The Web as a Jungle: Non-Linear Dynamical Systems for Co-evolving Online Activities

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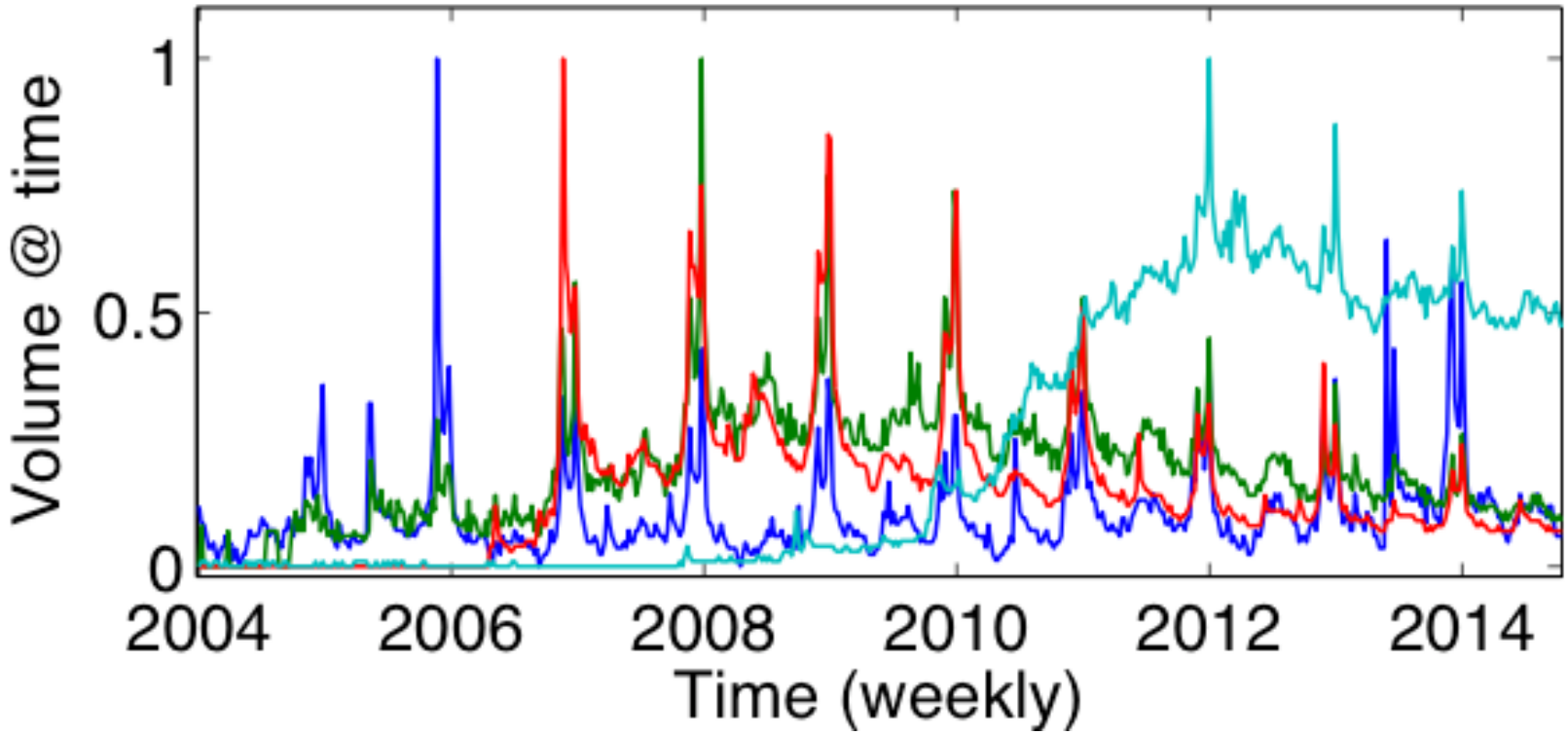
Yasushi Sakurai (Kumamoto University)
Christos Faloutsos (CMU)

Given: online user activities

e.g., *Google* search volumes for

Xbox, **PlayStation**, **Wii**, **Android**



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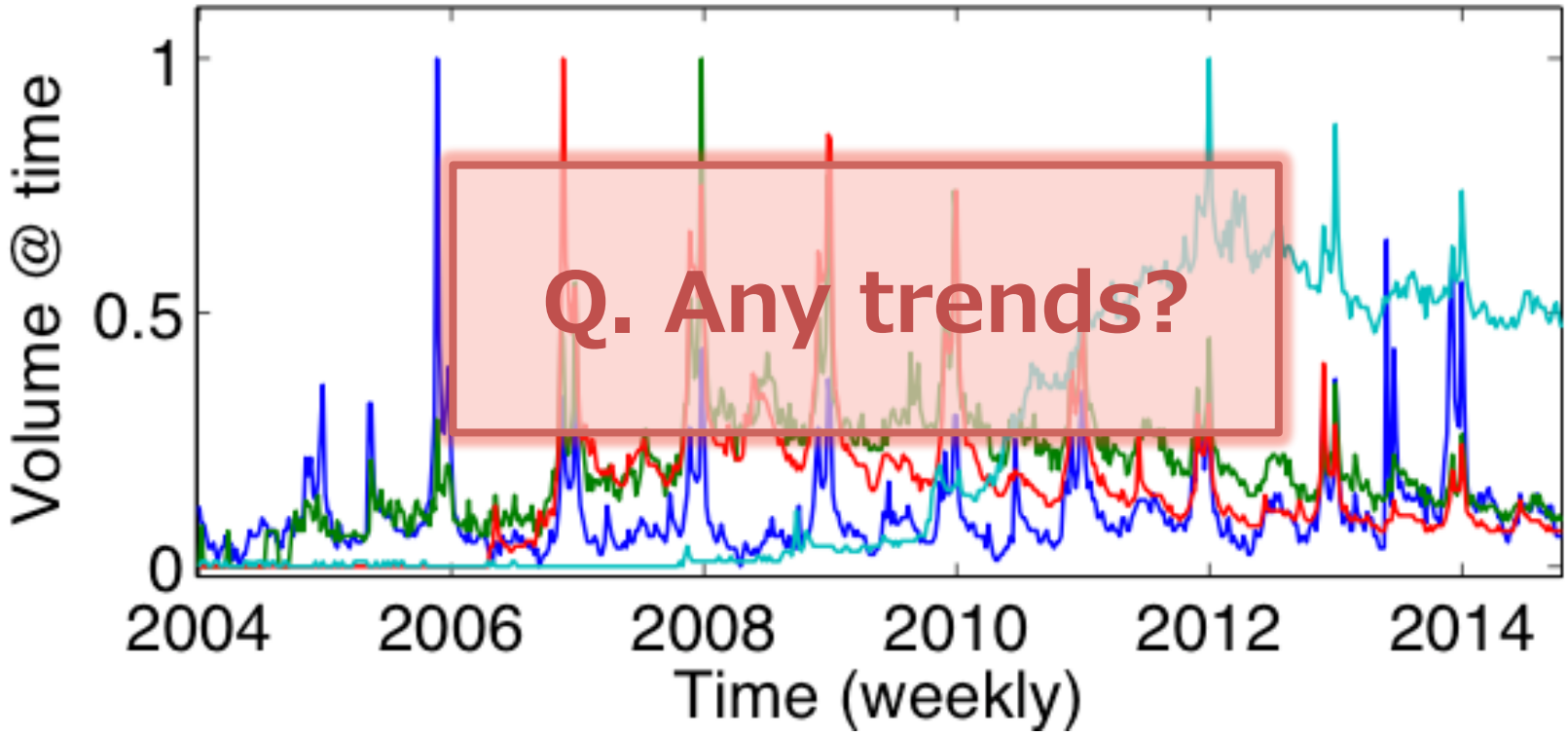

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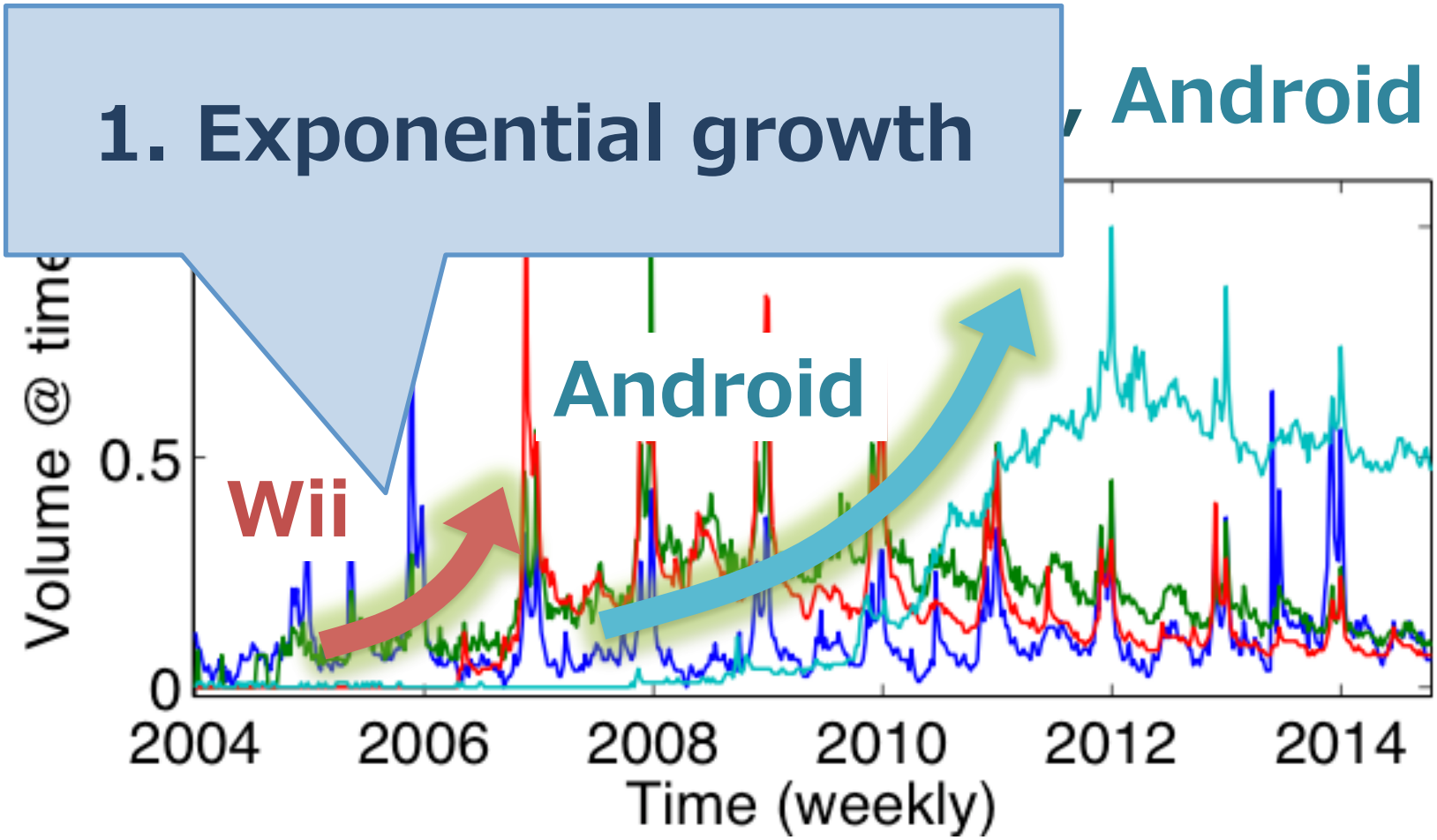

Given: online user activities

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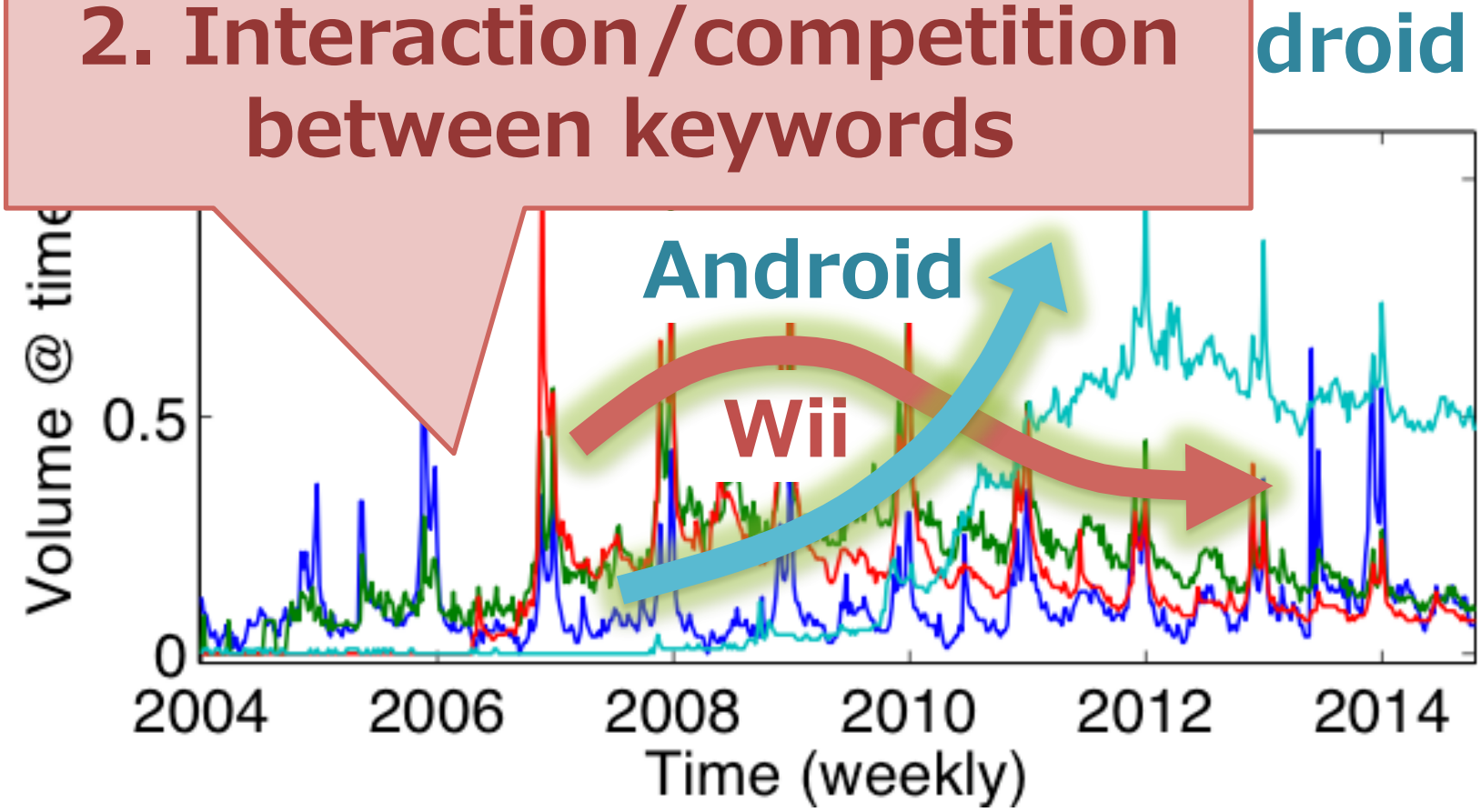
2. Interaction/competition between keywords



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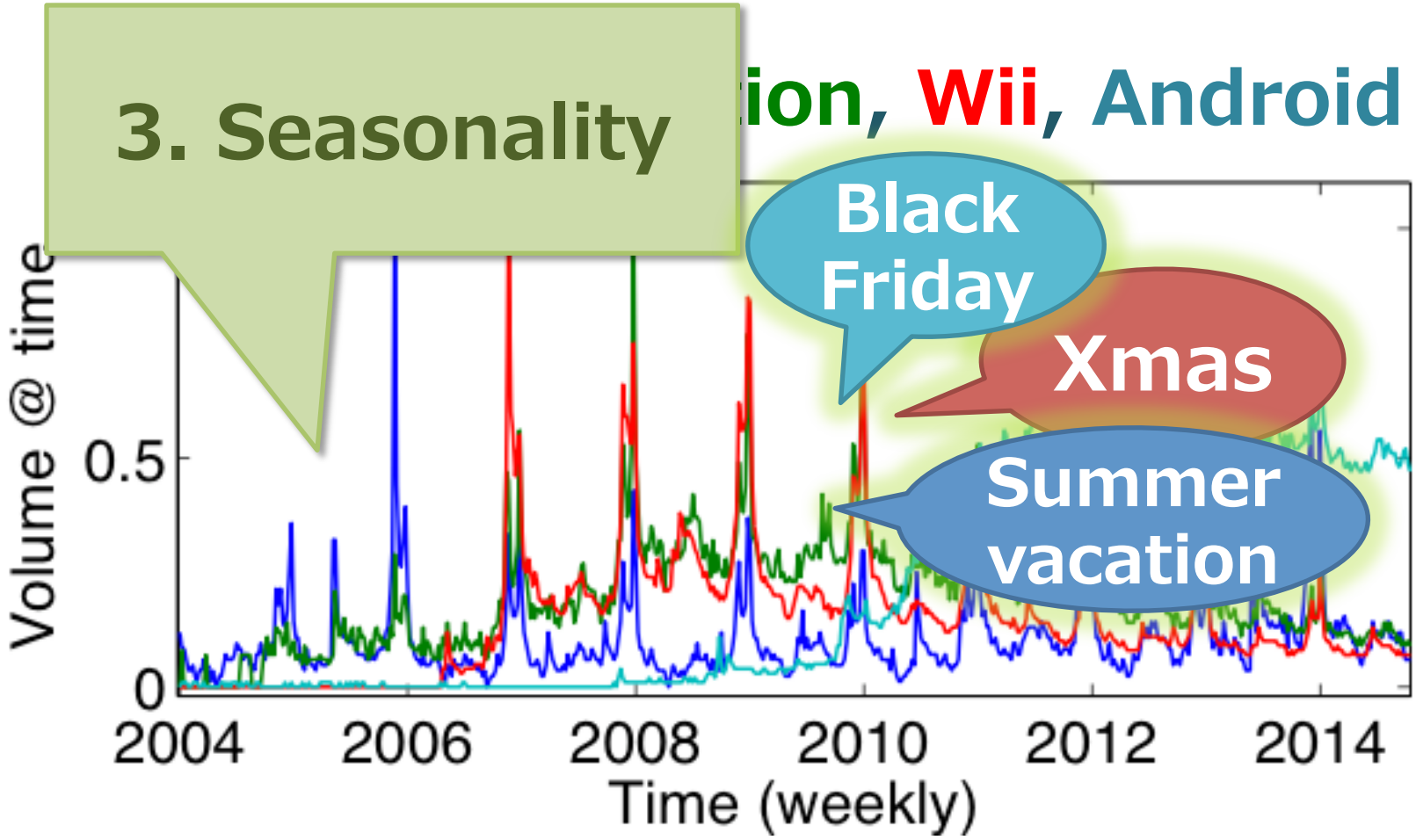

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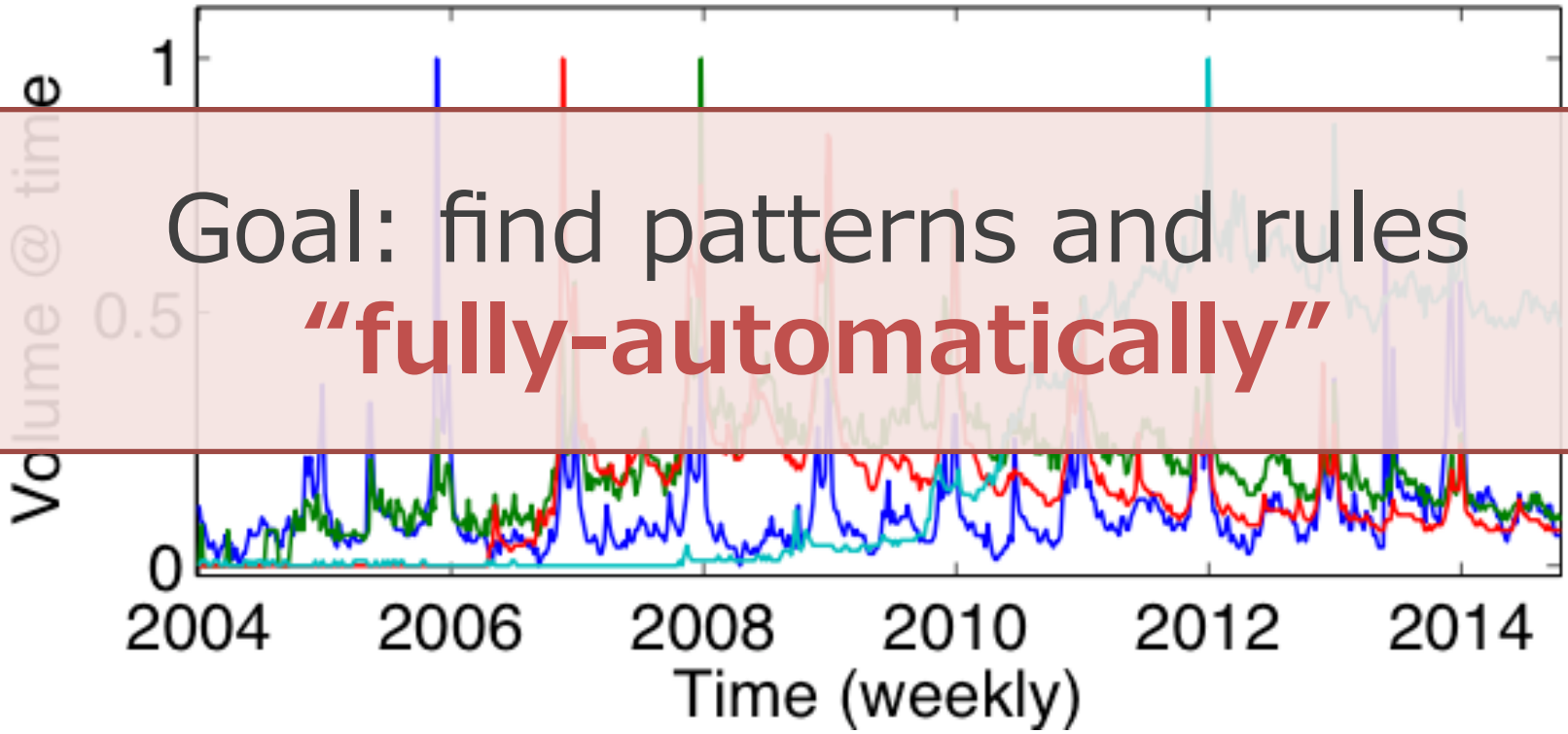
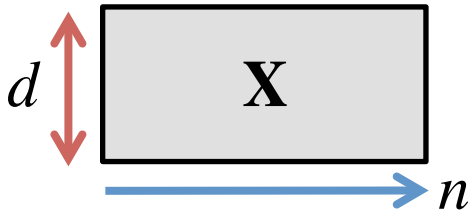


Goal: find patterns and rules
"fully-automatically"

Problem definition

Given: Co-evolving online activities

X (activity x time)



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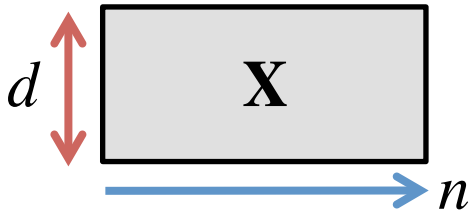
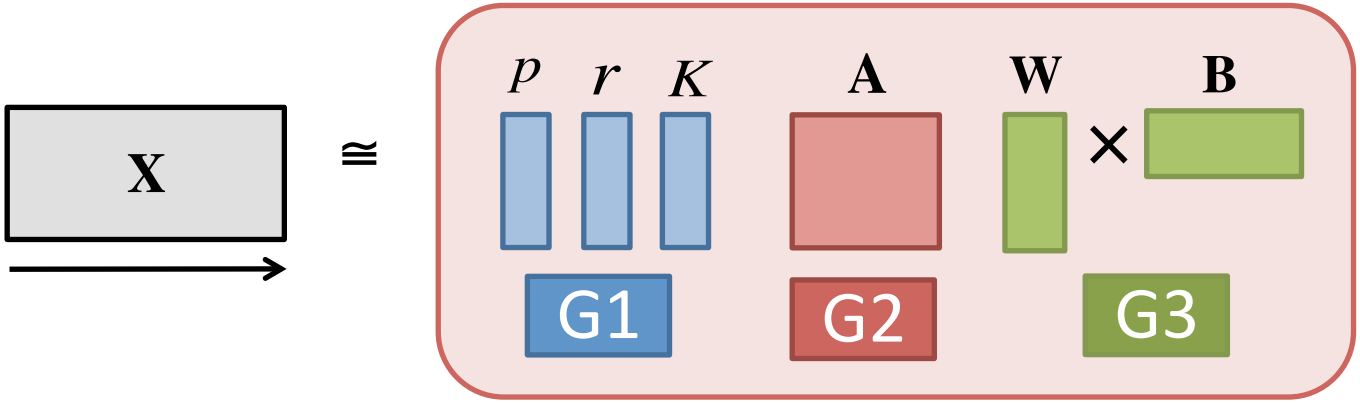


Find: Compact description of X

EcoWeb



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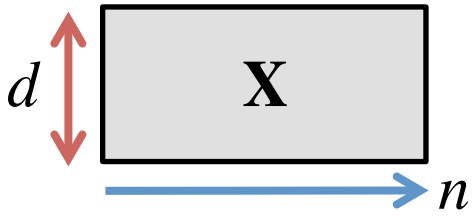
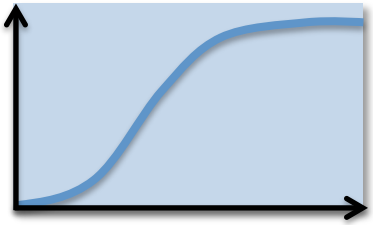
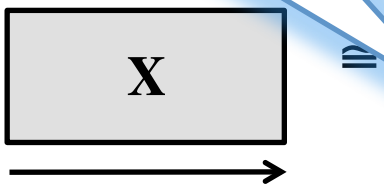


G1 **Non-linear evolution**



Fi scription of X

EcoWeb



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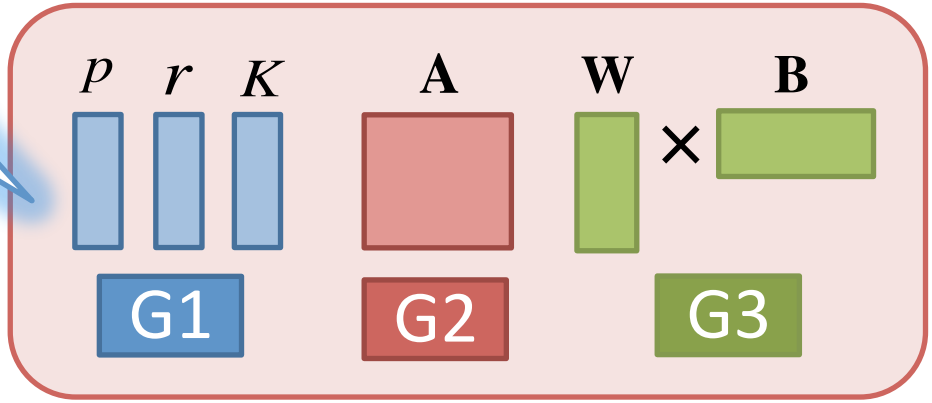

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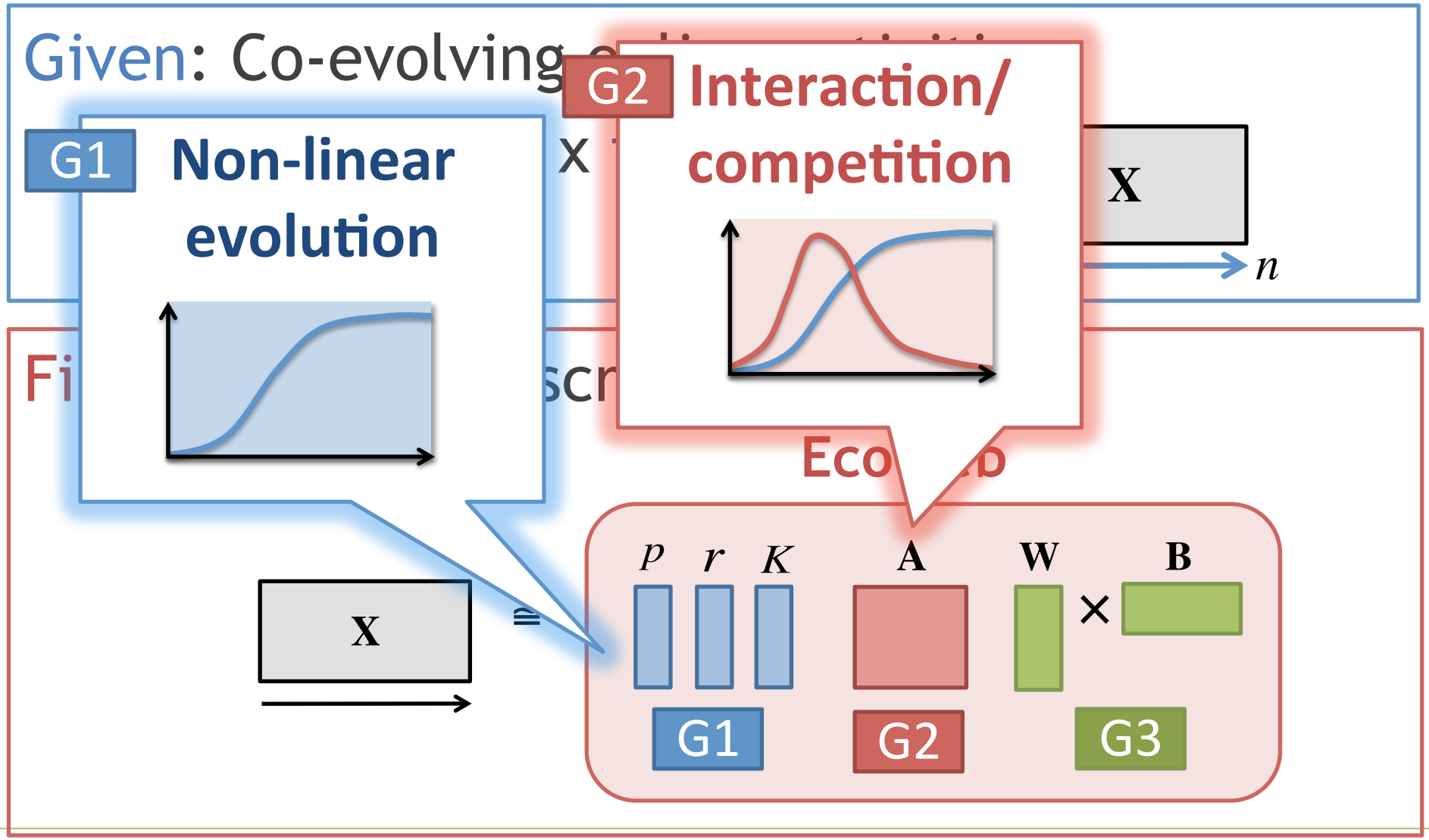

Problem definition

Given: Co-evolvi… …es

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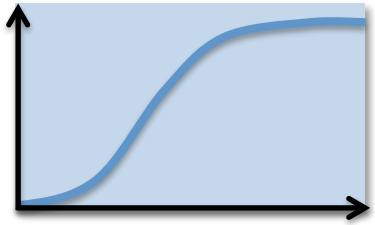
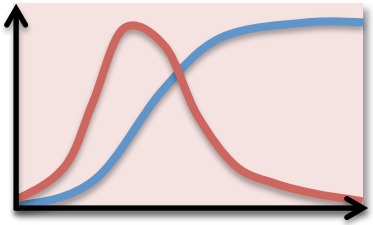
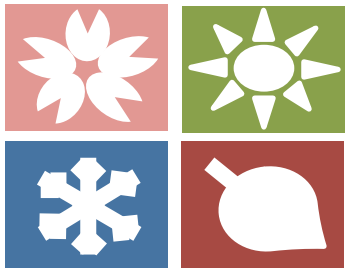


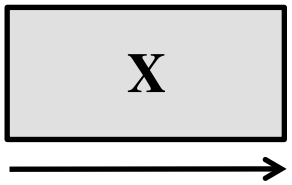
G2 **Interaction/ competition**



G3 **Seasonality**



F… …oWeb



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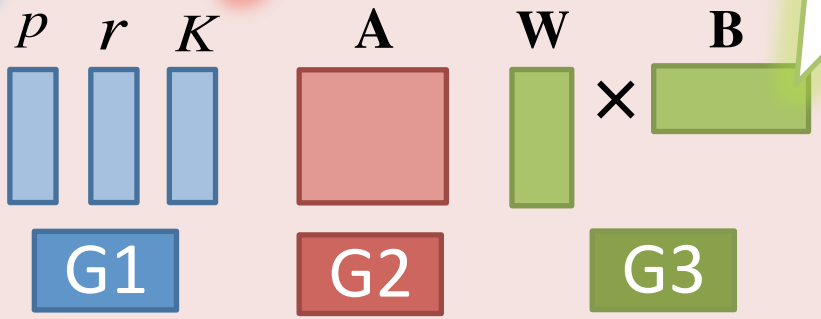
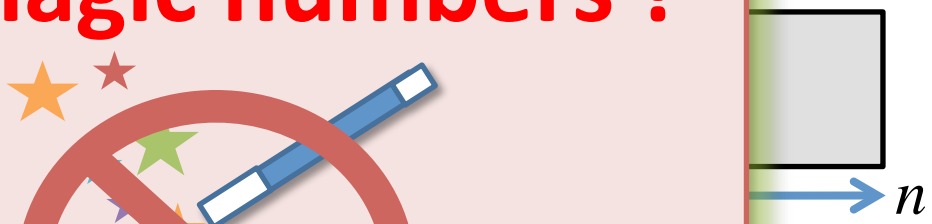


Problem definition

Given: Co-e

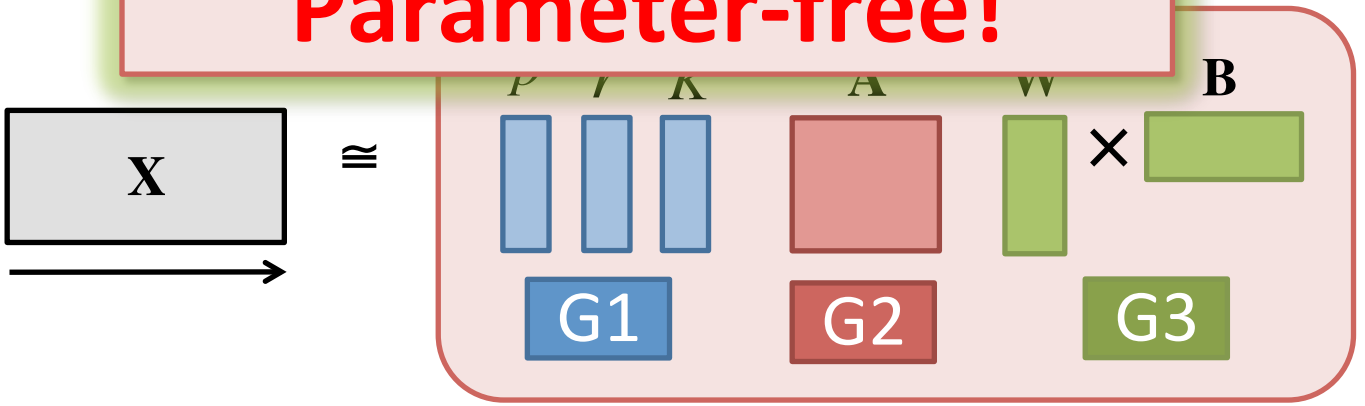
X (a



Find: Comp

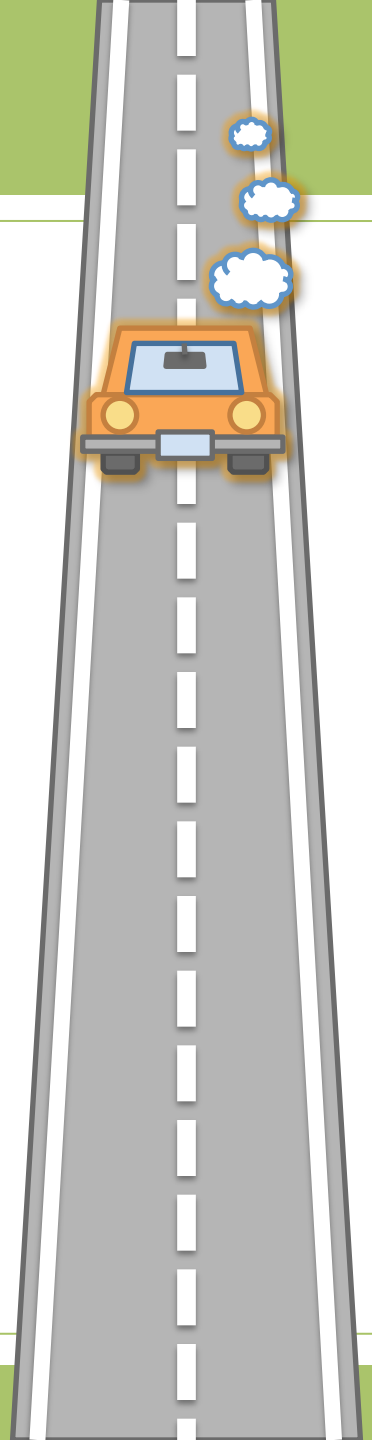
NO magic numbers !

