On the Complexity of Traffic Traces and Implications

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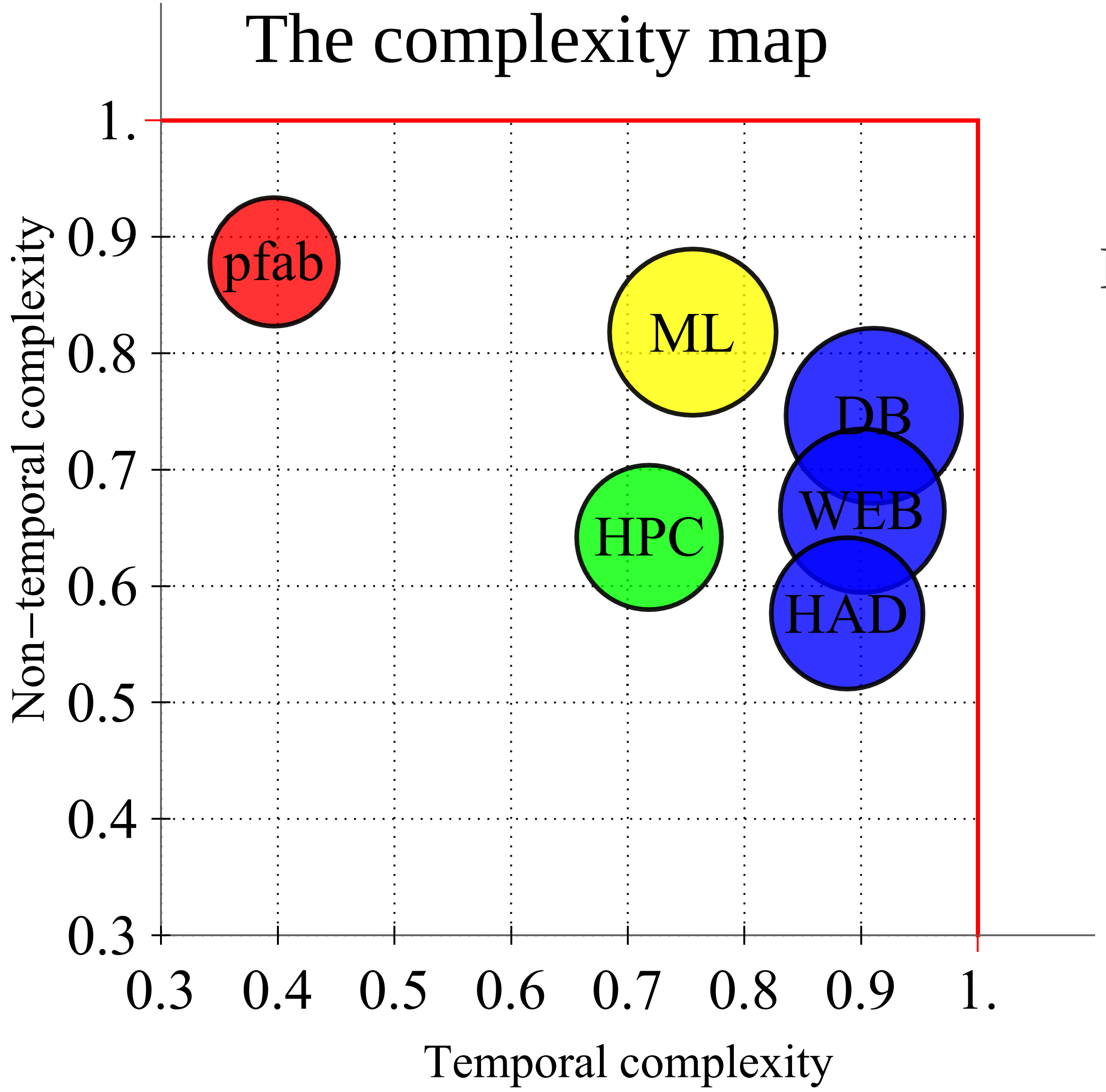
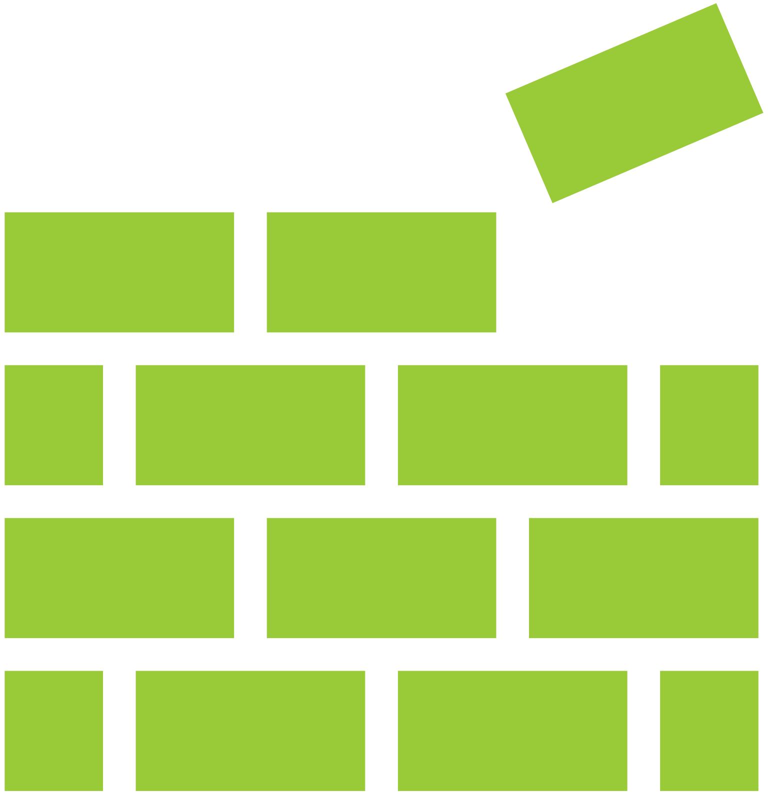
"It is not the strongest of the species that survives, nor the most intelligent that survives. But the one that is most adaptable to change."
(Leon C. Megginson)



