Forbidden subgraphs & Spherical two-distance sets

Forbidden subgraphs

* All subgraphs are induced.

Joint with Alexandr Polyanskii

Families of graphs

** Refer to adjacency matrix.

- $\mathcal{F}'(\lambda) = \{$ graphs with spectral radius** $\leq \lambda \}$.
- $\mathcal{F}(-\lambda) = \{$ graphs with smallest eigenvalue** $\geq -\lambda \}$.

Problems

- Classification of graphs in $\mathcal{F}'(\lambda)$ or $\mathcal{F}(-\lambda)$.
- Define $\mathcal{F}'(\lambda)$ or $\mathcal{F}(-\lambda)$ by a <u>finite</u> set of forbidden subgraphs?

(Observation: Cauchy interlacing $\Rightarrow$ $\mathcal{F}'(\lambda)$ and $\mathcal{F}(-\lambda)$ are closed under taking subgraphs.)

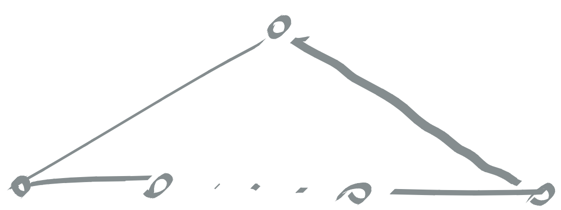
i.e. find <u>finite</u> $\underline{\mathcal{G}}$ of graphs s.t. $\underline{\underline{\mathcal{F}}} = \{ G :$ no member of $\mathcal{G}$ is a subgraph of $G. \}$.

$F'(\lambda) = \{\text{graphs with spectral radius} \leq \lambda\}$

$F(-\lambda) = \{\text{graphs with smallest e.v.} \geq -\lambda\}$

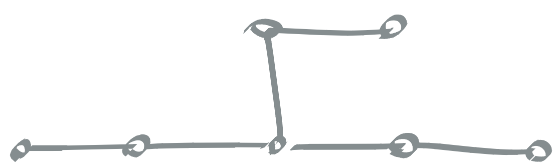
Results on $\lambda = 2$.

Maximal connected graphs in $F'(2)$

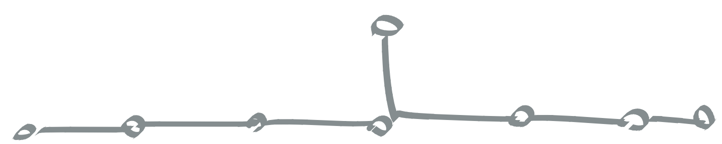


$\tilde{A}_n$ $(n \geq 2)$

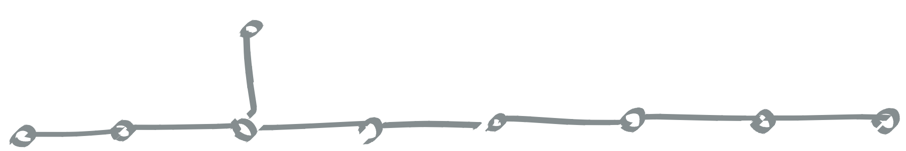
$\tilde{D}_n$ $(n \geq 4)$



$\tilde{E}_6$



$\tilde{E}_7$.



$\tilde{E}_8$. [Smith 70].

$F'(2)$ can be defined by $\underline{18}$ forbidden subgraphs.

$F(-2)$ is much richer.

- $F(-2) \supseteq F'(2)$.
- $F(-2) \supseteq \{\text{line graphs}\}$

Pf: Line graph $L(G)$.

adj. mat. of $L(G)$

$= \underline{B^T B} - 2I$ $\square$

B is incidence mat of G.

1976

[Cameron, Goethals, Seidel, Shult]

Connected graphs in $\mathcal{F}(-2)$ are either "generalized line graphs" or "representable by E_8 root system"* .

* finitely many exceptions

[Bussemaker, Neumair 1982]

$\mathcal{F}(-2)$ can be defined by 1812 forbidden subgraphs.