Parameter-free!



Roadmap

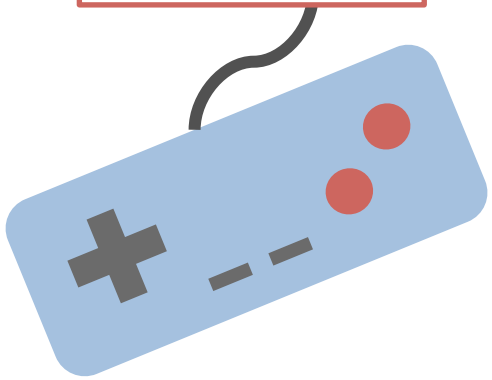
- ✔ Motivation
- Modeling power of EcoWeb
- Overview
- Proposed model
- Algorithm
- Experiments
- EcoWeb – at work
- Conclusions



Modeling power of EcoWeb

Questions

Q1



Q2

Q3

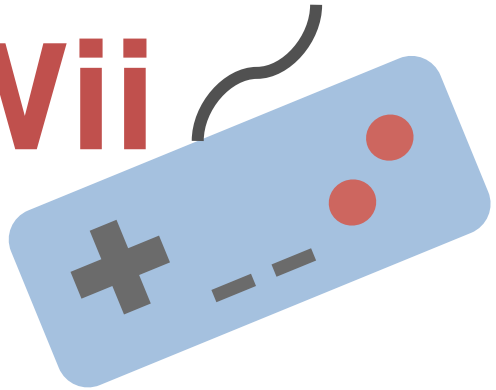
amazon

Modeling power of EcoWeb

Q1 (games)

Who is the competitor?

Wii

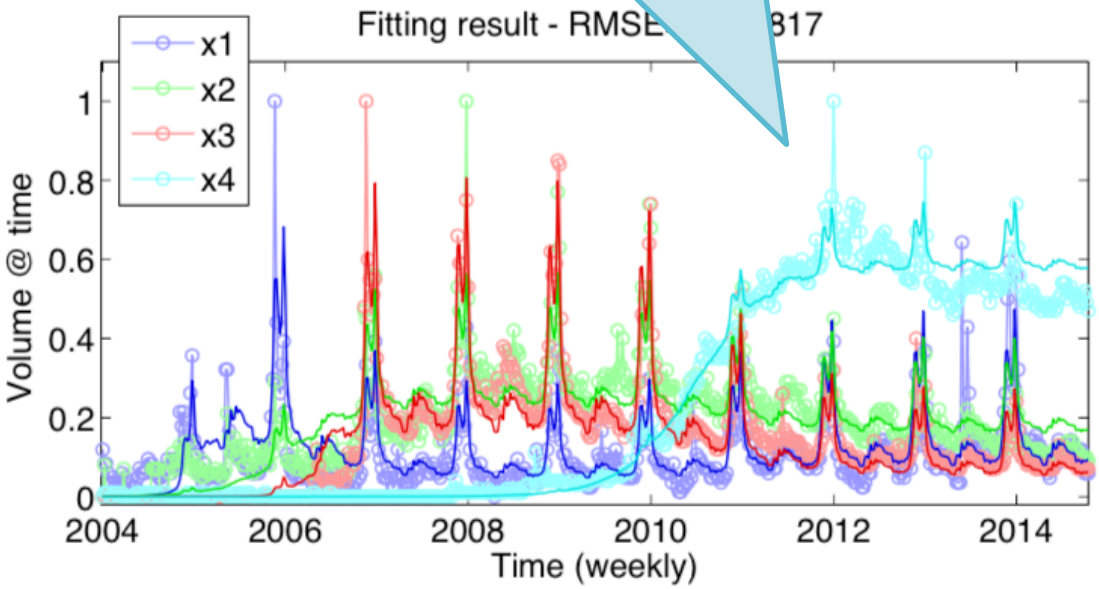


vs.

?

Modeling power of EcoWeb

A. Android!



EcoWeb-Fit

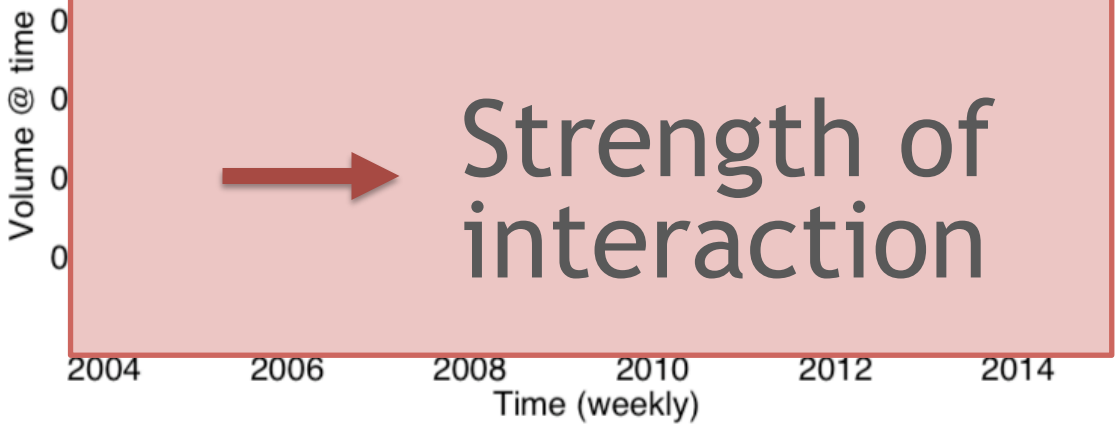
Interaction network (latent)

Modeling power of EcoWeb

A. Android!

Keyword

Strength of interaction



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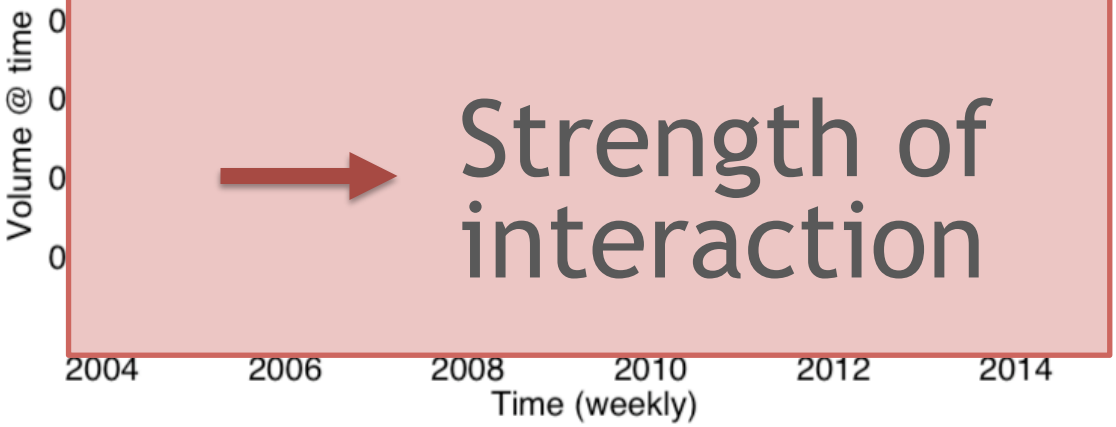

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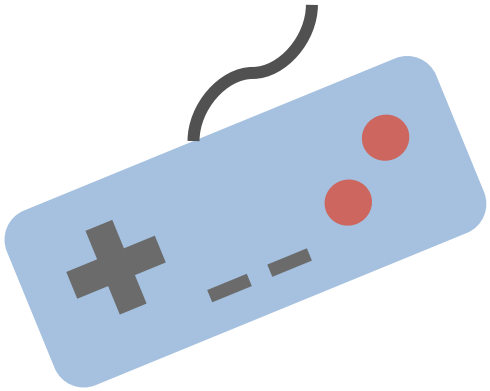
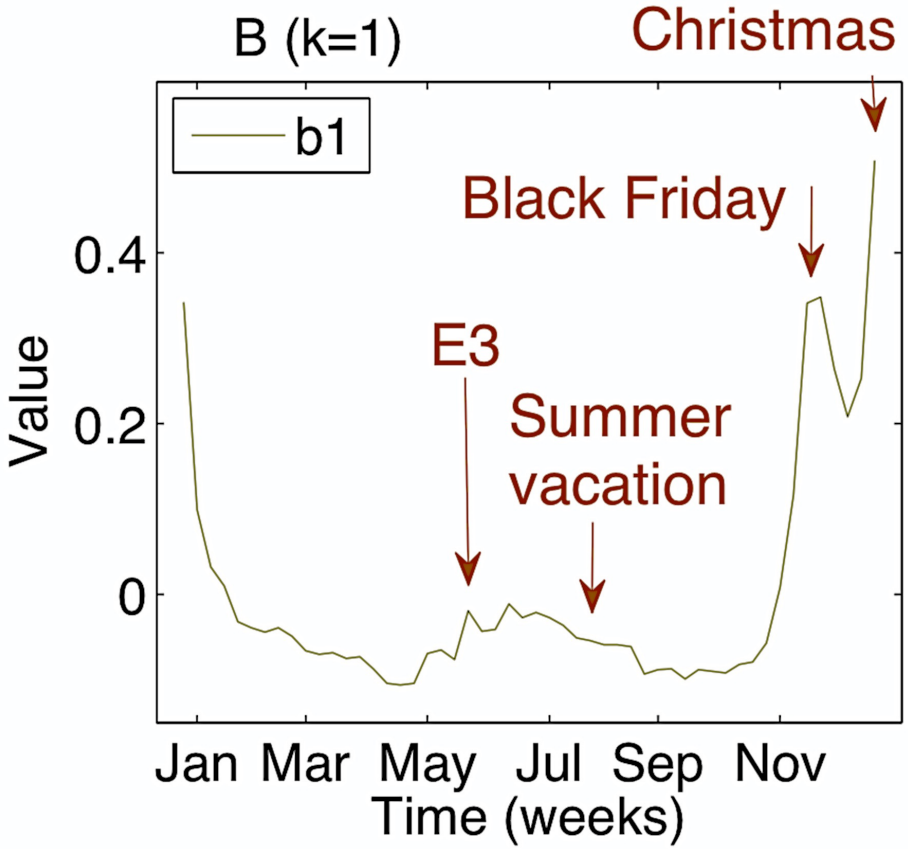
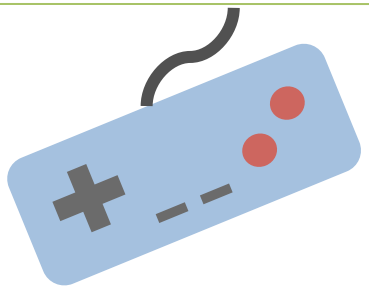
Q1 (games)

Any seasonal events?



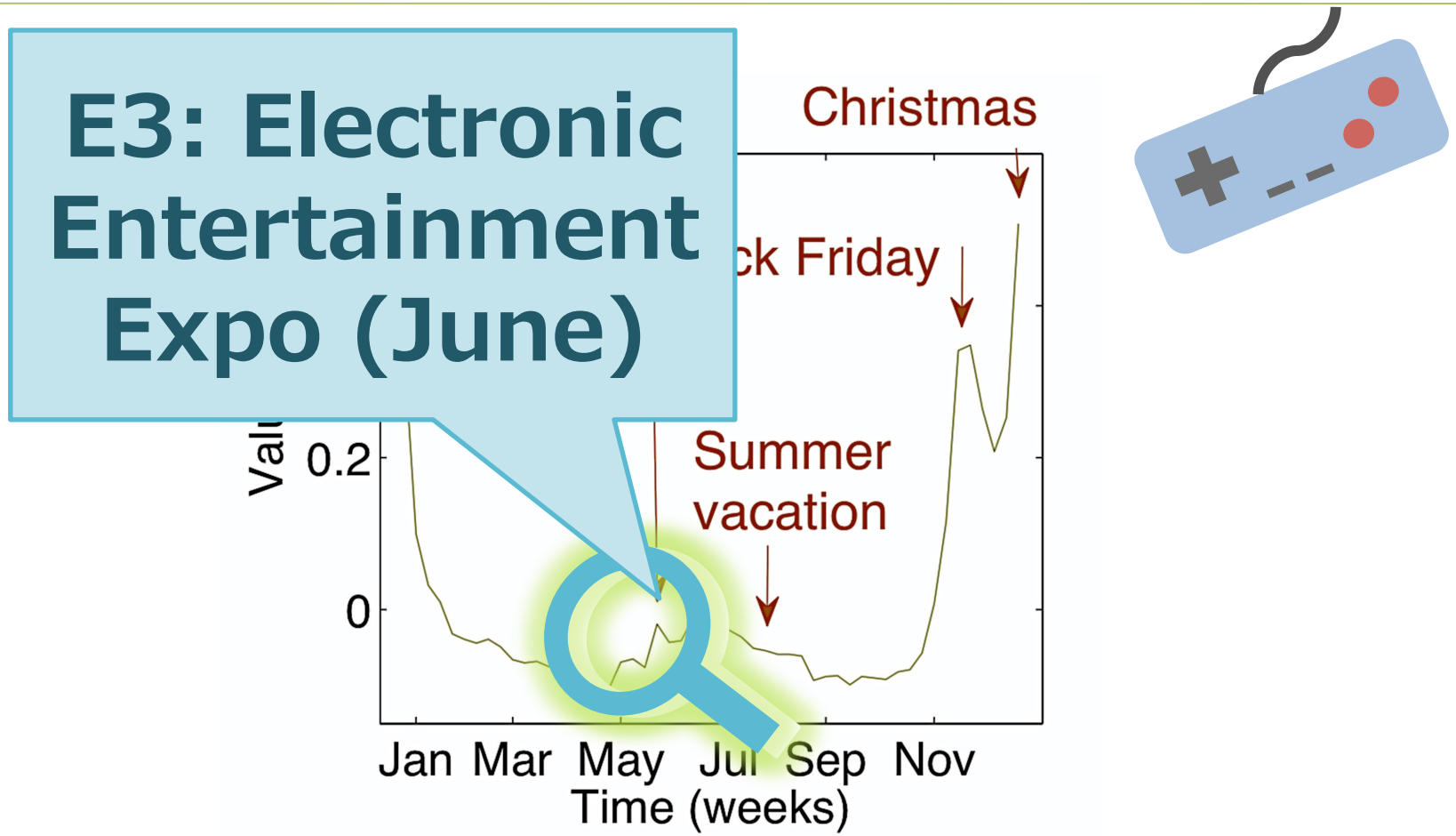
Modeling power of EcoWeb





EcoWeb: seasonal component

Modeling power of EcoWeb



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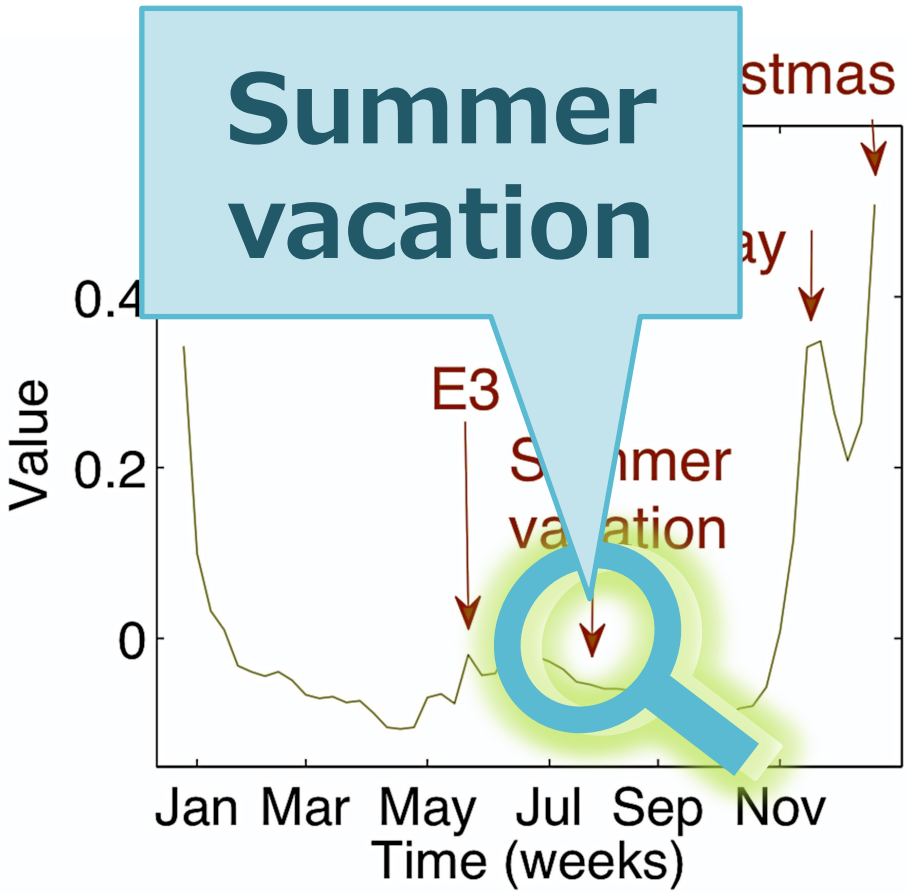
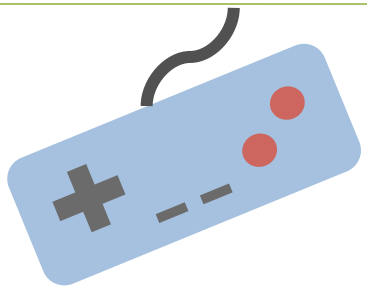
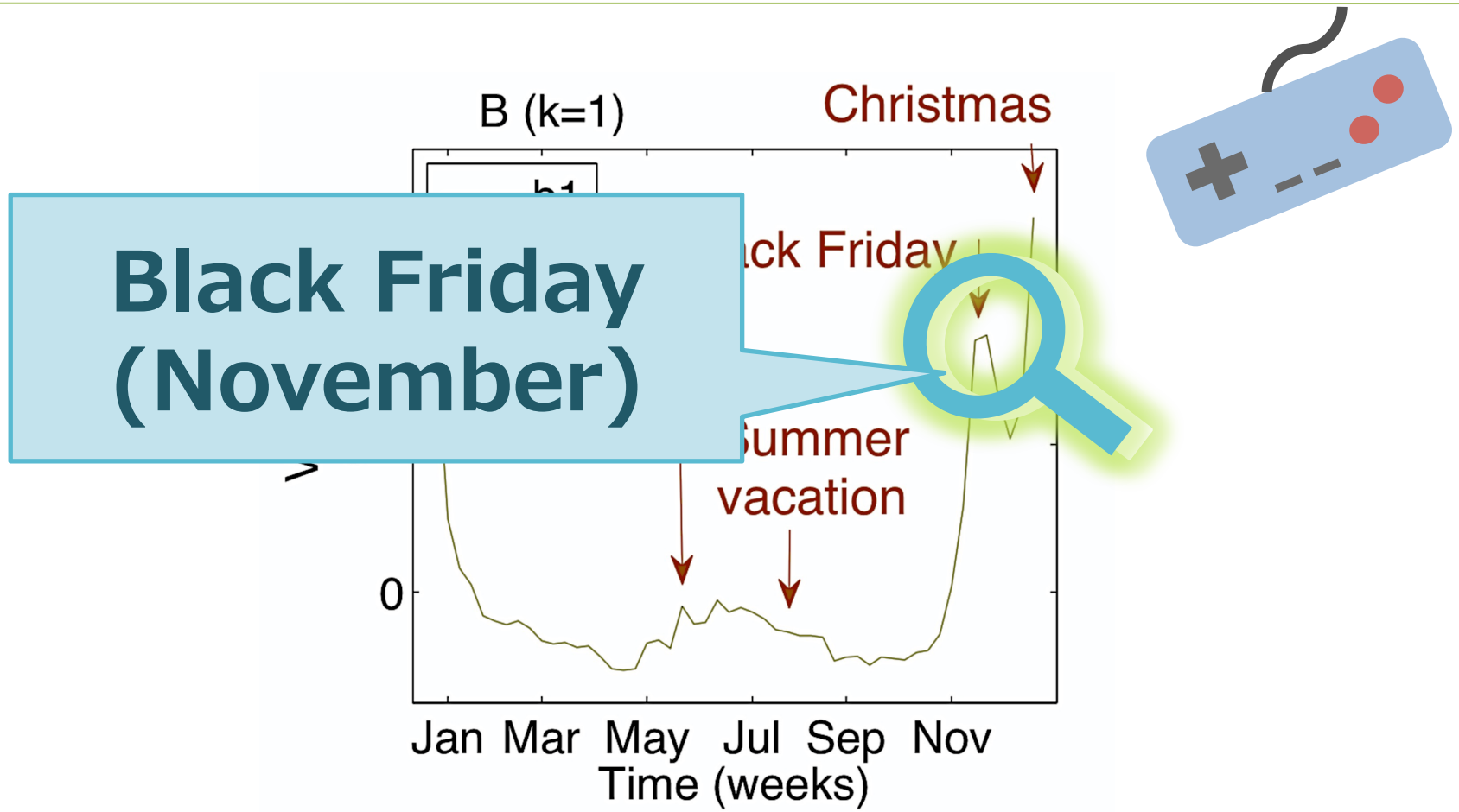




EcoWeb: seasonal component

Modeling power of EcoWeb



EcoWeb: seasonal component

Modeling power of EcoWeb

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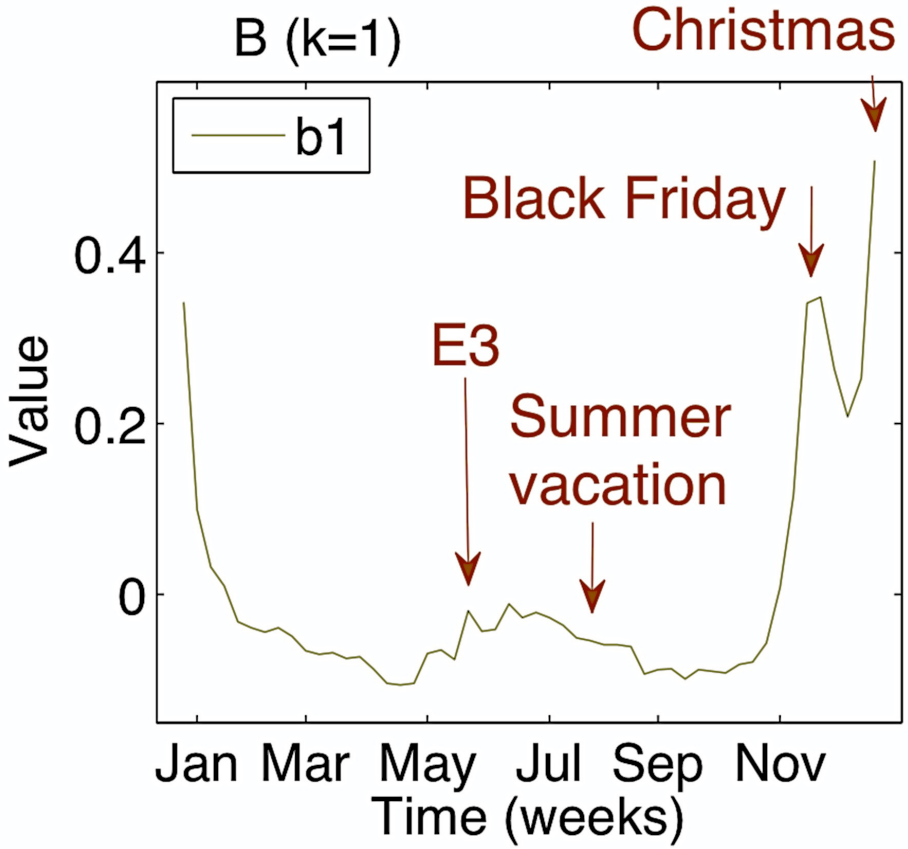

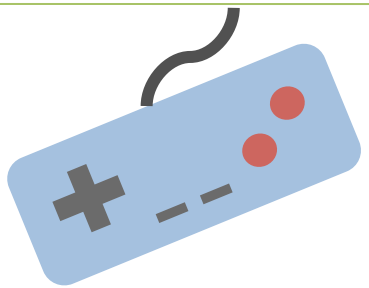

EcoWeb: seasonal component

Modeling power of EcoWeb

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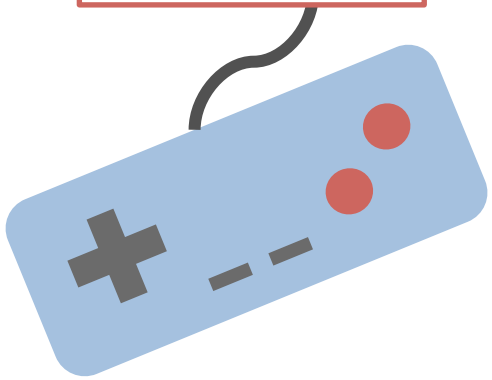


Q2

Q3

amazon

Modeling power of EcoWeb

Q2 (apparels)

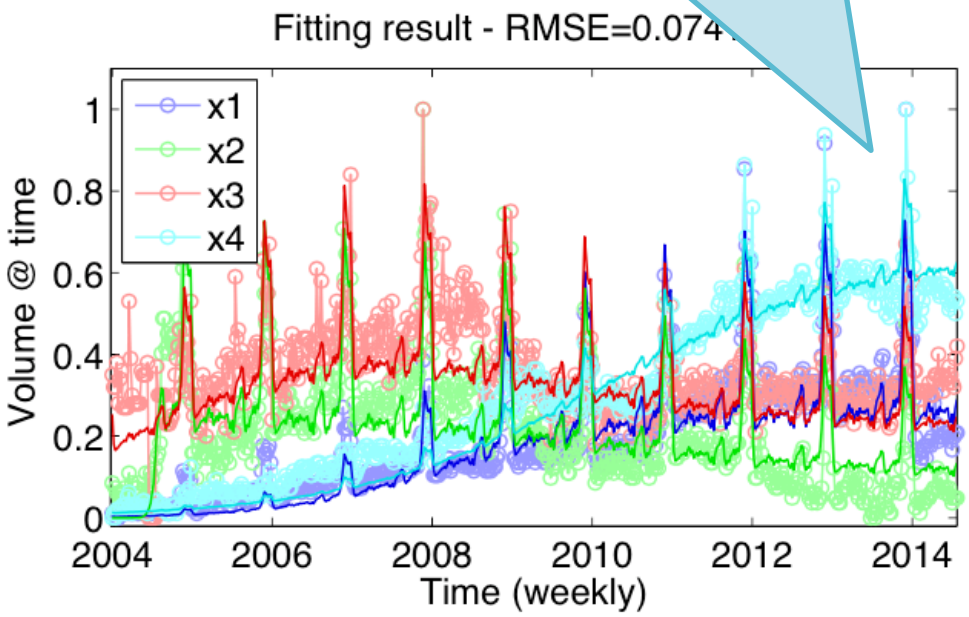
Who is the competitor?

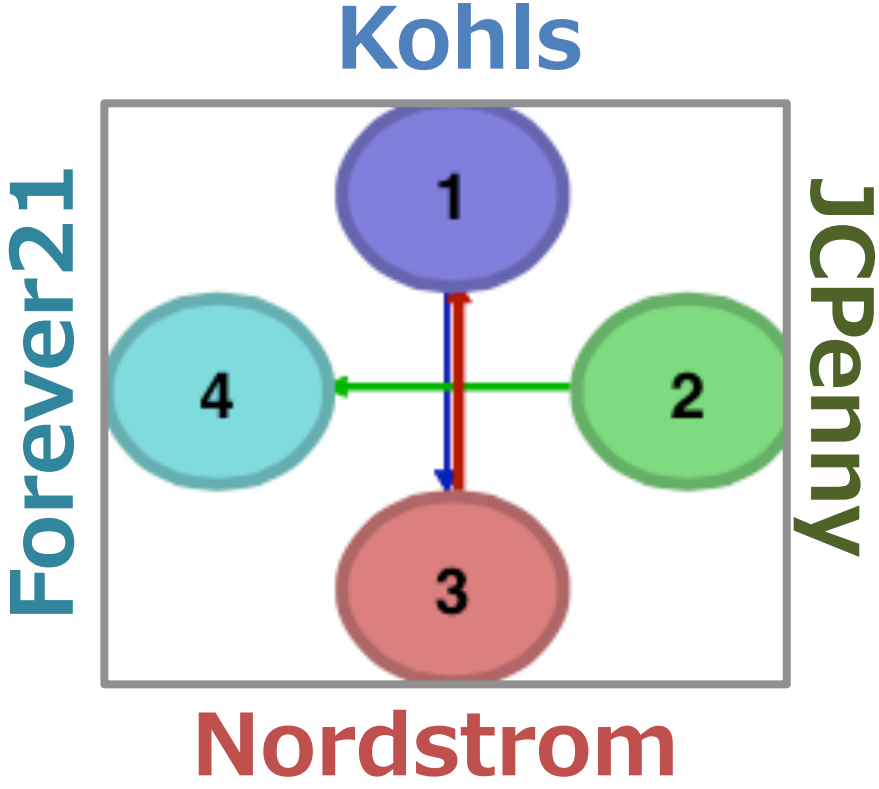
JCPenny

vs.

Modeling power of EcoWeb

A2. Forever21!





EcoWeb: Interaction network

Modeling power of EcoWeb

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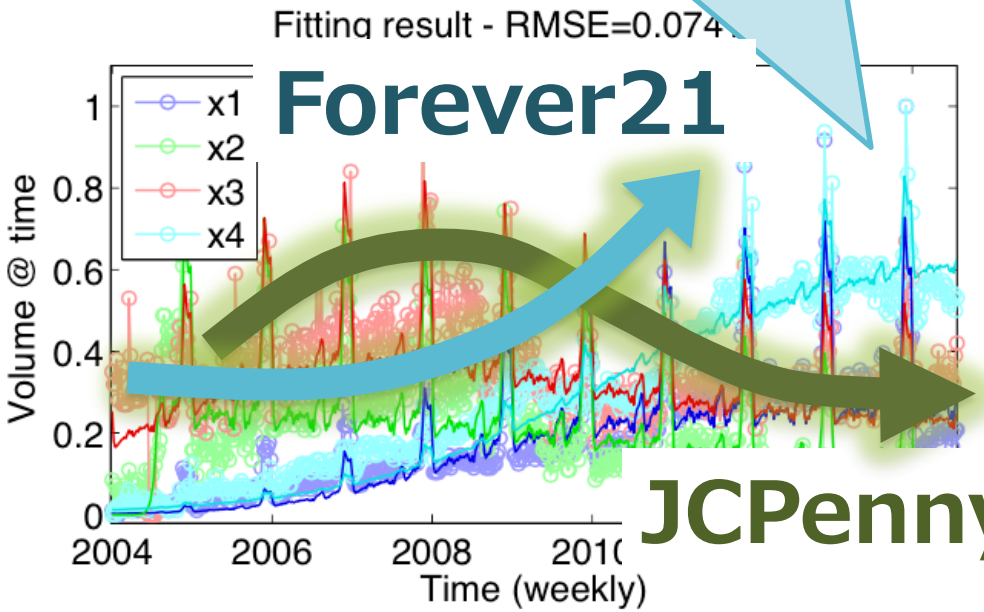
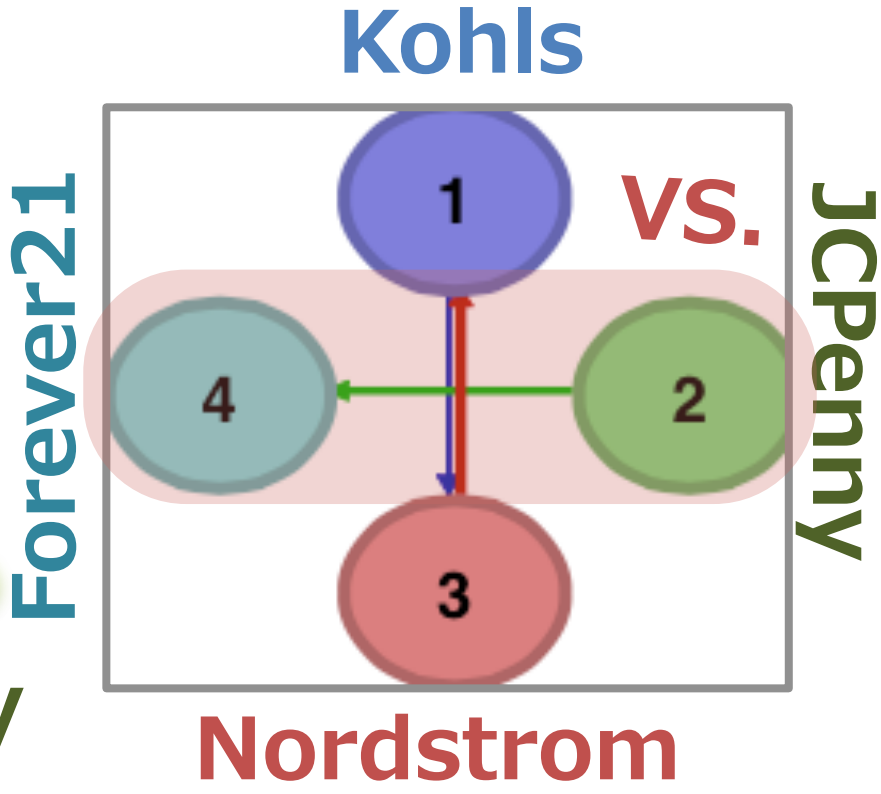




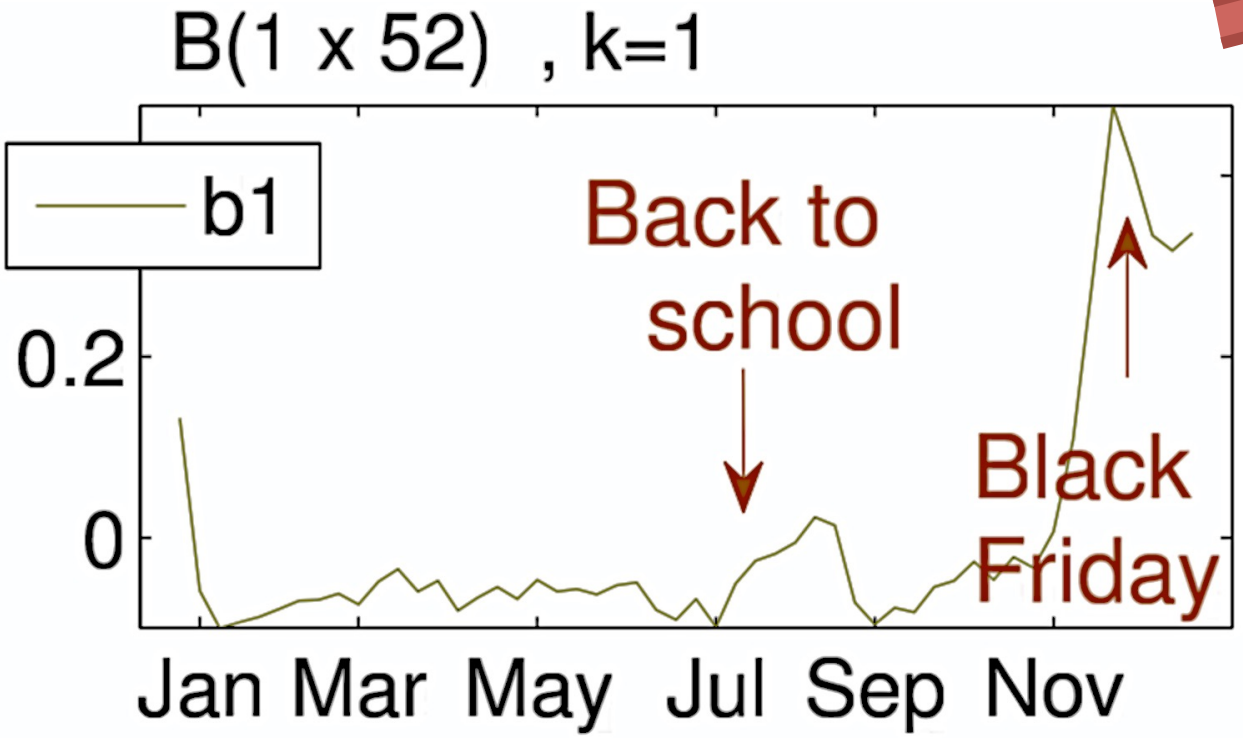
EcoWeb: Interaction network

Modeling power of EcoWeb

Q2 (apparels)

Any seasonal events?

