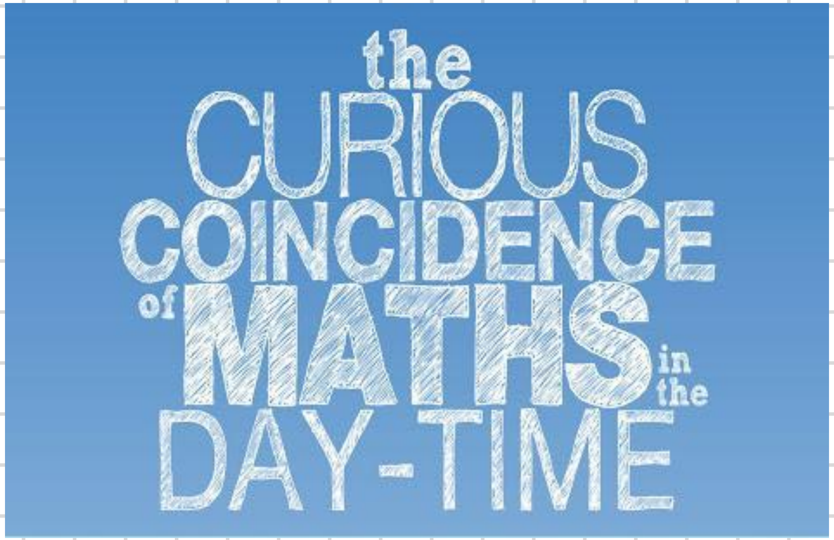
Igor Pak, UCLA

July 22, 2026

Combinatorics and computational complexity of counting coincidences

Lattice Path Conference, TU Wien



What is a counting problem?

$x \leftarrow$ *combinatorial object*

$f(x) :=$ # *combinatorial objects indexed by* x

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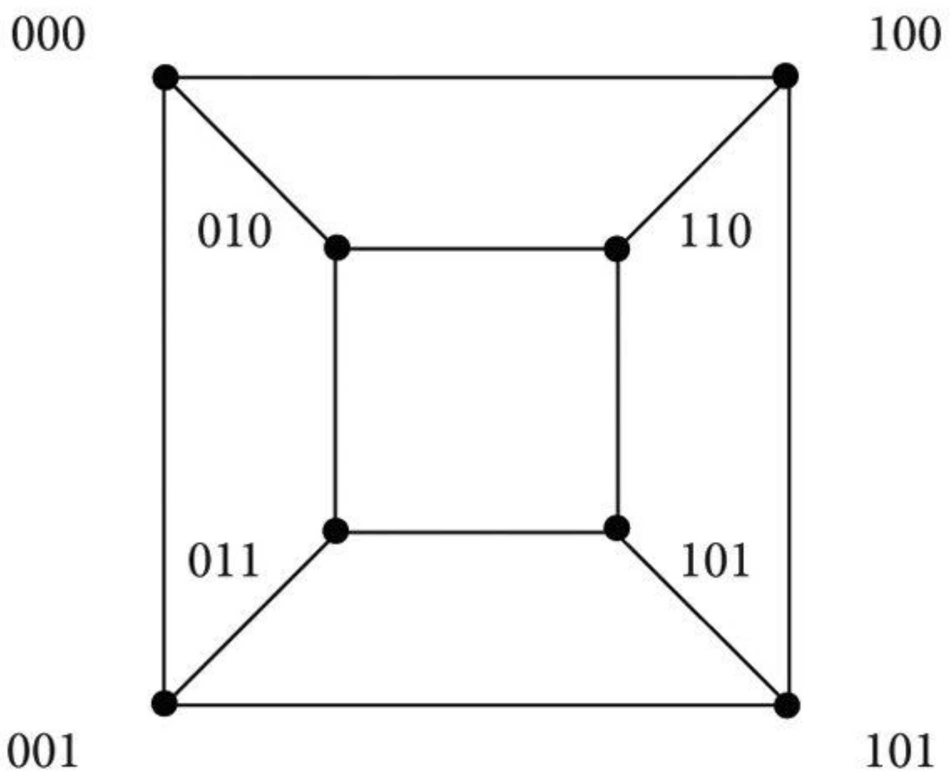
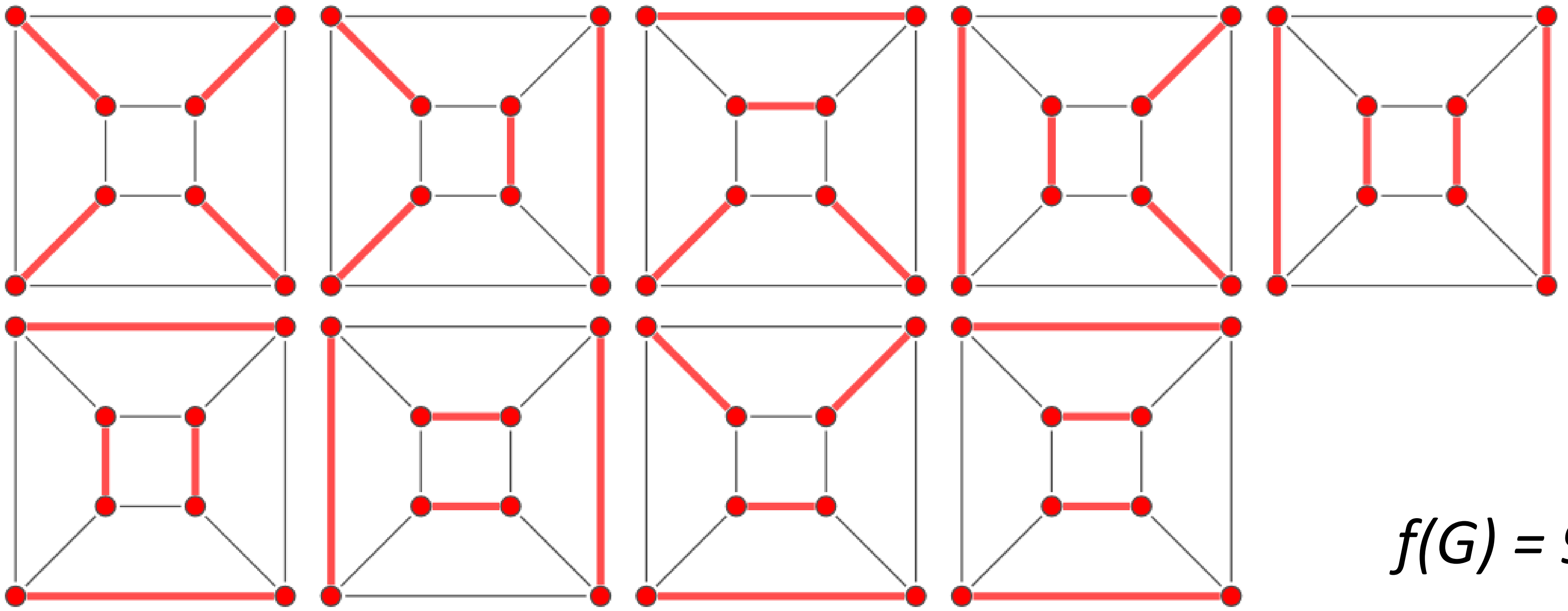


G=(V,E) graph on n=2k vertices

Perfect matching – collection of k pairwise disjoint edges of G

f(G) := the number of perfect matchings in graph G

What is a counting problem?



$f(G) = 9$

$f(G) :=$ *the number of perfect matchings in graph G*

What is a counting problem?

f(d-cube) =

1

2

9

272

589185

16332454526976

391689748492473664721077609089

factor	391 689 748 492 473 664 721 077 609 089

Result

$3 \times 7^2 \times 34981 \times 515929 \times 255681973 \times 577434331$ (7 prime f

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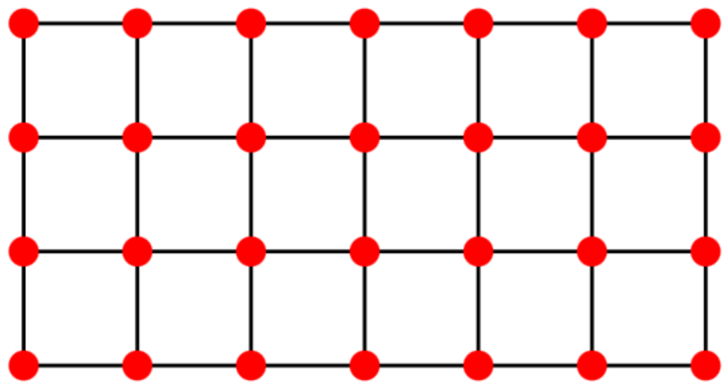

$G=(V,E)$ graph on n vertices

Spanning tree – collection of n-1 edges of G with no cycles

$f(G)$:= the number of spanning trees in graph G

What is a counting problem?

