A Bayesian Model for Detecting and Characterizing Events

Allison J.B. Chaney

David Blei, advisor

Pre-Final Public Oral
Department of Computer Science
Princeton University
February 24, 2016

We can do nothing but scrutinize historical events themselves if we want to discover what they are.

– Dean W.R. Matthews, *What is an Historical Event?*

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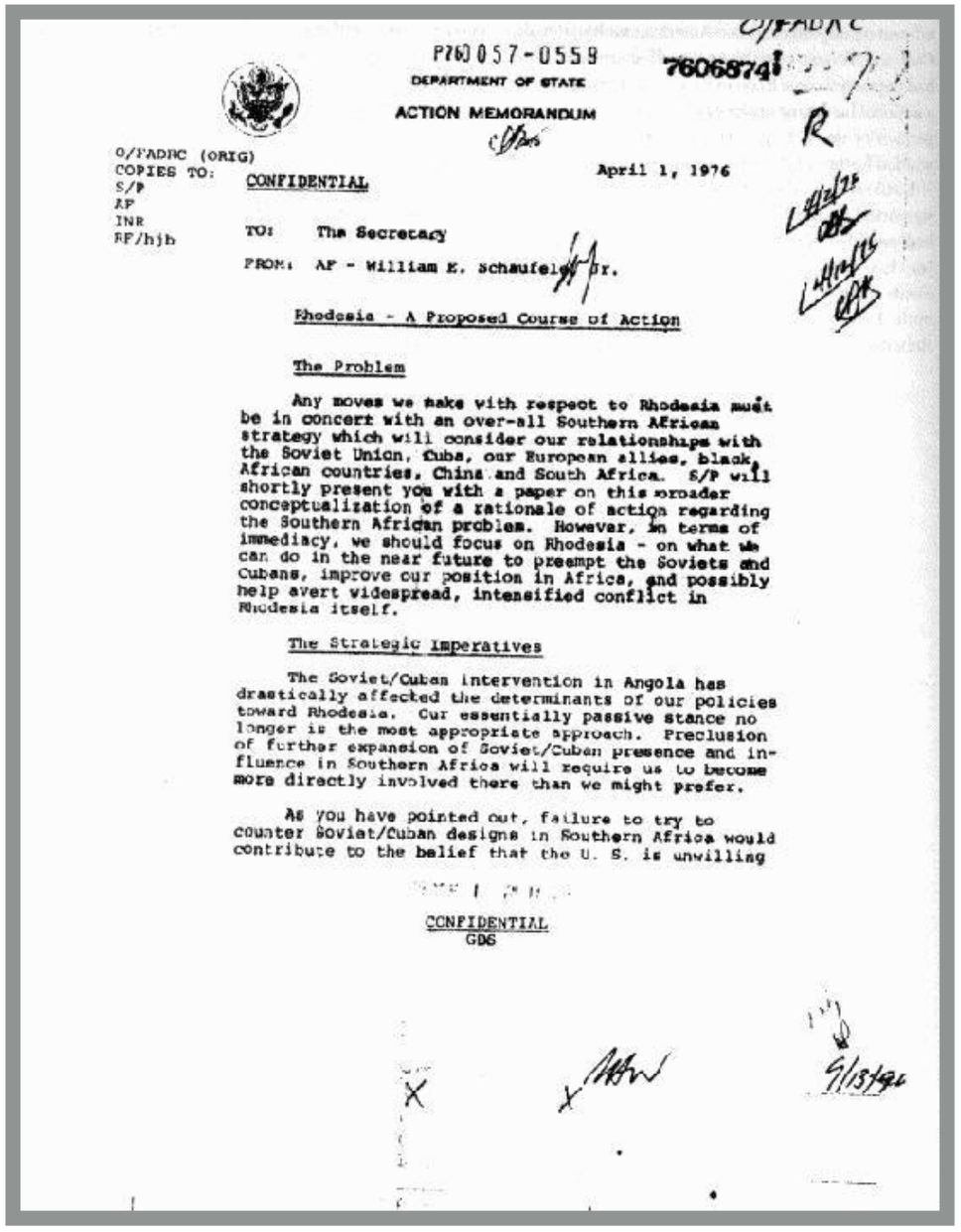
U.S. State Department Cables



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DEPARTMENT OF STATE

7606874

ACTION MEMORANDUM

O/FADRC (ORIG)
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CONFIDENTIAL

April 1, 1976

TO: The Secretary

FROM: AF - William E. Schaufele, Jr.

Rhodesia - A Proposed Course of Action

The Problem

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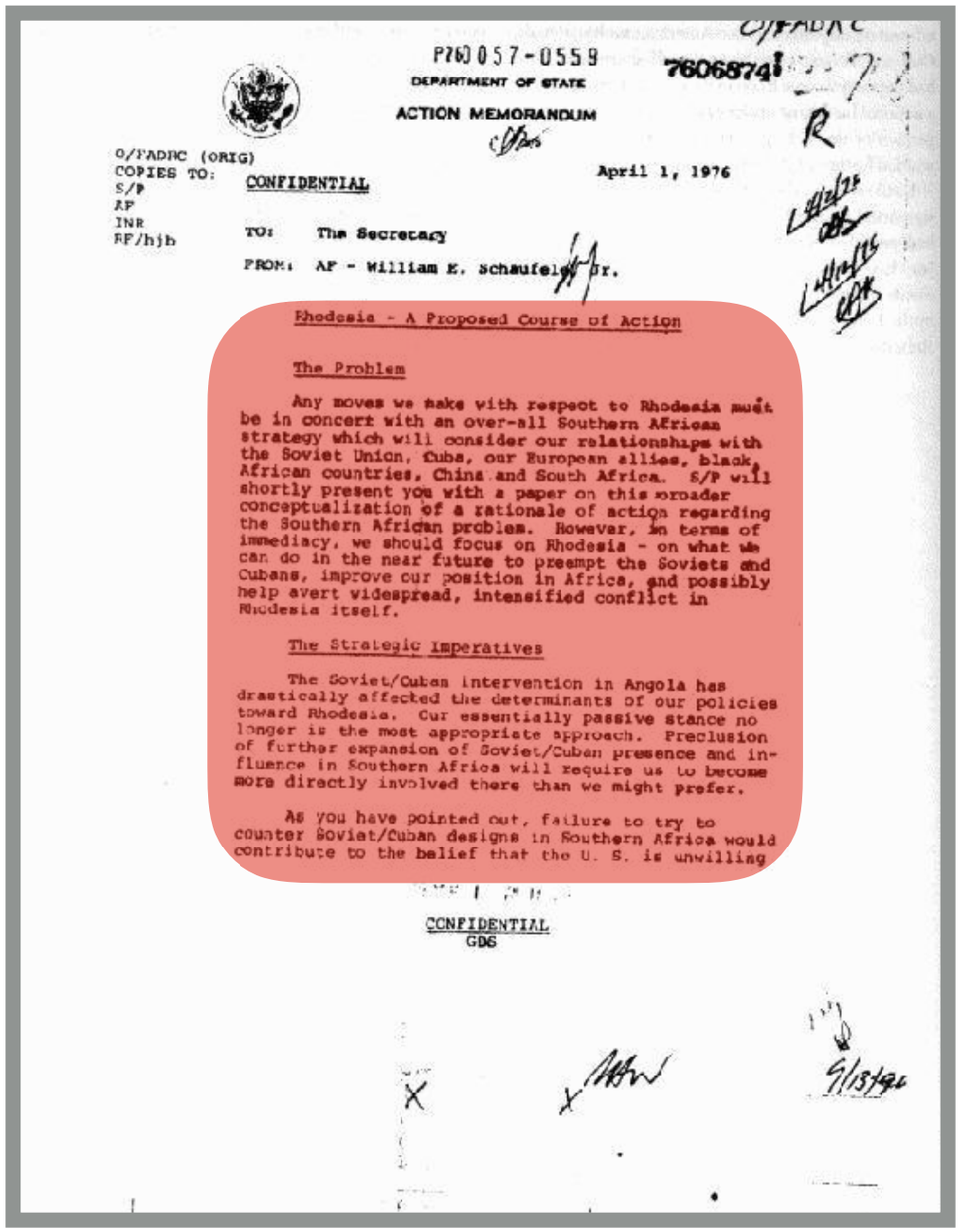
Message content (text)



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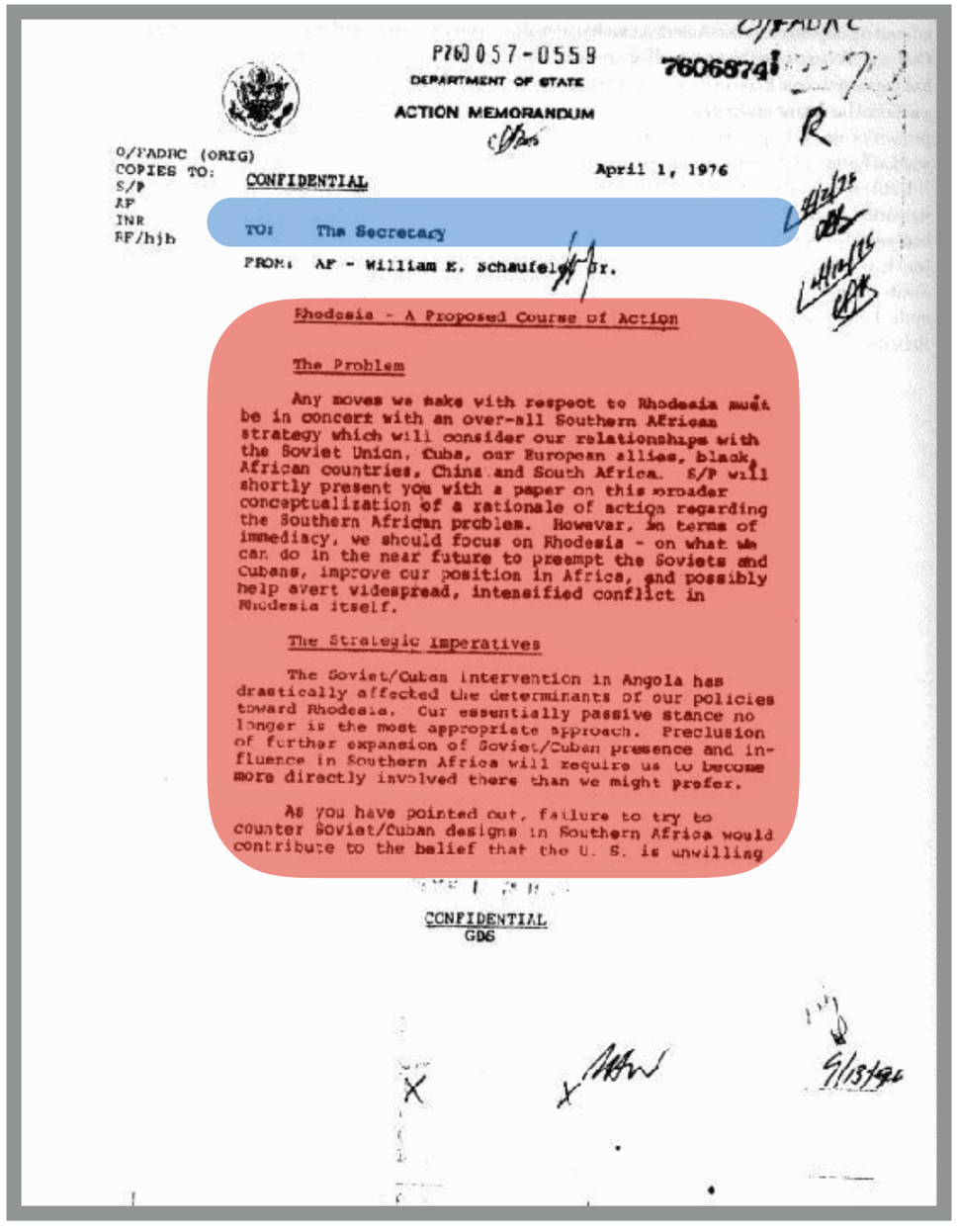

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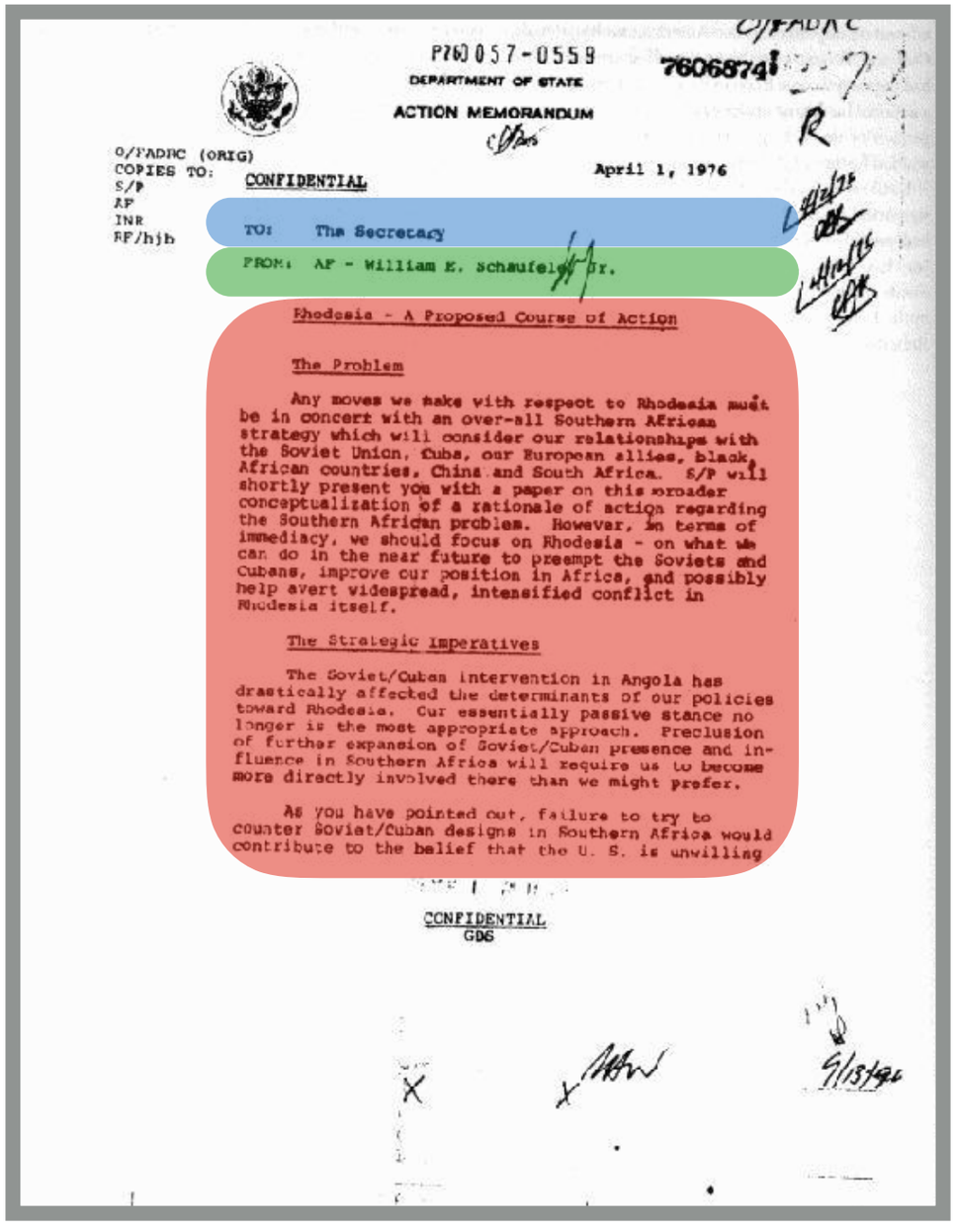

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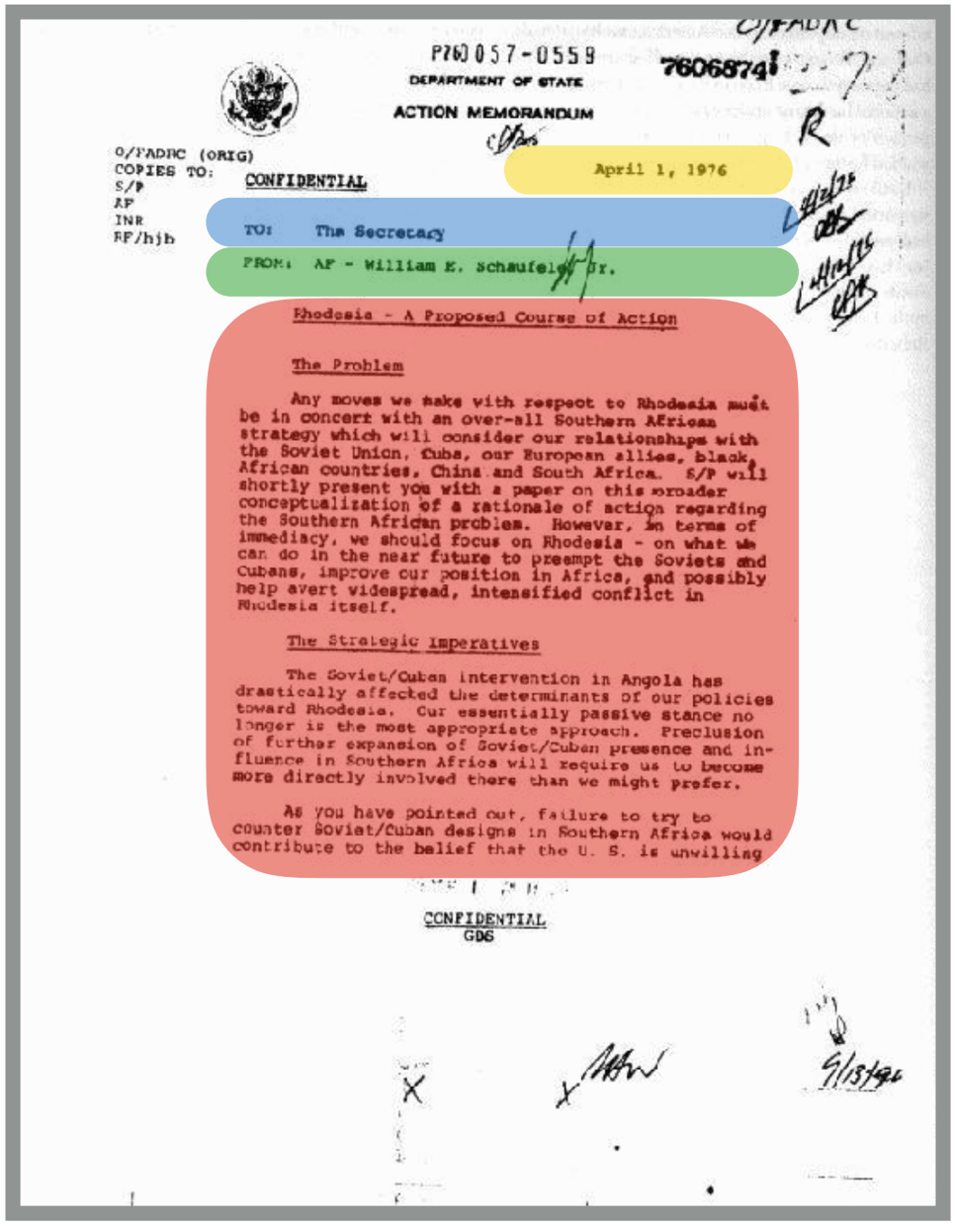
Send date



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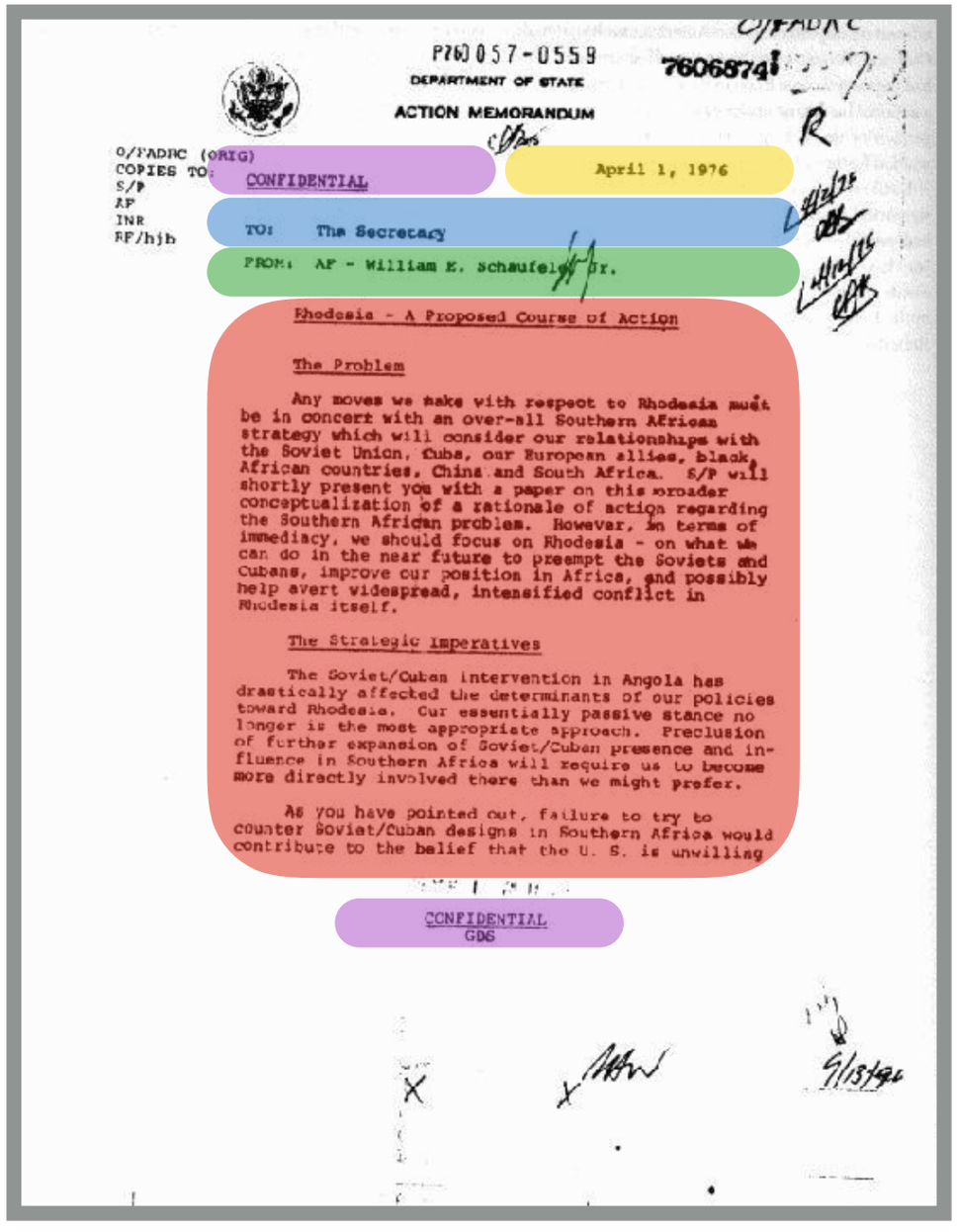
Classification level



