ICDM 2015

IEEE International Conference on Data Mining

A GENERAL **SUSPICIOUSNESS** METRIC FOR **DENSE BLOCKS** IN **MULTIMODAL** DATA

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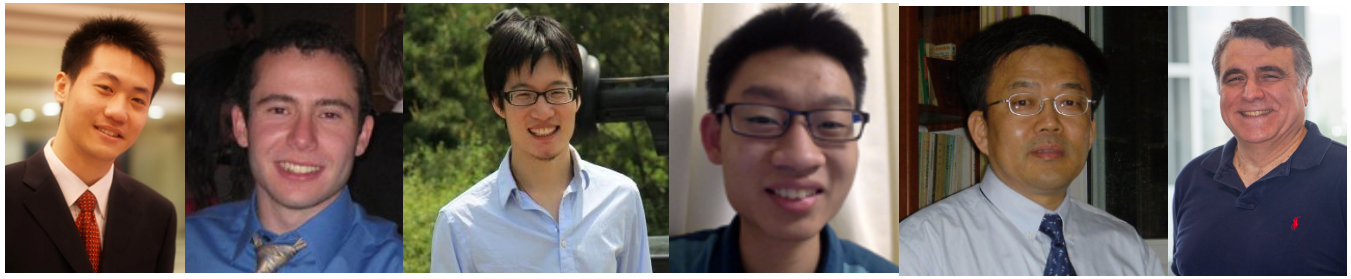
Joint work with
Alex Beutel (CMU), Peng Cui (Tsinghua), Bryan Hooi (CMU),
Shiqiang Yang (Tsinghua), Christos Faloutsos (CMU)



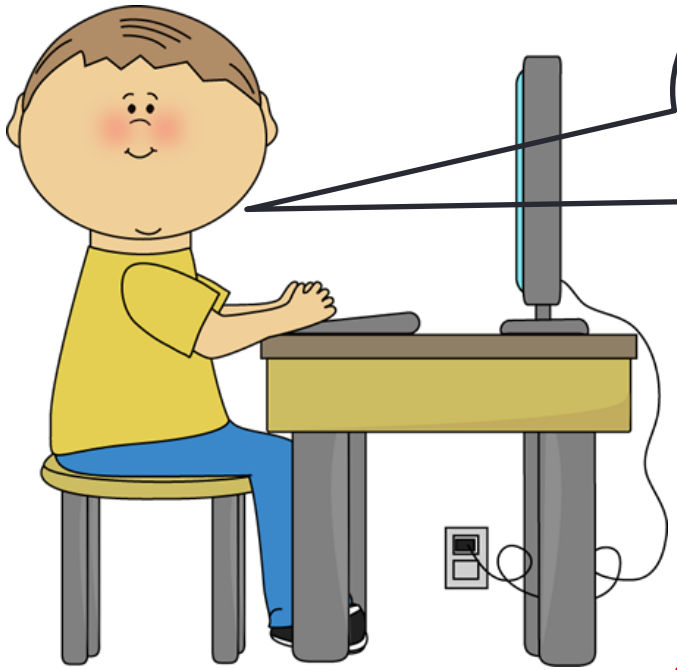
ROADMAP

1. Motivation & Problem

2. Proposed Method

3. Experiments

Suppose You Work in Twitter



My boss wants me to **catch fraud** in such a big table – **billions of records, tens of columns**!!! How?!

	ID	USER_NAME	CREATED_AT	TEXT	HASH_TAGS
1	251	SpiritSofts	Dec 14, 2013	SAP HANA ONLINE TRAINING COURSE CONTENT http://t.co/2DefOMC0Vi	
2	252	Blue net studiO	Dec 14, 2013	sap hana online training and placenet 2 http://t.co/S1wGh8n5Kk	
3	253	Hana Kingham	Dec 14, 2013	Right film fest today: love actually, elf, gravity, training day. #dayyym	dayyym,
4	254	Nora Apnila J...	Dec 14, 2013	Alhamdulilaaahhhh...selesai ikutin kelanjutan training dadakan mb Hana ...	
5	255	ZaranTech	Dec 14, 2013	I added a video to a @YouTube playlist http://t.co/O3qD9wfi8K SAP BUSI...	
6	256	ZaranTech	Dec 14, 2013	I added a video to a @YouTube playlist http://t.co/XxrfuCUqAS SAP BUSI...	
7	257	Helmich op t...	Dec 14, 2013	Reserveer alvast 15 januari 2014 training HANA Essentials #SAP #HANA	SAP,HANA,
8	258	Social News	Dec 13, 2013	sap hana online training and placenet 2 http://t.co/JlaA41IdnV	
9	259	Nurjanah	Dec 13, 2013	Baca notif fb .. ada training dadakaann dari eyang kita.... ayo wara wiri ca...	
10	260	Nora Apnila J...	Dec 13, 2013	lanjutt di rumaah dulu ikutan trainingnyaaa..mau buru buru pulang see u...	
11	261	madhu	Dec 13, 2013	SAP HANA TRAINING | SAP HANA PLACEMENT | SAP HANA INSTITUTE I...	
12	262	Hana O'Neill	Dec 13, 2013	@sarahsilvanator no I have life guard training Saturday and my final test t...	
13	263	arjun	Dec 13, 2013	sap grc online training |sap hana sap security online training@YEKTEK - A...	

fraud

Massive **Multi-Modal** Data: Lines (Mass) & Columns (Mode)

Dataset	Mode				Mass
Retweeting	**User**	**Root ID**	**IP**	**Time (min)**	**#retweet**
	29.5M	19.8M	27.8M	56.9K	211.7M
Trending (Hashtag)	**User**	**Hashtag**	**IP**	**Time (min)**	**#tweet**
	81.2M	1.6M	47.7M	56.9K	276.9M
Network attacks (LBNL)	**Src-IP**	**Dest-IP**	**Port**	**Time (sec)**	**#packet**
	2,345	2,355	6,055	3,610	230,836

Suspicious Behaviors in **Multi-Modal** Data

Wholesalebargain2015 Retweeted

Real Time Deals @ebayrt · 2h

Seattle Mariners Mlb #Majestic Authentic Diamond Blue Stitched 2 Xl M... (Sanford) USD 25 ebayrt.co/sports-mem-car… #eBay #eBayUS via @wil30225

2

Wholesalebargain2015 Retweeted

Real Time Deals @ebayrt · 2h

Embroidered Navy Blue Aztec Mexican Top/ Long Sleeve Ethnic Mod... USD 35 ebayrt.co/clothing-shoes… #Handmade #eBay #eBayUS via @smilingbluedog

