0.00
	S. Scott - Employee, Transwestern Pipeline Company (ETS)	-0.00	**0.08**	-0.00	0.04
Execs - trading	J. Lavorato - CEO, Enron America	0.02	-0.04	**0.49**	0.00
	M. Grigsby - Director, West Desk Gas Trading	0.00	-0.03	**0.20**	-0.00
	G. Whalley - President,	0.01	-0.01	**0.19**	0.00
	J. Steffes - VP, Government Affairs	0.00	-0.02	**0.18**	0.00
	K. Presto - VP, East Power Trading	0.01	-0.05	**0.18**	0.00
	S. Beck - COO,	0.01	-0.03	**0.17**	0.00
	B. Tycholiz - VP, Marketing	0.01	-0.02	**0.16**	0.00
	J. Arnold - VP, Financial Enron Online	0.03	-0.04	**0.16**	-0.00
	J. Williamson - Executive Assistant,	0.00	-0.02	**0.14**	0.01
Pipeline employees	K. Watson - Employee, Transwestern Pipeline Company (ETS)	-0.00	-0.00	0.01	**0.59**
	M. Lokay - Admin. Asst., Transwestern Pipeline Company (ETS)	-0.00	0.01	0.01	**0.42**
	L. Donoho - Employee, Transwestern Pipeline Company (ETS)	-0.00	0.01	0.01	**0.35**
	M. McConnell - Employee, Transwestern Pipeline Company (ETS)	0.00	-0.00	0.01	**0.26**
	L. Blair - Employee, Northern Natural Gas Pipeline (ETS)	-0.00	0.00	0.00	**0.22**
	K. Hyatt - Director, Asset Development TW Pipeline Business (ETS)	-0.00	0.01	0.00	**0.20**
	D. Schoolcraft - Employee, Gas Control (ETS)	-0.00	0.00	0.00	**0.18**
	T. Geaccone - Manager, (ETS)	0.00	-0.00	0.01	**0.17**
	R. Hayslett - VP, Also CFO and Treasurer	0.00	-0.00	0.02	**0.16**

Identify shared characteristics to label group

Communication Patterns



	Legal	Gov't affairs	Trade execs	Pipeline
Legal	440.2	1.6	-15.0	0.4
Government & regulatory affairs	1.6	278.3	135.4	1.6
Trade executives	-29.3	70.7	201.6	-6.2
Pipeline employees	1.4	-4.6	-7.5	172.3



- Mostly communication within roles
- Some large exchanges
- Negative values complicates interpretation
  - Non-negative factorization being investigated

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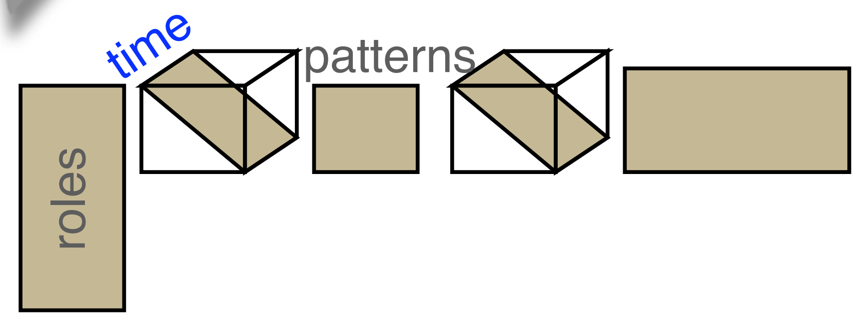
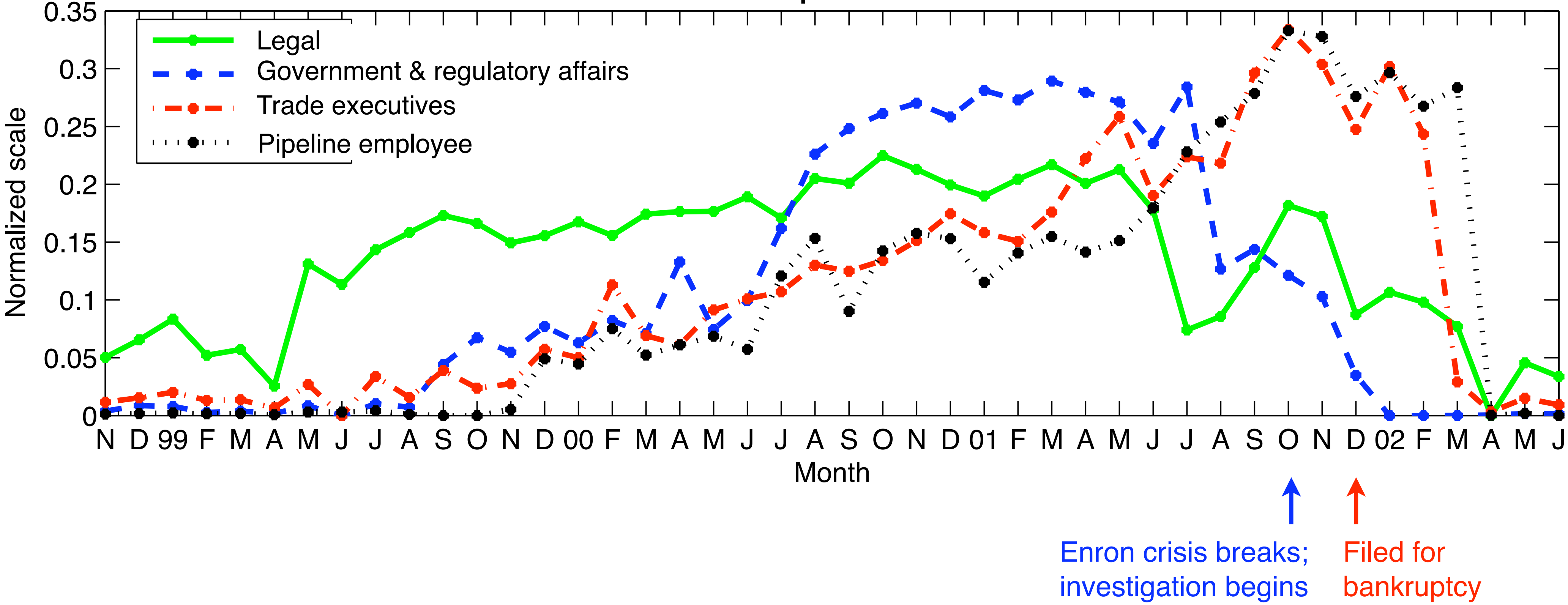
Temporal Patterns



Communication patterns over time



Summary

- Improvements to DEDICOM
  - New procedure for finding $\mathbf{A}$
  - Newton step for finding $\mathbf{D}$
- Modifications to handle large data arrays
  - Compression
- Novel approach to social network analysis using DEDICOM
  - Roles of employees
  - Communication patterns among roles and over time
- Future research
  - Nonnegative DEDICOM
  - Constrained DEDICOM
  - PARAFAC

More Information

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- DEDICOM paper on Social Network Analysis:
  - Tech report SAND2006-2161 available
- MATLAB Tensor Toolbox:
  - http://csmr.ca.sandia.gov/~tgkolda/TensorToolbox
  - Tech report SAND2004-5189 available on website
  - Paper to appear in ACM Trans. Math. Softw.
  - sparse_tensor class to be released soon