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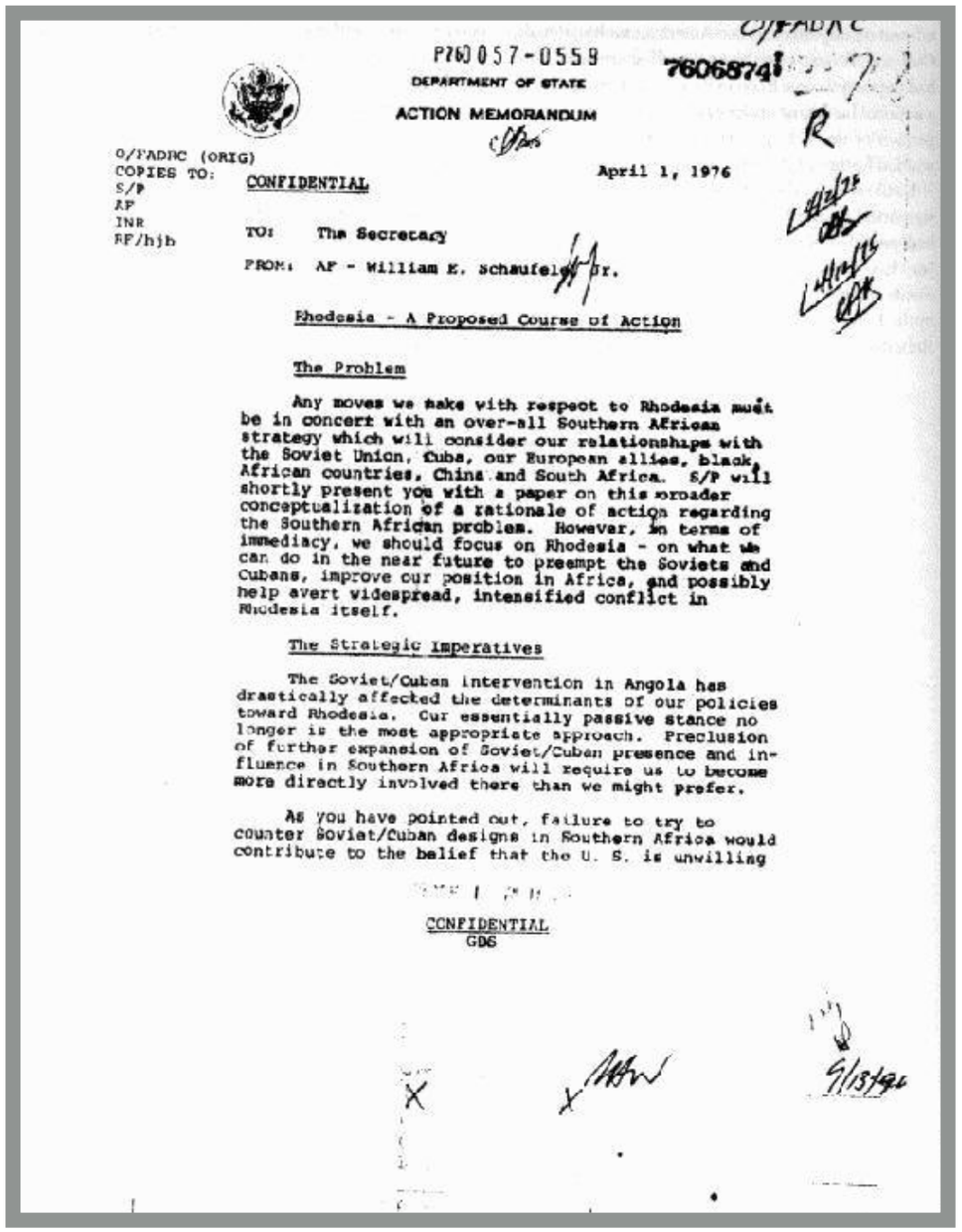
2,674,486 messages

sent between 1973 and 1978

34,204 unique sending entities

23.4% sent from State Dept.

41.6% sent to State Dept.



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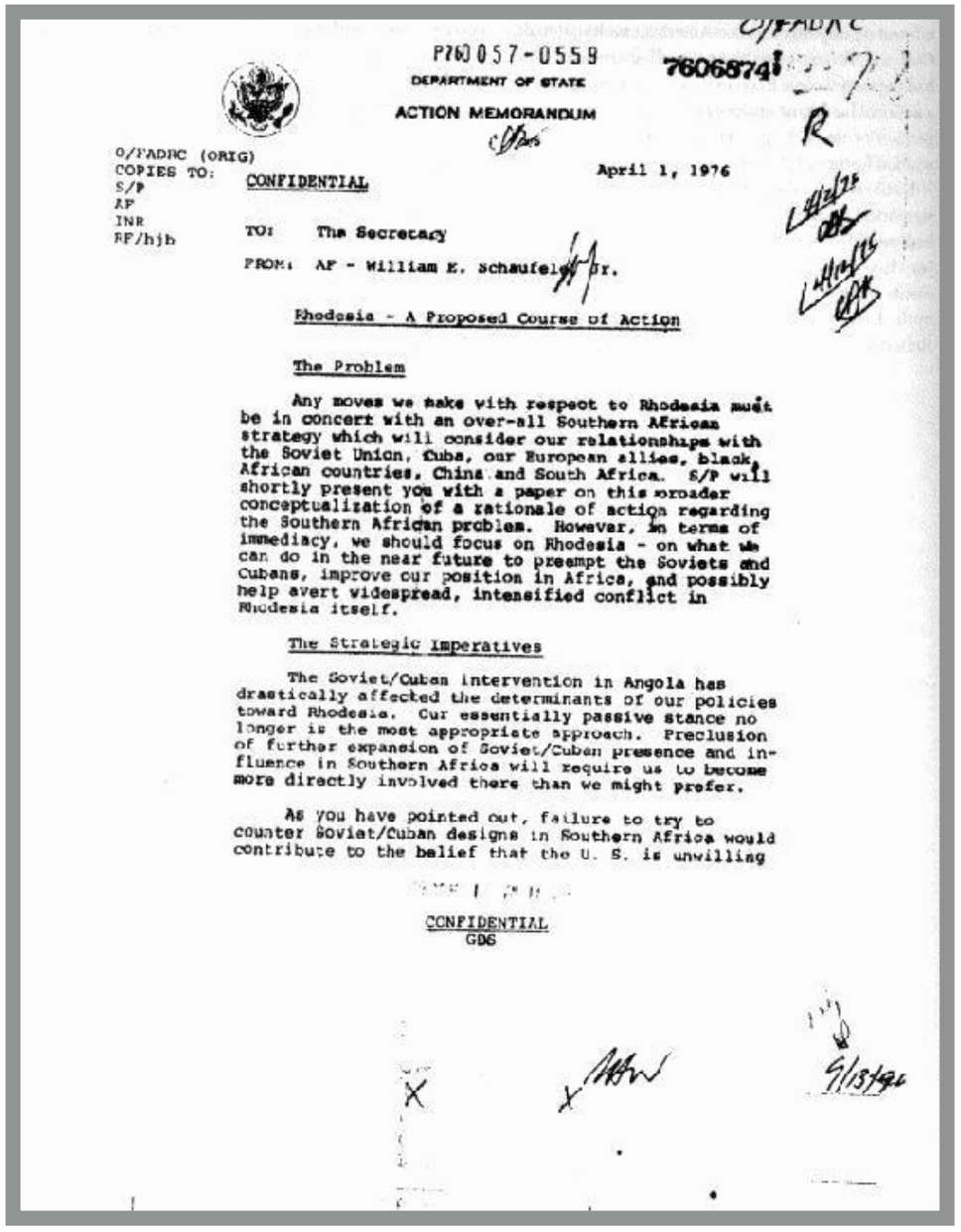

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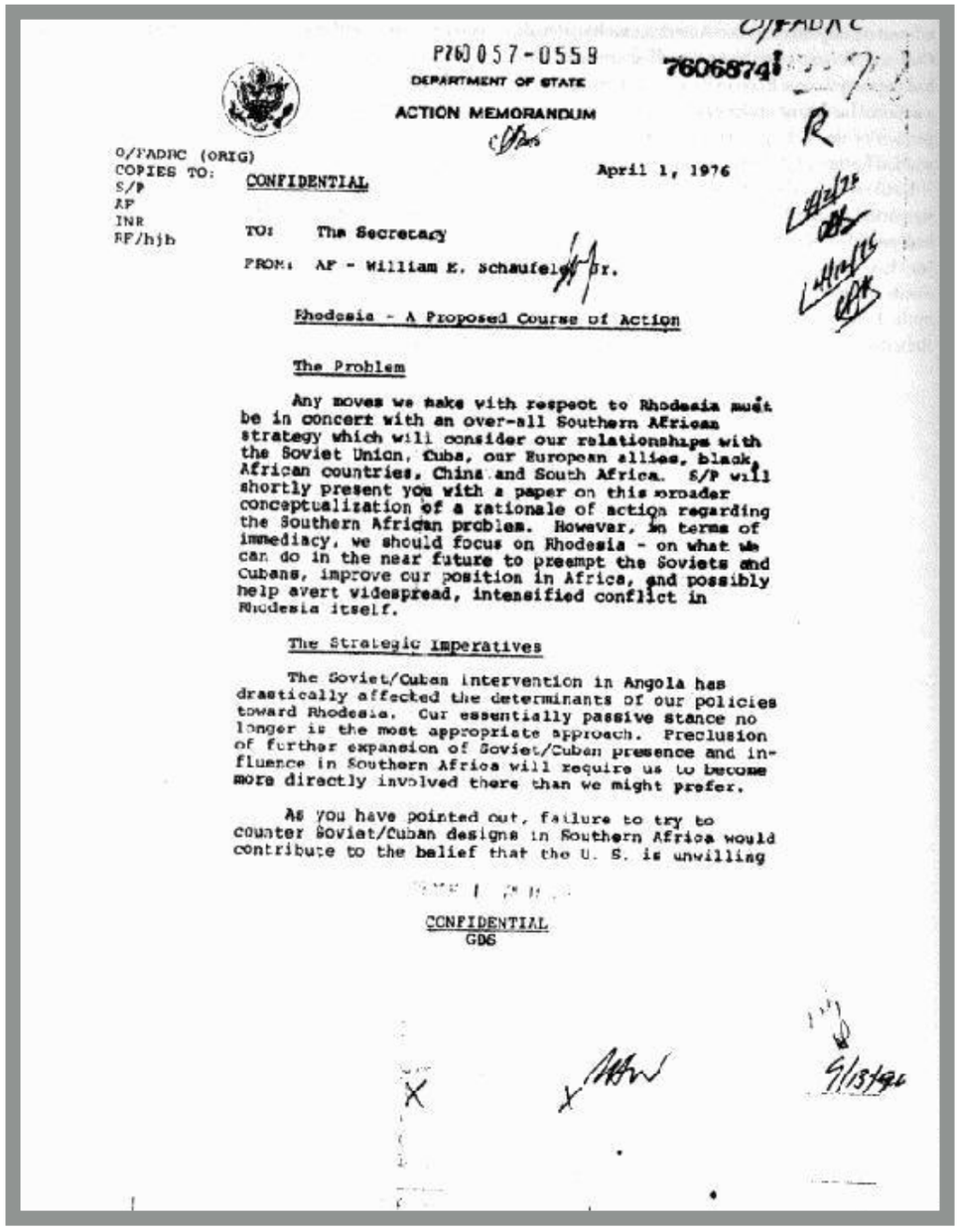

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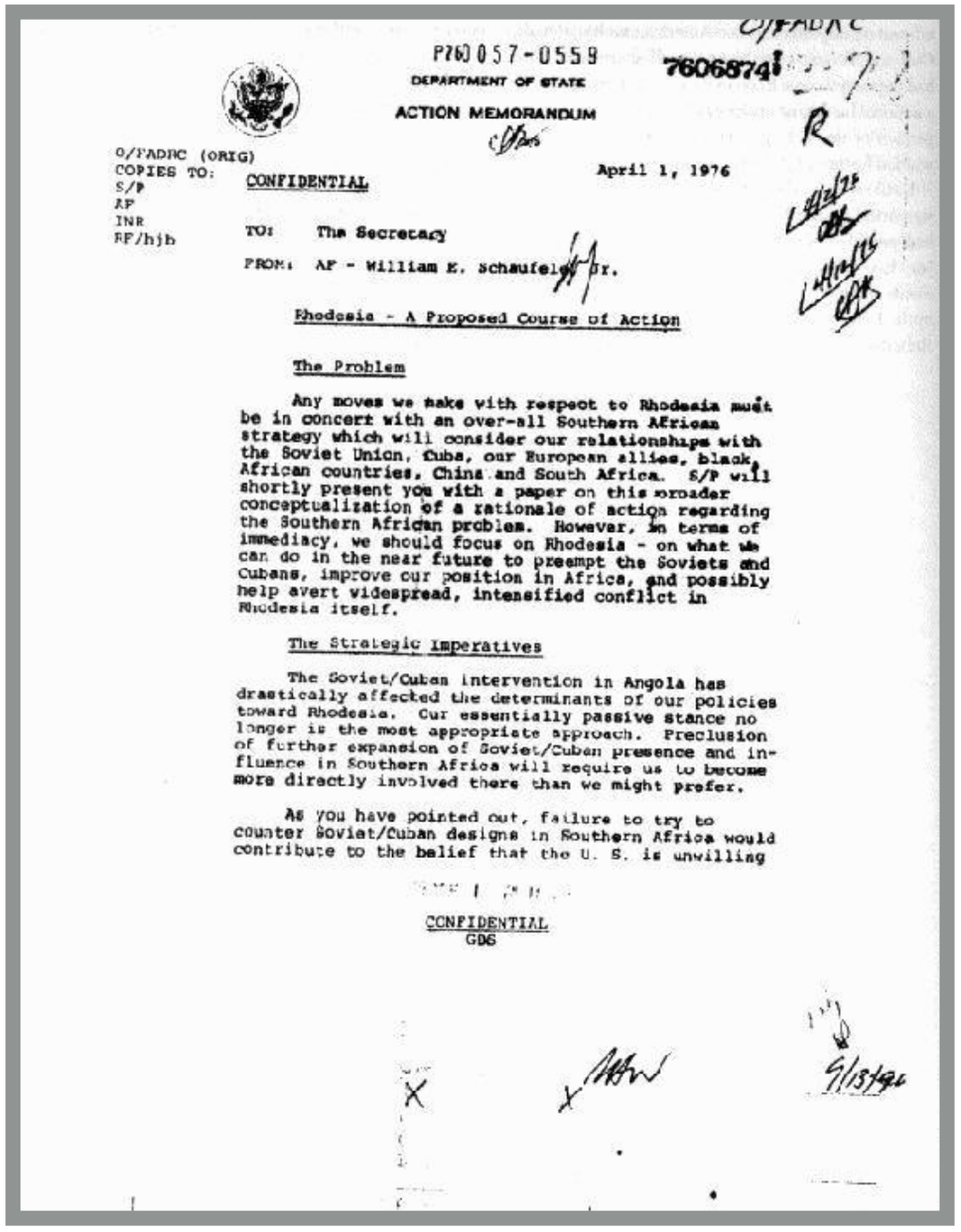
What interesting events can be found in these messages?

How can we describe events?



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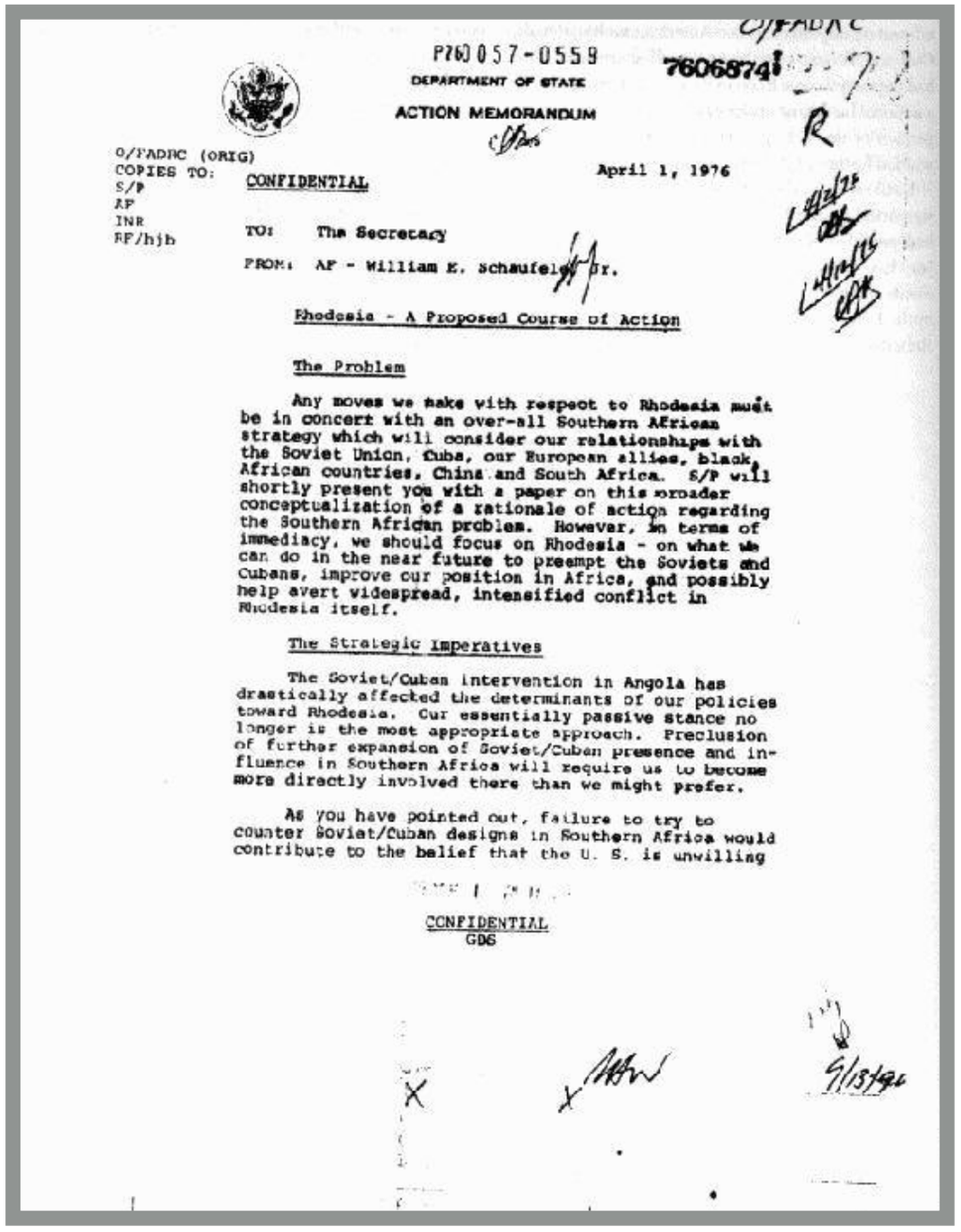
How can we describe events?

What relationships do different entities have?



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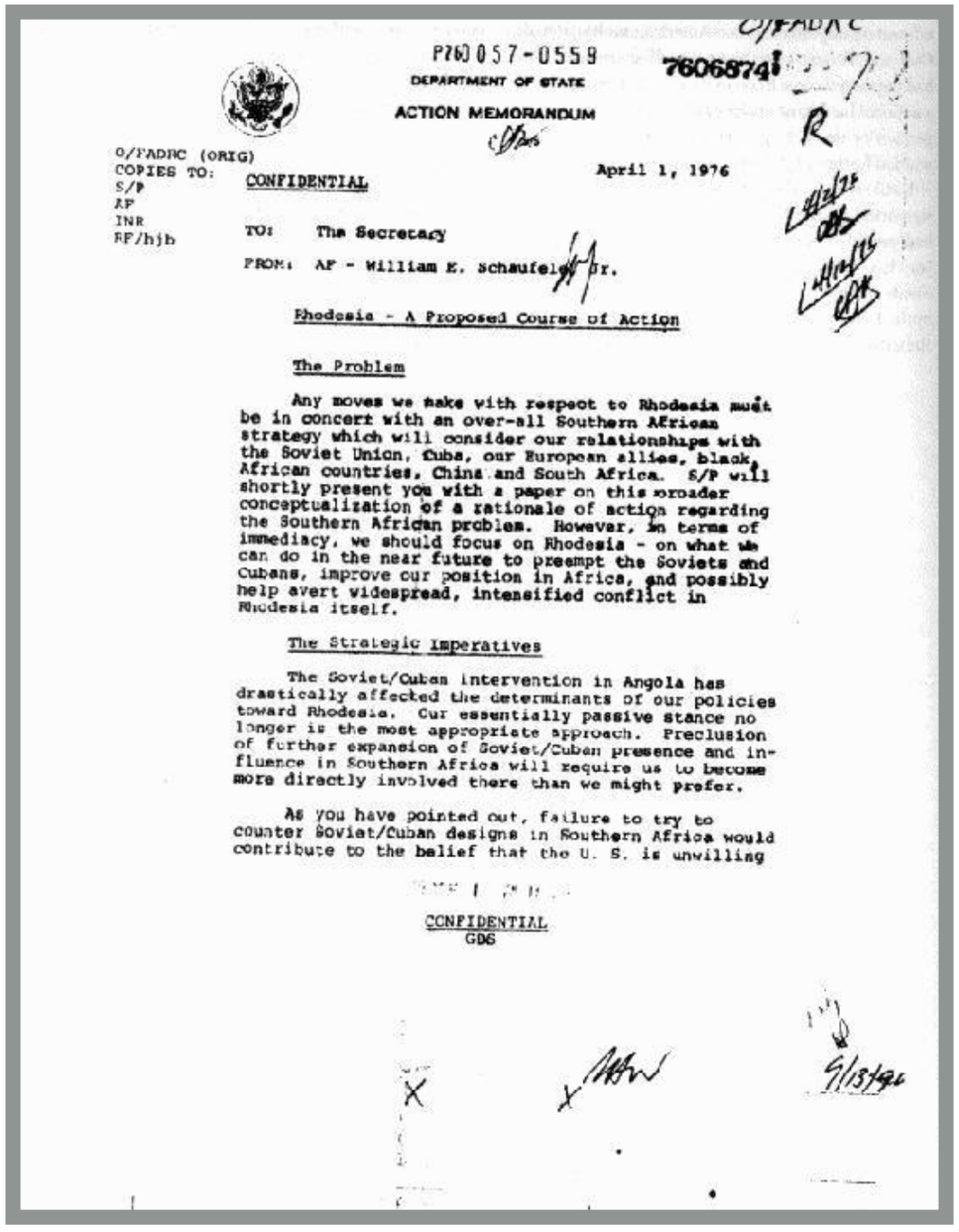
How can we describe events?

