Smart Analytics for Big Time-series Data

Yasushi Sakurai (Kumamoto University)
Yasuko Matsubara (Kumamoto University)
Christos Faloutsos (Carnegie Mellon University)

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Roadmap

- Motivation
- Similarity search, pattern discovery and summarization — Part 1
- Non-linear modeling and forecasting — Part 2
- **Extension of time-series data: tensor analysis** — **Part 3**

Part 3

Extension of time-series: tensor analysis

Yasushi Sakurai (Kumamoto University)
Yasuko Matsubara (Kumamoto University)
Christos Faloutsos (Carnegie Mellon University)

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Outline

- Tensor decomposition
- Mining and forecasting of complex time-stamped events
- New challenge: MANT analysis

Multi-Aspect Non-linear Time-series

M A N T

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Outline

- Tensor decomposition
  - Motivation
  - Basic approaches
- Mining and forecasting of complex time-stamped events
- New challenge: MANT analysis

Multi-Aspect Non-linear Time-series

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Examples of Matrices: Graph - social network

	John	Peter	Mary	Nick	...
John	0	11	22	55	...
Peter	5	0	6	7	...
Mary	...	...	...	...	...
Nick	...	...	...	...	...
...	...	...	...	...	...

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Examples of Matrices: cloud of n-dim points

	chol#	blood#	age	..	...
John	13	11	22	55	...
Peter	5	4	6	7	...
Mary	...	...	...	...	...
Nick	...	...	...	...	...
...	...	...	...	...	...

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Examples of Matrices: Market basket

- **market basket** as in Association Rules

	milk	bread	choc.	wine	...
John	13	11	22	55	...
Peter	5	4	6	7	...
Mary	...	...	...	...	...
Nick	...	...	...	...	...
...	...	...	...	...	...

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Examples of Matrices: Documents and terms

	data	mining	classif.	tree	...
Paper#1	13	11	22	55	...
Paper#2	5	4	6	7	...
Paper#3	...	...	...	...	...
Paper#4	...	...	...	...	...
...	...	...	...	...	...

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Examples of Matrices: Authors and terms

	data	mining	classif.	tree	...
John	13	11	22	55	...
Peter	5	4	6	7	...
Mary	...	...	...	...	...
Nick	...	...	...	...	...
...	...	...	...	...	...

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Examples of Matrices: sensor-ids and time-ticks

	temp1	temp2	humid.	pressure	...
t=1	13	11	22	55	...
t=2	5	4	6	7	...
t=3	...	...	...	...	...
t=4	...	...	...	...	...
...	...	...	...	...	...

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Motivation 2: Why tensors?

- Q: what is a tensor?
- A: N-D generalization of matrix:

kdd' 17	network	search	graph	mining	...
John	13	11	22	55	...
Peter	5	4	6	7	...
Mary	...	...	...	...	...
Nick	...	...	...	...	...
...	...	...	...	...	...

Motivation 2: Why tensors?

- Q: what is a tensor?
- A: N-D generalization of matrix:

kdd' 15

kdd' 16

kdd' 17

	network	search	graph	mining	...
John	13	11	22	55	...
Peter	5	4	6	7	...
Mary	...	...	...	...	...
Nick	...	...	...	...	...
...	...	...	...	...	...

Tensors are useful for 3 or more modes

Terminology: 'mode' (or 'aspect'):

Mode#3

Mode#2

network	search	graph	mining	...
13	11	22	55	...
5	4	6	7	...
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...

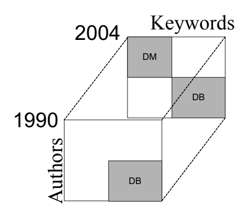
Mode (== aspect) #1

Motivating Applications

- Why tensors are useful?
  - P1: social networks
  - P2: web mining

P1: Social network analysis

- Monitoring networks and community structures over time



P2: Web graph mining

- How to order the importance of web pages?
  - Kleinberg's algorithm HITS
  - PageRank
  - Tensor extension on HITS (TOPHITS)
    - context-sensitive hypergraph analysis

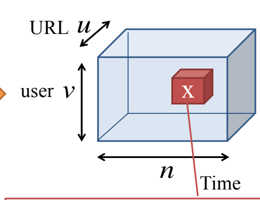
Tensor analysis for time-series data

- Time-stamped events
  - *e.g., web clicks*

Time	URL	User
08-01-12:00	CNN.com	Smith
08-02-15:00	YouTube.com	Brown
08-02-19:00	CNET.com	Smith
08-03-11:00	CNN.com	Johnson
…	…	…

Represent as M^{th} order tensor (M=3)

$\mathcal{X} \in \mathbb{N}^{u \times v \times n}$



Element x: # of events

e.g., 'Smith', 'CNN.com', 'Aug 1, 10pm'; 21 times

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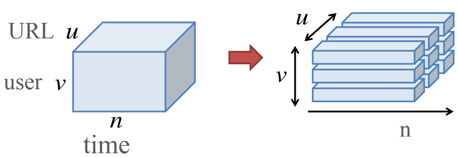
Tensor analysis for time-series data

- Individual-sequence mining
  - Create a set of (u * v) sequences of length (n)
  - Apply the mining algorithm for each sequence



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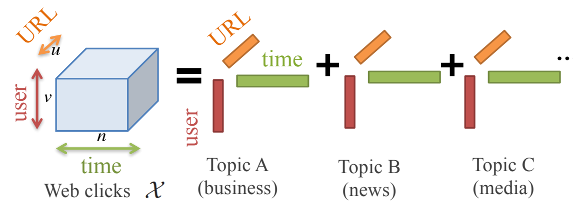
Tensor analysis for time-series data

- Multi-aspect time-series analysis



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Outline

- Tensor decomposition
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  - Basic approaches
- Mining and forecasting of complex time-stamped events
- New challenge: MANT analysis

Multi-Aspect Non-linear Time-series

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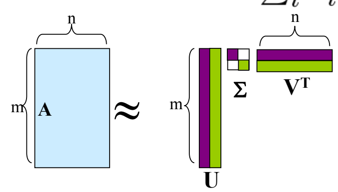
Reminder: SVD

$$\mathbf{A} \approx \mathbf{U\Sigma V}^T = \sum_i \sigma_i \mathbf{u}_i \circ \mathbf{v}_i$$



- Best rank-k approximation in L2

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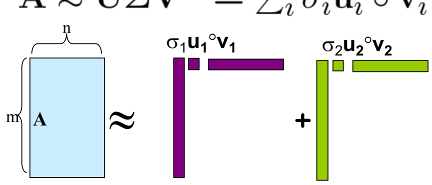
Reminder: SVD

$$\mathbf{A} \approx \mathbf{U\Sigma V}^T = \sum_i \sigma_i \mathbf{u}_i \circ \mathbf{v}_i$$



- Best rank-k approximation in L2

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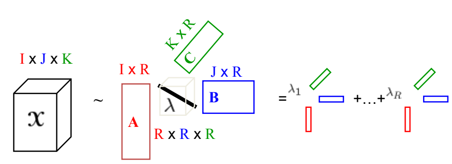
Goal: extension to >=3 modes



$$\mathcal{X} \approx [\![\lambda \, ; \mathbf{A}, \mathbf{B}, \mathbf{C}]\!] = \sum_r \lambda_r \, \mathbf{a}_r \circ \mathbf{b}_r \circ \mathbf{c}_r$$

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Main points:

- 2 major types of tensor decompositions: PARAFAC and Tucker
- both can be solved with ``alternating least squares'' (ALS)

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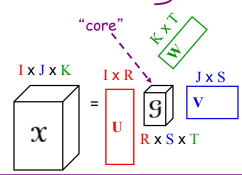
Specially Structured Tensors

- Tucker Tensor

$$\mathcal{X} = \mathcal{G} \times_1 \mathbf{U} \times_2 \mathbf{V} \times_3 \mathbf{W} = \sum_r \sum_s \sum_t g_{rst}\, \mathbf{u}_r \circ \mathbf{v}_s \circ \mathbf{w}_t \equiv [\![\mathcal{G}\,;\mathbf{U},\mathbf{V},\mathbf{W}]\!]$$

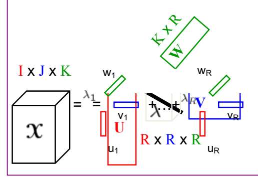
Our Notation



- Kruskal Tensor

$$\mathcal{X} = \sum_r \lambda_r\, \mathbf{u}_r \circ \mathbf{v}_r \circ \mathbf{w}_r \equiv [\![\lambda\,;\mathbf{U},\mathbf{V},\mathbf{W}]\!]$$

Our Notation



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Specially Structured Tensors

- Tucker Tensor

$$\mathcal{X} = \mathcal{G} \times_1 \mathbf{U} \times_2 \mathbf{V} \times_3 \mathbf{W} = \sum_r \sum_s \sum_t g_{rst}\, \mathbf{u}_r \circ \mathbf{v}_s \circ \mathbf{w}_t \equiv [\![\mathcal{G}\,;\mathbf{U},\mathbf{V},\mathbf{W}]\!]$$

In matrix form:

$$\mathbf{X}_{(1)} = \mathbf{U}\mathbf{G}_{(1)}(\mathbf{W}\otimes\mathbf{V})^{\mathsf{T}}$$
$$\mathbf{X}_{(2)} = \mathbf{V}\mathbf{G}_{(2)}(\mathbf{W}\otimes\mathbf{U})^{\mathsf{T}}$$
$$\mathbf{X}_{(3)} = \mathbf{W}\mathbf{G}_{(3)}(\mathbf{V}\otimes\mathbf{U})^{\mathsf{T}}$$

$$\mathrm{vec}(\mathcal{X}) = (\mathbf{W}\otimes\mathbf{V}\otimes\mathbf{U})\mathrm{vec}(\mathcal{G})$$

- Kruskal Tensor

$$\mathcal{X} = \sum_r \lambda_r\, \mathbf{u}_r \circ \mathbf{v}_r \circ \mathbf{w}_r \equiv [\![\lambda\,;\mathbf{U},\mathbf{V},\mathbf{W}]\!]$$

In matrix form:

Let $\Lambda = \mathrm{diag}(\lambda)$

$$\mathbf{X}_{(1)} = \mathbf{U}\,\Lambda\,(\mathbf{W}\odot\mathbf{V})^{\mathsf{T}}$$
$$\mathbf{X}_{(2)} = \mathbf{V}\,\Lambda\,(\mathbf{W}\odot\mathbf{U})^{\mathsf{T}}$$
$$\mathbf{X}_{(3)} = \mathbf{W}\,\Lambda\,(\mathbf{V}\odot\mathbf{U})^{\mathsf{T}}$$

$$\mathrm{vec}(\mathcal{X}) = (\mathbf{W}\odot\mathbf{V}\odot\mathbf{U})\,\lambda$$

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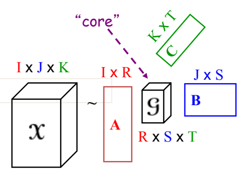
Tucker Decomposition - intuition



- author x keyword x conference
- A: author x author-group
- B: keyword x keyword-group
- C: conf. x conf-group
- $\mathcal{G}$: how groups relate to each other

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Intuition behind core tensor

- 2-d case: co-clustering
- [Dhillon et al. Information-Theoretic Co-clustering, KDD' 03]

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$$m \overset{n}{\begin{bmatrix} .05 & .05 & .05 & 0 & 0 & 0 \\ .05 & .05 & .05 & 0 & 0 & 0 \\ 0 & 0 & 0 & .05 & .05 & .05 \\ 0 & 0 & 0 & .05 & .05 & .05 \\ .04 & .04 & 0 & .04 & .04 & .04 \\ .04 & .04 & .04 & 0 & .04 & .04 \end{bmatrix}}$$

eg, terms x documents

$$m \overset{k}{\begin{bmatrix} .5 & 0 & 0 \\ .5 & 0 & 0 \\ 0 & .5 & 0 \\ 0 & .5 & 0 \\ 0 & 0 & .5 \\ 0 & 0 & .5 \end{bmatrix}} \; k \overset{l}{\begin{bmatrix} .3 & 0 \\ 0 & .3 \\ .2 & .2 \end{bmatrix}} \; l \overset{n}{\begin{bmatrix} .36 & .36 & .28 & 0 & 0 & 0 \\ 0 & 0 & 0 & .28 & .36 & .36 \end{bmatrix}} = \begin{bmatrix} .054 & .054 & .042 & 0 & 0 & 0 \\ .054 & .054 & .042 & 0 & 0 & 0 \\ 0 & 0 & 0 & .042 & .054 & .054 \\ 0 & 0 & 0 & .042 & .054 & .054 \\ .036 & .036 & 028 & .028 & .036 & .036 \\ .036 & .036 & .028 & .028 & .036 & .036 \end{bmatrix}$$

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med. doc — cs doc

$$\begin{bmatrix} .05 & .05 & .05 & 0 & 0 & 0 \\ .05 & .05 & .05 & 0 & 0 & 0 \\ 0 & 0 & 0 & .05 & .05 & .05 \\ 0 & 0 & 0 & .05 & .05 & .05 \\ .04 & .04 & 0 & .04 & .04 & .04 \\ .04 & .04 & .04 & 0 & .04 & .04 \end{bmatrix}$$

| med. terms

| cs terms

| common terms

term group x doc. group

$$\begin{bmatrix} .5 & 0 & 0 \\ .5 & 0 & 0 \\ 0 & .5 & 0 \\ 0 & .5 & 0 \\ 0 & 0 & .5 \\ 0 & 0 & .5 \end{bmatrix} \begin{bmatrix} .3 & 0 \\ 0 & .3 \\ .2 & .2 \end{bmatrix} \begin{bmatrix} .36 & .36 & .28 & 0 & 0 & 0 \\ 0 & 0 & 0 & .28 & .36 & .36 \end{bmatrix} = \begin{bmatrix} .054 & .054 & .042 & 0 & 0 & 0 \\ .054 & .054 & .042 & 0 & 0 & 0 \\ 0 & 0 & 0 & .042 & .054 & .054 \\ 0 & 0 & 0 & .042 & .054 & .054 \\ .036 & .036 & 028 & .028 & .036 & .036 \\ .036 & .036 & .028 & .028 & .036 & .036 \end{bmatrix}$$

doc x doc group

term x term-group

http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/ 31

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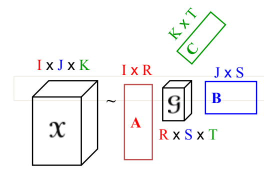
Tucker Decomposition



$$\mathcal{X} \approx [\![\mathcal{G} \,; \mathbf{A}, \mathbf{B}, \mathbf{C}]\!]$$

Given A, B, C, the optimal core is:

$$\mathcal{G} = [\![\mathcal{X} \,; \mathbf{A}^{\dagger}, \mathbf{B}^{\dagger}, \mathbf{C}^{\dagger}]\!]$$

- Proposed by Tucker (1966)
- AKA: Three-mode factor analysis, three-mode PCA, orthogonal array decomposition
- **A**, **B**, and **C** generally assumed to be orthonormal (generally assume they have full column rank)
- $\mathcal{G}$ is not diagonal
- Not unique

Recall the equations for converting a tensor to a matrix

$$\mathbf{X}_{(1)} = \mathbf{A}\mathbf{G}_{(1)}(\mathbf{C} \otimes \mathbf{B})^{\mathsf{T}}$$
$$\mathbf{X}_{(2)} = \mathbf{B}\mathbf{G}_{(2)}(\mathbf{C} \otimes \mathbf{A})^{\mathsf{T}}$$
$$\mathbf{X}_{(3)} = \mathbf{C}\mathbf{G}_{(3)}(\mathbf{B} \otimes \mathbf{A})^{\mathsf{T}}$$
$$\mathrm{vec}(\mathcal{X}) = (\mathbf{C} \otimes \mathbf{B} \otimes \mathbf{A})\mathrm{vec}(\mathcal{G})$$

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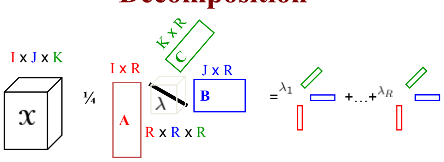
CANDECOMP/PARAFAC Decomposition



$$\mathcal{X} \approx [\![\lambda \,; \mathbf{A}, \mathbf{B}, \mathbf{C}]\!] = \sum_r \lambda_r \, \mathbf{a}_r \circ \mathbf{b}_r \circ \mathbf{c}_r$$

- CANDECOMP = Canonical Decomposition (Carroll & Chang, 1970)
- PARAFAC = Parallel Factors (Harshman, 1970)
- Core is diagonal (specified by the vector λ)
- Columns of **A**, **B**, and **C** are not orthonormal
- If R is *minimal*, then R is called the **rank** of the tensor (Kruskal 1977)
- Can have rank( ) > min{I,J,K}

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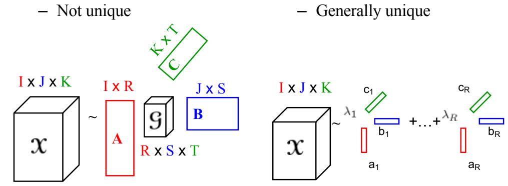
Tucker vs. PARAFAC Decompositions

- Tucker
  - Variable transformation in each mode
  - Core G may be dense
  - A, B, C generally orthonormal
  - Not unique
- PARAFAC
  - Sum of rank-1 components
  - No core, i.e., superdiagonal core
  - A, B, C may have linearly dependent columns
  - Generally unique



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Tensor tools - summary

- Two main tools
  - PARAFAC
  - Tucker
- Both find row-, column-, tube-groups
  - but in PARAFAC the three groups are identical
- To solve: Alternating Least Squares

- Toolbox: from Tamara Kolda:

http://csmr.ca.sandia.gov/~tgkolda/TensorToolbox/

http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/ 35

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Multi-Aspect Non-linear Time-series

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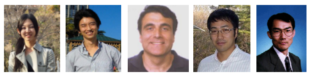


[Matsubara+ KDD'12]

Fast Mining and Forecasting of Complex Time-Stamped Events

Yasuko Matsubara (Kyoto University)
Yasushi Sakurai (NTT)
Christos Faloutsos (CMU)
Tomoharu Iwata (NTT)
Masatoshi Yoshikawa (Kyoto University)

Motivation

- Complex time-stamped events
  {timestamp + multiple attributes}

e.g., web click events:
{timestamp, URL, user ID, access devices, http referrer, …}

Timestamp	URL	User	Device
2012-08-01-12:00	CNN.com	Smith	iphone
2012-08-02-15:00	YouTube.com	Brown	iphone
2012-08-02-19:00	CNET.com	Smith	mac
2012-08-03-11:00	CNN.com	Johnson	ipad
…	…	…	…

Motivation

Q1. Are there any topics ?
- news, tech, media, sports, etc...

Timestamp	URL	User	Device
2012-08-01-12:00	CNN.com	Smith	iphone
2012-08-02-15:00	YouTube.com	Brown	iphone
2012-08-02-19:00	CNET.com	Smith	mac
2012-08-03-11:00	CNN.com	Johnson	ipad
…	…	…	…

e.g.,
CNN.com, CNET.com -> news topic
YouTube.com -> media topic

Motivation

Q2. Can we group URLs/users accordingly?

Timestamp	URL	User	Device
2012-08-01-12:00	CNN.com	Smith	iphone
2012-08-02-15:00	YouTube.com	Brown	iphone
2012-08-02-19:00	CNET.com	Smith	mac
2012-08-03-11:00	CNN.com	Johnson	ipad
…	…	…	…

e.g.,
CNN.com & CNET.com (related to news topic)
Smith & Johnson (related to news topic)

Motivation

Q3. Can we forecast future events?
- How many clicks from 'Smith' tomorrow?
- How many clicks to 'CNN.com' over next 7 days?

