Vanishing Signatures, Orbit Closure, and the Converse of the Holant Theorem

Jin-Yi Cai and **Ben Young**

University of Wisconsin-Madison

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Motivating example: trace indistinguishability

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- Goal: generalize to higher-arity tensors.

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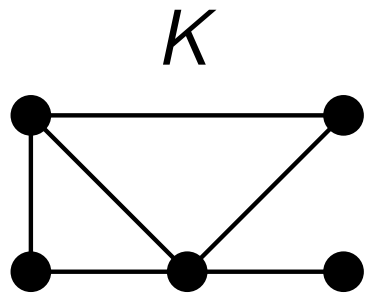

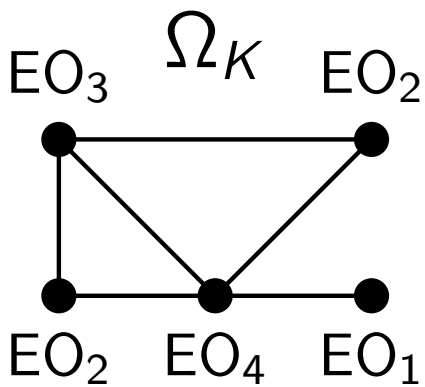

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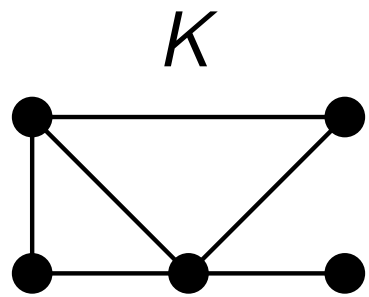

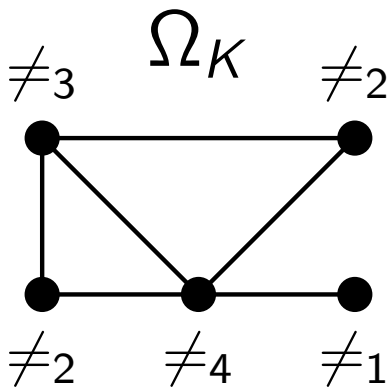

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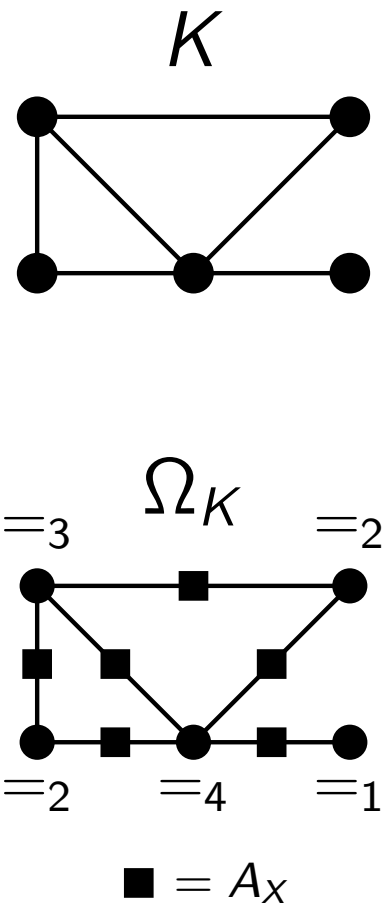

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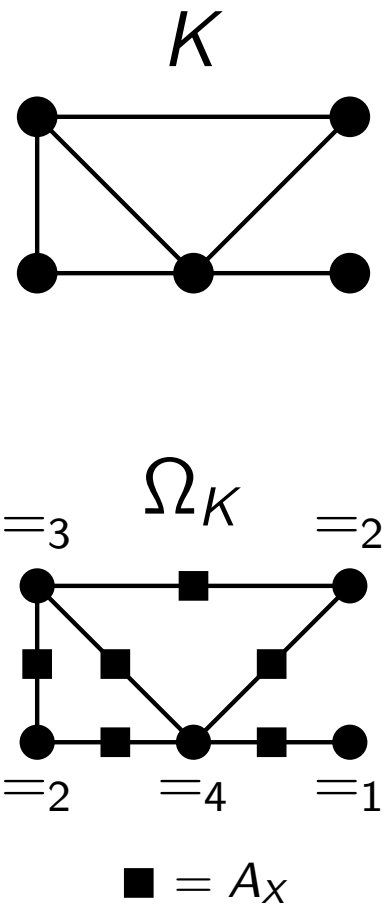

