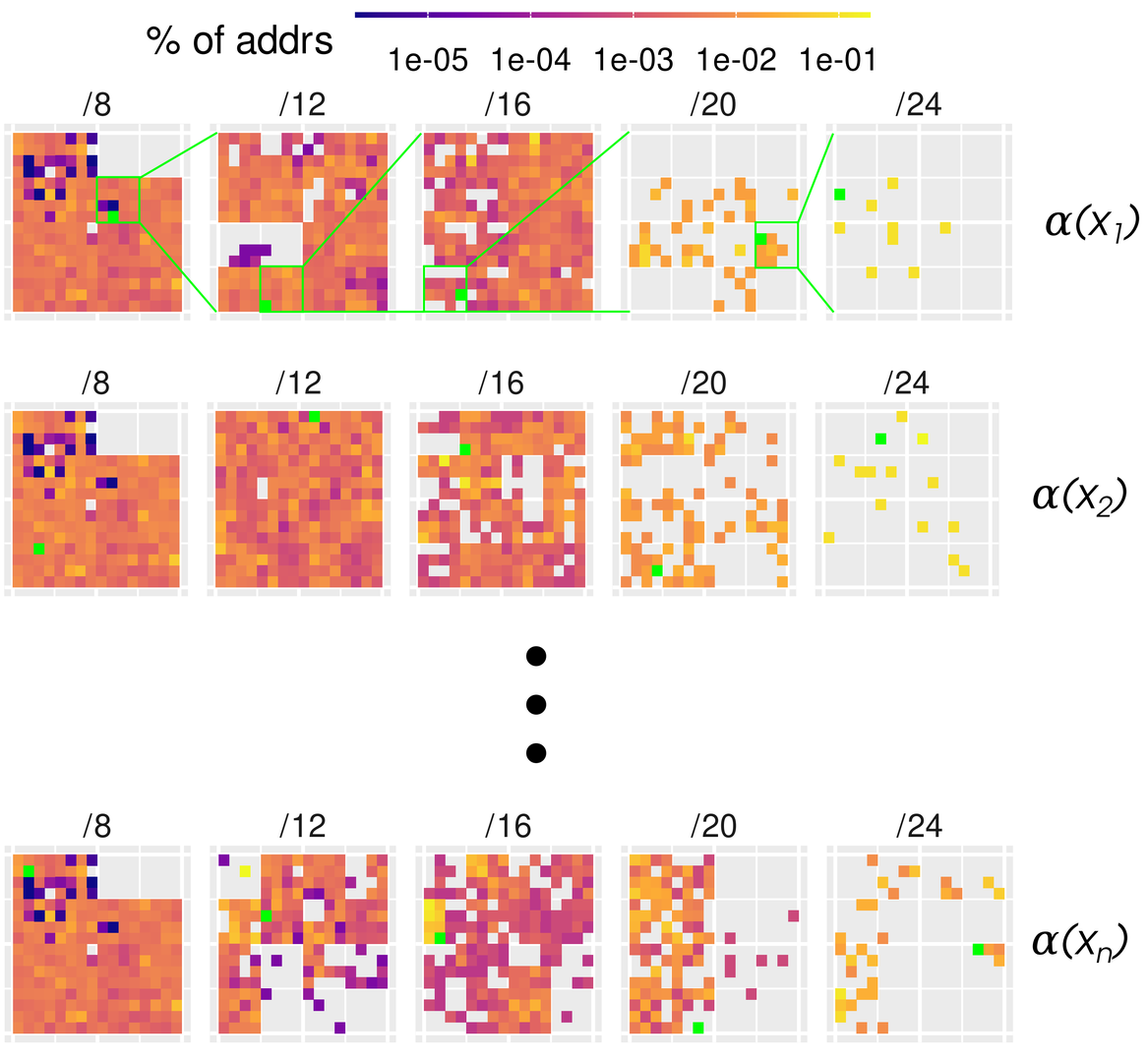
Using the Multifractal Spectrum for Fingerprinting Sets of Observed IP Addresses

Chris Misa[1] cmisa@cs.uoregon.edu
Walter Willinger[2]
Ramakrishnan Durairajan[1]
Reza Rejaie[1]
1. University of Oregon 2. NIKSUN, Inc.

1. IP addresses observed on the Internet form distinctive prefix-level clusters.



Let $\mu(l,x)$ be the number of IP addresses in the x-th $/l$ prefix.

Then $\mu(l,x)$ has a richly clustered structure as shown on the left.

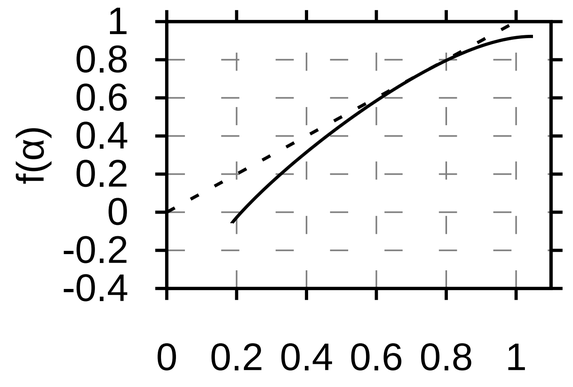
2. The multifractal spectrum can summarize this structure.