(computer assisted).

A result beyond $\lambda = 2$

[Cvetković, Doob, Gutman 1982].

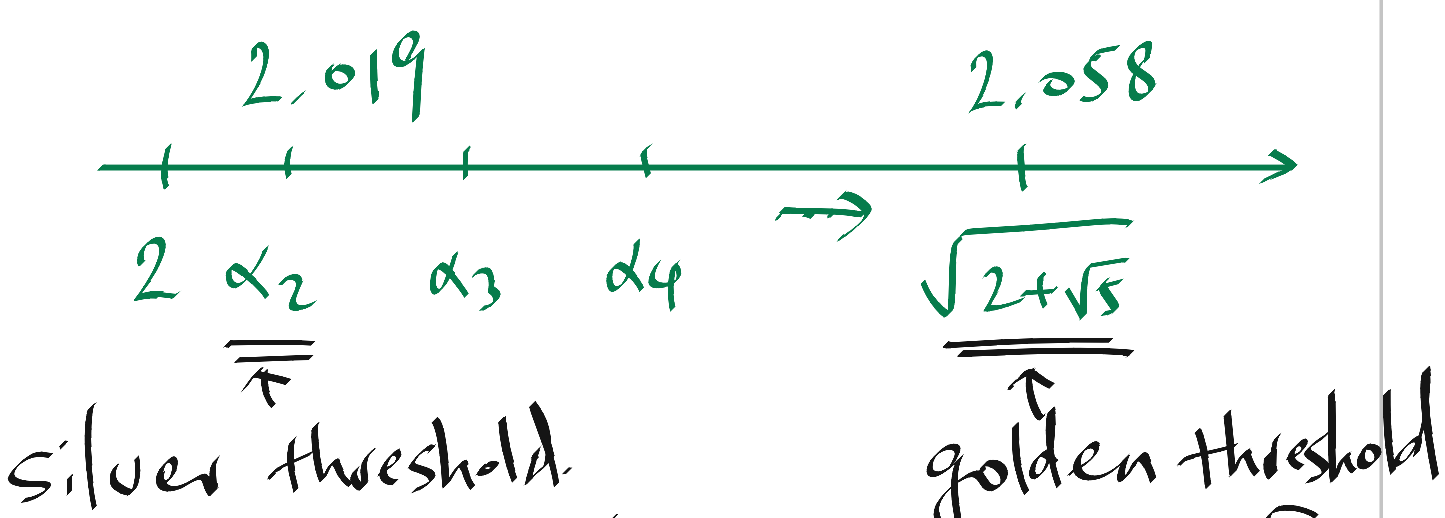
Classification of graphs in

$$\mathcal{F}'(\underbrace{\sqrt{2+\sqrt{5}}}_{\approx 2.058})$$

[BN92]: It would be interesting to know the set of λ s.t. $\mathcal{F}'(\lambda)$ or $\mathcal{F}(-\lambda)$ can be defined by finite set of forbidden subgraphs; "however, these seem to be very difficult".

THM [J. Polyanskii 2020].

$F'(\lambda)$ can be defined by a finite set of forbidden subgraphs iff $\lambda < \sqrt{2+\sqrt{5}}$ and $\lambda \notin \{\alpha_2, \alpha_3, \dots\}$



$\sqrt{2+\sqrt{5}} = \varphi^{1/2} + \varphi^{-1/2}$ $\varphi = \frac{1+\sqrt{5}}{2}$

$\alpha_2 = \beta^{1/2} + \beta^{-1/2}$. $\beta^3 = 1+\beta$.

THM [J. Polyanskii, in progress].

$F(-\lambda)$ can be defined by a finite set of forbidden subgraphs iff $\lambda < \alpha_2$.

Question: Characterize all graphs in $F(-\alpha_2) \setminus F(-2)$.

Generalization to signed graphs

$F^{\pm}(\lambda) = \{$signed graphs with largest e.v. $\le \lambda\}$.

