Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Chair for
INFORMATICS I
Efficient Algorithms and
Knowledge-Based Systems

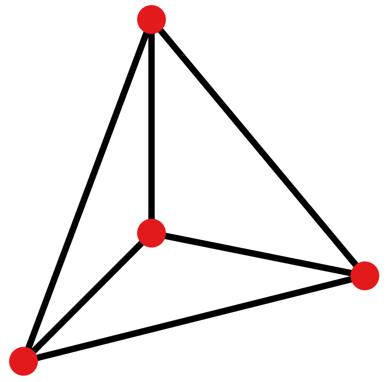
Institute for Informatics

Hypergraph Representation via Axis-Aligned Point-Subspace Cover

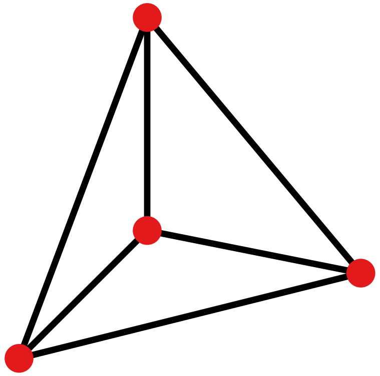
Oksana Firman Joachim Spoerhase

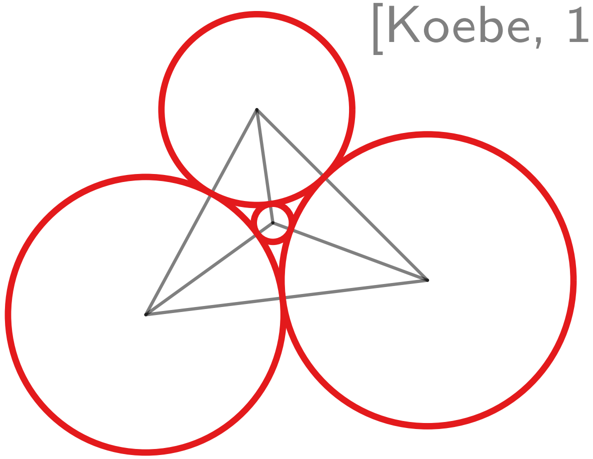
Julius-Maximilians-Universität Würzburg, Germany

Geometric Representation of (Hyper)graphs



Geometric Representation of (Hyper)graphs



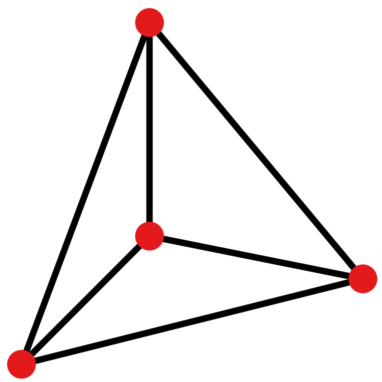


[Koebe, 1936]

contact representation

by discs

Geometric Representation of (Hyper)graphs



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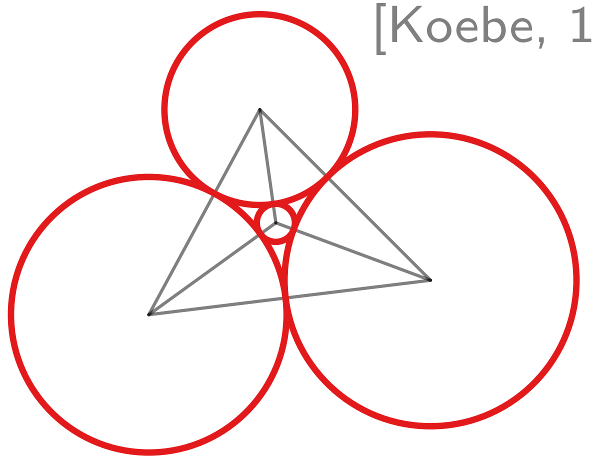