Modeling power of EcoWeb

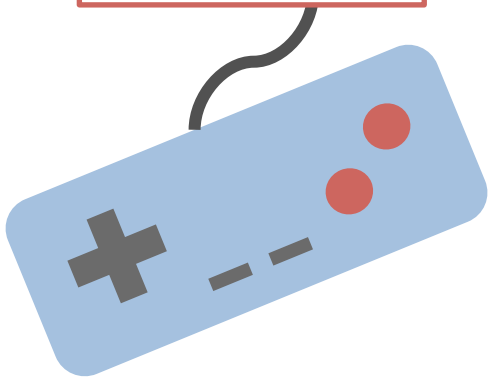


EcoWeb: seasonal component

Modeling power of EcoWeb

Questions

Q1



Q2

Q3

amazon

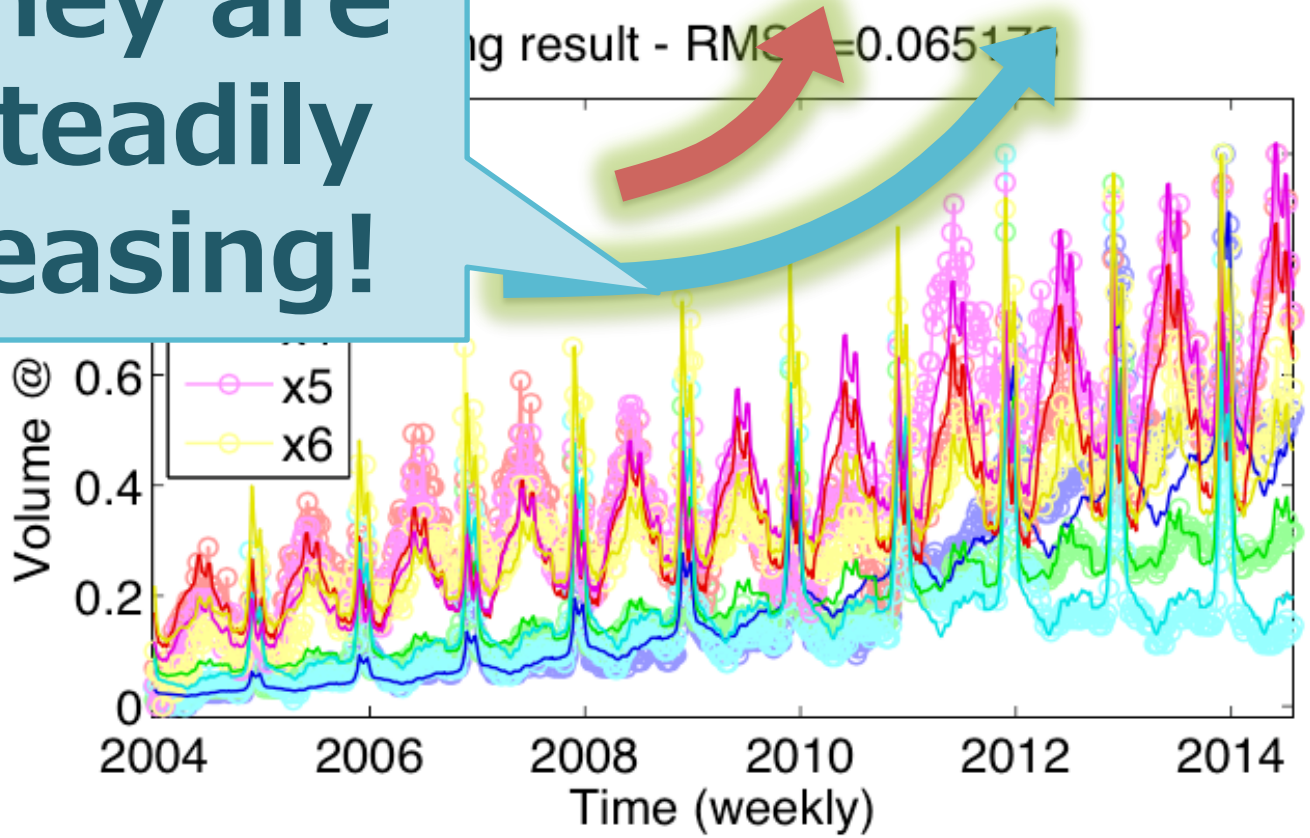
Modeling power of EcoWeb

Q3 (retails)

Any patterns/trends?

Modeling power of EcoWeb

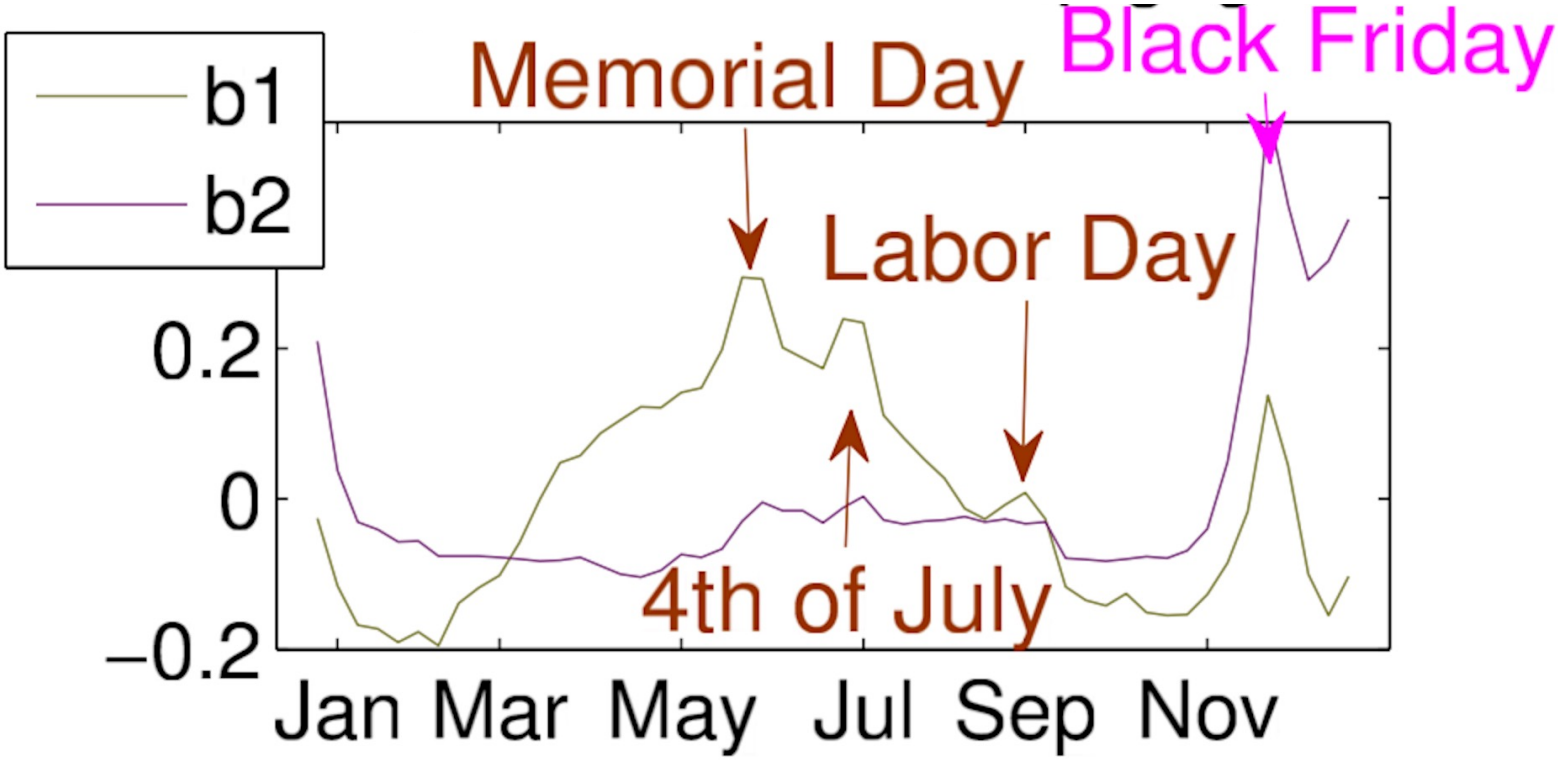
A. They are all steadily increasing!



Amazon, Walmart, Home Depot, Best buy, …

Modeling power of EcoWeb

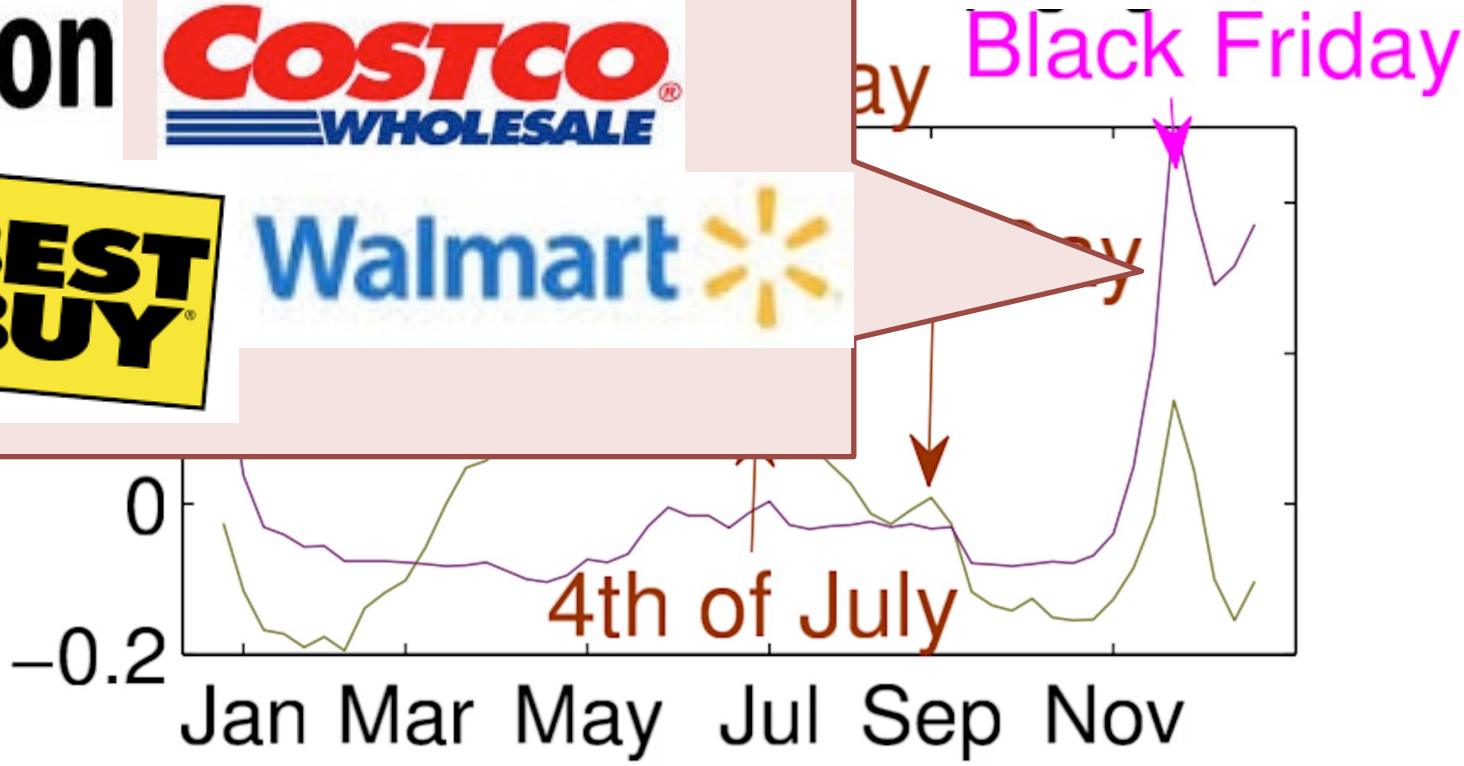
2 seasonal components



Modeling power of EcoWeb

2 seasonal components

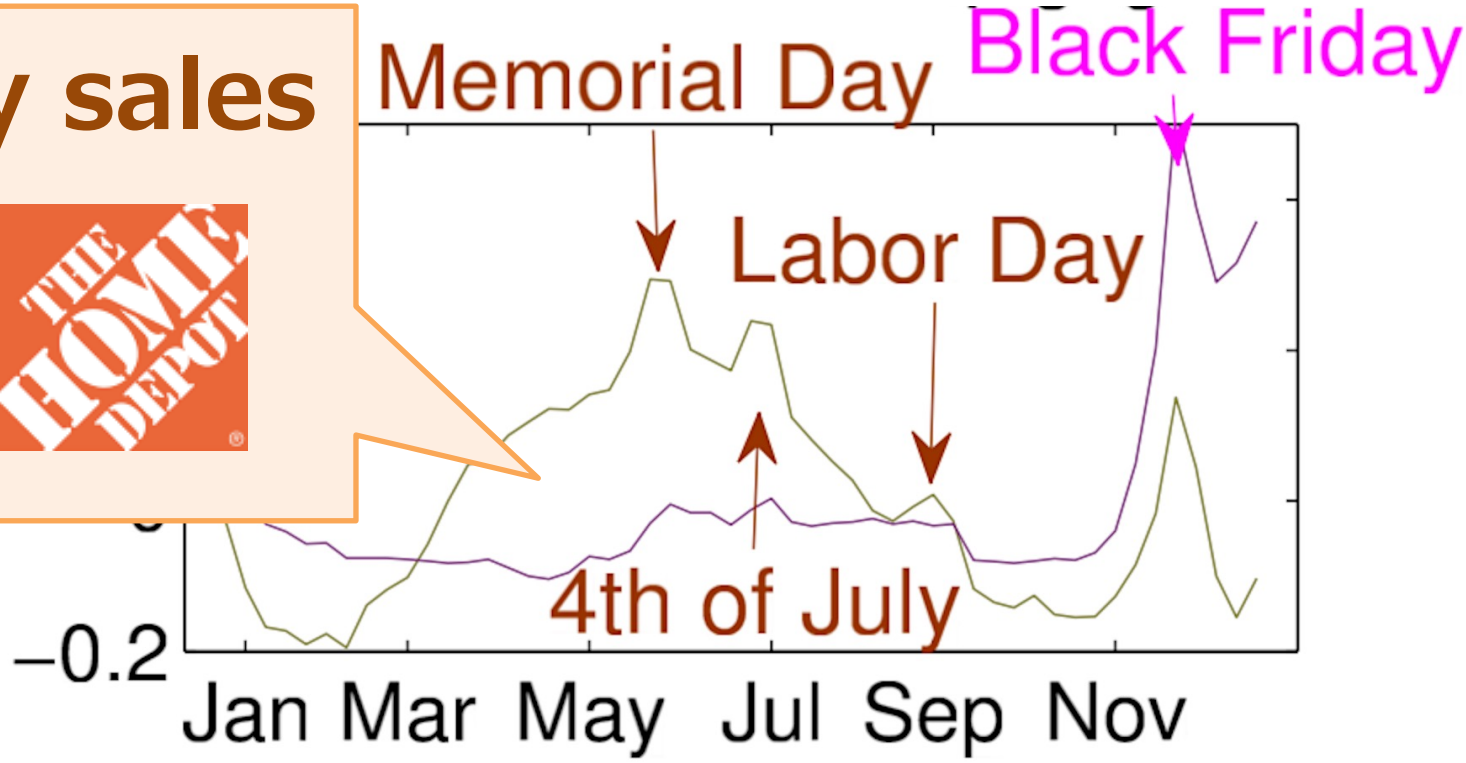
Black Friday sale



Modeling power of EcoWeb

2 seasonal components

Holiday sales



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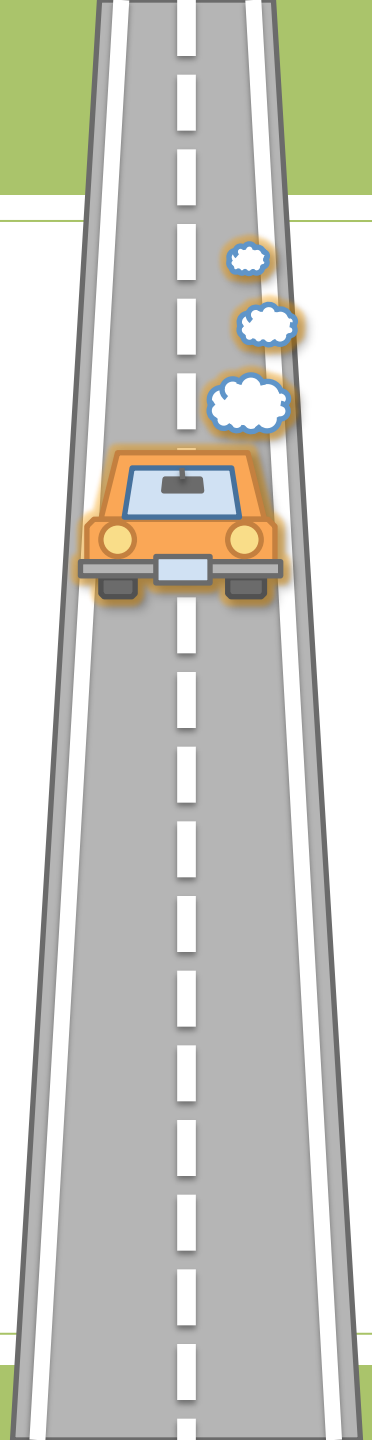

Problem definition

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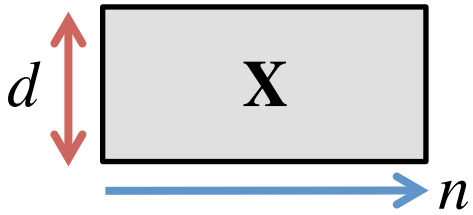

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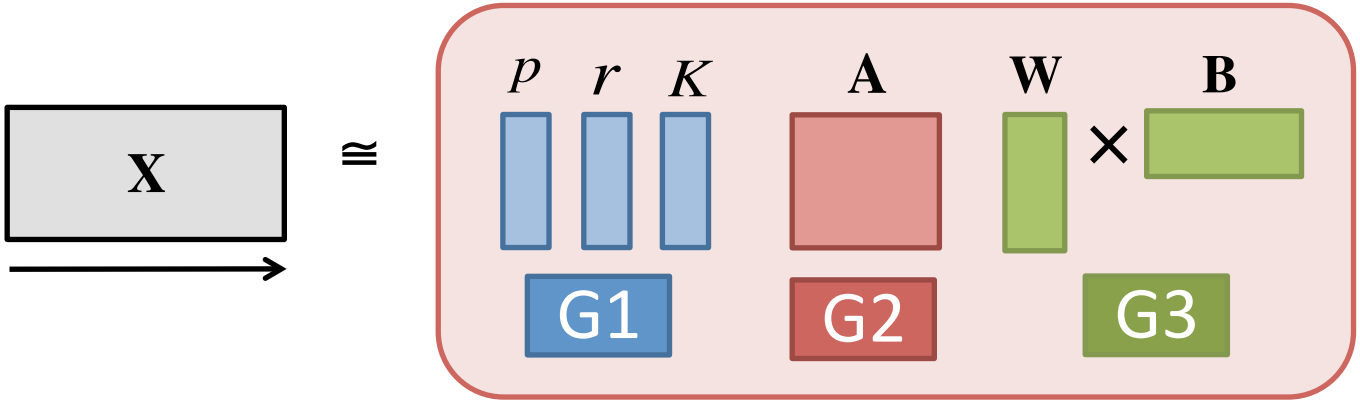
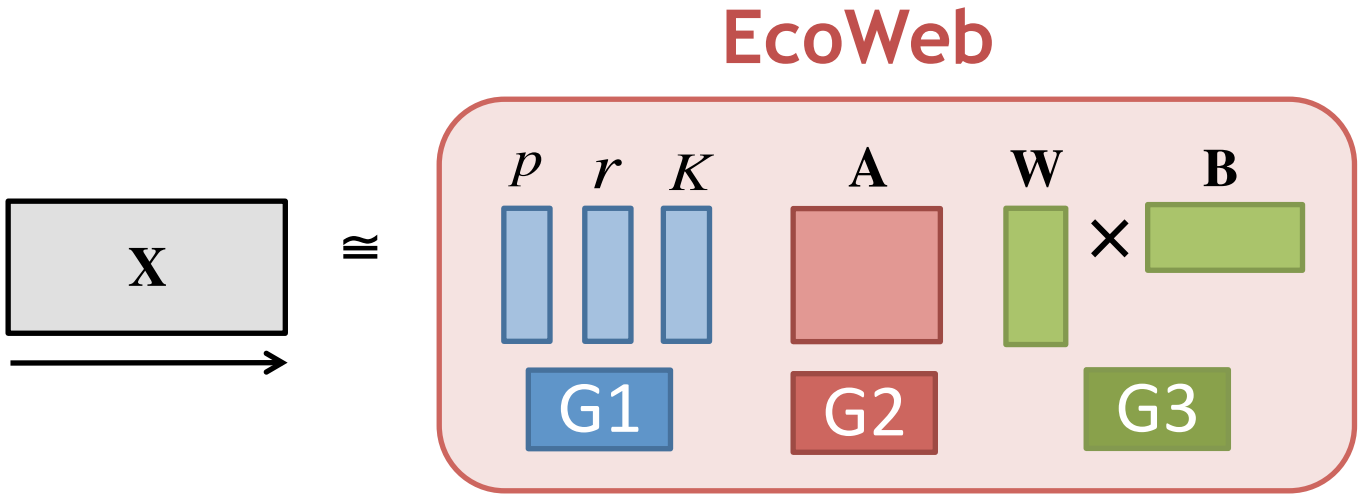
EcoWeb



EcoWeb: Main idea

Q. How can we describe the evolutions of X ?



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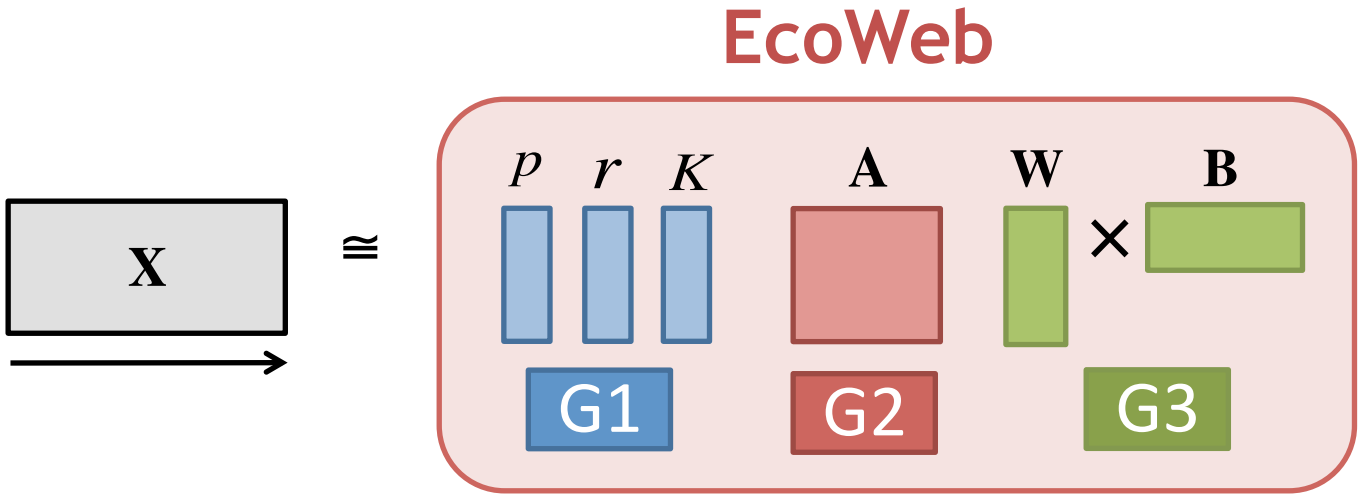
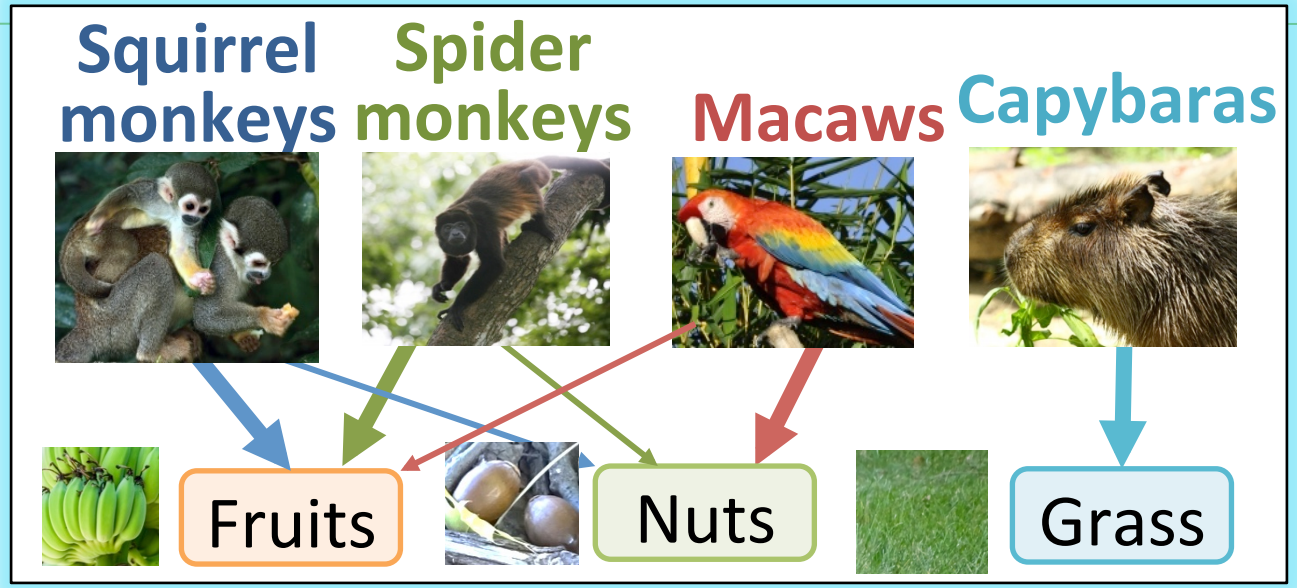


A. The Web as a jungle!

- "virtual species" living on the Web
- Interacting with other species (activities)

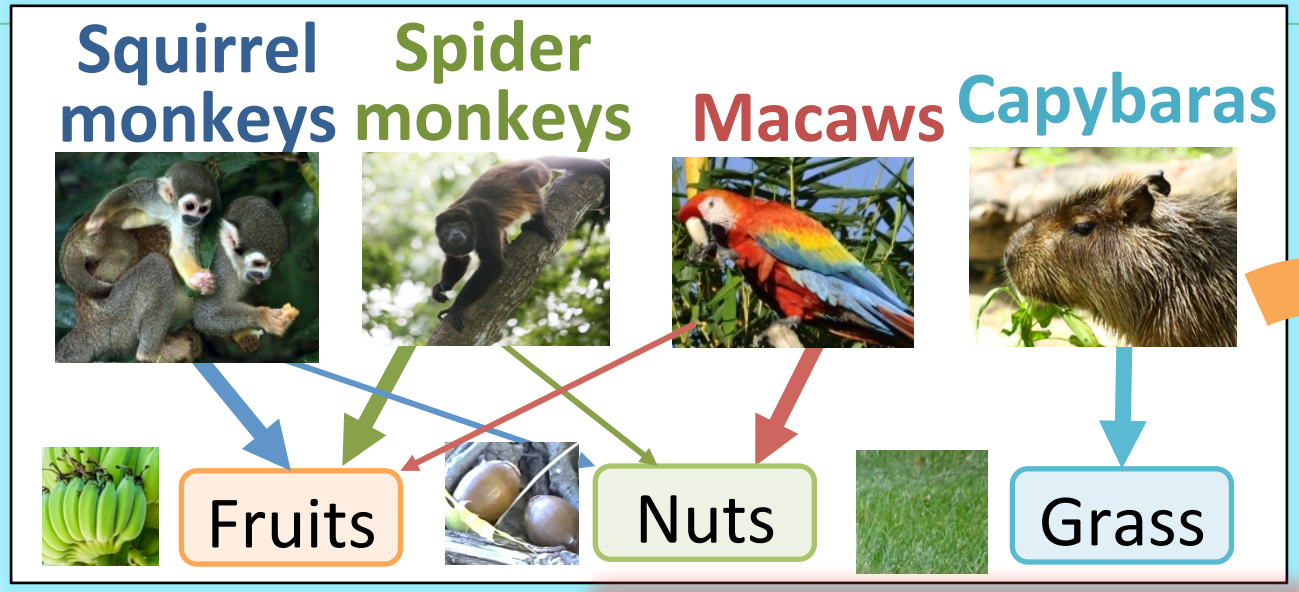
Main idea: the Web as a jungle



Ecosystem in the **Jungle**

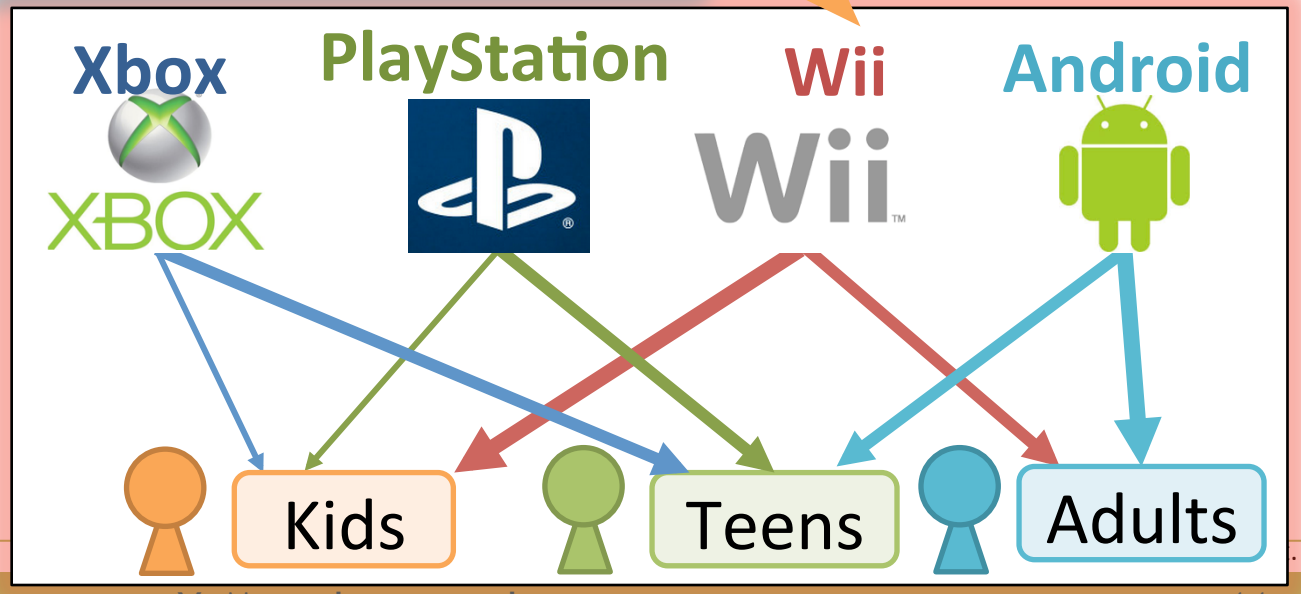
Image courtesy of xura, criminalatt, David Castillo Dominici, happykanppy at FreeDigitalPhotos.net.

Main idea: the Web as a jungle



Ecosystem in the **Jungle**

Ecosystem on the **Web**



Analogies: ecosystem on the Web

Biological species

Online activities

Jungle

Web

Image courtesy of xura, criminalatt, David Castillo Dominici, happykanppy at FreeDigitalPhotos.net.