Timestamp	URL	User	Device
2012-08-01-12:00	CNN.com	Smith	iphone
2012-08-02-15:00	YouTube.com	Brown	iphone
2012-08-02-19:00	CNET.com	Smith	mac
2012-08-03-11:00	CNN.com	Johnson	ipad
2012-08-05-12:00	CNN.com	Smith	iphone
2012-08-05-19:00	CNET.com	Smith	iphone

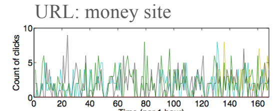
future clicks?

Motivation

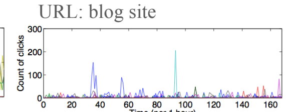
Web click events – can we see any trends?

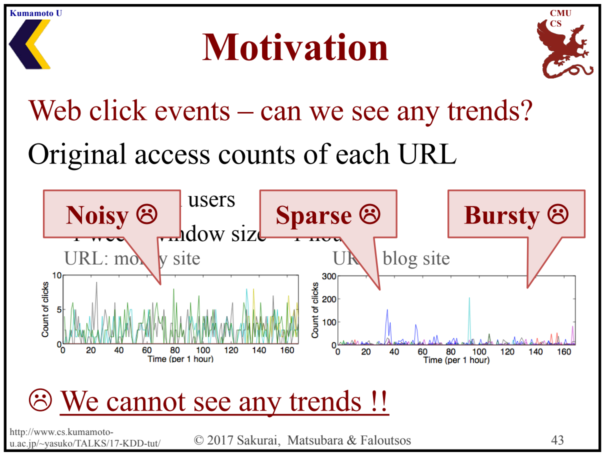
Original access counts of each URL
- 100 random users
- 1 week (window size = 1 hour)

URL: money site



URL: blog site

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Motivation
Web click events – can we see any trends?
Original access counts of each URL
Noisy ☹
Sparse ☹
Bursty ☹
users
URL: blog site
Count of clicks
Time (per 1 hour)
☹ We cannot see any trends !!
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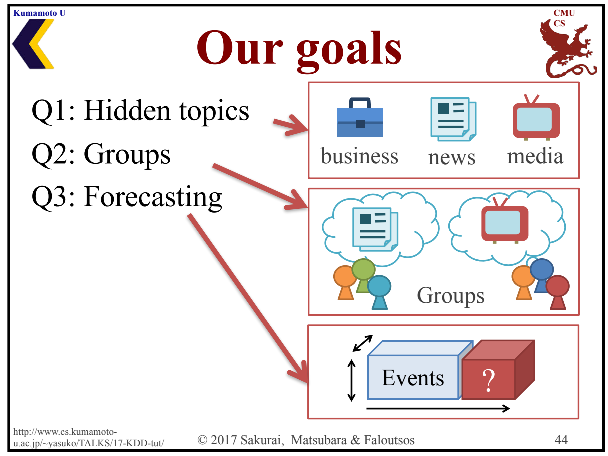
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Our goals
Q1: Hidden topics
Q2: Groups
Q3: Forecasting
business
news
media
Groups
Events
?
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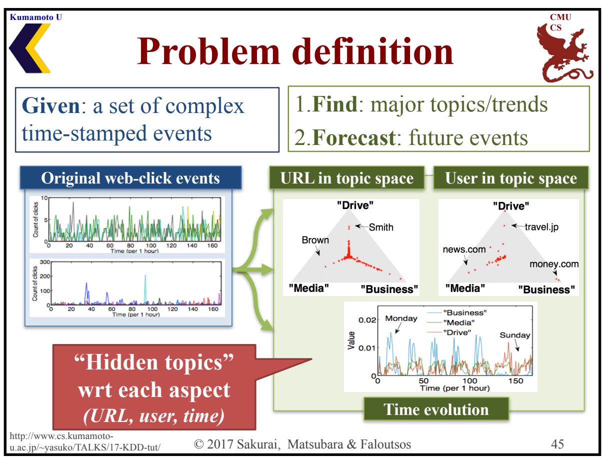
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Problem definition
Given: a set of complex time-stamped events
1.Find: major topics/trends
2.Forecast: future events
Original web-click events
URL in topic space
User in topic space
"Drive"
Smith
Brown
"Media"
"Business"
travel.jp
news.com
money.com
Monday
Sunday
Time (per 1 hour)
Time evolution
"Hidden topics" wrt each aspect (URL, user, time)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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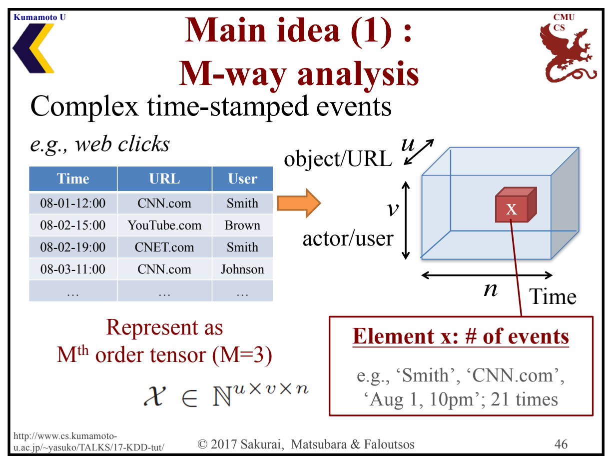
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Main idea (1) : M-way analysis
Complex time-stamped events
e.g., web clicks
Time | URL | User
08-01-12:00 | CNN.com | Smith
08-02-15:00 | YouTube.com | Brown
08-02-19:00 | CNET.com | Smith
08-03-11:00 | CNN.com | Johnson
… | … | …
object/URL
actor/user
Time
Represent as
M[th] order tensor (M=3)
$\mathcal{X} \in \mathbb{N}^{u \times v \times n}$
Element x: # of events
e.g., 'Smith', 'CNN.com', 'Aug 1, 10pm'; 21 times
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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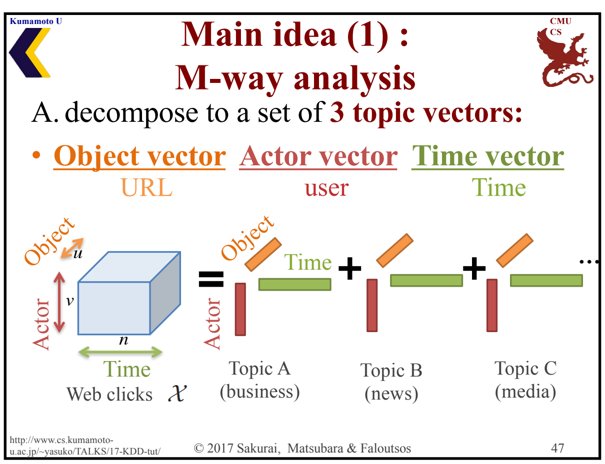
Kumamoto U
CMU CS
Main idea (1) : M-way analysis
A. decompose to a set of 3 topic vectors:
• Object vector Actor vector Time vector
URL user Time
Object
Actor
Time
Web clicks $\mathcal{X}$
Topic A (business)
Topic B (news)
Topic C (media)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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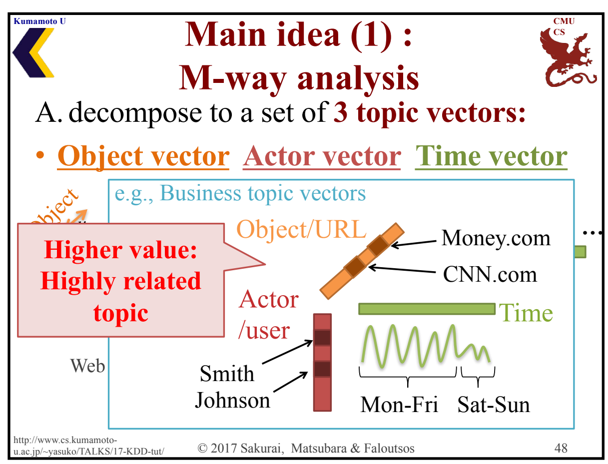
Kumamoto U
CMU CS
Main idea (1) : M-way analysis
A. decompose to a set of 3 topic vectors:
• Object vector Actor vector Time vector
e.g., Business topic vectors
Higher value: Highly related topic
Object/URL
Money.com
CNN.com
Actor /user
Time
Web
Smith
Johnson
Mon-Fri
Sat-Sun
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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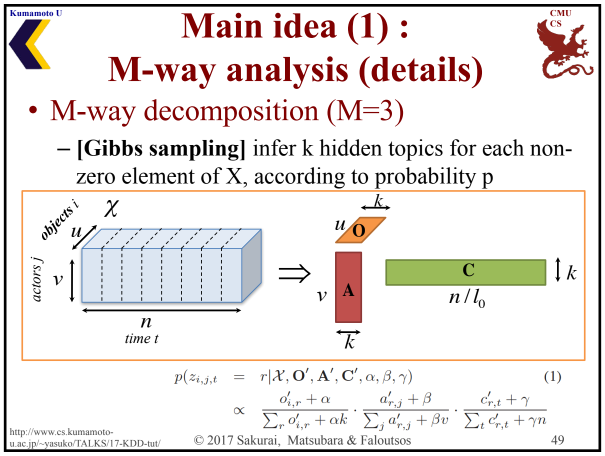
Kumamoto U
CMU CS
Main idea (1) :
M-way analysis (details)
• M-way decomposition (M=3)
– [Gibbs sampling] infer k hidden topics for each non-zero element of X, according to probability p
objects i
actors j
time t
$\mathcal{X}$
u
v
n
O
A
C
k
n/l_0
$p(z_{i,j,t} = r | \mathcal{X}, \mathbf{O}', \mathbf{A}', \mathbf{C}', \alpha, \beta, \gamma)$ (1)
$\propto \frac{o'_{i,r}+\alpha}{\sum_r o'_{i,r}+\alpha k} \cdot \frac{a'_{r,j}+\beta}{\sum_j a'_{r,j}+\beta v} \cdot \frac{c'_{r,t}+\gamma}{\sum_t c'_{r,t}+\gamma n}$
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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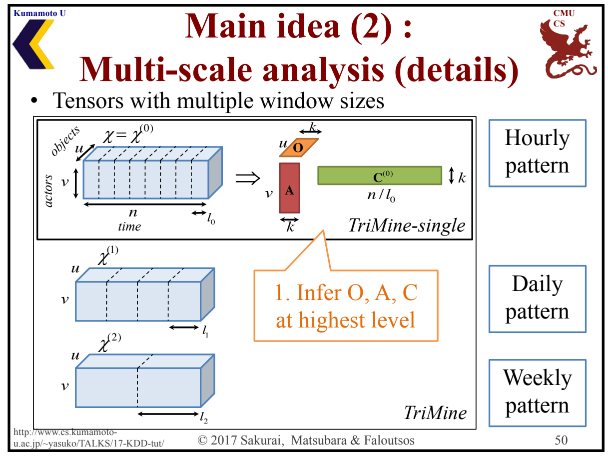
Kumamoto U
CMU CS
Main idea (2) :
Multi-scale analysis (details)
• Tensors with multiple window sizes
$\mathcal{X} = \mathcal{X}^{(0)}$
objects
actors
time
$\mathcal{X}^{(1)}$
$\mathcal{X}^{(2)}$
$C^{(0)}$
n/l_0
TriMine-single
1. Infer O, A, C at highest level
TriMine
Hourly pattern
Daily pattern
Weekly pattern
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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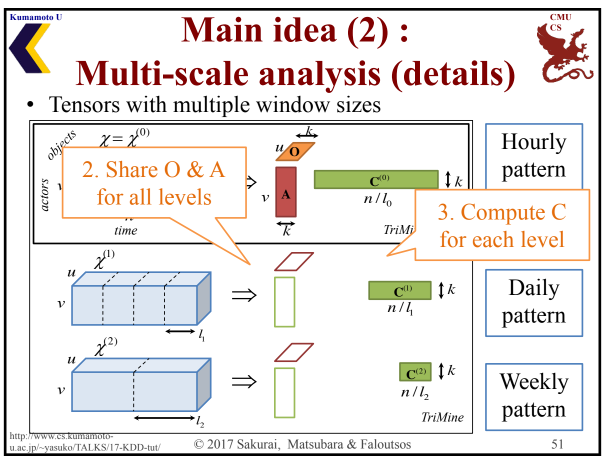
Kumamoto U
CMU CS
Main idea (2) :
Multi-scale analysis (details)
• Tensors with multiple window sizes
$\mathcal{X} = \mathcal{X}^{(0)}$
2. Share O & A for all levels
3. Compute C for each level
$C^{(0)}$
n/l_0
$C^{(1)}$
n/l_1
$C^{(2)}$
n/l_2
TriMine
Hourly pattern
Daily pattern
Weekly pattern
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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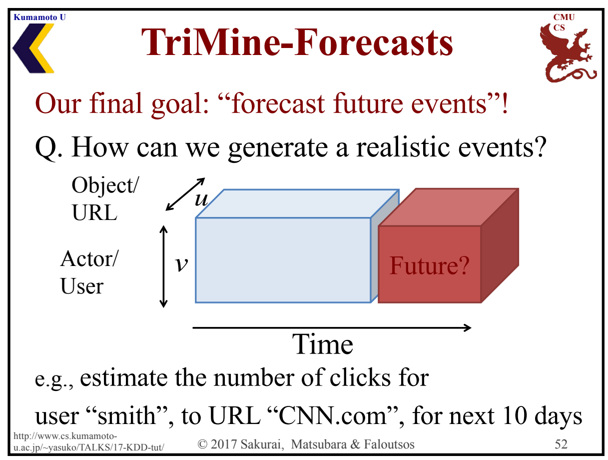
Kumamoto U
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TriMine-Forecasts
Our final goal: "forecast future events"!
Q. How can we generate a realistic events?
Object/ URL
Actor/ User
u
v
Future?
Time
e.g., estimate the number of clicks for user "smith", to URL "CNN.com", for next 10 days
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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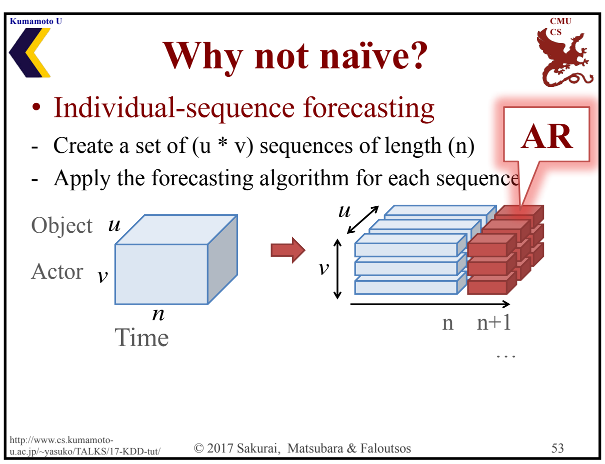
Kumamoto U
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Why not naïve?
• Individual-sequence forecasting
- Create a set of (u * v) sequences of length (n)
- Apply the forecasting algorithm for each sequence
AR
Object u
Actor v
n
Time
n n+1
…
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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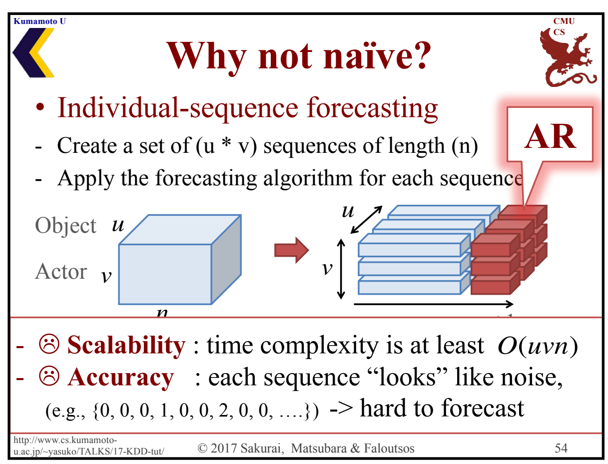
Kumamoto U
CMU CS
Why not naïve?
• Individual-sequence forecasting
- Create a set of (u * v) sequences of length (n)
- Apply the forecasting algorithm for each sequence
AR
Object u
Actor v
- ☹ Scalability : time complexity is at least $O(uvn)$
- ☹ Accuracy : each sequence "looks" like noise,
(e.g., {0, 0, 0, 1, 0, 0, 2, 0, 0, ….}) -> hard to forecast
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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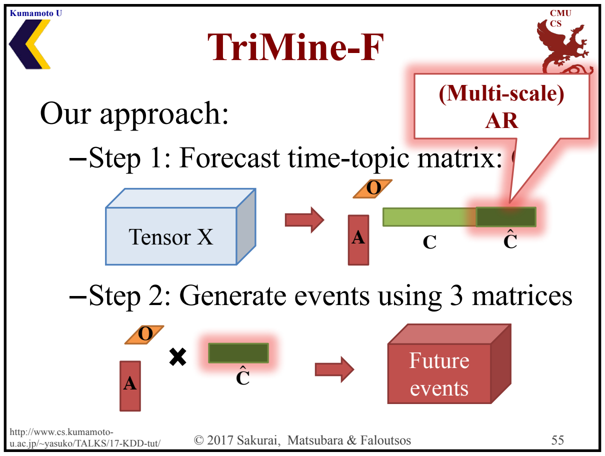

Kumamoto U
CMU CS
TriMine-F
Our approach:
–Step 1: Forecast time-topic matrix:
(Multi-scale) AR
Tensor X
O
A
C
Ĉ
–Step 2: Generate events using 3 matrices
O
A
Ĉ
Future events
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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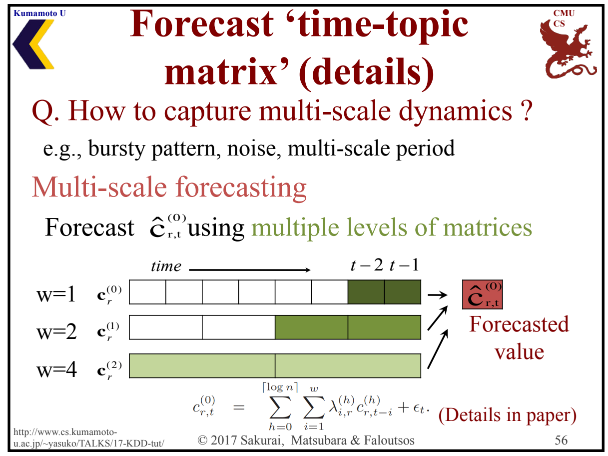

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Forecast 'time-topic matrix' (details)
Q. How to capture multi-scale dynamics ?
e.g., bursty pattern, noise, multi-scale period
Multi-scale forecasting
Forecast $\hat{c}^{(0)}_{r,t}$ using multiple levels of matrices
time
$t-2$ $t-1$
w=1 $c^{(0)}_r$
w=2 $c^{(1)}_r$
w=4 $c^{(2)}_r$
$\hat{c}^{(0)}_{r,t}$
Forecasted value
$c^{(0)}_{r,t} = \sum_{h=0}^{\lceil \log n \rceil} \sum_{i=1}^{w} \lambda^{(h)}_{i,r} c^{(h)}_{r,t-i} + \epsilon_t.$
(Details in paper)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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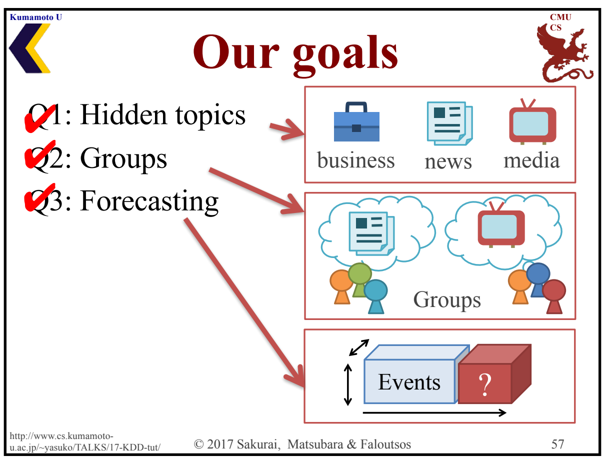