A007341	Number of spanning trees in n X n grid. (Formerly M3721)

1, 4, 192, 100352, 557568000, 32565539635200, 19872369301840986112,
126231322912498539682594816, 8326627661691818545121844900397056,
5694319004079097795957215725765328371712000,
40325021721404118513276859513497679249183623593590784,
2954540993952788006228764987084443226815814190099484786032640000

factor 2 954 540 993 952 788 006 228 764 987 084 443 226 815 814 190 \
099 484 786 032 640 000

Result

$2^{51} \times 3^5 \times 5^4 \times 7^6 \times 11^2 \times 13^2 \times 23^6 \times 71^2 \times 73^2 \times 97^2 \times 193^4 \times 263^2$

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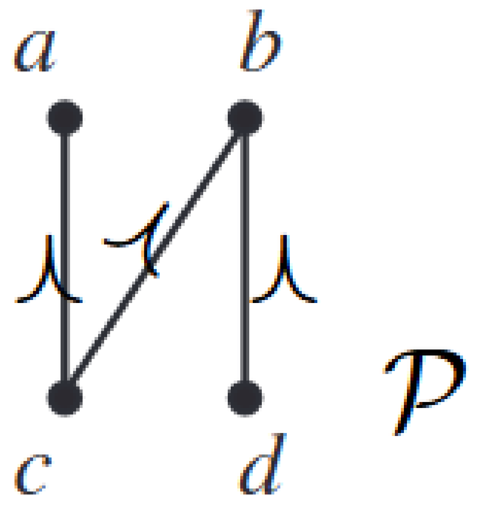

f(P) := the number of linear extensions in poset P

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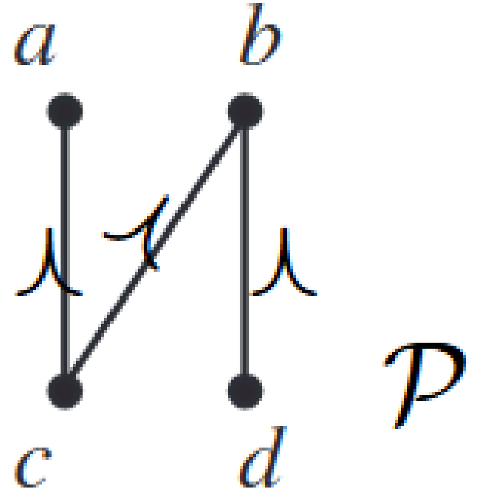
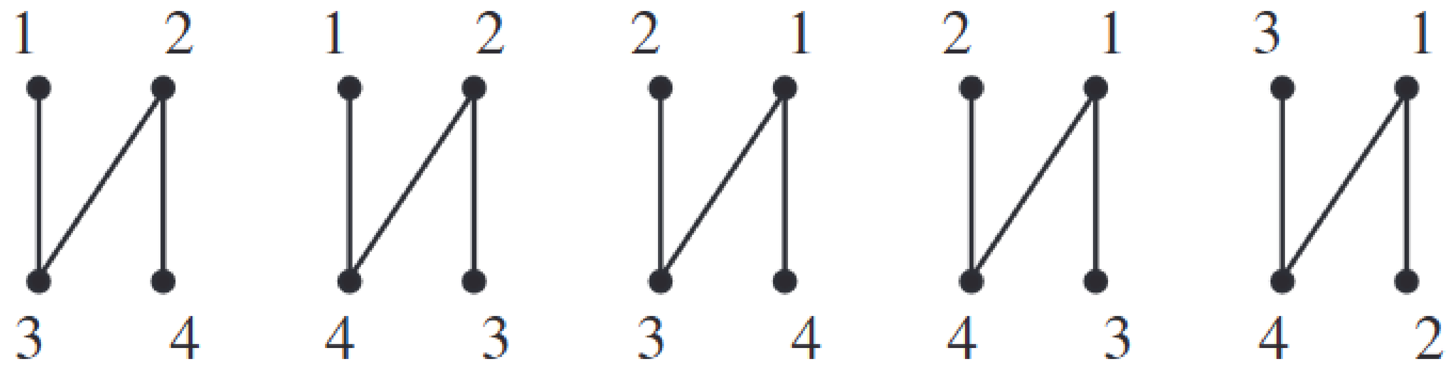


f(P) = 5



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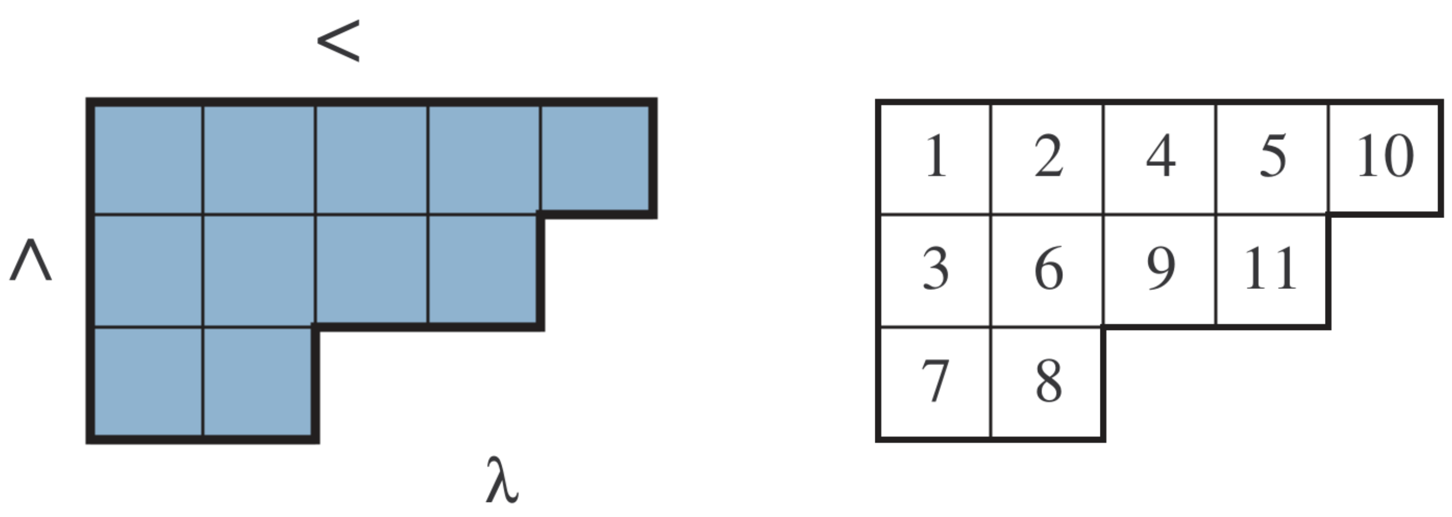

f(λ) = *number of standard Young tableaux of shape* λ

What’s a counting coincidence?

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$$\pi^4 + \pi^5 \approx e^6$$

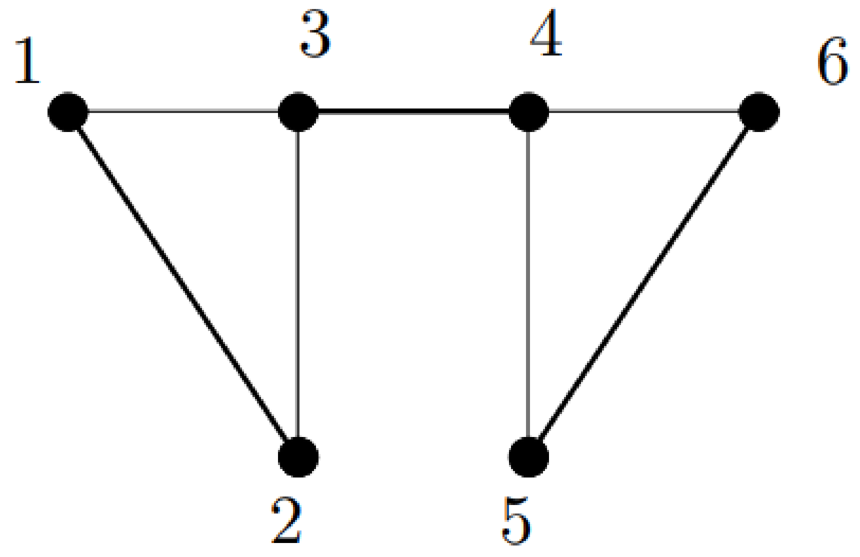
← *Not that!*

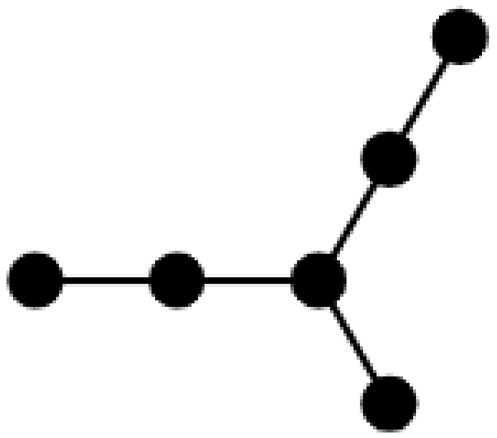
Let's compare:

$$\pi^4 + \pi^5 = 403.428793492735$$

$$e^6 = 403.428793492735$$

What's a counting coincidence?