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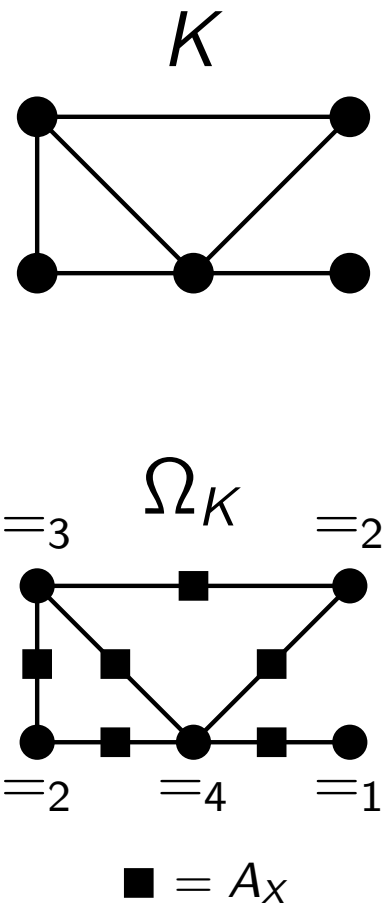

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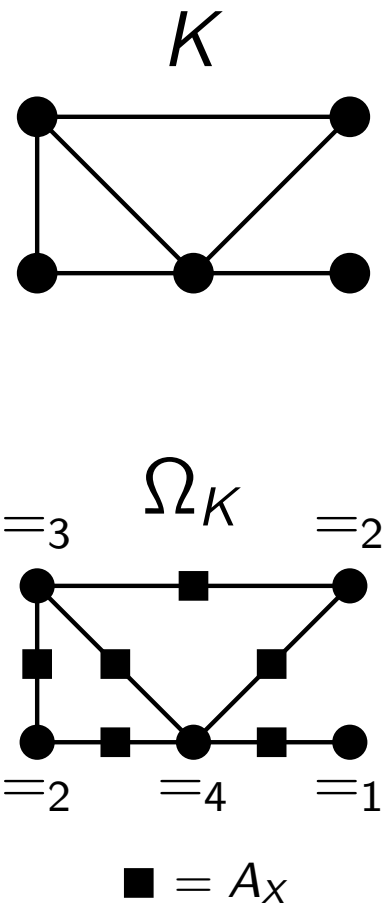

Bipartite Holant and Signature Transformations

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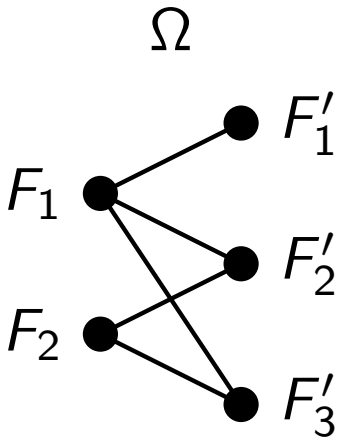

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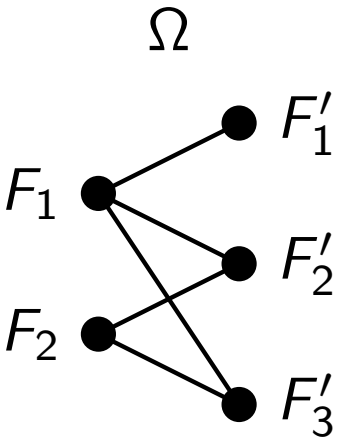

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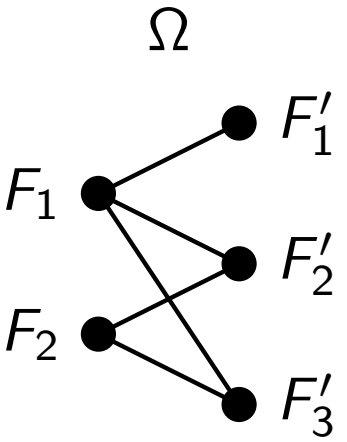