Analogies: ecosystem on the Web

Biological species

Food resources

Online activities

User resources

Jungle

Web

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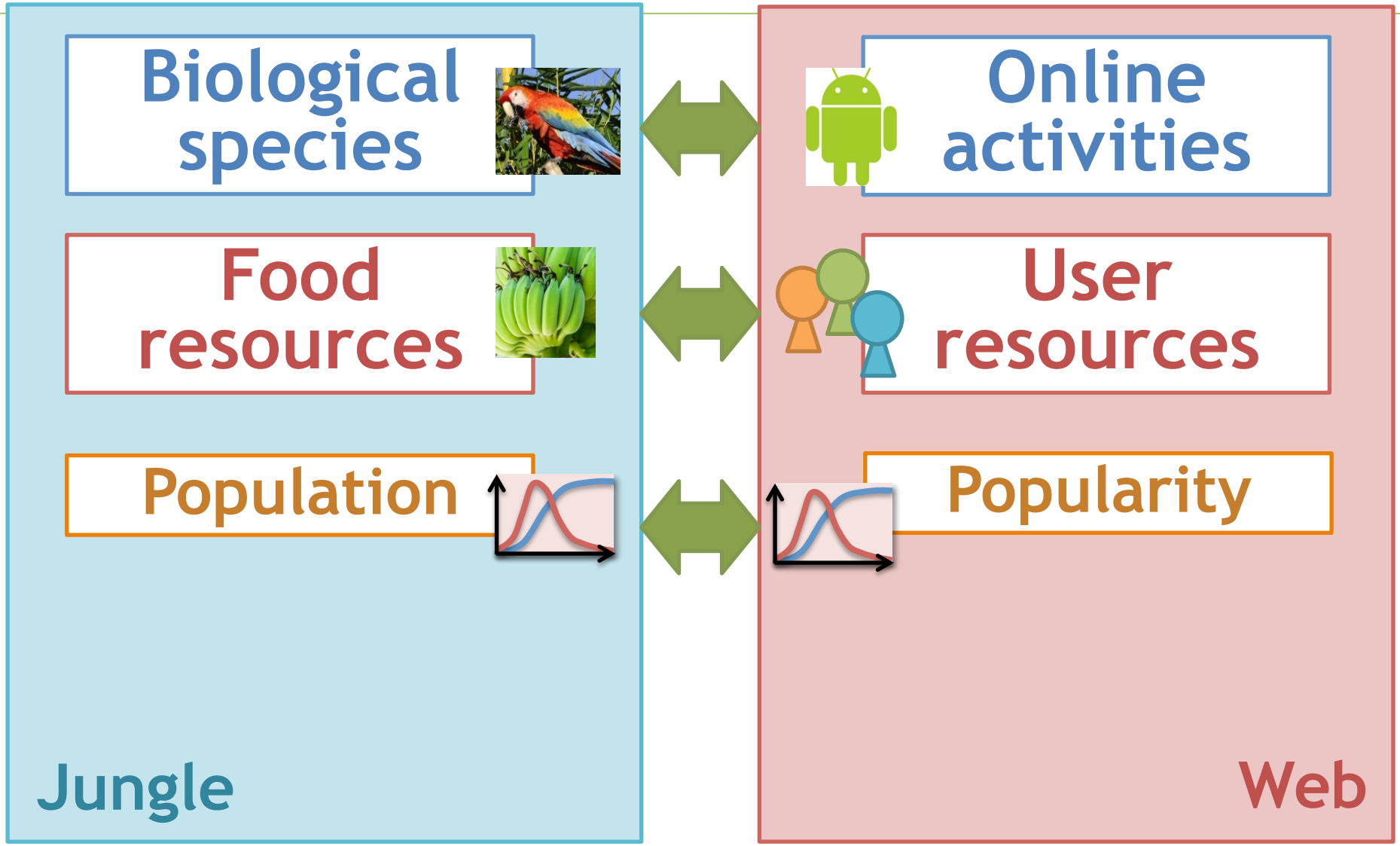
Analogies: ecosystem on the Web



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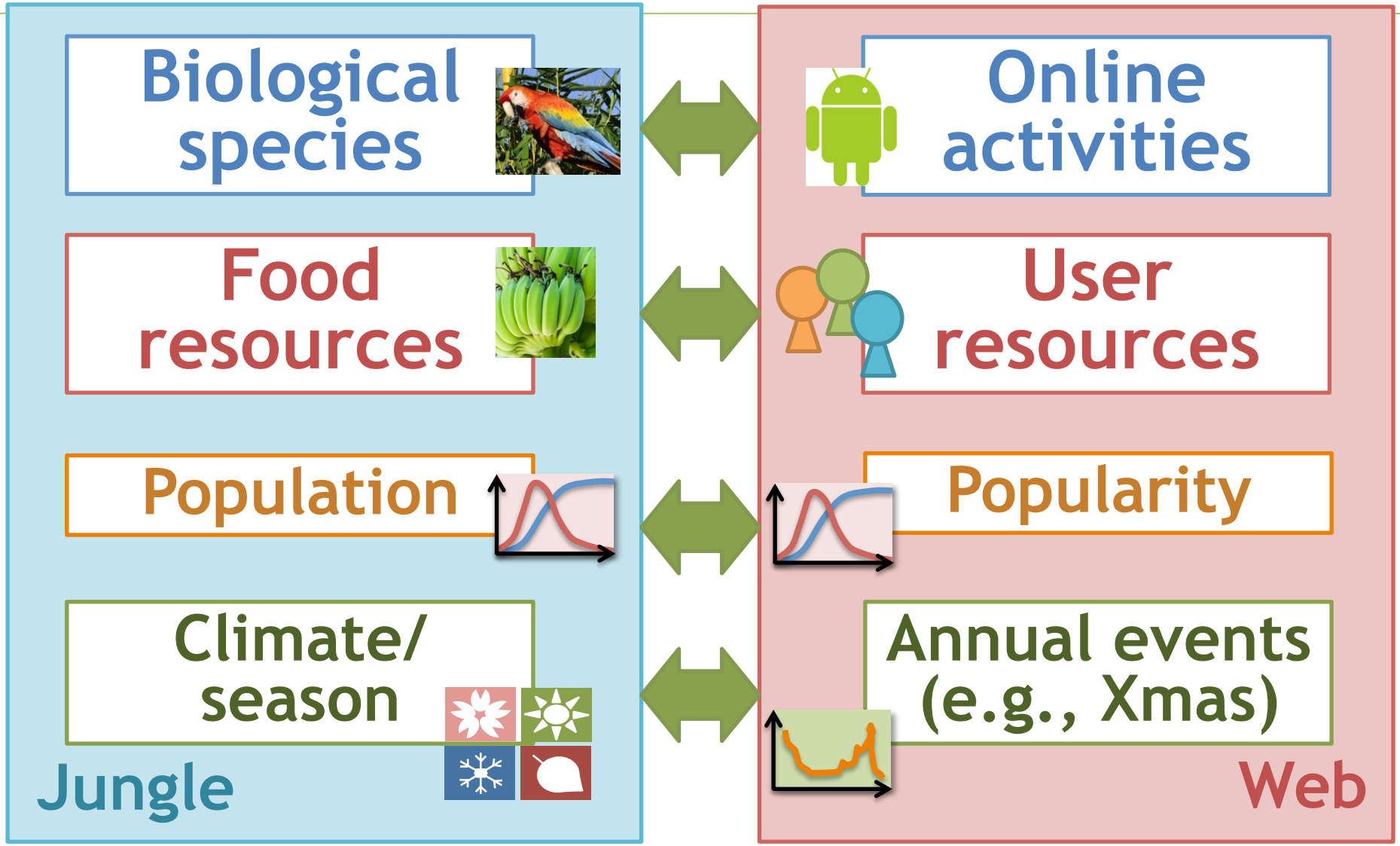
Analogies: ecosystem on the Web



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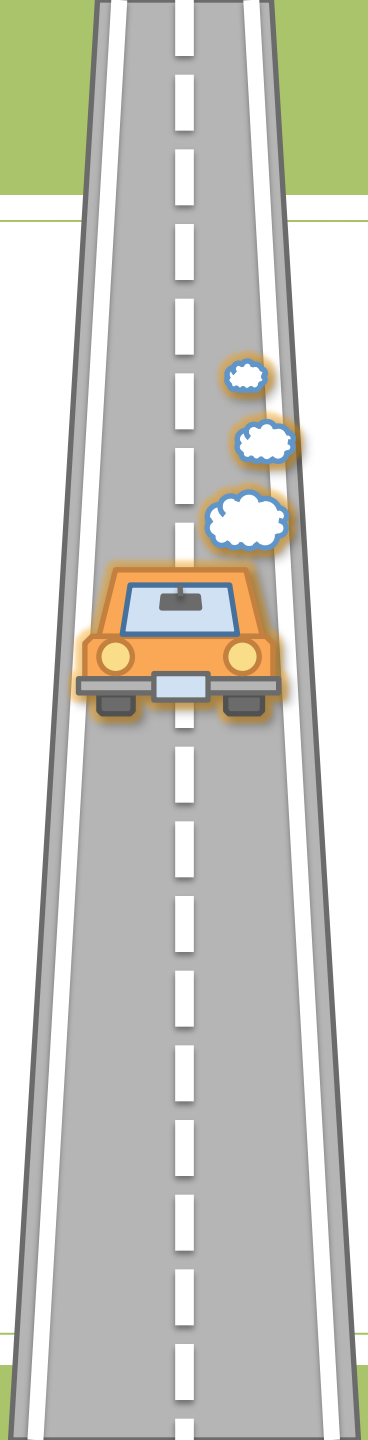
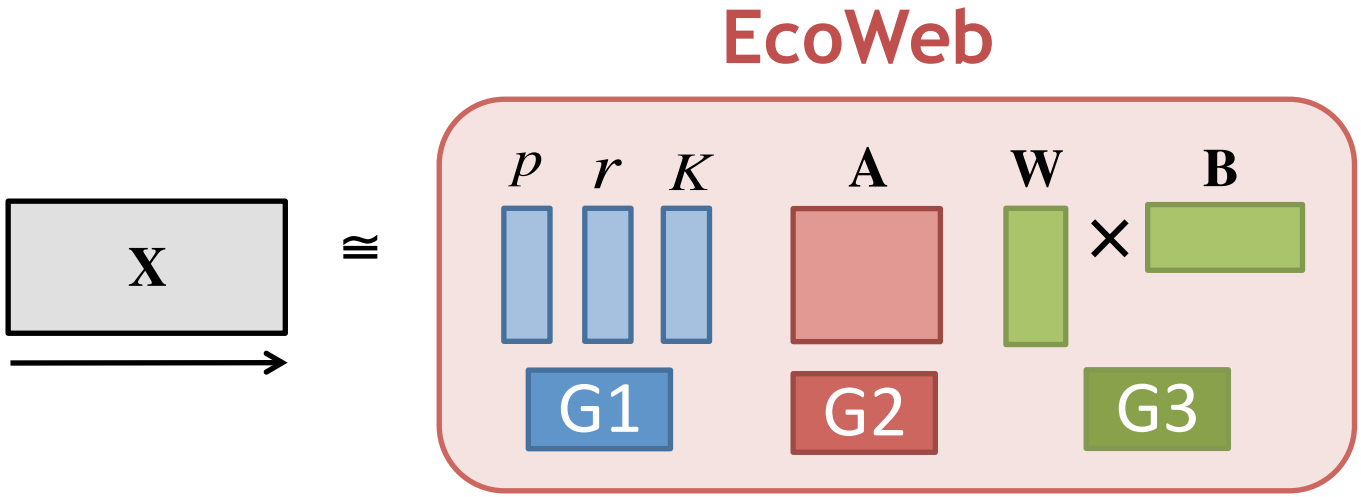
Roadmap

- ✔ Motivation
- ✔ Modeling power of EcoWeb
- ✔ Overview
- Proposed model
- Algorithm
- Experiments
- EcoWeb – at work
- Conclusions



EcoWeb: Main idea

Q. How can we describe the evolutions of X ?



A. Web as a jungle!

G1 G2 G3

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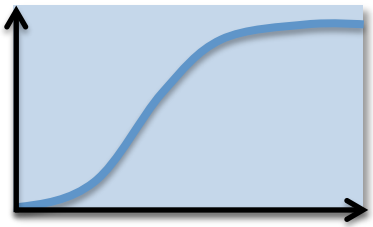
Non-linear evolution



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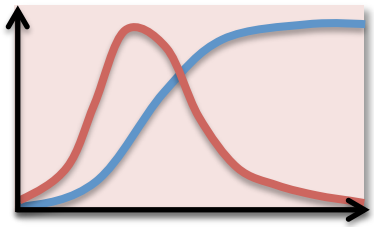
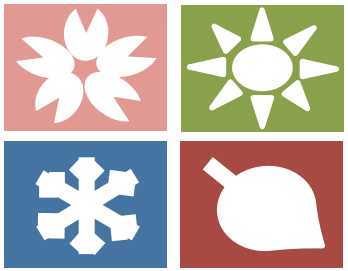
Interaction/ competition



Seasonality



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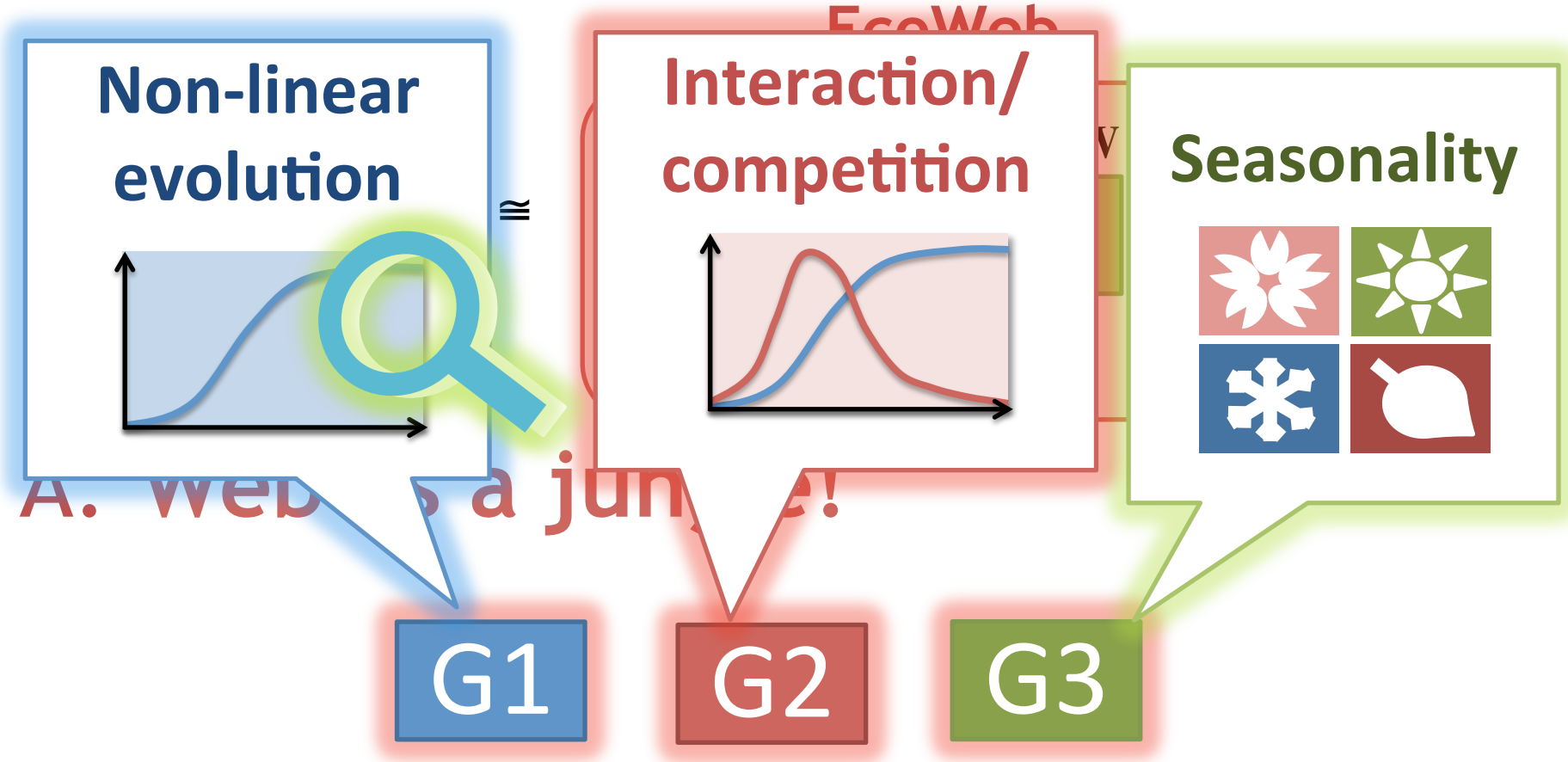
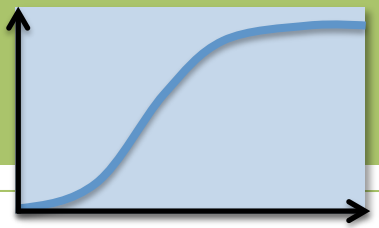


G1 EcoWeb-individual



Non-linear evolution of a single keyword

Jungle

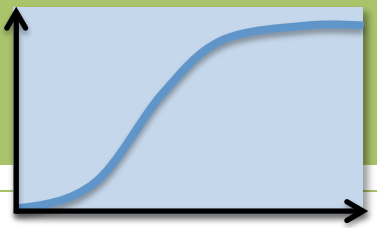
Species

Web

Keywords

t=0 t=1 t=2

G1 EcoWeb-individual



Non-linear evolution of a single keyword

Jungle

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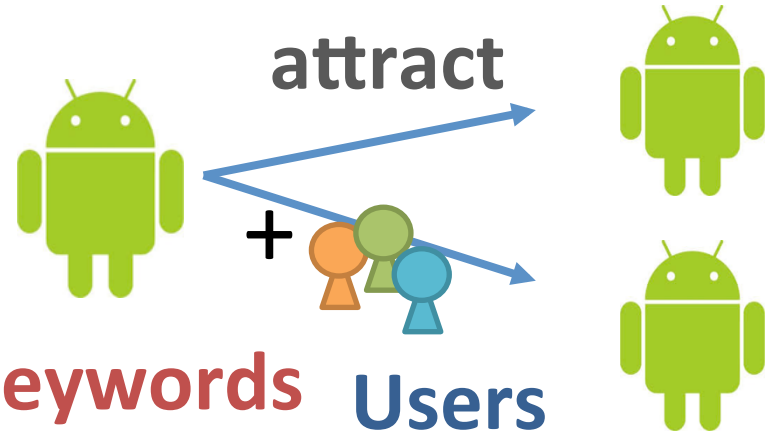

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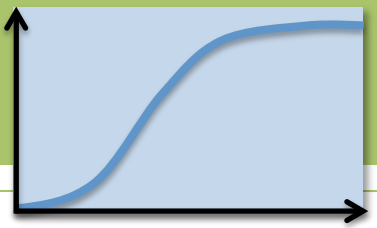
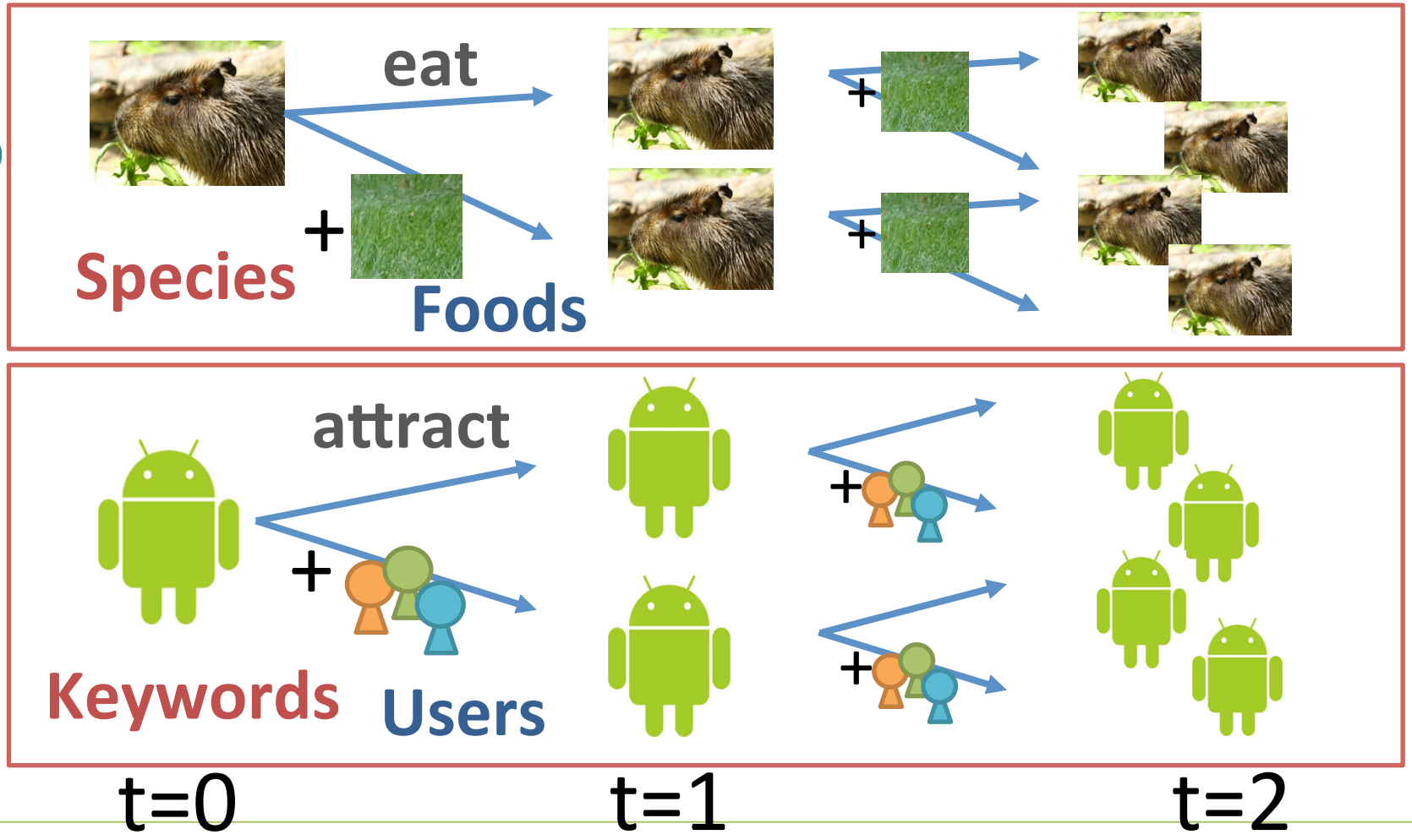


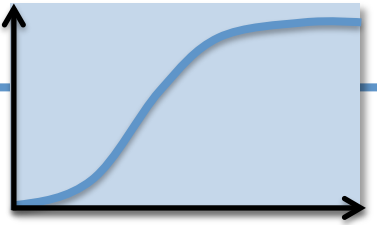
Popularity size increases over time



G1 EcoWeb-individual

Details

Non-linear evolution of a single keyword



Popularity size

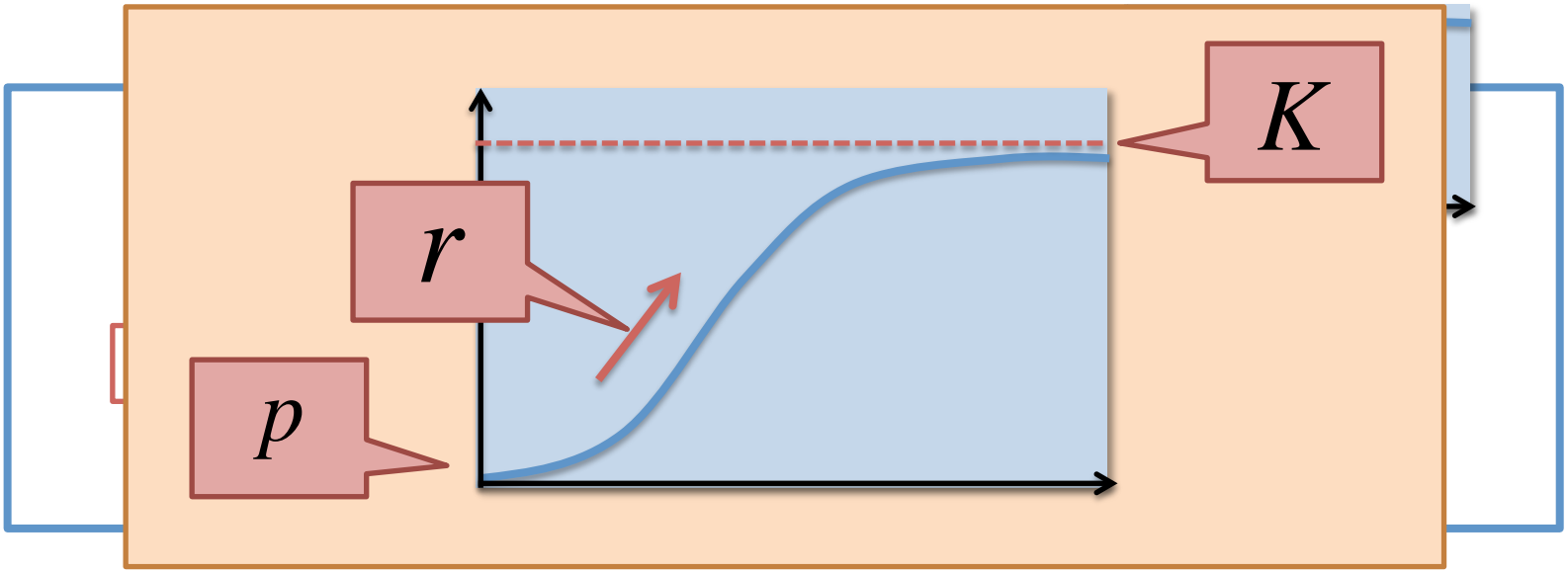
$$P(t+1) = P(t)\left[1 + r\left(1 - \frac{P(t)}{K}\right)\right],$$

- p – Initial condition (i.e., P(0) =p)
- r – Growth rate, attractiveness
- K – Carrying capacity (=available user resources)

G1 EcoWeb-individual

Details

Non-linear evolution of a single keyword



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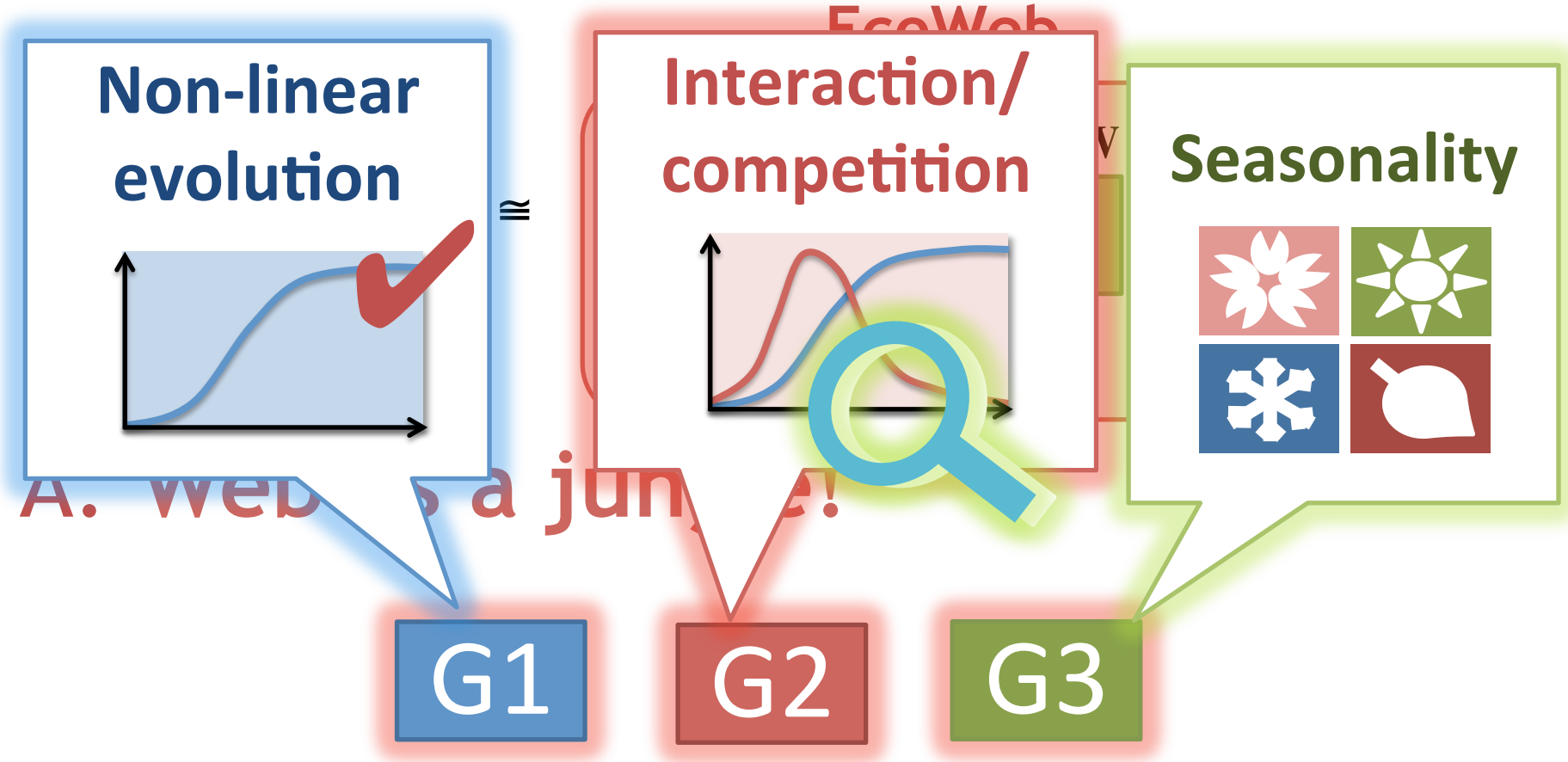
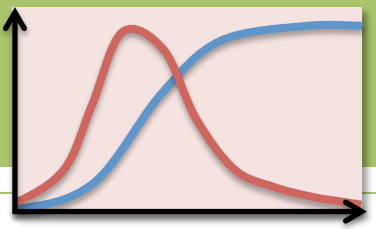
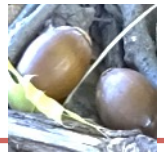


G2 EcoWeb-interaction



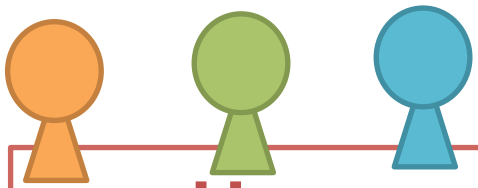
Interaction between multiple keywords

Species



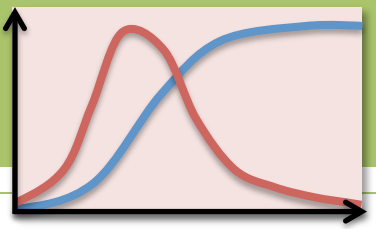
Food resources

Keywords

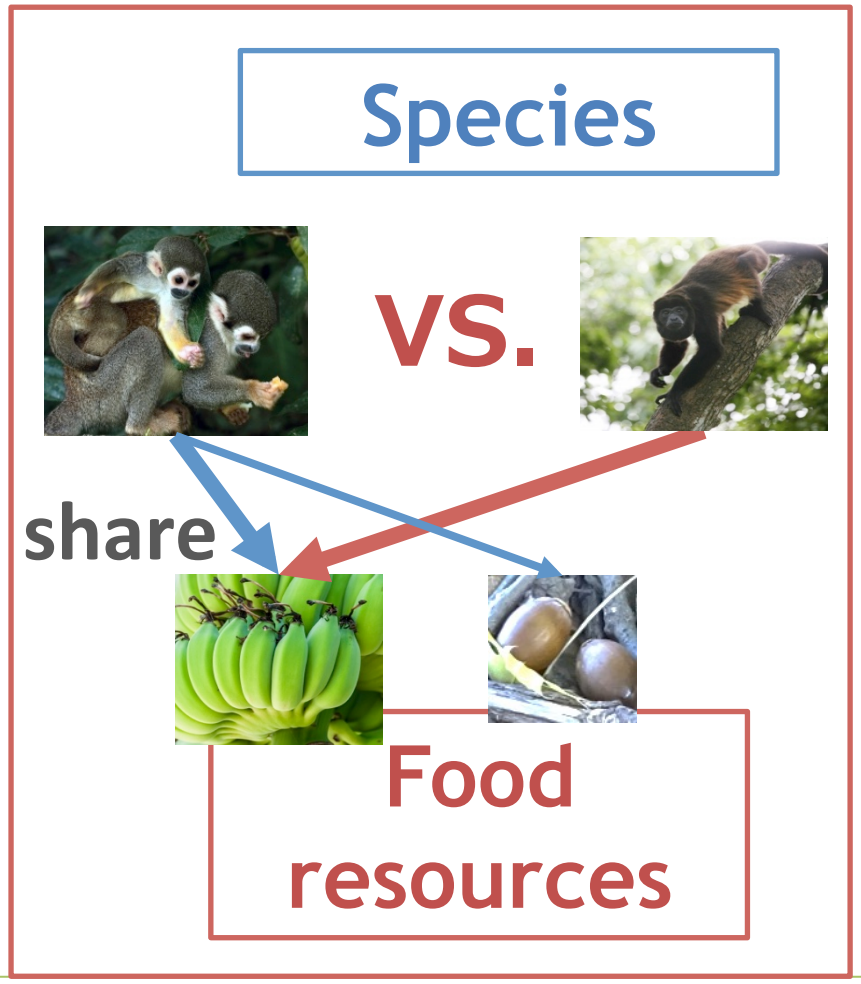


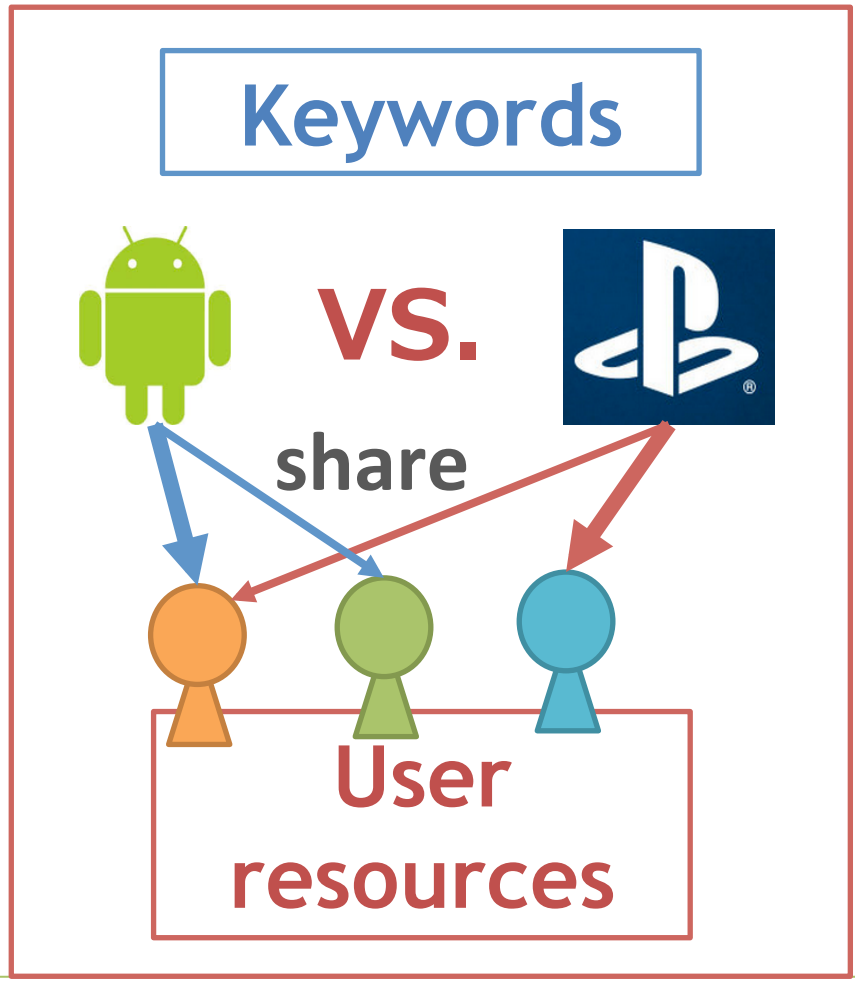
User resources

G2 EcoWeb-interaction



Interaction between multiple keywords





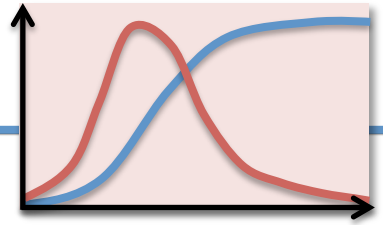
G2 EcoWeb-interaction

Details

Interaction between multiple keywords

Popularity of keyword i Popularity of j

$$P_i(t+1) = P_i(t)\left[1 + r_i\left(1 - \frac{\sum_{j=1}^{d} a_{ij} P_j(t)}{K_i}\right)\right], \quad (i = 1, \cdots, d), \quad (3)$$