Kumamoto U
CMU CS
Our goals
Q1: Hidden topics
Q2: Groups
Q3: Forecasting
business
news
media
Groups
Events
?
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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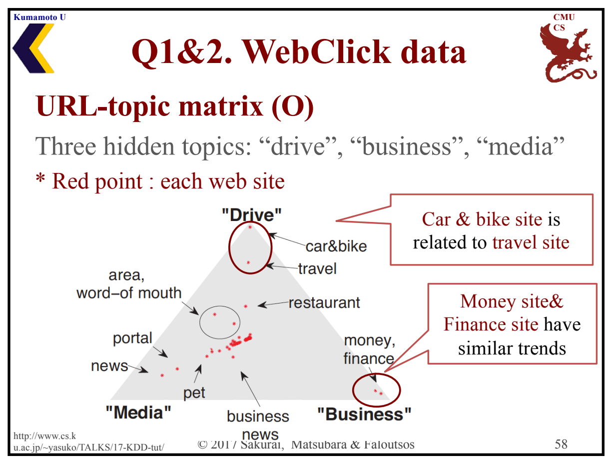

Kumamoto U
CMU CS
Q1&2. WebClick data
URL-topic matrix (O)
Three hidden topics: "drive", "business", "media"
* Red point : each web site
"Drive"
car&bike
travel
Car & bike site is related to travel site
area, word–of mouth
restaurant
portal
money, finance
Money site& Finance site have similar trends
news
pet
"Media"
business news
"Business"
http://www.cs.k u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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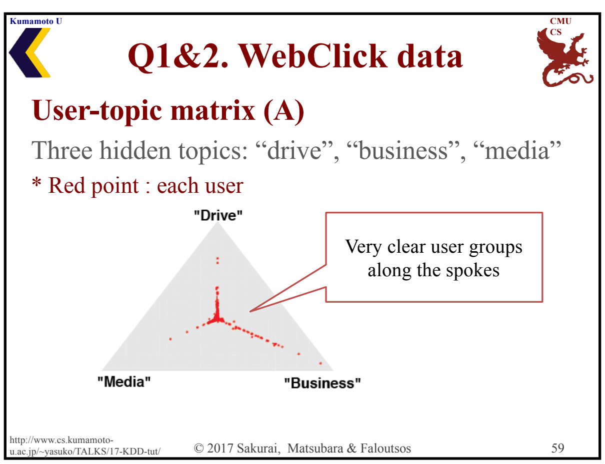

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Q1&2. WebClick data
User-topic matrix (A)
Three hidden topics: "drive", "business", "media"
* Red point : each user
"Drive"
Very clear user groups along the spokes
"Media"
"Business"
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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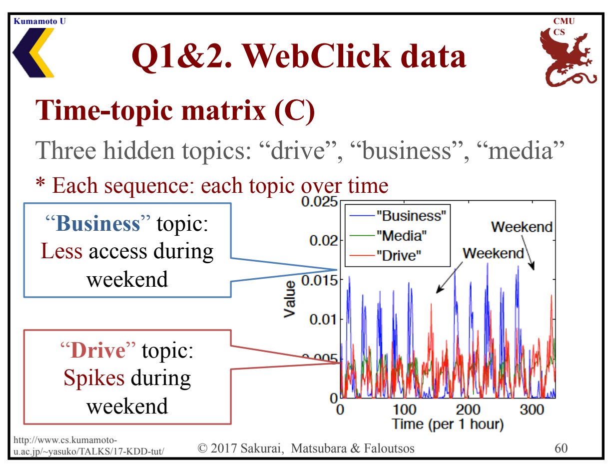

Kumamoto U
CMU CS
Q1&2. WebClick data
Time-topic matrix (C)
Three hidden topics: "drive", "business", "media"
* Each sequence: each topic over time
"Business" topic: Less access during weekend
"Drive" topic: Spikes during weekend
"Business"
"Media"
"Drive"
Weekend
Weekend
Value
0.025
0.02
0.015
0.01
0.005
0
0
100
200
300
Time (per 1 hour)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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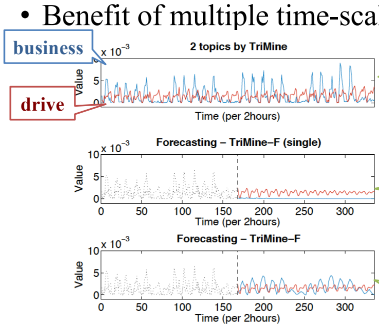
Q3. Forecasting accuracy

- Benefit of multiple time-scale forecasting



Original sequence of matrix (C)

Forecast C' using single level -> failed

Multi-scale forecast -> captured cyclic patterns

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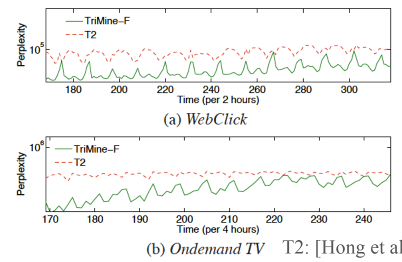
Q3. Forecasting accuracy

Temporal perplexity (entropy for each time-tick)

Lower perplexity: higher predictive accuracy



T2: [Hong et al. KDD'11]

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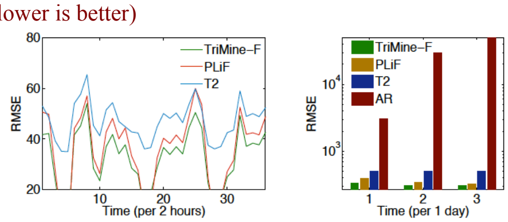
Q3. Forecasting accuracy

Accuracy of event forecasting

RMSE between original and forecasted events (lower is better)



PLiF [Li et al.VLDB'10] , T2: [Hong et al.KDD'11]

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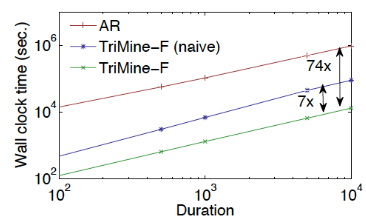
Q3. Scalability

- Computation cost (vs. AR)



- **TriMine** provides a reduction in computation time (up to 74x)

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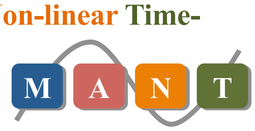
Outline

- Tensor decomposition
- Mining and forecasting of complex time-stamped events
- New challenge: MANT analysis

Multi-Aspect Non-linear Time-series



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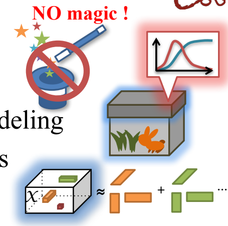
Non-linear tensor analysis

New research directions

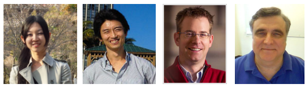
1. Automatic mining
2. Non-linear (gray-box) modeling
3. Large-scale tensor analysis



Put all together

New challenge: MANT analysis

Multi-Aspect Non-linear Time-series



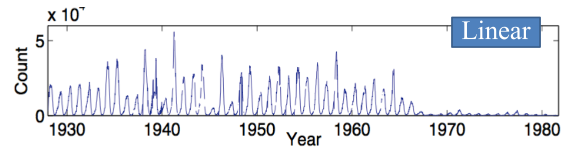
[Matsubara+ KDD'14]

FUNNEL: Automatic Mining of Spatially Coevolving Epidemics

Yasuko Matsubara, Yasushi Sakurai (Kumamoto University)
Willem G. van Panhuis (University of Pittsburgh)
Christos Faloutsos (CMU)

Motivation

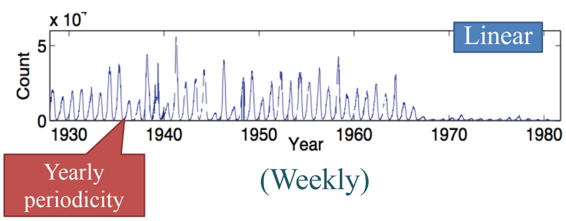
Given: Large set of epidemiological data
e.g., Measles cases in the U.S.



(Weekly)

Motivation

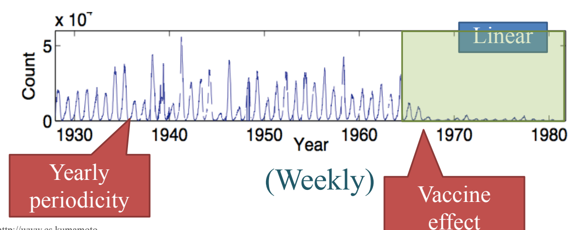
Given: Large set of epidemiological data
e.g., Measles cases in the U.S.



(Weekly)

Motivation

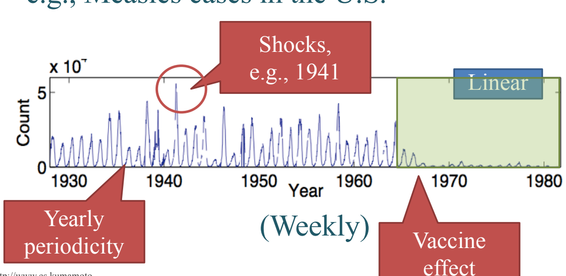
Given: Large set of epidemiological data
e.g., Measles cases in the U.S.



(Weekly)

Motivation

Given: Large set of epidemiological data
e.g., Measles cases in the U.S.

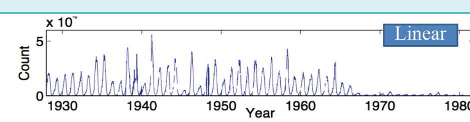


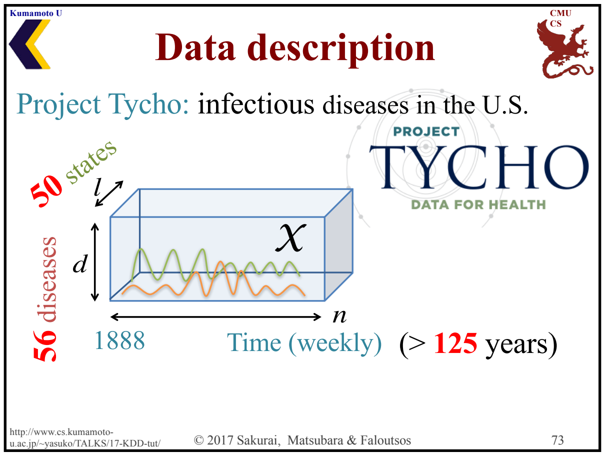
(Weekly)

Motivation

Given: Large set of epidemiological data
e.g., Measles cases in the U.S.

Goal: summarize all the epidemic time-series, **"fully-automatically"**




Kumamoto U
CMU CS
Data description
Project Tycho: infectious diseases in the U.S.
PROJECT TYCHO DATA FOR HEALTH
50 states
56 diseases
d
l
n
X
1888
Time (weekly)
(> 125 years)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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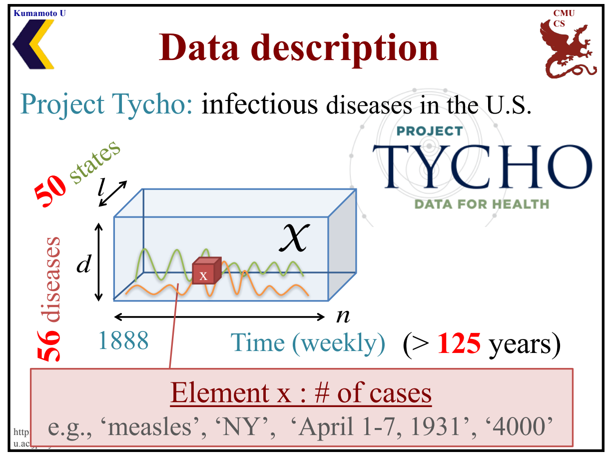
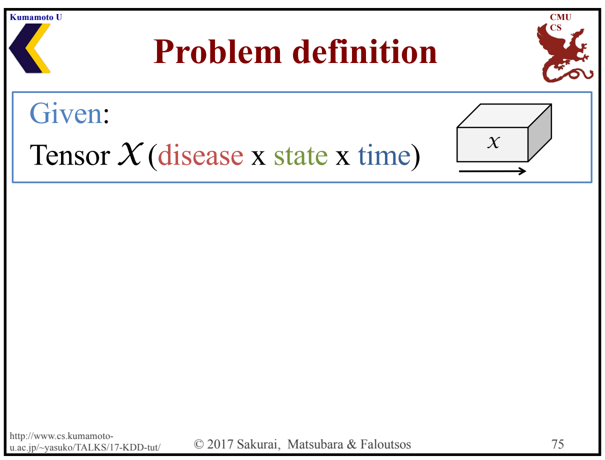

Kumamoto U
CMU CS
Data description
Project Tycho: infectious diseases in the U.S.
PROJECT TYCHO DATA FOR HEALTH
50 states
56 diseases
d
l
n
X
x
1888
Time (weekly)
(> 125 years)
Element x : # of cases
e.g., 'measles', 'NY', 'April 1-7, 1931', '4000'