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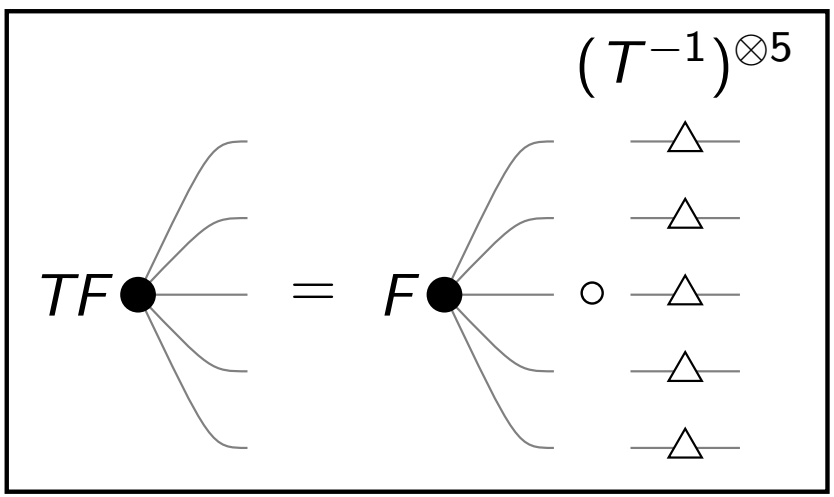

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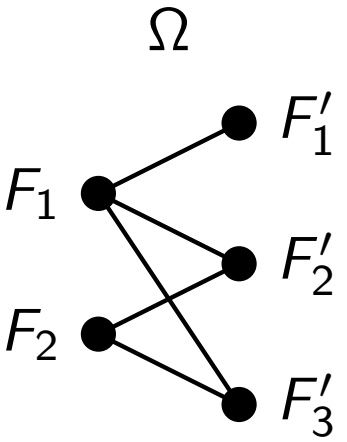

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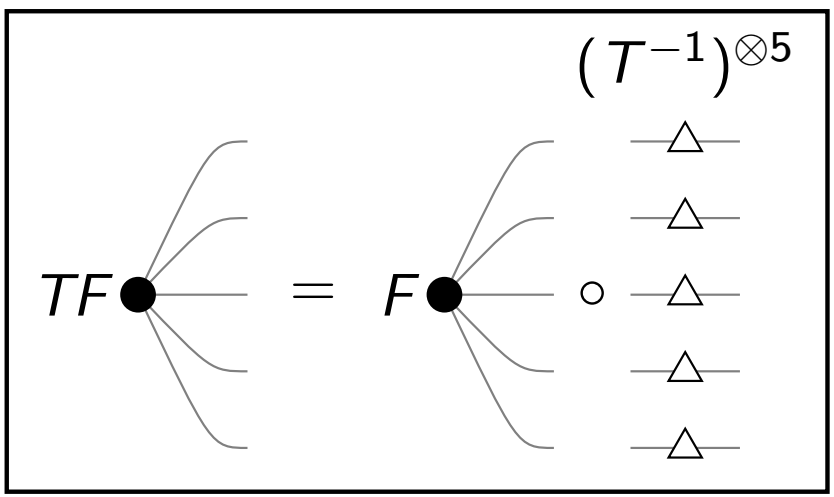