What relationships do different entities have?

What are the typical concerns of different entities?



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Events are unobserved.

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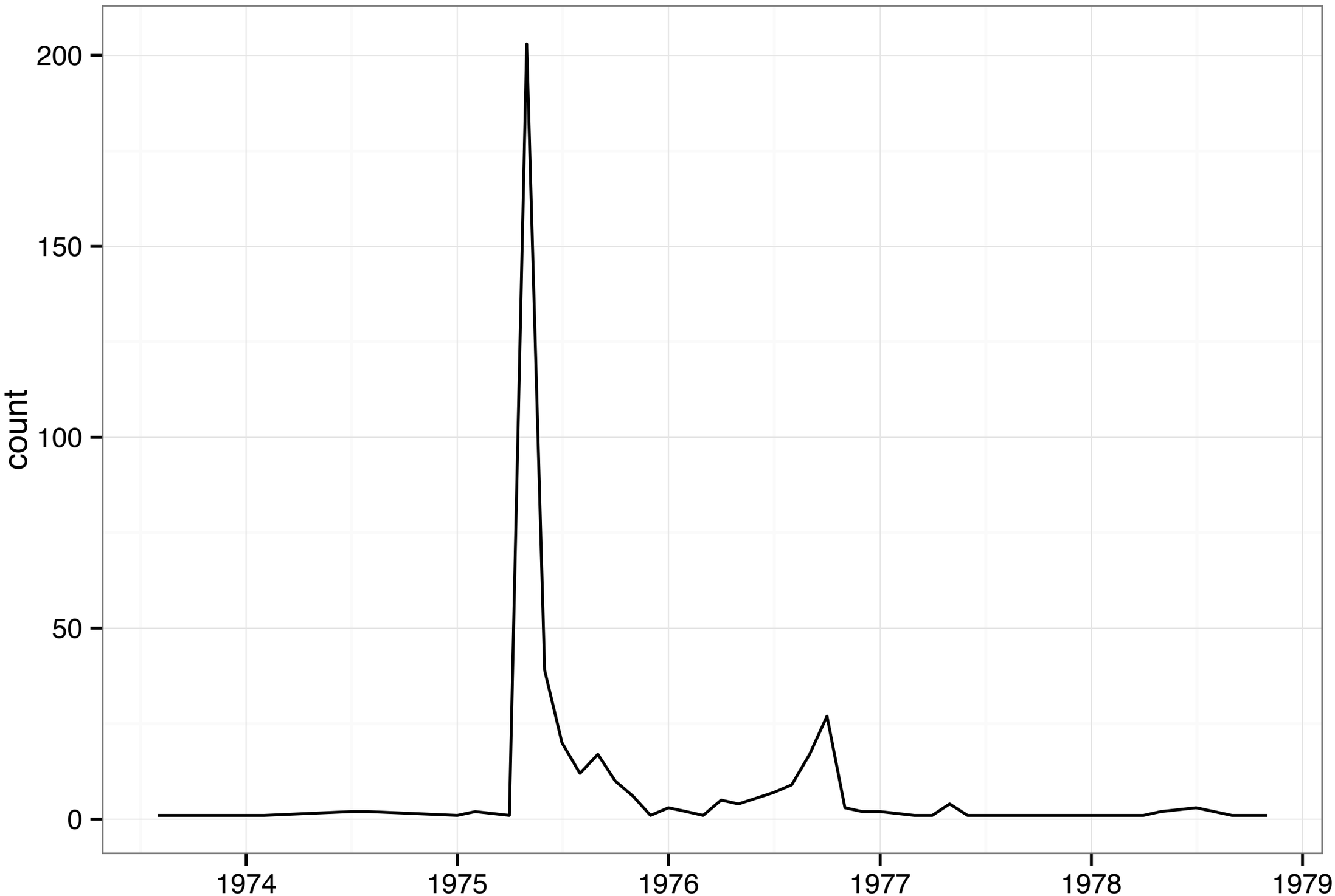
What are observed ways to characterize events?

Events are unobserved.

What are observed ways to characterize events?

Temporary shifts away
from business as usual
in message content

Mayaguez Incident



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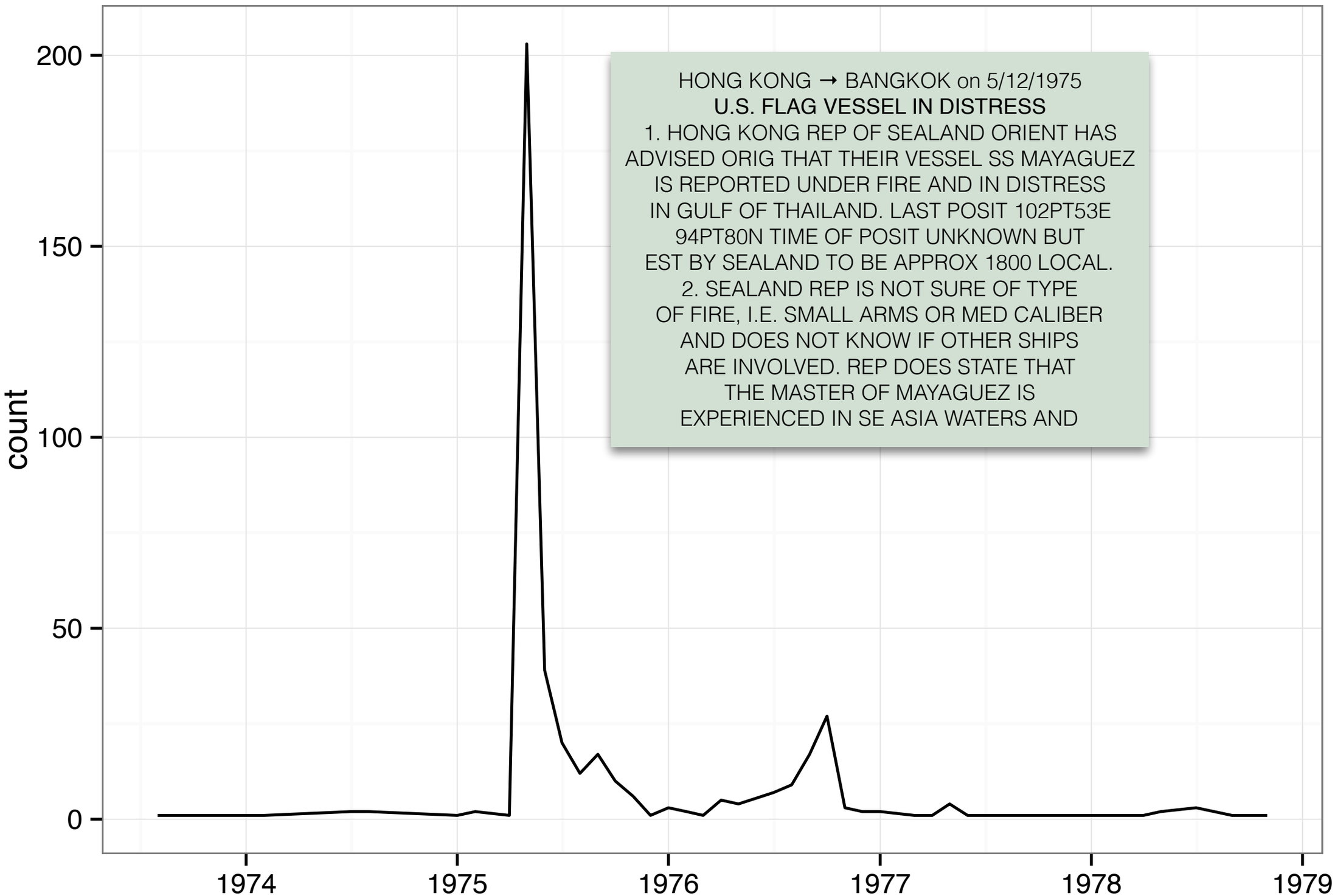

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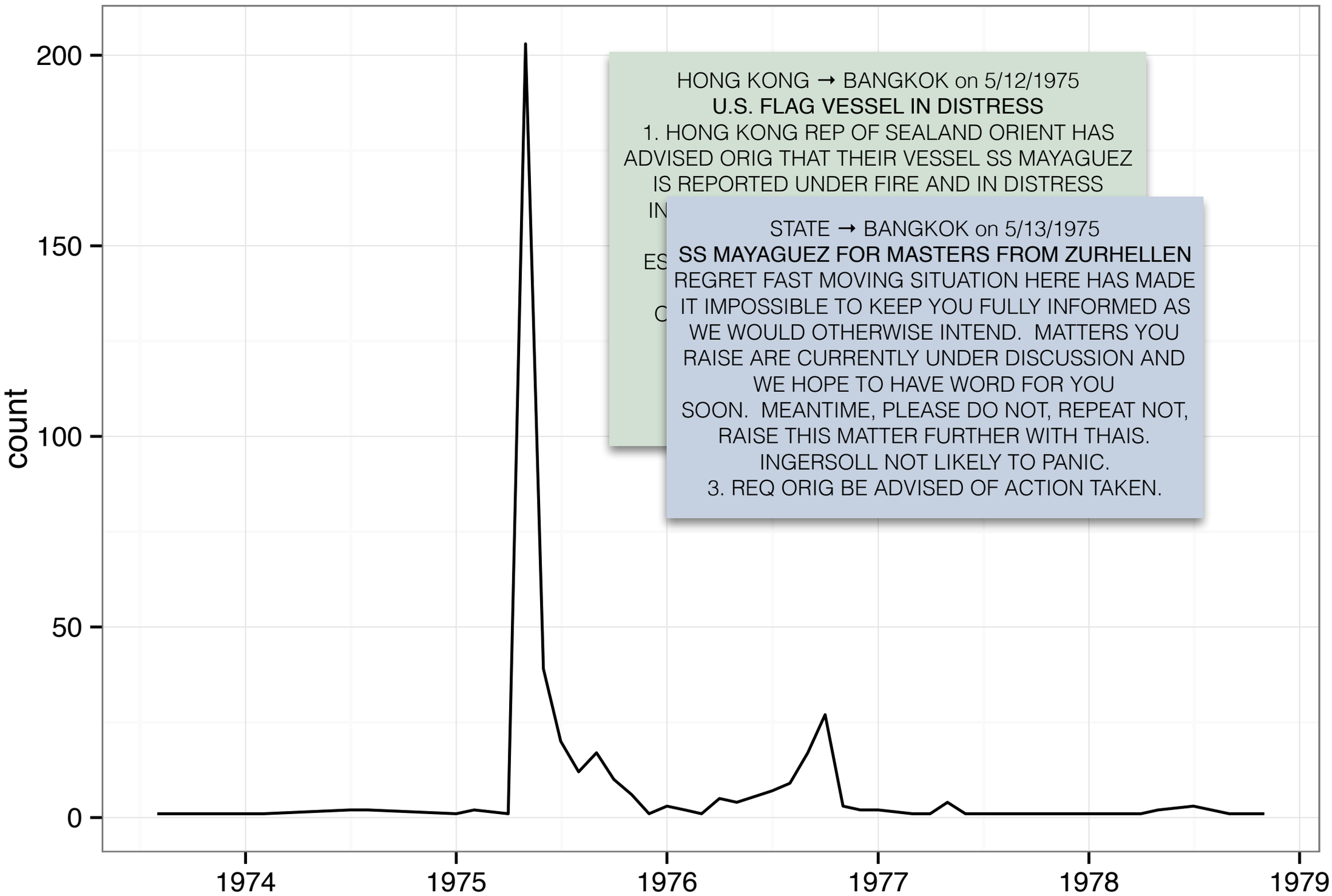

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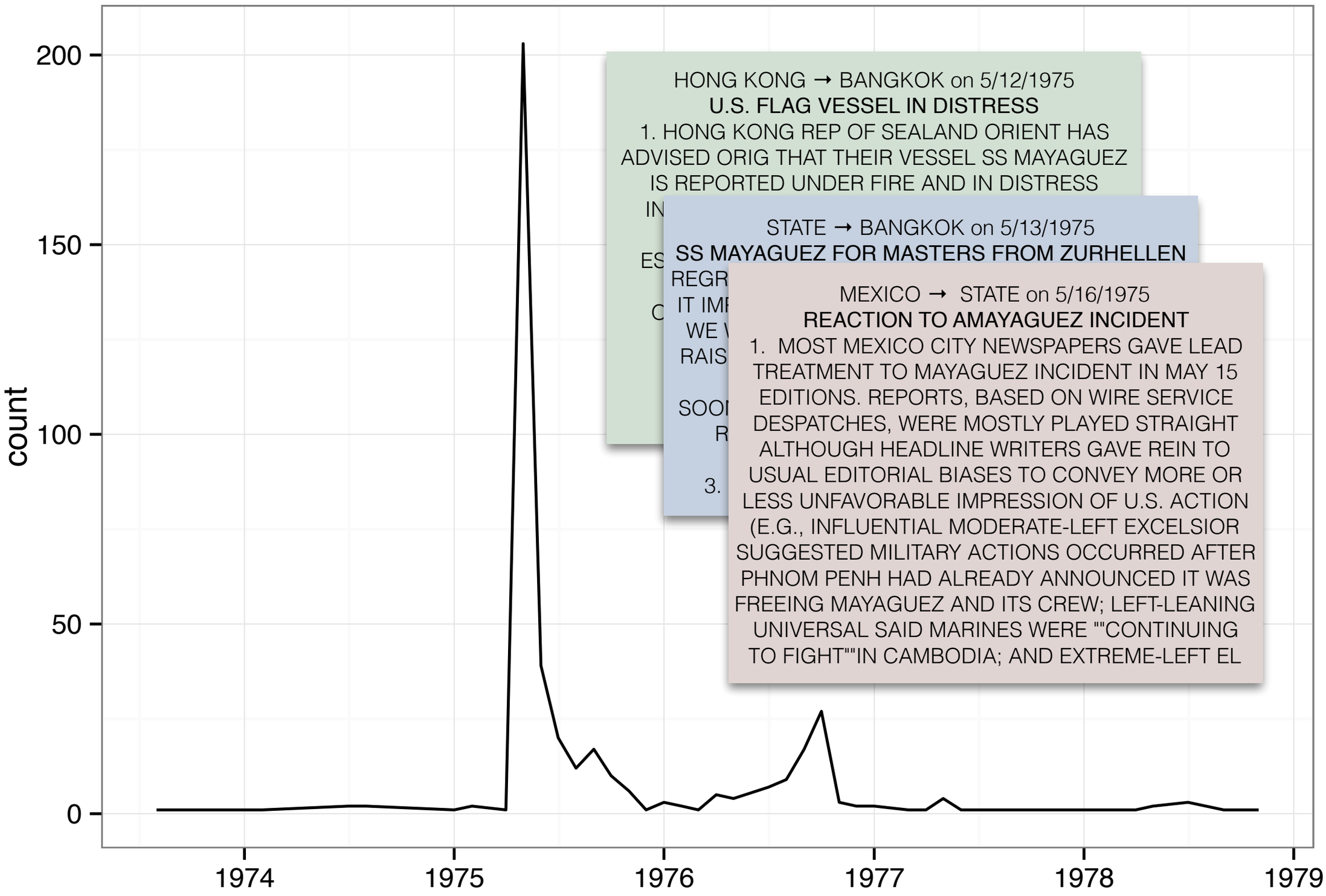
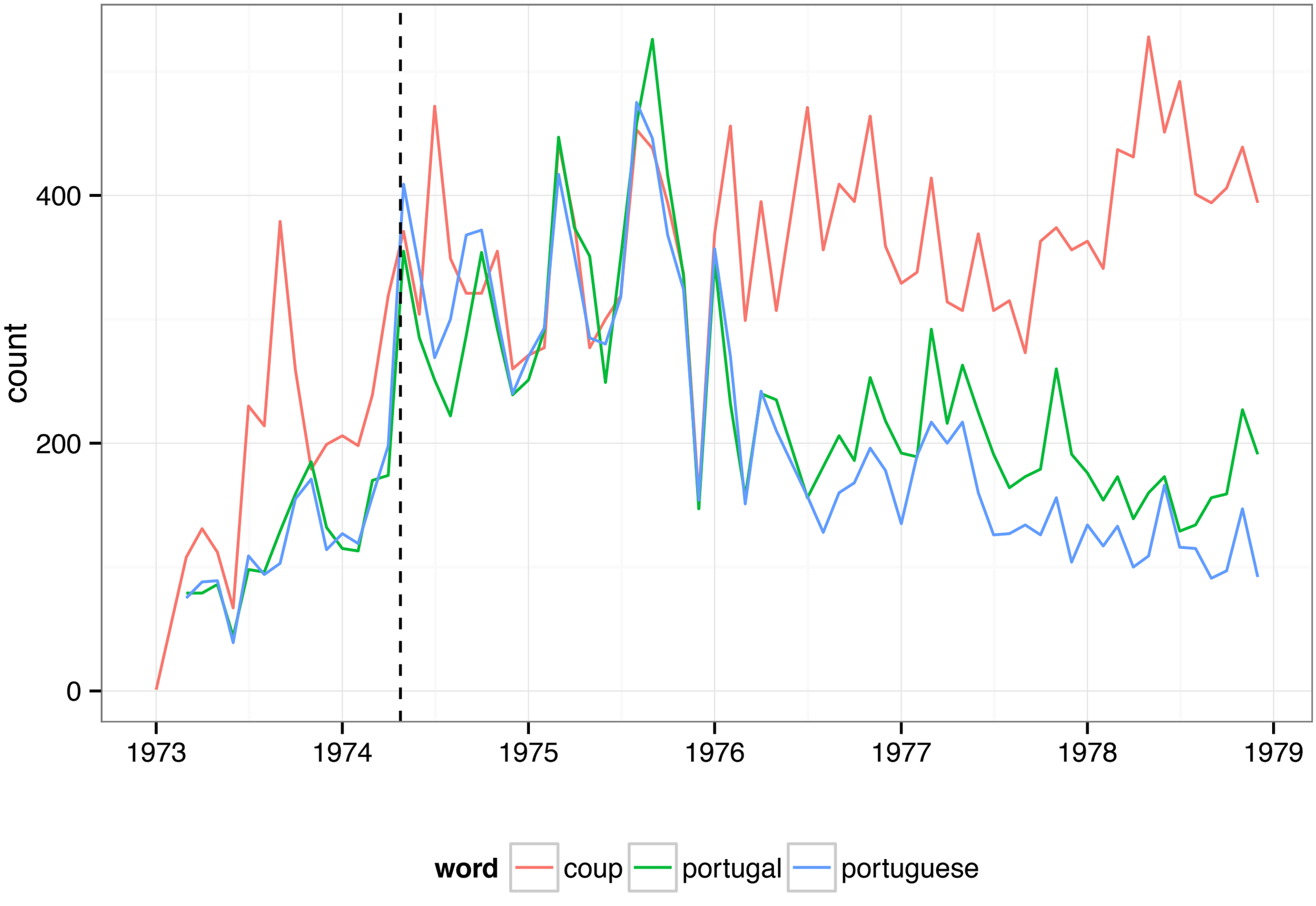
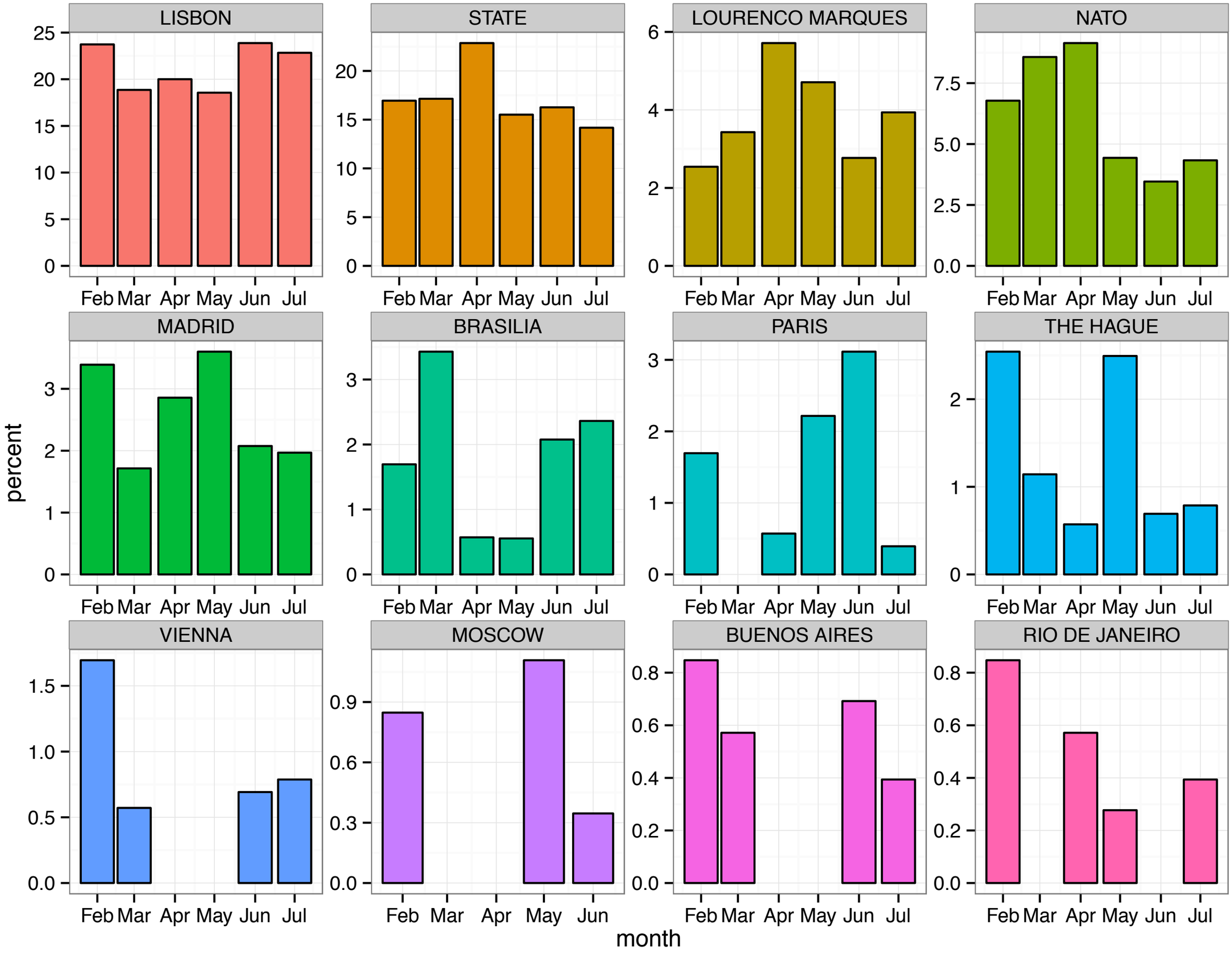


Carnation Revolution




LISBON
STATE
LOURENCO MARQUES
NATO
MADRID
BRASILIA
PARIS
THE HAGUE
VIENNA
MOSCOW
BUENOS AIRES
RIO DE JANEIRO
Feb Mar Apr May Jun Jul
percent
month

What are the key actors in constructing our model?

cables

HONG KONG → BANGKOK on 5/12/1975

U.S. FLAG VESSEL IN DISTRESS

1. HONG KONG REP OF SEALAND ORIENT HAS ADVISED ORIG THAT THEIR VESSEL SS MAYAGUEZ IS REPORTED UNDER FIRE AND IN DISTRESS
IN

ES

C

STATE → BANGKOK on 5/13/1975

SS MAYAGUEZ FOR MASTERS FROM ZURHELLEN

REGR
IT IMF
WE
RAIS

SOO
R

3.