contact representation

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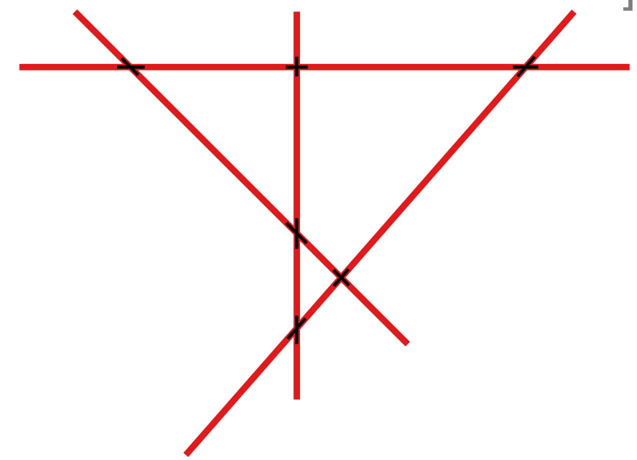
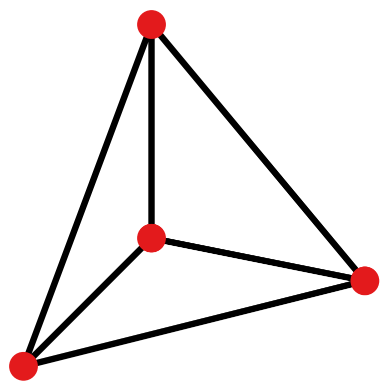
[Chalopin, Gonçalves, *STOC'09*]



intersection representation

by segments

Geometric Representation of (Hyper)graphs



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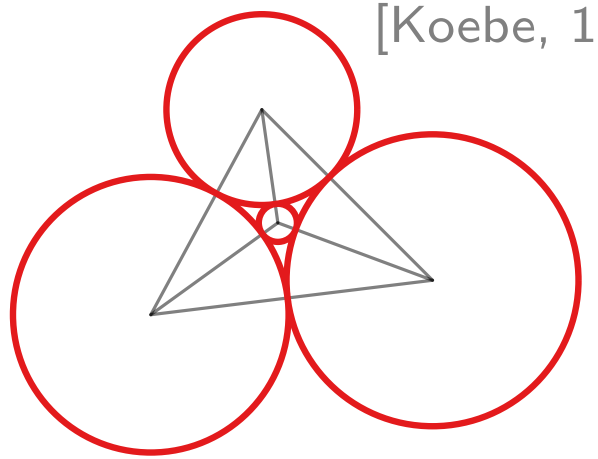

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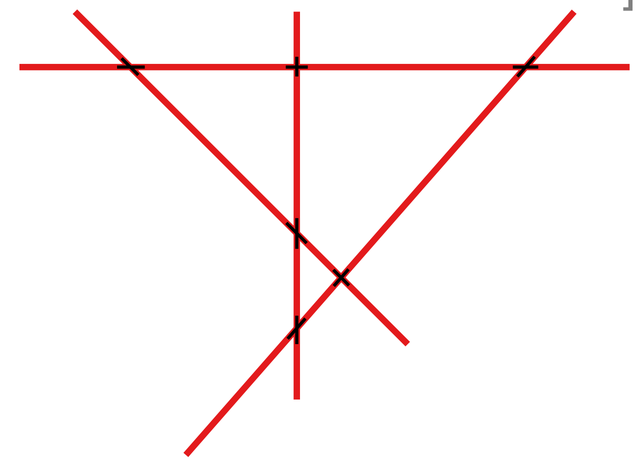