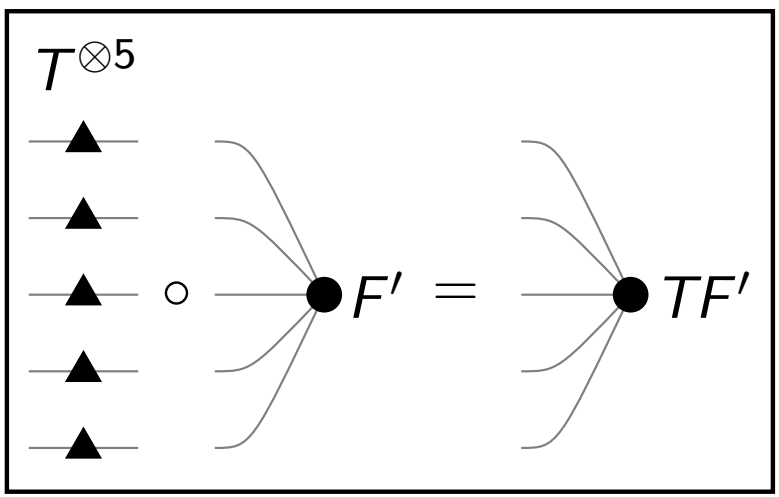

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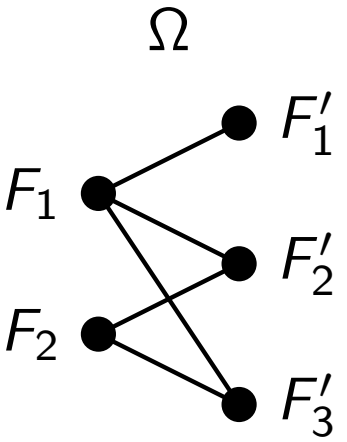

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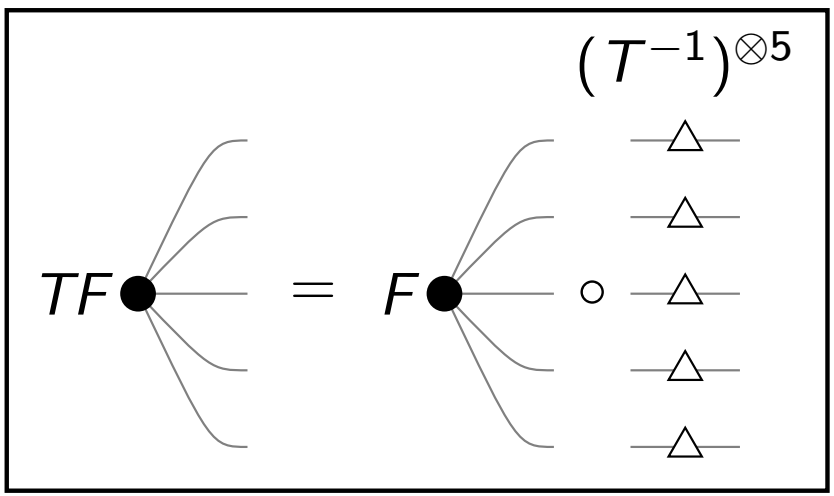

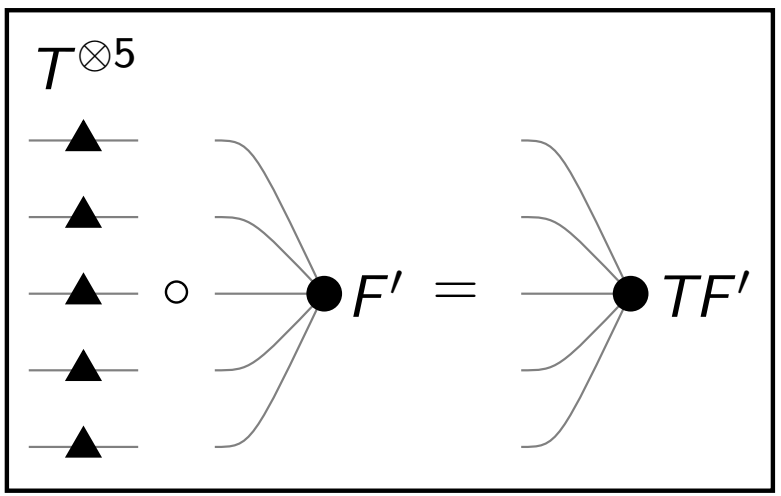

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If $\mathcal{F} \mid \mathcal{F}' = T(\mathcal{G} \mid \mathcal{G}')$, *then* $\mathcal{F} \mid \mathcal{F}'$ *and* $\mathcal{G} \mid \mathcal{G}'$ *are* **Holant-indistinguishable**.