MEXICO → STATE on 5/16/1975

REACTION TO AMAYAGUEZ INCIDENT

1. MOST MEXICO CITY NEWSPAPERS GAVE LEAD TREATMENT TO MAYAGUEZ INCIDENT IN MAY 15 EDITIONS. REPORTS, BASED ON WIRE SERVICE DESPATCHES, WERE MOSTLY PLAYED STRAIGHT ALTHOUGH HEADLINE WRITERS GAVE REIN TO USUAL EDITORIAL BIASES TO CONVEY MORE OR LESS UNFAVORABLE IMPRESSION OF U.S. ACTION (E.G., INFLUENTIAL MODERATE-LEFT EXCELSIOR SUGGESTED MILITARY ACTIONS OCCURRED AFTER PHNOM PENH HAD ALREADY ANNOUNCED IT WAS FREEING MAYAGUEZ AND ITS CREW; LEFT-LEANING UNIVERSAL SAID MARINES WERE ""CONTINUING TO FIGHT""IN CAMBODIA; AND EXTREME-LEFT EL

entities

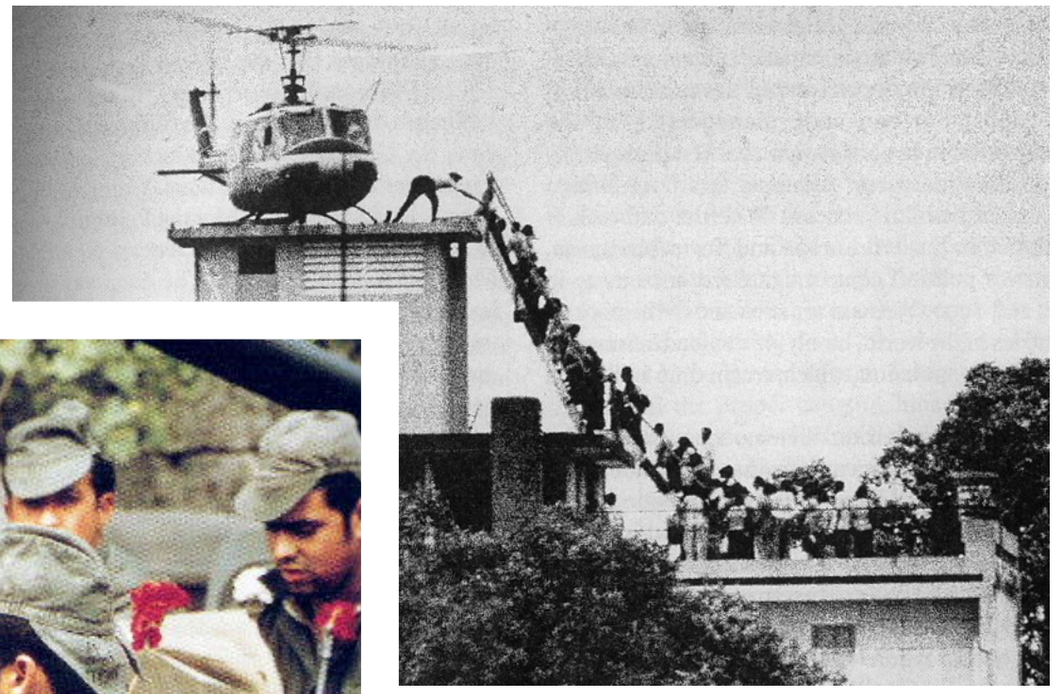
cables

HONG KONG → BANGKOK on 5/12/1975

STATE → BANGKOK on

MEXICO → STATE on 5/16/1975
REACTION TO AMAYAGUEZ INCIDENT
1. MOST MEXICO CITY NEWSPAPERS GAVE LEAD TREATMENT TO

events



cables

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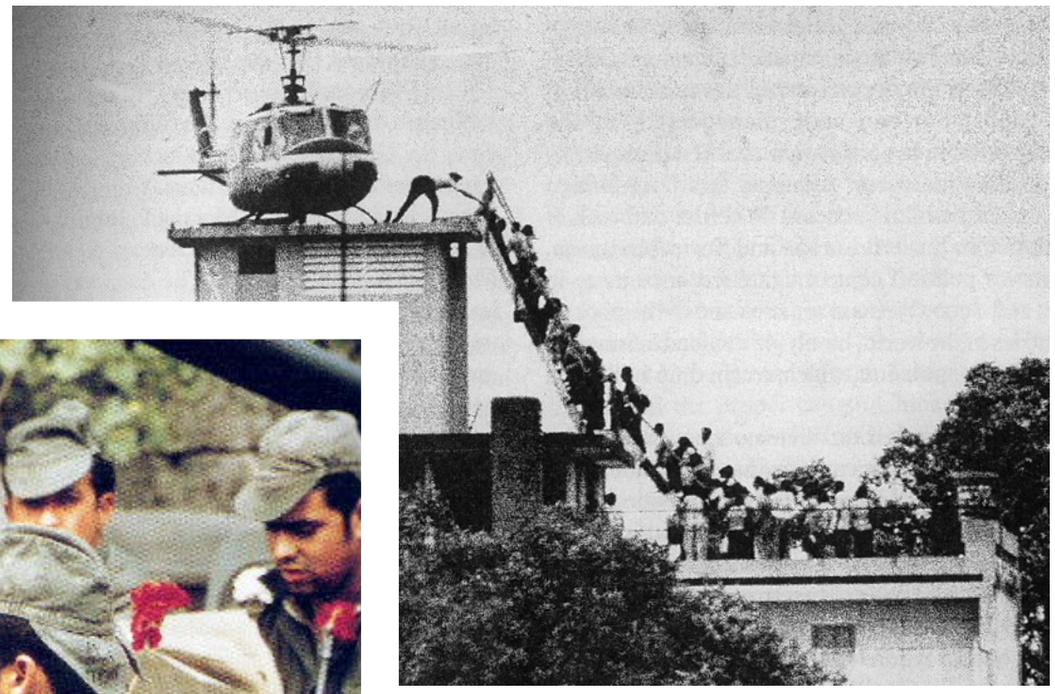

cables

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REACTION TO AMAYAGUEZ INCIDENT
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entities

representing cables with topics

11/28/197: EUROPEAN MINISTERS OF EDUCATION CONFERENCE BUCHAREST SECOND AND THIRD PLENARY SESSIONS OF CONFERENCE CONTINUED NOVEMBER 26 WITH SPEECHES BY 18 ADDITIONAL DELEGATIONS AND EIGHT OBSERVER DELEGATIONS ON DEVELOPMENTS IN NATIONAL EDUCATION SINCE1967. OF THREE COUNTRIES REPRESENTED AS OBSERVERS (U.S., CANADA, ISRAEL), ONLY CANADIAN DELEGATION ADDRESSED PLENARY WITH DESCRIPTION OF MUTUAL CANADIAN-EUROPEAN EDUCATIONAL PROBLEMS AND CONCERNS. CANADIAN DELEGATE CONCLUDED WITH EXPRESSION OF CANADIAN DESIRE FOR FULL MEMBERSHIP IN EUROPEAN REGION. FOLLOWING DEPARTMENT INSTRUCTIONS, U.S. DEL DID NOT ADDRESS PLENARY ALTHOUGH DELEGATION PLANS PARTICIPATION AS APPROPRIATE IN WORKING SESSIONS BEGINNING NOVEMBER 27.

Latent Dirichlet allocation. Blei, Ng, and Jordan, 2003.

representing cables with topics

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Latent Dirichlet allocation.
Blei, Ng, and Jordan, 2003.

Advantage: Good for discovering general, interpretable themes

useful for representing *entities' typical concerns*

Disadvantage: Does not capture word-level shifts in language or subject

not useful for representing *event descriptions*

representing cables with words

11/28/197: EUROPEAN MINISTERS OF EDUCATION CONFERENCE BUCHAREST
SECOND AND THIRD PLENARY SESSIONS OF CONFERENCE CONTINUED NOVEMBER 26 WITH SPEECHES BY 18 ADDITIONAL DELEGATIONS AND EIGHT OBSERVER DELEGATIONS ON DEVELOPMENTS IN NATIONAL EDUCATION SINCE1967. OF THREE COUNTRIES REPRESENTED AS OBSERVERS (U.S., CANADA, ISRAEL), ONLY CANADIAN DELEGATION ADDRESSED PLENARY WITH DESCRIPTION OF MUTUAL CANADIAN-EUROPEAN EDUCATIONAL PROBLEMS AND CONCERNS. CANADIAN DELEGATE CONCLUDED WITH EXPRESSION OF CANADIAN DESIRE FOR FULL MEMBERSHIP IN EUROPEAN REGION. FOLLOWING DEPARTMENT INSTRUCTIONS, U.S. DEL DID NOT ADDRESS PLENARY ALTHOUGH DELEGATION PLANS PARTICIPATION AS APPROPRIATE IN WORKING SESSIONS BEGINNING NOVEMBER 27.

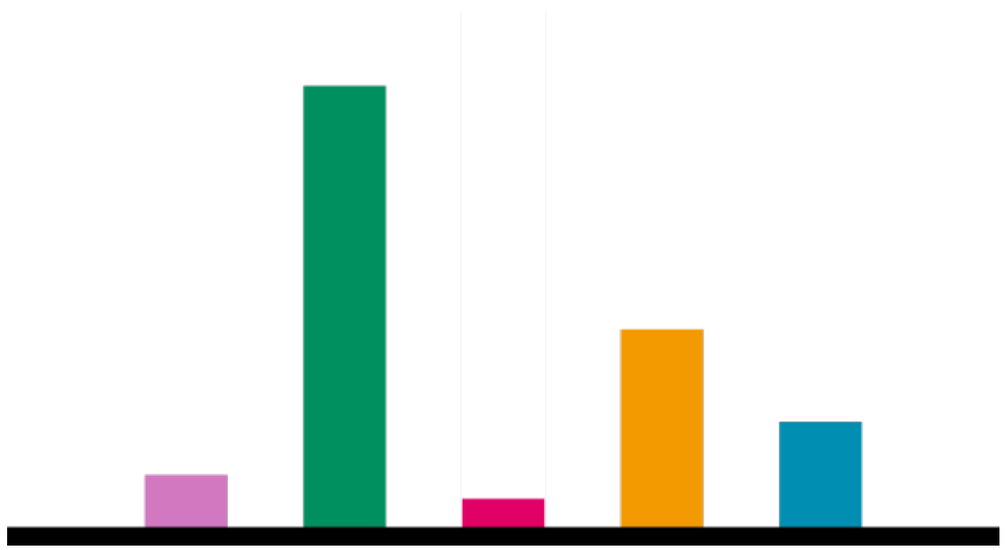
Advantage: Good for capturing shifts in specific subjects and terminology

useful for representing *event descriptions*

Disadvantage: harder to interpret, may cause scalability issues

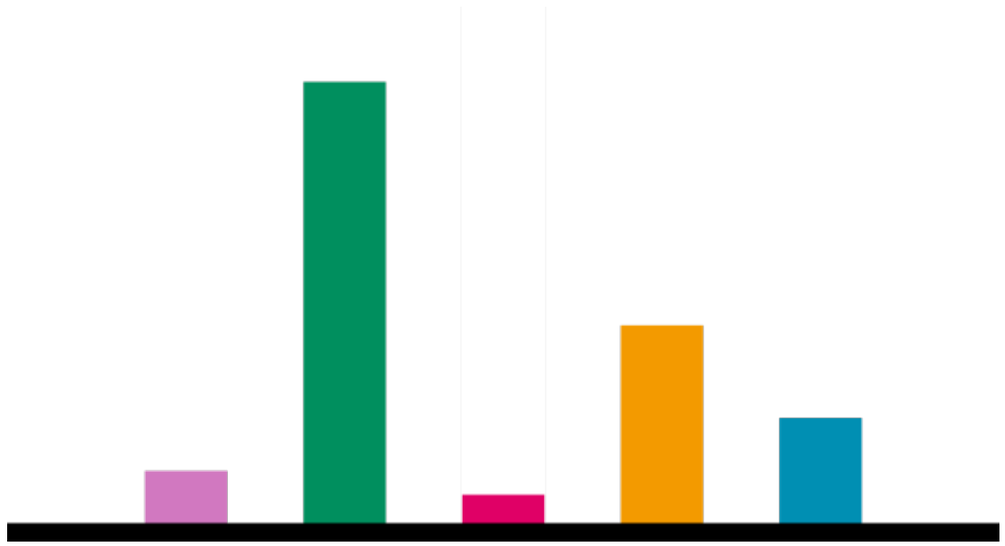
not useful for representing *entities' typical concerns*

modeling entities



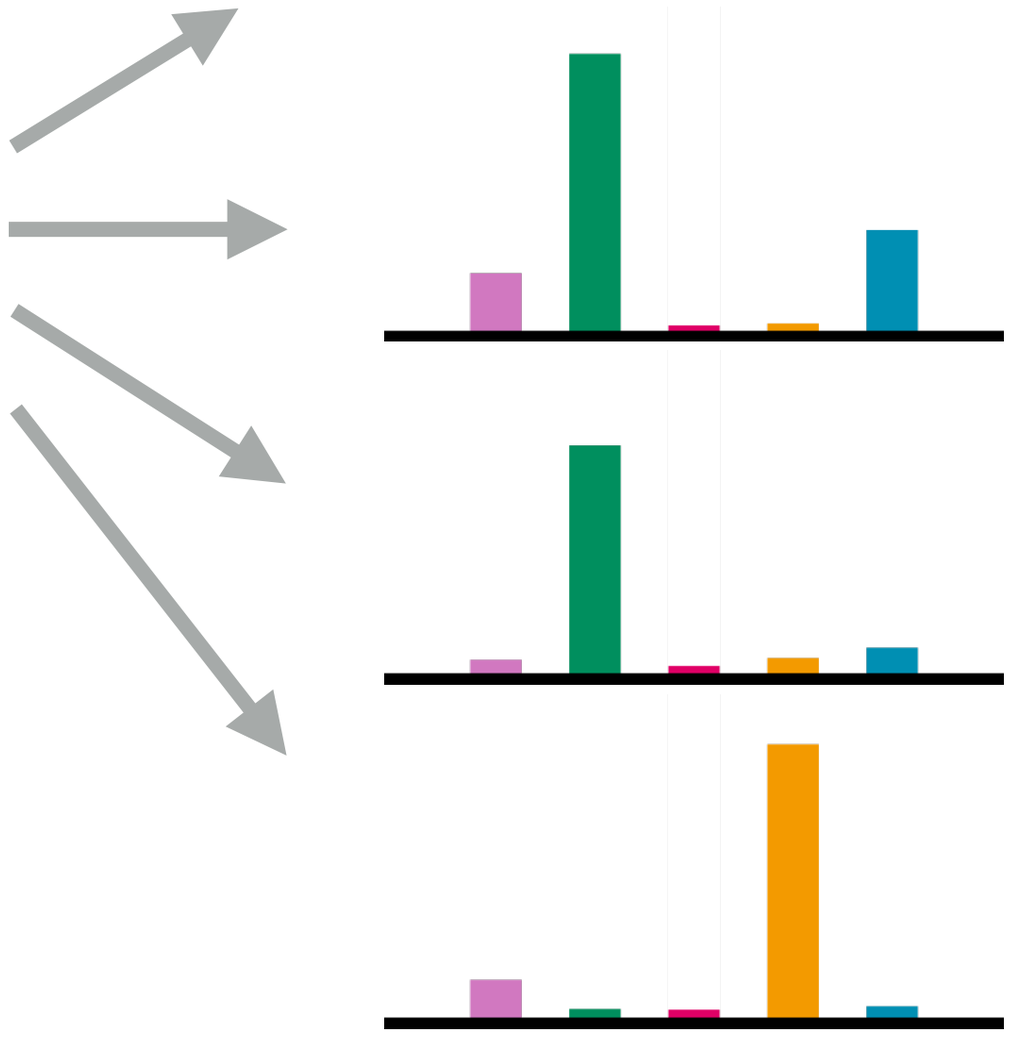
typical concerns
of the Bangkok Embassy

modeling entities



typical concerns
of the Bangkok Embassy

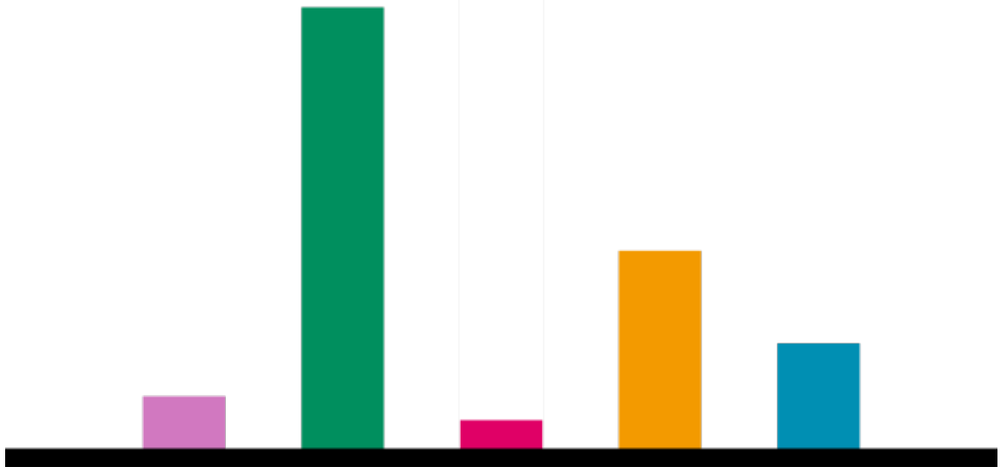
cables sent



modeling entities

for each entity *i* and topic *k*, draw typical concerns:

$$\phi_{i,k} \sim \mathrm{Gamma}(\alpha_\phi, \beta_\phi)$$



typical concerns
of entity *i*

entity-only model of cables

for each entity *i* and topic *k*, draw typical concerns:

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entity-only model of cables

for each entity *i* and topic *k*, draw typical concerns:

$$\phi_{i,k} \sim \mathrm{Gamma}(\alpha_\phi, \beta_\phi)$$

for each topic *k* and vocabulary term *v*, draw topics:

$$\theta_{k,v} \sim \mathrm{Gamma}(\alpha_\theta, \beta_\theta)$$

entity-only model of cables

for each entity *i* and topic *k*, draw typical concerns:

$$\phi_{i,k} \sim \mathrm{Gamma}(\alpha_\phi, \beta_\phi)$$

for each topic *k* and vocabulary term *v*, draw topics:

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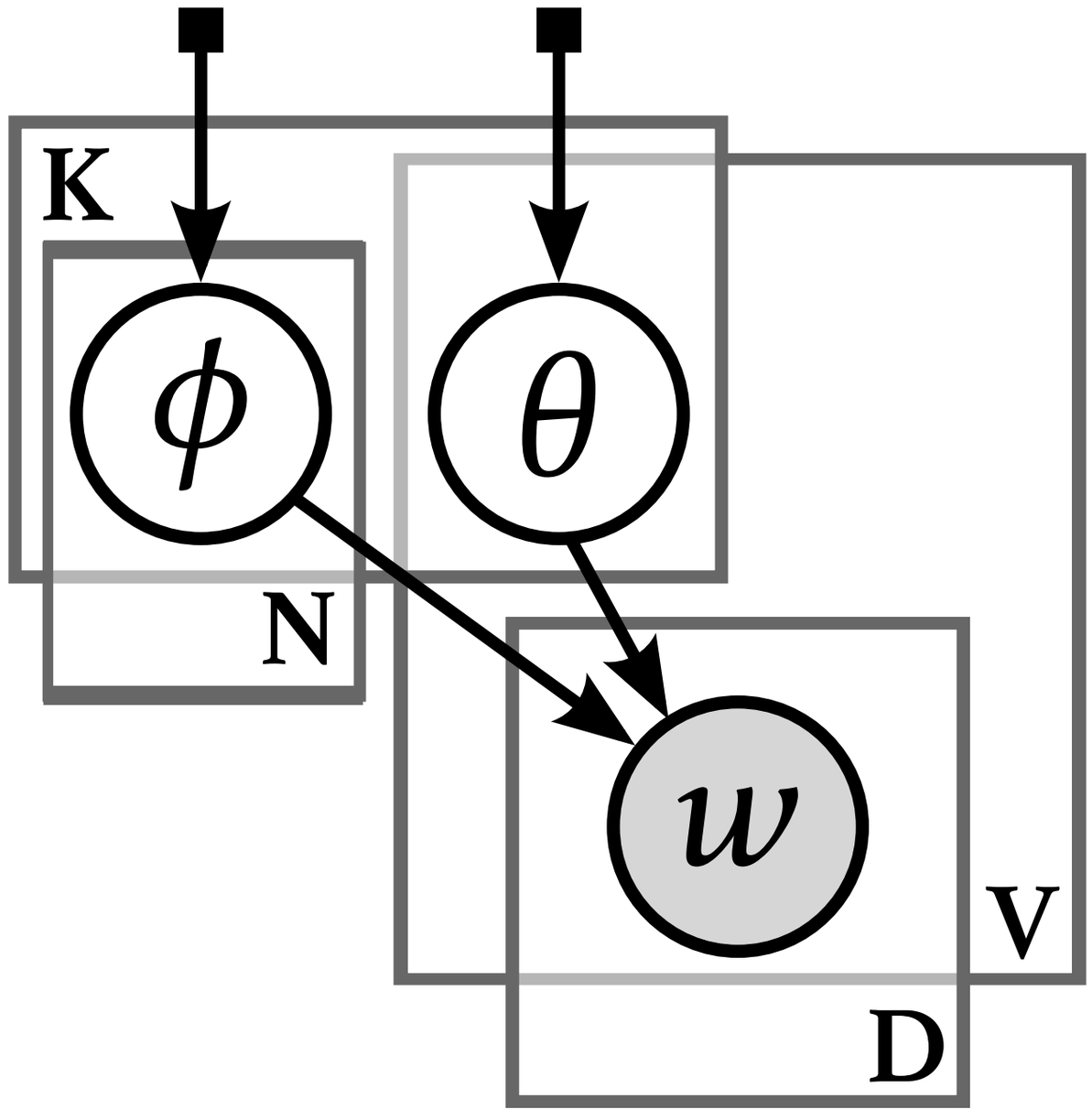
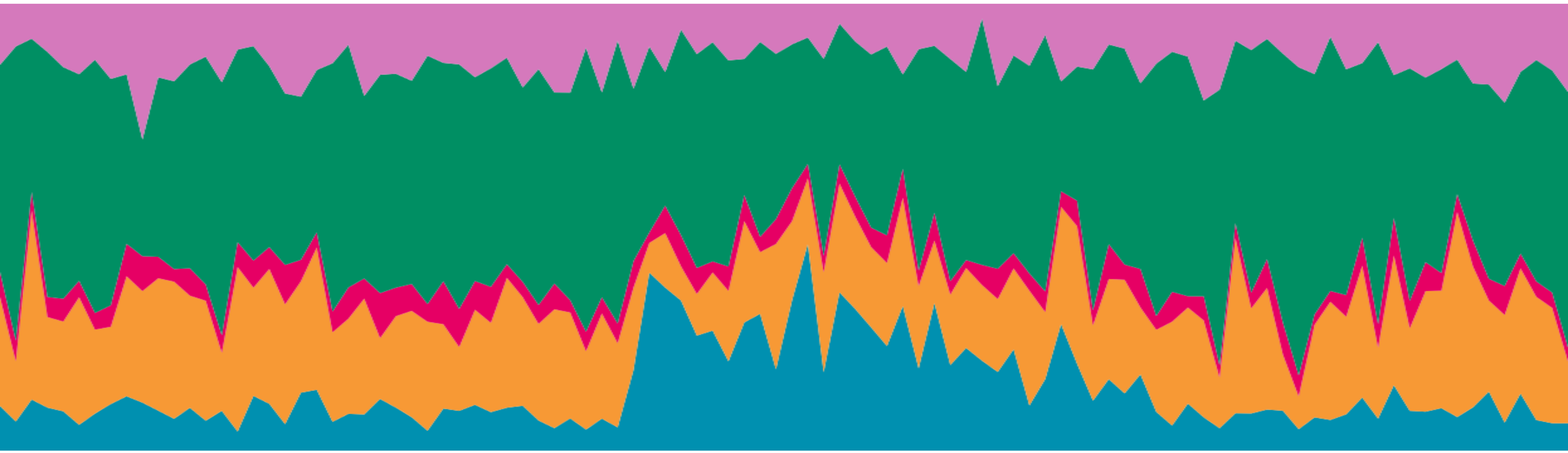
for each cable *n* (sent by entity *i*) and vocabulary term v:

$$w_{n,v} \sim \mathrm{Poisson}\left(\sum_k \phi_{i,k}\theta_{k,v}\right)$$

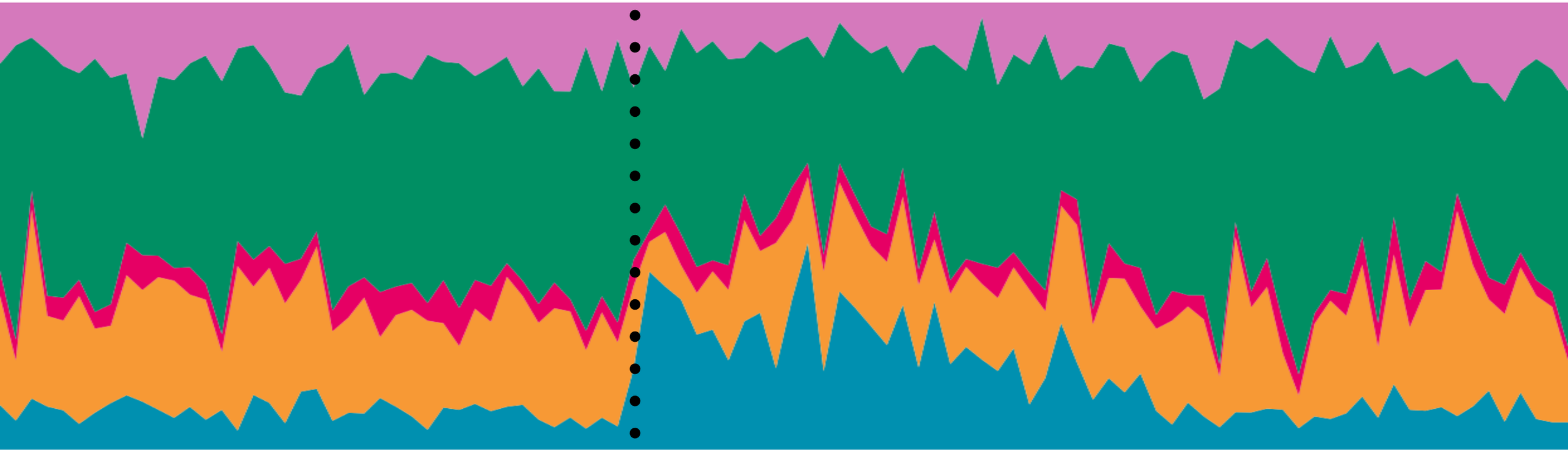
entity-only model of cables



modeling events

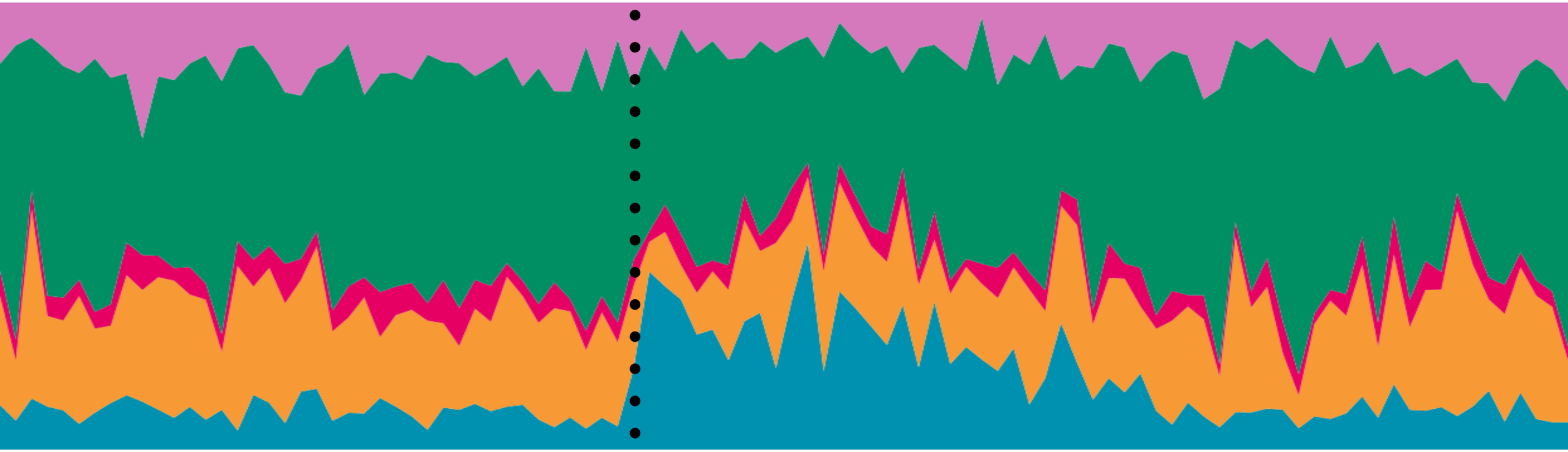


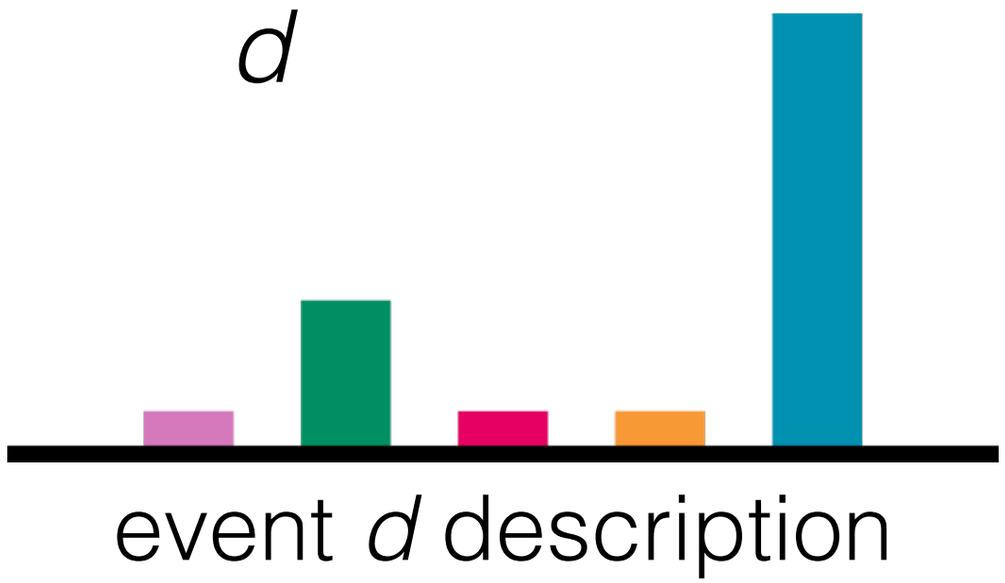
modeling events



d

modeling events





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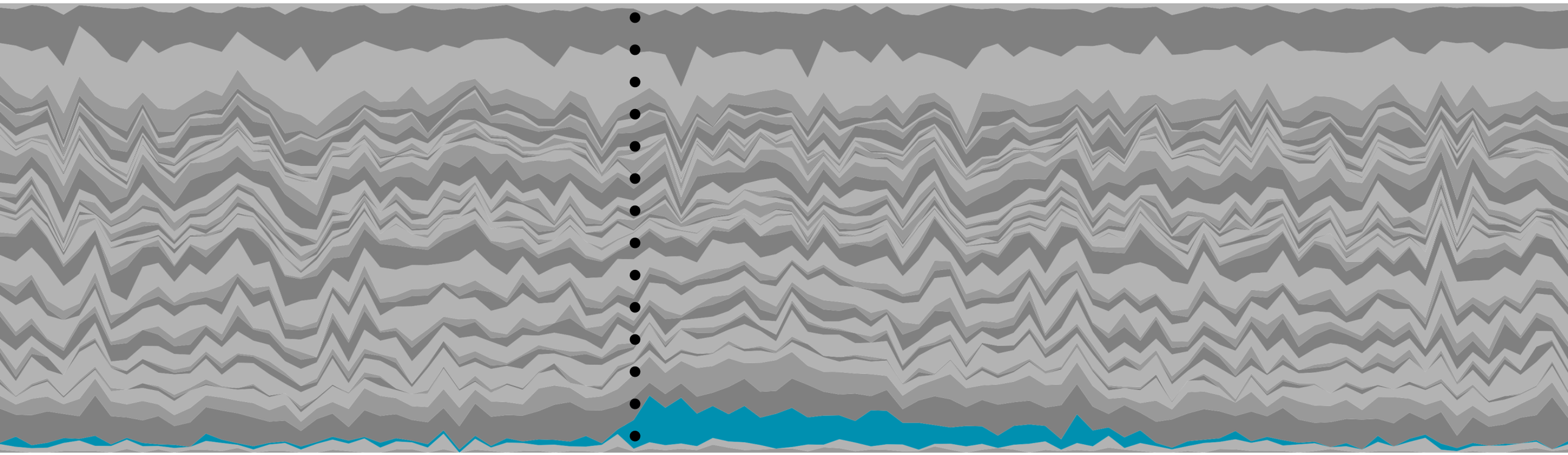
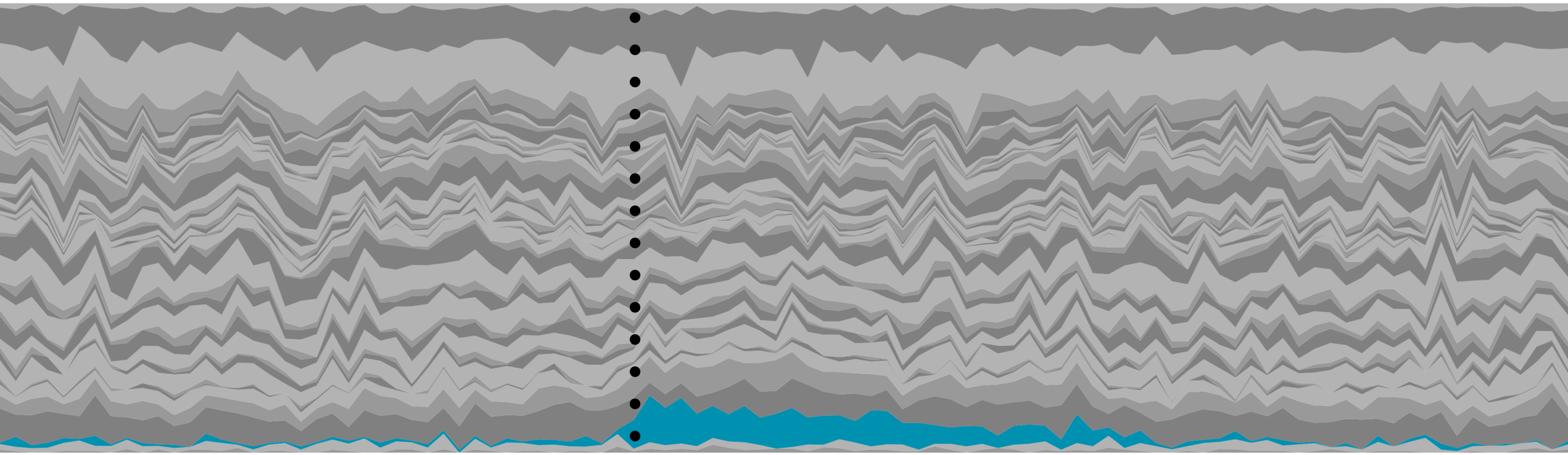
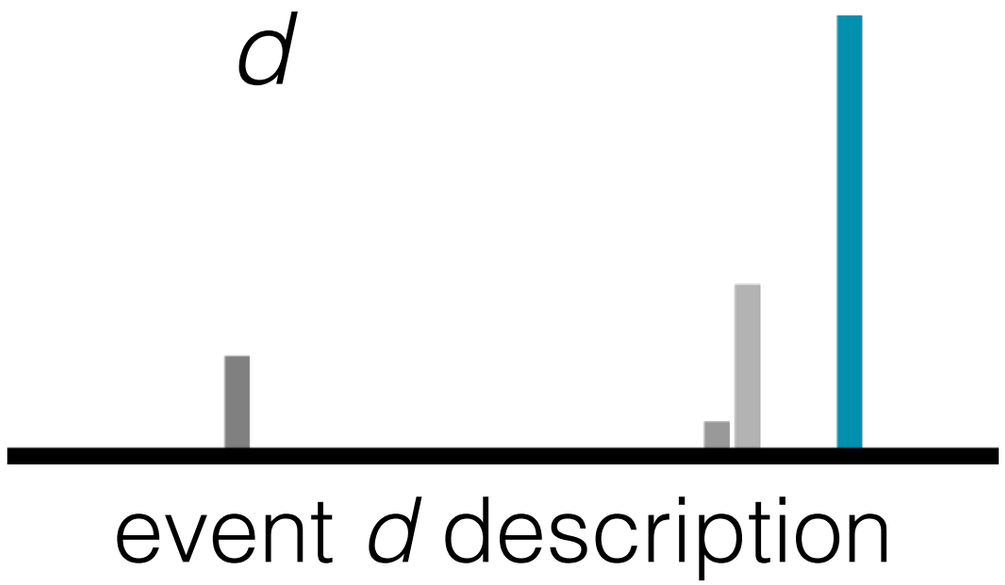


modeling events





event-only model of cables

for each time *t*, draw event strength:

$$\epsilon_t \sim \mathrm{Gamma}(\alpha_\epsilon, \beta_\epsilon)$$

event-only model of cables

for each time *t*, draw event strength:

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for each time *t* and vocab term *v*, draw event description:

$$\pi_{t,v} \sim \mathrm{Gamma}(\alpha_\pi, \beta_\pi)$$

event-only model of cables

for each time *t*, draw event strength:

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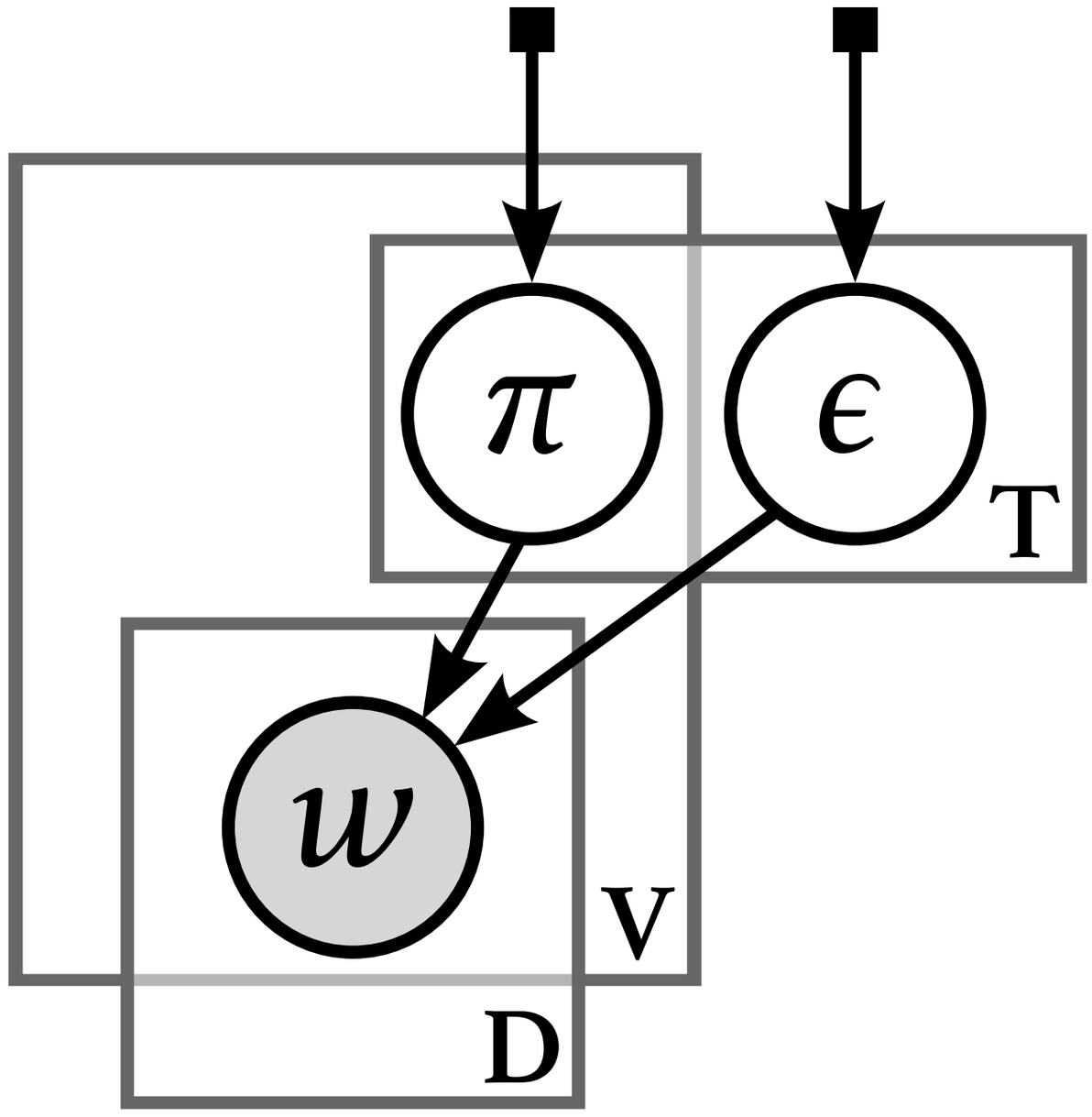
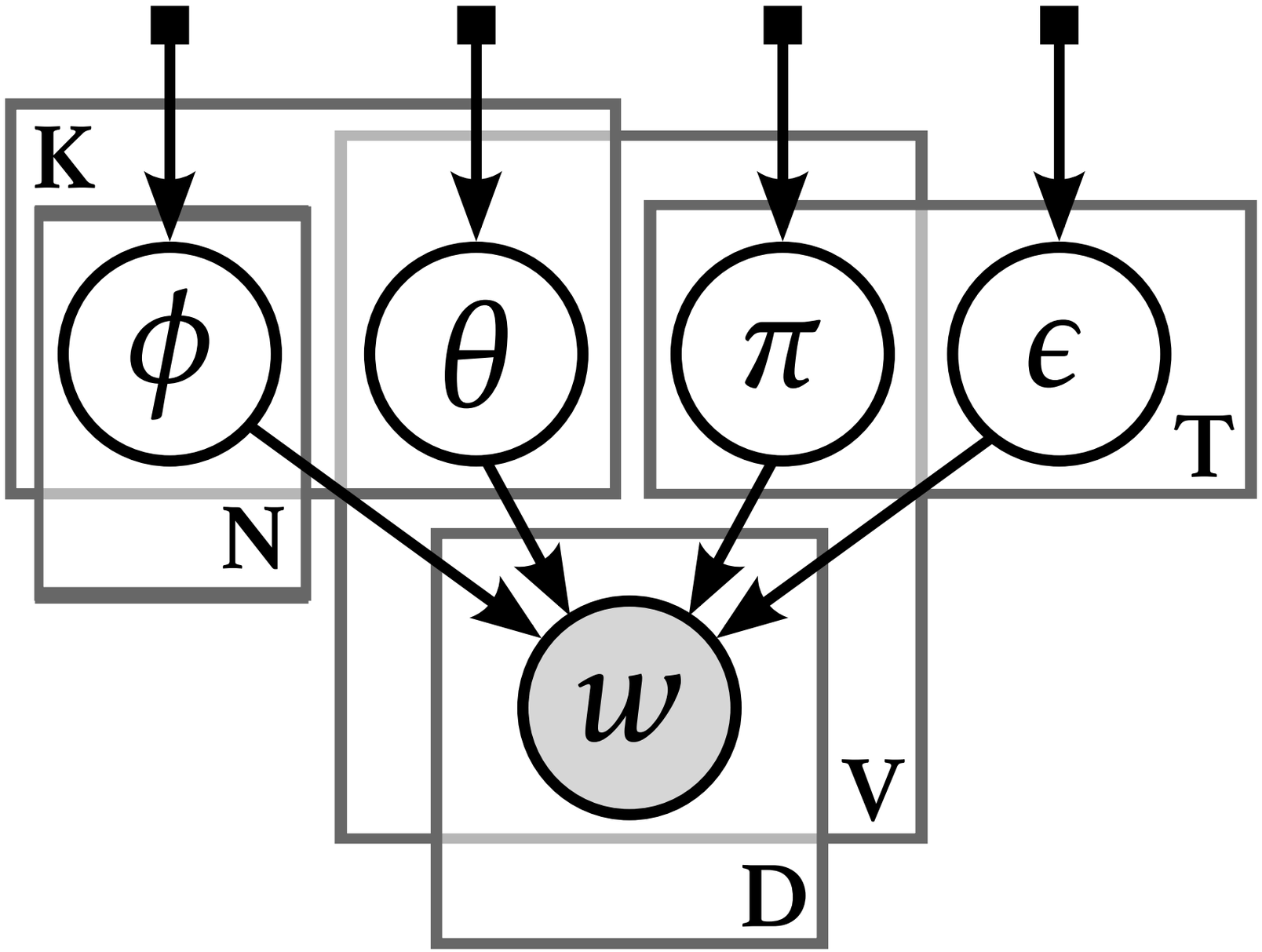


full model of cables



full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:

$$w_{n,v} \sim \text{Poisson}\left(\sum_k \phi_{i,k}\theta_{k,v} + \sum_t f(t,d)\epsilon_t, \pi_{t,v}\right)$$

full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:

sum over topics

$$w_{n,v} \sim \text{Poisson}\left(\sum_k \phi_{i,k}\theta_{k,v} + \sum_t f(t,d)\epsilon_t, \pi_{t,v}\right)$$