Kumamoto U
CMU CS
Problem definition
Given:
Tensor X (disease x state x time)
x
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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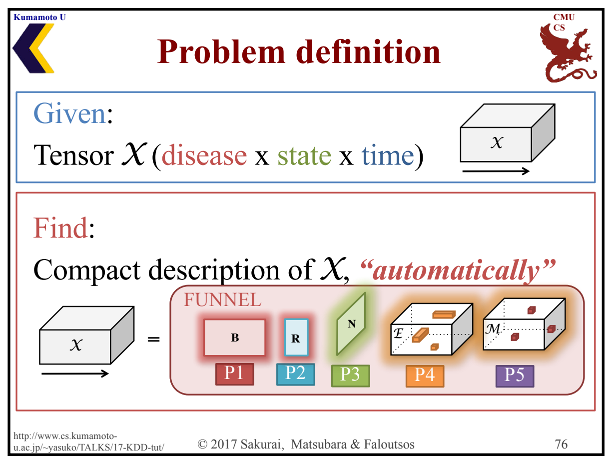
Kumamoto U
CMU CS
Problem definition
Given:
Tensor X (disease x state x time)
x
Find:
Compact description of X, "automatically"
FUNNEL
x =
B R N E M
P1 P2 P3 P4 P5
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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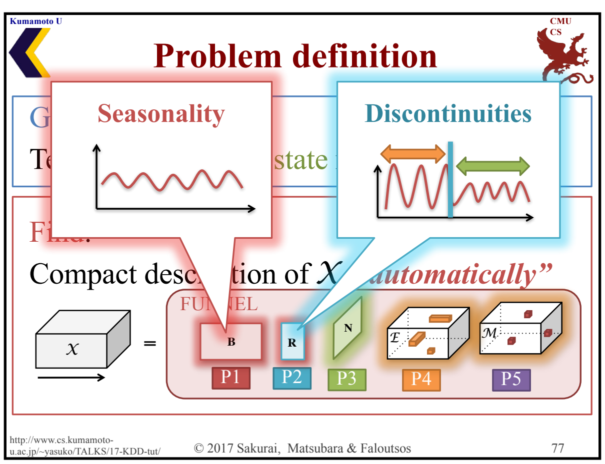
Kumamoto U
CMU CS
Problem definition
Seasonality
Discontinuities
Compact desc tion of X "automatically"
FUNNEL
x =
B R N E M
P1 P2 P3 P4 P5
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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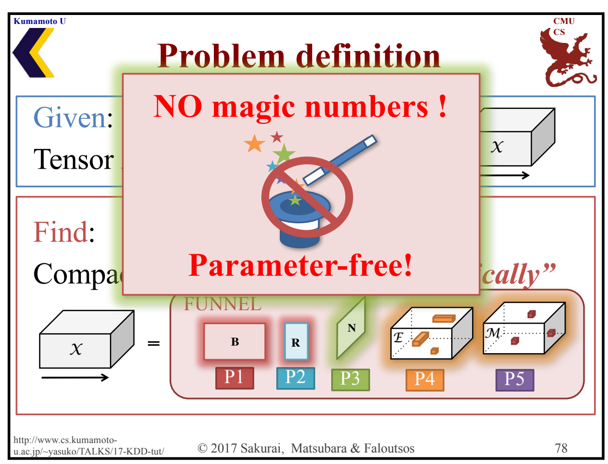
Kumamoto U
CMU CS
Problem definition
Given:
Tensor
NO magic numbers !
Parameter-free!
Find:
FUNNEL
x =
B R N E M
P1 P2 P3 P4 P5
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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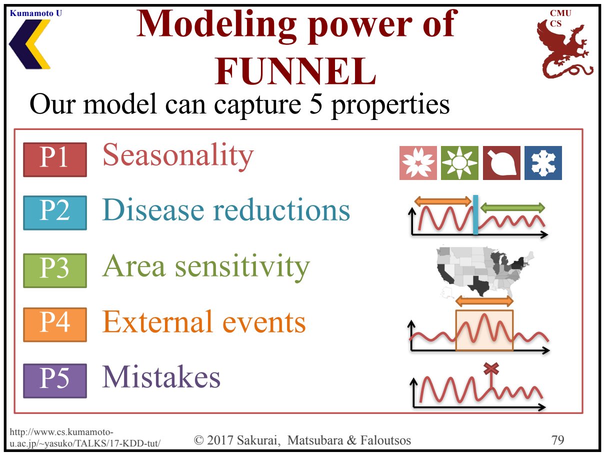
Kumamoto U
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Modeling power of FUNNEL
Our model can capture 5 properties
P1 Seasonality
P2 Disease reductions
P3 Area sensitivity
P4 External events
P5 Mistakes
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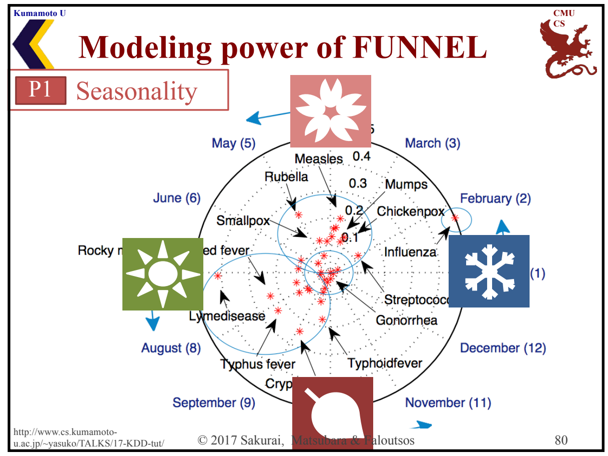
Kumamoto U
CMU CS
Modeling power of FUNNEL
P1 Seasonality
May (5)
March (3)
June (6)
February (2)
August (8)
December (12)
September (9)
November (11)
Measles
Rubella
Mumps
Chickenpox
Smallpox
Influenza
Lymedisease
Streptococc
Gonorrhea
Typhus fever
Typhoidfever
0.4
0.3
0.2
0.1
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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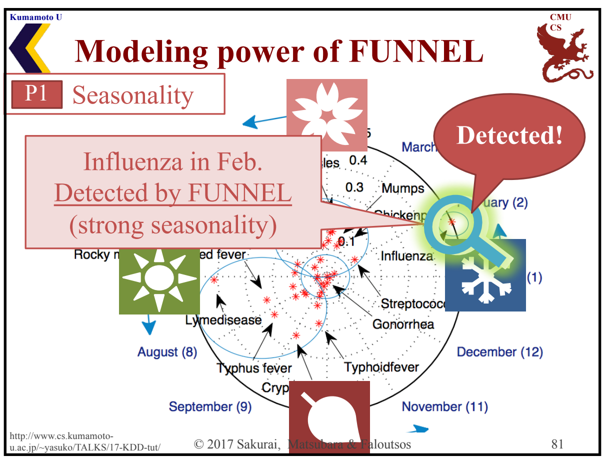
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CMU CS
Modeling power of FUNNEL
P1 Seasonality
Influenza in Feb.
Detected by FUNNEL
(strong seasonality)
Detected!
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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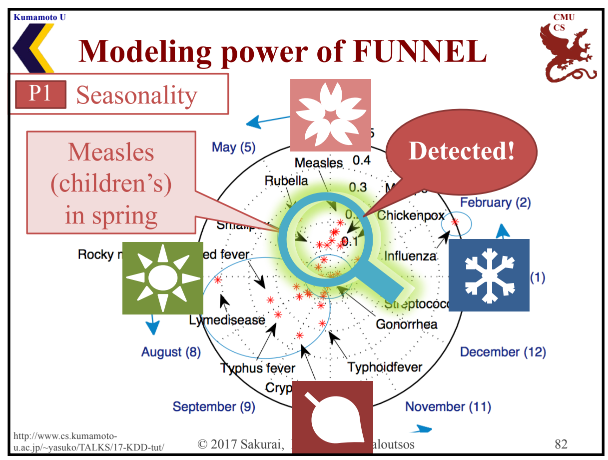
Kumamoto U
CMU CS
Modeling power of FUNNEL
P1 Seasonality
Measles
(children's)
in spring
Detected!
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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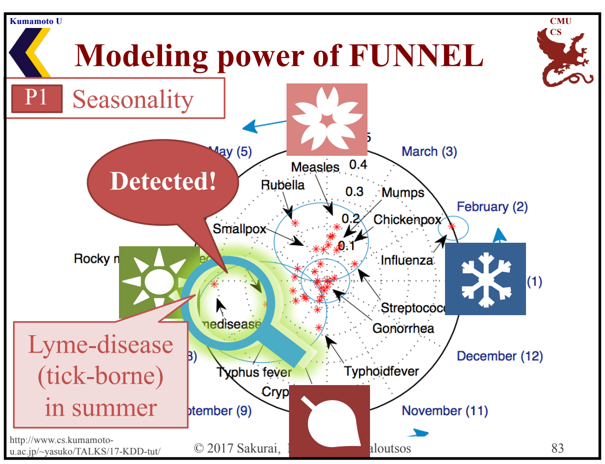
Kumamoto U
CMU CS
Modeling power of FUNNEL
P1 Seasonality
Detected!
Lyme-disease
(tick-borne)
in summer
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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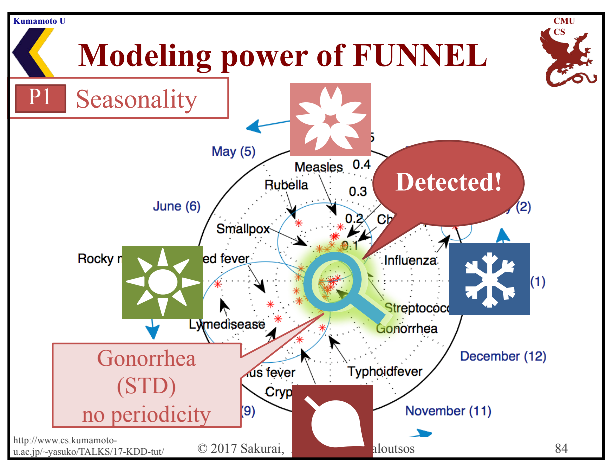
Kumamoto U
CMU CS
Modeling power of FUNNEL
P1 Seasonality
Detected!
Gonorrhea
(STD)
no periodicity
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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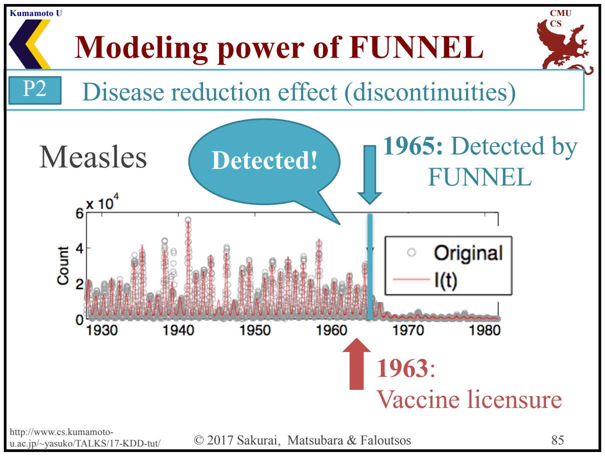
Kumamoto U
CMU CS
Modeling power of FUNNEL
P2 Disease reduction effect (discontinuities)
Measles
Detected!
1965: Detected by FUNNEL
x 10^4
Count
Original
I(t)
1963: Vaccine licensure
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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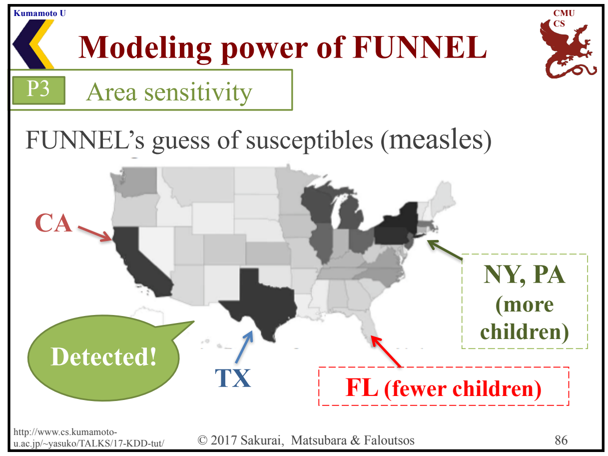
Kumamoto U
CMU CS
Modeling power of FUNNEL
P3 Area sensitivity
FUNNEL's guess of susceptibles (measles)
CA
NY, PA (more children)
Detected!
TX
FL (fewer children)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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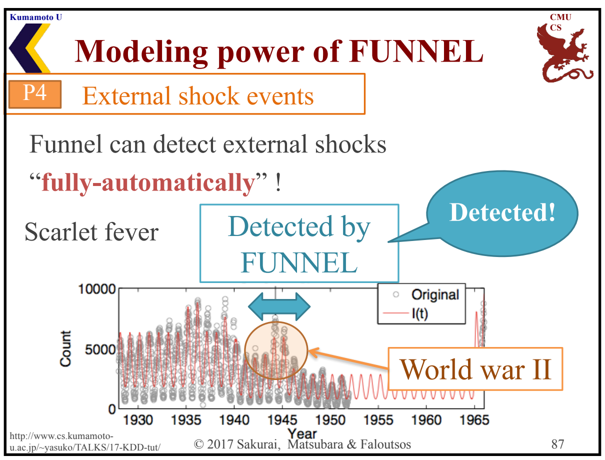
Kumamoto U
CMU CS
Modeling power of FUNNEL
P4 External shock events
Funnel can detect external shocks "fully-automatically" !
Scarlet fever
Detected by FUNNEL
Detected!
Original
I(t)
Count
World war II
Year
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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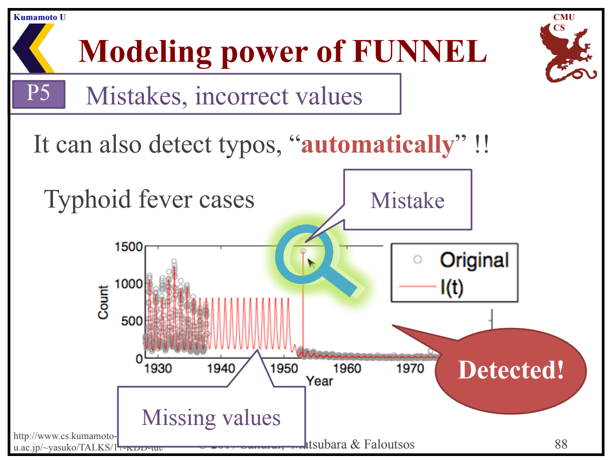
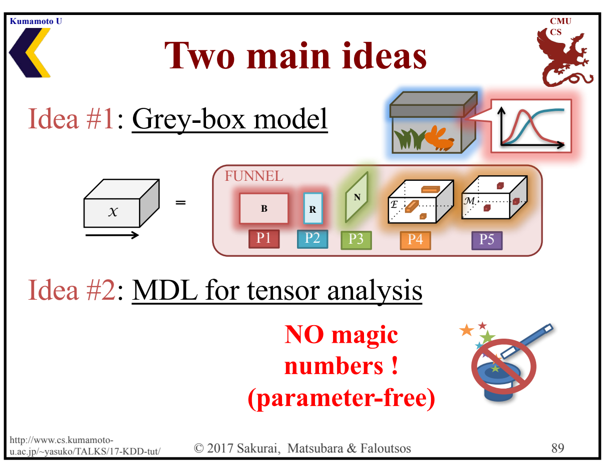

Kumamoto U
CMU CS
Modeling power of FUNNEL
P5 Mistakes, incorrect values
It can also detect typos, "automatically" !!
Typhoid fever cases
Mistake
Original
I(t)
Count
Year
Detected!
Missing values
88