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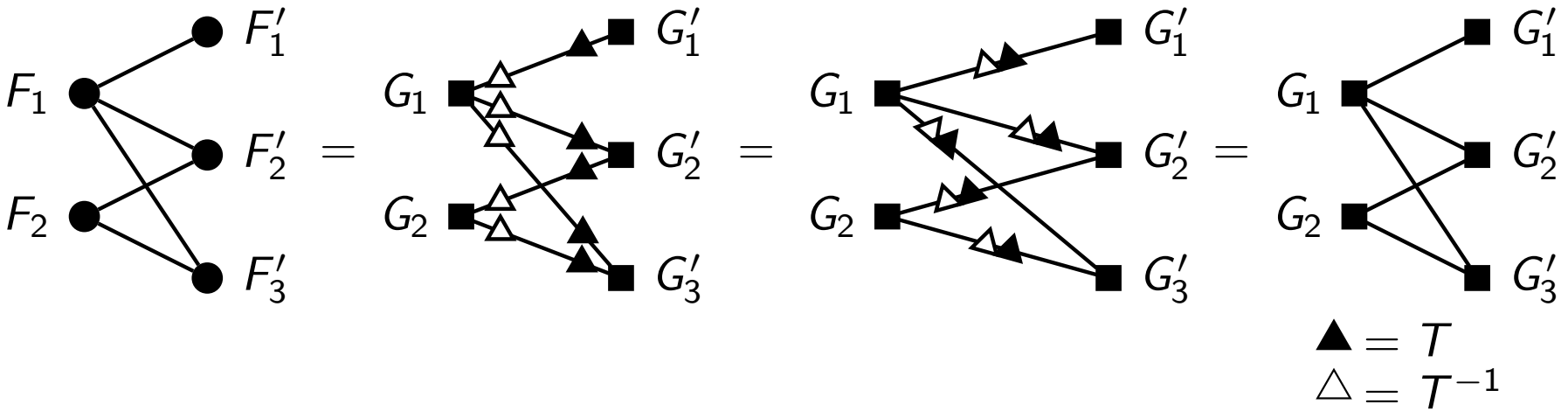

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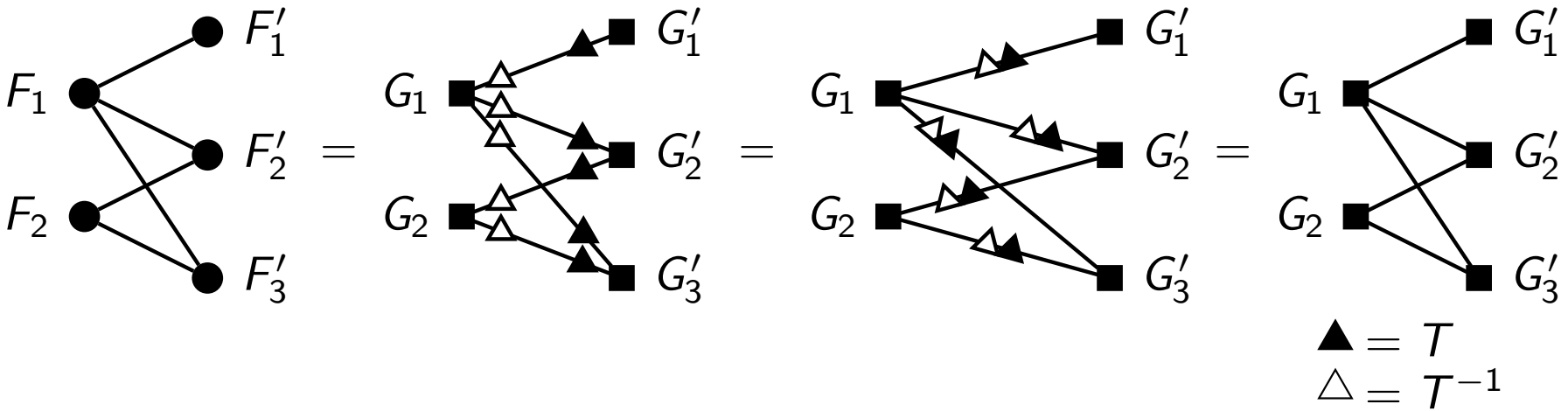