THM $F^{\pm}(\lambda) \dots$ iff $\lambda < \alpha_2$.

Spherical two-distane sets

Joint work with Jonathan Tidor, Yuan Yao, Shengtong Zhang, & Yufei Zhao.

Spherical two-distance set in $\mathbb{R}^d$

$= \{ v_1, v_2, \dots, v_N \in \mathbb{R}^d :$

$\forall i, \; \|v_i\| = 1$, & "angles"

$\forall i \neq j, \; \langle v_i, v_j \rangle = \underline{\alpha \text{ or } \beta} \}$.

Focus on $-1 \leq \beta < 0 \leq \alpha < 1$.

<u>Remark</u>: $\beta = -\alpha \Leftrightarrow$ equiangular lines

$N_{\alpha,\beta}(d) =$ max size of spherical two-distane sets in $\mathbb{R}^d$ with angles α, β.

<u>Prop</u> [JTYZZ 20+].

$$N_{\alpha,\beta}(d) \geq \frac{k_p(\lambda)\, d}{k_p(\lambda) - 1} + O_{\alpha,\beta}(1),$$

where $\lambda = \dfrac{1-\alpha}{\alpha - \beta}$, $p = \left\lfloor \dfrac{-\alpha}{\beta} \right\rfloor + 1$

and $k_p(\lambda) = \inf \left\{ \dfrac{|G^{\pm}|}{\text{mult}(\lambda, \underline{\underline{G^{\pm}}})} : \right.$

$\left. \underline{\chi}(G^{\pm}) \leq p \text{ and } \underline{\underline{\lambda}}'(G^{\pm}) = \lambda \right\}$.

chromatic #   largest e.v.

<u>Conj</u>: Lower bound is tight.

($\underline{\underline{\lambda}}$ and $\underline{\underline{p}}$ governs $N_{\alpha,\beta}(d)$)

Conj $N_{\alpha,\beta}(d) = \dfrac{kp(\lambda)\, d}{kp(\lambda)-1} + O(1)$

where $\lambda = \dfrac{1-\alpha}{\alpha-\beta}$, $p = \left\lfloor \dfrac{-\alpha}{\beta} \right\rfloor + 1$.

THM [JTYZZ 20+].

Conj holds when

$p \le 2$, or $\lambda \in \{1, \sqrt{2}, \sqrt{3}\}$.