Kumamoto U
CMU CS
Two main ideas
Idea #1: Grey-box model
FUNNEL
P1 P2 P3 P4 P5
Idea #2: MDL for tensor analysis
NO magic numbers ! (parameter-free)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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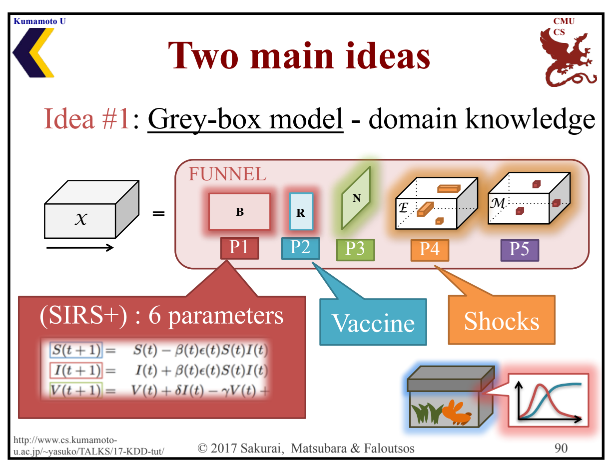
Kumamoto U
CMU CS
Two main ideas
Idea #1: Grey-box model - domain knowledge
FUNNEL
P1 P2 P3 P4 P5
(SIRS+) : 6 parameters
Vaccine
Shocks
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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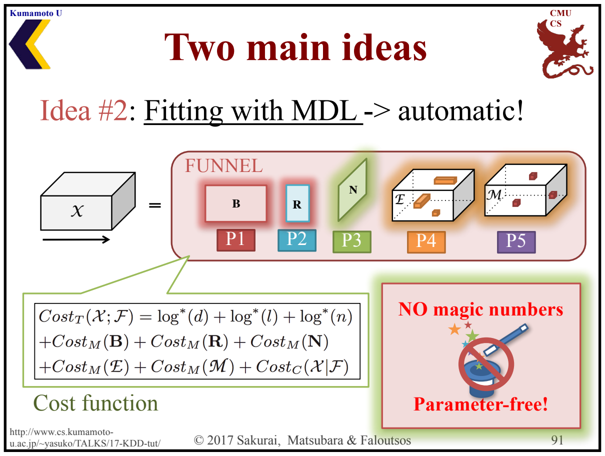
Kumamoto U
CMU CS
Two main ideas
Idea #2: Fitting with MDL -> automatic!
FUNNEL
B R N
P1 P2 P3 P4 P5
$Cost_T(\mathcal{X};\mathcal{F}) = \log^*(d) + \log^*(l) + \log^*(n)$
$+Cost_M(\mathbf{B}) + Cost_M(\mathbf{R}) + Cost_M(\mathbf{N})$
$+Cost_M(\mathcal{E}) + Cost_M(\mathcal{M}) + Cost_C(\mathcal{X}|\mathcal{F})$
Cost function
NO magic numbers
Parameter-free!
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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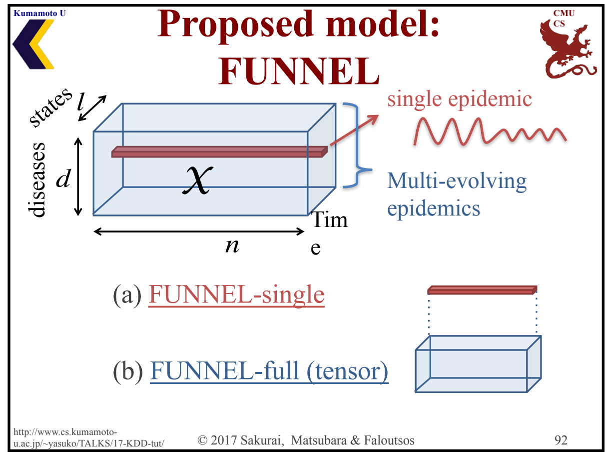
Kumamoto U
CMU CS
Proposed model: FUNNEL
states l
diseases d
n
Time
single epidemic
Multi-evolving epidemics
(a) FUNNEL-single
(b) FUNNEL-full (tensor)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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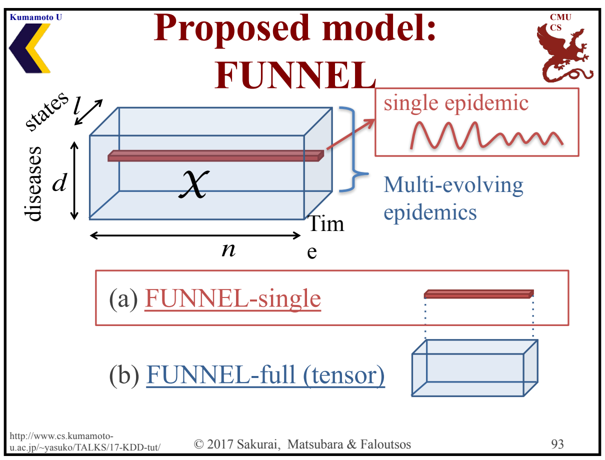
Kumamoto U
CMU CS
Proposed model: FUNNEL
states l
diseases d
n
Time
single epidemic
Multi-evolving epidemics
(a) FUNNEL-single
(b) FUNNEL-full (tensor)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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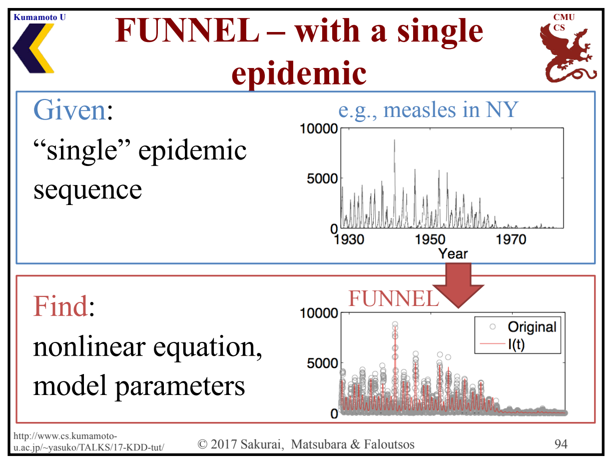
Kumamoto U
CMU CS
FUNNEL – with a single epidemic
Given:
"single" epidemic sequence
e.g., measles in NY
10000
5000
0
1930 1950 1970
Year
Find:
nonlinear equation, model parameters
FUNNEL
Original
I(t)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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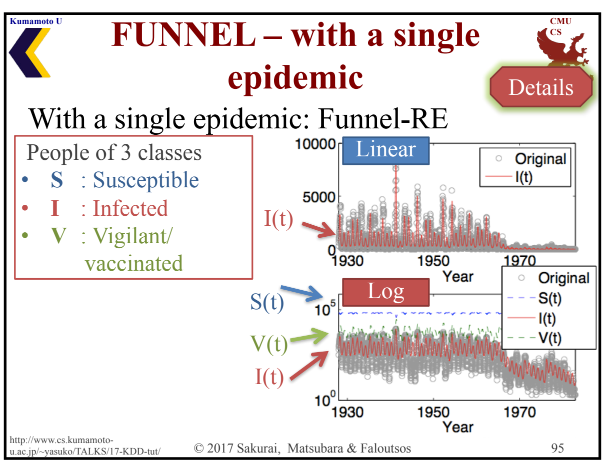
Kumamoto U
CMU CS
FUNNEL – with a single epidemic
Details
With a single epidemic: Funnel-RE
People of 3 classes
• S : Susceptible
• I : Infected
• V : Vigilant/ vaccinated
Linear
Original
I(t)
10000
5000
0
1930 1950 1970
Year
Log
S(t)
V(t)
I(t)
Original
S(t)
I(t)
V(t)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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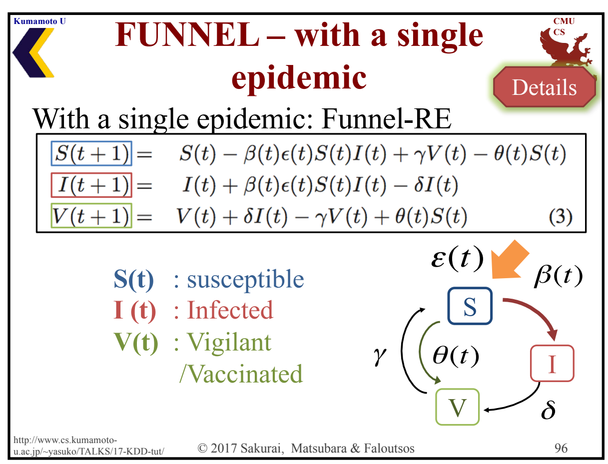
Kumamoto U
CMU CS
FUNNEL – with a single epidemic
Details
With a single epidemic: Funnel-RE
$\boxed{S(t+1)} = S(t) - \beta(t)\epsilon(t)S(t)I(t) + \gamma V(t) - \theta(t)S(t)$
$\boxed{I(t+1)} = I(t) + \beta(t)\epsilon(t)S(t)I(t) - \delta I(t)$
$\boxed{V(t+1)} = V(t) + \delta I(t) - \gamma V(t) + \theta(t)S(t)$ (3)
S(t) : susceptible
I (t) : Infected
V(t) : Vigilant /Vaccinated
$\varepsilon(t)$
$\beta(t)$
S
I
V
γ
$\theta(t)$
δ
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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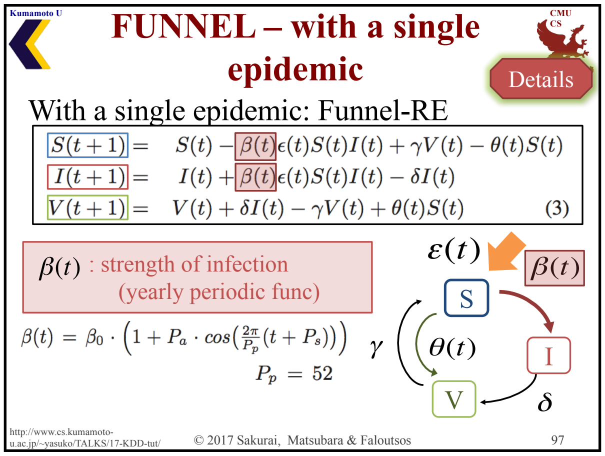
Kumamoto U
FUNNEL – with a single epidemic
CMU CS
Details
With a single epidemic: Funnel-RE
$S(t+1) = S(t) - \beta(t)\epsilon(t)S(t)I(t) + \gamma V(t) - \theta(t)S(t)$
$I(t+1) = I(t) + \beta(t)\epsilon(t)S(t)I(t) - \delta I(t)$
$V(t+1) = V(t) + \delta I(t) - \gamma V(t) + \theta(t)S(t)$ (3)
$\beta(t)$: strength of infection (yearly periodic func)
$\beta(t) = \beta_0 \cdot \left(1 + P_a \cdot cos\left(\frac{2\pi}{P_p}(t + P_s)\right)\right)$
$P_p = 52$
$\varepsilon(t)$
$\beta(t)$
S
I
V
γ
$\theta(t)$
δ
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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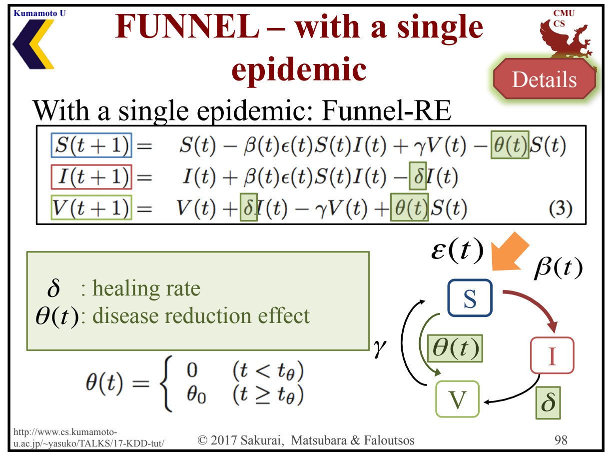
Kumamoto U
FUNNEL – with a single epidemic
CMU CS
Details
With a single epidemic: Funnel-RE
$S(t+1) = S(t) - \beta(t)\epsilon(t)S(t)I(t) + \gamma V(t) - \theta(t)S(t)$
$I(t+1) = I(t) + \beta(t)\epsilon(t)S(t)I(t) - \delta I(t)$
$V(t+1) = V(t) + \delta I(t) - \gamma V(t) + \theta(t)S(t)$ (3)
δ : healing rate
$\theta(t)$: disease reduction effect
$\theta(t) = \begin{cases} 0 & (t < t_\theta) \\ \theta_0 & (t \geq t_\theta) \end{cases}$
$\varepsilon(t)$
$\beta(t)$
S
I
V
γ
$\theta(t)$
δ
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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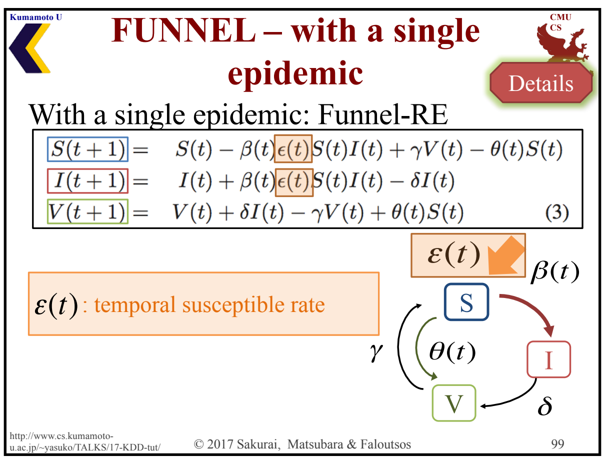
Kumamoto U
FUNNEL – with a single epidemic
CMU CS
Details
With a single epidemic: Funnel-RE
$S(t+1) = S(t) - \beta(t)\epsilon(t)S(t)I(t) + \gamma V(t) - \theta(t)S(t)$
$I(t+1) = I(t) + \beta(t)\epsilon(t)S(t)I(t) - \delta I(t)$
$V(t+1) = V(t) + \delta I(t) - \gamma V(t) + \theta(t)S(t)$ (3)
$\varepsilon(t)$: temporal susceptible rate
$\varepsilon(t)$
$\beta(t)$
S
I
V
γ
$\theta(t)$
δ
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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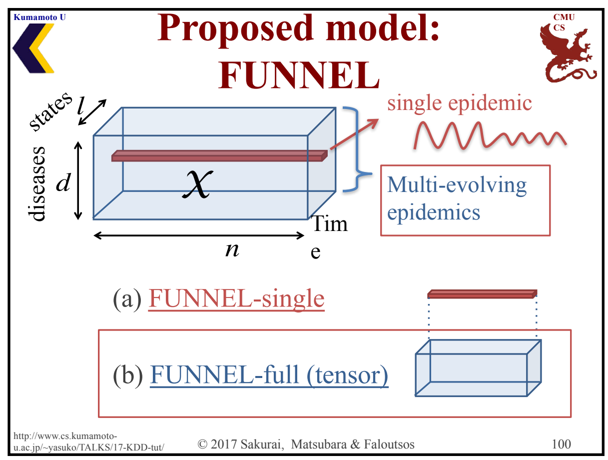
Kumamoto U
Proposed model: FUNNEL
CMU CS
states
l
diseases
d
$\mathcal{X}$
n
Time
single epidemic
Multi-evolving epidemics
(a) FUNNEL-single
(b) FUNNEL-full (tensor)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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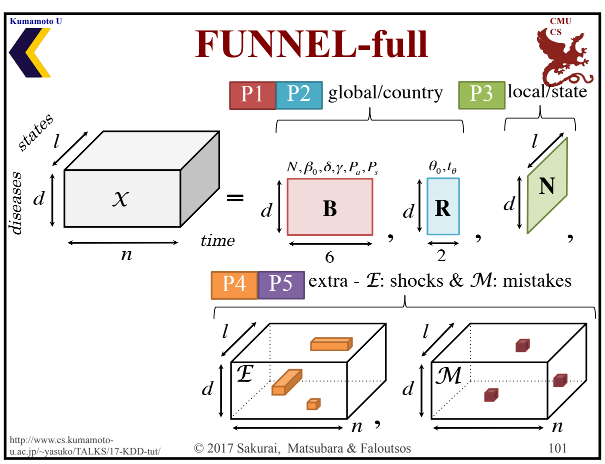
Kumamoto U
FUNNEL-full
CMU CS
P1 P2 global/country
P3 local/state
states
diseases
l
d
$\mathcal{X}$
n
time
=
$N, \beta_0, \delta, \gamma, P_a, P_s$
B
6
θ_0, t_θ
R
2
N
P4 P5 extra - $\mathcal{E}$: shocks & $\mathcal{M}$: mistakes
$\mathcal{E}$
$\mathcal{M}$
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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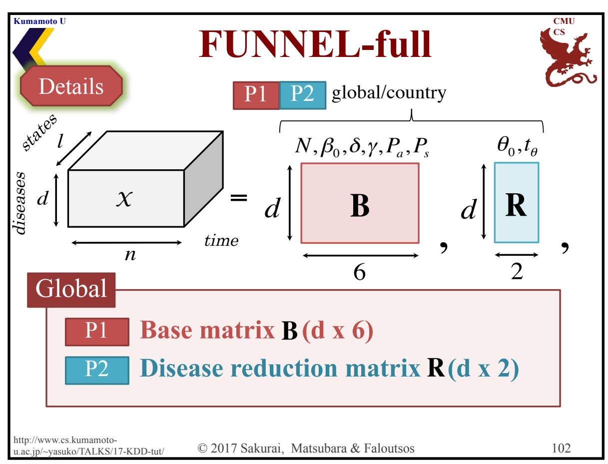
Kumamoto U
FUNNEL-full
CMU CS
Details
P1 P2 global/country
states
diseases
l
d
$\mathcal{X}$
n
time
=
$N, \beta_0, \delta, \gamma, P_a, P_s$
B
6
θ_0, t_θ
R
2
Global
P1 Base matrix B (d x 6)
P2 Disease reduction matrix R (d x 2)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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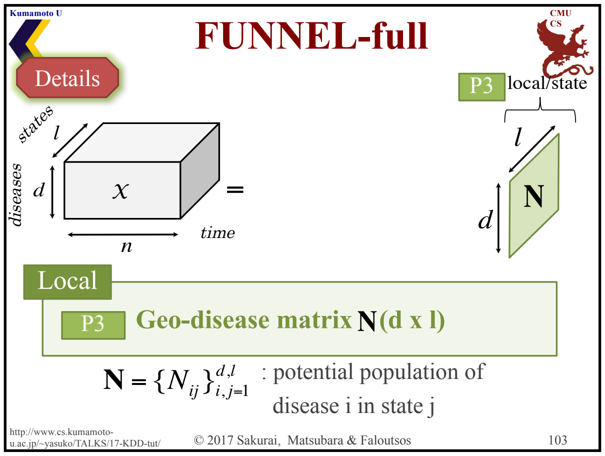
Kumamoto U
FUNNEL-full
CMU CS
Details
P3 local/state
states
diseases
time
N
Local
P3 Geo-disease matrix N (d x l)
N = {N_ij}^{d,l}_{i,j=1} : potential population of disease i in state j
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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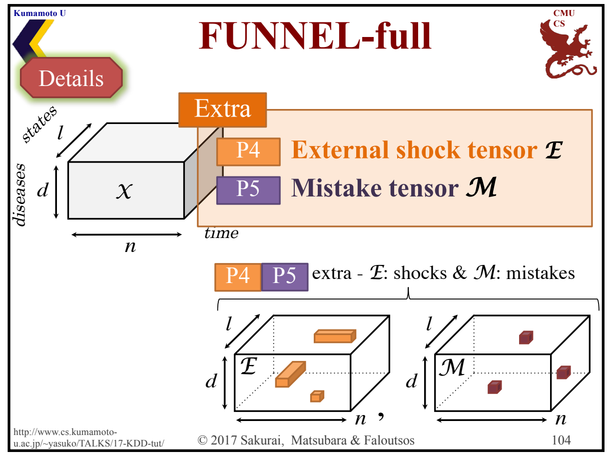
Kumamoto U
FUNNEL-full
CMU CS
Details
Extra
P4 External shock tensor ℰ
P5 Mistake tensor ℳ
diseases
states
time
P4 P5 extra - ℰ: shocks & ℳ: mistakes
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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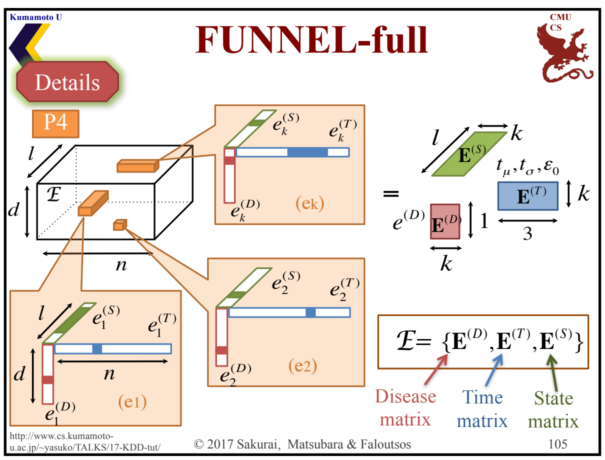
Kumamoto U
FUNNEL-full
CMU CS
Details
P4
(ek)
(e2)
(e1)
ℰ= {E(D),E(T),E(S)}
Disease matrix
Time matrix
State matrix
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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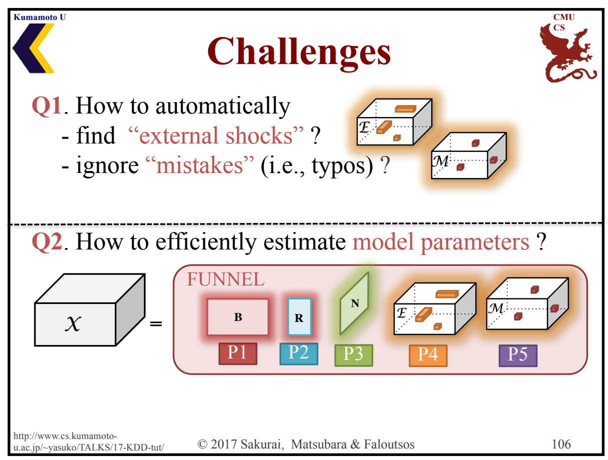
Kumamoto U
Challenges
CMU CS
Q1. How to automatically
- find "external shocks" ?
- ignore "mistakes" (i.e., typos) ?
Q2. How to efficiently estimate model parameters ?
FUNNEL
P1 P2 P3 P4 P5
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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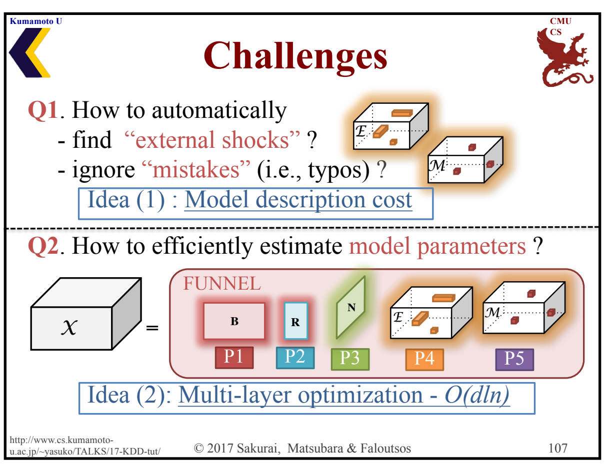
Kumamoto U
Challenges
CMU CS
Q1. How to automatically
- find "external shocks" ?
- ignore "mistakes" (i.e., typos) ?
Idea (1) : Model description cost
Q2. How to efficiently estimate model parameters ?
FUNNEL
P1 P2 P3 P4 P5
Idea (2): Multi-layer optimization - O(dln)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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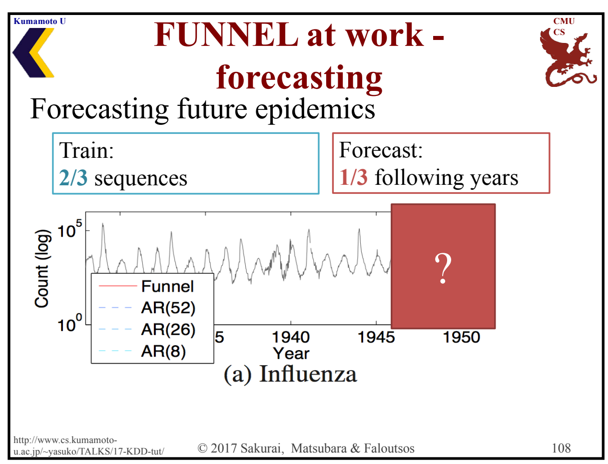
Kumamoto U
FUNNEL at work - forecasting
CMU CS
Forecasting future epidemics
Train: 2/3 sequences
Forecast: 1/3 following years
Count (log)
Funnel
AR(52)
AR(26)
AR(8)
1940
1945
1950
Year
?
(a) Influenza
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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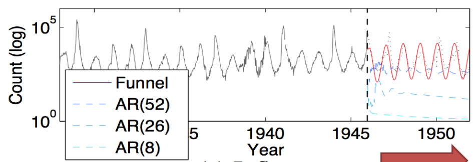
108

FUNNEL at work - forecasting

Forecasting future epidemics

Train: 2/3 sequences

Forecast: 1/3 following years



(a) Influenza

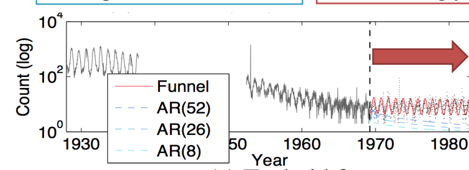
Funnel can capture future epidemics (AR: fail)

FUNNEL at work - forecasting

Forecasting future epidemics

Train: 2/3 sequences

Forecast: 1/3 following years

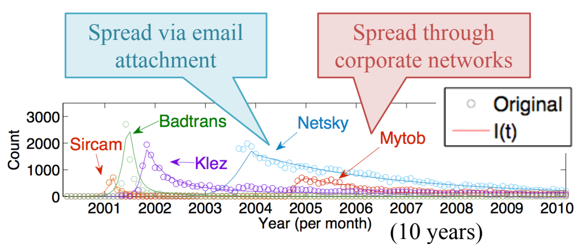


(c) Typhoid fever

Funnel can capture future epidemics (AR: fail)

Generality of FUNNEL

Epidemics on computer networks



(10 years)

Funnel is general: it fits computer virus very well!

[Matsubara+ WWW'16]

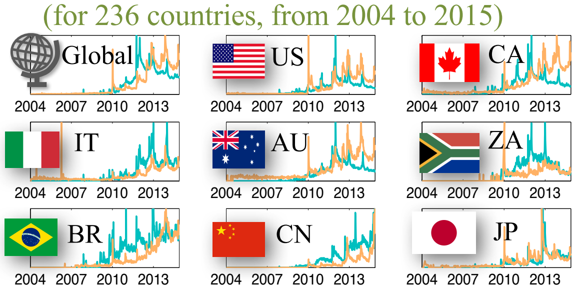
Non-linear Mining of Competing Local Activities

Yasuko Matsubara (Kumamoto University)
Yasushi Sakurai (Kumamoto University)
Christos Faloutsos (CMU)

Given: local user activities

e.g., *Google* search volumes for **Kindle, Nexus**

(for 236 countries, from 2004 to 2015)



Given: local user activities

e.g., *Google* search volumes for **Kindle, Nexus**

(for 236 countries, from 2004 to 2015)


Kumamoto U
CMU CS
Given: local user activities
e.g., *Google* search volumes for Kindle, Nexus
(for 236 countries, from 2004 to 2015)
Global
2004 2007 2010 2013
CA
2004 2007 2010 2013
Nexus
Kindle
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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Kumamoto U
CMU CS
Given: local user activities
e.g., *Google* search volumes for Kindle, Nexus
(for 236 countries, from 2004 to 2015)
Global
1. Exponential growth
CA
2004 2007 2010 2013
Nexus
Kindle
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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Kumamoto U
CMU CS
Given: local user activities
e.g., *Google* search volumes for Kindle, Nexus
(for 236 countries, from 2004 to 2015)
Global
VS.
2. Competition
2004 2007 2010 2013
CA
VS.
2004 2007 2010 2013
Nexus
Kindle
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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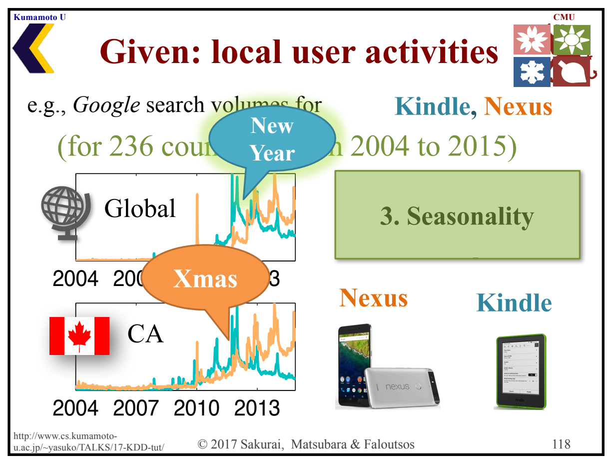
Kumamoto U
CMU CS
Given: local user activities
e.g., *Google* search volumes for Kindle, Nexus
New Year
Global
3. Seasonality
Xmas
CA
2004 2007 2010 2013
Nexus
Kindle
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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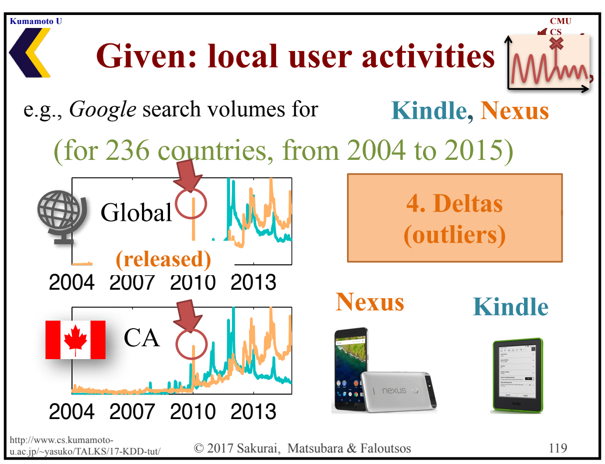
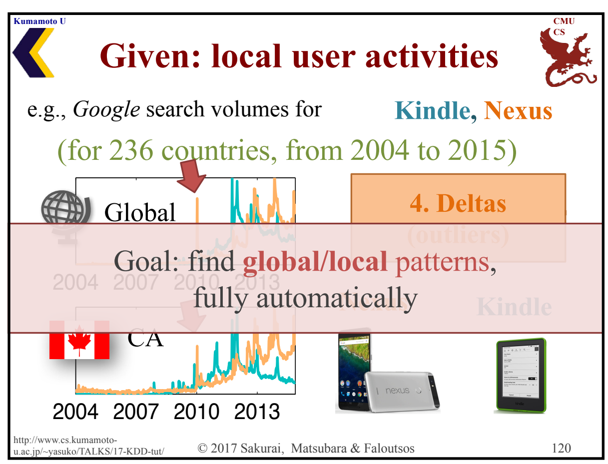
118