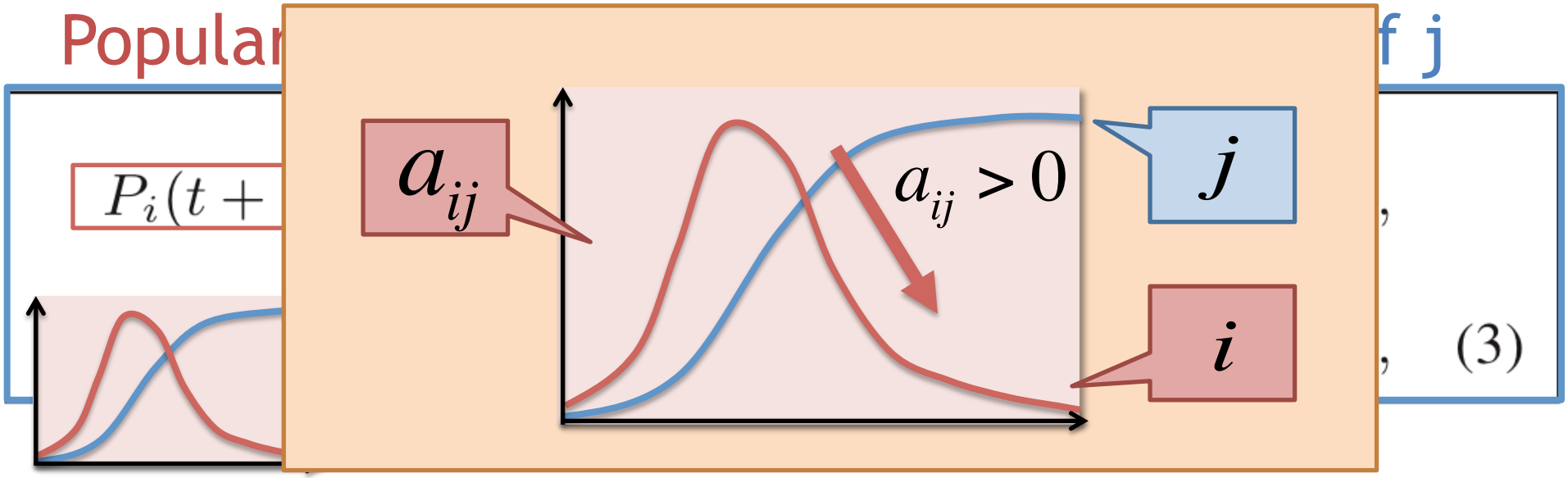
a_{ij} – Interaction coefficient

– i.e., effect rate of keyword j on i

G2 EcoWeb-interaction

Details

Interaction between multiple keywords



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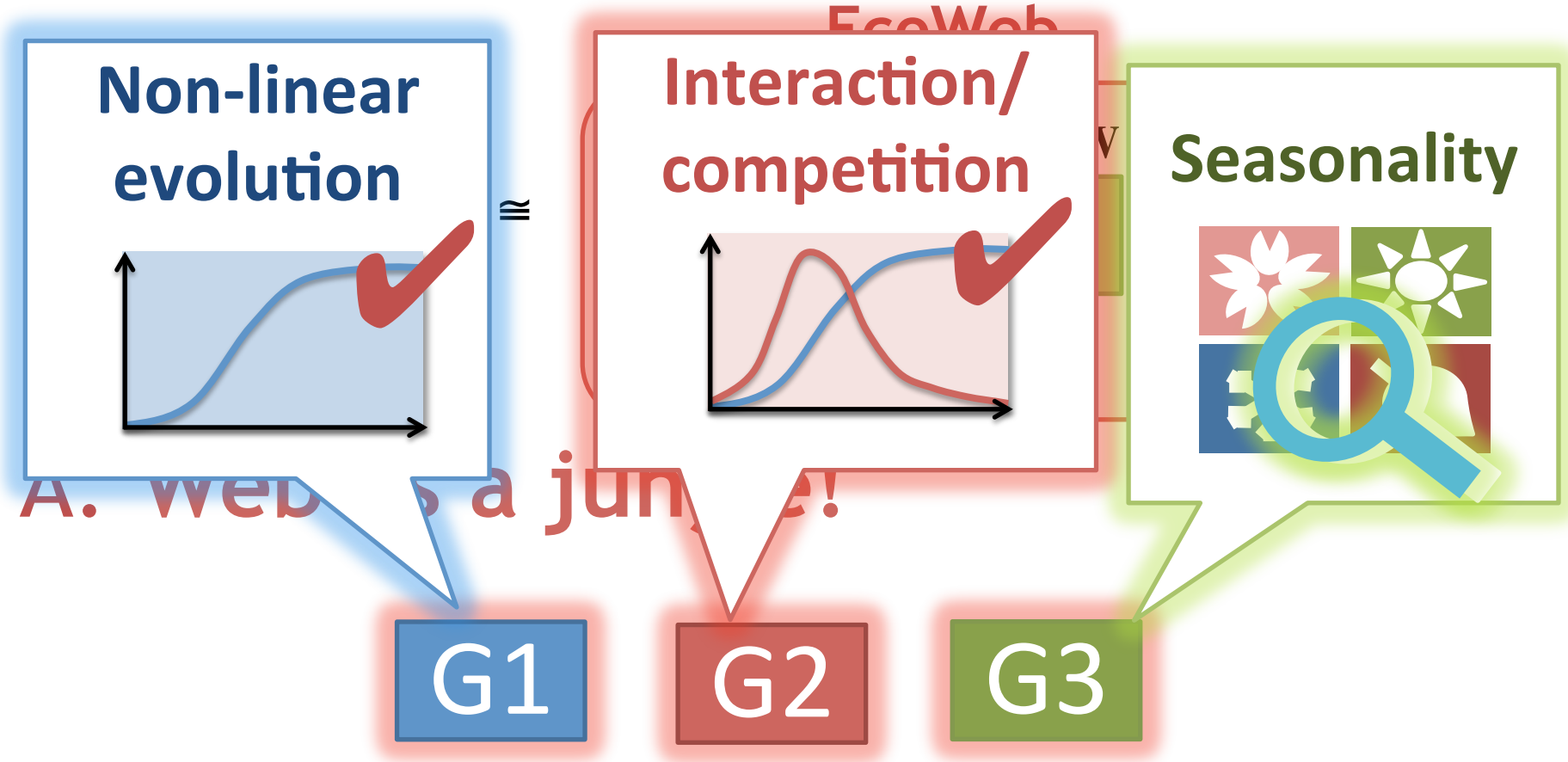
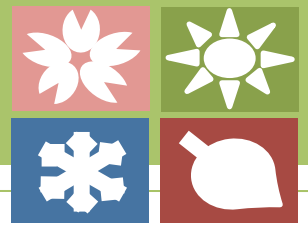
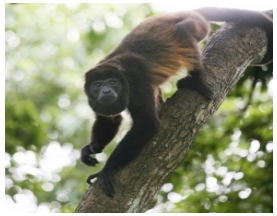


G3 EcoWeb-seasonality



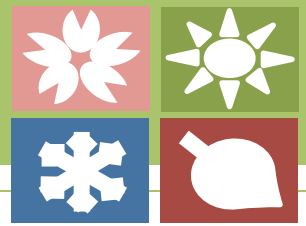
“Hidden” seasonal activities

Season/ Climate

Seasonal events

G3 EcoWeb-seasonality



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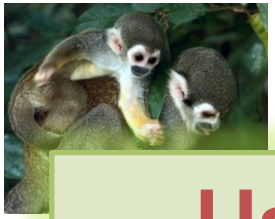
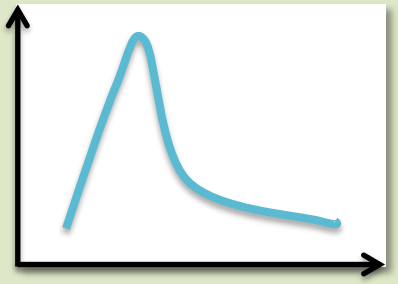
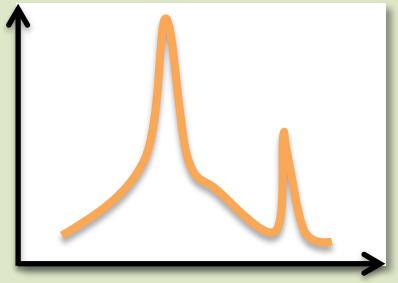


LOWE'S

amazon

Users change their behavior according to **seasonal events**!

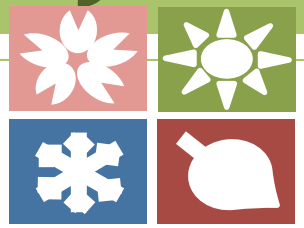




Climate

events

G3 EcoWeb-seasonality



Details

"Hidden" seasonal activities

Estimated volume of keyword i

$$C_i(t) = P_i(t)\,[1 + e_i(t)] \qquad (i = 1, \cdots, d),$$

$$e_i(t) \simeq f(i, t|\mathbf{W}, \mathbf{B}) = \sum_{j=1}^{k} w_{ij} b_j(\tau) \qquad (\tau = [t \mod n_p])$$

Seasonal activities of i

$\mathbf{W}$ – Participation (weight) matrix

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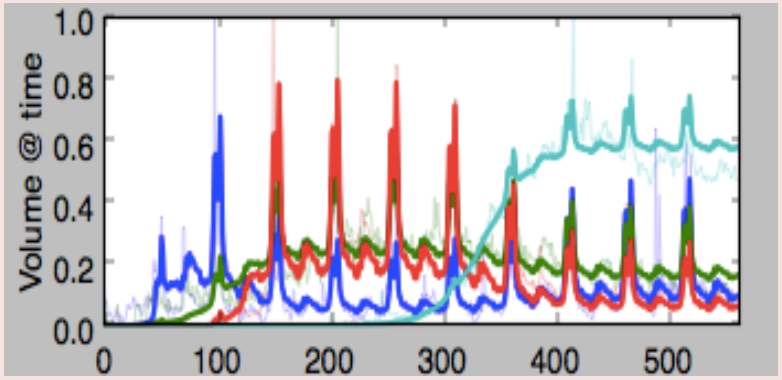
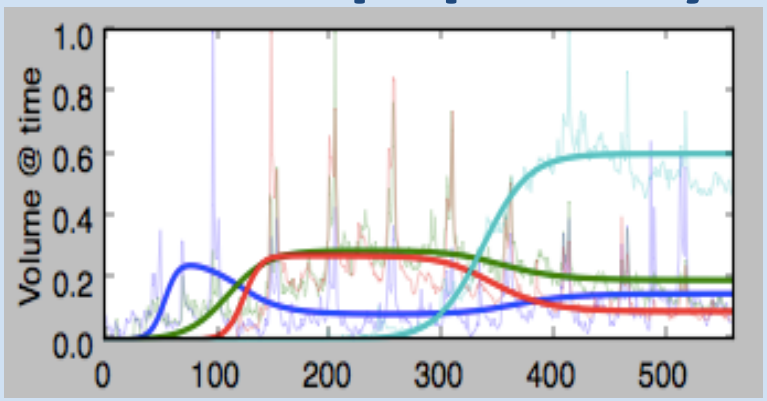
C: volume



P: latent popularity



G3 EcoWeb-seasonality

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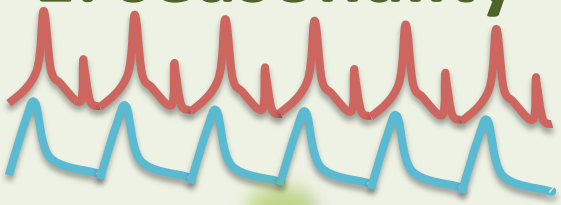

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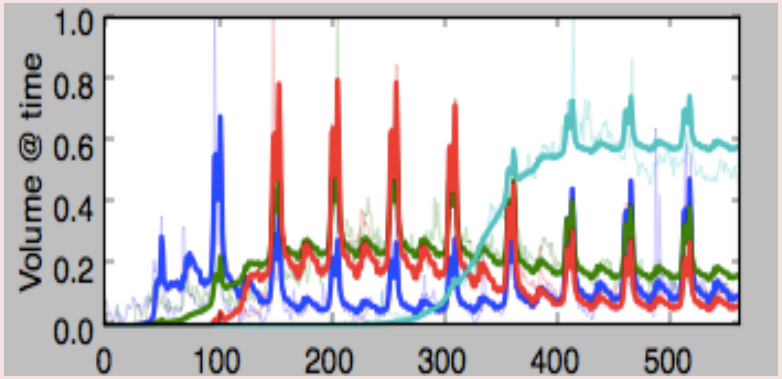

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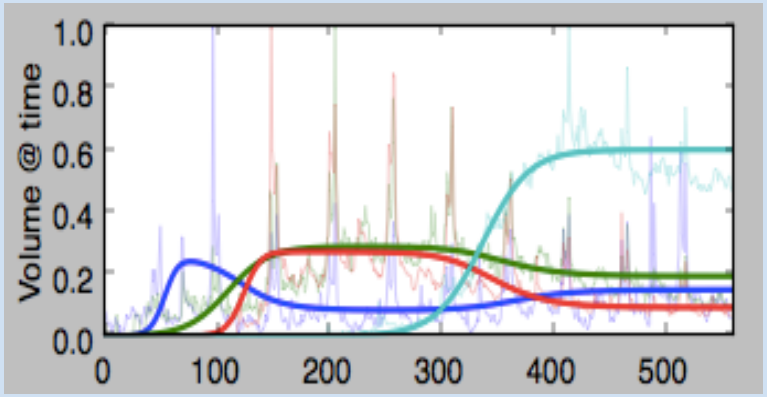

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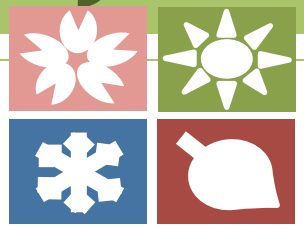

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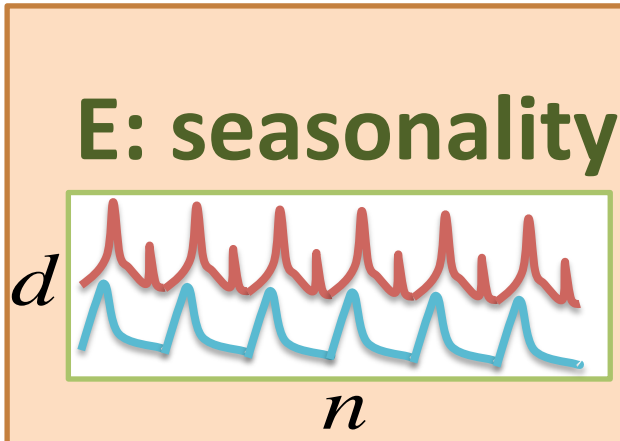

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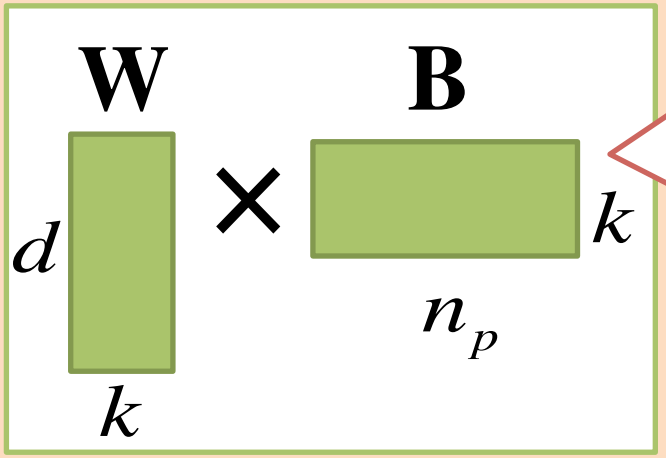

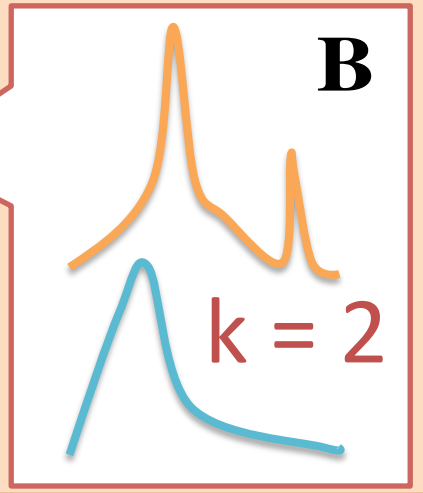

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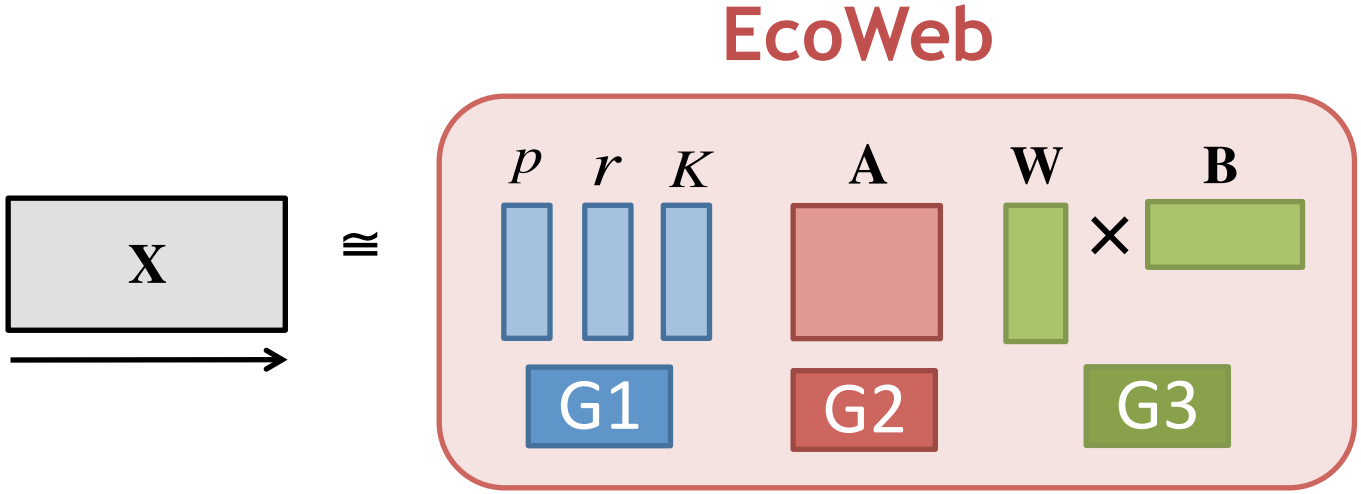

Full parameters (6)

$$\mathcal{S} = \{\boldsymbol{p}, \boldsymbol{r}, \boldsymbol{K}, \mathbf{A}, \mathbf{W}, \mathbf{B}\}$$

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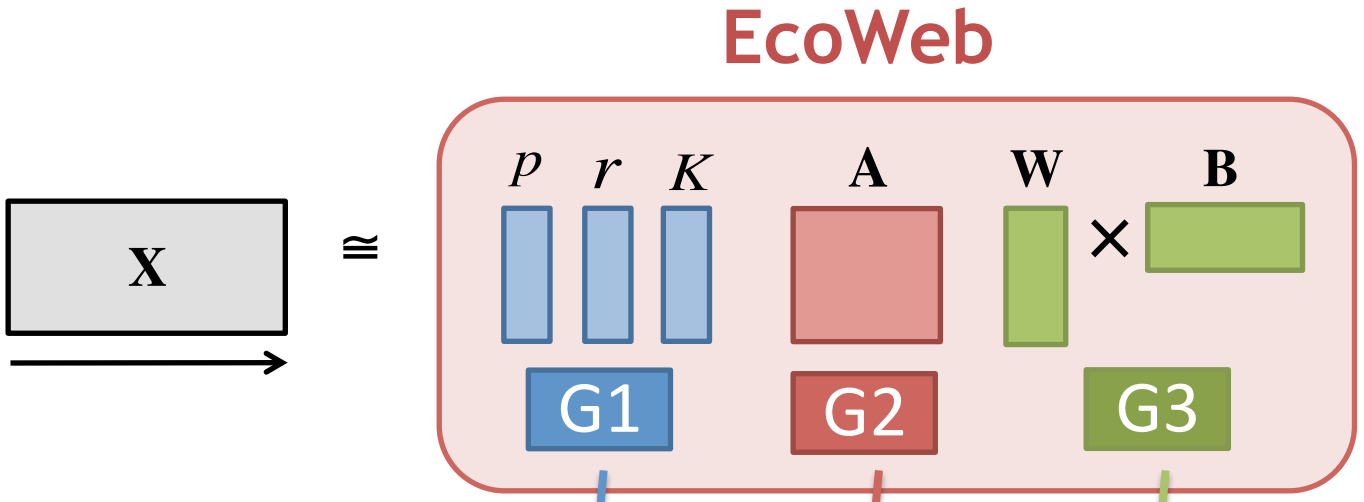

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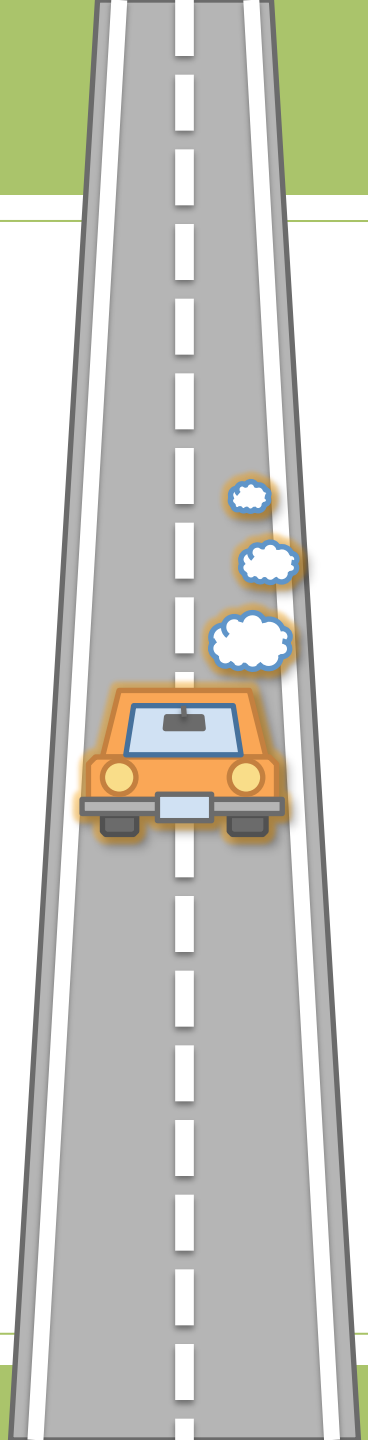
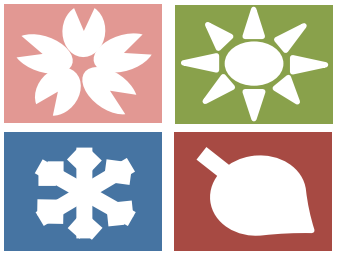
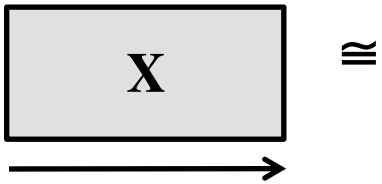


Challenges

Q1. How can we automatically find "seasonal components" ?



Q2. How can we efficiently estimate full-parameters ?



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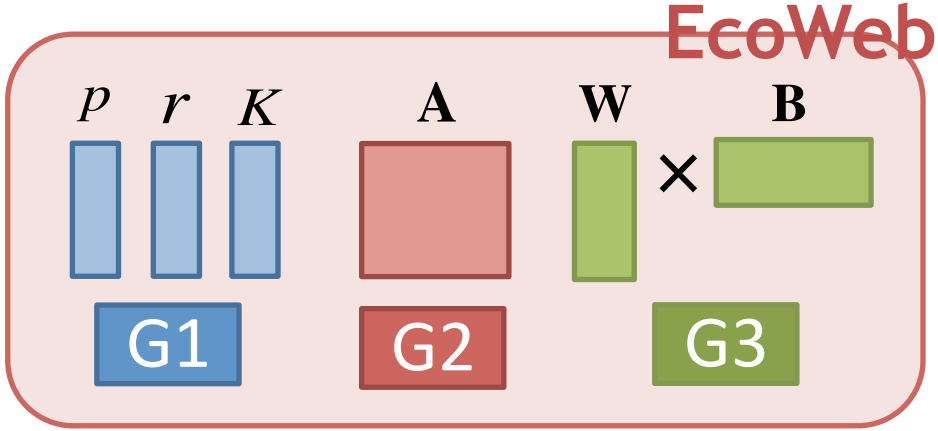

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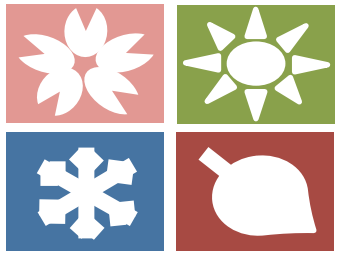
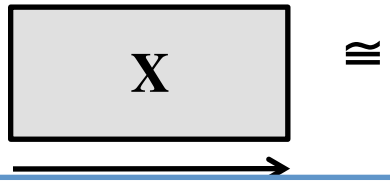
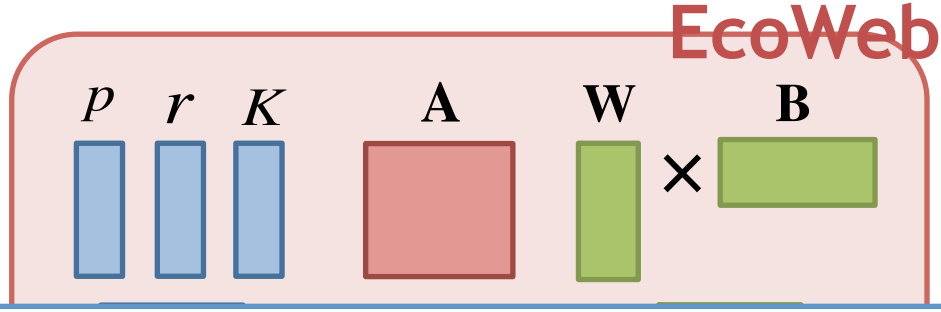


Idea (1) : Seasonal component analysis

Q2. How can we efficiently estimate full-parameters ?



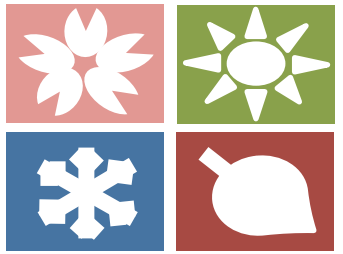
≅



Idea (2): Multi-step fitting

Challenges

Q1. How can we automatically find "seasonal components" ?



Idea (1) : Seasonal component analysis

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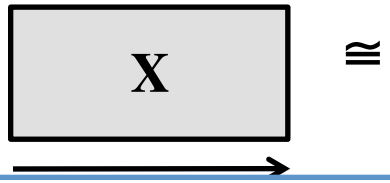
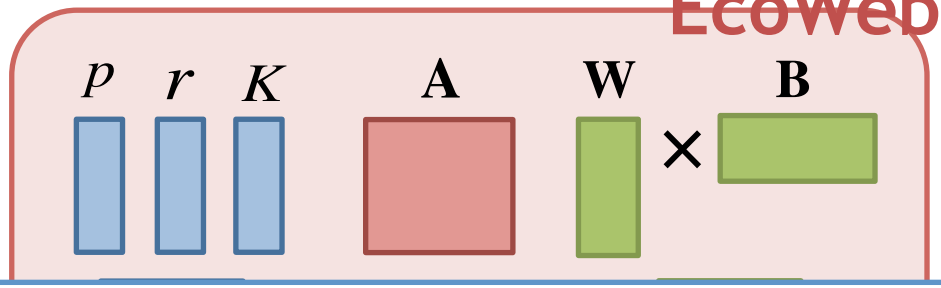


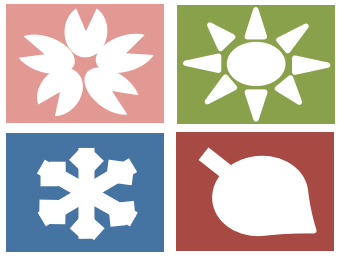
≅

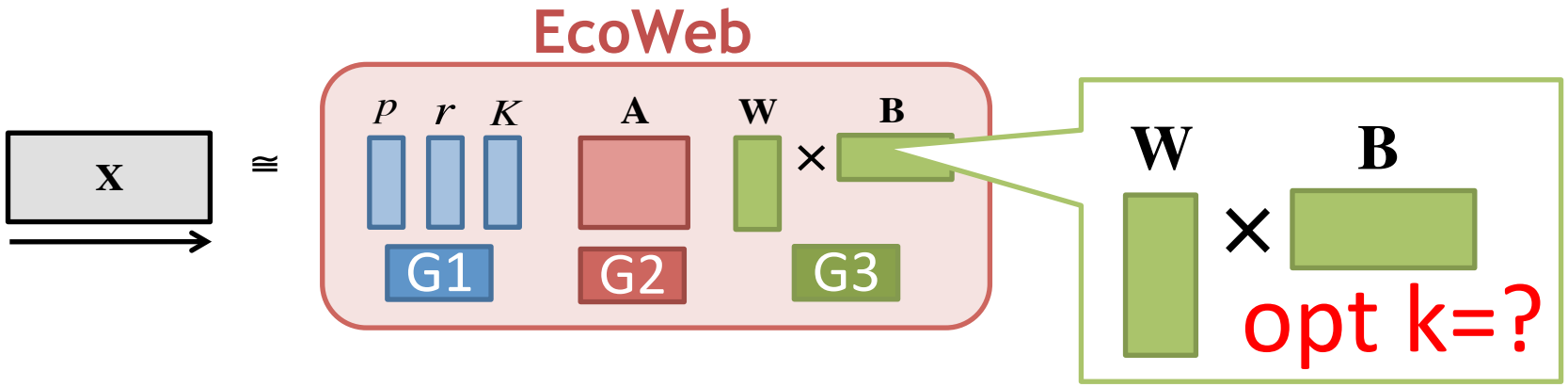


Idea (2): Multi-step fitting

Idea (1): Seasonal component analysis

Q1. How can we automatically find "k-seasonal components" ?





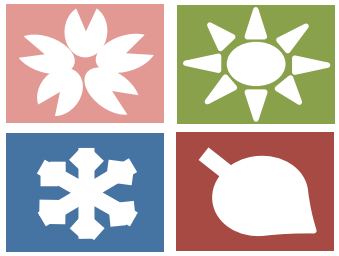
Idea (1) :

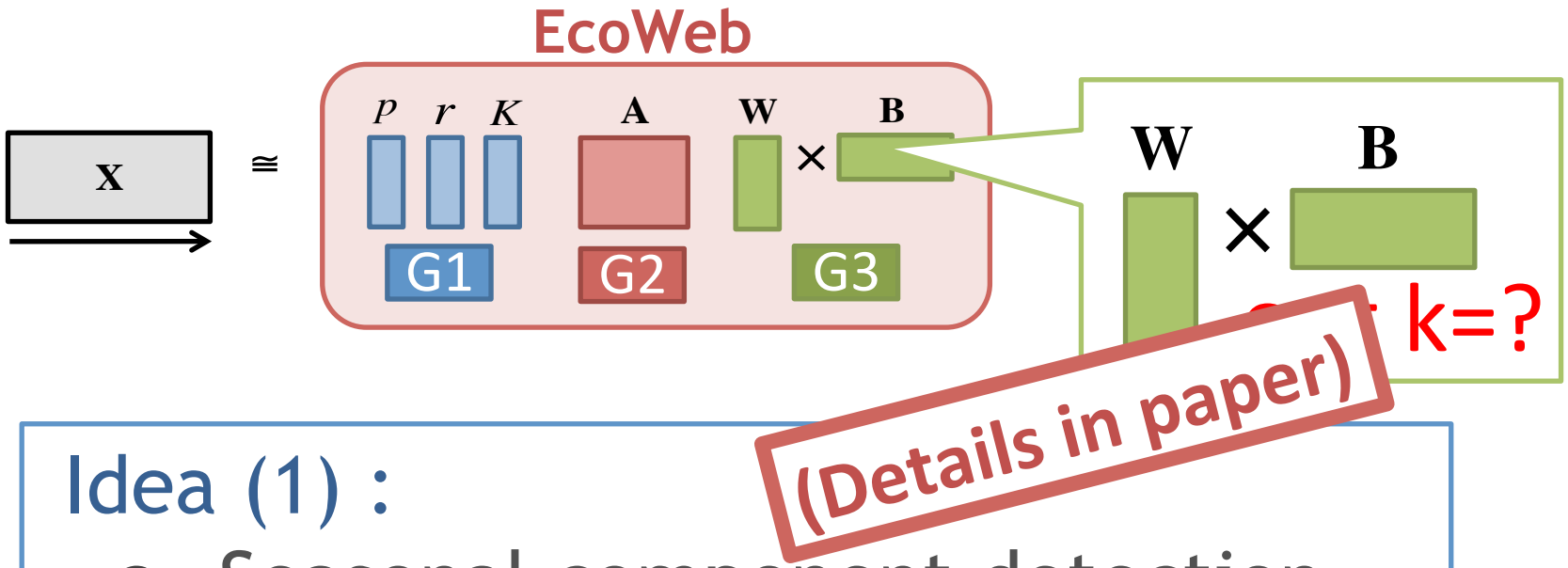
a. Seasonal component detection

b. Automatic component analysis

Idea (1): Seasonal component analysis

Q1. How can we automatically find "k-seasonal components" ?