Mapping a Landscape of Network Traffic

- Define
- Categorize
- Quantify
- *Map different types of structure*
- Better design of networks?

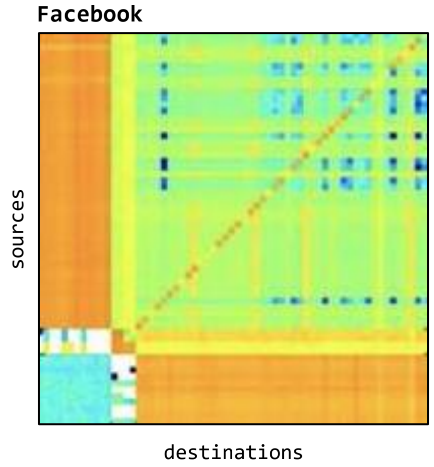


What is Structure?

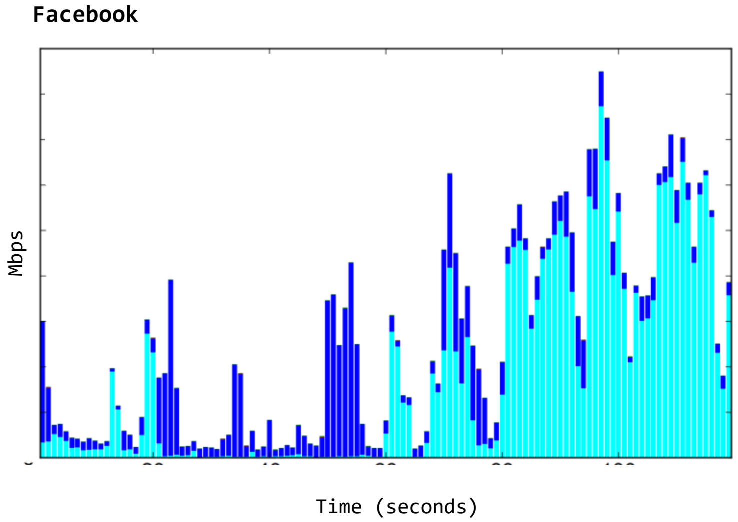
Visible Structure?