Two graphs with the same number of perfect matchings

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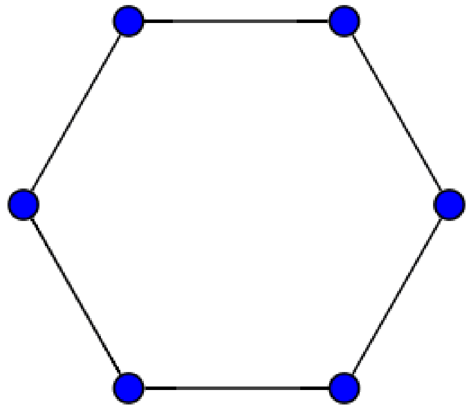
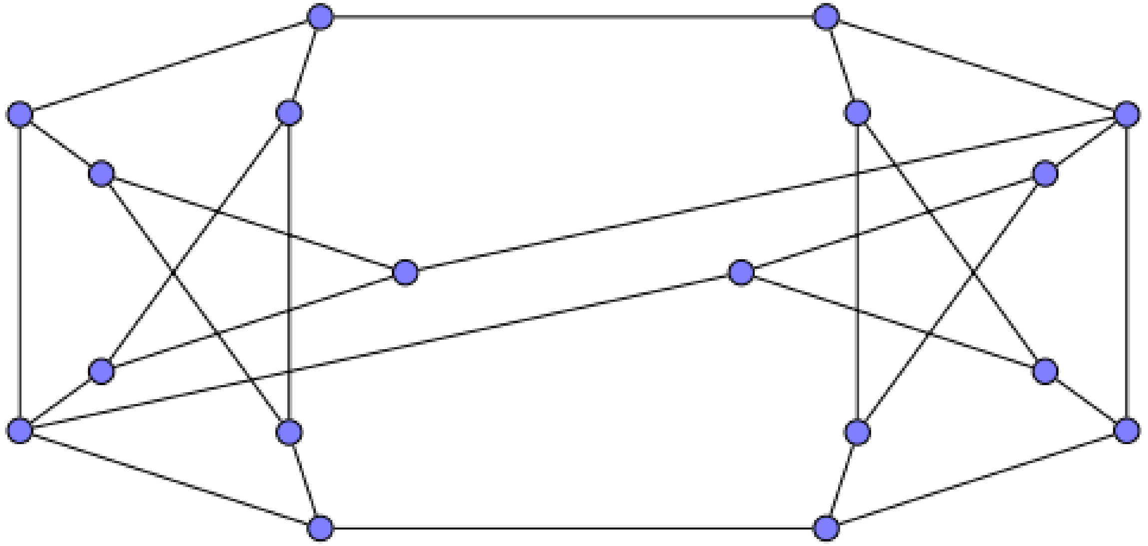
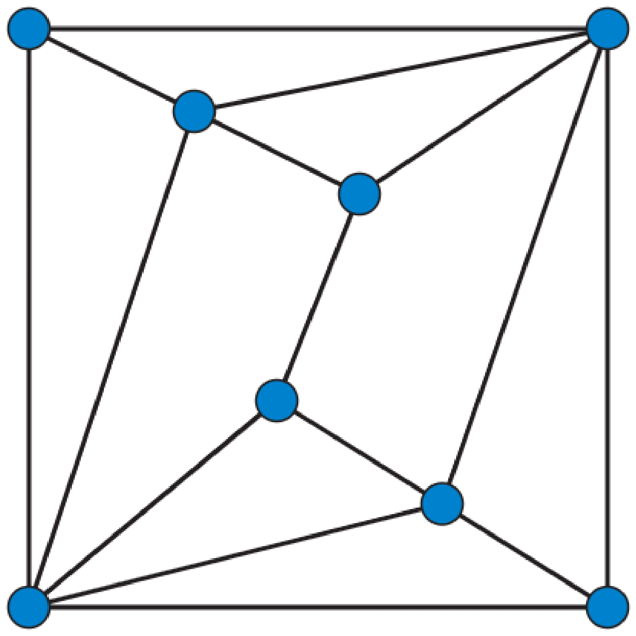
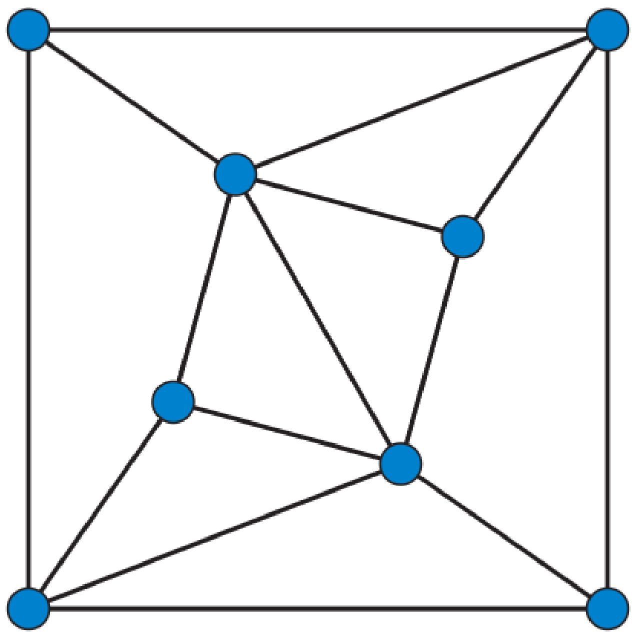




Two graphs with the same number of Hamiltonian cycles

What’s a counting coincidence?





Two graphs with the same number of spanning trees

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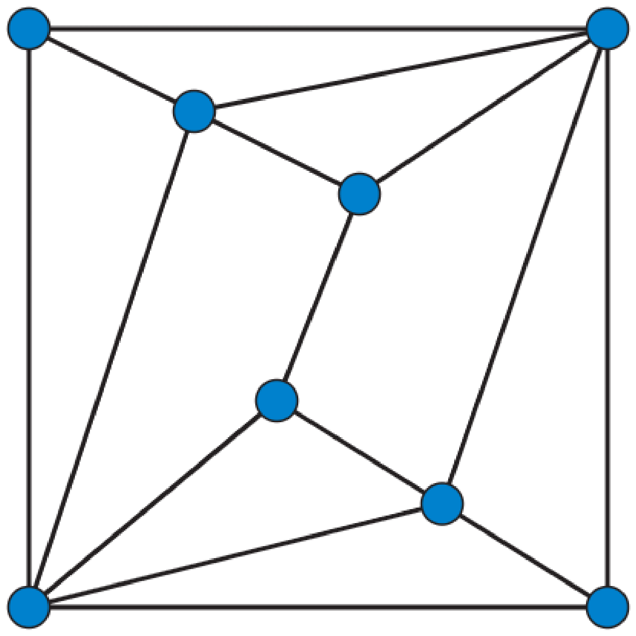

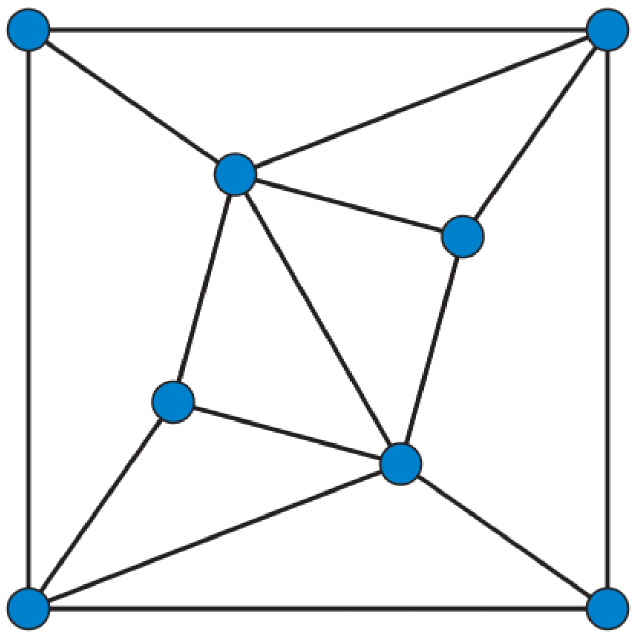

Two graphs with the same number of spanning trees

Note: These graphs are isospectral

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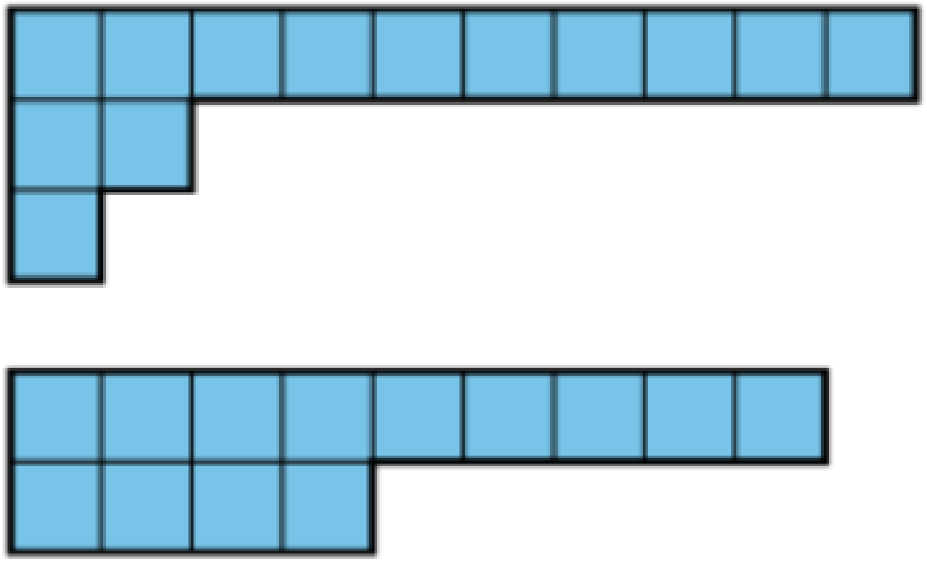

1	2	4	6
3	5	8	
7			

Two partitions with the same number of standard Young tableaux:

#SYT(10,2,1) = #SYT(9,4) = 429

Definition of counting coincidences

Let $f \in \#\mathrm{P}$ counting function. The *coincidence problem* for f is defined as:

$$\mathrm{C}_f := \{f(x) \stackrel{?}{=} f(y)\}$$

Computational Complexity

Problems with parsimonious reductions

- number of Hamiltonian cycles in a graph
- number of 3-colorings of a planar graph
- number of π-patterns in a permutation $\sigma \in S_n$
- Kronecker coefficients $g(\lambda, \mu, \nu)$

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Karp reducible

In all these cases $f \in \#\text{P-complete}$

Theorem [Chan–P.'23]

For all f as above, $\text{C}_f \notin \text{PH}$ unless PH collapses

easy

Problems without parsimonious reductions

- number of perfect matchings in a simple bipartite graph
- number of independent sets in a planar graph
- number of order ideals of a poset
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HARD

Inverse counting problem

Computational Complexity

Fix $f : X \rightarrow \{0,1,2,\ldots\}$

Given k, find a combinatorial object $x \in X$ of smallest size, such that $f(x) = k$.