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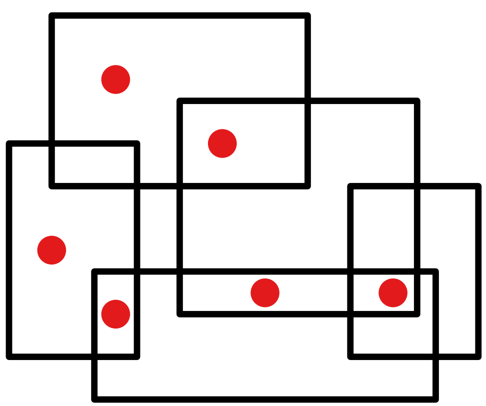
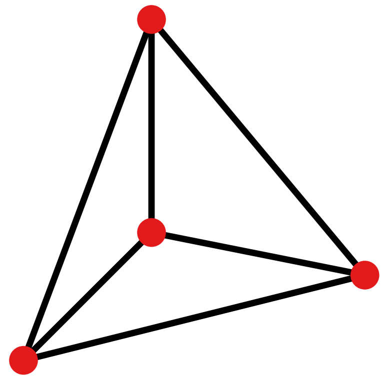
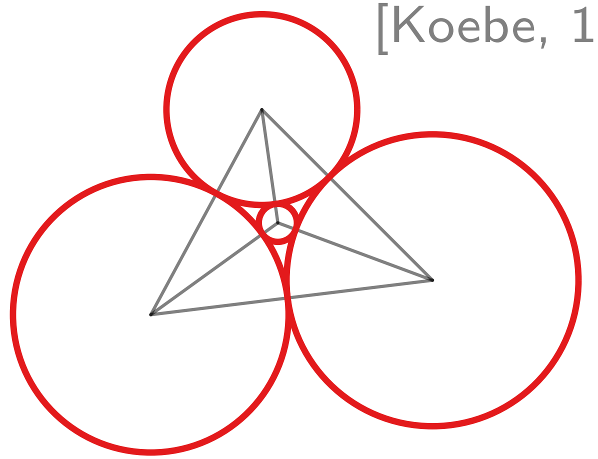


covering representation

points by rectangles

Geometric Representation of (Hyper)graphs





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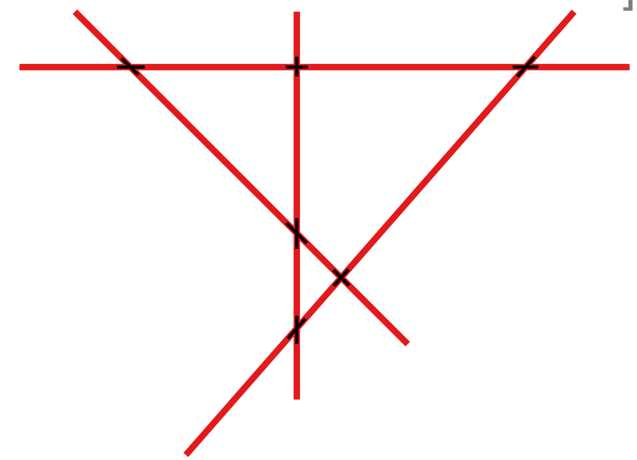

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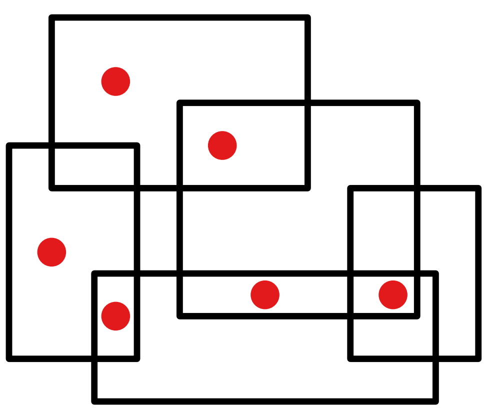

covering representation

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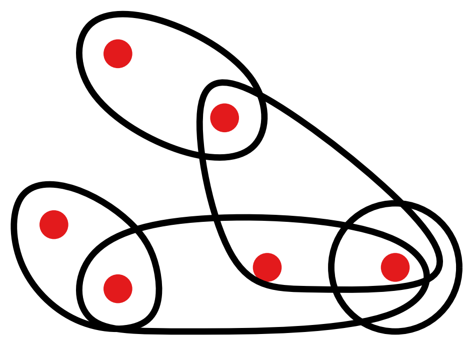
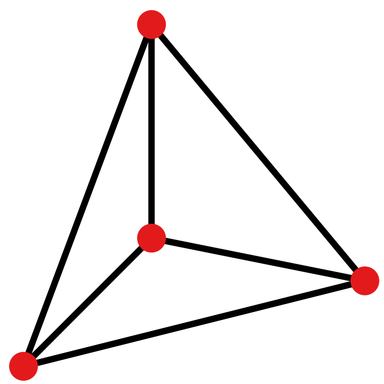