- Can we see patterns in real network traffic?
  - *Yes!*

Real

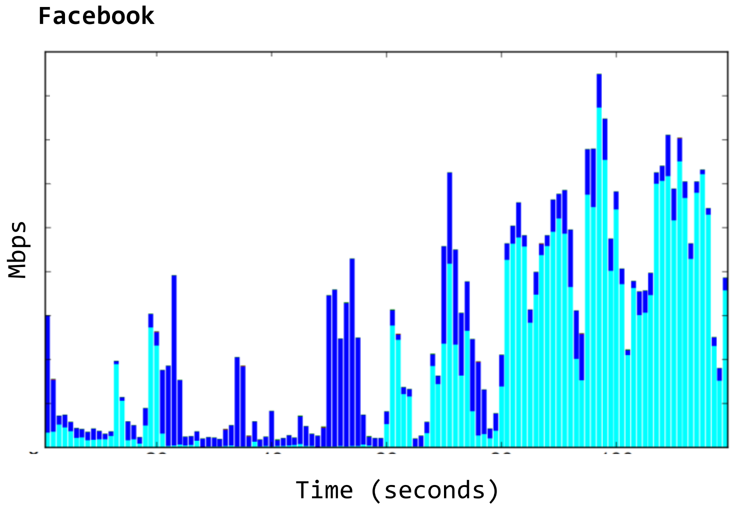


Rack-to-rack, Frontend cluster
FB @ SIGCOMM 2015

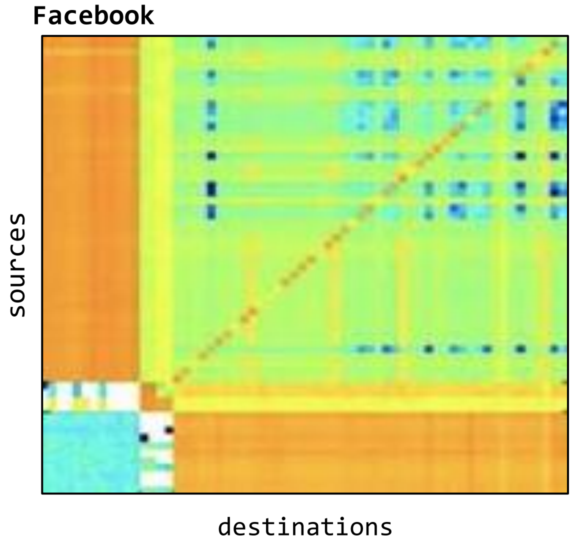


Structure: Two Types

- Temporal

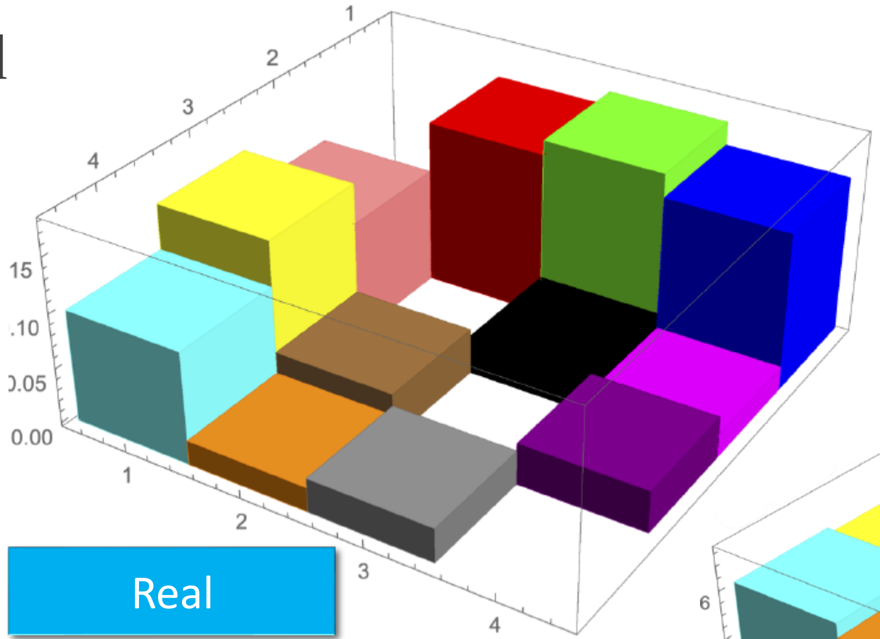


- Non temporal(spatial)

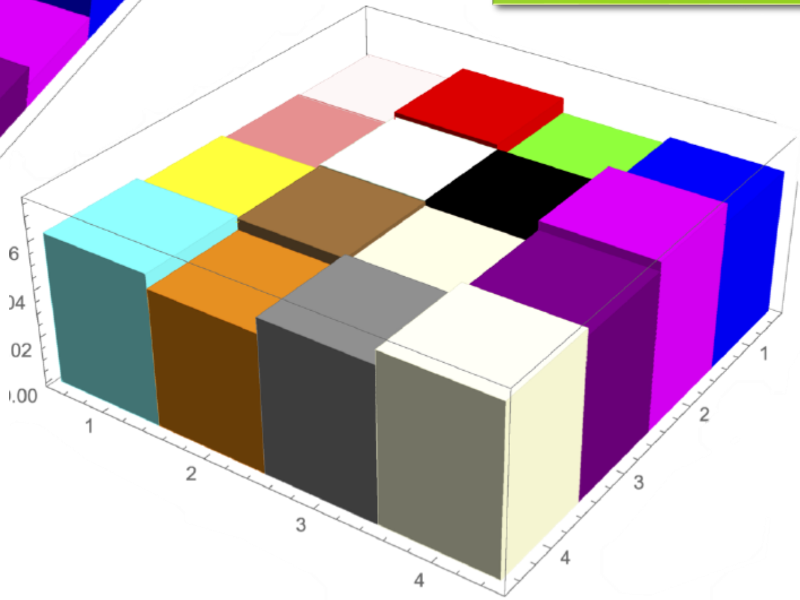


ML Example: Non temporal structure

- A traffic matrix of a distributed ML application
- Source destination denoted by color
- Height denotes amount of traffic
- **How would a matrix without structure look like?**