Kumamoto U
CMU CS
Given: local user activities
e.g., *Google* search volumes for Kindle, Nexus
(for 236 countries, from 2004 to 2015)
Global
4. Deltas (outliers)
(released)
2004 2007 2010 2013
CA
2004 2007 2010 2013
Nexus
Kindle
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
119


Kumamoto U
CMU CS
Given: local user activities
e.g., *Google* search volumes for Kindle, Nexus
(for 236 countries, from 2004 to 2015)
Global
4. Deltas
Goal: find global/local patterns, fully automatically
CA
2004 2007 2010 2013
Nexus
Kindle
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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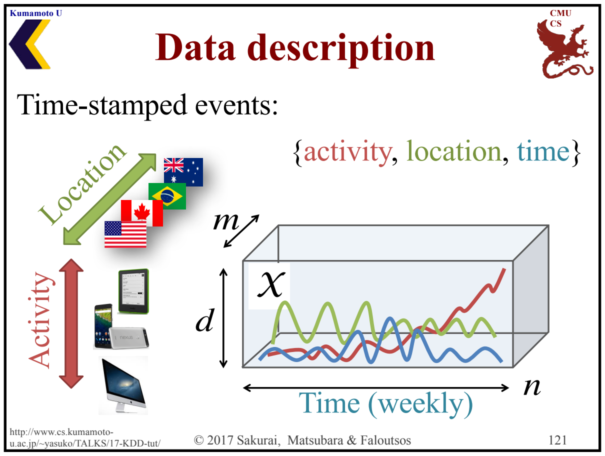
120


Kumamoto U
CMU CS
Data description
Time-stamped events:
{activity, location, time}
Location
Activity
m
d
n
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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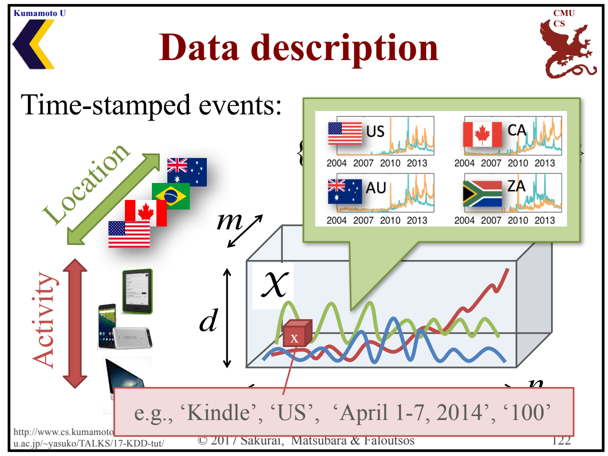
121


Kumamoto U
CMU CS
Data description
Time-stamped events:
US
CA
AU
ZA
2004 2007 2010 2013
Location
Activity
m
d
e.g., 'Kindle', 'US', 'April 1-7, 2014', '100'
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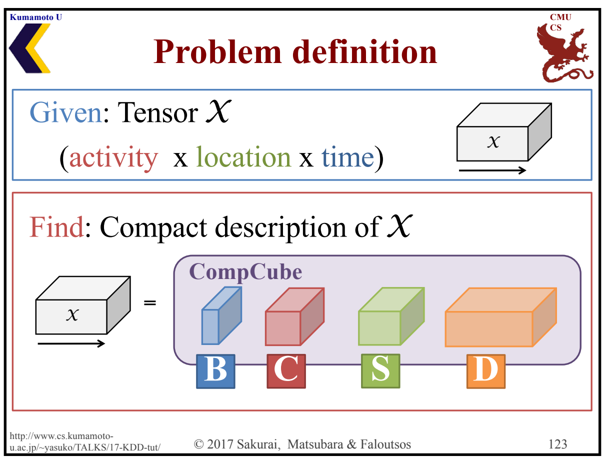
122


Kumamoto U
CMU CS
Problem definition
Given: Tensor $\mathcal{X}$
(activity x location x time)
Find: Compact description of $\mathcal{X}$
CompCube
B
C
S
D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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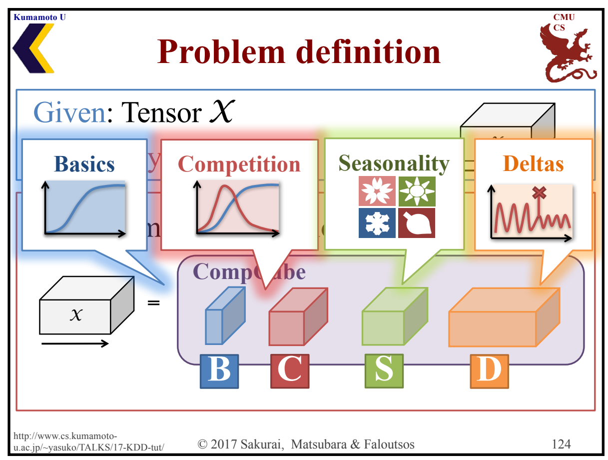
123


Kumamoto U
CMU CS
Problem definition
Given: Tensor $\mathcal{X}$
Basics
Competition
Seasonality
Deltas
CompCube
B
C
S
D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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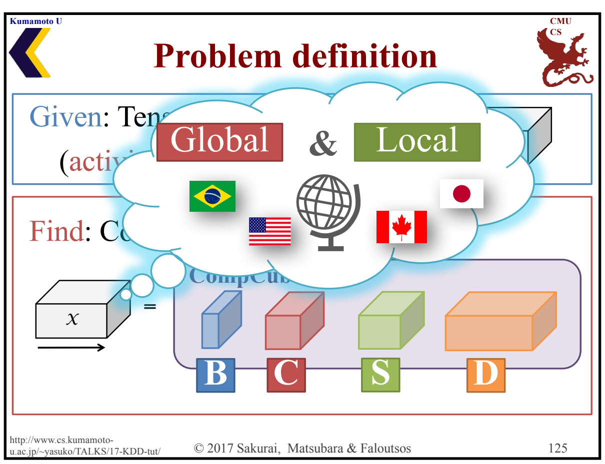
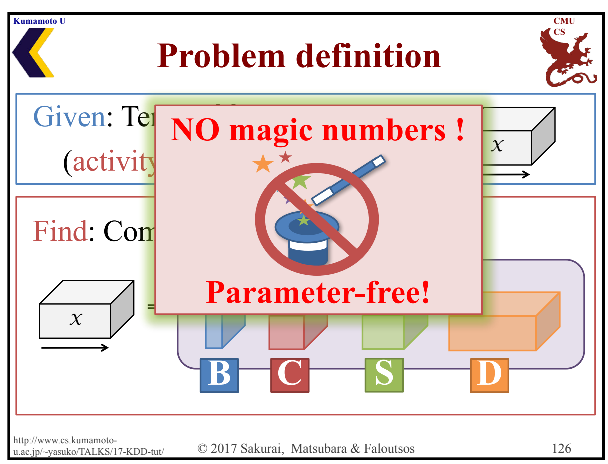
124


Kumamoto U
CMU CS
Problem definition
Global
&
Local
B
C
S
D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
125


Kumamoto U
CMU CS
Problem definition
NO magic numbers !
Parameter-free!
B
C
S
D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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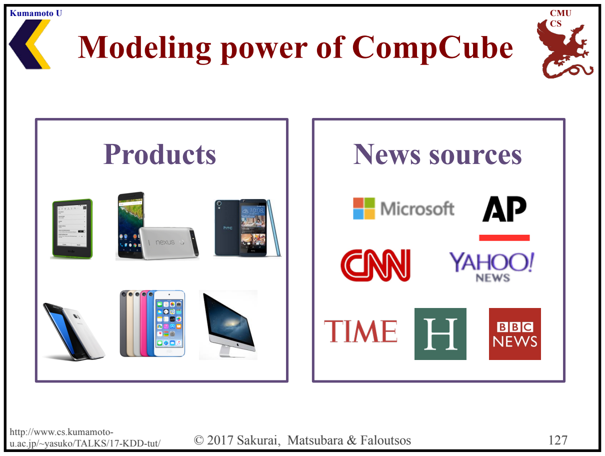
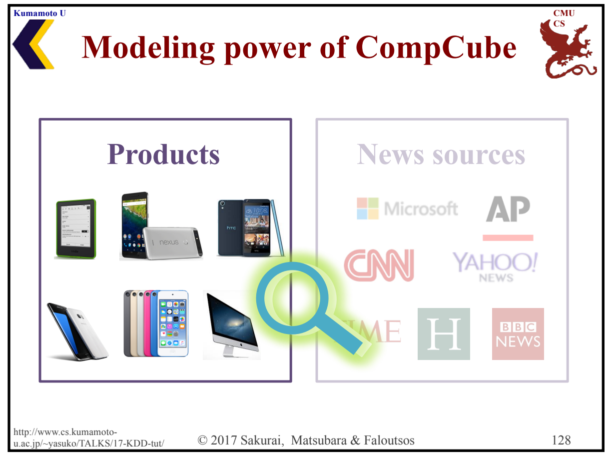
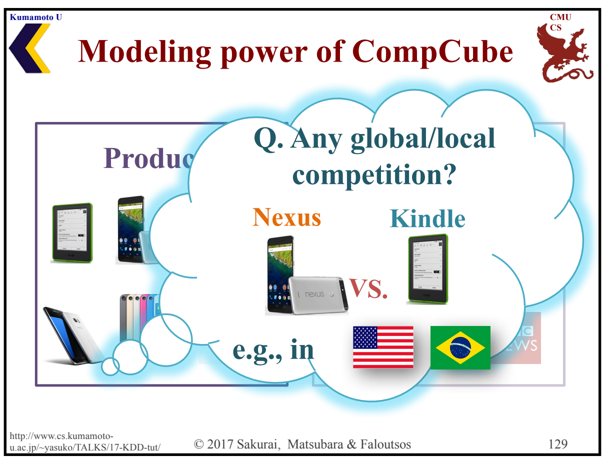
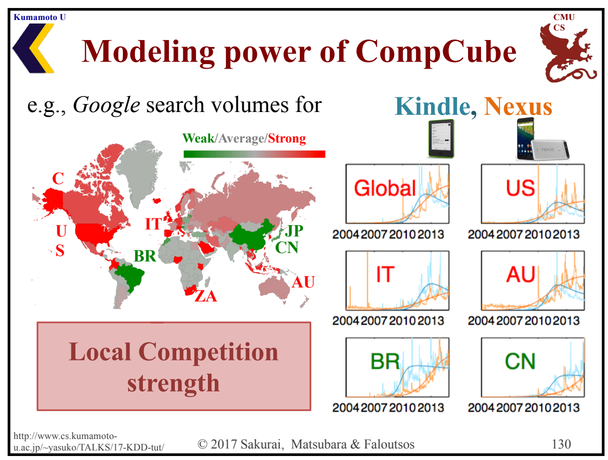
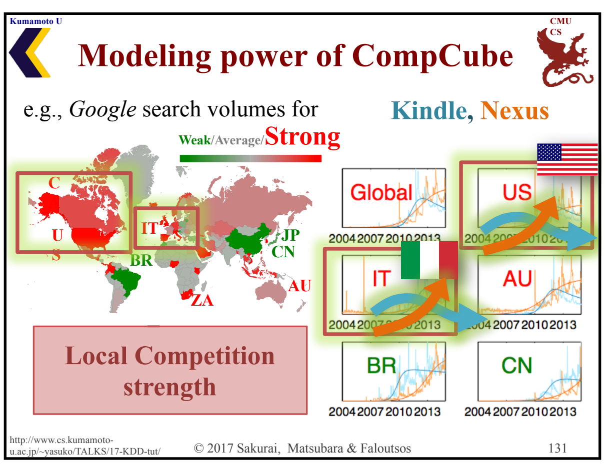
126

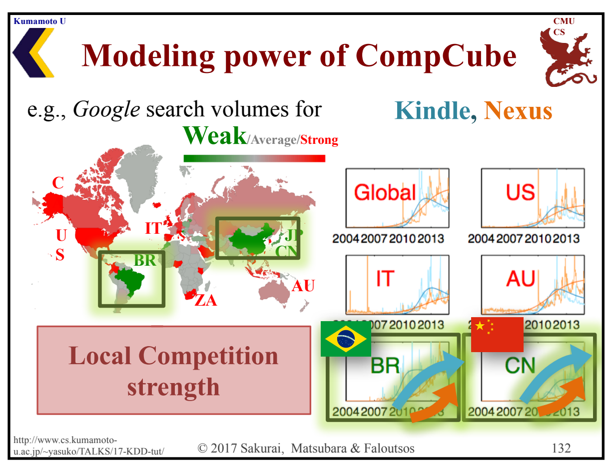

Kumamoto U
CMU CS
Modeling power of CompCube
Products
News sources
Microsoft
AP
CNN
YAHOO! NEWS
TIME
H
BBC NEWS
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
127

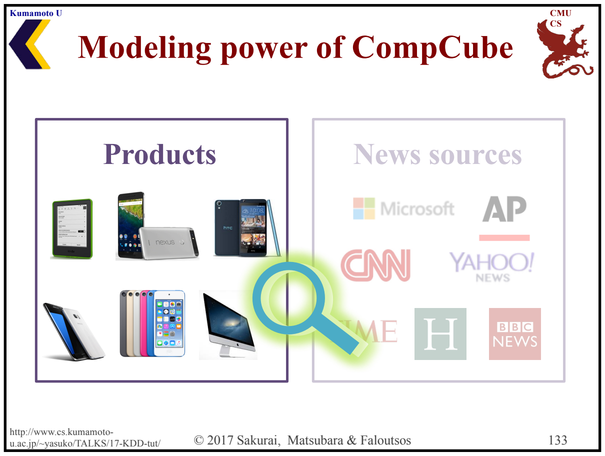

Kumamoto U
CMU CS
Modeling power of CompCube
Products
News sources
Microsoft
AP
CNN
YAHOO! NEWS
H
BBC NEWS
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
128

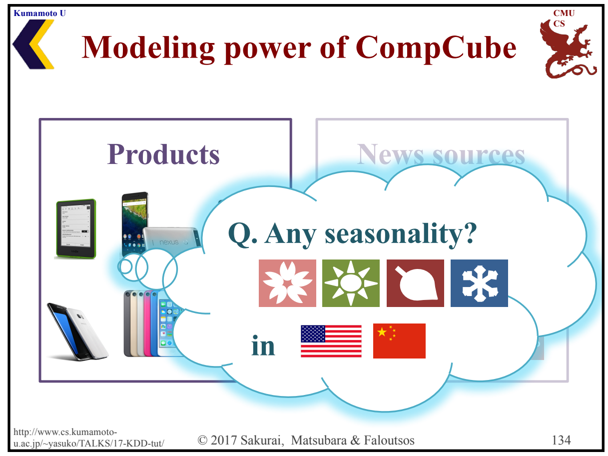

Kumamoto U
CMU CS
Modeling power of CompCube
Q. Any global/local competition?
Nexus
Kindle
VS.
e.g., in
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
129

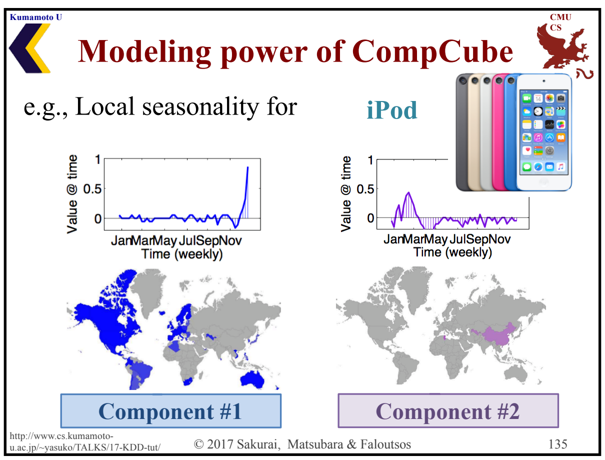

Kumamoto U
CMU CS
Modeling power of CompCube
e.g., Google search volumes for
Kindle, Nexus
Weak/Average/Strong
Global
US
IT
AU
BR
CN
JP
ZA
2004 2007 2010 2013
Local Competition strength
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
130

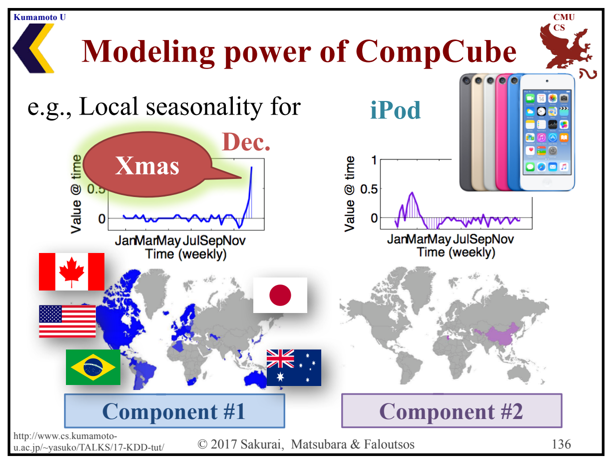

Kumamoto U
CMU CS
Modeling power of CompCube
e.g., Google search volumes for
Kindle, Nexus
Weak/Average/Strong
Global
US
IT
AU
BR
CN
JP
ZA
2004 2007 2010 2013
Local Competition strength
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
131

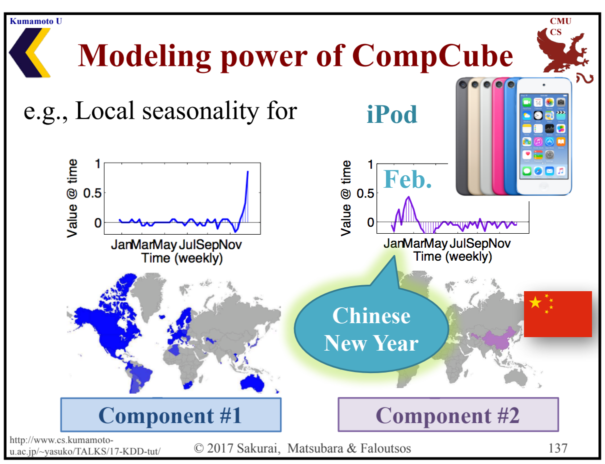

Kumamoto U
CMU CS
Modeling power of CompCube
e.g., Google search volumes for
Kindle, Nexus
Weak/Average/Strong
Global
US
IT
AU
BR
CN
JP
ZA
2004 2007 2010 2013
Local Competition strength
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
132

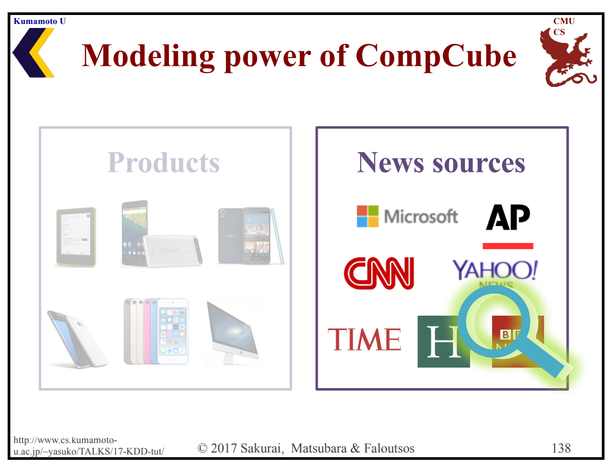

Kumamoto U
CMU CS
Modeling power of CompCube
Products
News sources
Microsoft
AP
CNN
YAHOO! NEWS
TIME
H
BBC NEWS
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
133