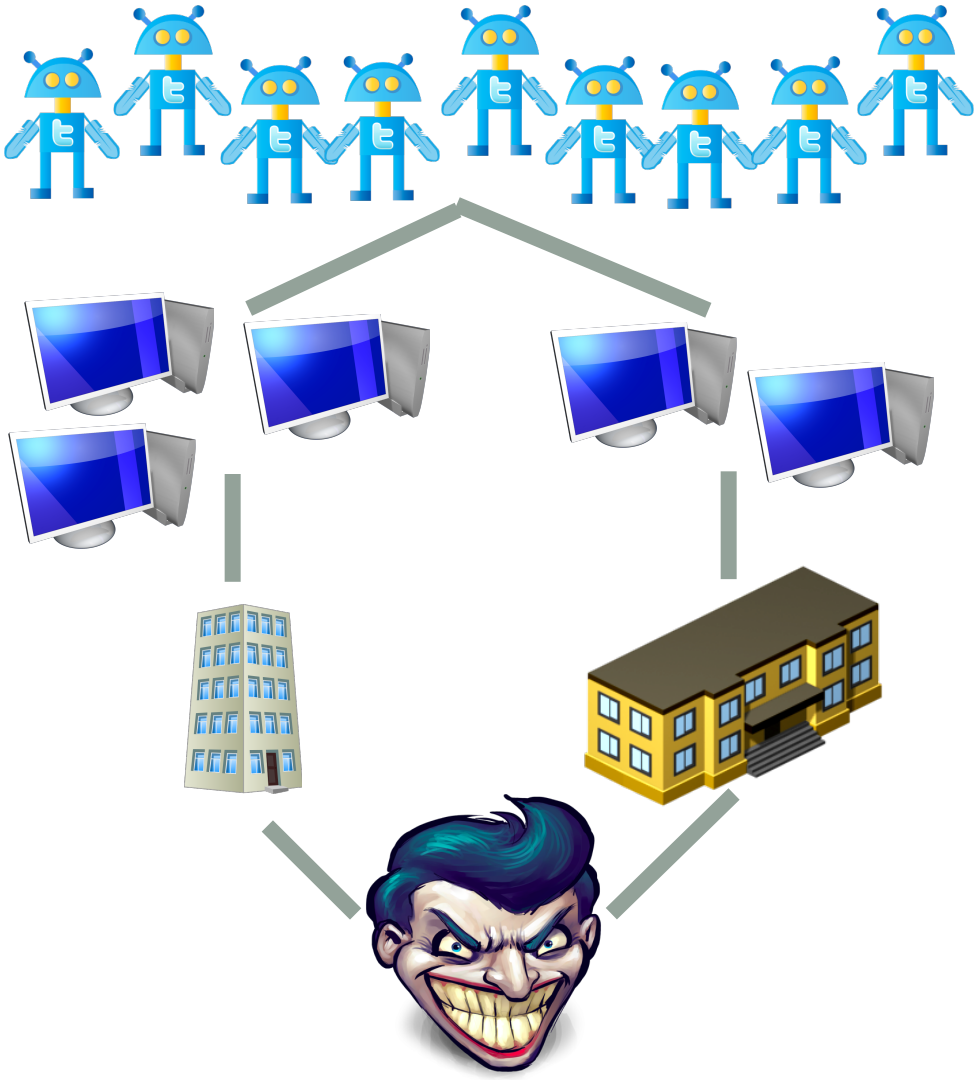
4

Wholesalebargain2015 Retweeted

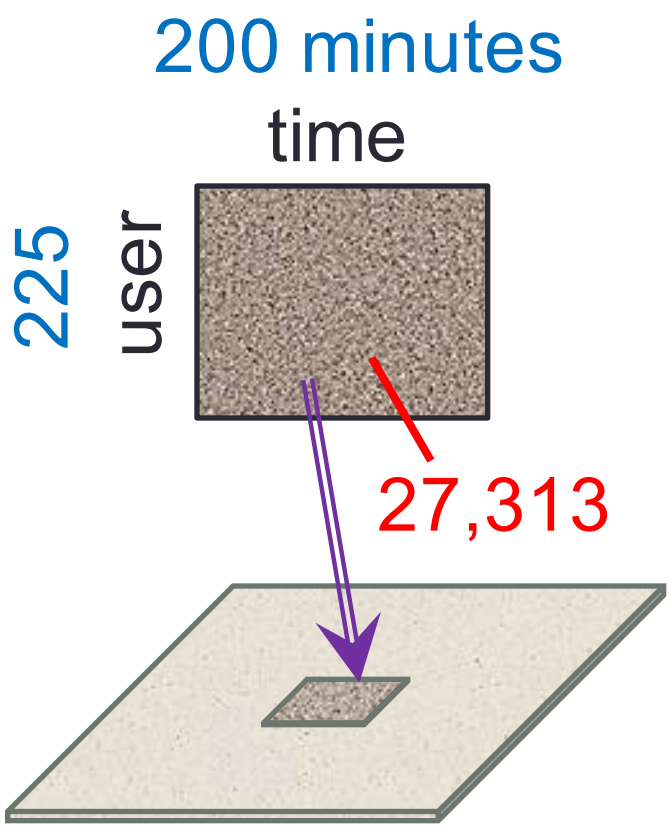
Real Time Deals @ebayrt · 1h

Contractubex Children Cartoon Boxing Gloves Red (Bloomington) USD 21.78 ebayrt.co/sporting-goods… #eBay #eBayUS via @GaroldFrenz

