VC dimensions and regularity

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Joint with Lior Gishboliner and Asaf Shapira

PCMI

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which yonder starry sphere
Of planets and of fixed in all her wheels
Resembles nearest, mazes intricate,
Eccentric, intervolved, yet regular
Then most, when most irregular they seem;

John Milton, *Paradise Lost* V.620–4

Talk overview

Goal: Understand the regularity lemma.

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Can we make small smaller if we assume that the object is simple?

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Question 2

Can we make small smaller if we assume that the object is simple?

Question 3

What does it mean for a (hyper)graph to be simple?

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Many combinatorial questions become much simpler when restricted to graphs of bounded VC dimension.

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Corollary (Regularity lemma for bounded VC dimension)

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Quantitative bounds

Szemerédi, Gowers: Every graph G has an ε-regular partition into $m \leqslant \mathrm{twr}(\varepsilon^{-5})$ parts, and for some G such a bound is necessary.

If G has bounded VC dimension, we can strengthen this to an ε-homogeneous partition. What about the bounds?

Theorem (Alon–Fischer–Newman, Lovász–Szegedy)

If G has bounded VC dimension, it has an ε-homogeneous partition into $m \leqslant \mathrm{poly}(\frac{1}{\varepsilon})$ parts (and this is best possible).

Theorem

The following are equivalent for a hereditary family of graphs G.

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In k-uniform hypergraphs, there are $\geqslant 2$ notions of regularity... and $\geqslant k$ notions of VC dimension.

Also, the regularity notions can be very hard to work with.

A statement of the hypergraph regularity lemma

Theorem 11 (Hypergraph Regularity Lemma). *For all positive reals* μ *and* δ_k *and functions*

$$\delta_j\colon (0,1]^{k-j} \to (0,1] \quad \text{for } j = 2, \ldots, k-1,$$

$$\text{and } r\colon \mathbb{N} \times (0,1]^{k-2} \to \mathbb{N},$$

there exist T_0 *and* n_0 *so that the following holds. For every k-graph* $\mathcal{H}^{(k)}$ *on* $n \geq n_0$ *vertices, there exist a family of partitions* $\mathcal{P} = \mathcal{P}(k-1, \mathbf{a})$ *and a vector* $\mathbf{d} = (d_2, \ldots, d_{k-1})$ *so that, for* $\boldsymbol{\delta} = (\delta_2, \ldots, \delta_{k-1})$, *where* $\delta_j = \delta_j(d_j, \ldots, d_{k-1})$ *for all j, and* $r = r(a_1, \mathbf{d})$, *the following holds:*

(i) $\mathcal{P}$ *is a* $(\mu, \boldsymbol{\delta}, \mathbf{d}, r)$*-equitable family of partitions and* $a_i \leq T_0$ *for every* $i = 1, \ldots, k-1$ *and*
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We'll see three different answers to this question.

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Time to come up with some other notions!

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This "definition" is of central importance in the theory of high-dimensional expanders, and shows up in many Ramsey- and Turán-type questions in hypergraphs.

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Corollary (Gishboliner–Shapira–W.)

$M(\varepsilon) = 2^{\mathrm{poly}(1/\varepsilon)}$, i.e., single exponential is necessary and sufficient.

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- *H has an* ε*-homogeneous partition with* $\leqslant \mathrm{poly}(\frac{1}{\varepsilon})$ *parts.*
- *H has a weakly* ε*-regular partition with* $\leqslant \mathrm{poly}(\frac{1}{\varepsilon})$ *parts.*

Bounded strong VC dimension implies bounded VC_1 dimension.

Theorem (Terry, CT, TW, GSW)

The following are equivalent for a hereditary family of 3-graphs H:

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VC_2 dimension

Question

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Definition (Shelah)

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Tri-induced: Edges across all 3 parts are induced, all other edges 🤷.

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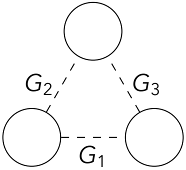

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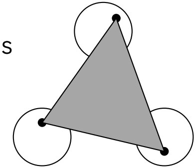

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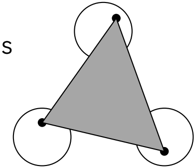

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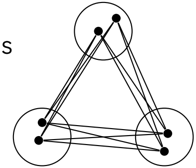

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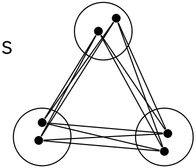

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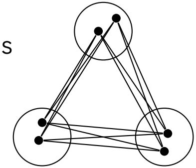

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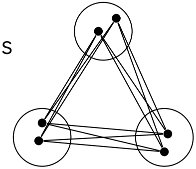

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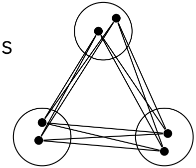

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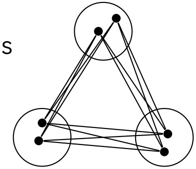

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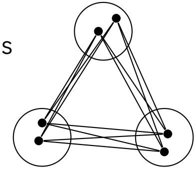

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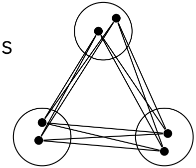

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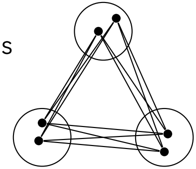

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Theorem (Terry)

If H has bounded VC_2 dimension and f is arbitrary, then wowzer-type bounds are necessary.

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Upshot: Bounded VC$_r$ dimension $\iff$ "looks like an r-graph".

Proof non-sketch

If every link of H has an ε-homogeneous partition with $\leqslant m$ parts, then H has an ε-homogeneous partition with $\leqslant 2^{\text{poly}(m/\varepsilon)}$ parts.

If H has bounded VC_2 dimension, $M_f(\varepsilon) \leqslant \text{twr}(\varepsilon^{-C})$ for sane f (and this is best possible).

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Conjecture: We can take $\delta = \text{poly}(\varepsilon)$.

Thank you!