Idea (1) :

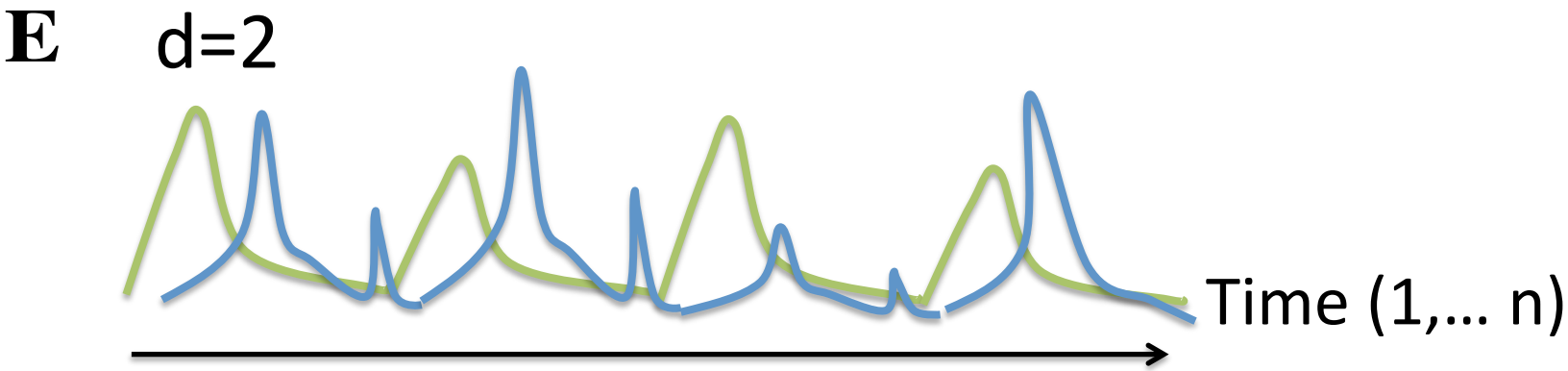
a. Seasonal component detection

b. Automatic component analysis

Idea (1): Seasonal component analysis

Details

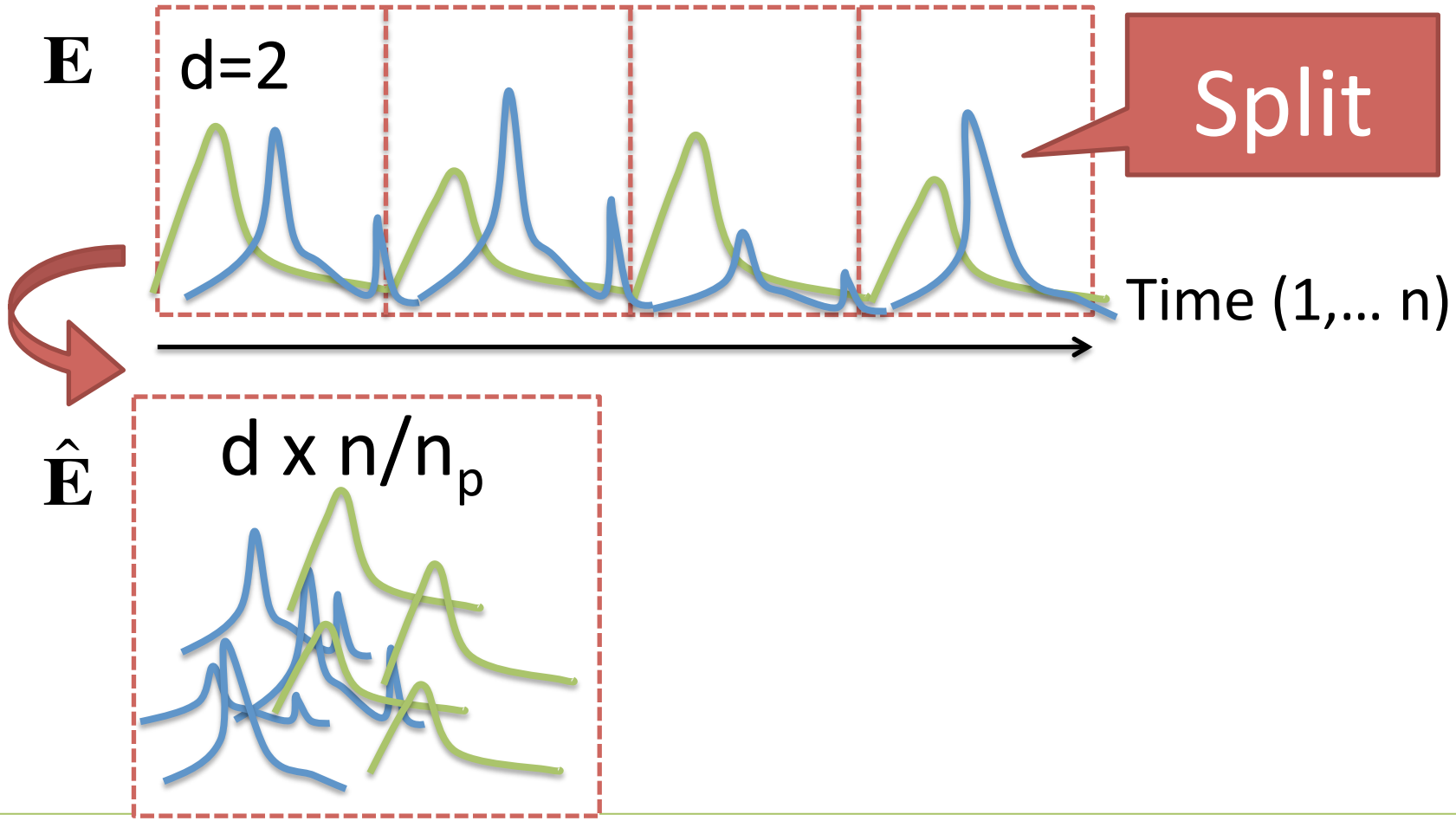
Idea(1-a) Seasonal component detection



Idea (1): Seasonal component analysis

Details

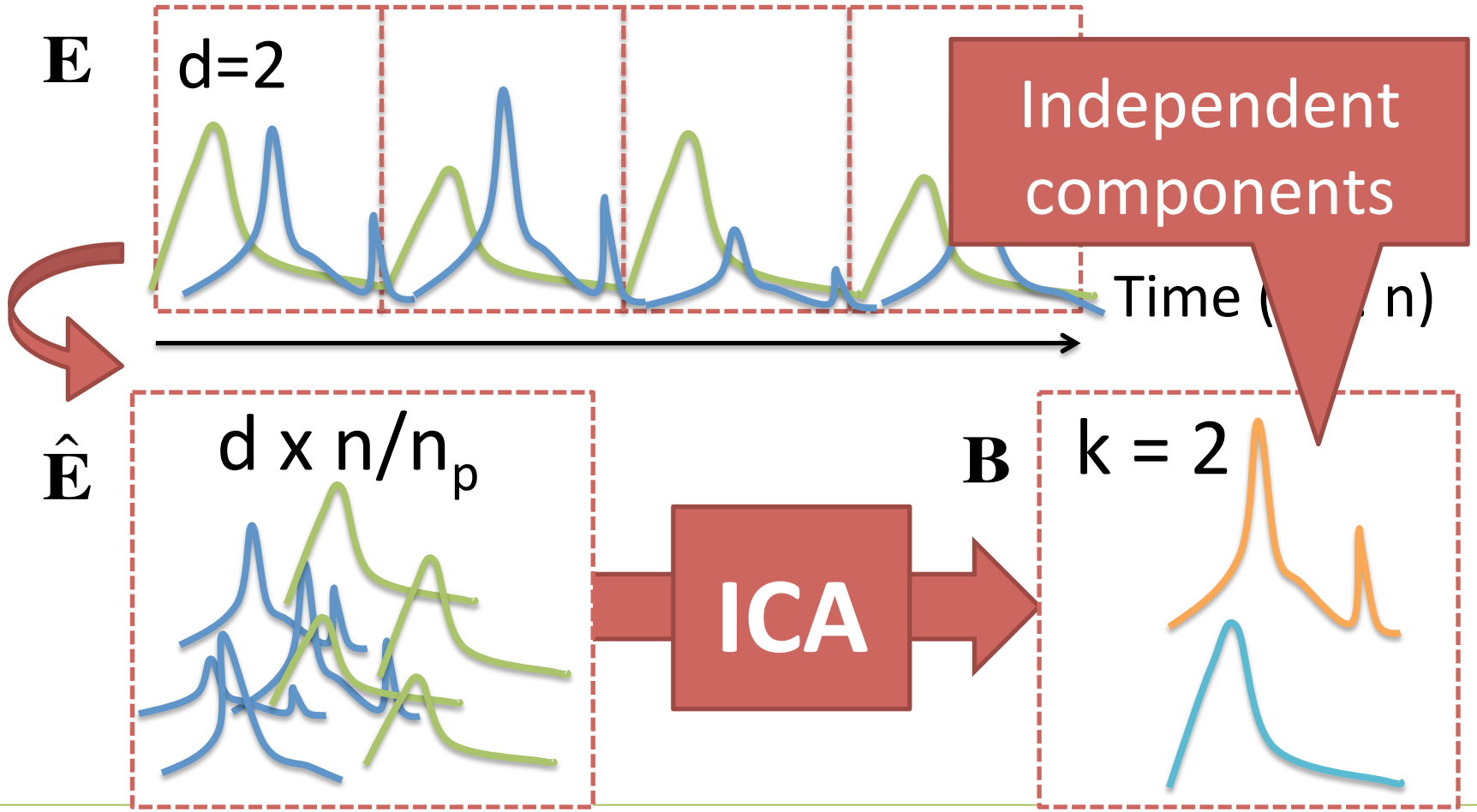
Idea(1-a) Seasonal component detection



Idea (1): Seasonal component analysis

Details

Idea(1-a) Seasonal component detection



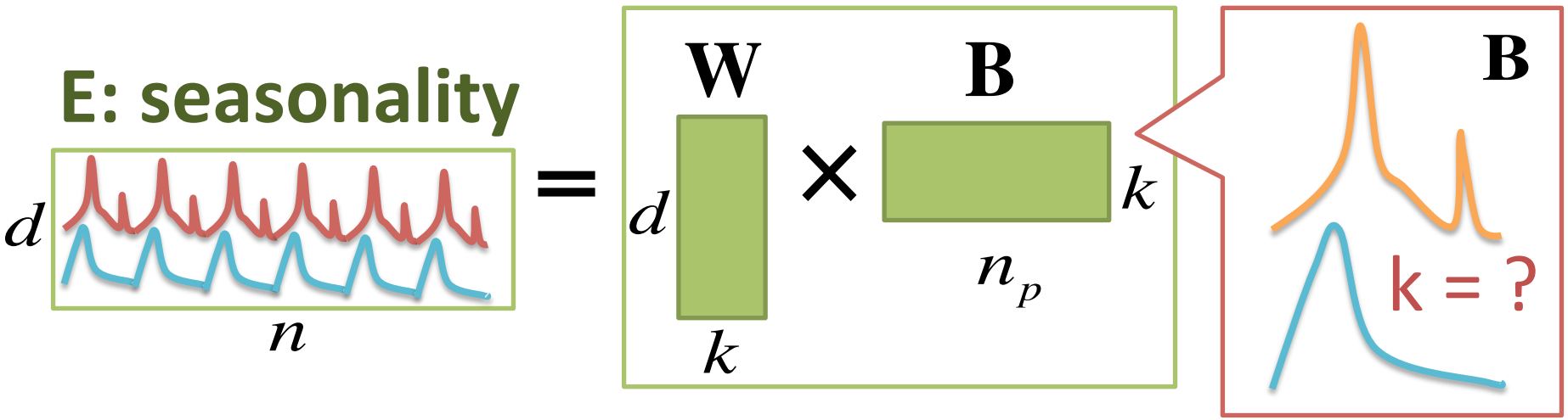
Idea (1): Seasonal component analysis

Details

Idea(1-b) Automatic component analysis

Find optimal number k (1≤k≤d)

d: dimension



opt k=?

Idea (1): Seasonal component analysis

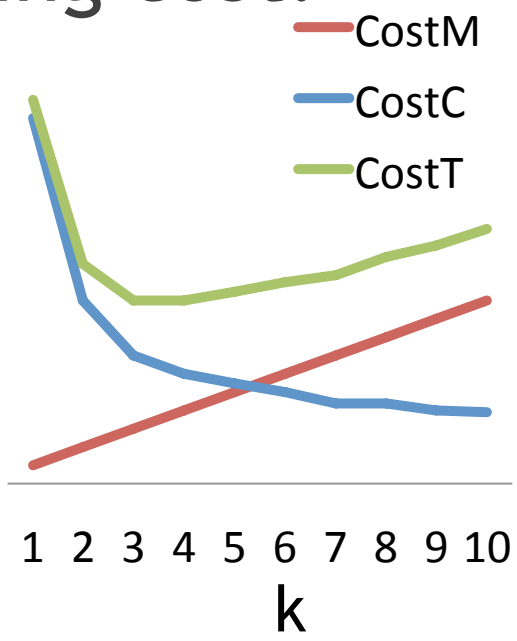
Details

Idea(1-b) MDL -> Minimize encoding cost!

$$\min \left(\boxed{\text{Cost}_M(S)} + \boxed{\text{Cost}_c(\mathcal{X} \mid S)} \right)$$

Model cost

Coding cost



Good compression

Good description

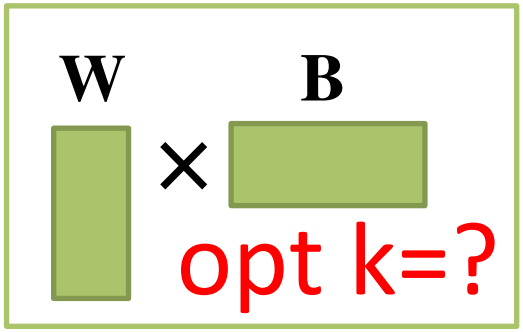
Idea (1): Seasonal component analysis

Details

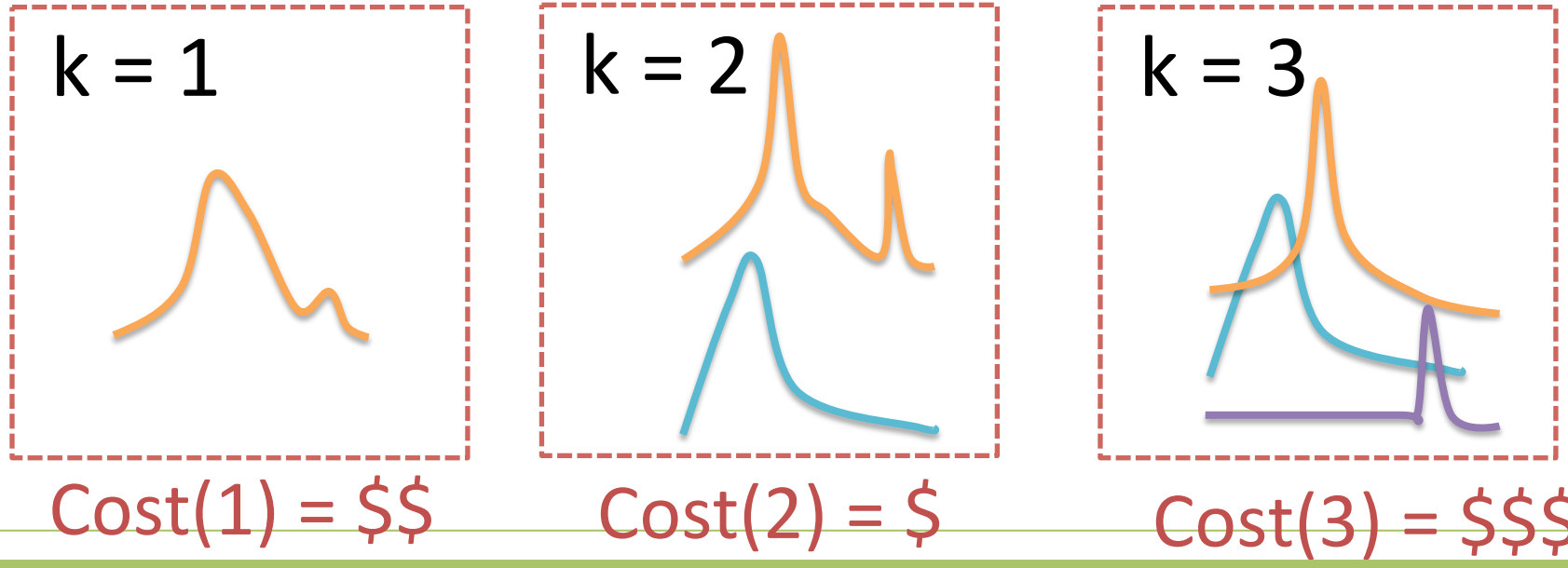
Idea(1-b) Automatic component analysis

Find optimal number k (1≤k≤d)

d: dimension



B

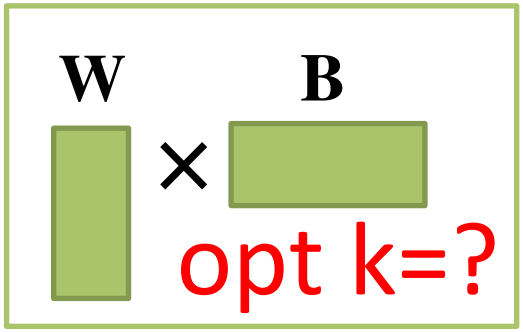


Idea (1): Seasonal component analysis

Details

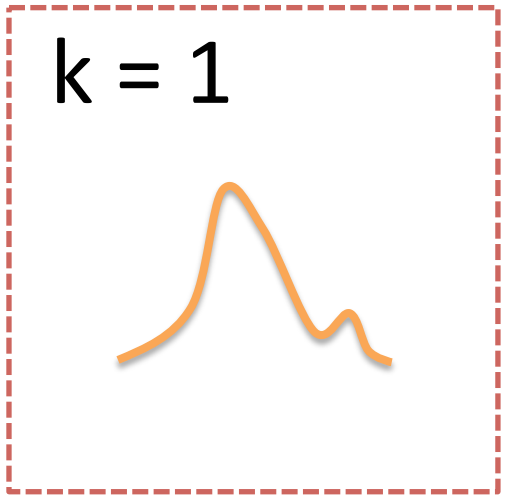
Idea(1-b) Automatic component analysis

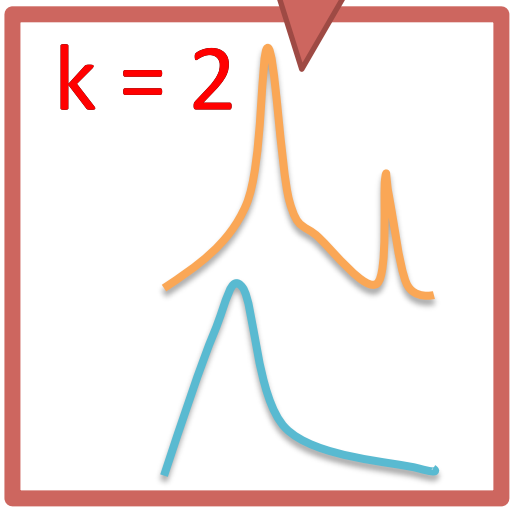
Find optimal number k (1≤k≤d)

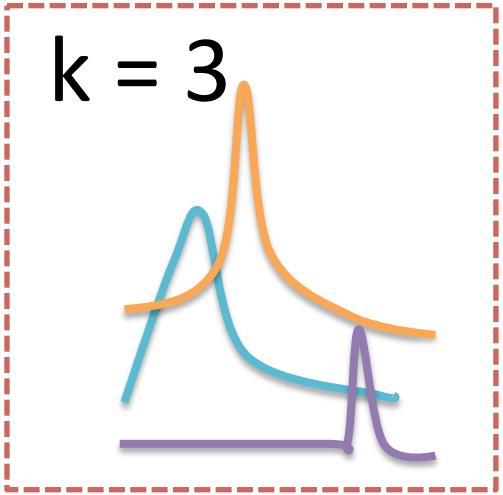


Optimal k

B







Cost(1) = $$

Cost(2) = $

Cost(3) = $$$

Idea (1): Seasonal component analysis

Details

Idea(1-b) MDL -> Minimize encoding cost!

$$Cost_T(X;\mathcal{S}) = \log^*(d) + \log^*(n) + Cost_M(\boldsymbol{p},\boldsymbol{r},\boldsymbol{K}) + Cost_M(\mathbf{A}) + Cost_M(k,\mathbf{W},\mathbf{B}) + Cost_C(X|\mathcal{S})$$

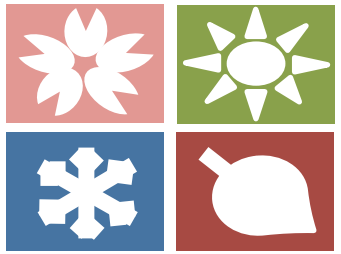
$$k_{opt} = \arg\min_k Cost_T(X;\mathcal{S})$$

Good compression

Good description

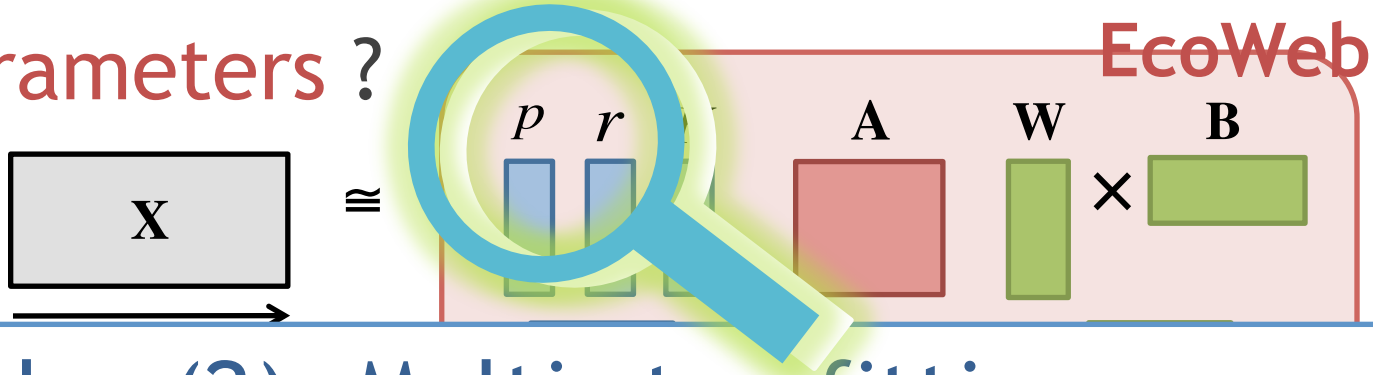
Challenges

Q1. How can we automatically find "seasonal components" ?



Idea (1) : Seasonal component analysis

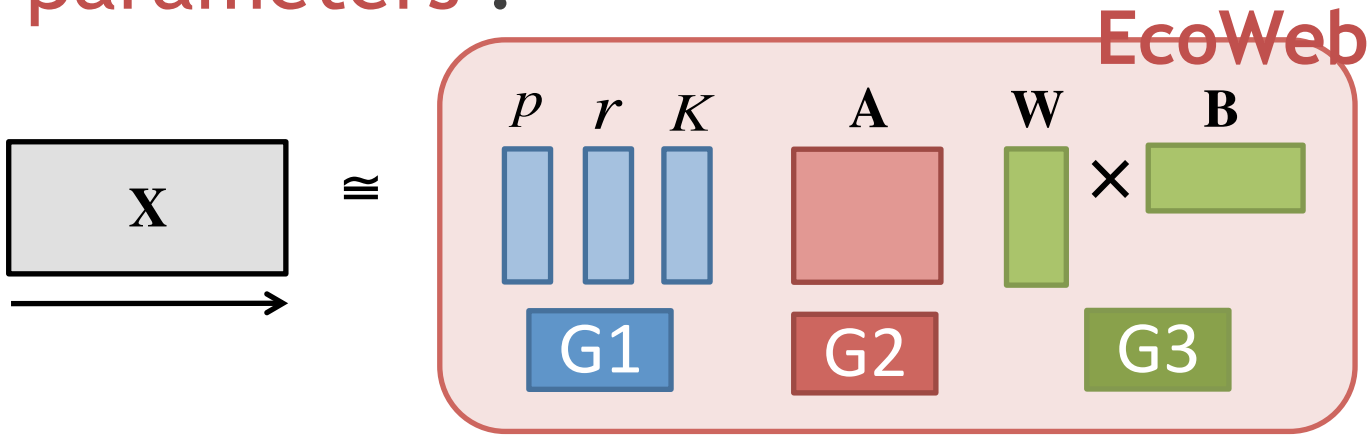
Q2. How can we efficiently estimate full-parameters ?



Idea (2): Multi-step fitting

Idea (2): Multi-step fitting

Q2. How can we efficiently estimate model parameters ?



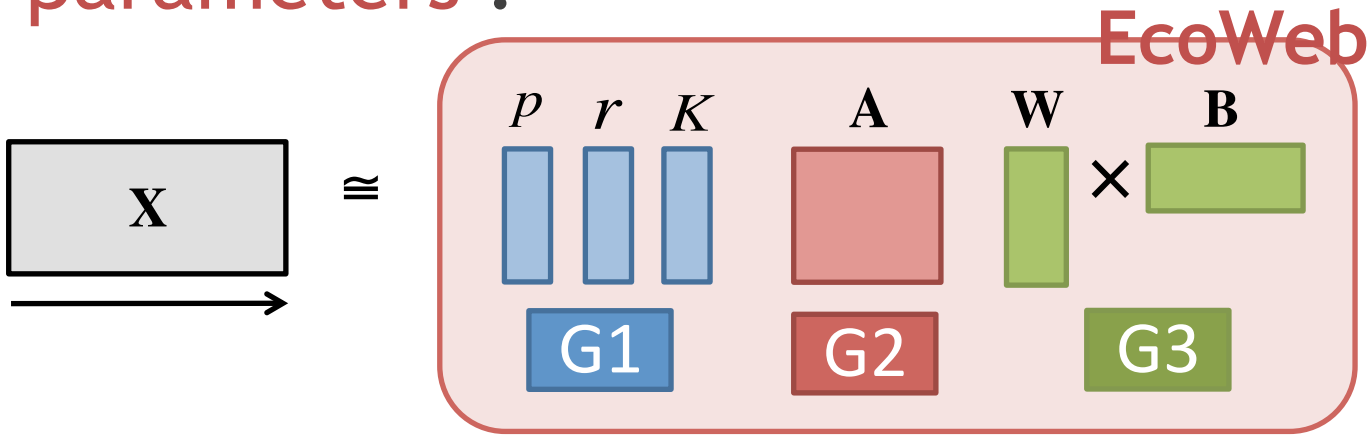
Idea (2): Multi-step fitting

a. **StepFit** (sub)

b. **EcoWeb-Fit** (full)

Idea (2): Multi-step fitting

Q2. How can we efficiently estimate model parameters ?

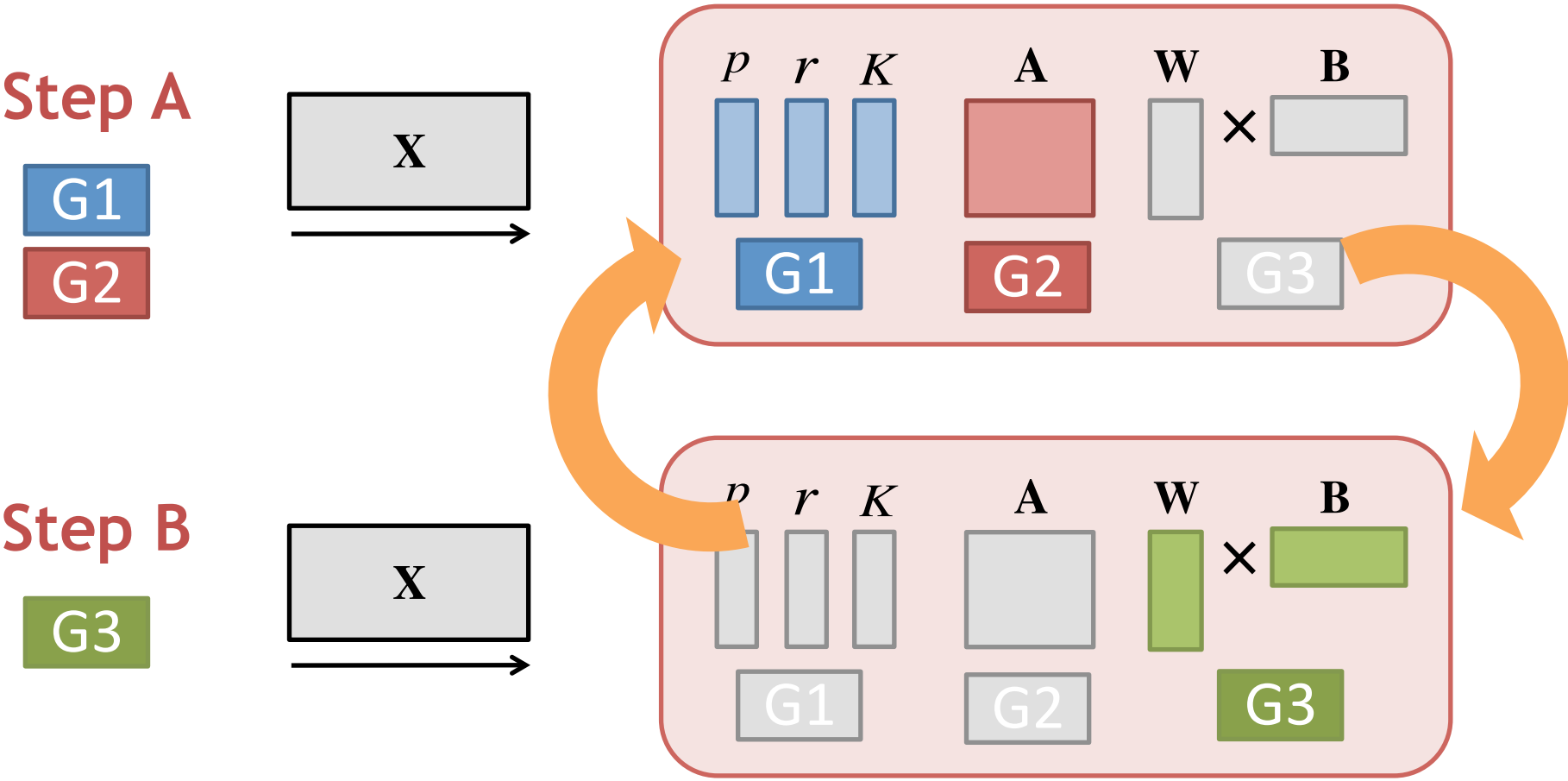


Idea (2): Multi-step fitting

- **a. StepFit** (sub)
- **b. EcoWeb-Fit** (full)

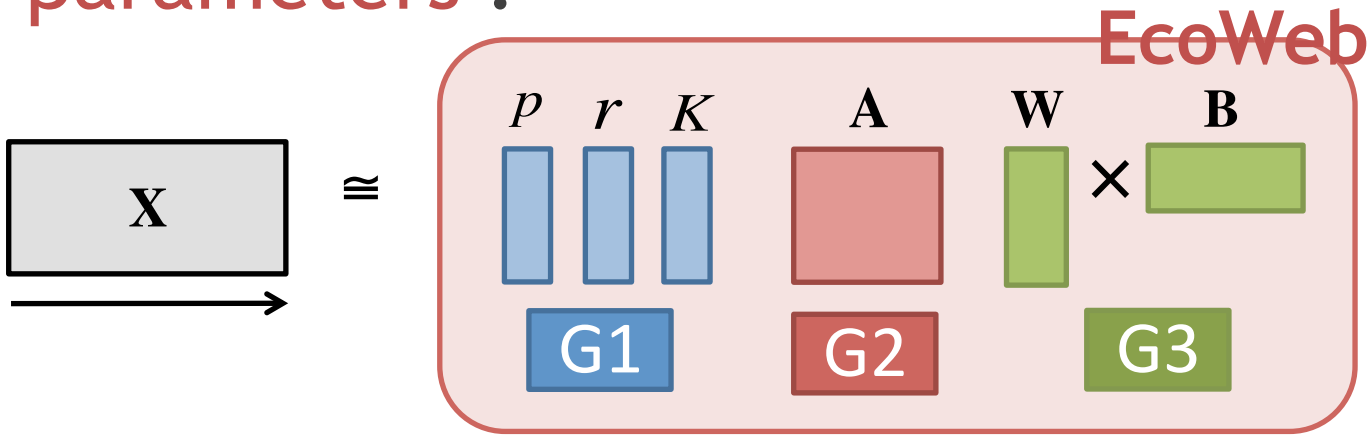
Idea (2): Multi-step fitting

(2-a). StepFit: Update parameters *alternately*



Idea (2): Multi-step fitting

Q2. How can we efficiently estimate model parameters ?