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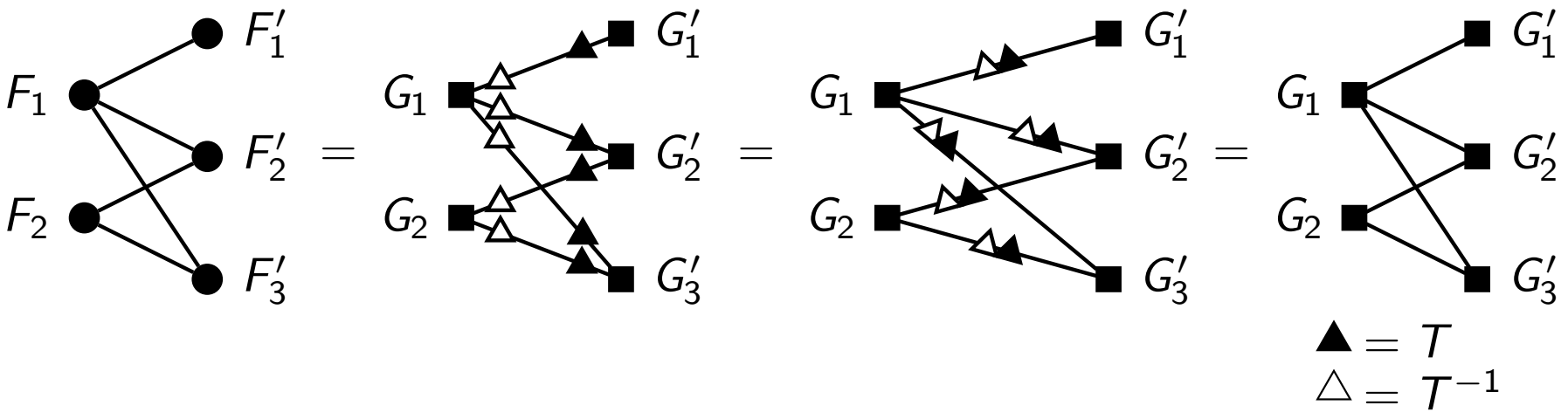

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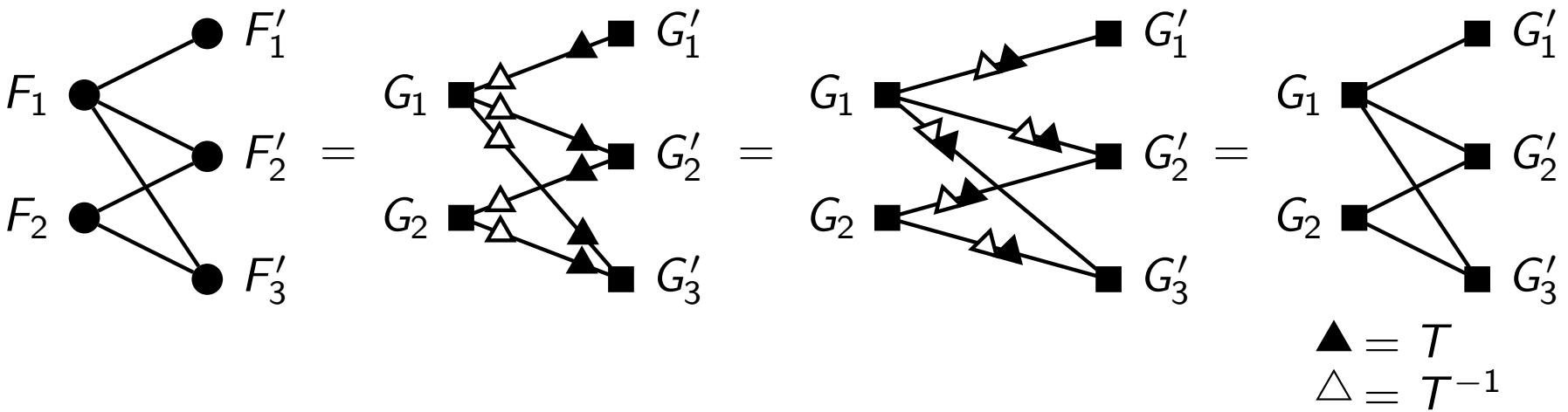

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- We prove two near-converses.