points $\longrightarrow$ vertices

covering objects $\longrightarrow$ hyperedges

Geometric Representation of (Hyper)graphs



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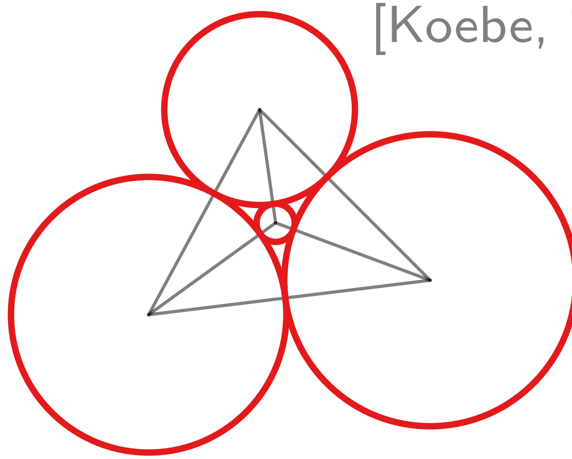

contact representation

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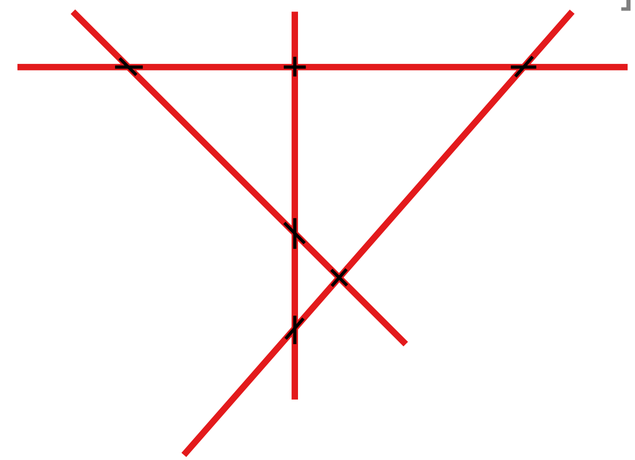
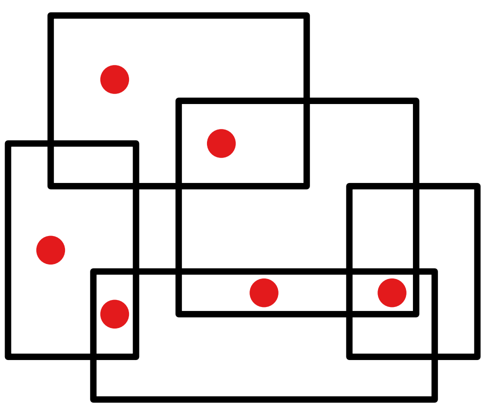
[Chalopin, Gonçalves, *STOC'09*]