4



Dense Blocks Indicates **Suspiciousness**



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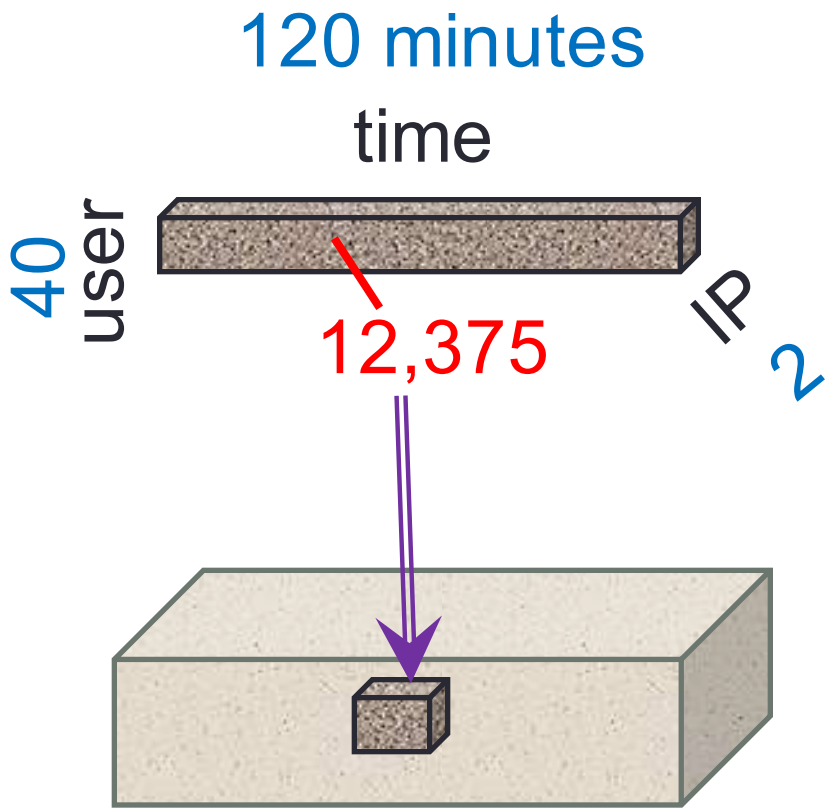
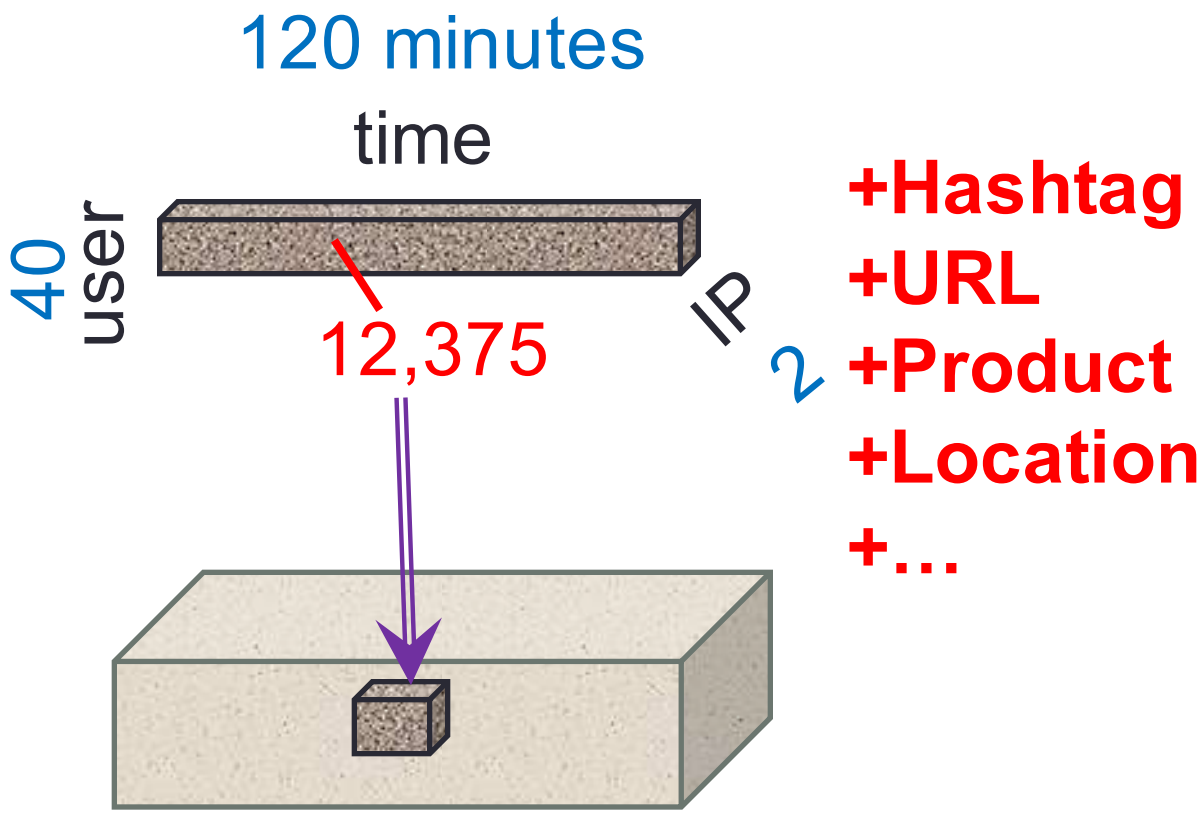
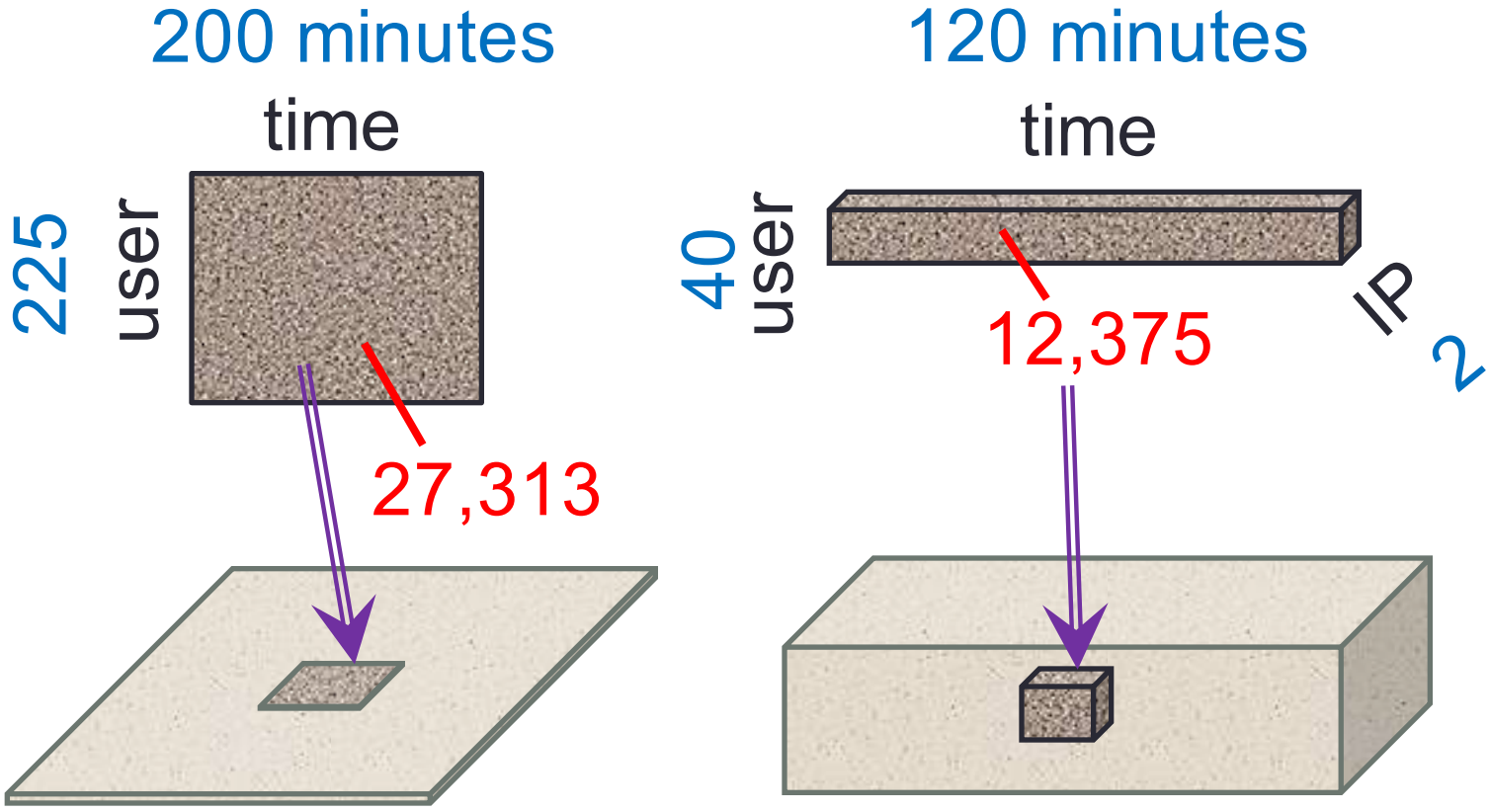


Dense Blocks Indicates **Suspiciousness**



Dense Blocks Indicates **Suspiciousness**



Question: Which is more suspicious?

We need a metric to evaluate the suspiciousness.

ROADMAP

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2. Proposed Method

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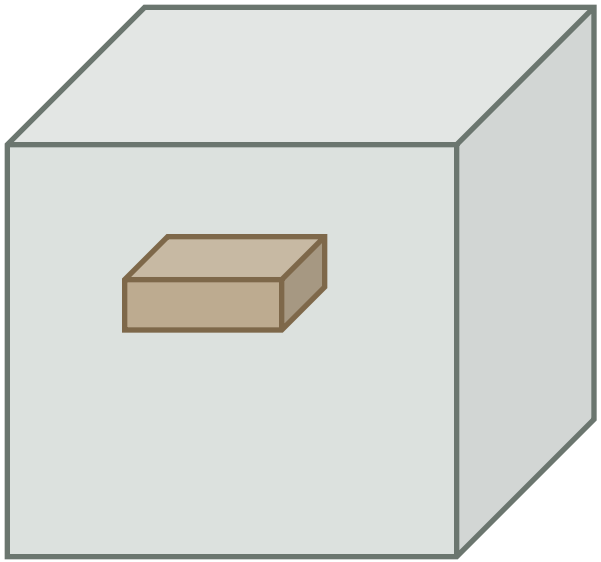
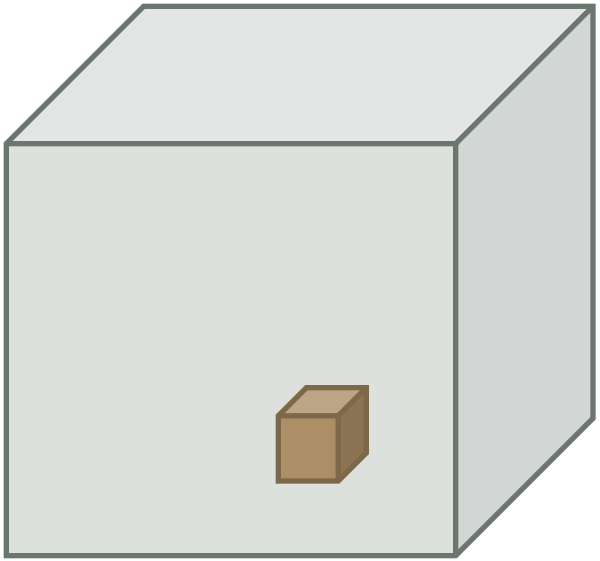
Metric Criteria

What properties are required of a good metric?