Idea (2): Multi-step fitting

a. **StepFit** (sub)

b. **EcoWeb-Fit** (full)

Idea (2): Multi-step fitting

EcoWeb-Fit: full algorithm

e.g., 4 keywords: 

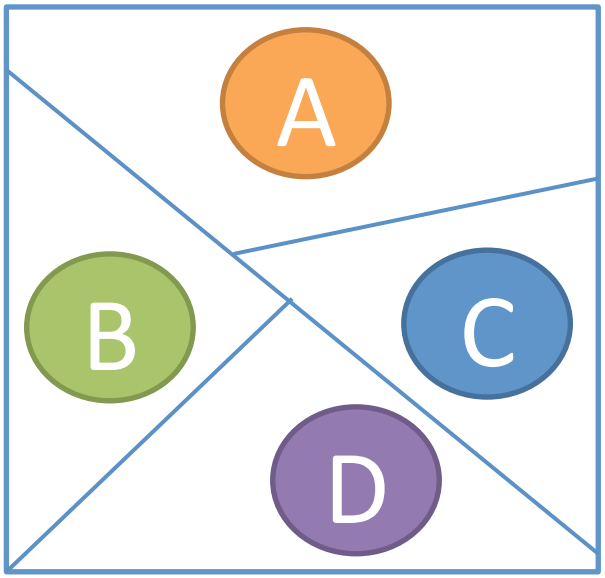
EcoWeb-Fit updates parameters, separately

Idea (2): Multi-step fitting

EcoWeb-Fit: full algorithm

e.g., 4 keywords: A B C D

1. Individual-Fit



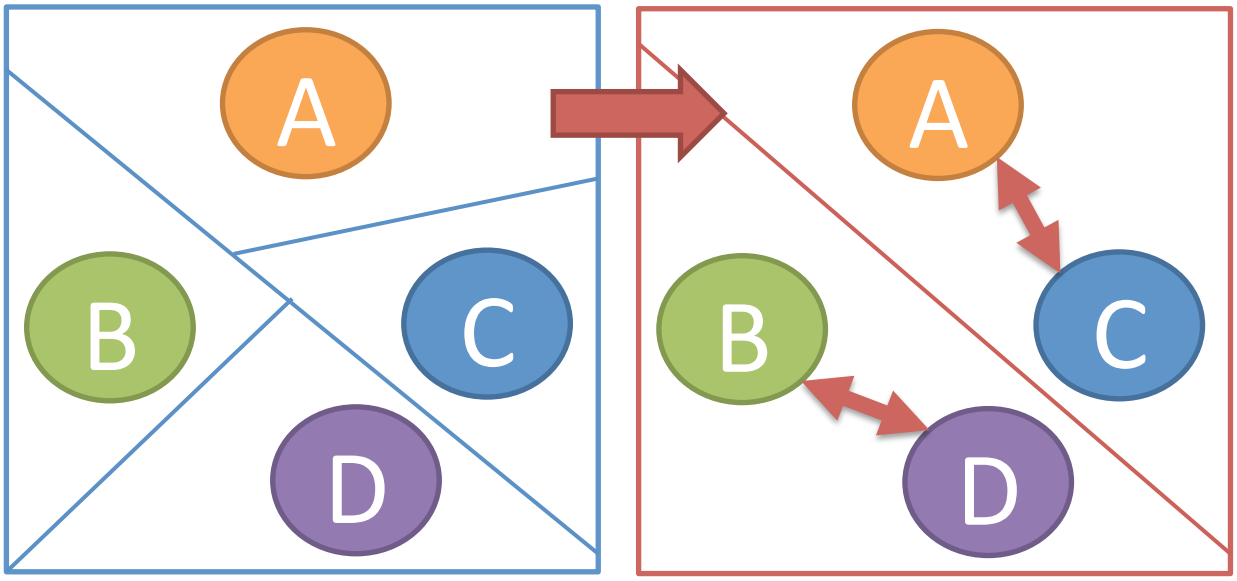
EcoWeb-Fit updates parameters, separately

Idea (2): Multi-step fitting

EcoWeb-Fit: full algorithm

e.g., 4 keywords: A B C D

1. Individual-Fit **2. Pair-Fit**



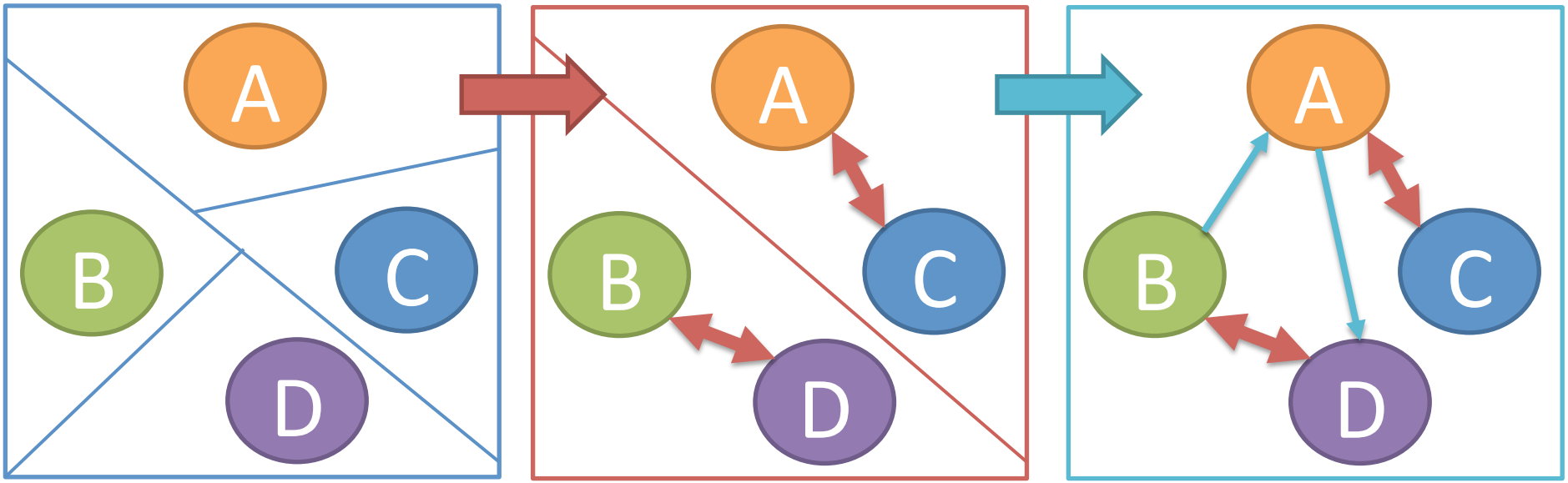
EcoWeb-Fit updates parameters, separately

Idea (2): Multi-step fitting

EcoWeb-Fit: full algorithm

e.g., 4 keywords: A B C D

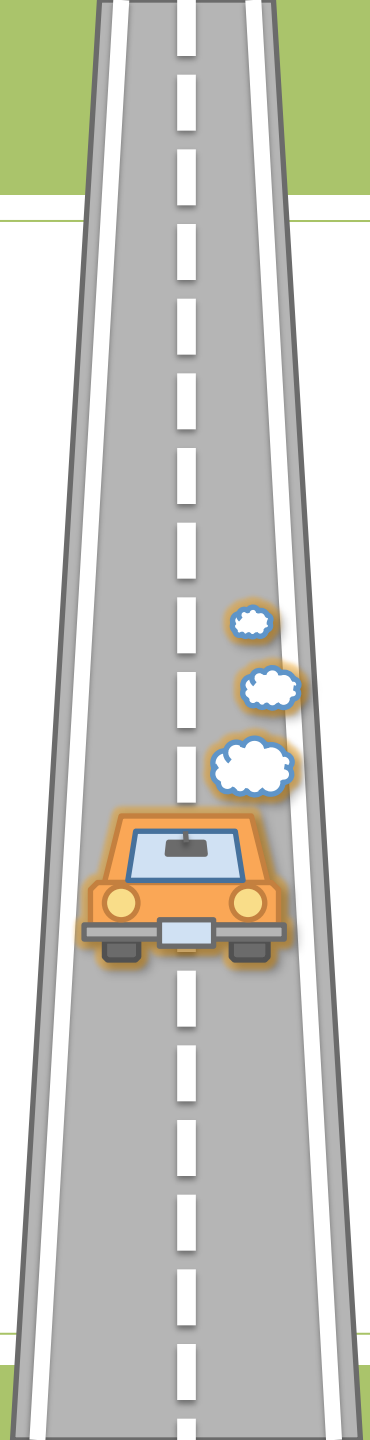
1. Individual-Fit **2. Pair-Fit** **3. Full-Fit**



EcoWeb-Fit updates parameters, separately

Roadmap

- ✔ Motivation
- ✔ Modeling power of EcoWeb
- ✔ Overview
- ✔ Proposed model
- ✔ Algorithm
- Experiments
- EcoWeb – at work
- Conclusions



Experiments

We answer the following questions…

Q1. Effectiveness

How successful is it in spotting patterns?

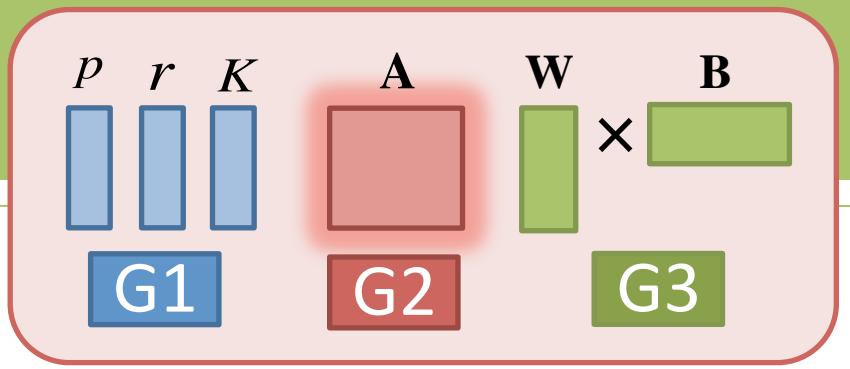
Q2. Accuracy

How well does it match the data?

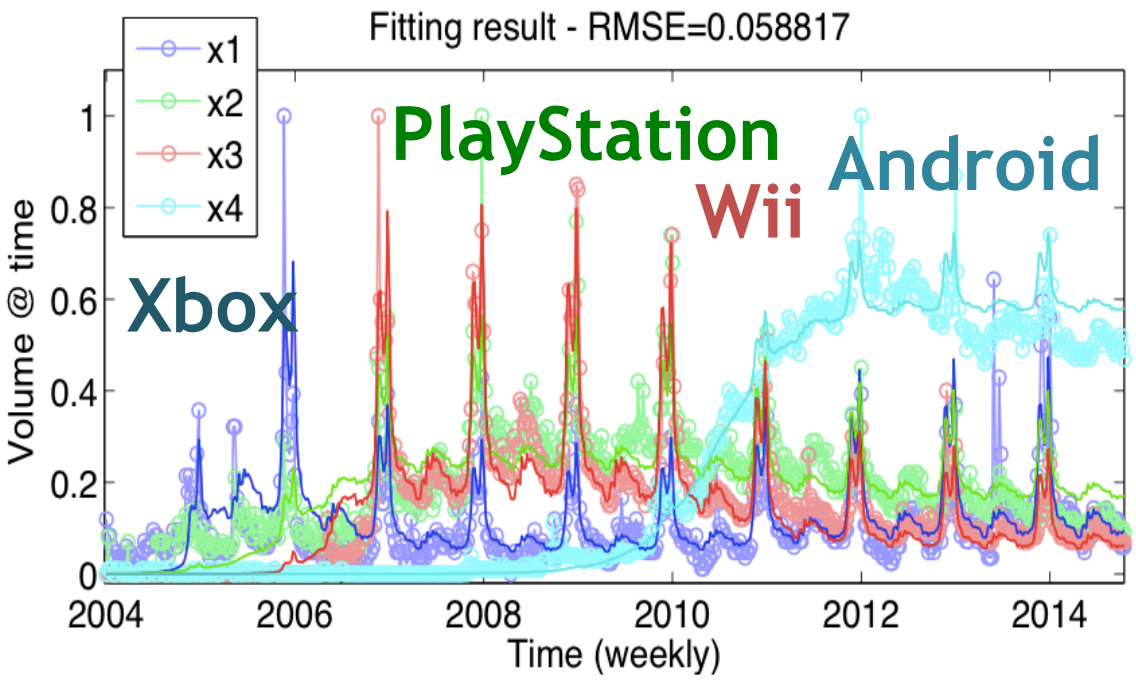
Q3. Scalability

How does it scale in terms of computational time?

Q1. Effectiveness

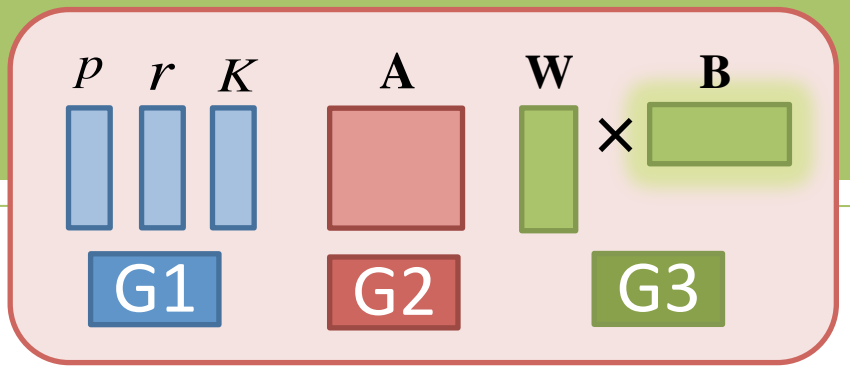


(#1) Video games

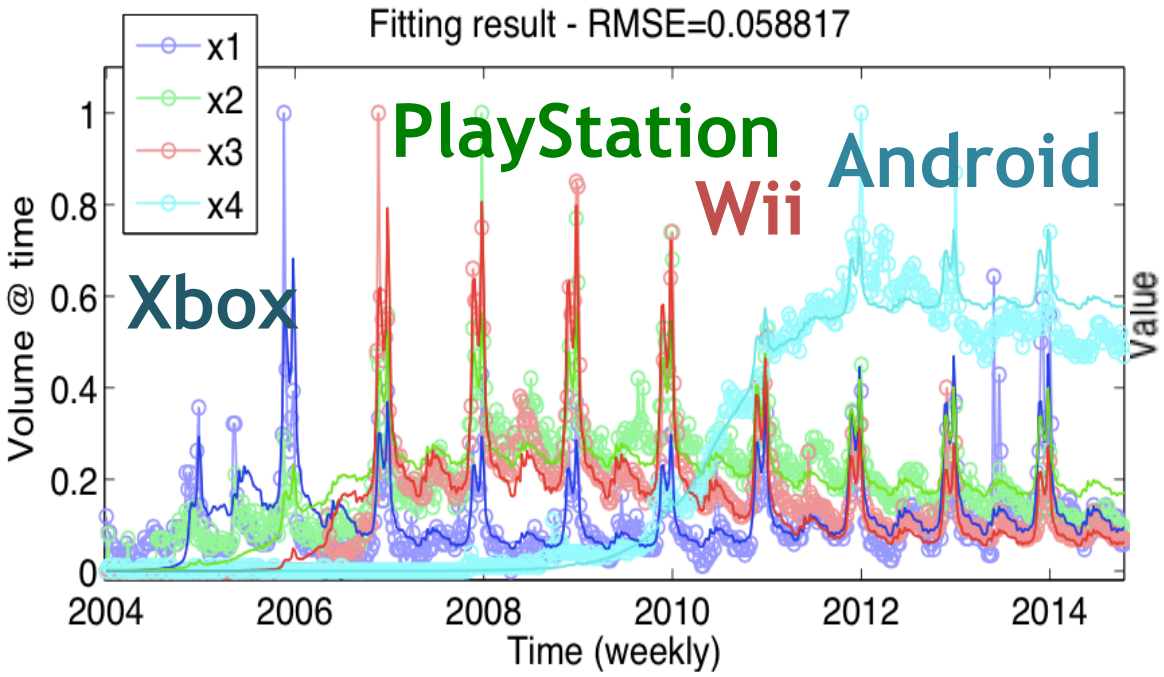


Interactions between keywords

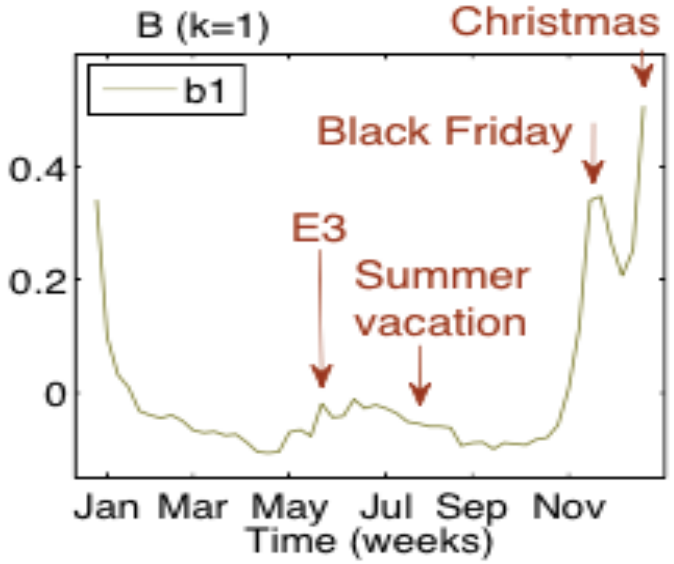
Q1. Effectiveness



(#1) Video games



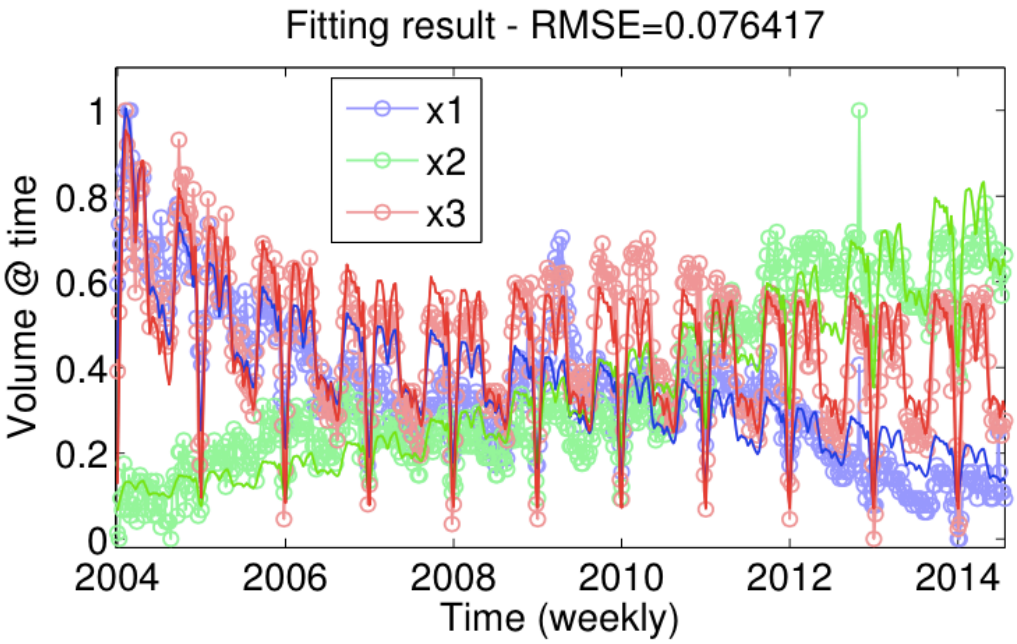
Seasonality



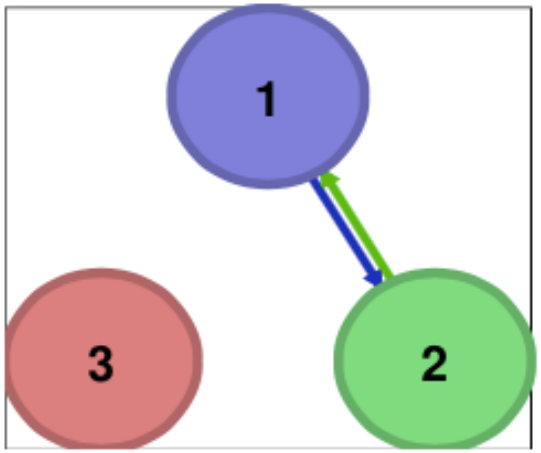
Q1. Effectiveness

(#2) Programming language

C , R , MATLAB



Interactions



Q1. Effectiveness

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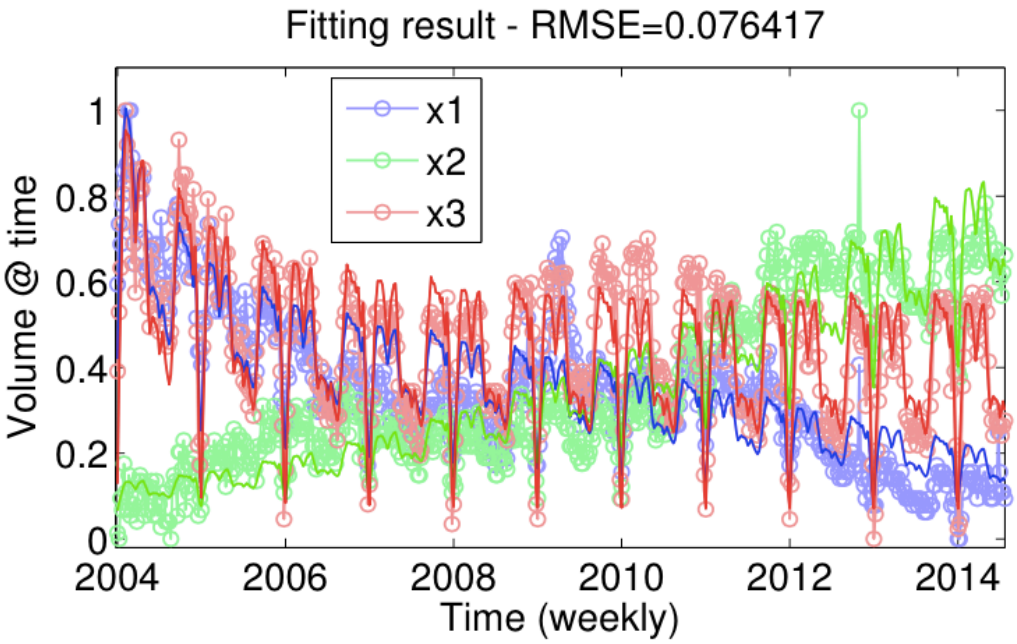
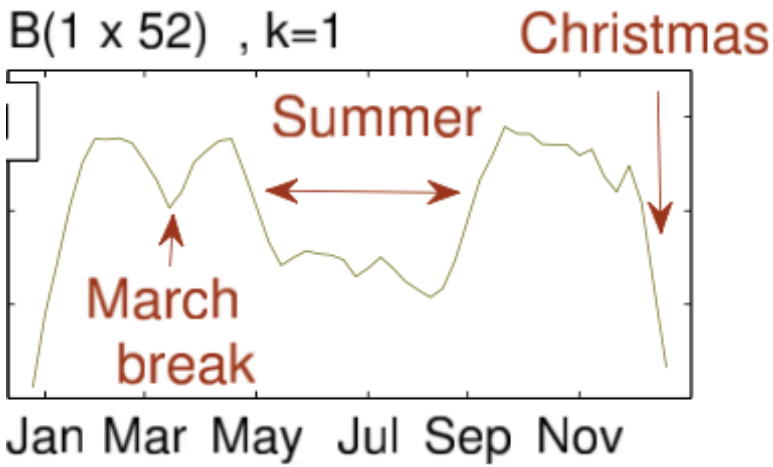


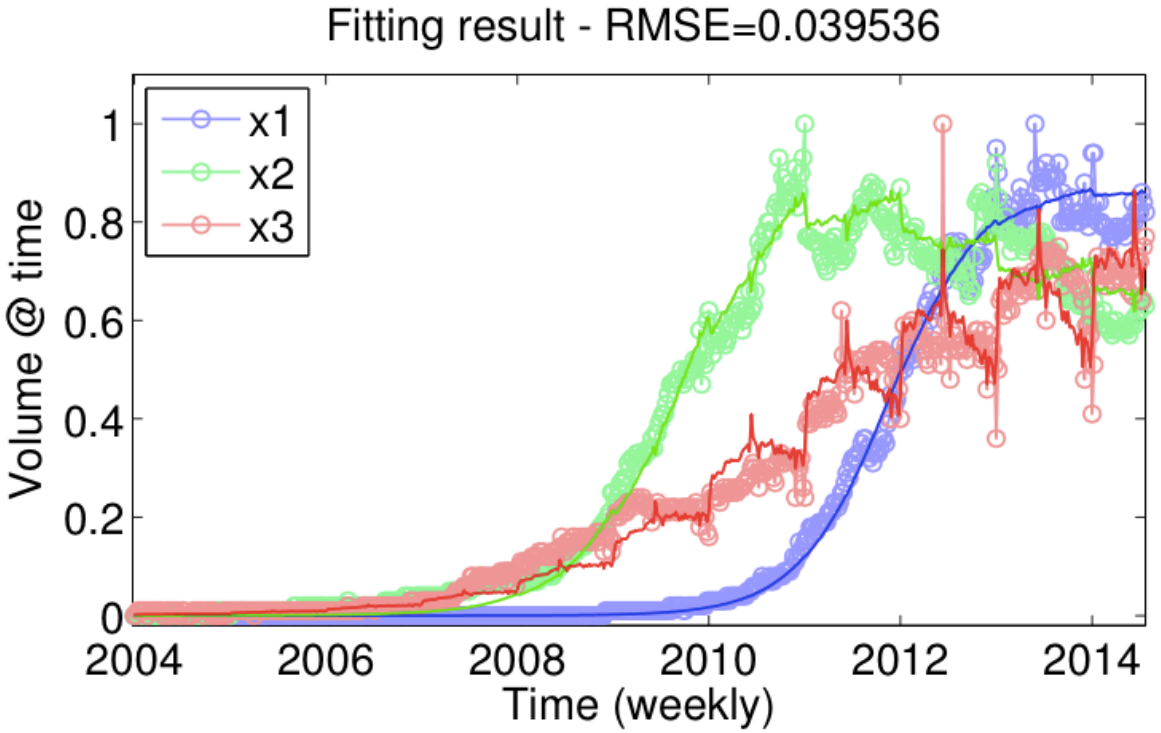
Seasonality



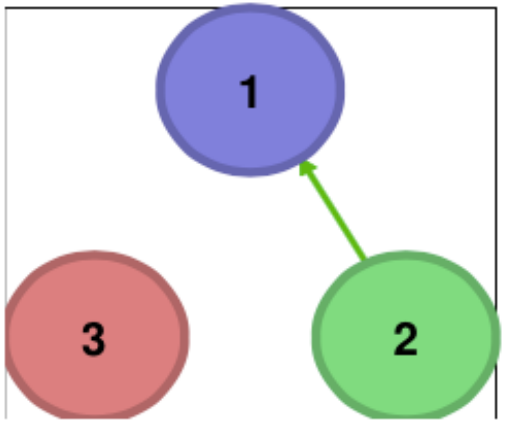
Q1. Effectiveness

(#3) Social media

Tumblr , Facebook , LinkedIn



Interactions



Q1. Effectiveness

(#3) Social media

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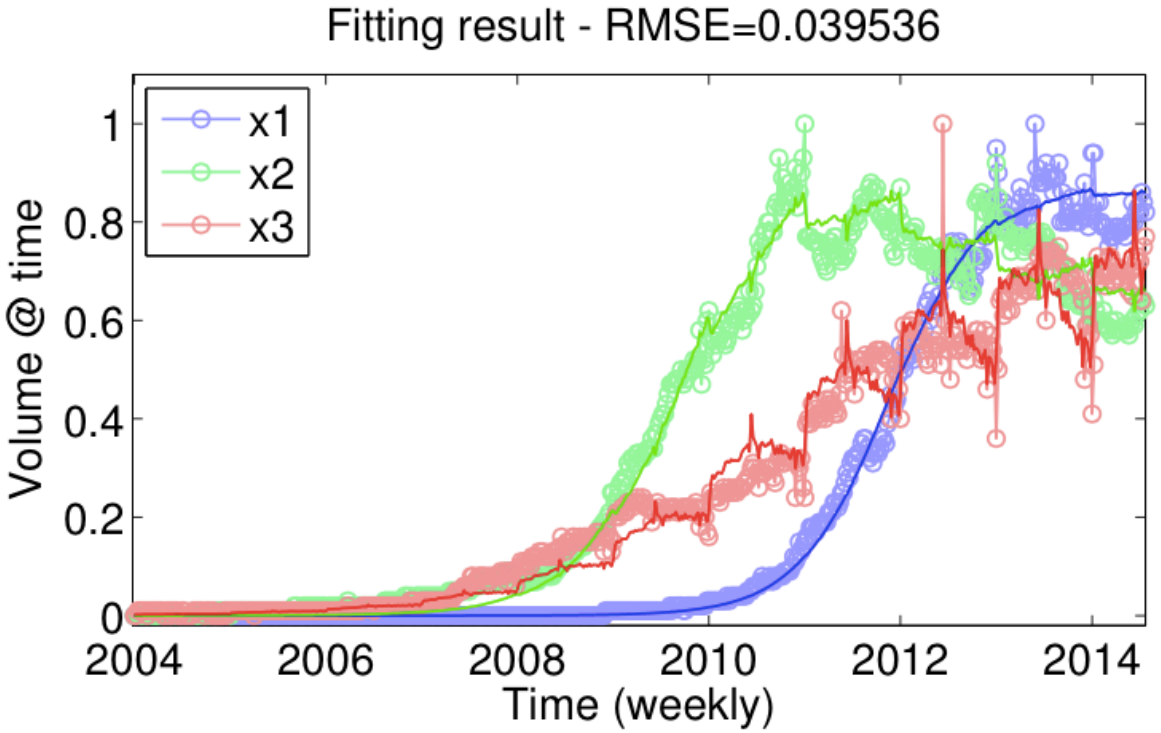
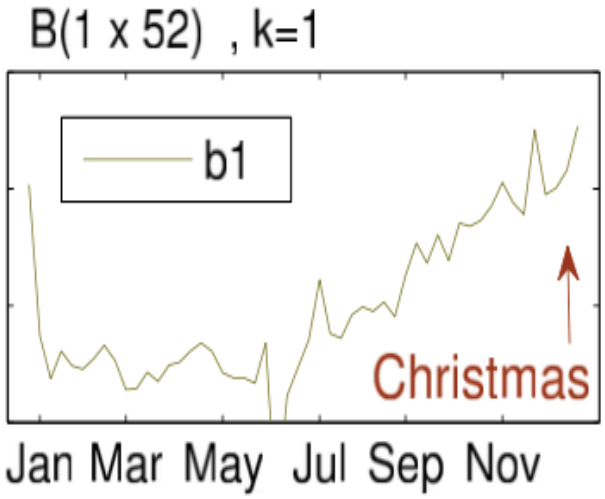


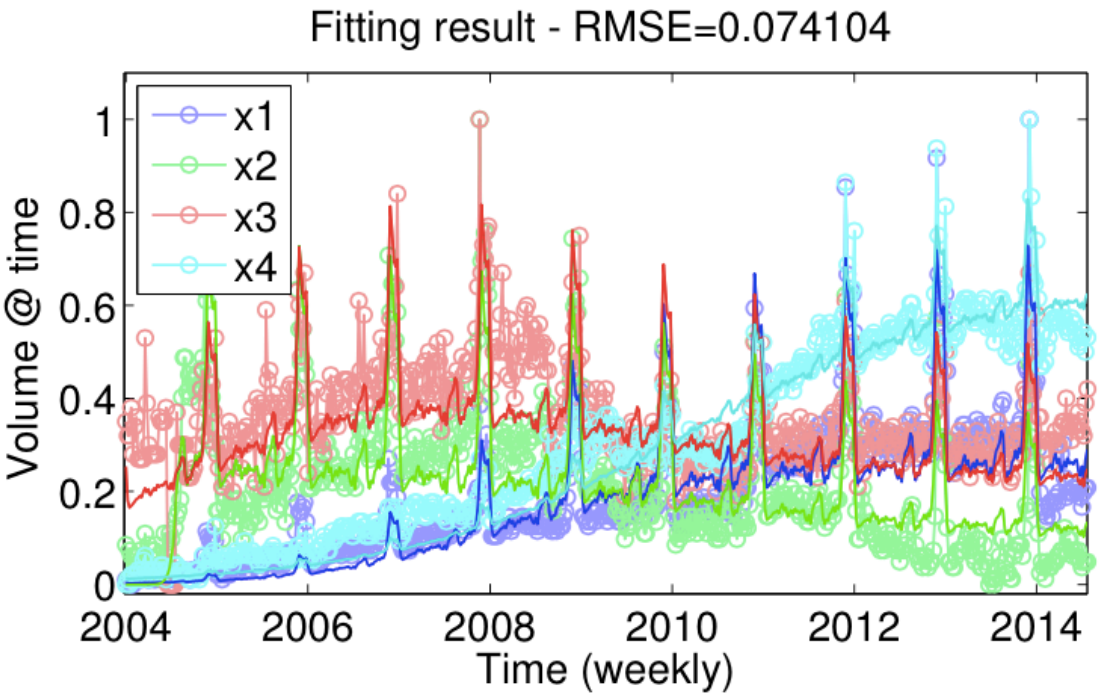
Seasonality



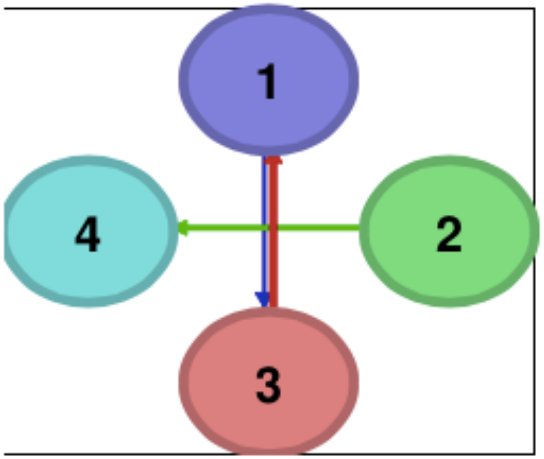
Q1. Effectiveness

(#4) Apparel companies

Kohls , JCPenny , Nordstrom , Forever21



Interactions



Q1. Effectiveness

(#4) Apparel companies

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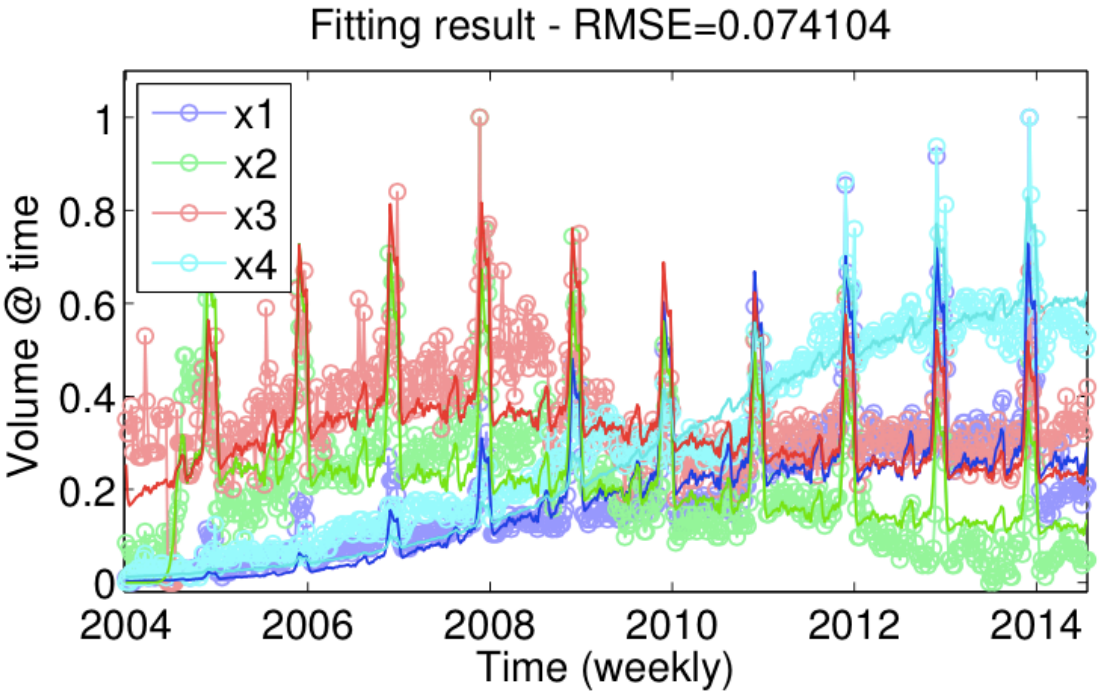
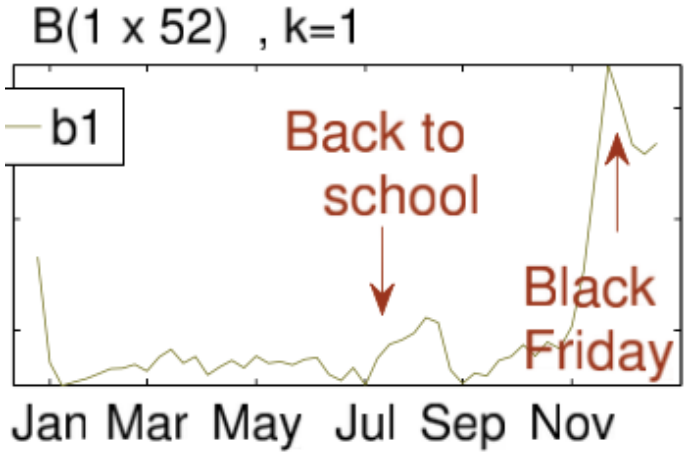