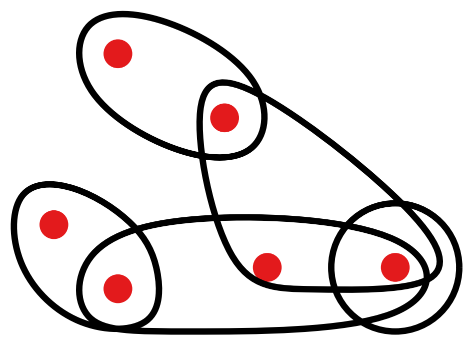
intersection representation

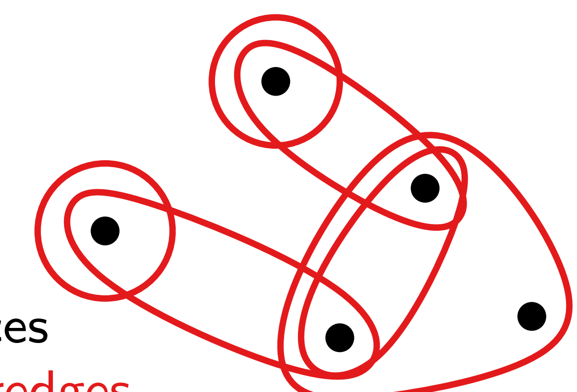
by segments



covering representation

points by rectangles

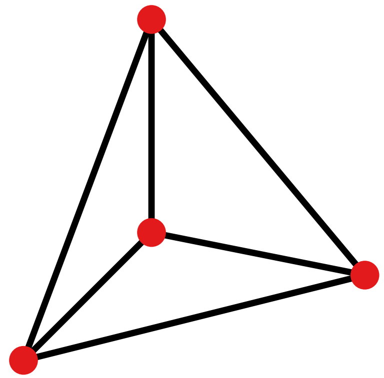


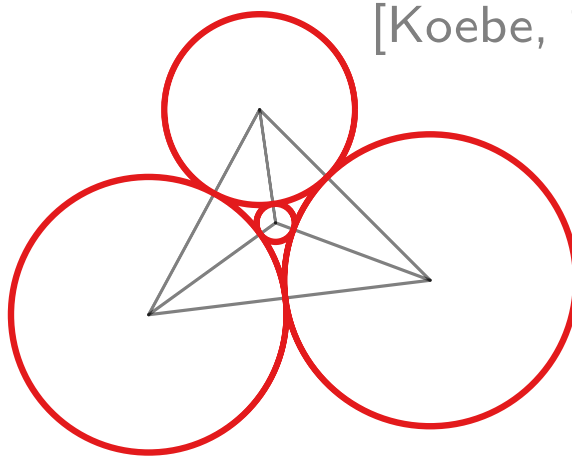


points → vertices

covering objects → hyperedges

Geometric Representation of (Hyper)graphs





[Koebe, 1936]

contact representation

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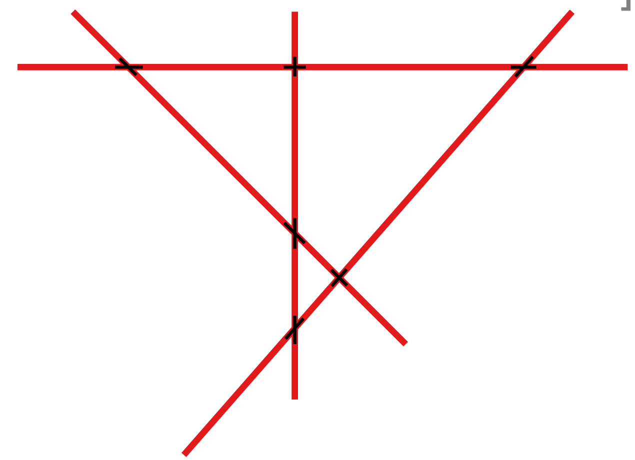
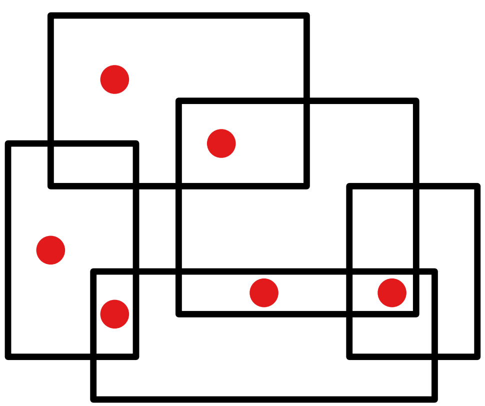
[Chalopin, Gonçalves, *STOC'09*]