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Main Definition:

Let $X = \cup_n X_n$ be set of combinatorial objects.

Let $\mathcal{T}_f := \{f(x) : x \in X\}$ set of all values of f.

Function $f : X \to \mathbb{N}$ is *concise* if $\exists C, c > 0$, s.t.

for all $k \in \mathcal{T}_f$ there is $x \in X_n$ with $f(x) = k$ and $n < C(\log k)^c$.

Proof idea: these functions are *concise*

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Meta Lemma:

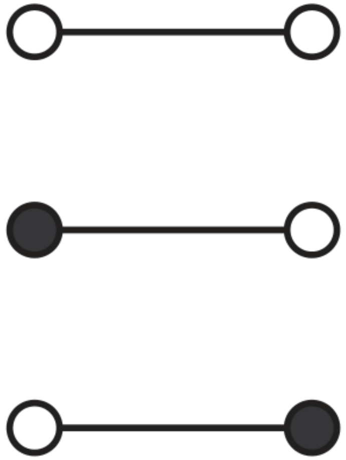
All functions f above are concise.

Easy example: independent sets

Let $f : G=(V,E) \rightarrow$ *number of independent sets in* G

independent set := *subset of nonadjacent vertices in graph* G

e



$f(e) = 3$

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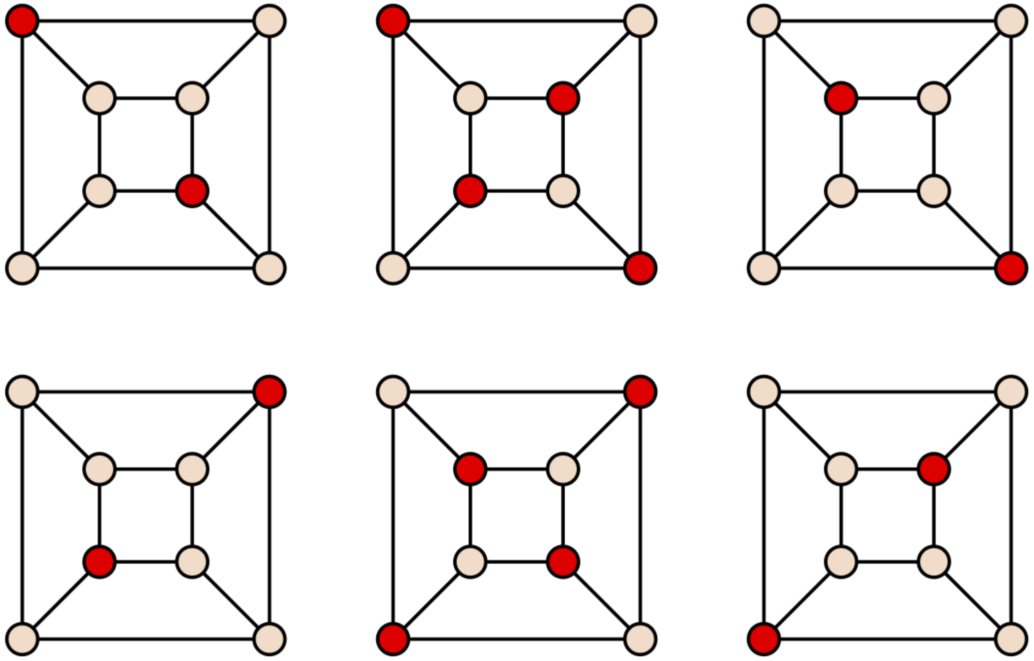

#P-complete

Easy example: independent sets

Let *f* : *G*=(*V*,*E*) → *number of independent sets in G*

independent set := *subset of nonadjacent vertices in graph G*

$$\mathcal{T}(n) \ := \ \{ f(G), \ \text{ where } \ G = (V,E), \ |V| \le n \} \ \subseteq \ \{2, \ldots, 2^n\}$$

Theorem [easy] $(\Rightarrow f$ is concise$)$

We have $\mathcal{T}(n) \supseteq \{2, 3, \ldots, 2^n\}$, for all $n \ge 1$.

Note: the number of non-isomorphic graphs on n vertices is $\sim 2^{\binom{n}{2}}/n!$

Easy example: independent sets

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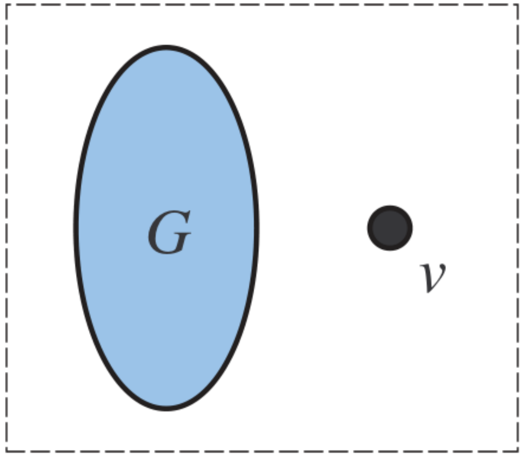
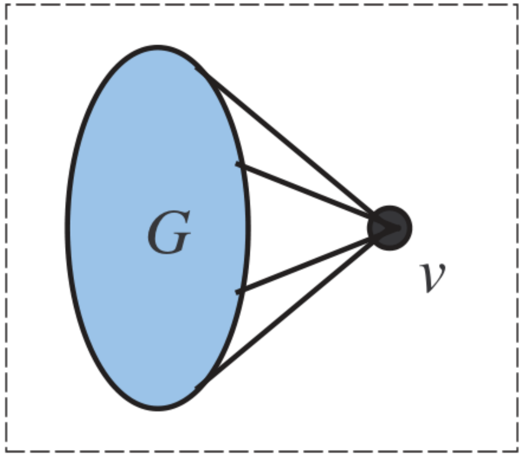
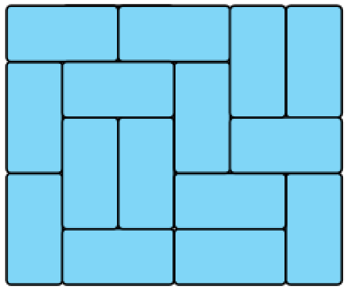




$f(G + v) = 2\, f(G)$

$f(G \times v) = f(G) + 1$

Domino tilings

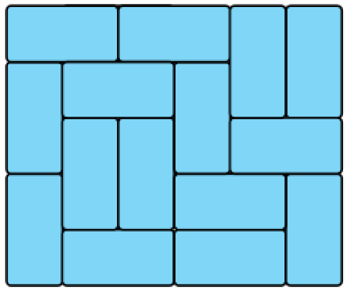


Let $\Gamma \subset \mathbb{Z}^2$ be a finite region of area $2n$, $\tau(\Gamma)$ number of domino tilings of Γ.

Let $\mathcal{T}(n)$ the set of numbers of domino tilings over all regions of size $2n$:

$$\mathcal{T}(n) \;:=\; \{\tau(\Gamma), \;\text{ where }\; \Gamma \subset \mathbb{Z}^2, \; |\Gamma| = 2n\} \;\subseteq\; \{0, 1, \ldots, 4^n\}$$

Domino tilings



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Theorem [Chan–P'23] ($\Rightarrow \tau$ is concise)

There is a constant $c > 1$, such that $\mathcal{T}(n) \supseteq \{0, 1, \ldots, c^n\}$, for all $n \geq 1$.

Proof idea

Denote by $\mathcal{D}(a, b)$ the set of regions Γ such that $\tau(\Gamma) = a$ and $\tau(\Gamma - x - y) = b$

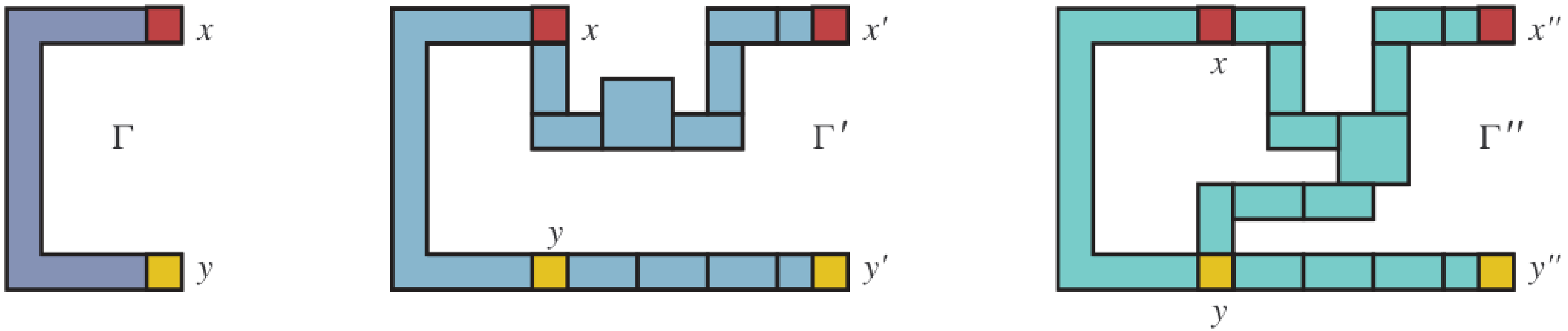

FIGURE 3.1. Region $\Gamma \in \mathcal{D}(1, 1)$, and two transformations $\Gamma \in \mathcal{D}(a, 1) \Rightarrow \Gamma' \in \mathcal{D}(2a, 1)$, and $\Gamma \in \mathcal{D}(a, 1) \Rightarrow \Gamma'' \in \mathcal{D}(2a + 1, 1)$.