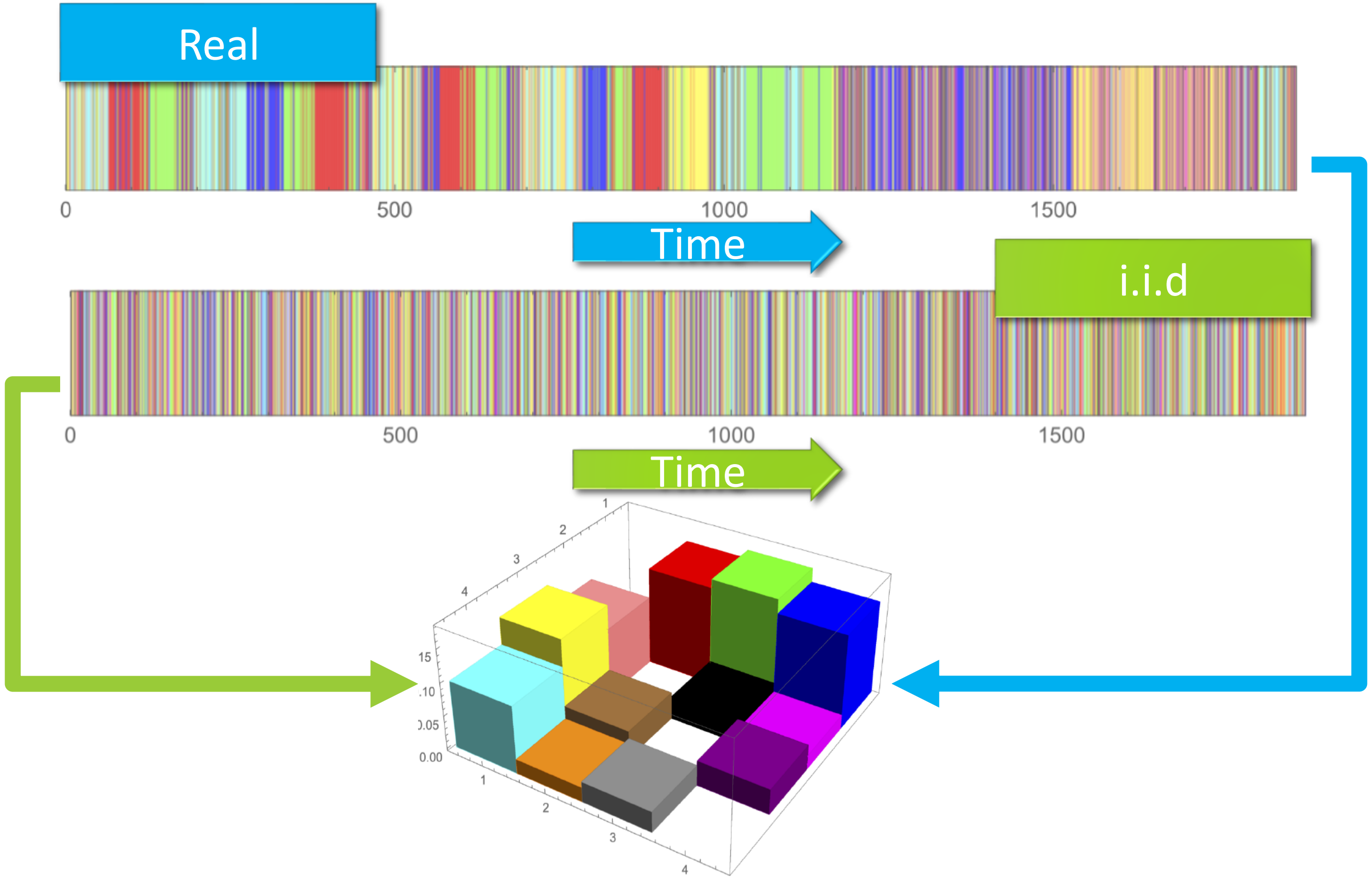
Real

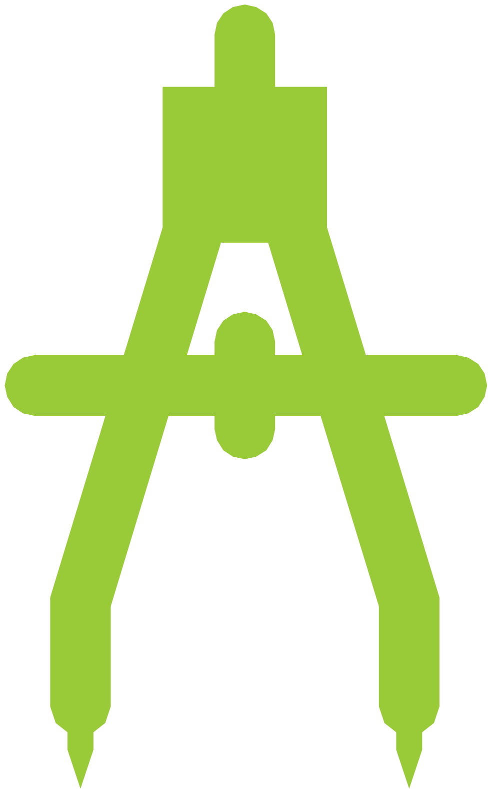


Uniform

Temporal structure

- Not all structure is related to frequency
- ***Temporal*** structure, represents the dependency of future events on recent events
  - Example: bursts of traffic
  - Both traces have the same traffic matrix but are different in time