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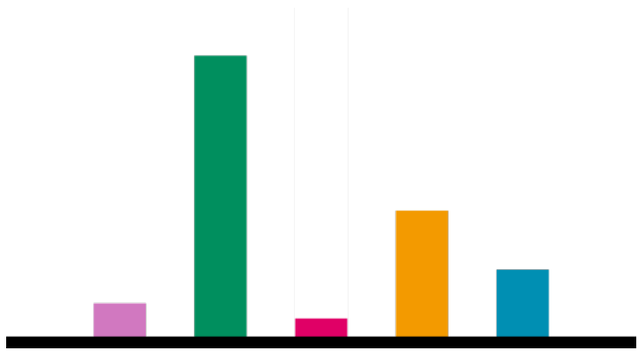

typical concerns of entity *i*

full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:

sum over topics

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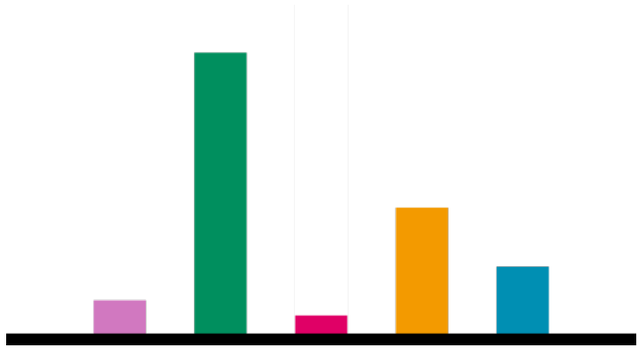
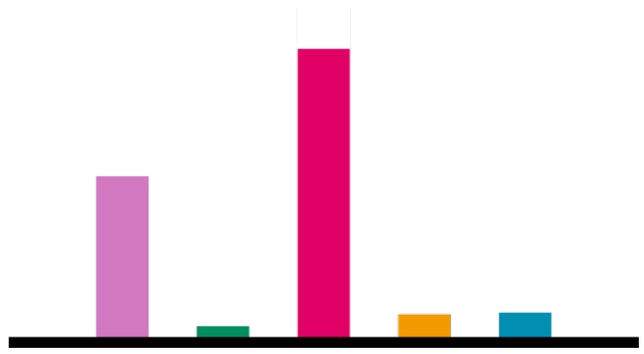


typical concerns of entity *i*



topics for word *v*

full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:

$$w_{n,v} \sim \text{Poisson}\left(\sum_k \phi_{i,k}\theta_{k,v} + \sum_t f(t,d)\epsilon_t, \pi_{t,v}\right)$$

full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:

1973 1978

sum over all time steps

$$w_{n,v} \sim \text{Poisson}\left(\sum_k \phi_{i,k}\theta_{k,v} + \sum_t f(t,d)\epsilon_t, \pi_{t,v}\right)$$

full model of cables

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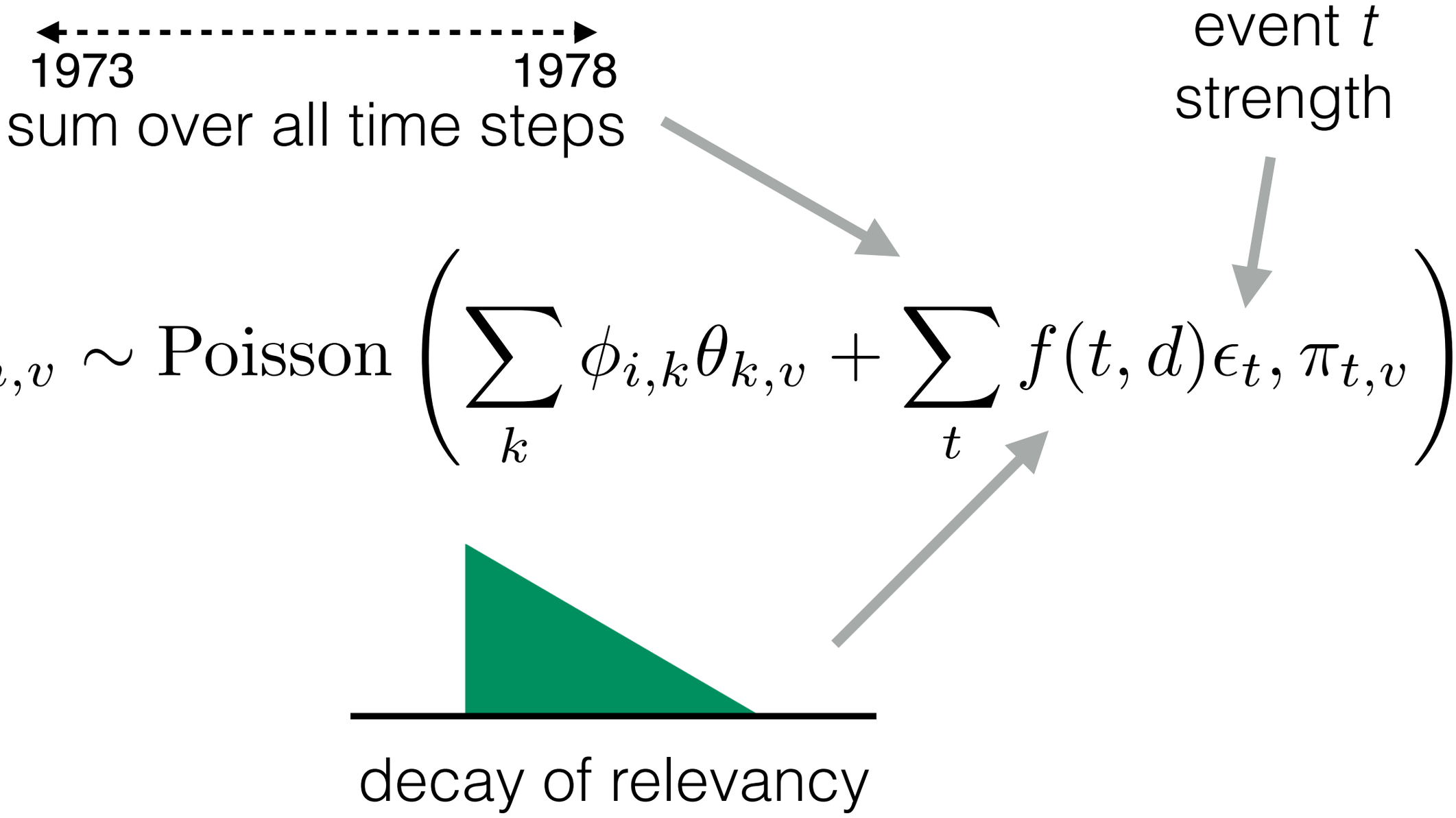
decay of relevancy

full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:



full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:

1973 — 1978

sum over all time steps

event *t* strength

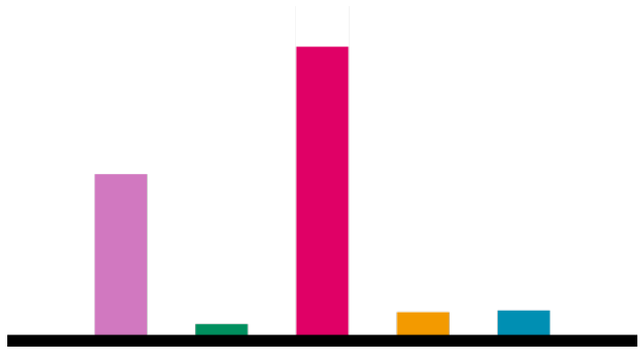
$$w_{n,v} \sim \text{Poisson}\left(\sum_k \phi_{i,k}\theta_{k,v} + \sum_t f(t,d)\epsilon_t, \pi_{t,v}\right)$$

decay of relevancy

event descriptions in vocabulary space

full model of cables

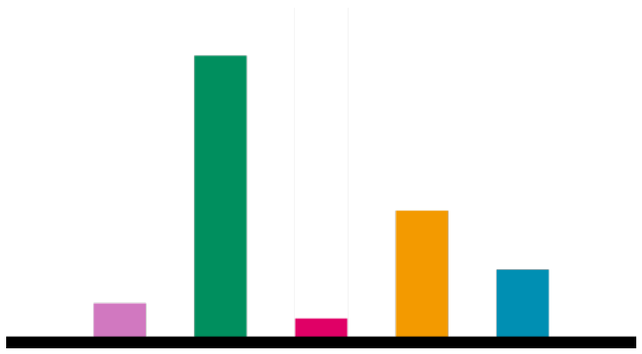
for each cable *n* (sent by entity *i* at time *d*) and vocab term v:



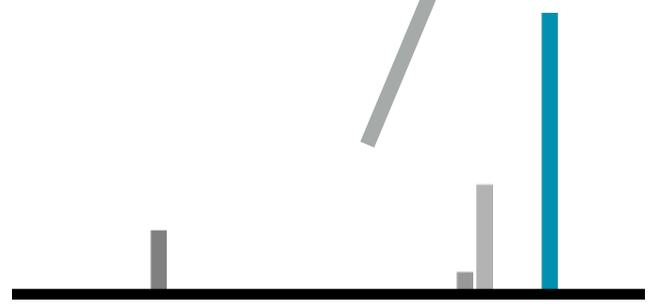
topics

event strengths

$$w_{n,v} \sim \text{Poisson}\left(\sum_k \phi_{i,k}\theta_{k,v} + \sum_t f(t,d)\epsilon_t, \pi_{t,v}\right)$$



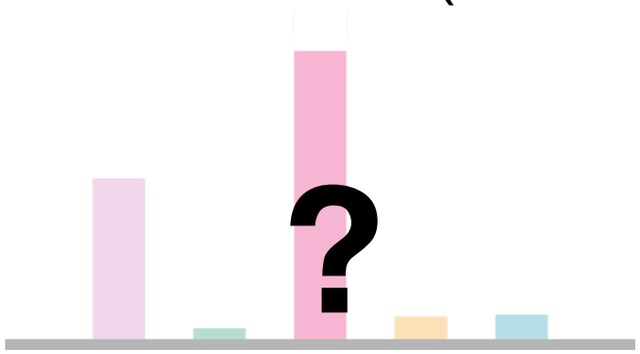
typical concerns



event descriptions

full model of cables

for each cable *n* (sent by entity *i* at time *d*) and vocab term v:



topics

event strengths

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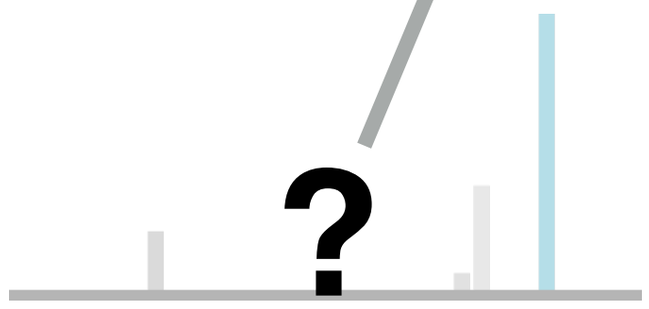
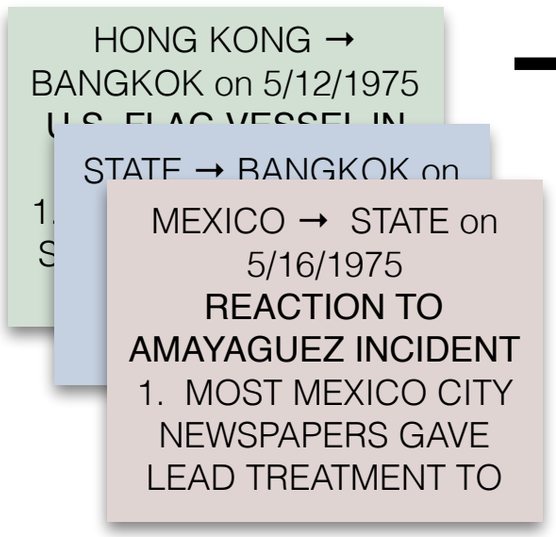
typical concerns



event descriptions

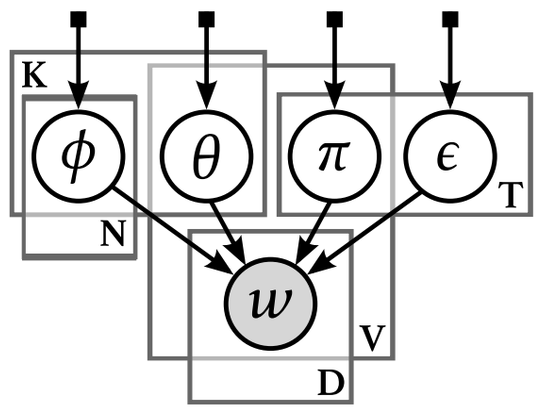
How do we find the values of the hidden parameters that best fit the data?

observed data



inference algorithm

model assumptions



learned parameters

entity typical concerns

topics

event strengths

event descriptions

visualization & exploration

Posterior Distribution

latent model parameters

easy to compute

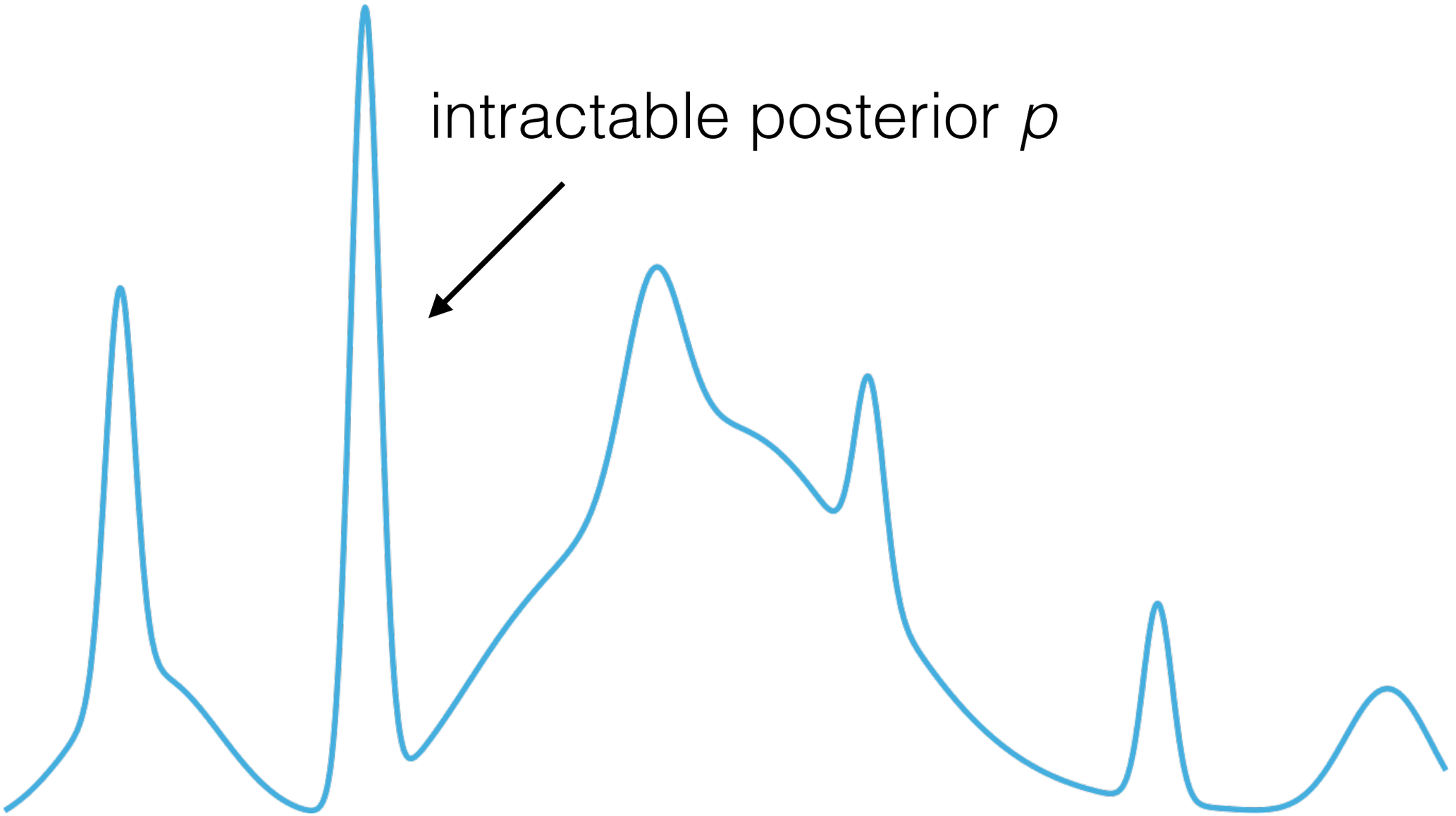
$$p(\phi, \theta, \epsilon, \pi \mid w, \alpha, \beta) = \frac{p(\phi, \theta, \epsilon, \pi, w \mid \alpha, \beta)}{\int_\phi \int_\theta \int_\epsilon \int_\pi p(\phi, \theta, \epsilon, \pi, w \mid \alpha, \beta)}$$

observed data

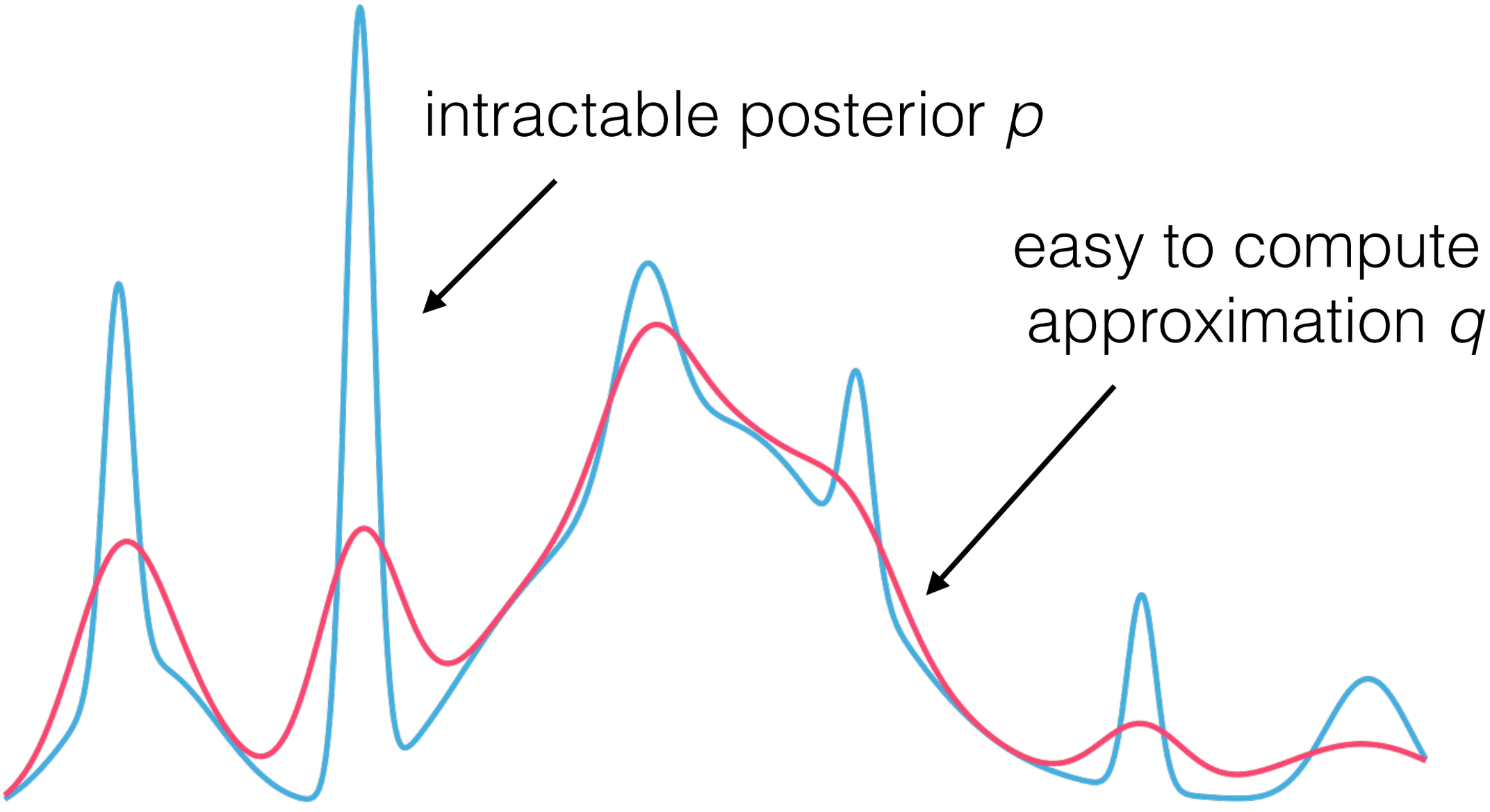
model hyperparameters

intractable

Variational Inference



Variational Inference



Variational Inference

Black box variational inference. Ranganath, Gerrish, and Blei, 2014.