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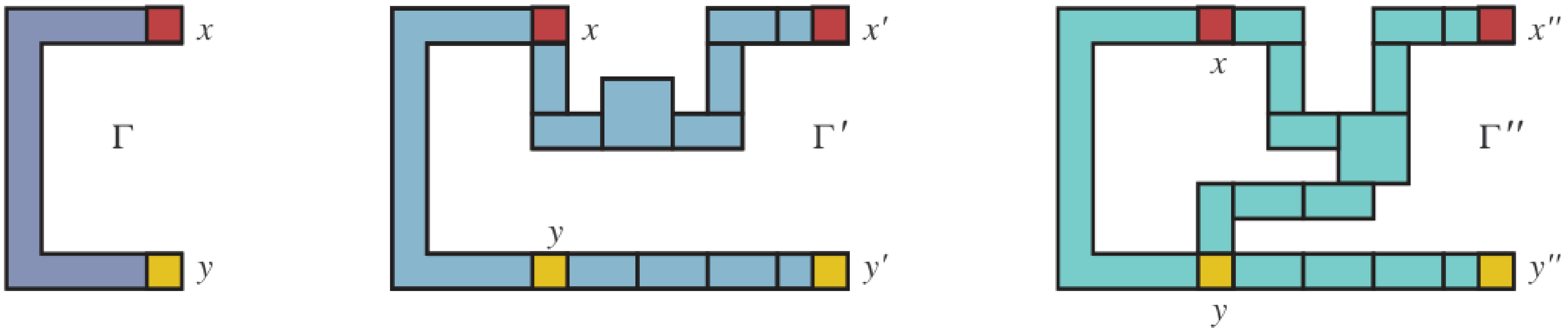

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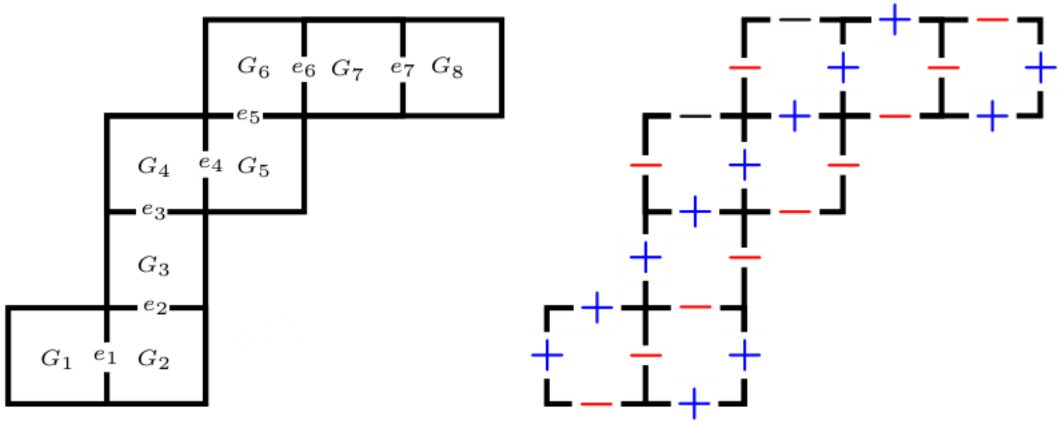
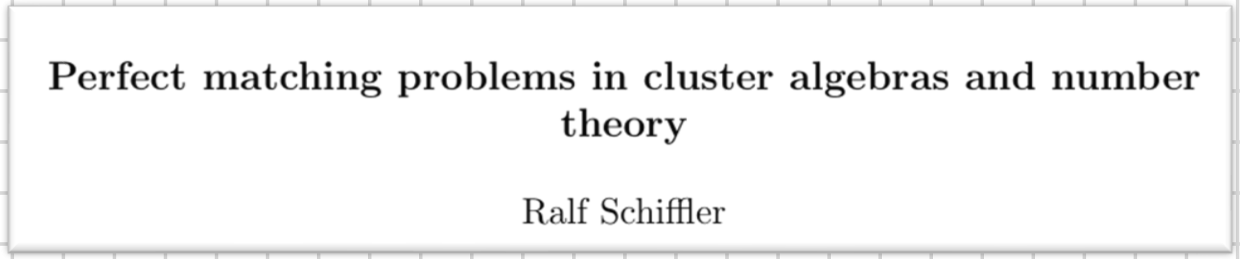
Note: The exponential bound in the theorem still holds for *simply-connected regions*. Proof is *much* harder.

Perfect matchings of snake regions



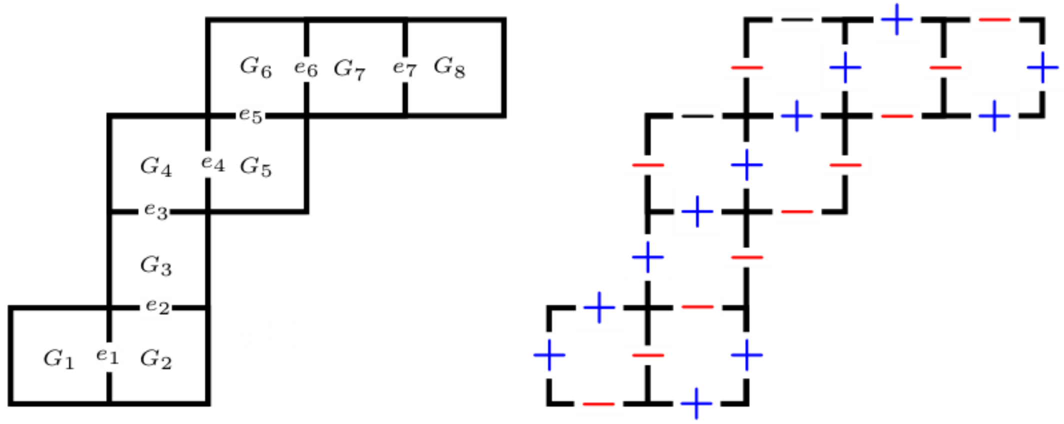
sign sequence = (+ – – + + + + – –)

$(a_1, a_2, a_3, a_4) = (1, 2, 4, 2)$


Perfect matching problems in cluster algebras and number theory

Ralf Schiffler

Perfect matchings of snake regions



$$[a_1, a_2, \ldots, a_n] = a_1 + \cfrac{1}{a_2 + \cfrac{1}{\ddots + \cfrac{1}{a_n}}}$$

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$$\frac{\#\mathrm{PM}(a_1, \ldots, a_n)}{\#\mathrm{PM}(a_2, \ldots, a_n)} = [a_1, \ldots, a_n]$$

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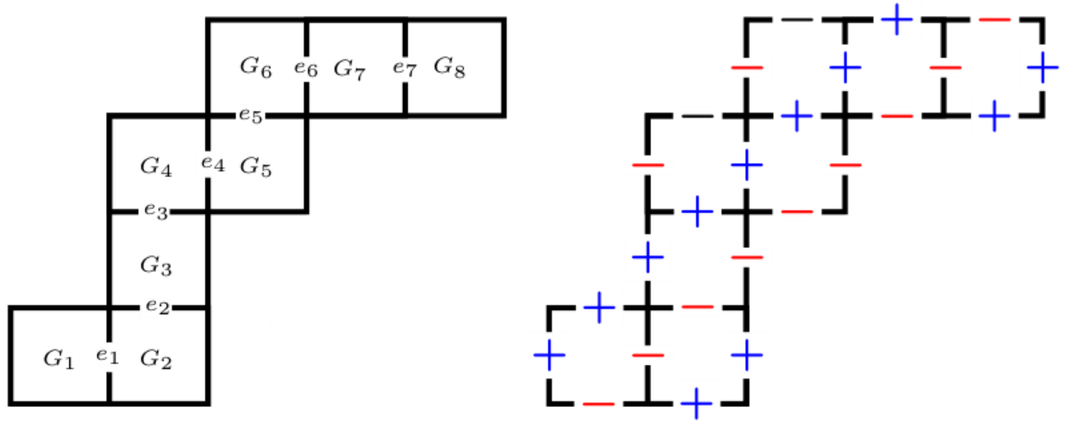

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$$1 + \cfrac{1}{2 + \cfrac{1}{4 + \cfrac{1}{2}}} = \frac{29}{20}$$

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Observation [Chan-P.'24] *Zaremba's conjecture implies*

$\mathcal{T}_{\mathrm{snake}}(n) \supseteq \{0, 1, 2, \ldots, c^n\}$ *for some* $c > 1$ *and all* $n \geq 1$.

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Conjecture 1.13 (*Zaremba's Conjecture* [Zar72, p. 76]). *There is a universal constant $A>0$ so that, for every integer $u\geq 1$, there is a coprime integer $1\leq t<u$, such that $t/u=[a_1,\ldots,a_\ell]$ and $a_1,\ldots,a_\ell\leq A$.*

Perfect matchings of snake regions

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Theorem [Chan-P.'24] *There is* $c > 1$, *such that*
$\mathcal{T}_{\text{snake}}(n) \supseteq \left\{0, 1, \ldots, c^{n/(\log n)}\right\}$, *for all* $n \geq 1$.

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Primes are enough!

Perfect matchings of snake regions

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Mathematics > Number Theory

arXiv:2603.14116 (math)

[Submitted on 14 Mar 2026 (v1), last revised 24 Jun 2026 (this version, v2)]

On some results of Korobov and Larcher and Zaremba's conjecture

Ilya D. Shkredov

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Primes are enough!