$N_1 \times N_2 \times N_3$

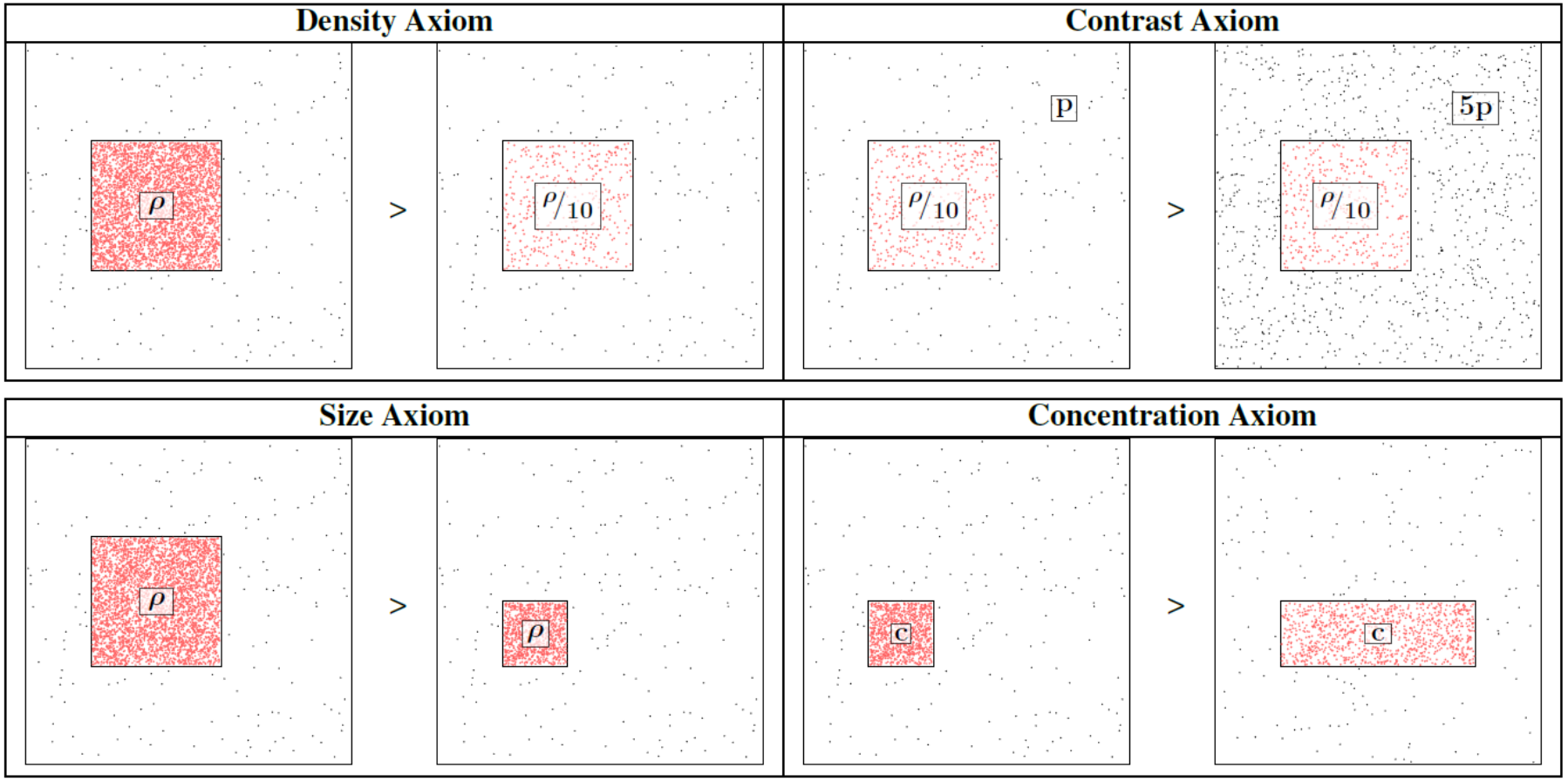
Count data with total "mass" *C*



$f(\ n_1 \times n_2 \times n_3$ mass c density ρ $)$ **vs** $f(\ n'_1 \times n'_2 \times n'_3$ mass c' density ρ' $)$

Axioms 1-4

$$c_1 > c_2 \iff f(\mathbf{n}, c_1, \mathbf{N}, C) > f(\mathbf{n}, c_2, \mathbf{N}, C)$$

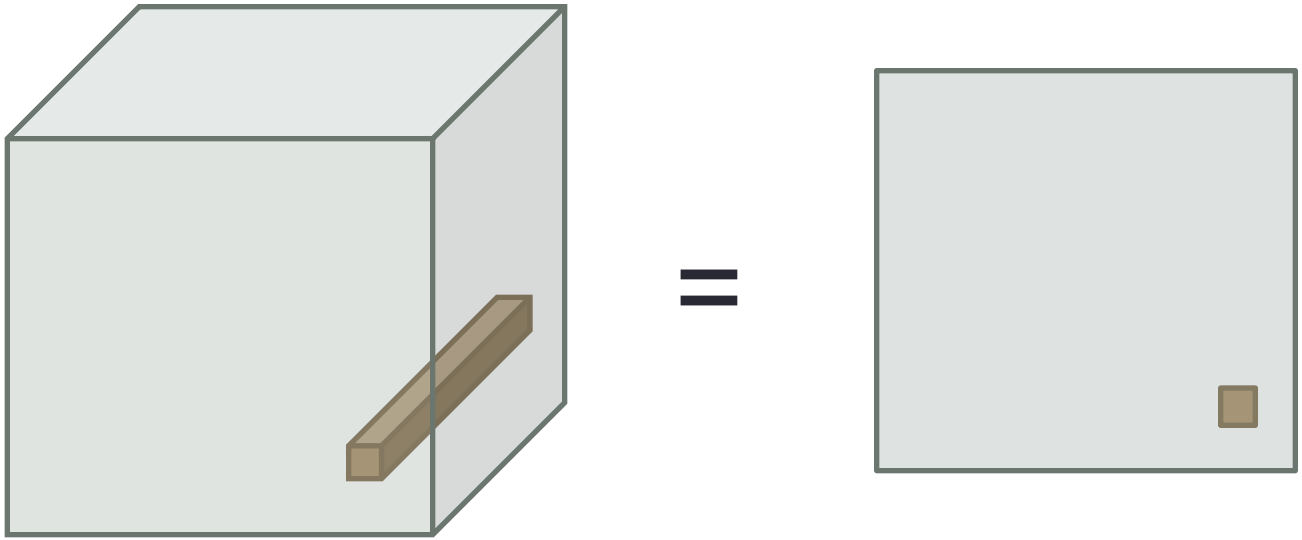


$$p_1 < p_2 \iff \hat{f}(\mathbf{n}, \rho, \mathbf{N}, p_1) > \hat{f}(\mathbf{n}, \rho, \mathbf{N}, p_2)$$