Suppose $\mu(l,x) \approx (2^{-l})^{\alpha(x)}$ (as $l \to \infty$)

$$\alpha(x) \approx -\log_2 \mu(l,x) / l$$

Let $E_\alpha = \{ x \text{ s.t. } \alpha(x) = \alpha \}$

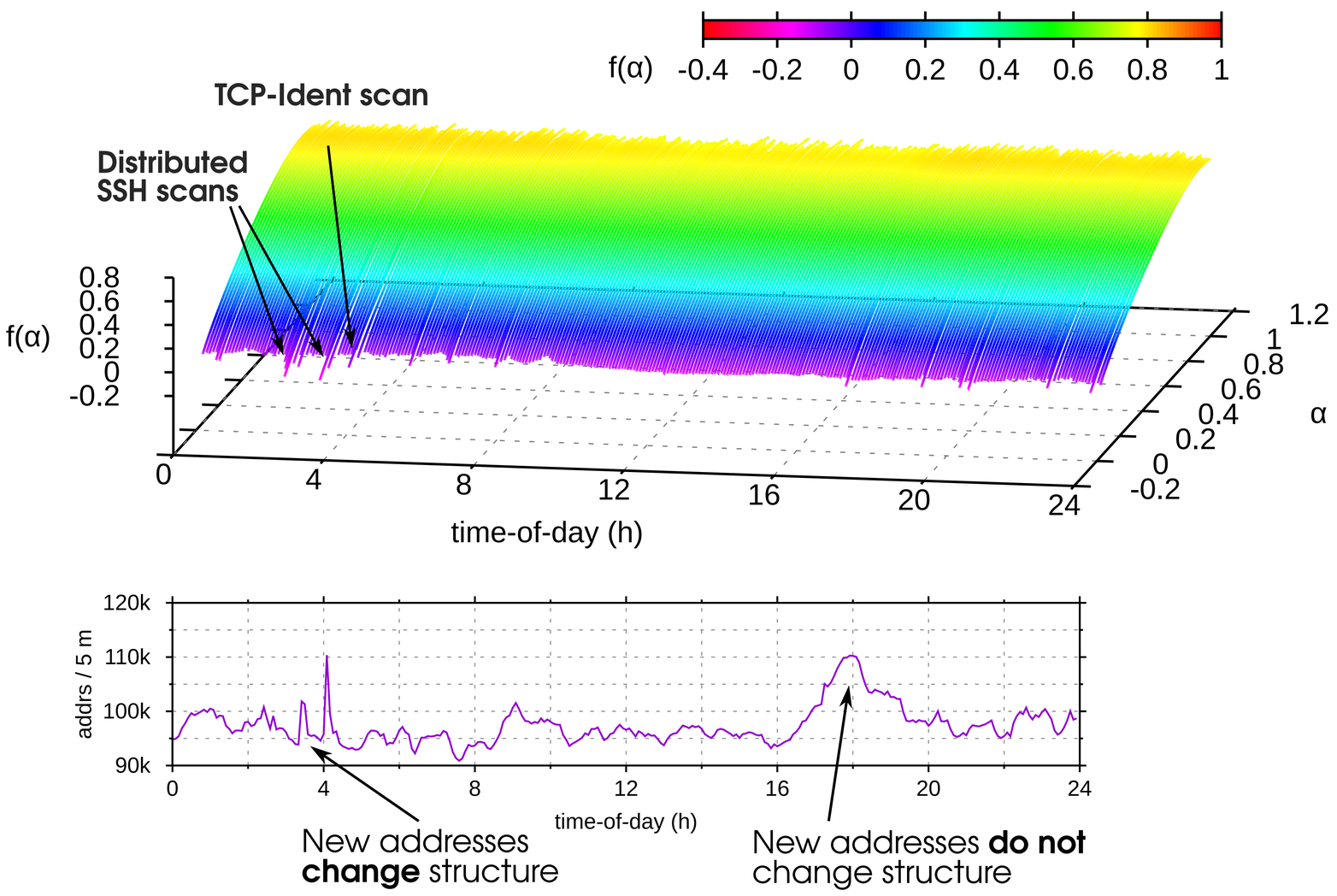
Then $f(\alpha)$ is the fractal dimension of E_α.



3. Computing the multifractal spectrum for each time window exposes structural changes over time.

We illustrate using unsampled netflow data from our campus network.[1]

Structural anomalies like scanning bursts cause $f(\alpha)$ extends to smaller α.



1. Our campus serves ~25k full-time undergraduate and graduate students.

Executive Summary:

→ Internet traffic is composed of interleaved conversations between large numbers of distinct IP addresses. Measuring structural properties or "fingerprints" of the addresses that are interleaved at particular points and times provides critical insights about network operations (e.g., to detect anomalous changes in traffic composition).

→ A promising approach is to view IP addresses as points in a discrete space ($[0,2^{32})$ for IPv4 or $[0,2^{128})$ for IPv6). Although it is known that IP addresses (when viewed in this way) exhibit multifractal structure (1), prior methods fall short of providing robust fingerprints to quantify this structure.

→ This work proposes such a new, robust method to "fingerprint" sets of IPv4 addresses using multifractal analysis. In particular, we build on prior work that used a tool known as the method-of-moments and extend this work to compute the multifractal spectrum.

→ We illustrate this new fingerprinting method by detecting structural anomalies in real-world netflow data captured on our campus network.

[1] Chris Misa, Ram Durairajan, Arpit Gupta, Reza Rejaie, and Walter Willinger. 2025. The Multifractal IP Address Structure: Physical Explanation and Implications. https://arxiv.org/abs/2504.01374.