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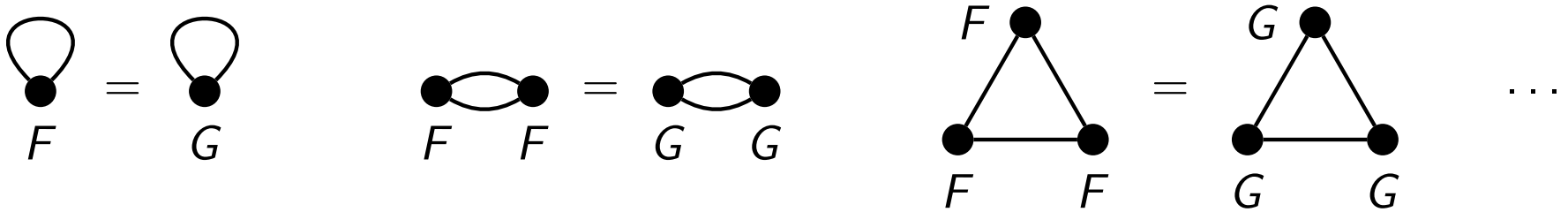

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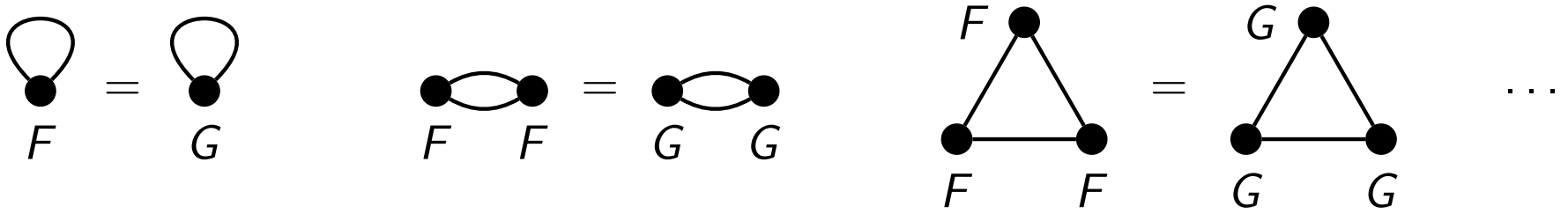

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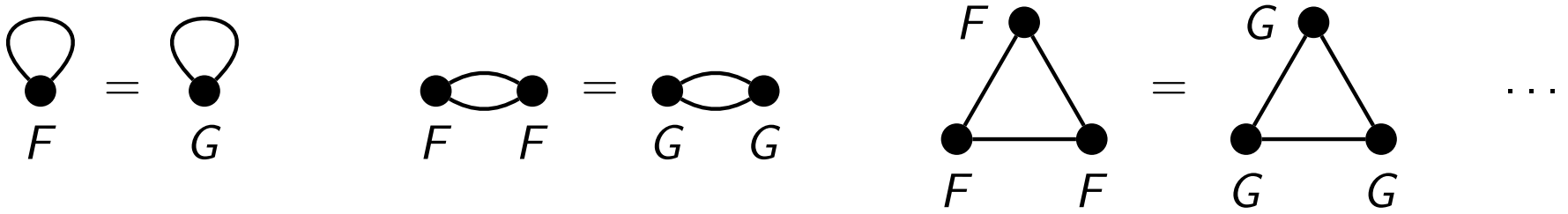

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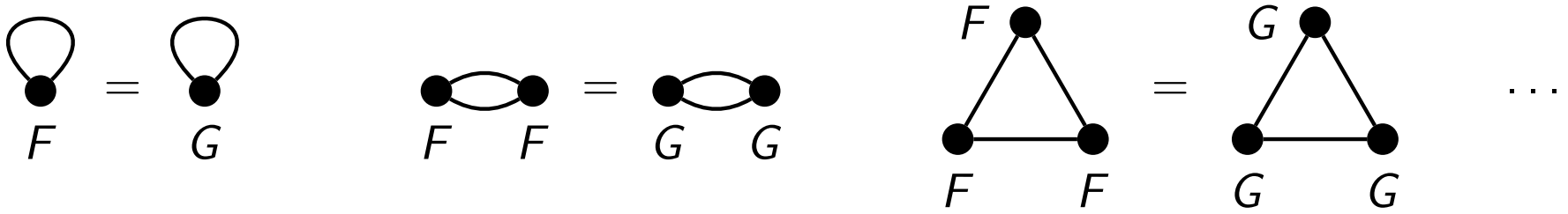

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- Connections to geometric complexity theory (border rank and matrix multiplication) [BI11].