Axiom 5: Multimodal

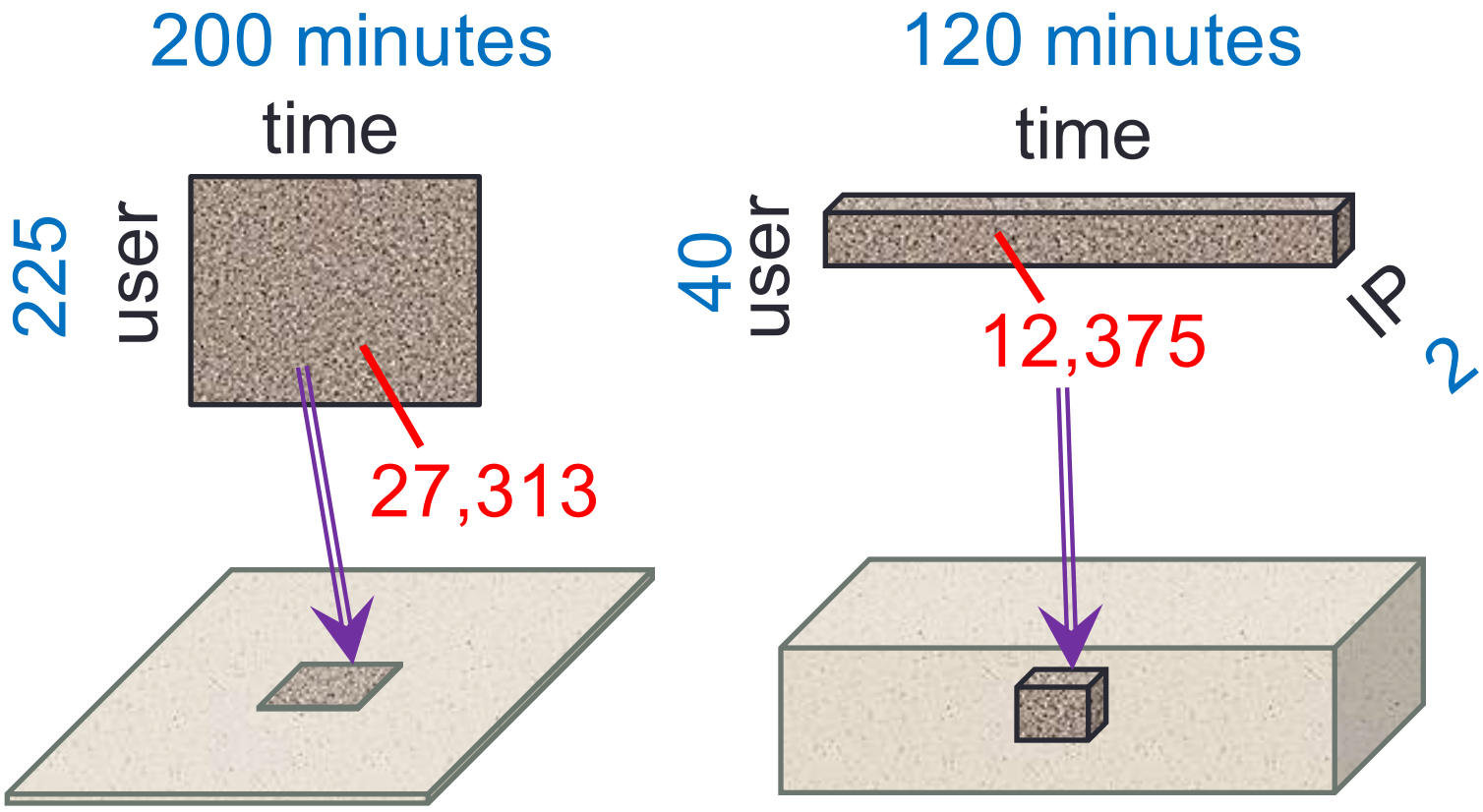
$$f_{K-1}\left([n_k]_{k=1}^{K-1}, c, [N_k]_{k=1}^{K-1}, C\right) = f_K\left(([n_k]_{k=1}^{K-1}, N_K), c, [N_k]_{k=1}^{K}, C\right)$$

Not including a mode is the same as including all values for that mode.

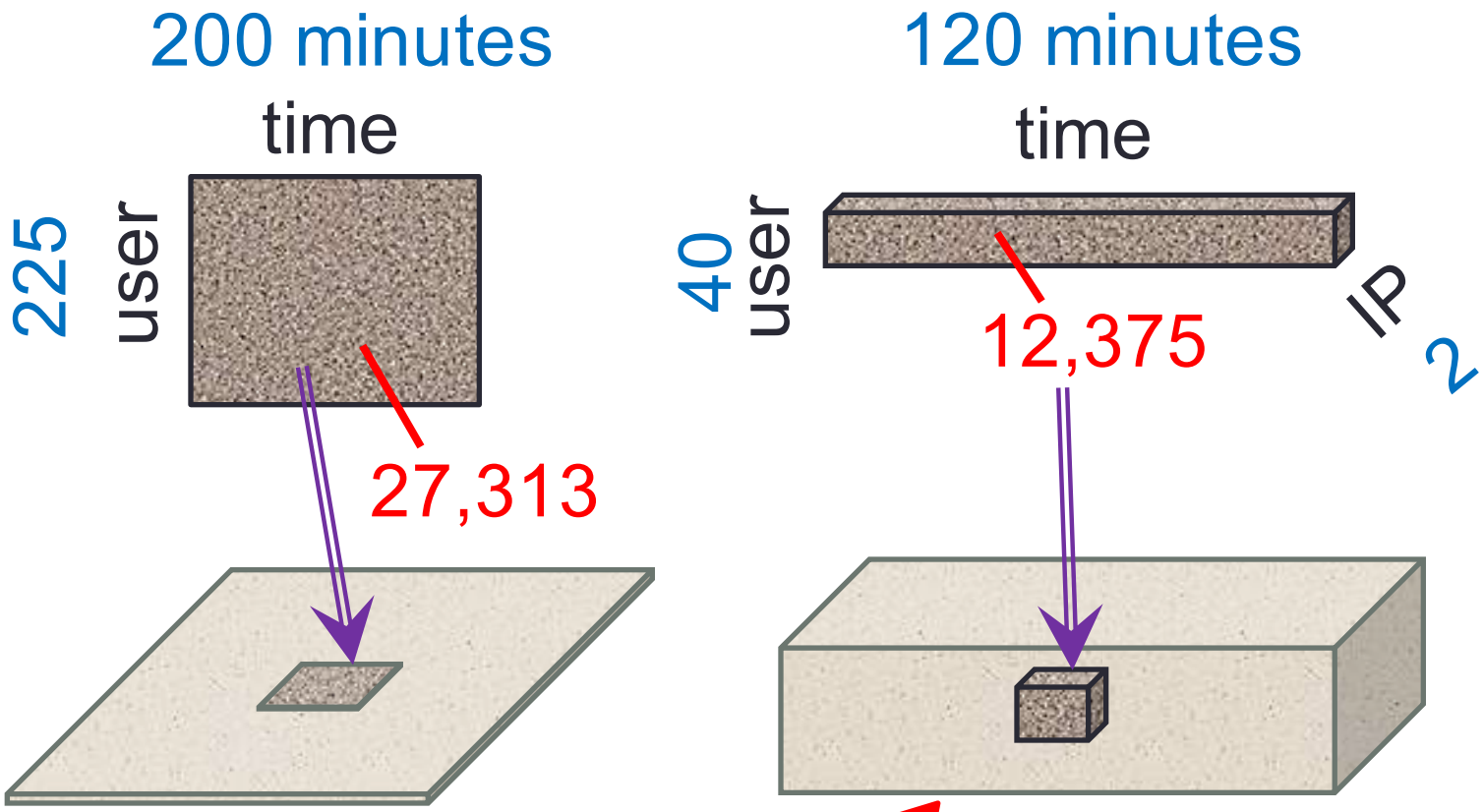


- New information (more modes) can only make our blocks more suspicious

Our Principled Idea: **Scoring Suspiciousness**



Our Principled Idea: **Scoring Suspiciousness**



0.9% **Probability** **0.05%**

A General **Suspiciousness** Metric

- Negative log likelihood of block's probability

$$f(n, c, N, C) = -\log\left[Pr(Y_n = c)\right]$$

Lemma *Given an $n_1 \times \cdots \times n_K$ block of mass c in $N_1 \times \cdots \times N_K$ data of total mass C, the suspiciousness function is*