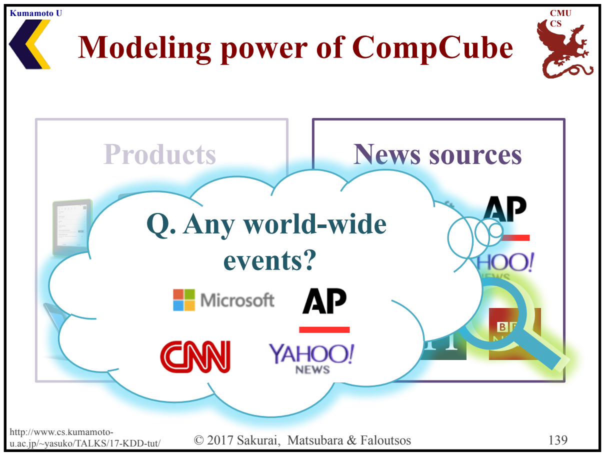

Kumamoto U
CMU CS
Modeling power of CompCube
Products
News sources
Q. Any seasonality?
in
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
134

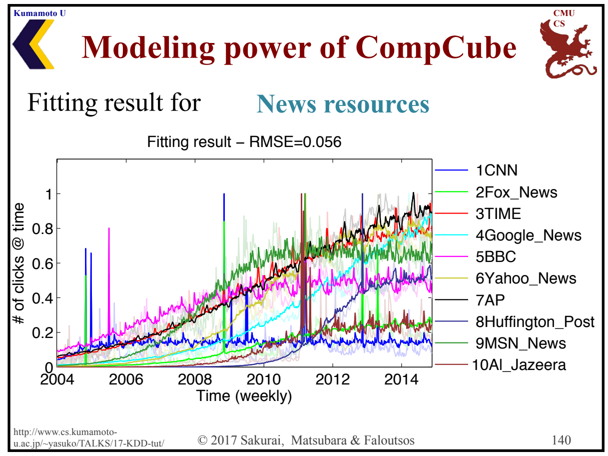

Kumamoto U
CMU CS
Modeling power of CompCube
e.g., Local seasonality for
iPod
Value @ time
Jan Mar May Jul Sep Nov
Time (weekly)
Component #1
Component #2
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
135

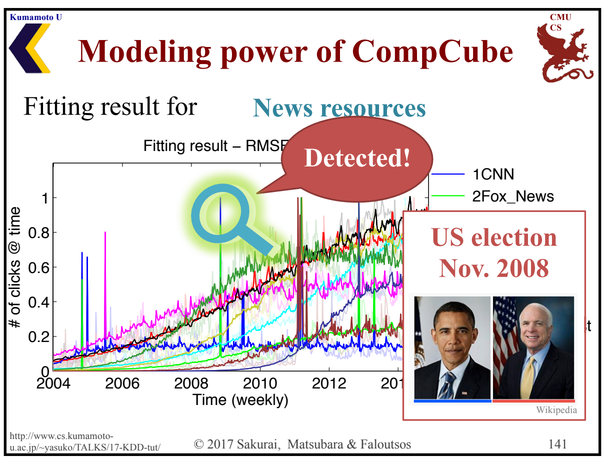

Kumamoto U
CMU CS
Modeling power of CompCube
e.g., Local seasonality for
iPod
Xmas
Dec.
Value @ time
Jan Mar May Jul Sep Nov
Time (weekly)
Component #1
Component #2
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
136

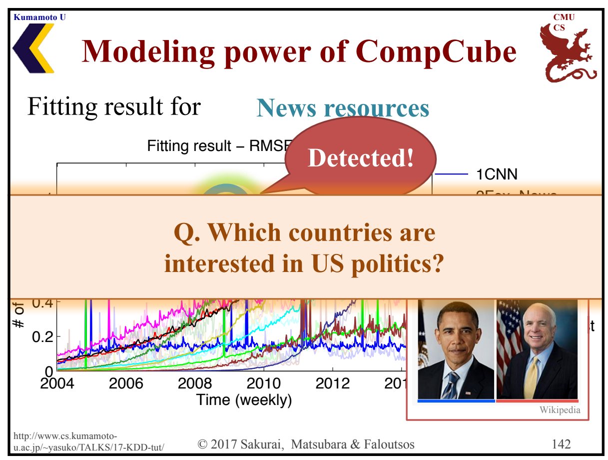

Kumamoto U
CMU CS
Modeling power of CompCube
e.g., Local seasonality for
iPod
Feb.
Value @ time
Jan Mar May Jul Sep Nov
Time (weekly)
Chinese New Year
Component #1
Component #2
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
137

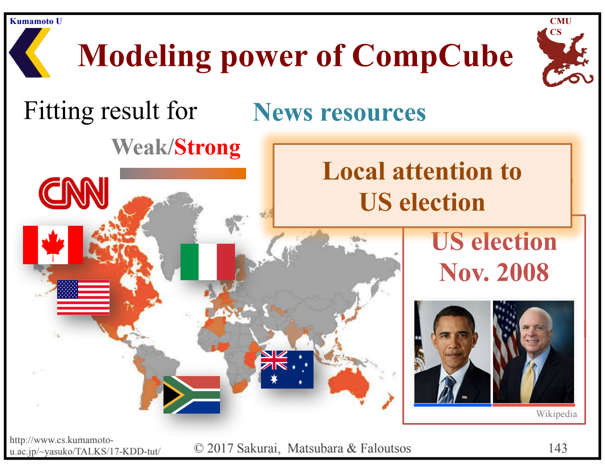

Kumamoto U
CMU CS
Modeling power of CompCube
Products
News sources
Microsoft
AP
CNN
YAHOO!
TIME
H
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
138

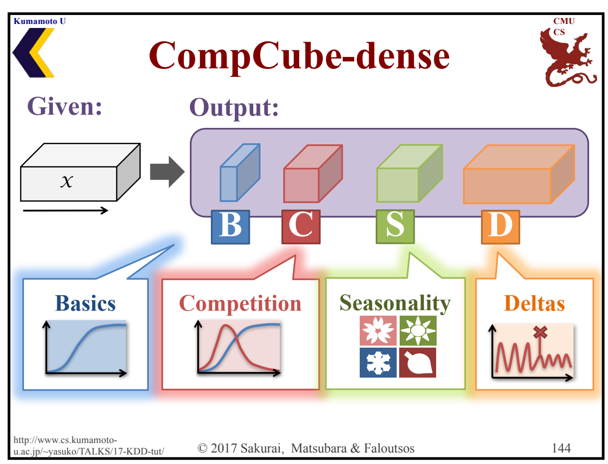

Kumamoto U
CMU CS
Modeling power of CompCube
Products
News sources
Q. Any world-wide events?
Microsoft
AP
CNN
YAHOO! NEWS
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
139


Kumamoto U
CMU CS
Modeling power of CompCube
Fitting result for News resources
Fitting result – RMSE=0.056
# of clicks @ time
Time (weekly)
1CNN
2Fox_News
3TIME
4Google_News
5BBC
6Yahoo_News
7AP
8Huffington_Post
9MSN_News
10Al_Jazeera
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
140


Kumamoto U
CMU CS
Modeling power of CompCube
Fitting result for News resources
Detected!
US election
Nov. 2008
Wikipedia
1CNN
2Fox_News
# of clicks @ time
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
141


Kumamoto U
CMU CS
Modeling power of CompCube
Fitting result for News resources
Detected!
1CNN
Q. Which countries are interested in US politics?
Time (weekly)
Wikipedia
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
142


Kumamoto U
CMU CS
Modeling power of CompCube
Fitting result for News resources
Weak/Strong
CNN
Local attention to US election
US election
Nov. 2008
Wikipedia
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
143


Kumamoto U
CMU CS
CompCube-dense
Given:
Output:
x
B
C
S
D
Basics
Competition
Seasonality
Deltas
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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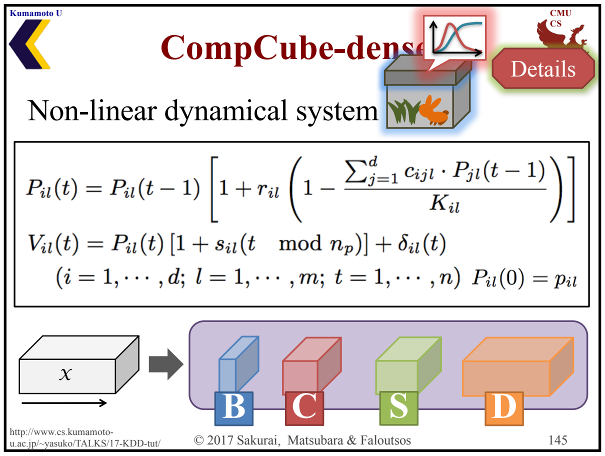
144


Kumamoto U
CMU CS
CompCube-dense
Details
Non-linear dynamical system
$P_{il}(t) = P_{il}(t-1)\left[1 + r_{il}\left(1 - \frac{\sum_{j=1}^{d} c_{ijl} \cdot P_{jl}(t-1)}{K_{il}}\right)\right]$
$V_{il}(t) = P_{il}(t)\,[1 + s_{il}(t \mod n_p)] + \delta_{il}(t)$
$(i = 1, \cdots, d;\ l = 1, \cdots, m;\ t = 1, \cdots, n)\ \ P_{il}(0) = p_{il}$
x
B C S D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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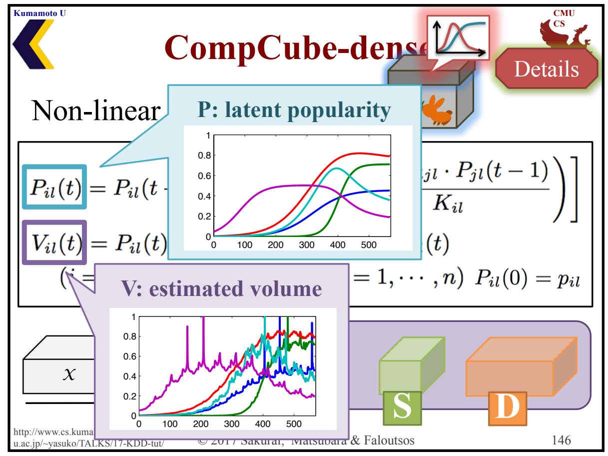
145


Kumamoto U
CMU CS
CompCube-dense
Details
Non-linear
P: latent popularity
V: estimated volume
$P_{il}(t)$
$V_{il}(t)$
$P_{il}(0) = p_{il}$
x
S D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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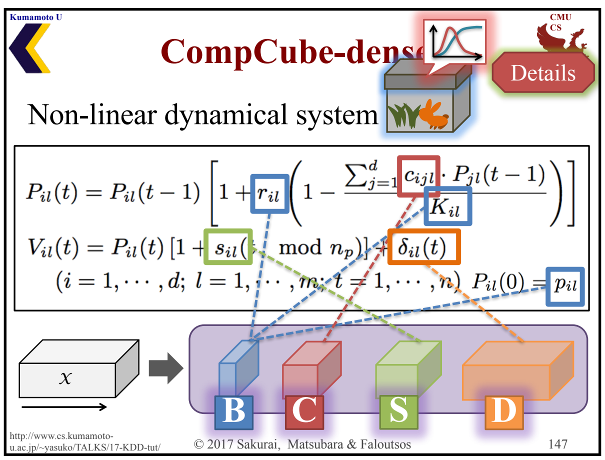
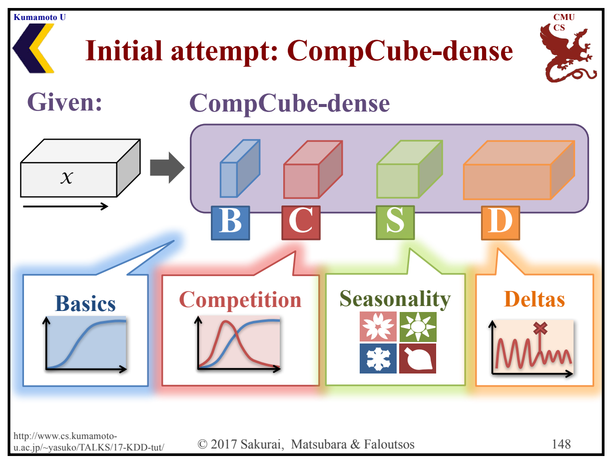
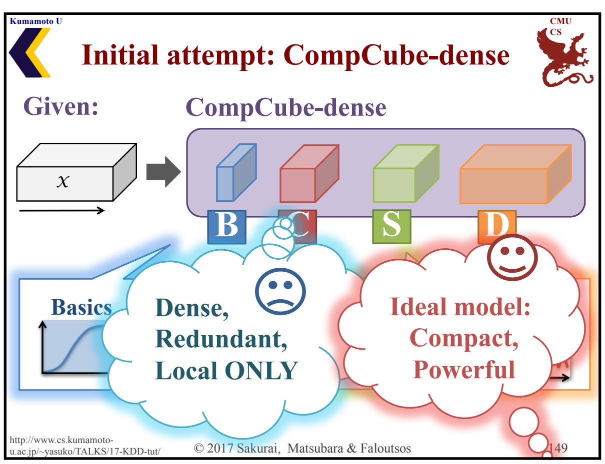
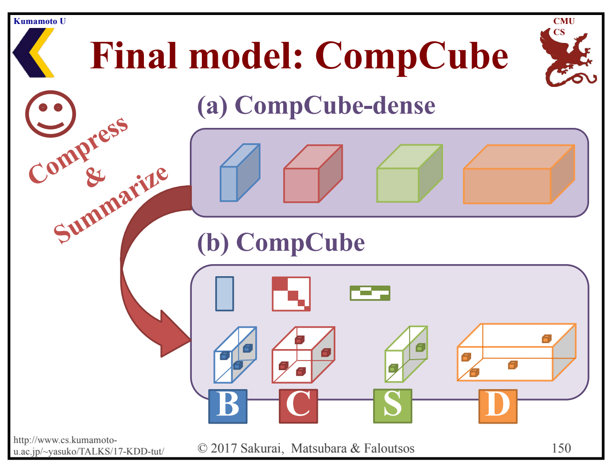
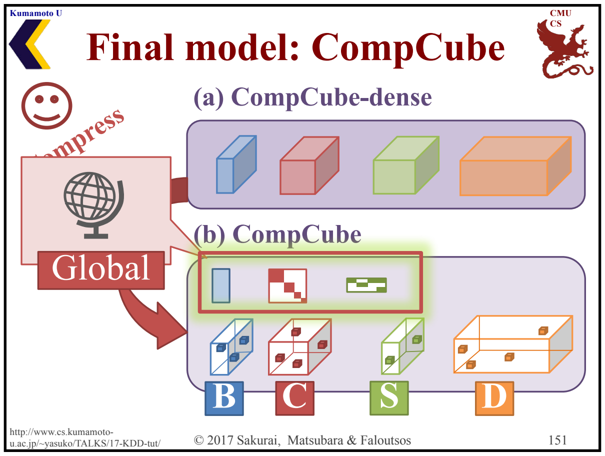
146

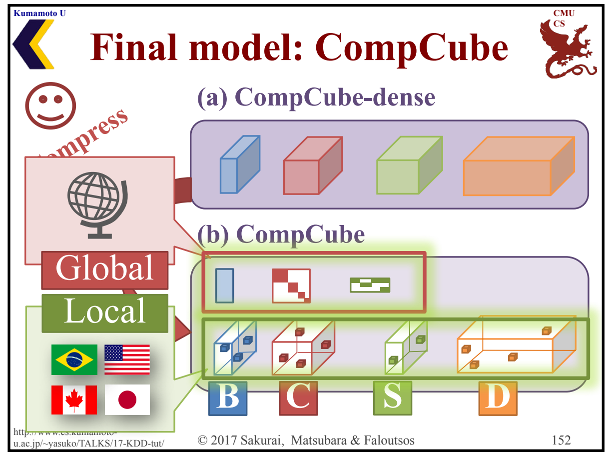

Kumamoto U
CMU CS
CompCube-dense
Details
Non-linear dynamical system
$P_{il}(t) = P_{il}(t-1)\left[1 + r_{il}\left(1 - \frac{\sum_{j=1}^{d} c_{ijl} \cdot P_{jl}(t-1)}{K_{il}}\right)\right]$
$V_{il}(t) = P_{il}(t)\,[1 + s_{il}(t \mod n_p)] + \delta_{il}(t)$
$(i = 1, \cdots, d;\ l = 1, \cdots, m;\ t = 1, \cdots, n)\ \ P_{il}(0) = p_{il}$
x
B C S D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
147

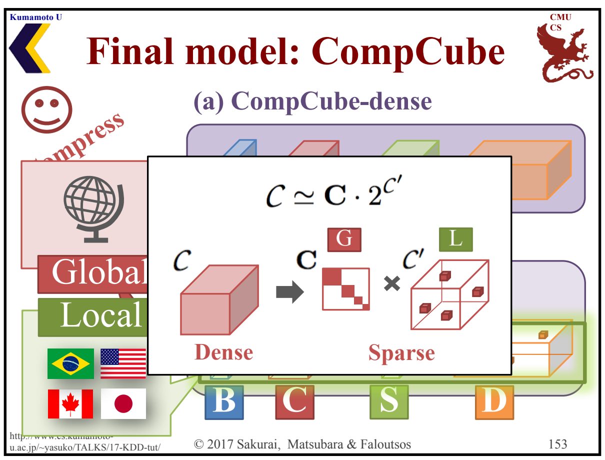

Kumamoto U
CMU CS
Initial attempt: CompCube-dense
Given:
CompCube-dense
x
B C S D
Basics
Competition
Seasonality
Deltas
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
148

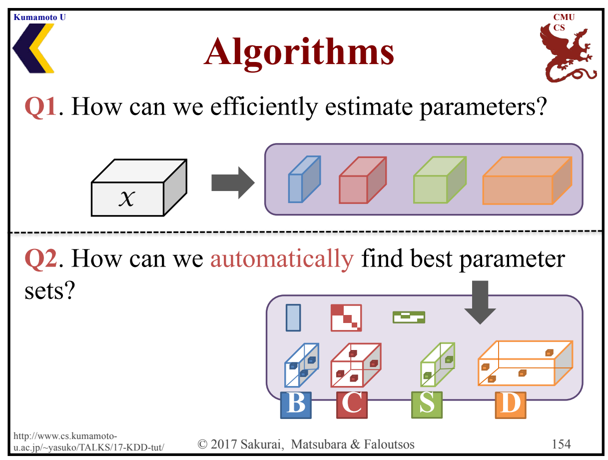

Kumamoto U
CMU CS
Initial attempt: CompCube-dense
Given:
CompCube-dense
x
B C S D
Basics
Dense, Redundant, Local ONLY
Ideal model: Compact, Powerful
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
149

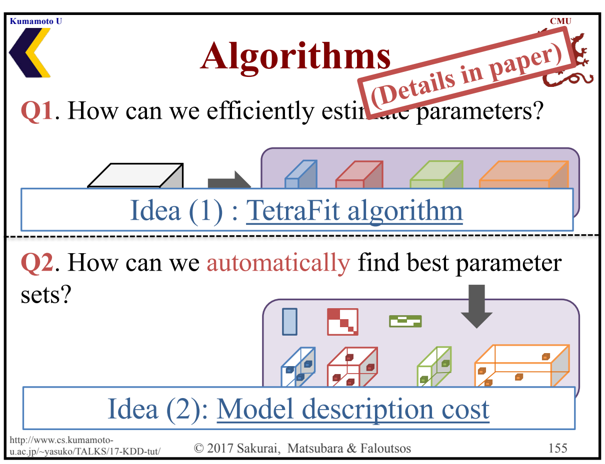

Kumamoto U
CMU CS
Final model: CompCube
Compress & Summarize
(a) CompCube-dense
(b) CompCube
B C S D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
150


Kumamoto U
CMU CS
Final model: CompCube
(a) CompCube-dense
(b) CompCube
Global
B C S D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
151


Kumamoto U
CMU CS
Final model: CompCube
(a) CompCube-dense
(b) CompCube
Global
Local
B C S D
© 2017 Sakurai, Matsubara & Faloutsos
152


Kumamoto U
CMU CS
Final model: CompCube
(a) CompCube-dense
Global
Local
$\mathcal{C} \simeq \mathbf{C} \cdot 2^{\mathcal{C}'}$
G
L
Dense
Sparse
B C S D
© 2017 Sakurai, Matsubara & Faloutsos
153