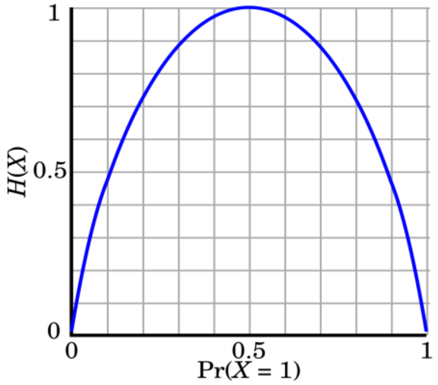




How to Measure Structure

An information theoretic perspective

- In Information theory *entropy* (entropy rate) is a measure "randomness"
- Lower *entropy* ⇒ More predictable traffic
- Traffic with more "structure" is less "complex"
- *Compression* offers a way to estimate *entropy*
- But how to represent traffic?



Traffic as a Network Trace

Source	Destination
(192.168.1.3)=s_0	(192.168.1.1)=d_0
s_1	d_1
s_2	d_2
s_3	d_3
s_4	d_4
s_5	d_5
s_6	d_6

Time

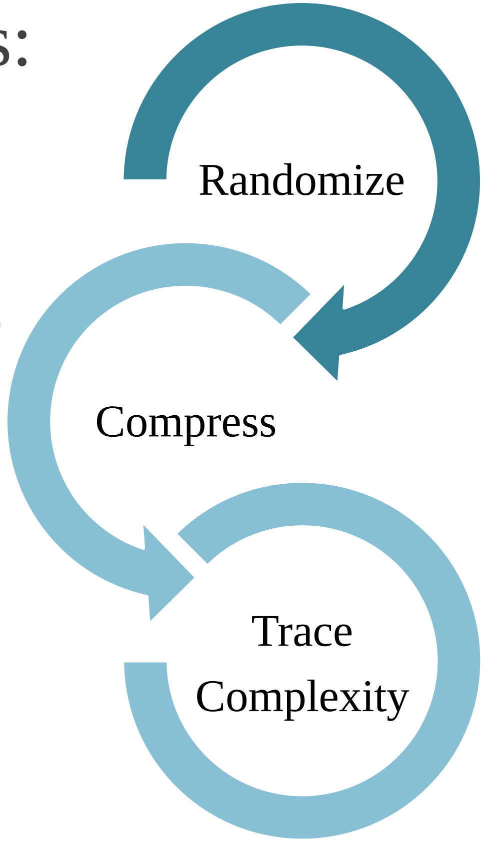
- A Simplified **time ordered** list of **source-destination** pairs
- How to use it?

Methodology

- Measuring complexity with two steps:

1. Sequentially randomize a trace, remove a specific types of structure

2. Compress the trace, compare their size.



Source	Destination
s_0	d_0
s_1	d_1
s_2	d_2
s_3	d_3
s_4	d_4
s_5	d_5
s_6	d_6

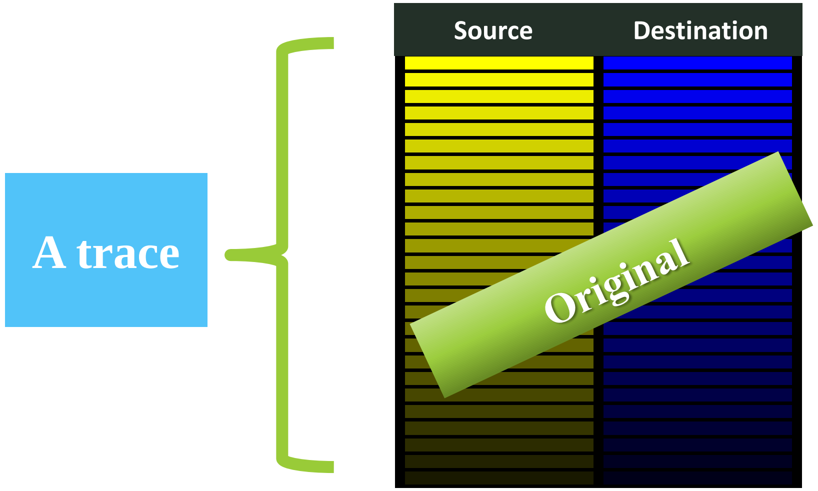
Systematic randomization

A trace

Source	Destination
s_0	d_0
s_1	d_1
s_2	d_2
s_3	d_3
s_4	d_4
s_5	d_5
s_6	d_6

Systematic randomization

Increasing complexity

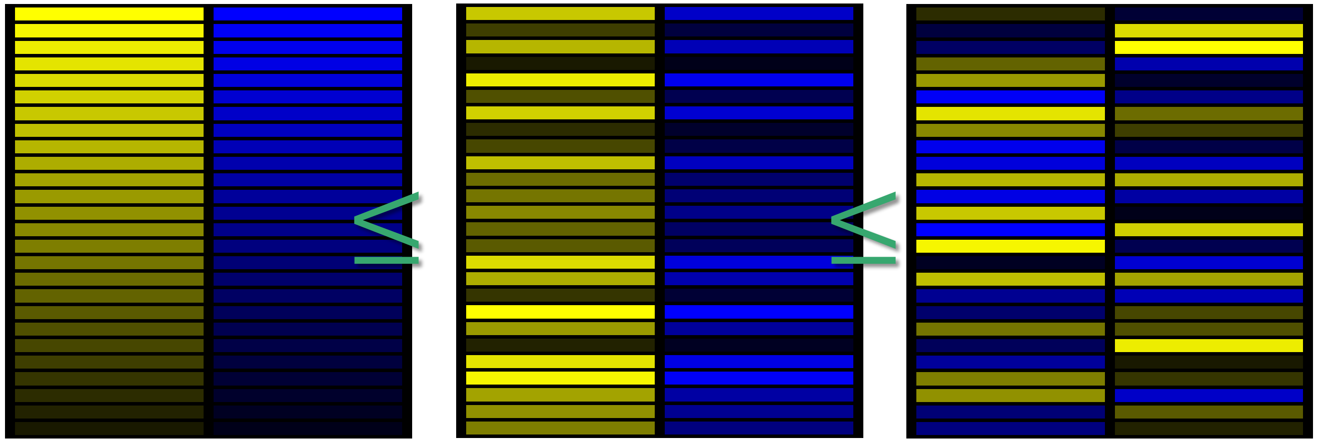


Original trace $\boldsymbol{\sigma}$
- ✓ Temporal
- ✓ Non Temporal

Row Randomized $\Gamma(\sigma)$
- X Temporal
- ✓ Non Temporal

Uniform Trace $\mathsf{u}(\sigma)$
- X Temporal
- X Non Temporal

Compression



Formal Definitions of Trace Complexity

Let $c(\sigma)$ is the *size* of a compressed trace σ:

We define:

Total complexity: $\psi(\sigma) = \frac{\mathrm{c}(\sigma)}{\mathrm{c}(\mathrm{u}(\sigma))}$

Uniform transformation

Temporal complexity:$\mathrm{T}(\sigma) = \frac{\mathrm{c}(\sigma)}{\mathrm{c}(\Gamma(\sigma))}$

Row transformation

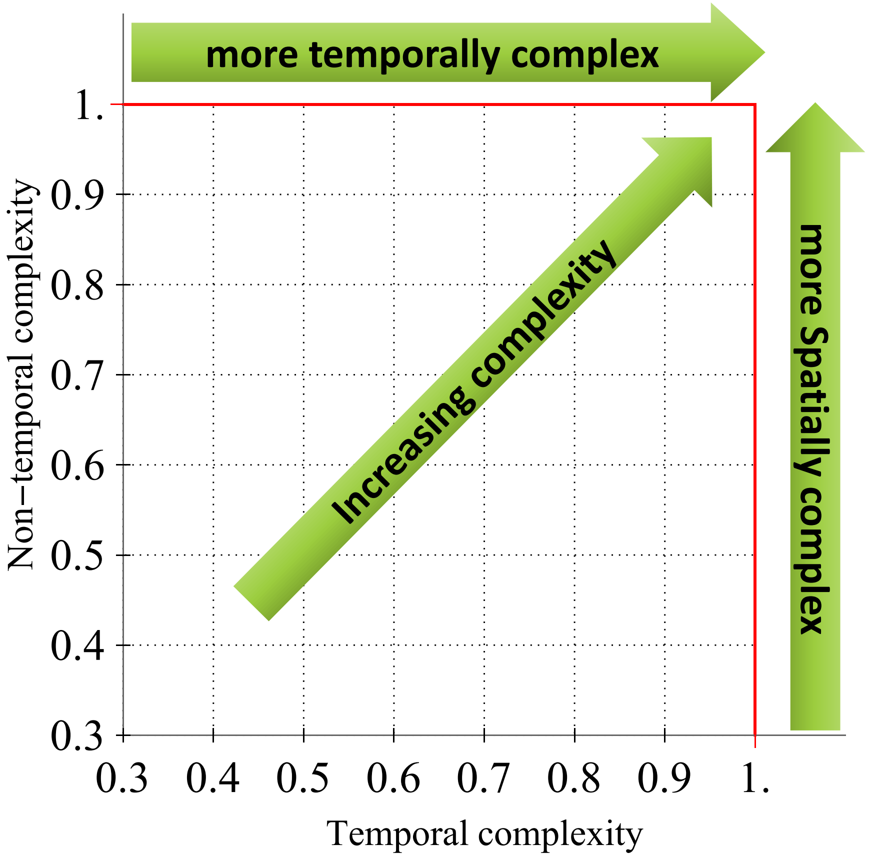
Non-temporal complexity: $\mathrm{NT}(\sigma) = \frac{\mathrm{c}(\Gamma(\sigma))}{\mathrm{c}(\mathrm{u}(\sigma))}$