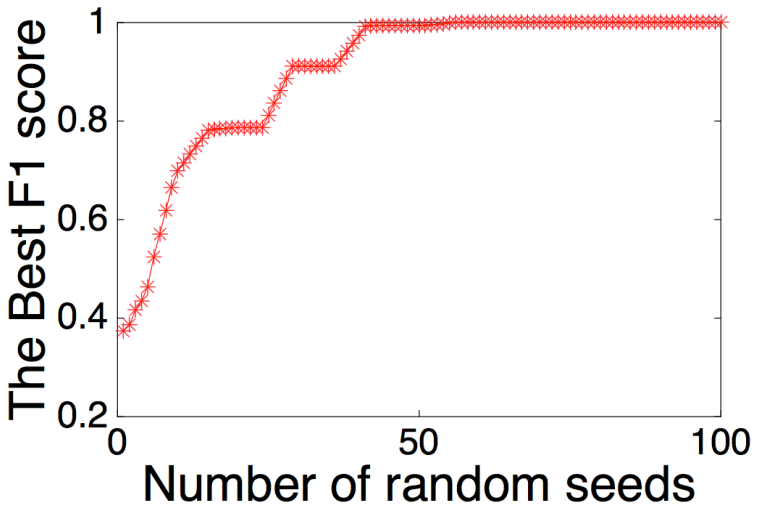
$$f(\mathbf{n}, c, \mathbf{N}, C) = c(\log \frac{c}{C} - 1) + C \prod_{i=1}^{K} \frac{n_i}{N_i} - c \sum_{i=1}^{K} \log \frac{n_i}{N_i}$$

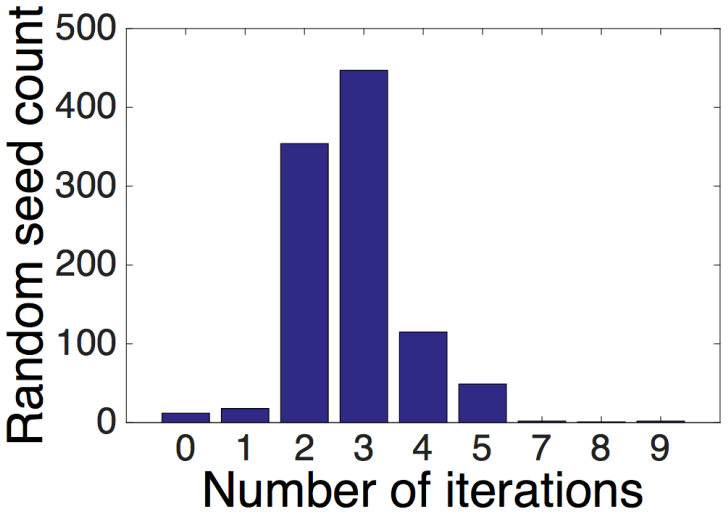
Using ρ as the block's density and p is the data's density, we have the simpler formulation

$$\hat{f}(\mathbf{n}, \rho, \mathbf{N}, p) = \left(\prod_{i=1}^{K} n_i\right) D_{KL}(\rho || p)$$

CrossSpot: Local Search with the Metric

- Seed block, adjust modes, select a mode, adjust values in mode, until convergence.
- Seed selection: HOSVD, or with LockInfer [PAKDD'14]
- Fast convergence





- Parallelize to multiple machines: Scalable!

Advantage: "Suspiciousness"+CrossSpot

- Score dense blocks
- Target multi-modal data
- Satisfy all the axioms

	Method	Scores Blocks	Axioms: Density 1	Size 2	Concentration 3	Contrast 4	Multi-modal 5
Metrics	**SUSPICIOUSNESS**	✔	✔	✔	✔	✔	✔
	Mass	✓	✓	✗	✗	✗	✓
	Density	✓	✓	✗	✓	✗	✗
	Average Degree [9]	✓	✓	✗	✗	✗	N/A
	Singular Value [10]	✓	✓	✓	✓	✗	✗
Methods	**CROSSSPOT**	✔	✔	✔	✔	✔	✔
	Subgraph [30, 10, 36]	✓	✓	✓	✓	✗	N/A
	CopyCatch [6]	✓	✓	✓	✓	✗	N/A
	EigenSpokes [31]	✗	N/A				
	TrustRank [14, 8]	✗	N/A				
	BP [28, 1]	✗	N/A				

ROADMAP

1. Motivation & Problem

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Performance: Synthetic Data

- Experiments: Synthetic data
  - 1,000 × 1,000 × 1,000 of 10,000 random data
  - Block#1: 30 × 30 × 30 of 512 — 3 modes
  - Block#2: 30 × 30 × 1,000 of 512 — 2 modes
  - Block#3: 30 × 1,000 × 30 of 512 — 2 modes
  - Block#4: 1,000 × 30 × 30 of 512 — 2 modes

	Recall				Overall Evaluation		
	Block #1	Block #2	Block #3	Block #4	Precision	Recall	F1 score
HOSVD (r=20)	93.7%	29.5%	23.7%	21.3%	**0.983**	0.407	0.576
HOSVD (r=10)	91.3%	24.4%	18.5%	19.2%	0.972	0.317	0.478
HOSVD (r=5)	85.7%	10.0%	9.5%	11.4%	0.952	0.195	0.324
CrossSpot	**100%**	**99.9%**	**94.9%**	**95.4%**	0.978	**0.967**	**0.972**

Performance: Manipulating Trends

User × hashtag × IP × minute	Mass c	Suspiciousness
582 × 3 × 294 × **56,940**	5,941,821	111,799,948
188 × 1 × 313 × **56,943**	2,344,614	47,013,868
75 × 1 × 2 × 2,061	689,179	19,378,403

User ID	Time	IP address (city, province)	Tweet text with hashtag
USER-D	11-18 12:12:51	IP-1 (Deyang, Shandong)	**#Snow#** the Samsung GALAXY SII QQ Service customized version...
USER-E	11-18 12:12:53	IP-1 (Deyang, Shandong)	**#Snow#** the Samsung GALAXY SII QQ Service customized version...
USER-F	11-18 12:12:54	IP-2 (Zaozhuang, Shandong)	**#Snow#** the Samsung GALAXY SII QQ Service customized version...
USER-E	11-18 12:17:55	IP-1 (Deyang, Shandong)	**#Li Ning - a weapon with a hero#** good support activities!
USER-F	11-18 12:17:56	IP-2 (Zaozhuang, Shandong)	**#Li Ning - a weapon with a hero#** good support activities!
USER-D	11-18 12:18:40	IP-1 (Deyang, Shandong)	**#Toshiba Bright Daren#** color personality test to find out your sense...
USER-E	11-18 17:00:31	IP-2 (Zaozhuang, Shandong)	**#Snow#** the Samsung GALAXY SII QQ Service customized version...
USER-D	11-18 17:00:49	IP-2 (Zaozhuang, Shandong)	**#Toshiba Bright Daren#** color personality test to find out your sense...
USER-F	11-18 17:00:56	IP-2 (Zaozhuang, Shandong)	**#Li Ning - a weapon with a hero#** good support activities!

Performance: Network Blocks

	#	Src-IP × dst-IP × port × second	Mass c	Suspiciousness
CrossSpot	1	411 × 9 × 6 × **3,610**	47,449	552,465
	2	533 × 6 × 1 × **3,610**	30,476	400,391
	3	5 × 5 × 2 × **3,610**	18,881	317,529
	4	11 × 7 × 7 × **3,610**	20,382	295,869
HOSVD	1	15 × 1 × 1 × 1,336	4,579	80,585
	2	1 × 2 × 2 × 1,035	1,035	18,308
	3	1 × 1 × 1 × 1,825	1,825	34,812
	4	1 × 13 × 6 × 181	1,722	29,224

Conclusion

- Proposed a general “suspiciousness” metric based on **probability** for multi-modal behaviors
- CrossSpot: Proposed a local search algorithm for catching suspicious behaviors

Thank you!