- reduces model-specific mathematical derivations
- uses stochastic optimization
    - noisy gradient is computed from Monte Carlo samples from the variational distribution
    - downsides: looser fit, slower to converge

Standard conjugate variational inference

- model-specific mathematical derivations of closed-form updates
- uses coordinate ascent: iteratively updates each parameter while holding the others fixed

quick model comparison

current model

previous model

quick model comparison

current model	previous model
word counts are observations	fit LDA then hold document topics fixed as observations

quick model comparison

current model	previous model
word counts are observations	fit LDA then hold document topics fixed as observations
gamma-distributed event strengths	Poisson or Bernoulli-distributed event occurrences

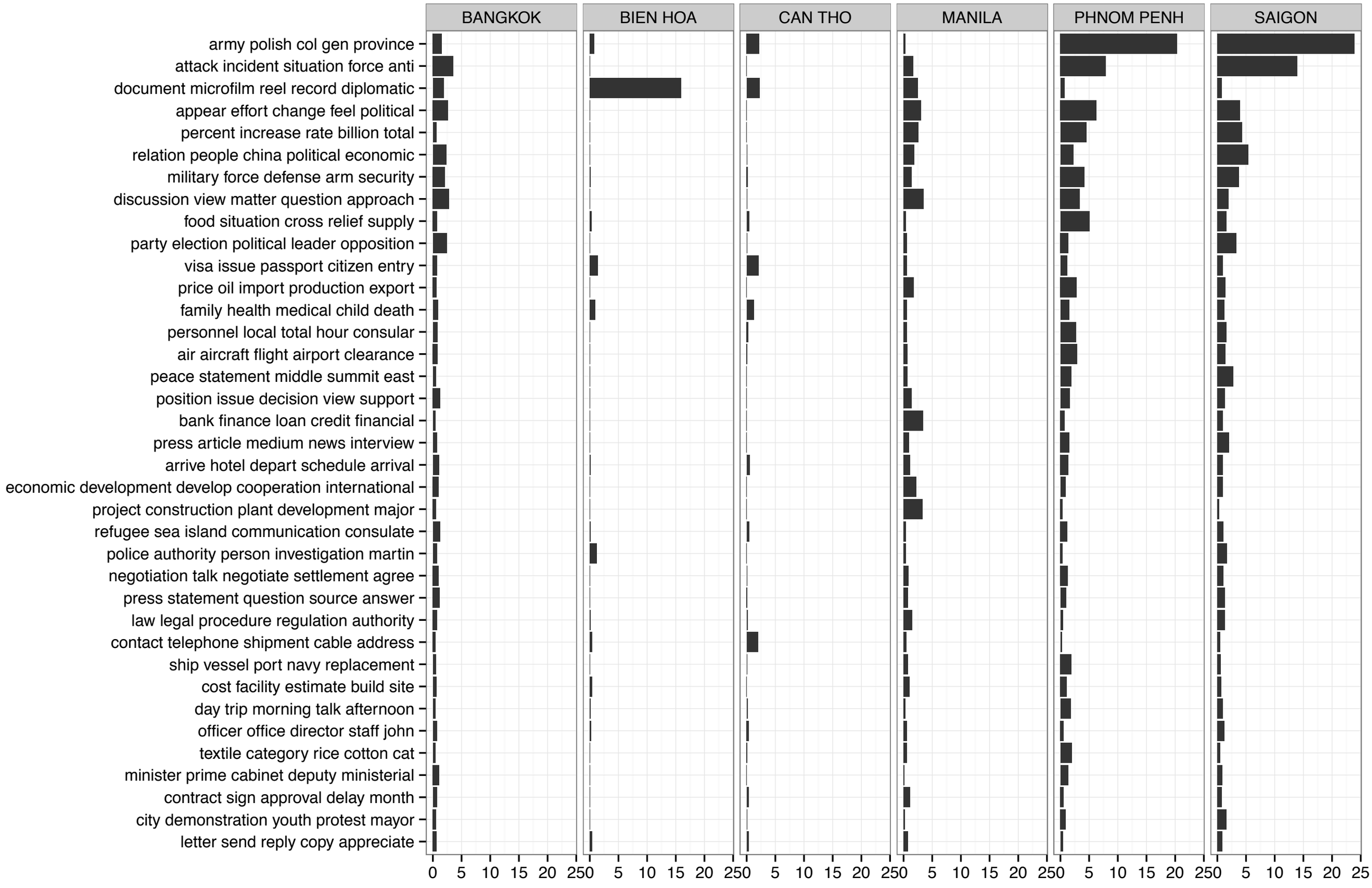
quick model comparison

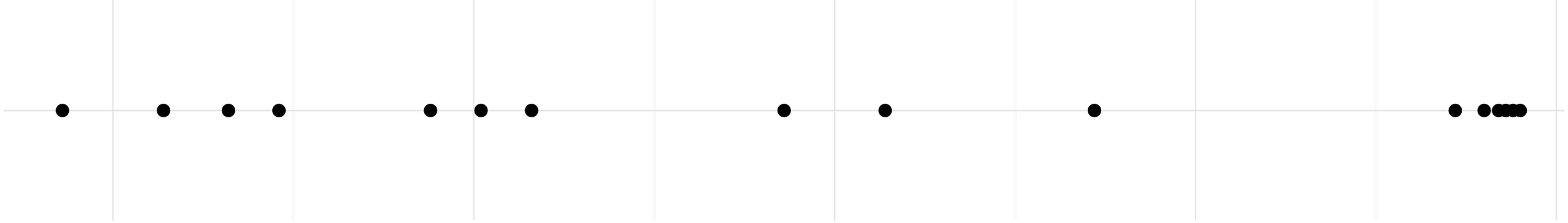
current model	previous model
word counts are observations	fit LDA then hold document topics fixed as observations
gamma-distributed event strengths	Poisson or Bernoulli-distributed event occurrences
event descriptions in vocabulary space	event descriptions in topic space

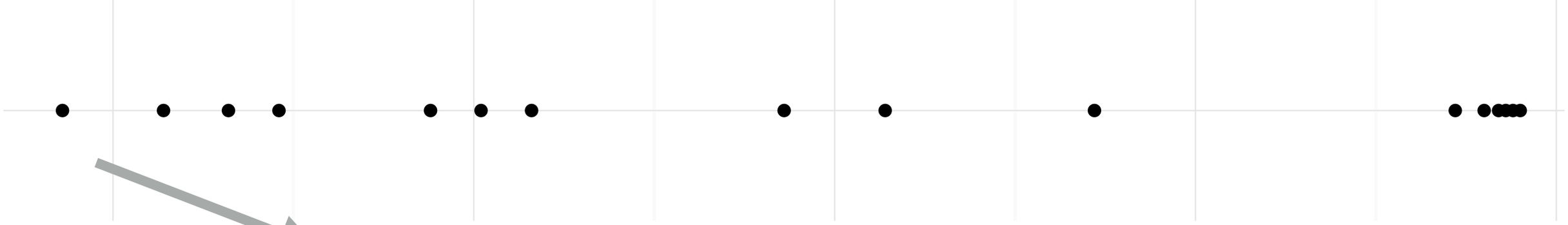
quick model comparison

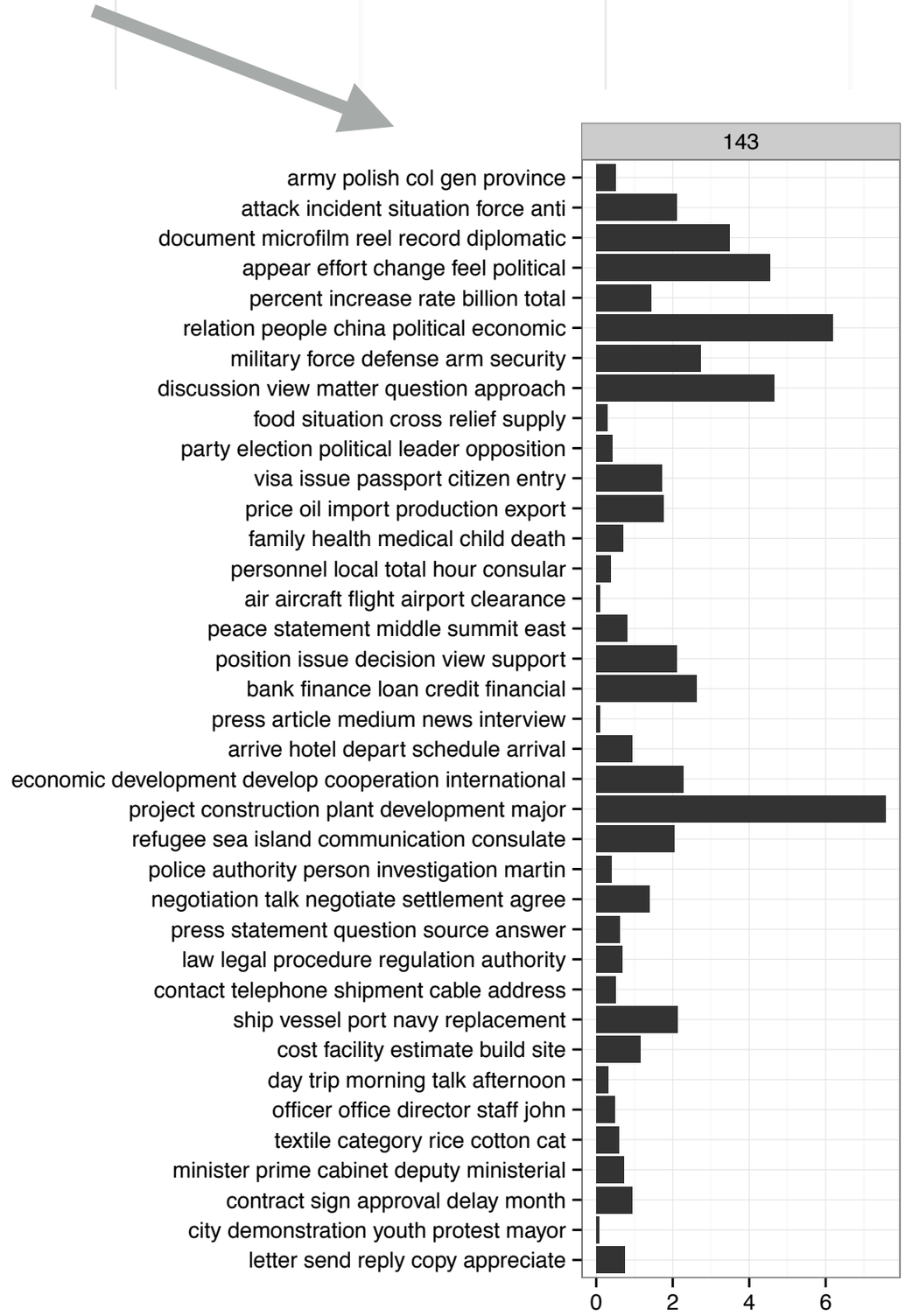
current model	previous model
word counts are observations	fit LDA then hold document topics fixed as observations
gamma-distributed event strengths	Poisson or Bernoulli-distributed event occurrences
event descriptions in vocabulary space	event descriptions in topic space
conjugate model, closed-form updates	non-conjugate model, BBVI

Exploration: Multiple Entities





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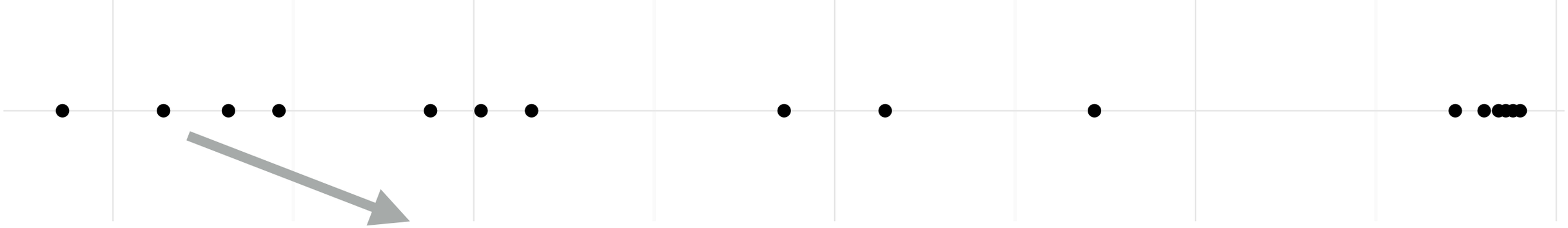

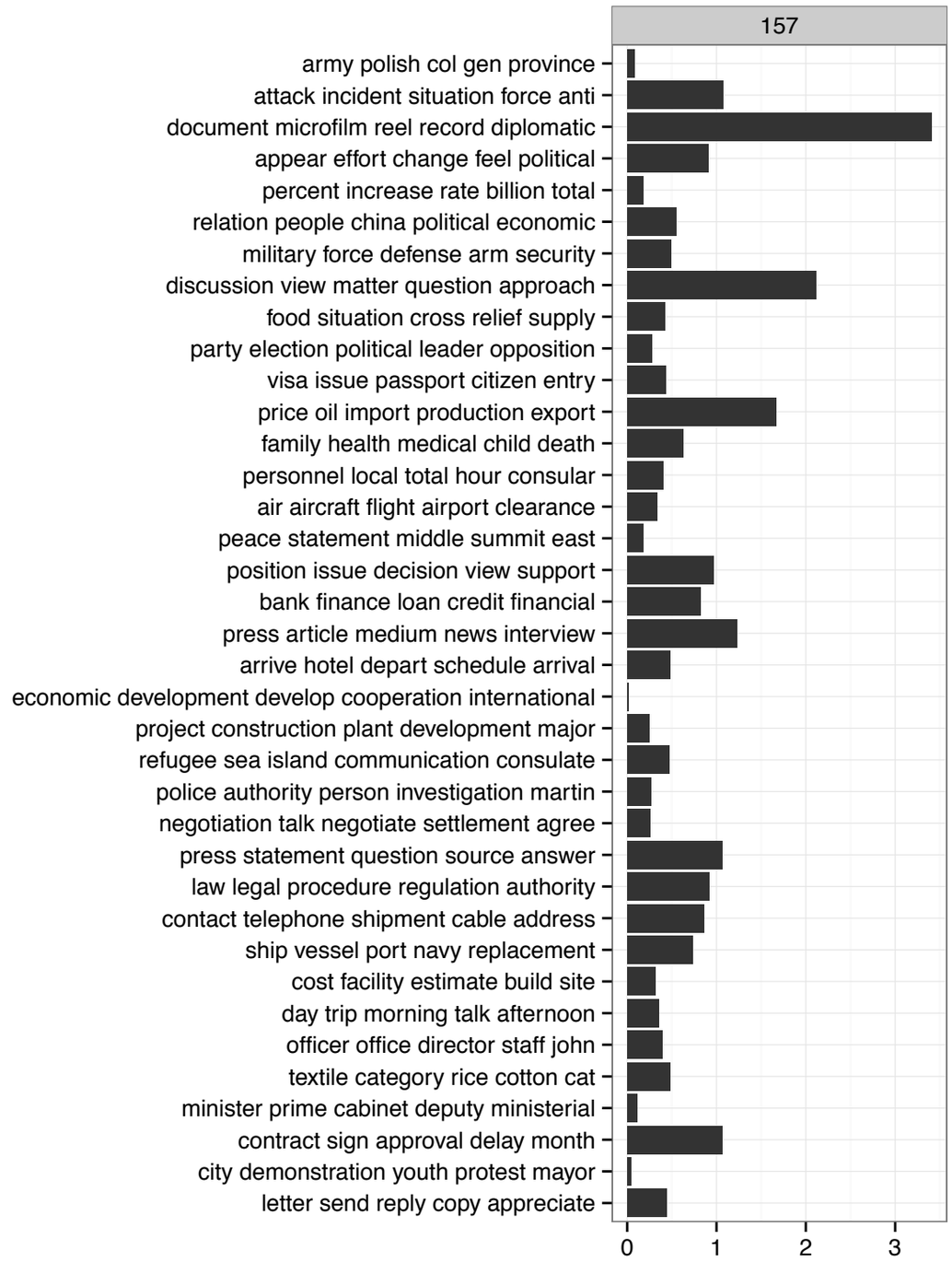
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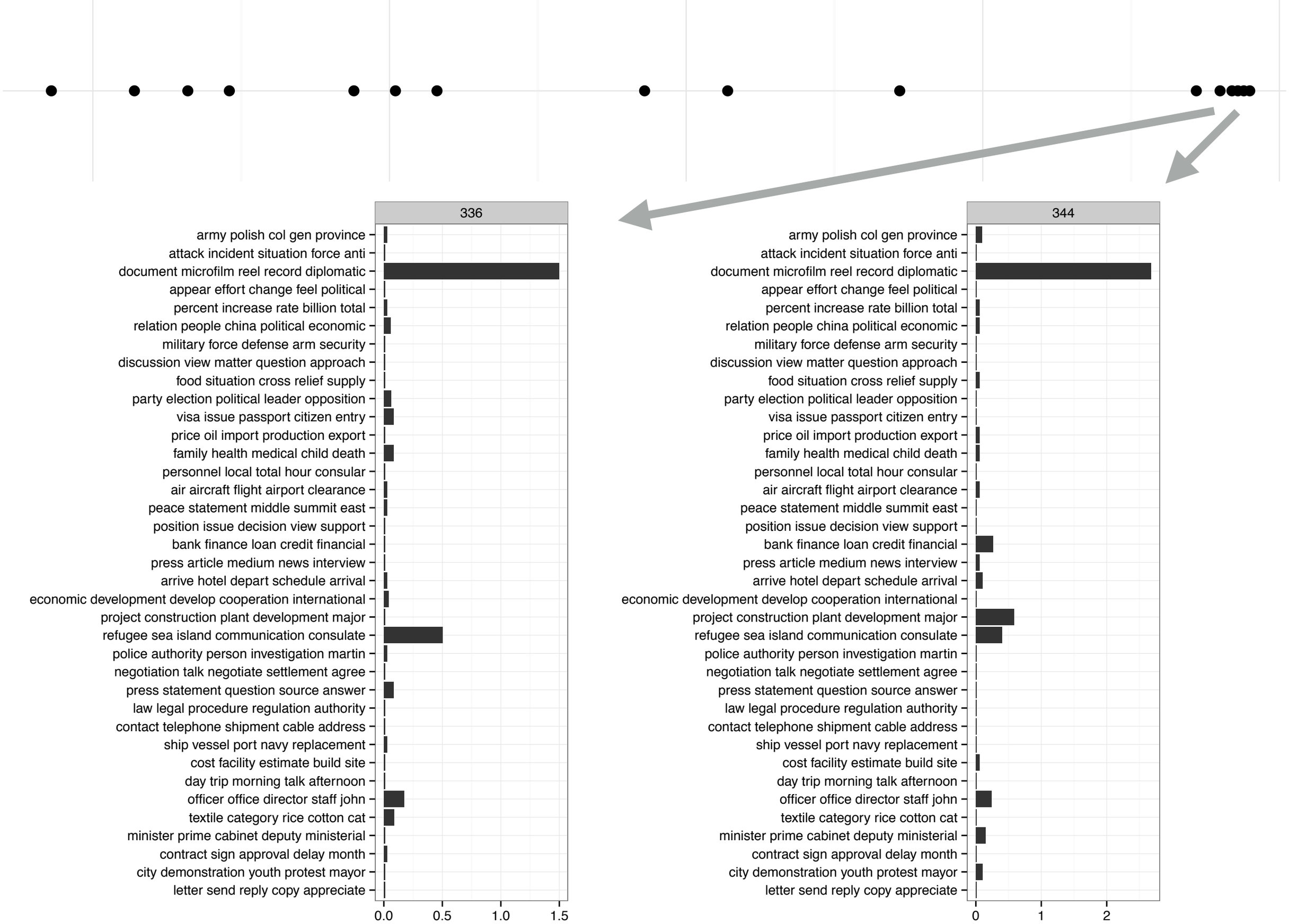
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Validation

- compare discovered events to manually collected examples of known historical events (and corresponding cables)
    - How many of the known events are recovered?
    - How does the average distributions of the known cables compares to the discovered event distribution?
- present the discovered events (date, topic distribution, and entities involved) to an expert historian

Current Work

Current Work

- Currently verifying implementation of inference algorithm on simulated data

Current Work

- Currently verifying implementation of inference algorithm on simulated data
- Goals:

Current Work

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- Goals:
    - show that our model outperforms heuristic baselines on simulated data

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- Goals:
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    - explore model sensitivity to hyperparameters

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- Model extensions

Current Work

- Currently verifying implementation of inference algorithm on simulated data

- Goals:
    - show that our model outperforms heuristic baselines on simulated data
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- Model extensions
    - include interactions between entities

Current Work

- Currently verifying implementation of inference algorithm on simulated data

- Goals:
    - show that our model outperforms heuristic baselines on simulated data
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    - explore real-world data with the model

- Model extensions
    - include interactions between entities
    - learn event duration