Zaremba for primes!

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Corollary: $\mathcal{T}_{\text{snake}}(n) \supseteq \{0, 1, 2, \ldots, c^n\}$ for some $c > 1$ and all $n \geq 1$.

Linear extensions

1	2	4	6
3	5	8	
7			

Theorem [Tenner'09] $\mathcal{T}_e(n) \supseteq \{1, \ldots, cn^2\}$ for some $c > 1$.

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Theorem [Kravitz–Sah'21] ($\Rightarrow$ e is concise)

Let $\mathcal{T}_e(n)$ the set of numbers of linear extensions of all posets of size n. Then:

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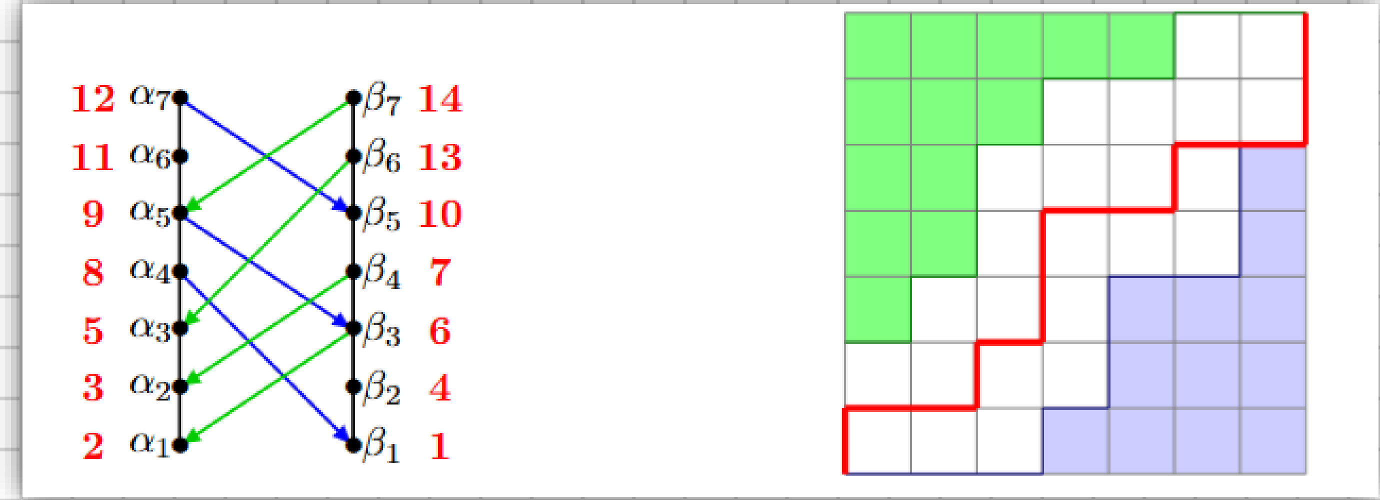
Conjecture: e is concise on posets of height 2.

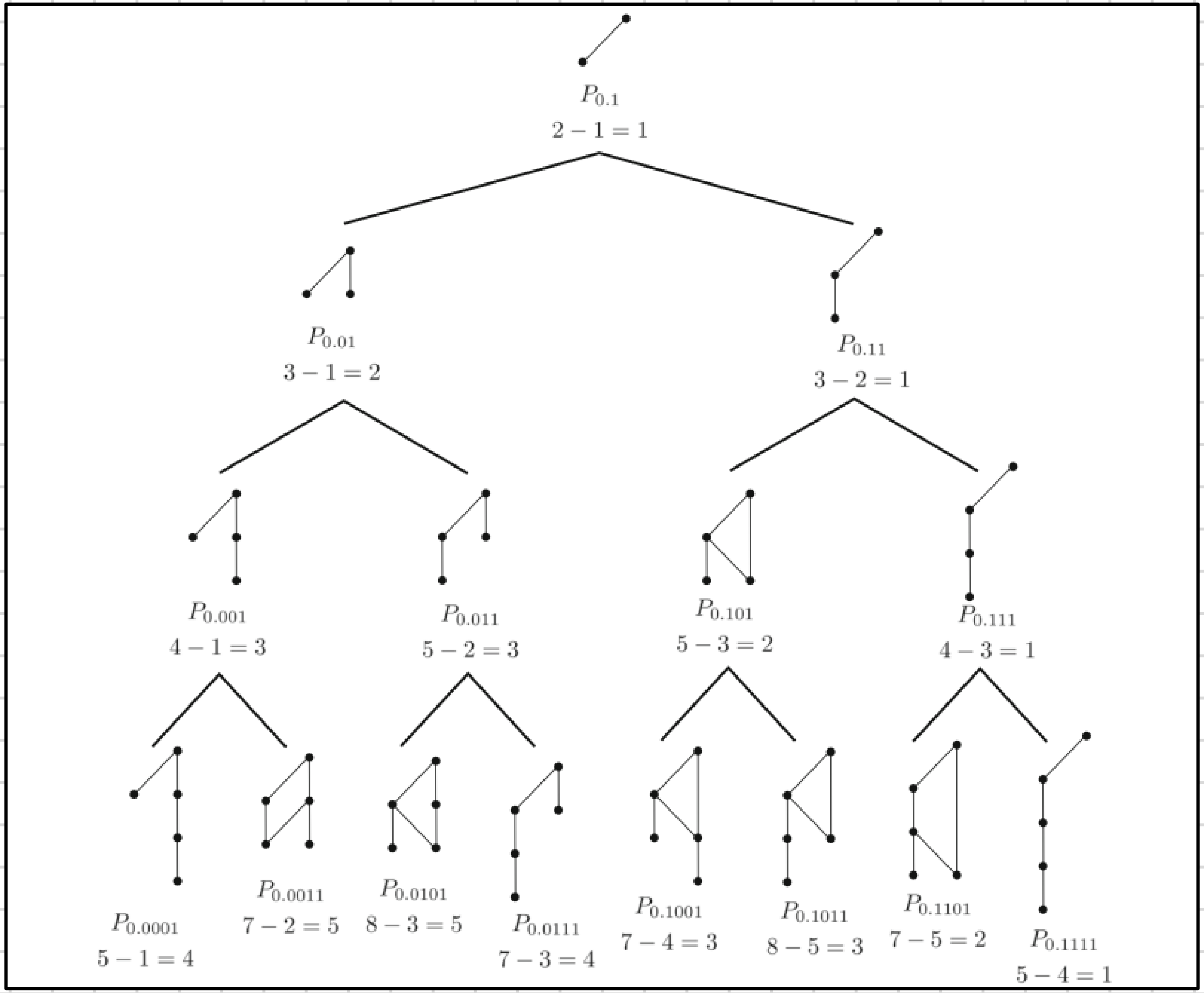
Linear extensions

Lemma [Kravitz–Sah]:

recursive construction of width two posets $P = P(a_1, \ldots, a_m)$ *such that* $[a_1, \ldots, a_m] = e(P)/e(P - x)$ *for some maximal element* x *in* P.



Proof idea of KS Lemma: *Stern-Brocot tree*



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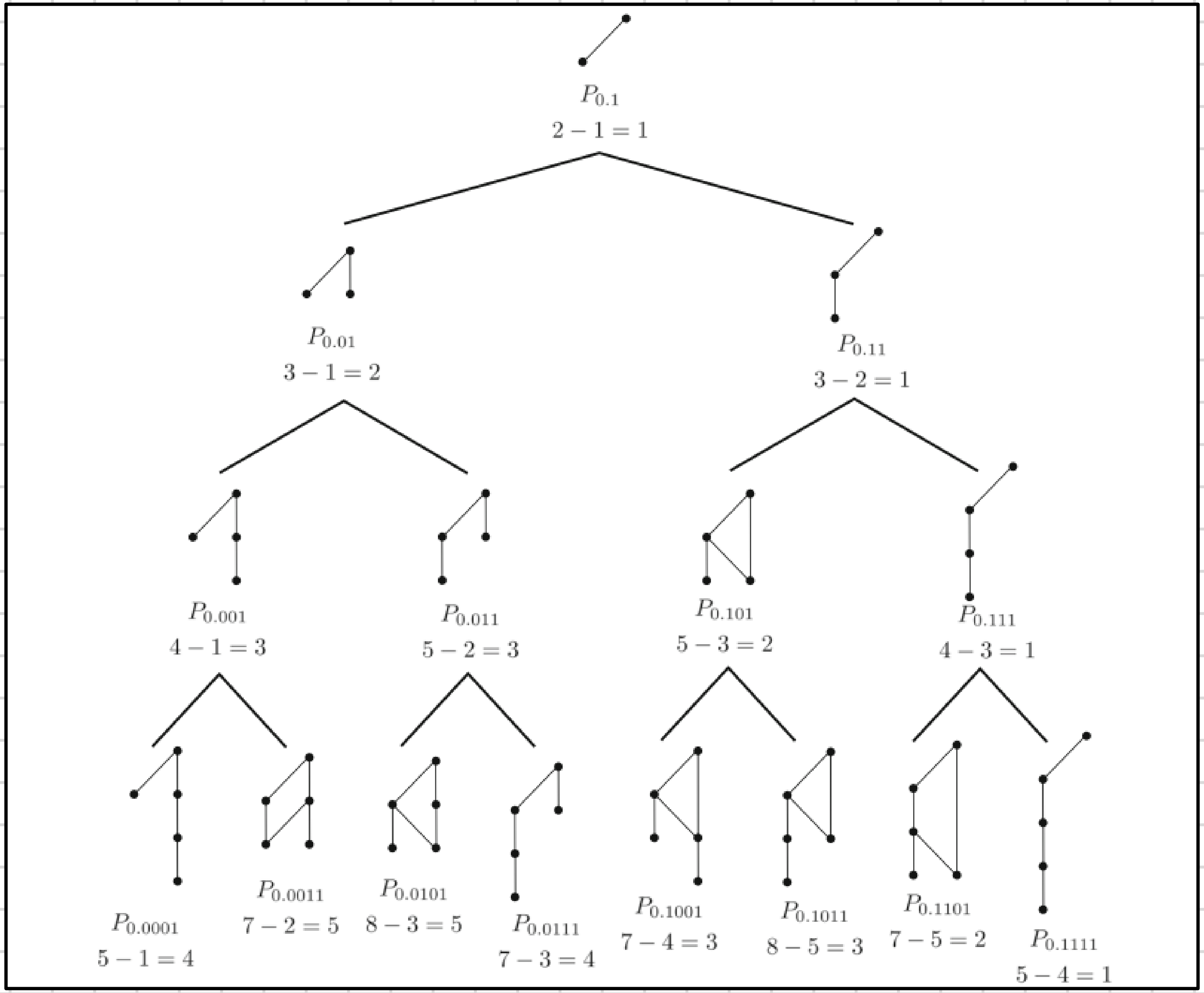