Complexity is in the range of $[0 \ldots 1]$

Mapping Trace Complexity

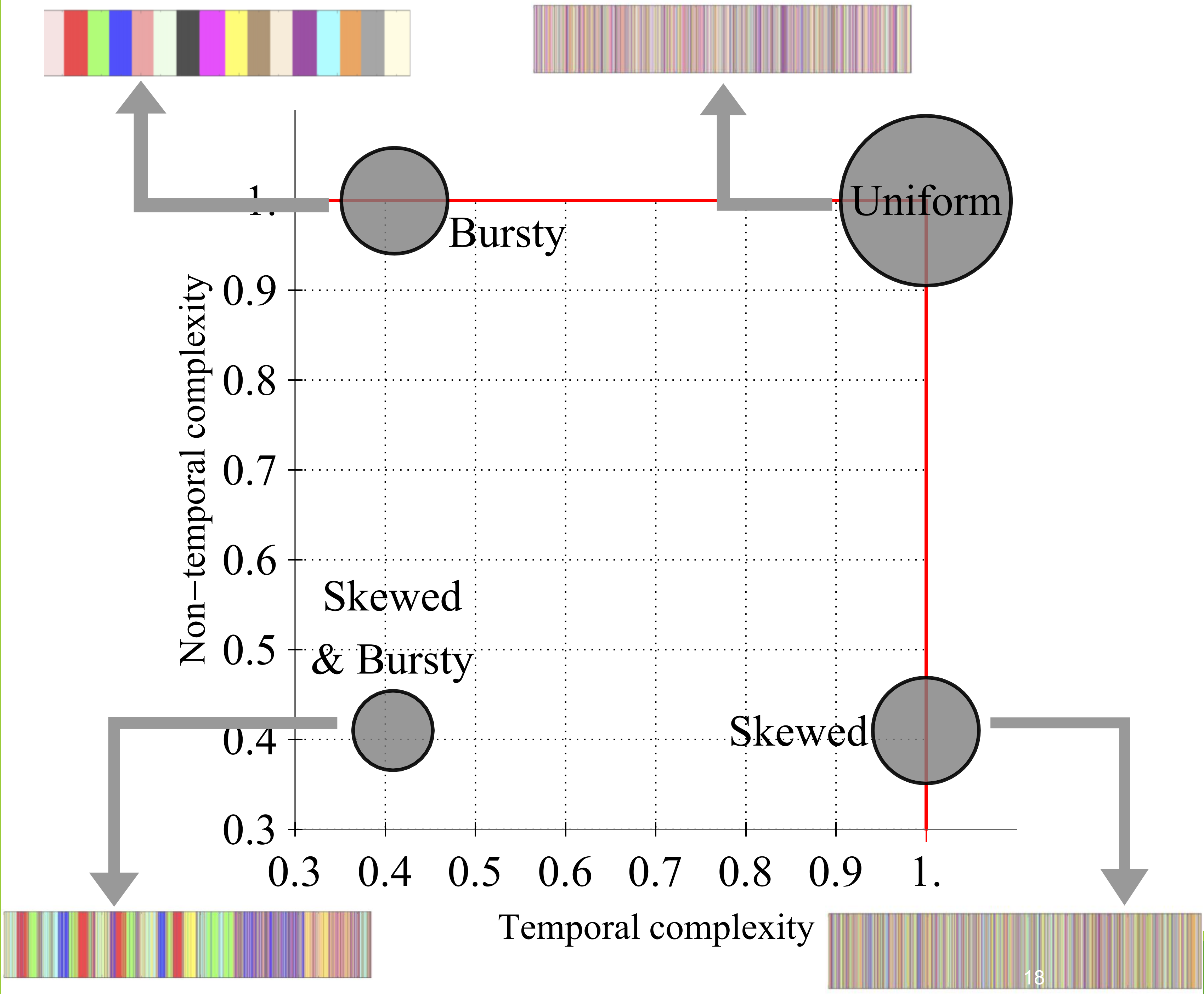
The Complexity Map

- *X* axis: temporal complexity
- *Y* axis: non-temporal complexity
- Rule of thumb:
  Closer to the axis's origin, means lower complexity