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- mjiang89@gmail.com
- www.meng-jiang.com

(Erdös-Rényi-)Poisson Model

$$X_i \sim \text{Poisson}(p)$$

$$f(Y) = -\log\left(\prod_{i \in Y} \text{Poisson}(Y_i|p)\right)$$

Suspiciousness metric is the negative log-likelihood of the sub-block's mass

Suspiciousness Metric

$$f(\mathbf{n}, c, \mathbf{N}, C) = c(\log \frac{c}{C} - 1) + C \prod_{i=1}^{K} \frac{n_i}{N_i} - c \sum_{i=1}^{K} \log \frac{n_i}{N_i}$$

$$\hat{f}(\mathbf{n}, \rho, \mathbf{N}, p) = \left(\prod_{i=1}^{K} n_i \right) D_{KL}(\rho || p)$$

Suspiciousness metric is the negative log-likelihood of the sub-block's mass

Suspiciousness Metric

$$f(\mathbf{n}, c, \mathbf{N}, C) = c(\log \frac{c}{C} - 1) + C \prod_{i=1}^{K} \frac{n_i}{N_i} - c \sum_{i=1}^{K} \log \frac{n_i}{N_i}$$

$$\hat{f}(\mathbf{n}, \rho, \mathbf{N}, p) = \left(\prod_{i=1}^{K} n_i \right) D_{KL}(\rho || p)$$

Satisfies all axioms!

Search Algorithm

Can use previous methods to seed algorithm

Algorithm 1 Local Search

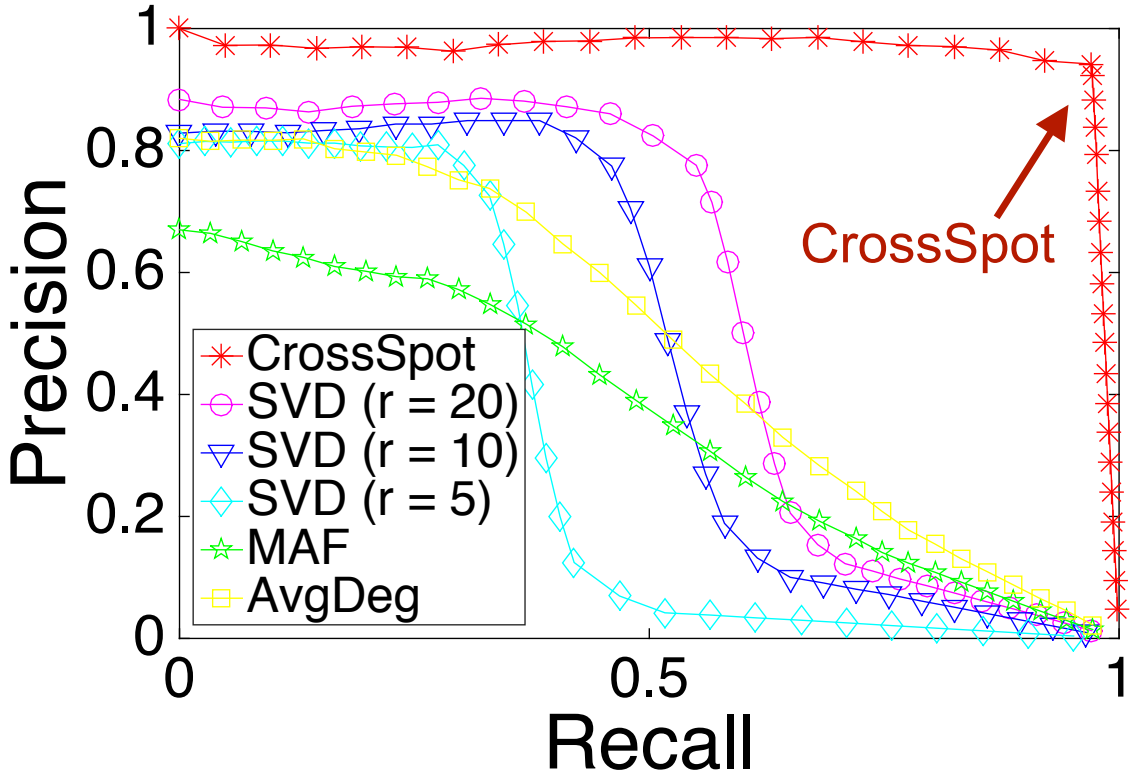
Require: Data $\mathcal{X}$, seed region $\mathcal{Y}$ with $\tilde{\mathcal{P}} = \{\tilde{\mathcal{P}}_j\}_{j=1}^{K}$

1: **while** not converged **do**
2: **for** $j = 1 \ldots K$ **do**
3: $\tilde{\mathcal{P}}_j \leftarrow$ AdjustMode(j)
4: **end for**
5: **end while**
6: **return** $\tilde{\mathcal{P}}$

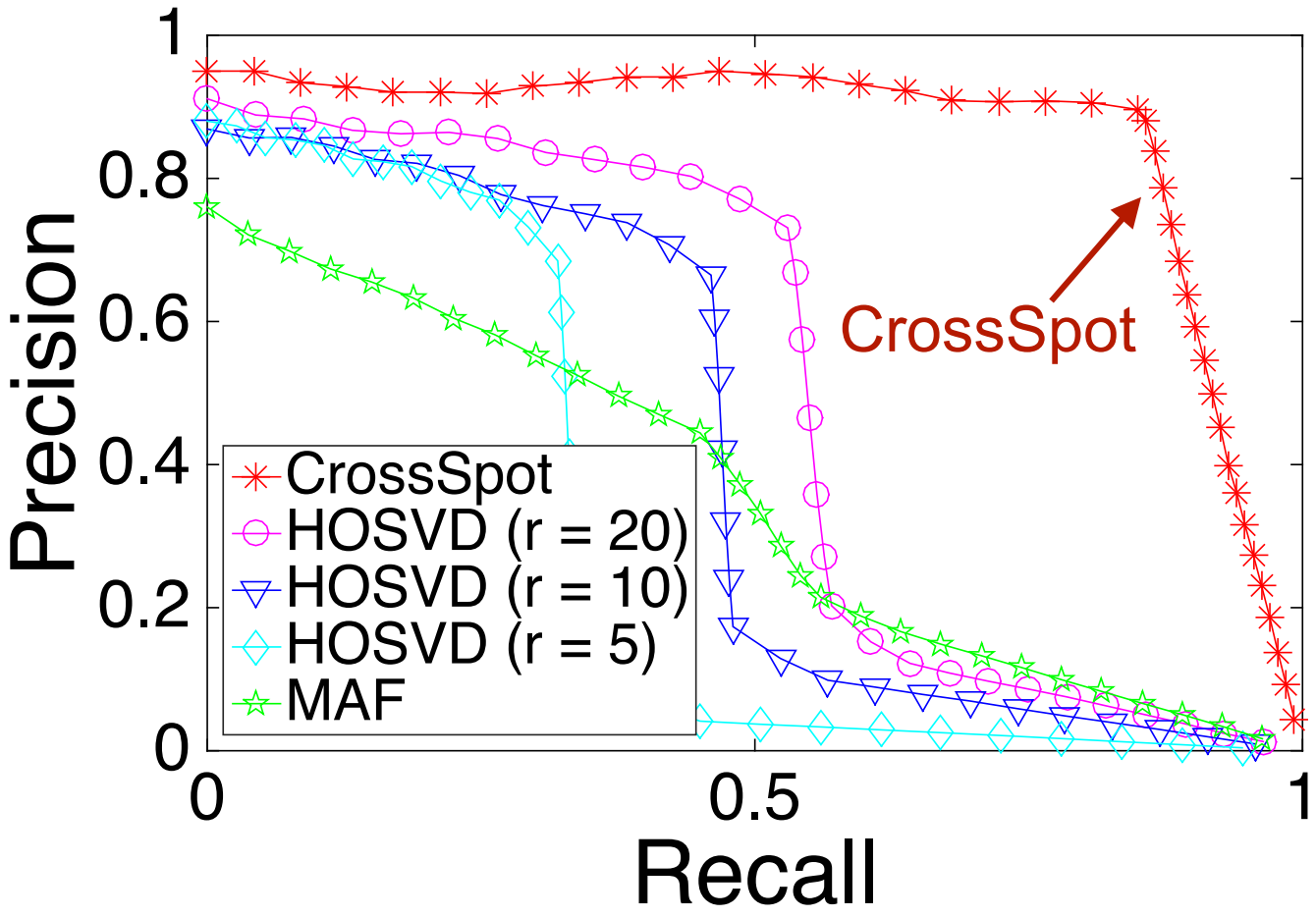
Find optimal* subset of indices in mode *j* **in O(N_j log N_j) time.**