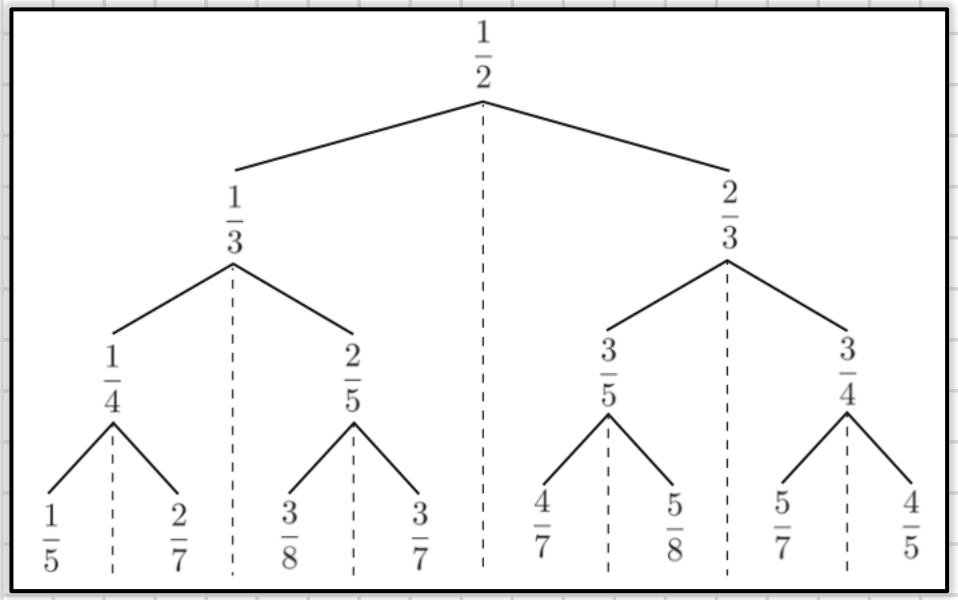

Calkin-Wilf tree

Linear extensions

Conjecture: [Kravitz-Sah'21]

$\mathcal{T}_e(n) \supseteq \{1, 2, \ldots, c^n\}$ *for some* $c > 1$ *and all* $n \geq 1$.

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Observation [Chan-P.'24] *Zaremba's conjecture implies KS Conjecture.*

Linear extensions

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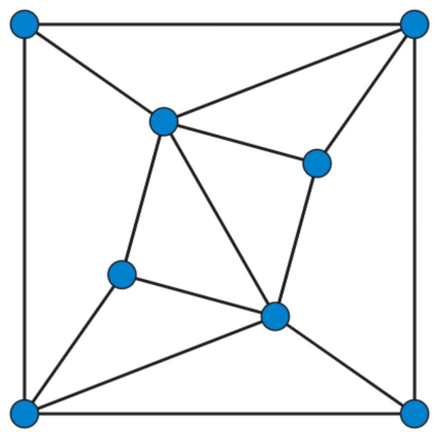
Observation [Chan-P.'24] *Zaremba's conjecture implies KS Conjecture.*

Corollary: $\mathcal{T}_e(n) \supseteq \{1, 2, \ldots, c^n\}$ for some $c > 1$ and all $n \geq 1$.

Spanning trees



Sedláček's First Problem (1966)

Describe the set of spanning tree numbers

$\mathcal{T}_s(5) = \{0, 1, 3, 4, 5, 8, 9, 11, 12, 16, 20, 21, 24, 40, 45, 75, 125\}$

Spanning trees

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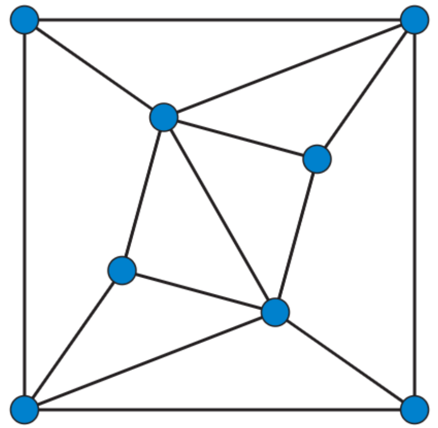

ON THE SPANNING TREES OF FINITE GRAPHS

JIŘÍ SEDLÁČEK, Praha

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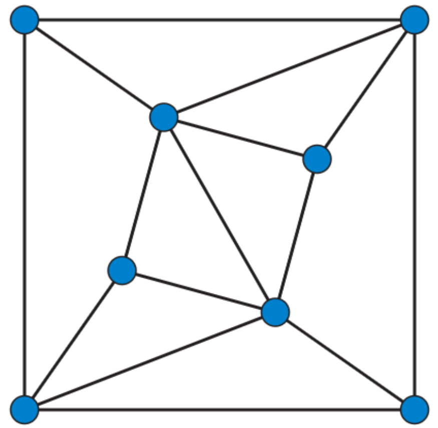

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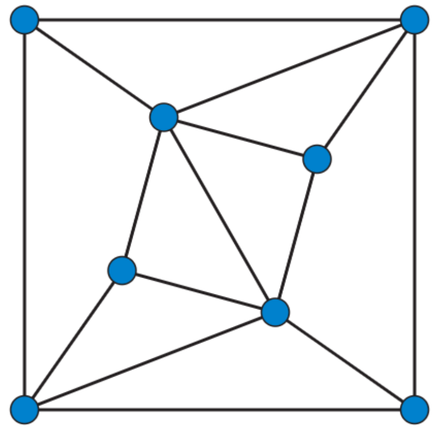
Theorem [Stong'22] ($\Rightarrow$ number of spanning trees is concise)

Let $\mathcal{T}_s(n)$ the set of numbers of spanning trees of all graphs with n vertices. Then:

$$\mathcal{T}_s(n) \supseteq \{0, 1, 3, 4, \ldots, c^{n^{2/3}}\} \quad \text{for some } \ c > 1.$$

Spanning trees



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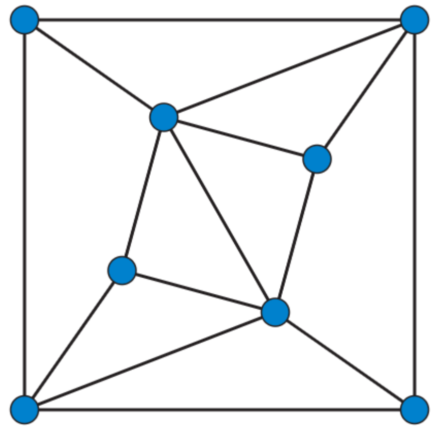
Conjecture [Sedláček'67, Azarija–Škrekovski'12]: $\mathcal{T}_s(n) \supseteq \{3, \ldots, c^n\}$ for some $c > 1$.

Spanning trees



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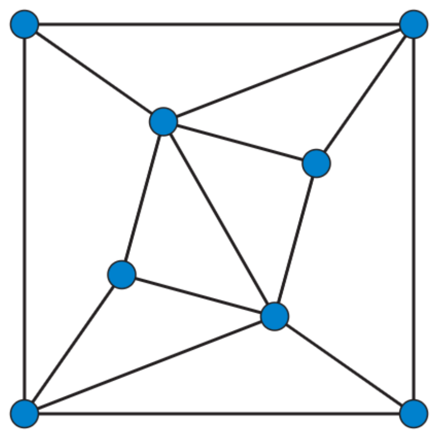
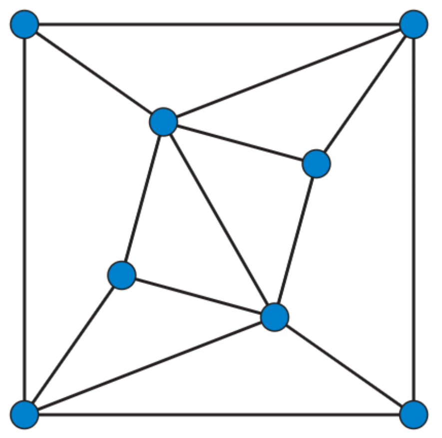


Conjecture [Sedláček'67]: $|\mathcal{T}_{sp}(n)| \geq c^n$ for some $c > 1$.