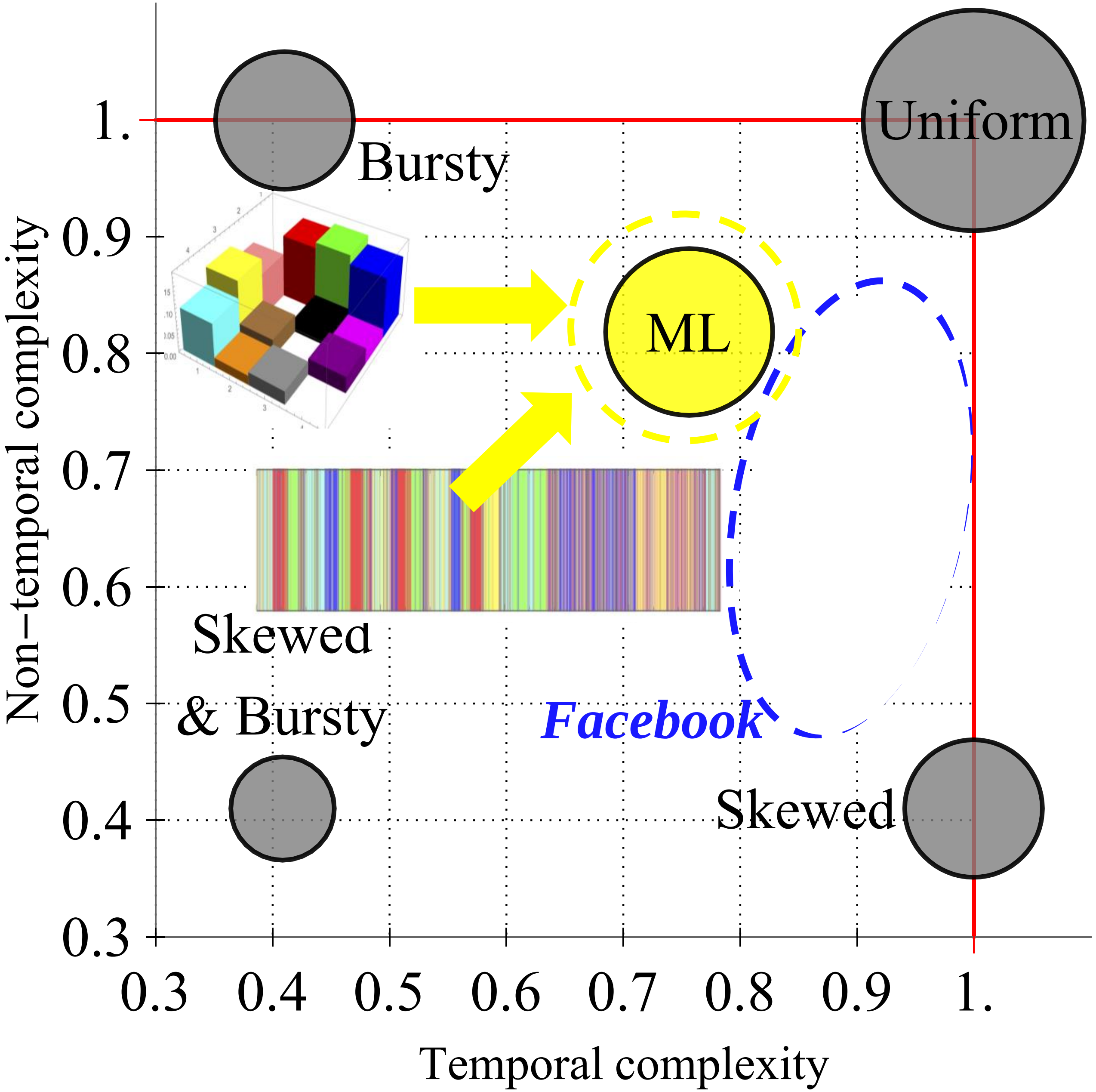
The Complexity Map

- Uniform Traffic
  - Lacking any structure, maximal entropy
- Bursty Traffic
  - Has temporal correlations
- Skewed Traffic
  - From a skewed distribution
- Skewed & Bursty Traffic
  - Has both temporal and non temporal elements



Case Study

- ML
- Facebook
  - Database, Web, Hadoop
- High Power Computing (HPC)
- pFabric



What can we expect to learn from trace complexity?

- Lower complexity means better optimization
- Identify and quantify different structures
- Compare different traces?
- Differentiate between different workloads?

Future work

- Test trace with more metadata
  - Interarrival times, ports etc
- What are the other dimensions of complexity?
- Practical implementation of complexity in online algorithms?
- Trace website:
  - https://self-adjusting.net
- Further details are found in the paper:

On the Complexity of Traffic Traces and Implications.
Chen Avin, Manya Ghobadi, Chen Griner, Stefan Schmid. ***Sigmetrics 2020***