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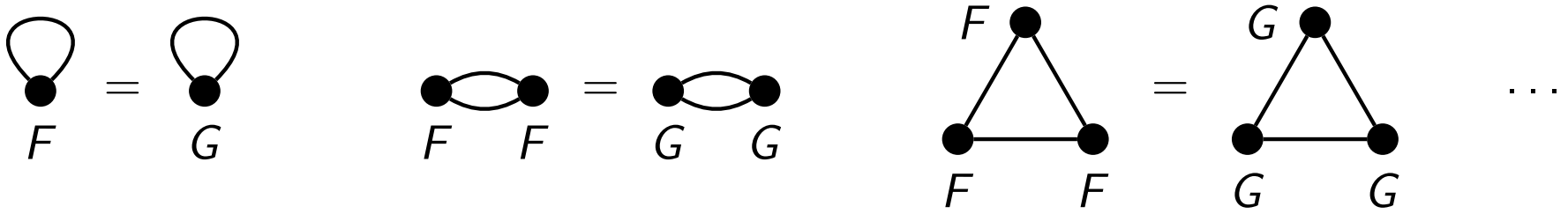

Theorem (The Approximate Converse)

$\mathcal{F} \mid \mathcal{F}'$ and $\mathcal{G} \mid \mathcal{G}'$ are Holant-indistinguishable iff their GL_q-orbit closures intersect.

- Complexity of orbit closure intersection has seen much study recently.
- Connections to geometric complexity theory (border rank and matrix multiplication) [BI11].
- Lysikov and Walter [LW24] define complexity class **TOCI**.

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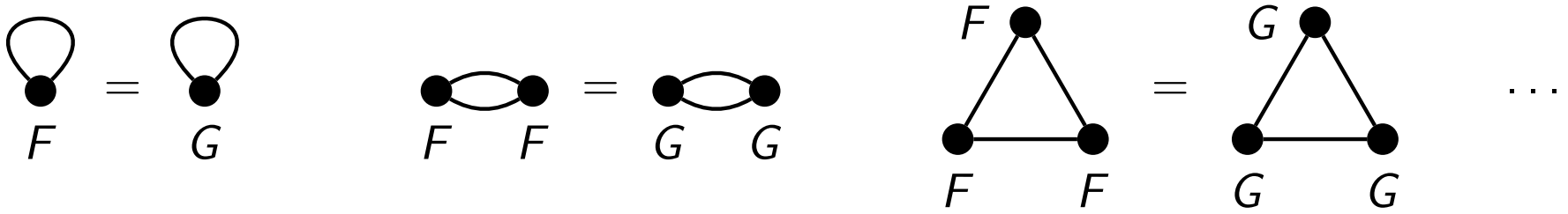

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- Also previous connections with tensor network theory [AMN$^+$23].

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Corollary

X and Y are homomorphism-indistinguishable over graphs of degree $\leq d$ iff the GL_q-orbit closures of $A_X|\{=_n\}_{n\leq d}$ and $A_Y|\{=_n\}_{n\leq d}$ intersect.

The Conditional Converse: Quantum Nonvanishing

- $\mathcal{F} \,|\, \mathcal{F}'$ is **quantum-nonvanishing** if the contraction bilinear form is nondegenerate.

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If $\mathcal{F} \mid \mathcal{F}'$ and $\mathcal{G} \mid \mathcal{G}'$ are Holant-indistinguishable & quantum-nonvanishing, then there is a $T \in \mathsf{GL}_q$ such that $\mathcal{F} \mid \mathcal{F}' = T(\mathcal{G} \mid \mathcal{G}')$.

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Corollary

If A_X, A_Y are invertible, then $X \cong Y$ iff X and Y are homomorphism-indistinguishable over graphs of degree ≤ 3.

Thank you!

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