*Optimal given other modes are held constant.

Synthetic Tests (Matrix)



Synthetic Tests (3-mode Tensor)



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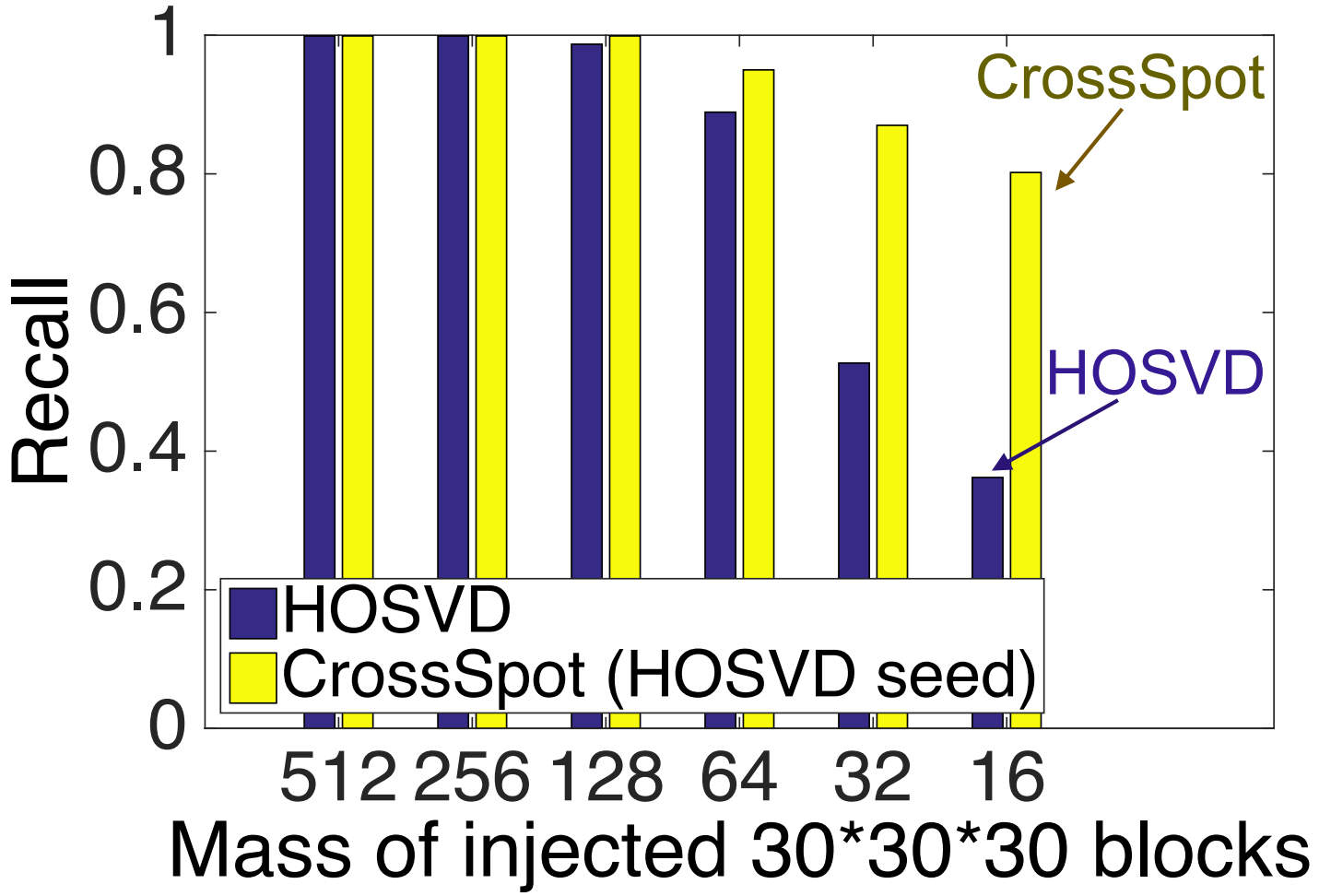

Suspicious Retweet Blocks

	#	User × tweet × IP × minute	Mass c	Suspiciousness
CrossSpot	1	14 × 1 × 2 × 1,114	41,396	1,239,865
	2	225 × 1 × 2 × 200	27,313	777,781
	3	8 × 2 × 4 × 1,872	17,701	491,323
HOSVD	1	24 × 6 × 11 × 439	3,582	131,113
	2	18 × 4 × 5 × 223	1,942	74,087
	3	14 × 2 × 1 × 265	9,061	381,211

TABLE VII. RETWEETING BOOSTING: WE SPOT A GROUP OF USERS RETWEET "GALAXY NOTE DREAM PROJECT: HAPPY HAPPY LIFE TRAVELLING THE WORLD" IN LOCKSTEP (EVERY 5 MINUTES) ON THE SAME GROUP OF IP ADDRESSES. (RETWEETING LOG IN BLOCK $225\times1\times2\times200$ IN TABLE VI)

User ID	Time	IP address (city, province)	Retweet comment (Google translator: from Simplified Chinese to English)
USER-A	11-26 10:08:54	IP-1 (Liaocheng Shandong)	Qi Xiao Qi: "unspoken rules count ass ah, the day listening...
USER-B	11-26 10:08:54	IP-1 (Liaocheng Shandong)	You gave me a promise, I will give you a result...
USER-C	11-26 10:09:07	IP-2 (Liaocheng Shandong)	Clouds have dispersed, the horse is already back to God...
USER-A	11-26 10:13:55	IP-1 (Liaocheng Shandong)	People always disgust smelly socks, it remains to his bed...
USER-B	11-26 10:13:57	IP-2 (Liaocheng Shandong)	Next life do koalas sleep 20 hours a day, eat two hours...
USER-C	11-26 10:14:03	IP-1 (Liaocheng Shandong)	all we really need to survive is one person who truly...
USER-A	11-26 10:18:57	IP-1 (Liaocheng Shandong)	Coins and flowers after the same amount of time...
USER-C	11-26 10:19:18	IP-2 (Liaocheng Shandong)	My computer is blue screen
USER-B	11-26 10:19:31	IP-1 (Liaocheng Shandong)	Finally believe that in real life there is no so-called...
USER-A	11-26 10:23:50	IP-1 (Liaocheng Shandong)	Do not be obsessed brother, only a prop.
USER-B	11-26 10:24:04	IP-2 (Liaocheng Shandong)	Life is like stationery, every day we loaded pen
USER-C	11-26 10:24:19	IP-1 (Liaocheng Shandong)	"The sentence: the annual party 1.25 Hidetoshi premature...