Kumamoto U
CMU CS
Algorithms
Q1. How can we efficiently estimate parameters?
Q2. How can we automatically find best parameter sets?
B C S D
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
© 2017 Sakurai, Matsubara & Faloutsos
154


Kumamoto U
CMU CS
Algorithms
(Details in paper)
Q1. How can we efficiently estimate parameters?
Idea (1) : TetraFit algorithm
Q2. How can we automatically find best parameter sets?
Idea (2): Model description cost
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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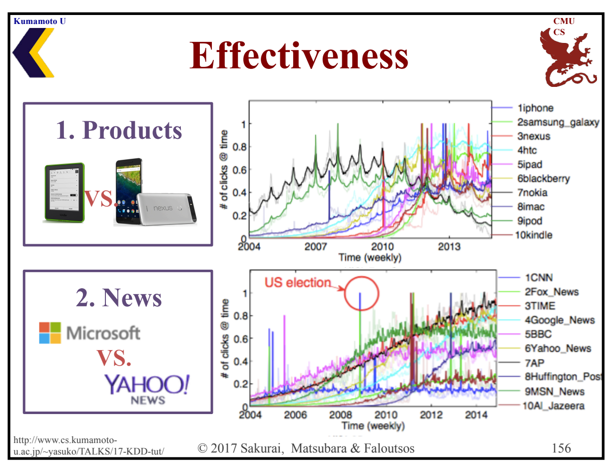
Kumamoto U
CMU CS
Effectiveness
1. Products
VS.
2. News
Microsoft
VS.
YAHOO! NEWS
# of clicks @ time
Time (weekly)
1iphone
2samsung_galaxy
3nexus
4htc
5ipad
6blackberry
7nokia
8imac
9ipod
10kindle
US election
1CNN
2Fox_News
3TIME
4Google_News
5BBC
6Yahoo_News
7AP
8Huffington_Post
9MSN_News
10Al_Jazeera
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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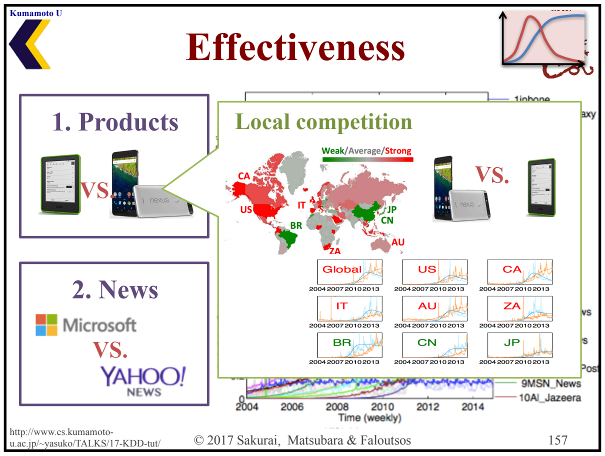
Kumamoto U
Effectiveness
1. Products
VS.
Local competition
Weak/Average/Strong
VS.
Global
US
CA
IT
AU
ZA
BR
CN
JP
2. News
Microsoft
VS.
YAHOO!
NEWS
9MSN_News
10Al_Jazeera
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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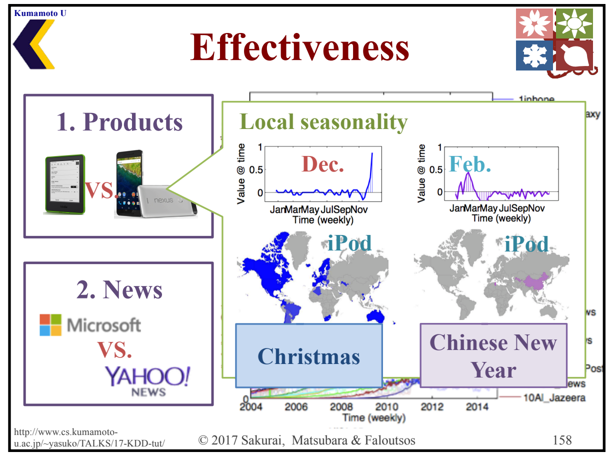
Kumamoto U
Effectiveness
1. Products
VS.
Local seasonality
Dec.
Feb.
iPod
iPod
Christmas
Chinese New Year
2. News
Microsoft
VS.
YAHOO!
NEWS
10Al_Jazeera
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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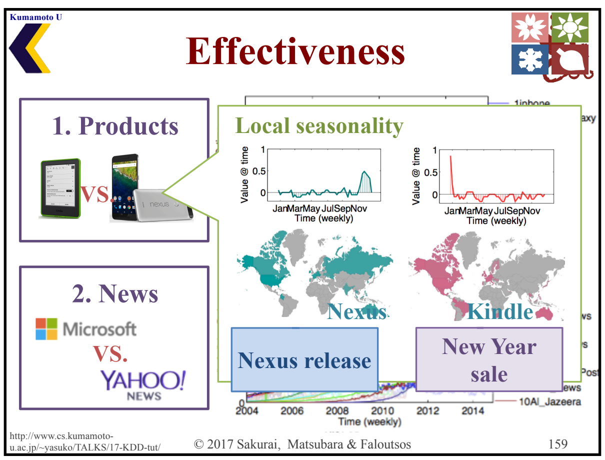
Kumamoto U
Effectiveness
1. Products
VS.
Local seasonality
Nexus
Kindle
Nexus release
New Year sale
2. News
Microsoft
VS.
YAHOO!
NEWS
10Al_Jazeera
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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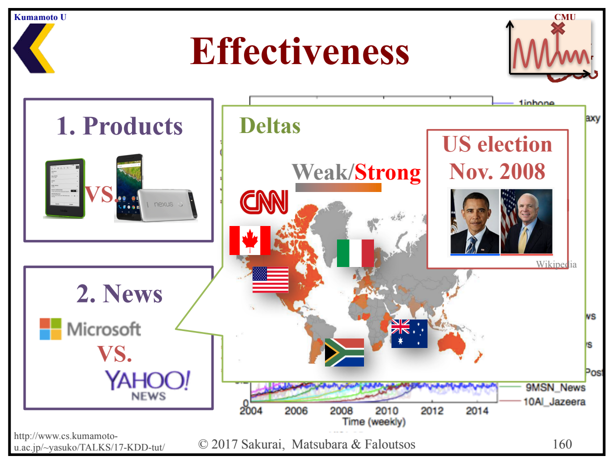
Kumamoto U
Effectiveness
1. Products
VS.
Deltas
Weak/Strong
CNN
US election
Nov. 2008
2. News
Microsoft
VS.
YAHOO!
NEWS
9MSN_News
10Al_Jazeera
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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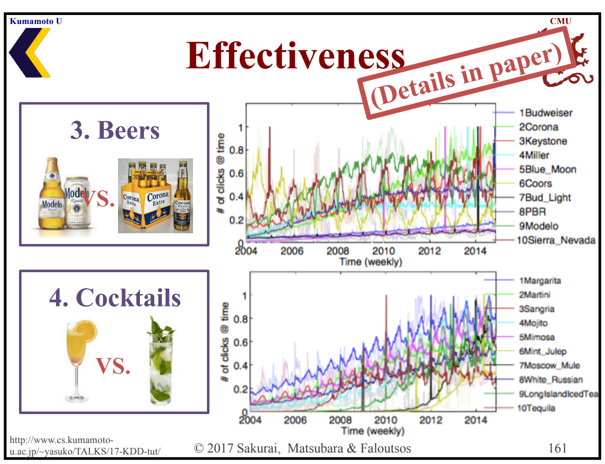
Kumamoto U
CMU
Effectiveness
(Details in paper)
3. Beers
VS.
1Budweiser
2Corona
3Keystone
4Miller
5Blue_Moon
6Coors
7Bud_Light
8PBR
9Modelo
10Sierra_Nevada
Time (weekly)
4. Cocktails
VS.
1Margarita
2Martini
3Sangria
4Mojito
5Mimosa
6Mint_Julep
7Moscow_Mule
8White_Russian
9LongIslandIcedTea
10Tequila
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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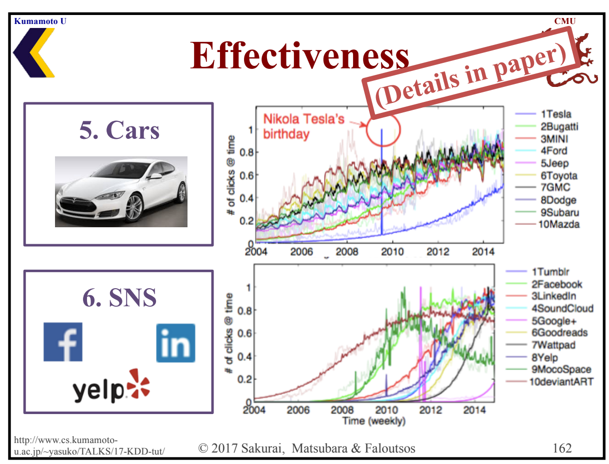
Kumamoto U
CMU
Effectiveness
(Details in paper)
5. Cars
Nikola Tesla's birthday
1Tesla
2Bugatti
3MINI
4Ford
5Jeep
6Toyota
7GMC
8Dodge
9Subaru
10Mazda
6. SNS
yelp
1Tumblr
2Facebook
3LinkedIn
4SoundCloud
5Google+
6Goodreads
7Wattpad
8Yelp
9MocoSpace
10deviantART
Time (weekly)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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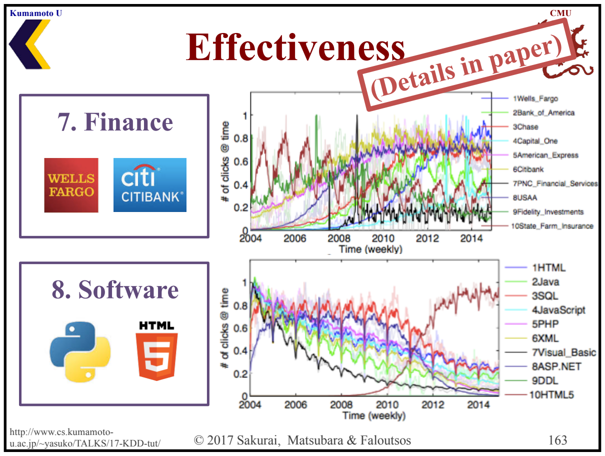
Kumamoto U
CMU
Effectiveness
(Details in paper)
7. Finance
WELLS FARGO
citi CITIBANK
8. Software
HTML
# of clicks @ time
Time (weekly)
1Wells_Fargo
2Bank_of_America
3Chase
4Capital_One
5American_Express
6Citibank
7PNC_Financial_Services
8USAA
9Fidelity_Investments
10State_Farm_Insurance
1HTML
2Java
3SQL
4JavaScript
5PHP
6XML
7Visual_Basic
8ASP.NET
9DDL
10HTML5
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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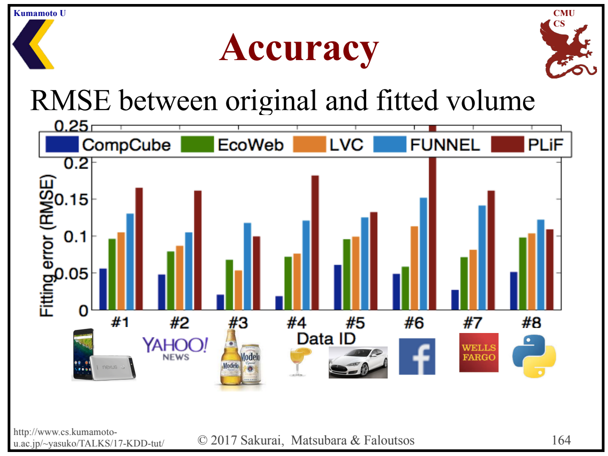
Kumamoto U
CMU CS
Accuracy
RMSE between original and fitted volume
CompCube EcoWeb LVC FUNNEL PLiF
Fitting error (RMSE)
#1 #2 #3 #4 #5 #6 #7 #8
Data ID
YAHOO! NEWS
WELLS FARGO
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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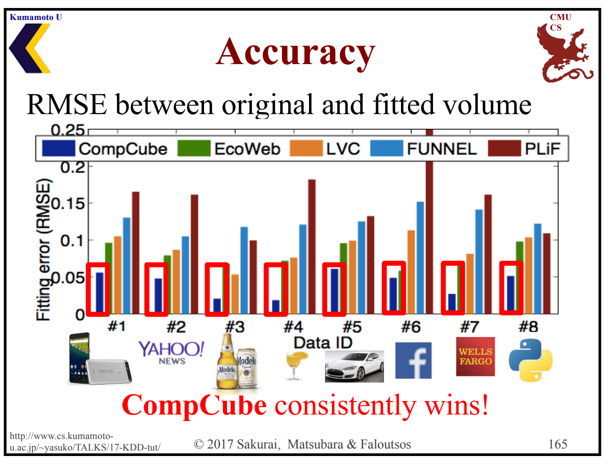
Kumamoto U
CMU CS
Accuracy
RMSE between original and fitted volume
CompCube EcoWeb LVC FUNNEL PLiF
Fitting error (RMSE)
#1 #2 #3 #4 #5 #6 #7 #8
Data ID
YAHOO! NEWS
WELLS FARGO
CompCube consistently wins!
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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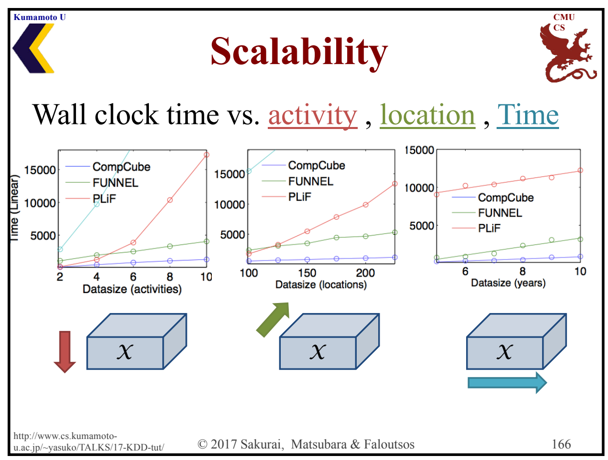
Kumamoto U
CMU CS
Scalability
Wall clock time vs. activity , location , Time
CompCube
FUNNEL
PLiF
Time (Linear)
Datasize (activities)
Datasize (locations)
Datasize (years)
X
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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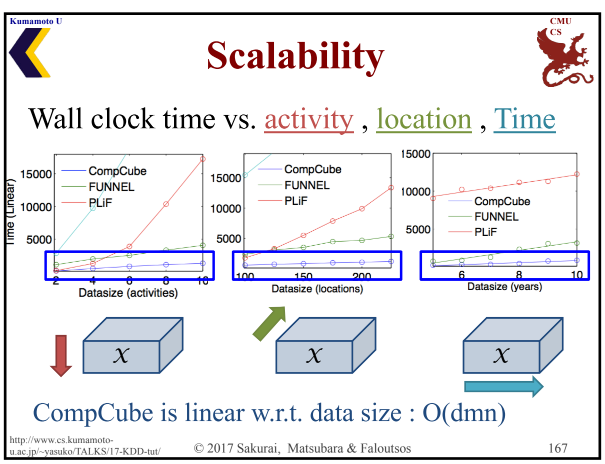
Kumamoto U
CMU CS
Scalability
Wall clock time vs. activity , location , Time
CompCube
FUNNEL
PLiF
Time (Linear)
Datasize (activities)
Datasize (locations)
Datasize (years)
X
CompCube is linear w.r.t. data size : O(dmn)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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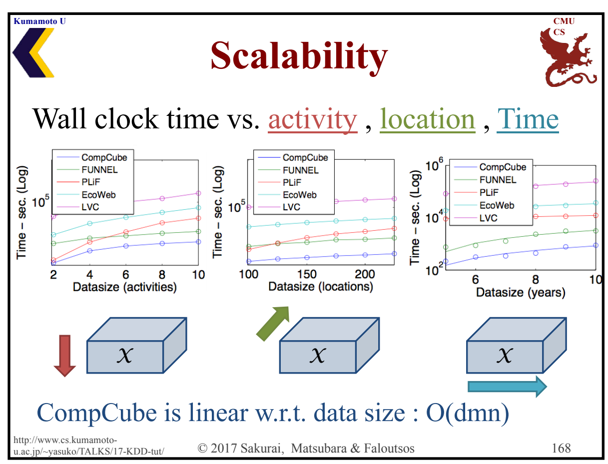
Kumamoto U
CMU CS
Scalability
Wall clock time vs. activity , location , Time
CompCube
FUNNEL
PLiF
EcoWeb
LVC
Time – sec. (Log)
Datasize (activities)
Datasize (locations)
Datasize (years)
X
CompCube is linear w.r.t. data size : O(dmn)
http://www.cs.kumamoto-u.ac.jp/~yasuko/TALKS/17-KDD-tut/
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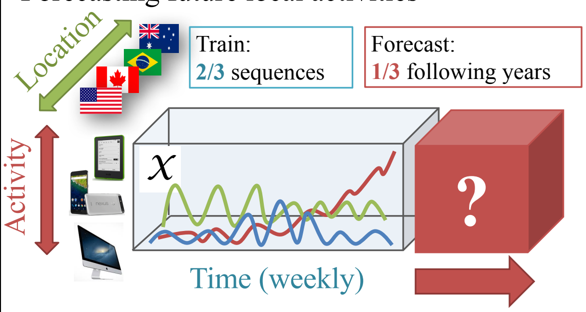
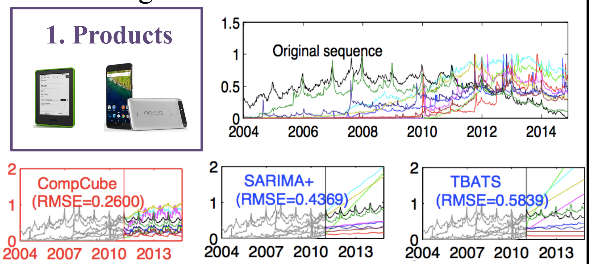
CompCube at work - forecasting

Forecasting future local activities



CompCube at work - forecasting

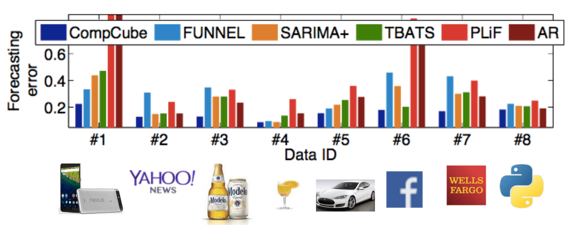
Forecasting results for #1 Products



CompCube captures future activities very well

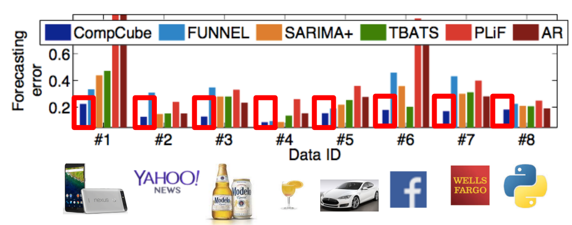
CompCube at work - forecasting

Forecasting error (original vs. forecasts)



CompCube at work - forecasting

Forecasting error (original vs. forecasts)

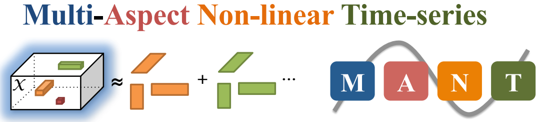


CompCube consistently wins!

Part 3 Conclusions

- Real data are often in high dimensions with multiple aspects (modes)
- Matrices and tensors provide elegant theory and algorithms
- MANT analysis

Multi-Aspect Non-linear Time-series



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Part 3

Extension of time-series: tensor analysis

Yasushi Sakurai (Kumamoto University)
Yasuko Matsubara (Kumamoto University)
Christos Faloutsos (Carnegie Mellon University)