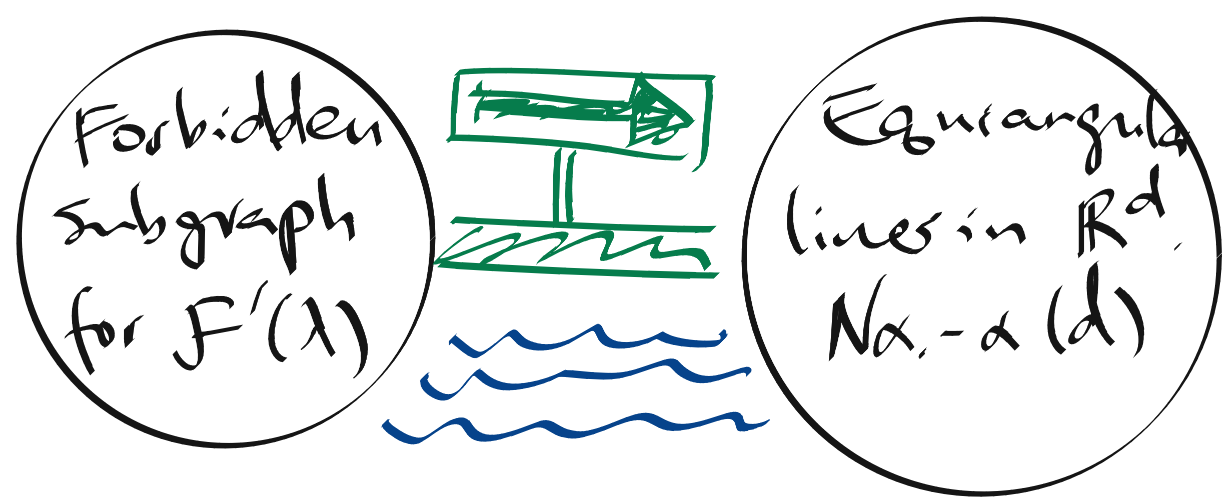
Tool: 2nd eigenvalue multiplicity

Tool fails for signed graphs

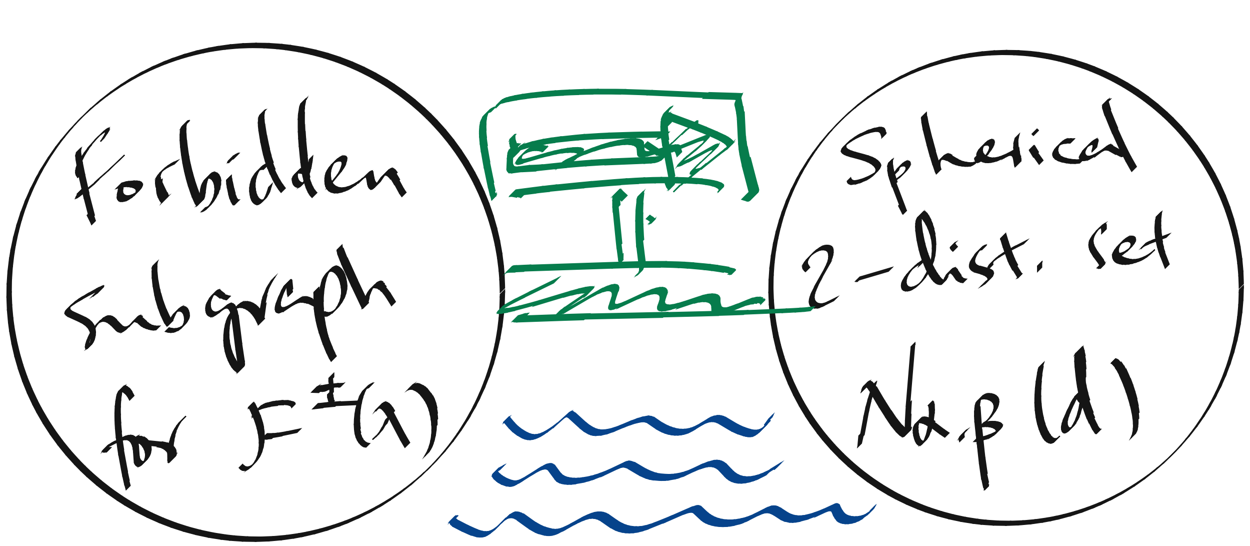
Equiangular lines $\beta = -\alpha$ (or $p = 2$)

Recent work: Bukh, BDSK...

[J. Polyanskii 20]. If $F'(\lambda)$ can be defined by a finite set of forb. subgraph, then conj holds when $\dfrac{1-\alpha}{\alpha-\beta} = \lambda$ and $p = 2$.



[JTYZZ 19+] Conj holds when $\beta = -\alpha$.



[JTYZZ 20+]. If $\mathcal{F}^{\pm}(\lambda)$ can be defined by a finite set of forbidden subgraphs, then conj holds for $\frac{1-\alpha}{\alpha-\beta} = \lambda$.

Cor [J. Polyanskii] Conj holds for $p \le 2$ or $\lambda < \alpha_2 \approx 2.019$.

Recall. $\mathcal{F}^{\pm}(\lambda) = \{$ signed graphs with largest e.v. $\le \lambda \}$.

Cor. $Q(x_1, \cdots, x_n)$ $\quad c_i \in \{0, 1\}$

$$= \sum_i x_i^2 + \sum_{i<j} c_i x_i x_j .$$

$c_i \in \mathbb{Z}$. If $Q(x) < 0$ $\exists x$.

then $\exists x$ supported on 10 coordinates s.t. $Q(x) < 0$.