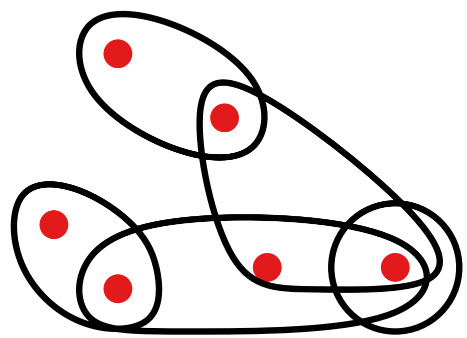
intersection representation

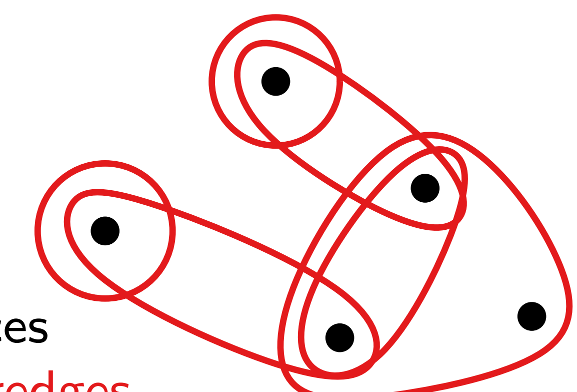
by segments



covering representation

points by rectangles



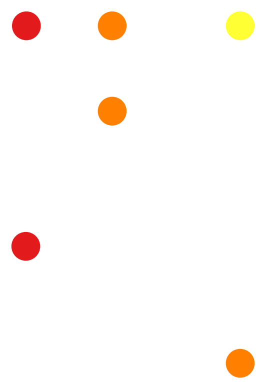


points ⇄ vertices

covering objects ⇄ hyperedges

Point Line Cover

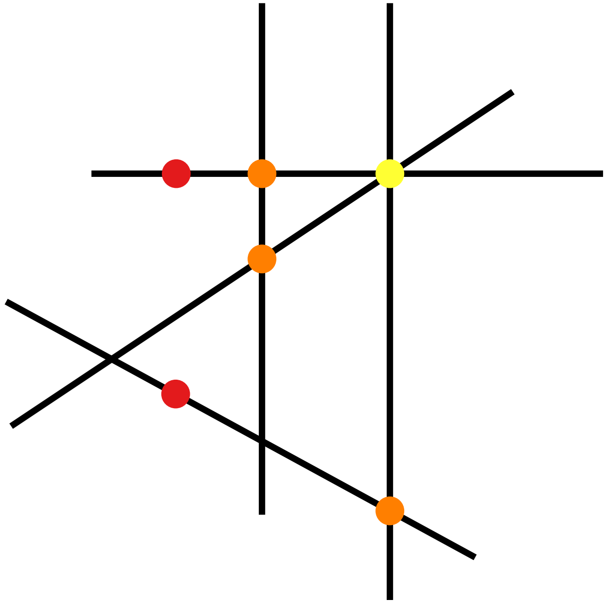
set of points P in 2D



Point Line Cover

set of points P in 2D

set of lines