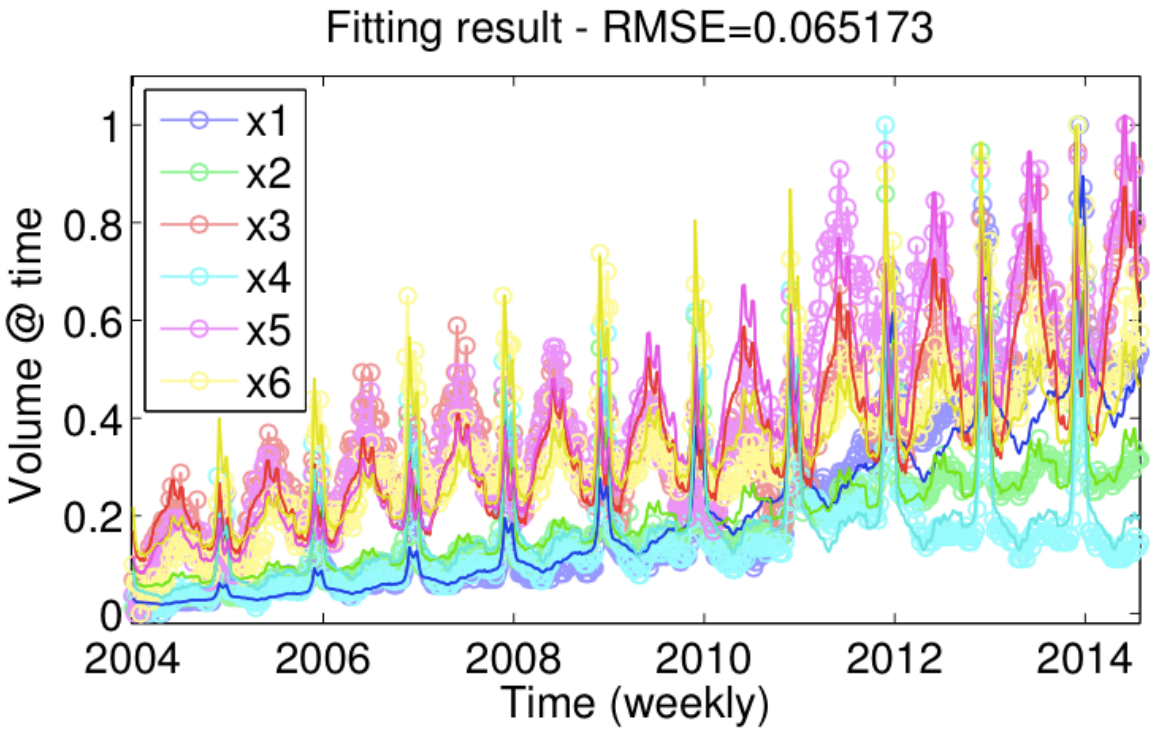
Seasonality



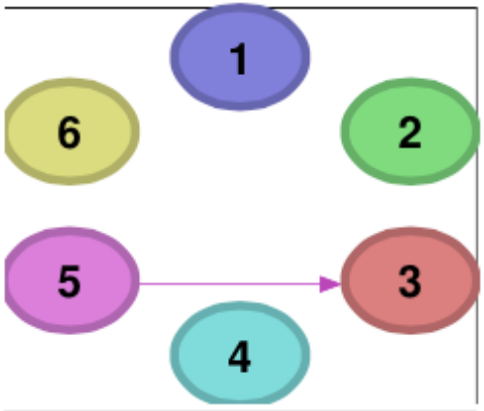
Q1. Effectiveness

(#5) Retail companies

Amazon , Walmart , Home Depot , BestBuy , Lowes , Costco



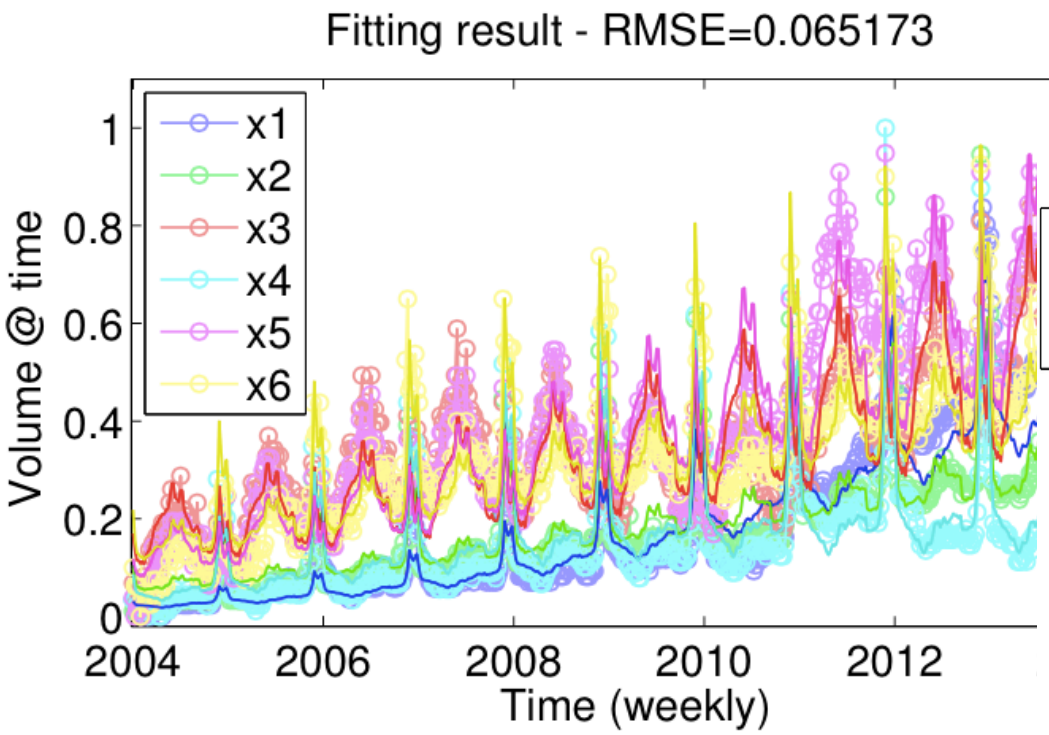
Interaction



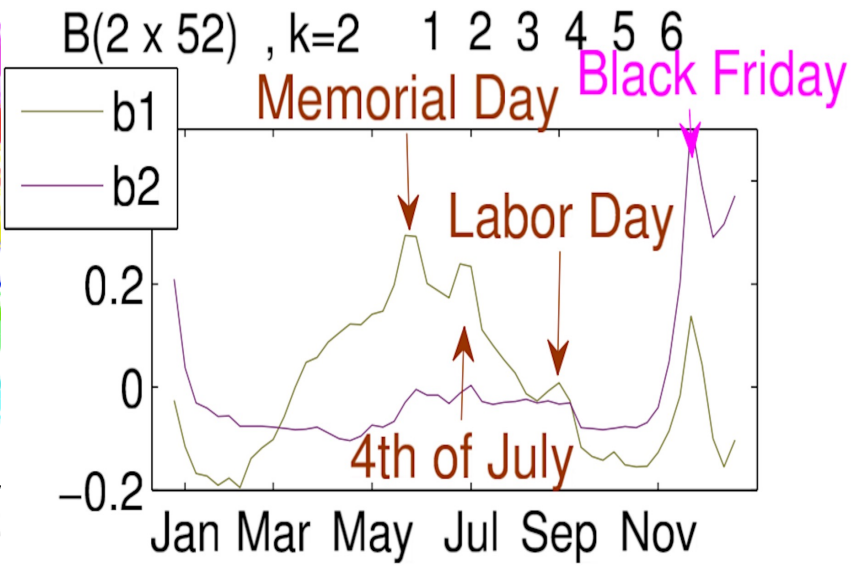
Q1. Effectiveness

(#5) Retail companies

Amazon , Walmart , Home Depot , BestBuy , Lowes , Costco



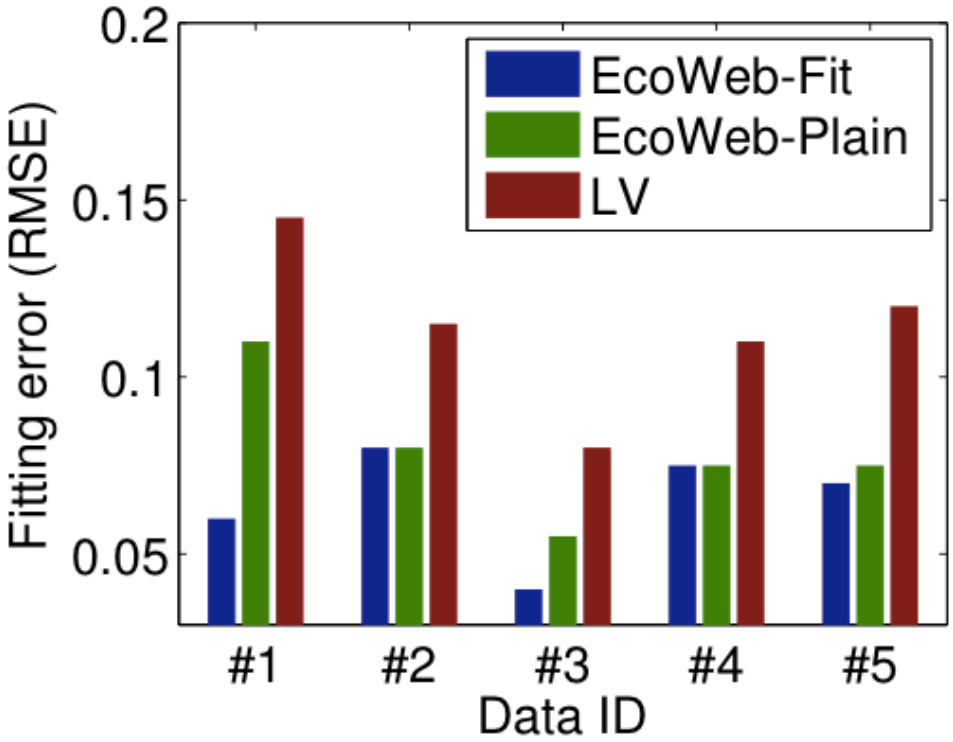
Seasonality



Q2. Accuracy

RMSE between original and fitted volume

(Lower is better)

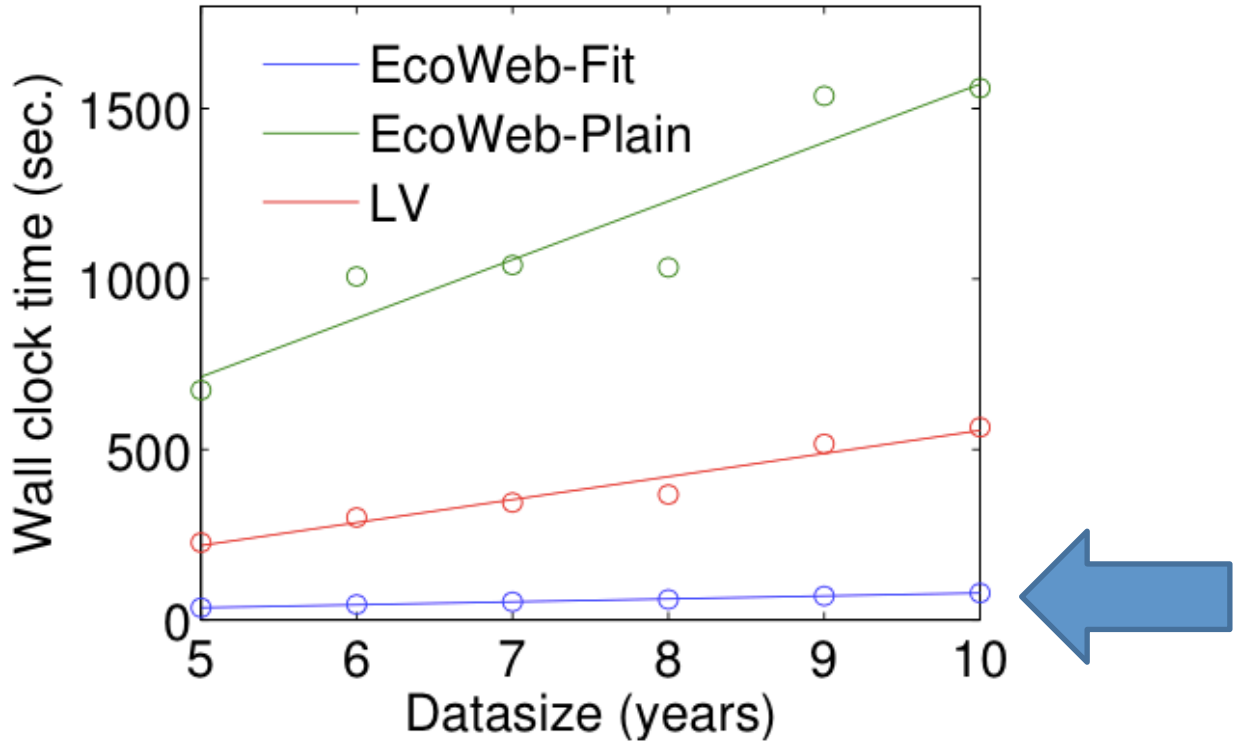


EcoWeb consistently wins!

Q3. Scalability

Wall clock time vs. dataset size (years)

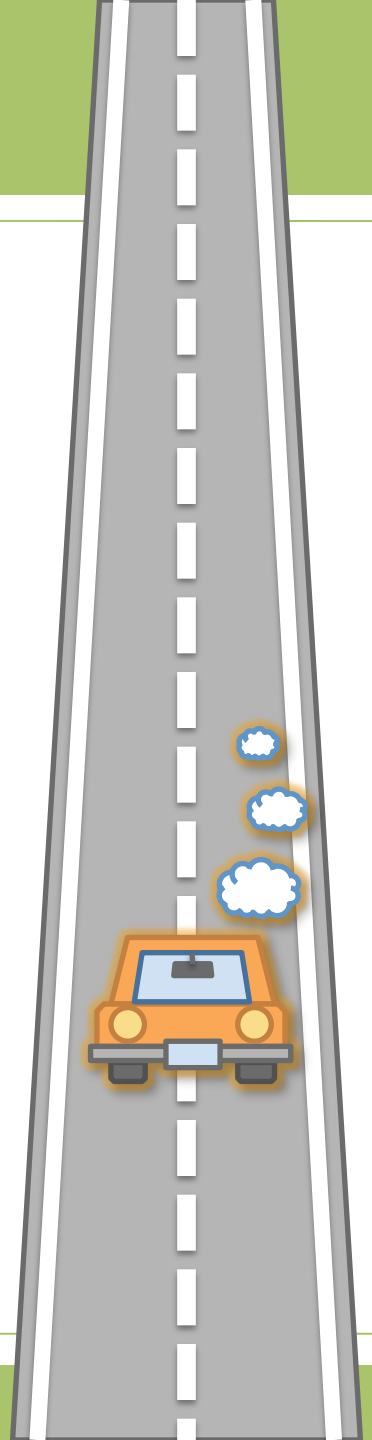
EcoWeb-Fit scales linearly, i.e., O(n)



7x faster than **LV**, 20x faster than **EcoWeb-Plain**

Roadmap

- ✔ Motivation
- ✔ Modeling power of EcoWeb
- ✔ Overview
- ✔ Proposed model
- ✔ Algorithm
- ✔ Experiments
- – EcoWeb – at work
- – Conclusions

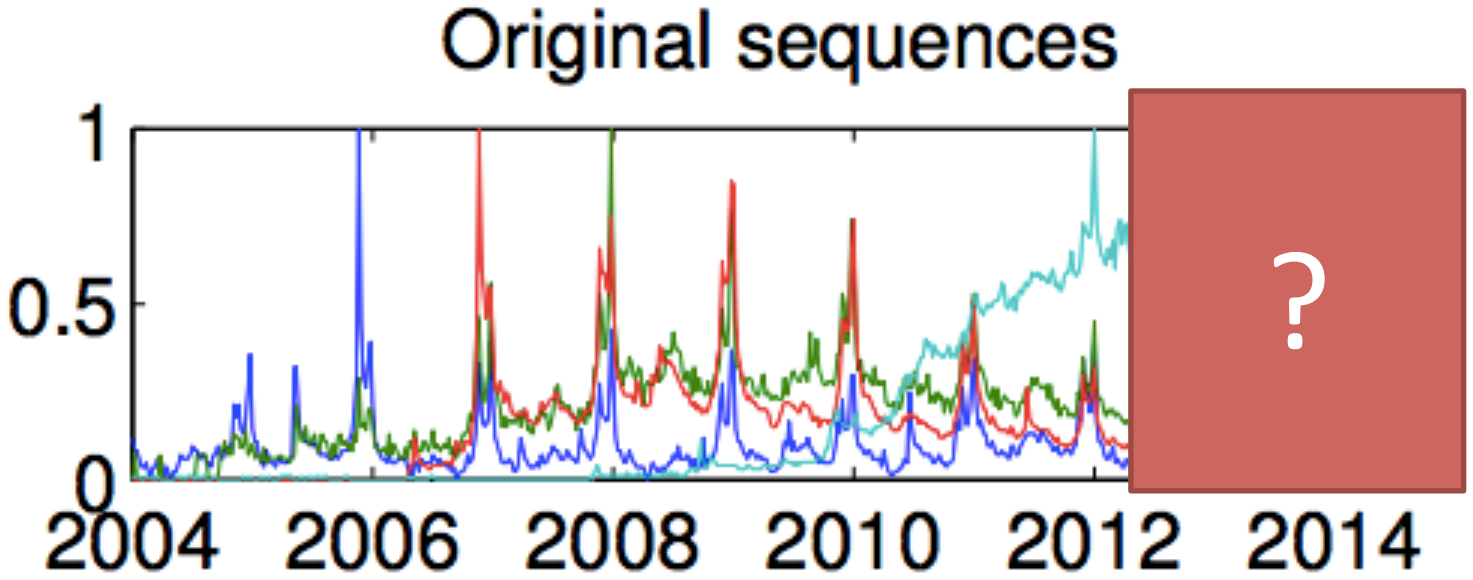


EcoWeb at work - forecasting

Forecasting future activities

Train:
2/3 sequences

Forecast:
1/3 following years



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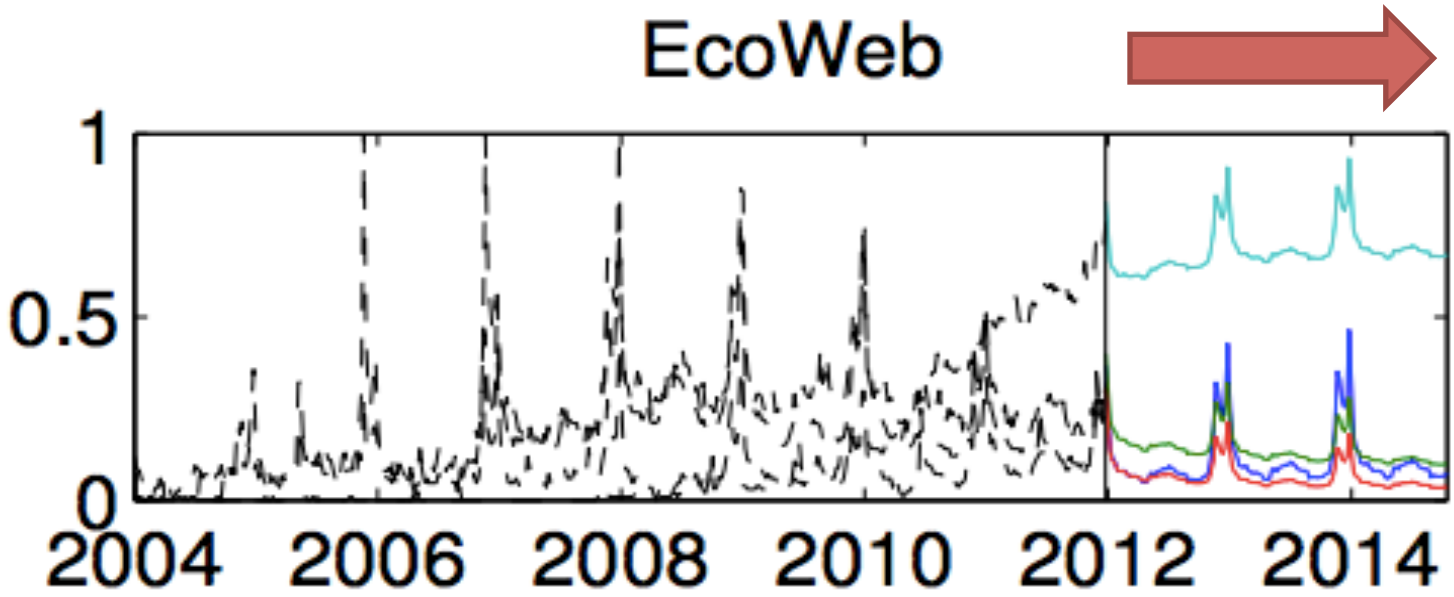
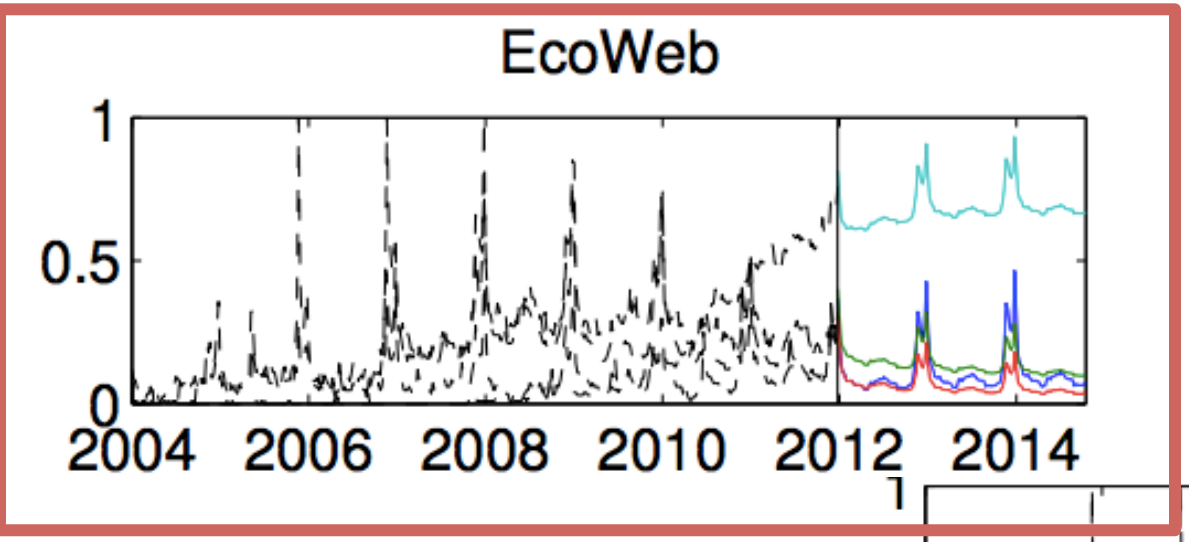
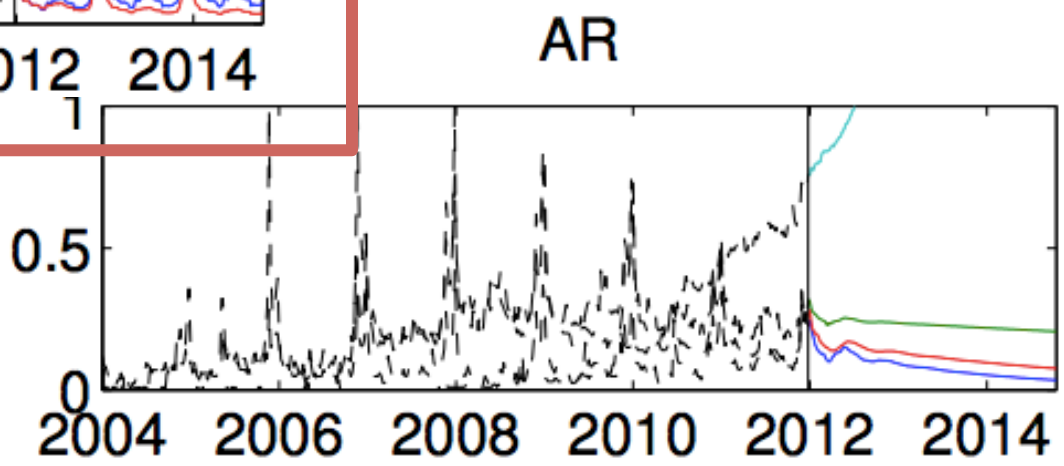


EcoWeb can capture future patterns

EcoWeb at work - forecasting

Forecasting future activities

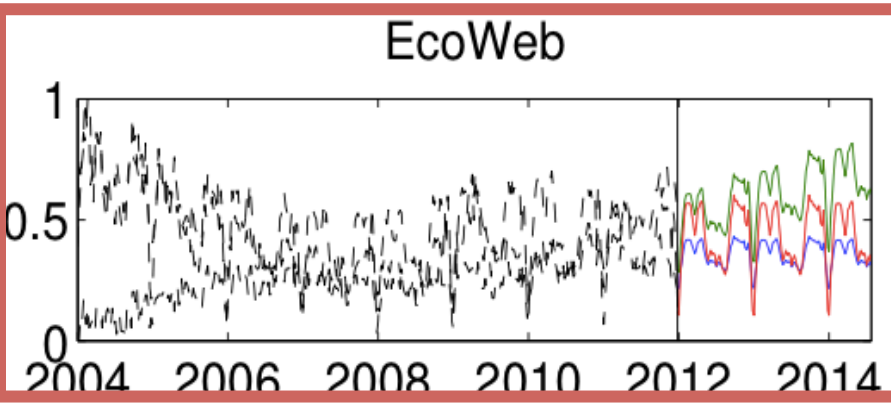


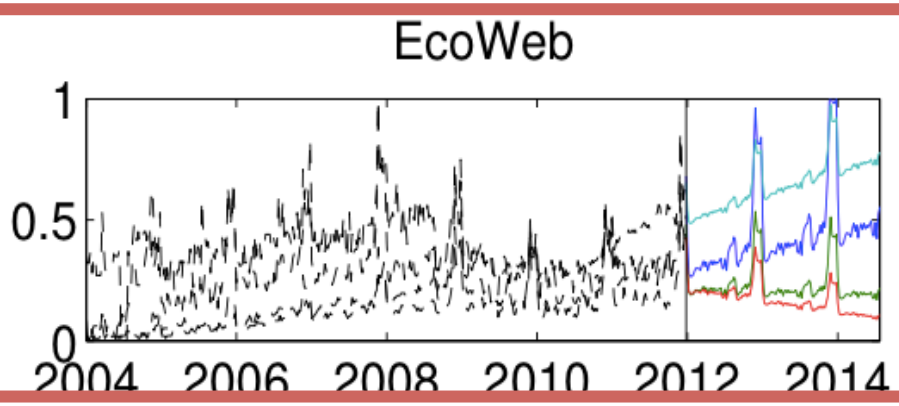


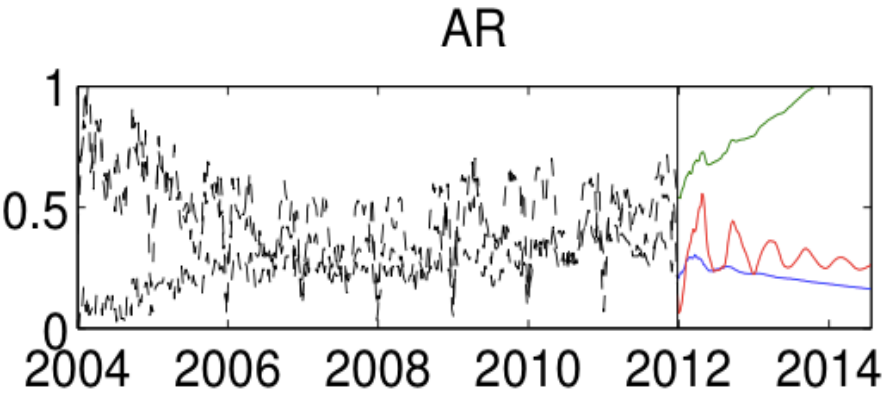
EcoWeb can capture future patterns!

EcoWeb at work - forecasting

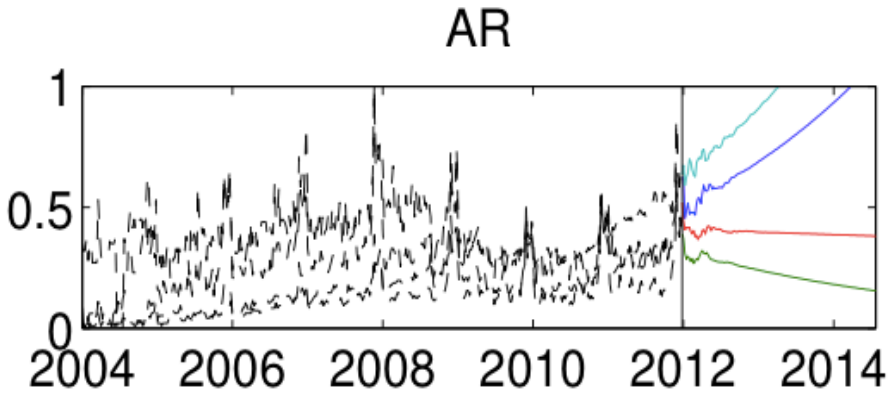
Forecasting future activities







(b) Programming languages (#2)



(c) Apparel companies (#4)

EcoWeb can capture future patterns!

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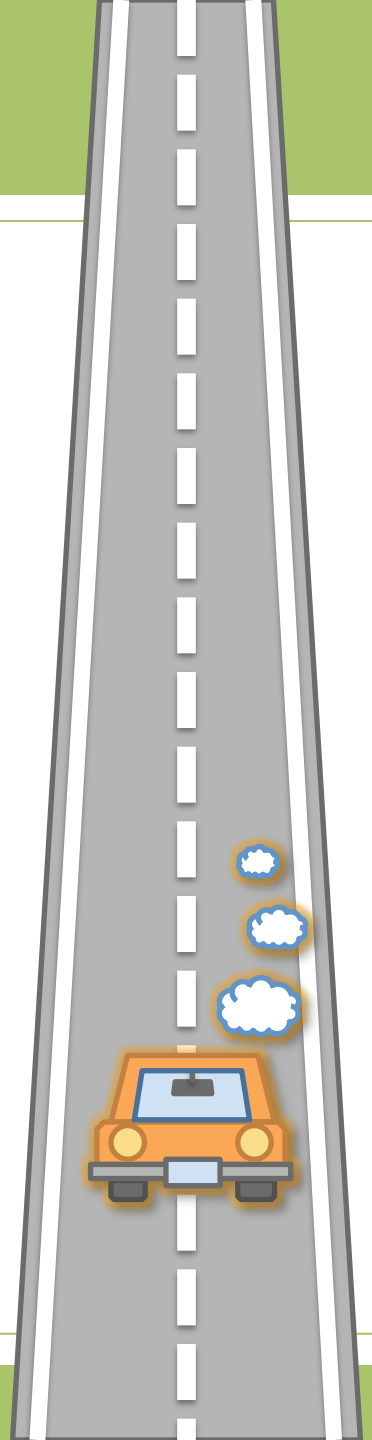
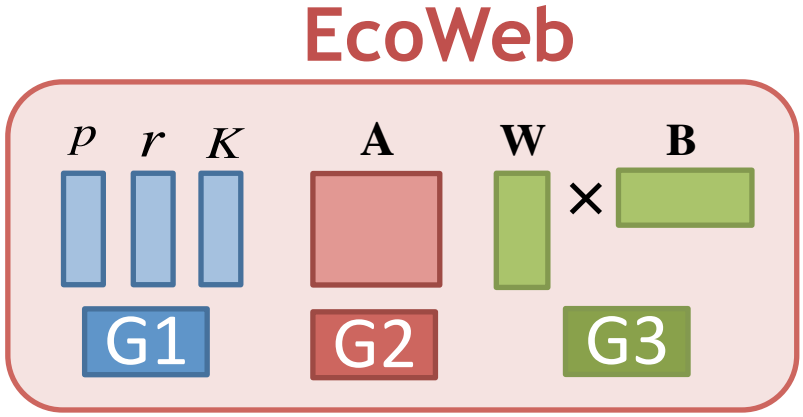
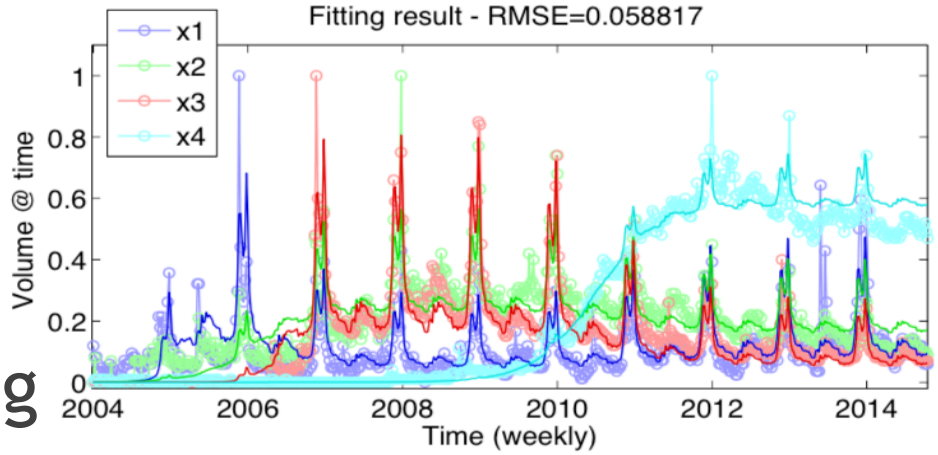


Conclusions

EcoWeb has the following advantages

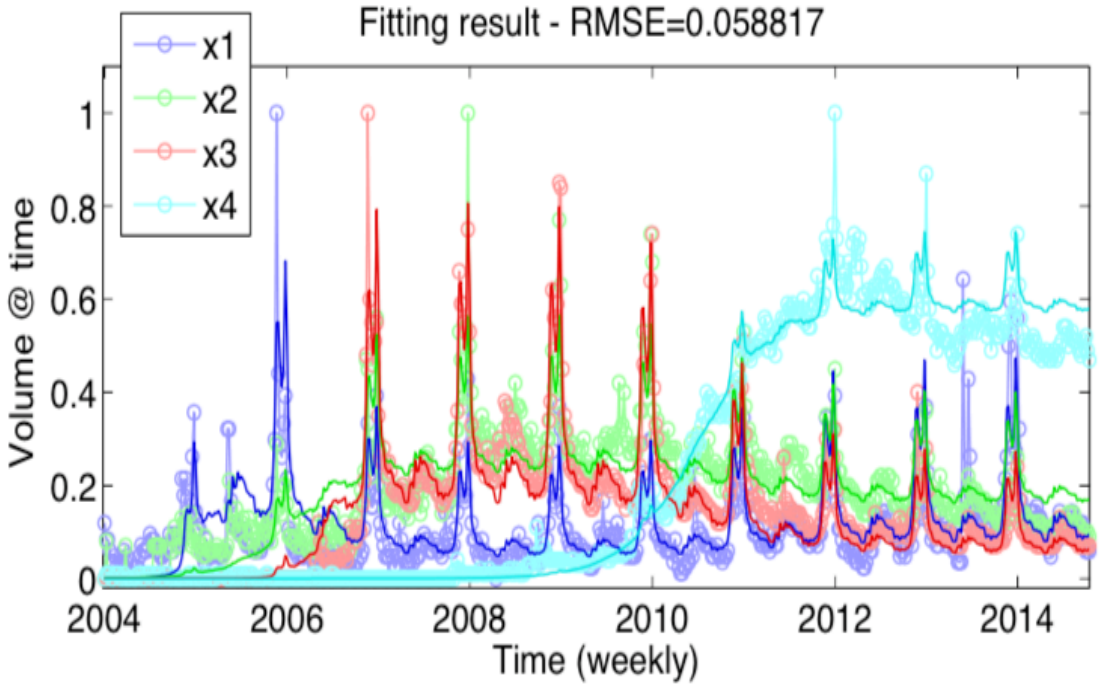
- ✔ **Effective**
  Finds important patterns
- ✔ **Fully-automatic**
  No parameter tuning
- ✔ **Scalable**
  It is linear
- ✔ **Practical**
  Long-range forecasting

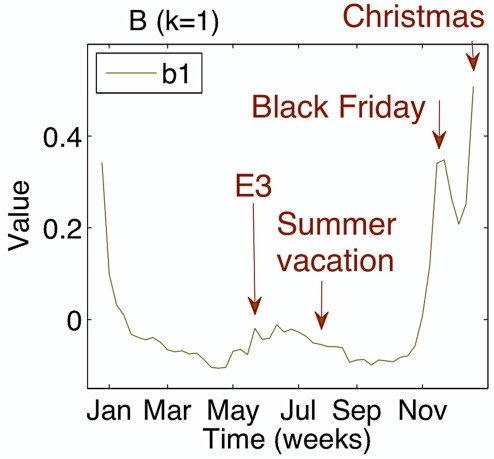




Thank you!







Data & Code:

http://www.cs.kumamoto-u.ac.jp/~yasuko