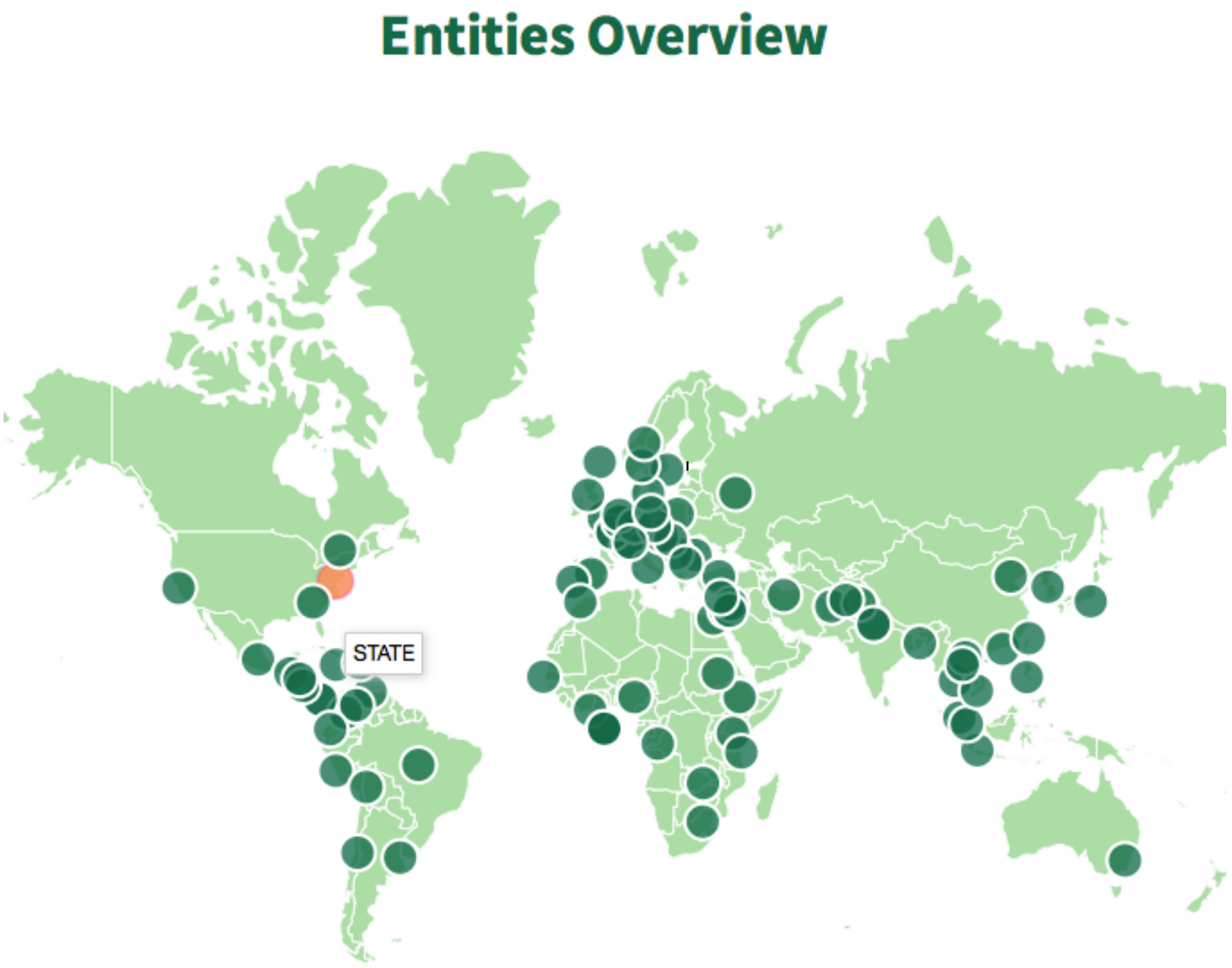
Current Work

- Currently verifying implementation of inference algorithm on simulated data

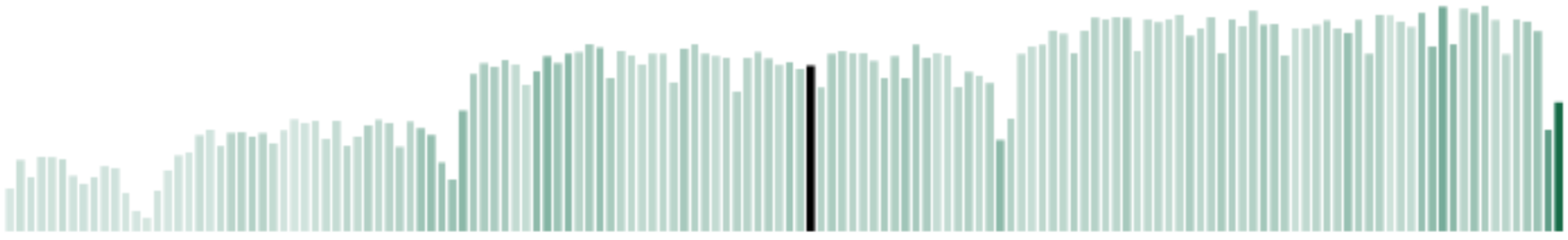
- Goals:
    - show that our model outperforms heuristic baselines on simulated data
    - explore model sensitivity to hyperparameters
    - explore real-world data with the model

- Model extensions
    - include interactions between entities
    - learn event duration
    - explore different event decay shapes

Visualization



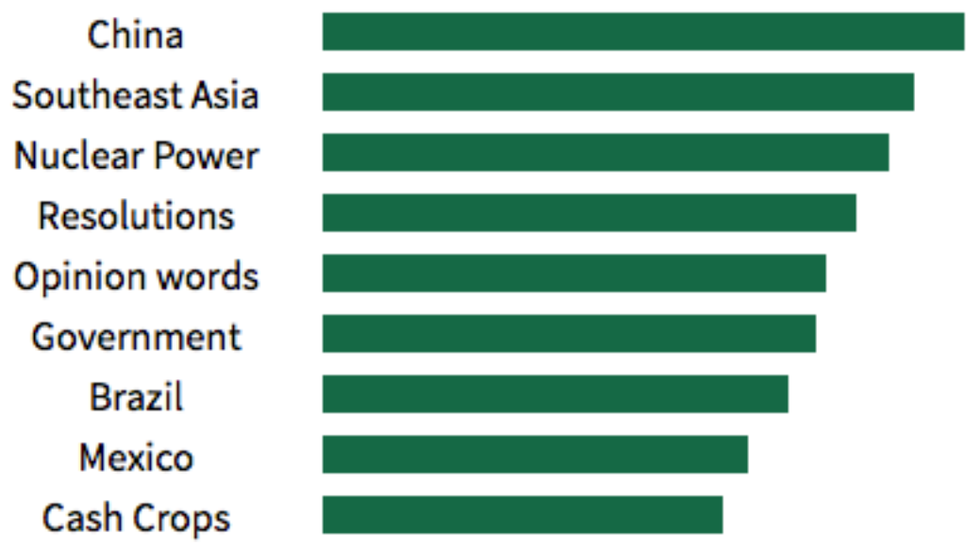
Events Overview



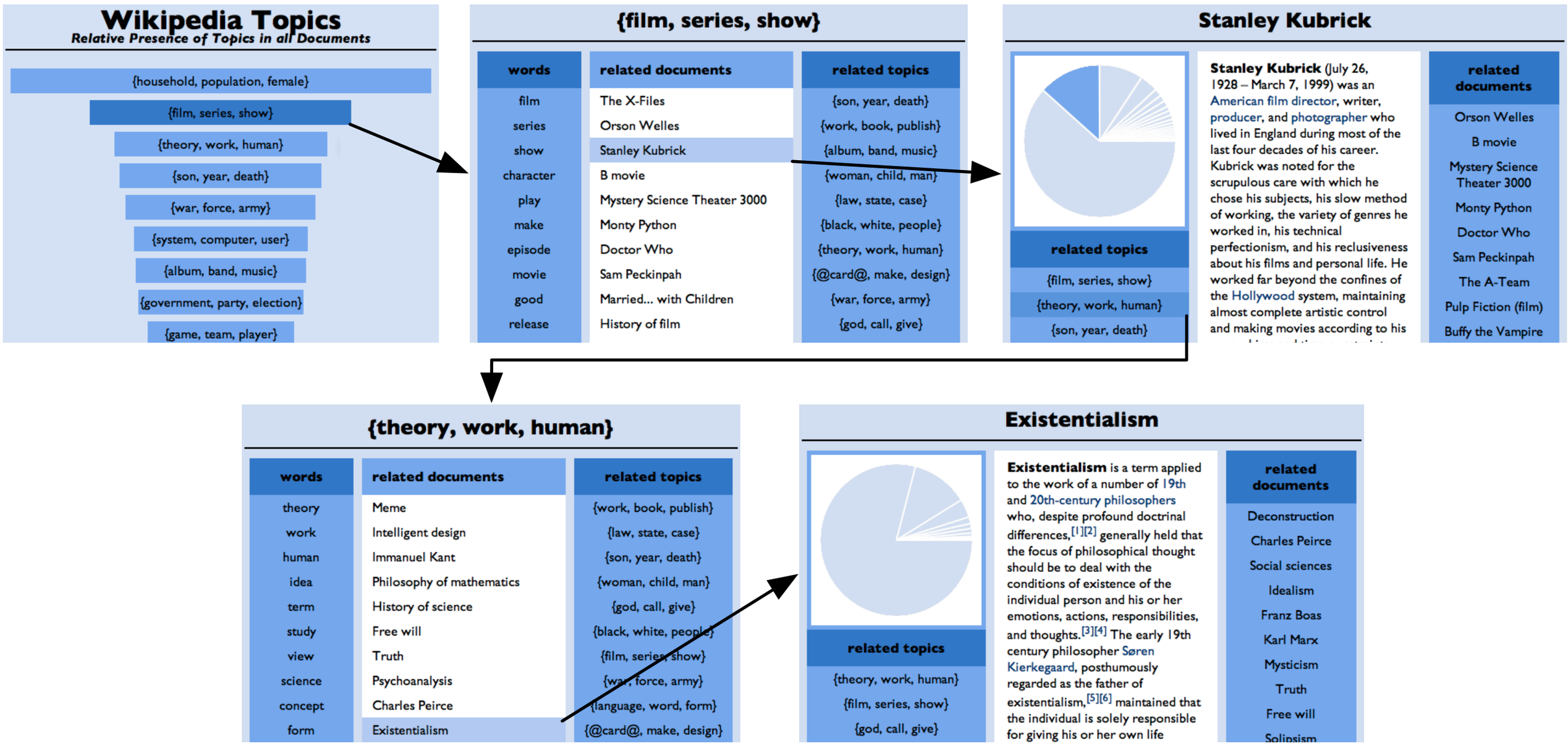
Aug. 21, 1974

8321 cables sent

Event strength: 0.085411

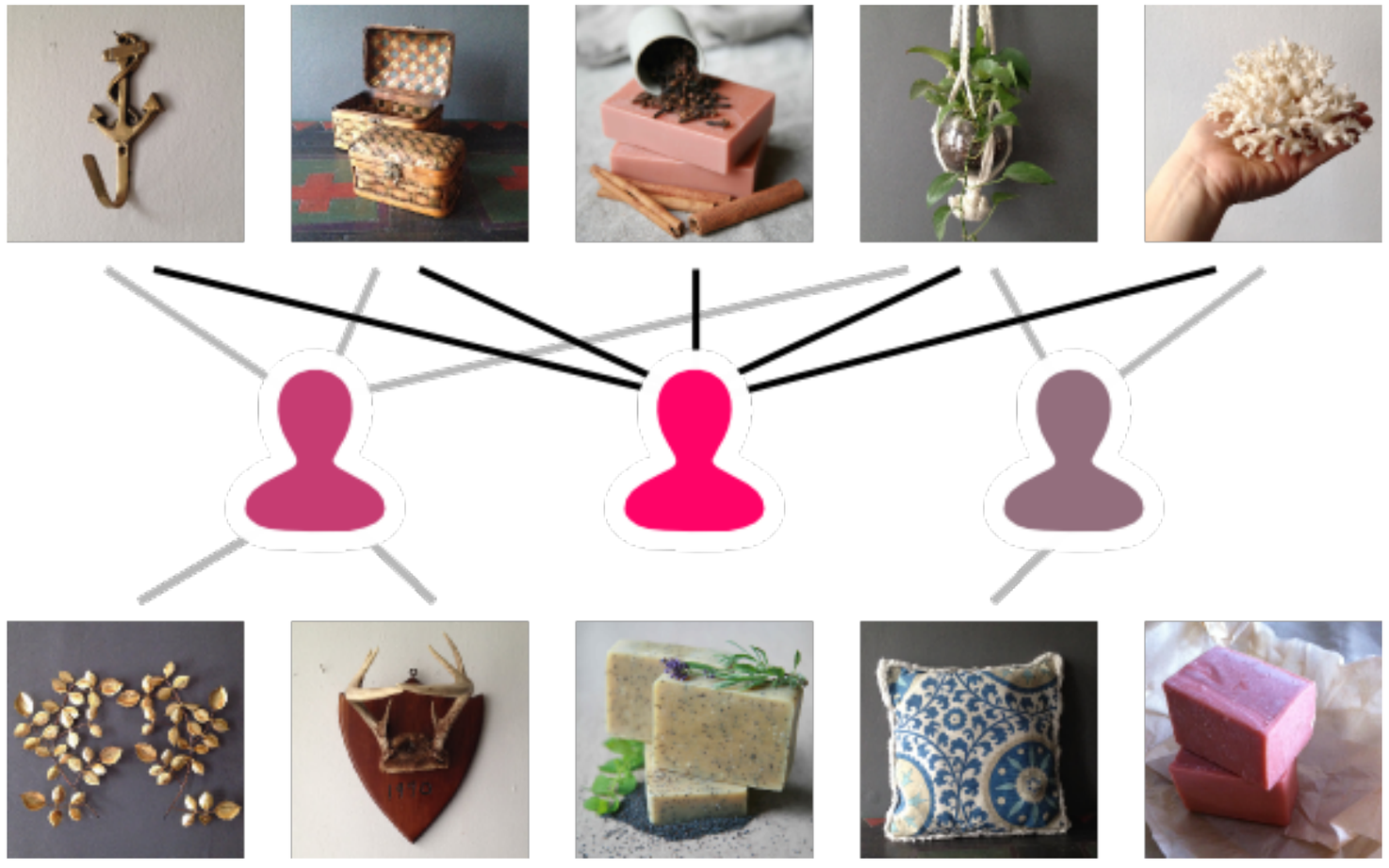


Visualizing Topic Models



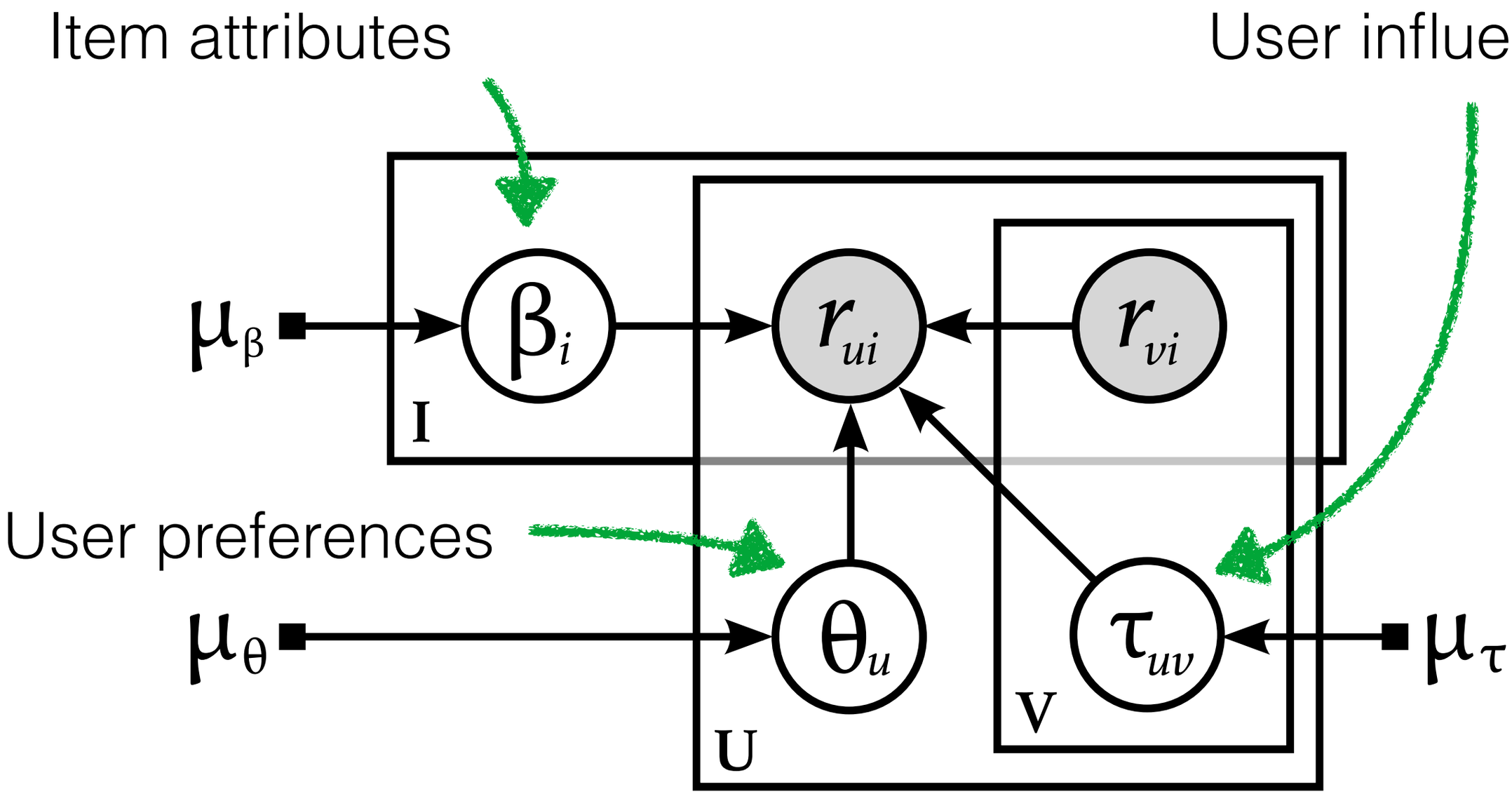
In collaboration with David Blei

Social Poisson Factorization



In collaboration with David Blei and Tina Eliassi-Rad

Social Poisson Factorization



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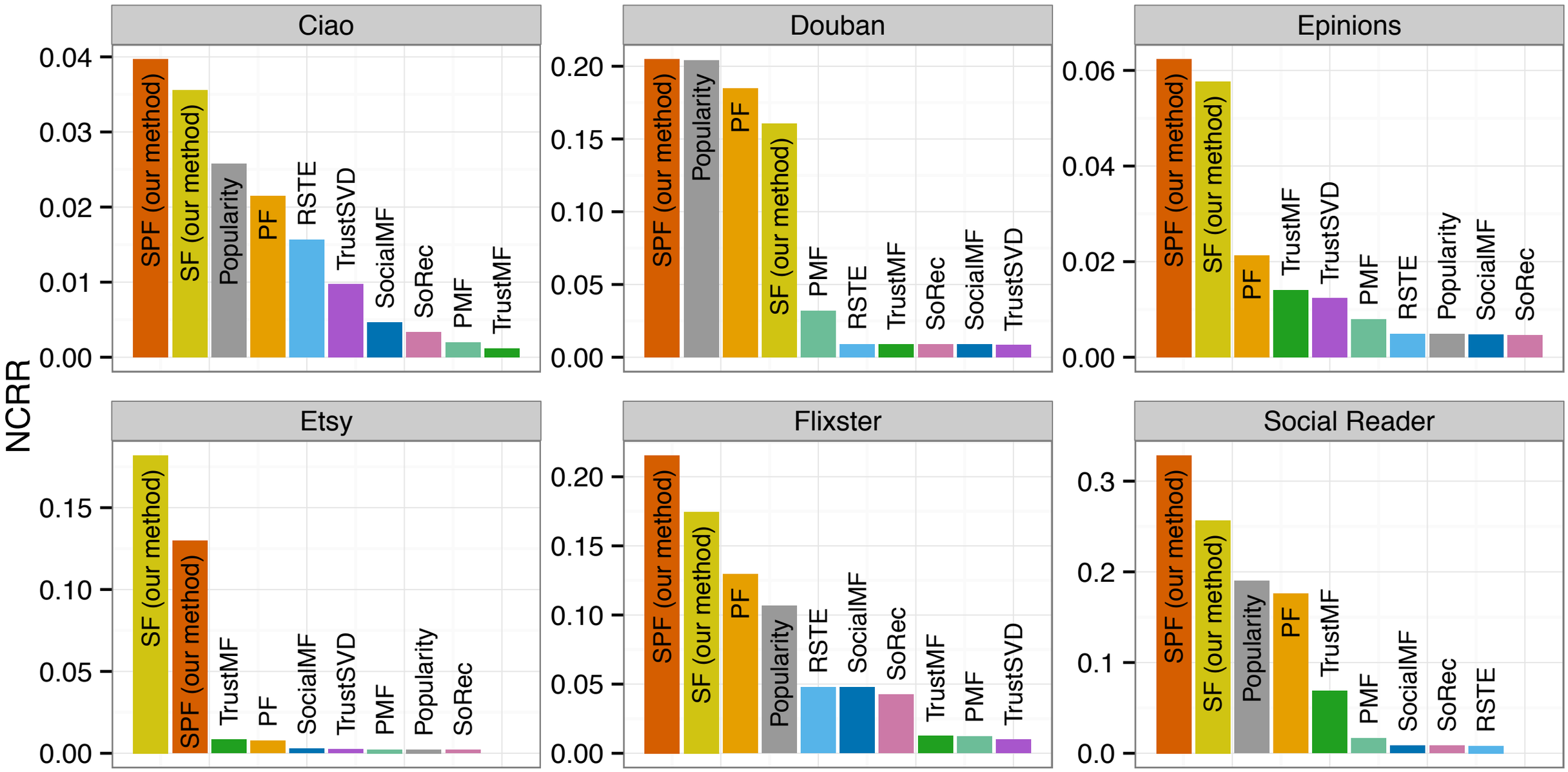
Social Poisson Factorization



In collaboration with David Blei and Tina Eliassi-Rad

Dissertation Themes

Dissertation Themes

- Analysis of discrete human behavior data

Dissertation Themes

- Analysis of discrete human behavior data
- Poisson additive models for attribution

Dissertation Themes

- Analysis of discrete human behavior data
- Poisson additive models for attribution
- Visualization and exploration as first-class research problems

Thank you!

Questions and suggestions welcome.

Committee

David Blei (advisor)
Barbara Engelhardt
Elad Hazan
Brandon Stewart

Additional Collaborators

Hanna Wallach
Matthew Connelly
Rohan Shah

Core Dissertation Chapters

Social Poisson Factorization

Chaney, Allison J.B., David M. Blei, and Tina Eliassi-Rad. "A probabilistic model for using social networks in personalized item recommendation." *RecSys*. 2015.

Detecting and Characterizing Historical Events

Visualizing Topic Models

Chaney, Allison J.B., and David M. Blei. "Visualizing Topic Models." *ICWSM*. 2012.

Complete Conditionals

$$\phi_{i,k} \mid \theta, \epsilon, \pi, \mathbf{W} \sim \text{Gamma}\left(\alpha_\phi + \sum_{v,n \in N_i} z^{entity}_{n,v,k}, \beta_\phi + |N_i| \sum_v \theta_{k,v}\right)$$

$$\theta_{k,v} \mid \phi, \epsilon, \pi, \mathbf{W} \sim \text{Gamma}\left(\alpha_\theta + \sum_{v,n} z^{entity}_{n,v,k}, \beta_\theta + \sum_i |N_i| \phi_{i,k}\right)$$

$$\epsilon_t \mid \phi, \theta, \pi, \mathbf{W} \sim \text{Gamma}\left(\alpha_\epsilon + \sum_{v,n \in N_t} z^{event}_{n,v,t}, \beta_\epsilon + \sum_v \sum_{d=0}^{\delta} |N_{t+d}| f(t+d,t) \sum_k \pi_{t,k}\right)$$

$$\pi_{t,v} \mid \phi, \theta, \epsilon, \mathbf{W} \sim \text{Gamma}\left(\alpha_\pi + \sum_{v,n \in N_t} z^{event}_{n,v,t}, \beta_\pi + \sum_v \sum_{d=0}^{\delta} |N_{t+d}| f(t+d,t) \epsilon_d\right)$$