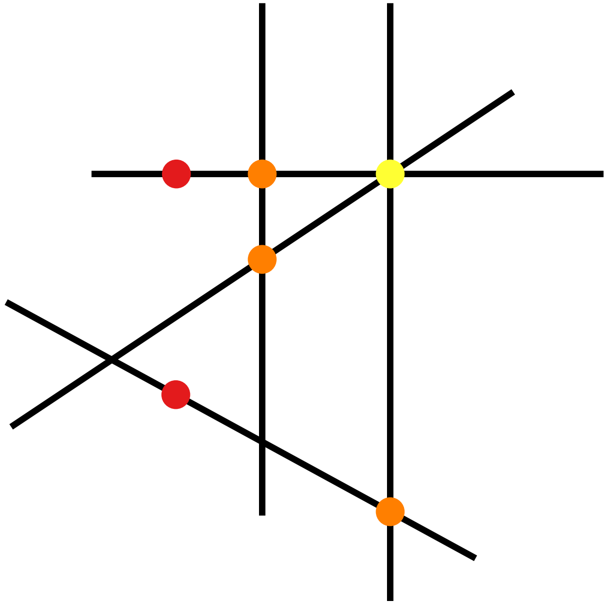


Point Line Cover

set of points P in 2D

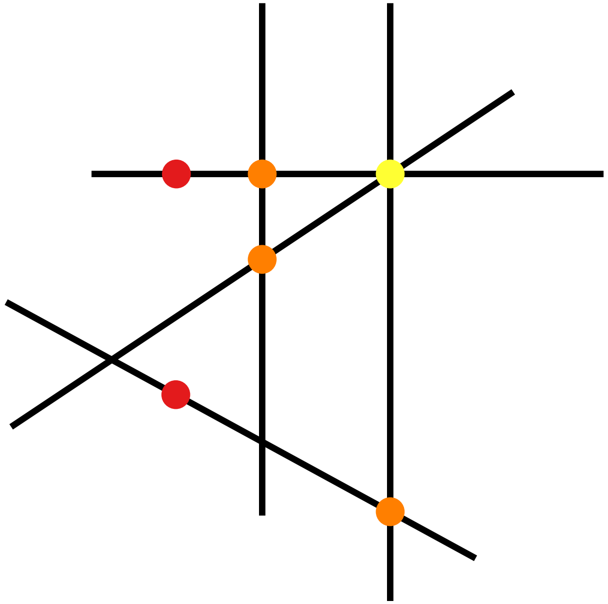
set of lines

Hypergraph representation



Point Line Cover

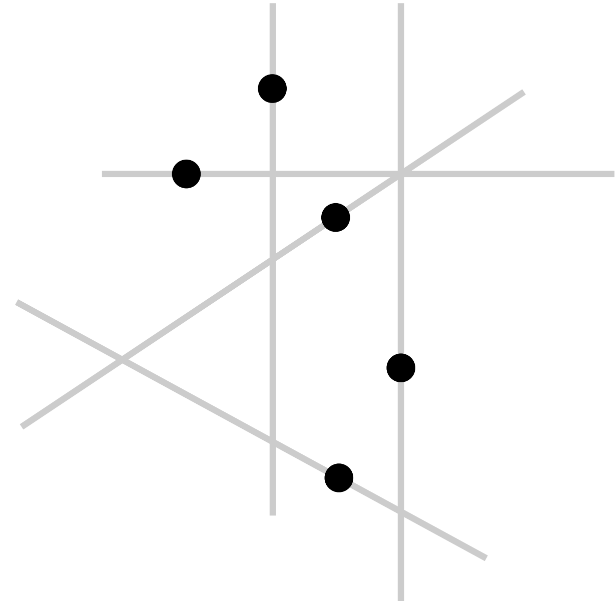
set of points P in 2D



vertices

set of lines

Hypergraph representation



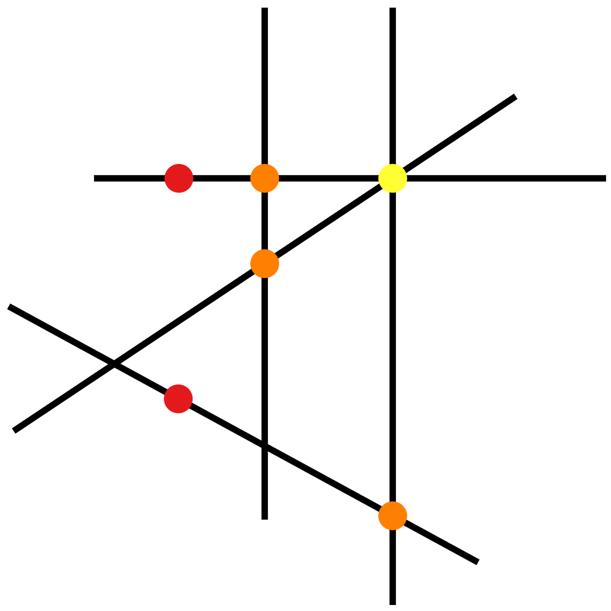
Point Line Cover

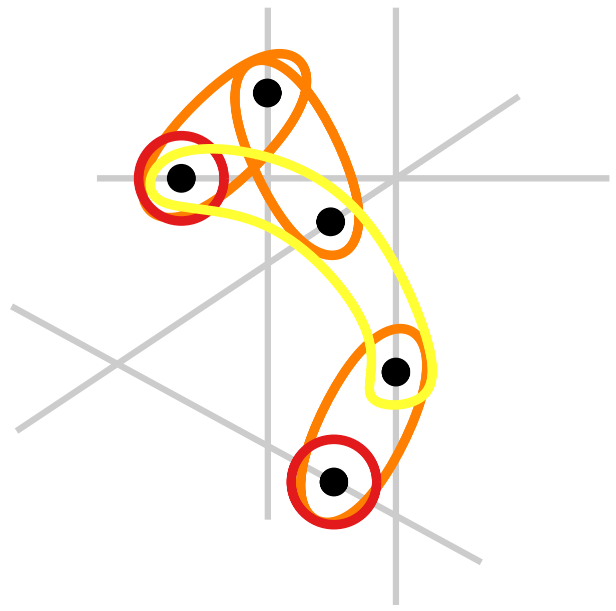
hyperedges

set of points P in 2D