Spanning trees



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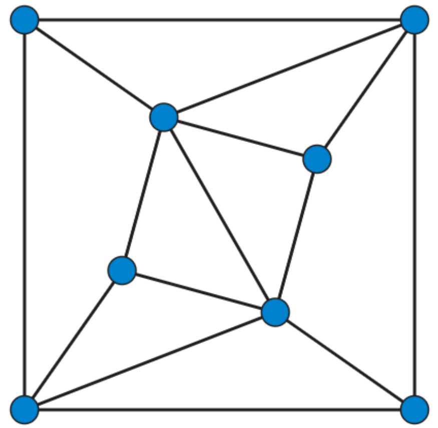
Note: This is best possible since # planar graphs with n vertices is $O(30.061^n)$.
Additionally, the maximal number of spanning trees of a planar graph is $O(5.2852^n)$.

Spanning trees



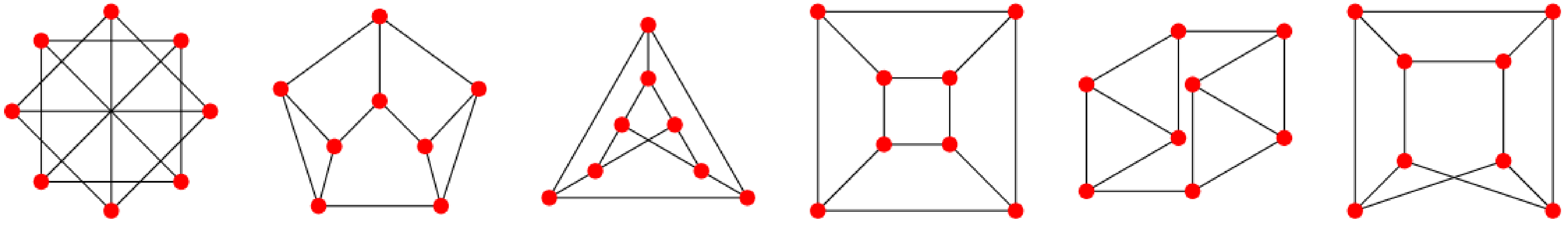
Conjecture [Sedláček'67]: $|\mathcal{T}_{sp}(n)| \geq c^n$ for some $c > 1$.

Theorem [Chan-Kontorovich-P.'24]

For some $c > 1$, we have $|\mathcal{T}_{sp}(n)| > c^n$. Moreover,

$$\frac{1}{c^n}\left|\mathcal{T}_{sp}(n) \cap \{1, 2, \ldots, c^n\}\right| \to 1 \quad as \quad n \to \infty.$$

Graphs with given degrees



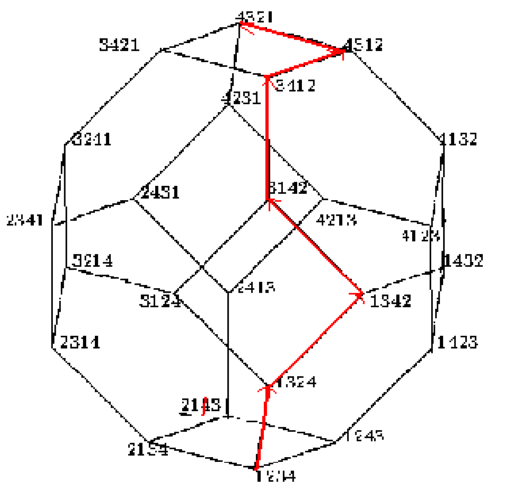
Definition:

Let $\boldsymbol{d} = (d_1, \ldots, d_n) \in \mathbb{N}^n$, s.t. $0 \leq d_1, \ldots, d_n \leq n-1$.

Denote by $g(\boldsymbol{d})$ the number of simple graphs with *degree sequence* $\boldsymbol{d}$.

Conjecture: Function g is concise (in unary).

Reduced factorizations



Definition:

Let $\sigma \in S_n$. A *reduced factorization* is a shortest product $\sigma = (i_1, i_1 + 1) \cdots (i_\ell, i_\ell + 1)$

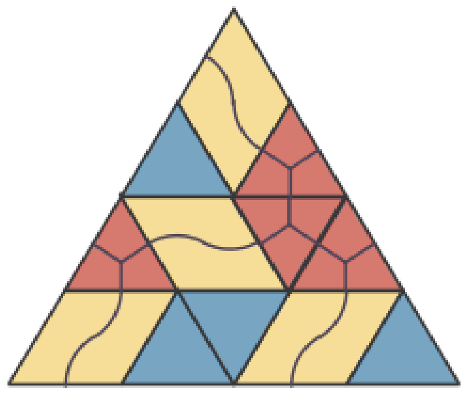
Denote by $\mathrm{red}(\sigma)$ the number of reduced factorizations of σ, for example:

$$\mathrm{red}(2, 1, n, 3, 4, \ldots, n-1) \; = \; n - 2 \quad \text{for} \quad n \geq 3.$$

Conjecture: red is concise.

Littlewood-Richardson coefficients

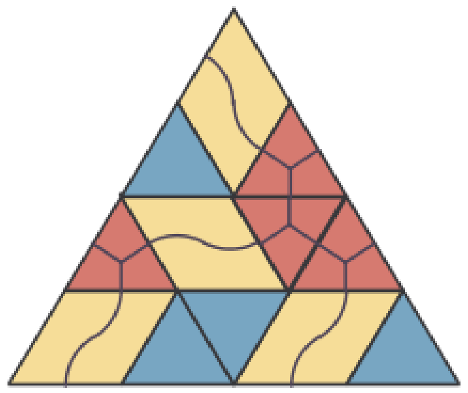
$$s_\mu \cdot s_\nu = \sum_\lambda c^\lambda_{\mu\nu} \, s_\lambda$$



Conjecture:

Littlewood–Richardson coefficients $c^\lambda_{\mu\nu}$ is a concise function (in unary).

Littlewood-Richardson coefficients



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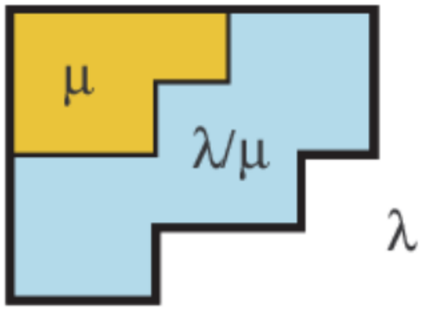
Conjecture:

Littlewood–Richardson coefficients $c^\lambda_{\mu\nu}$ is a concise function (in unary).

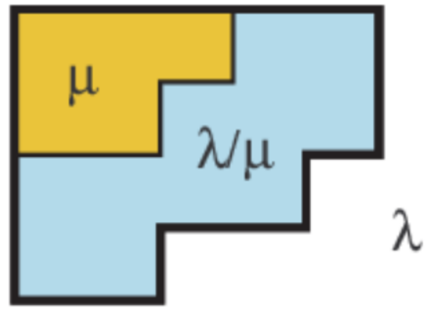
$$c^3_{1,1^2} = 0, \quad c^2_{1,1} = 1 \quad \text{and} \quad c^{k(321)}_{k(21),k(21)} = k+1 \ \text{ for all } \ k \geq 1$$

Skew Schur functions



Open Problem: *Characterize all coincidences* $s_{\lambda/\mu} = s_{\alpha/\beta}$

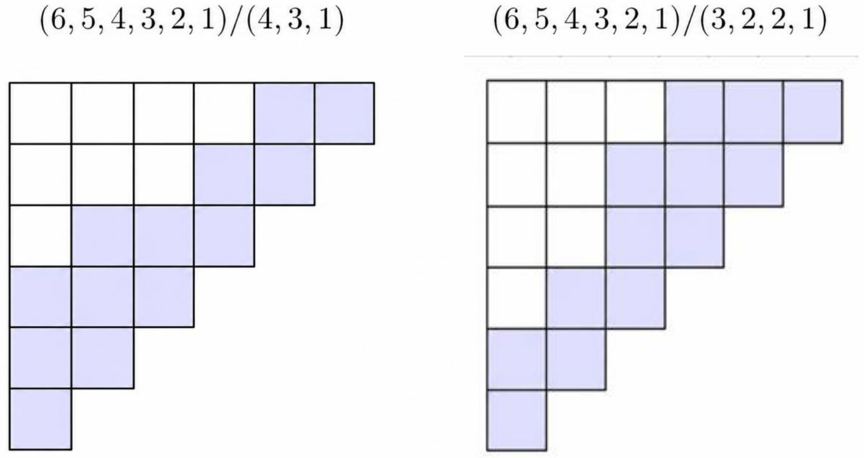
Skew Schur functions



Open Problem: *Characterize all coincidences* $s_{\lambda/\mu} = s_{\alpha/\beta}$

Example: [Stembridge'04] $s_{\rho_k/\mu} = s_{\rho_k/\mu'}$ where $\rho_k = (k, k-1, \ldots, 1)$

$$c^{\rho_k}_{\mu\nu} = c^{\rho_k}_{\mu'\nu} \qquad \forall \nu$$



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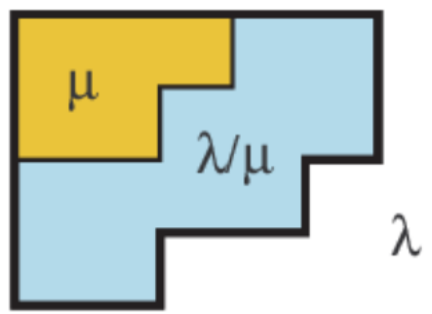

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TOWARDS A COMBINATORIAL CLASSIFICATION OF SKEW SCHUR FUNCTIONS

PETER R. W. MCNAMARA AND STEPHANIE VAN WILLIGENBURG

Thank you!