set of lines

Hypergraph representation



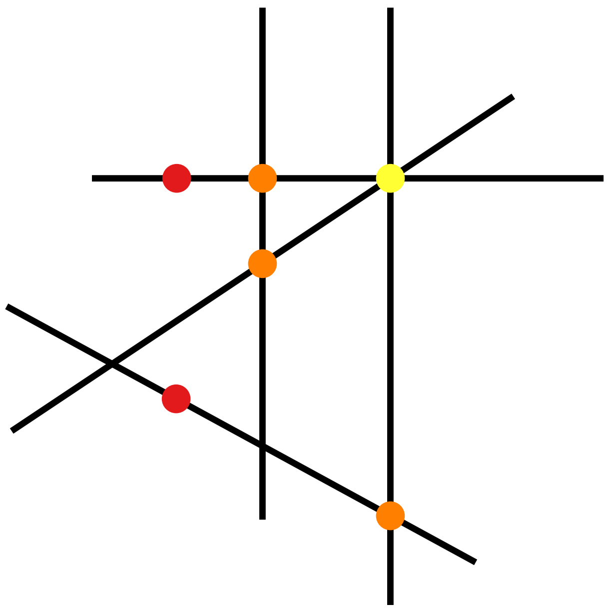


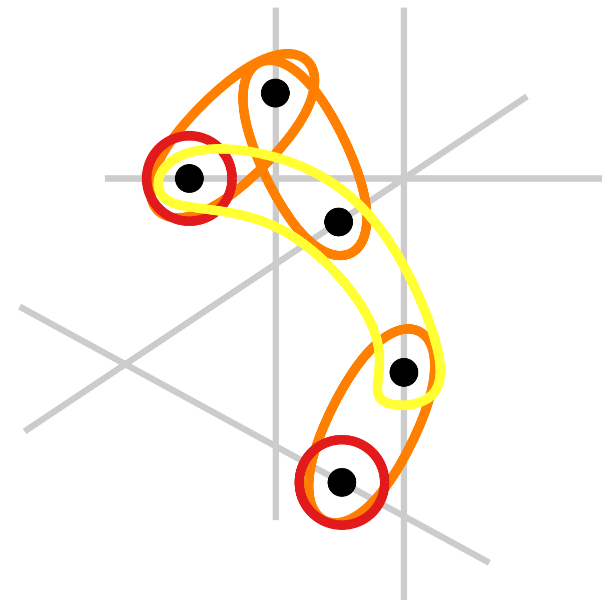
Point Line Cover – Motivation

set of points P in 2D

set of lines

Hypergraph representation





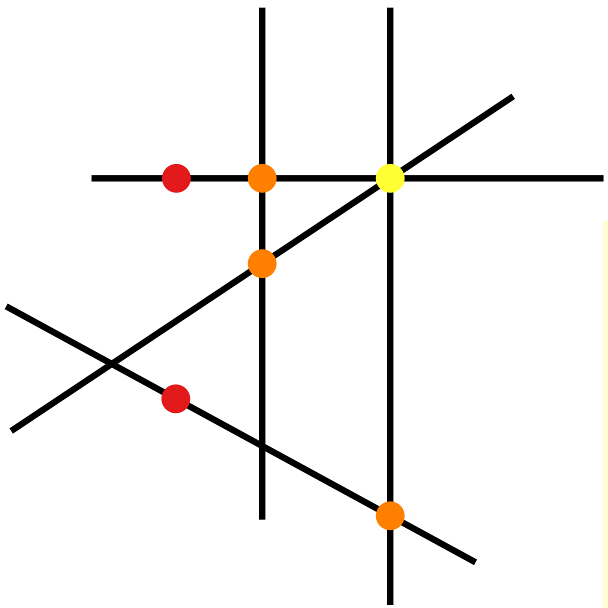
point line cover instances $\subset$ general hypergraphs

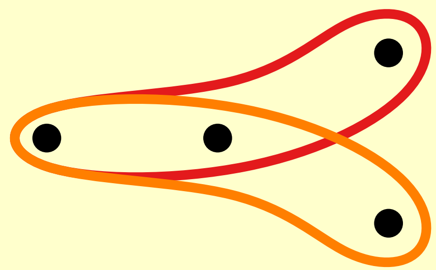
Point Line Cover – Motivation

set of points P in 2D

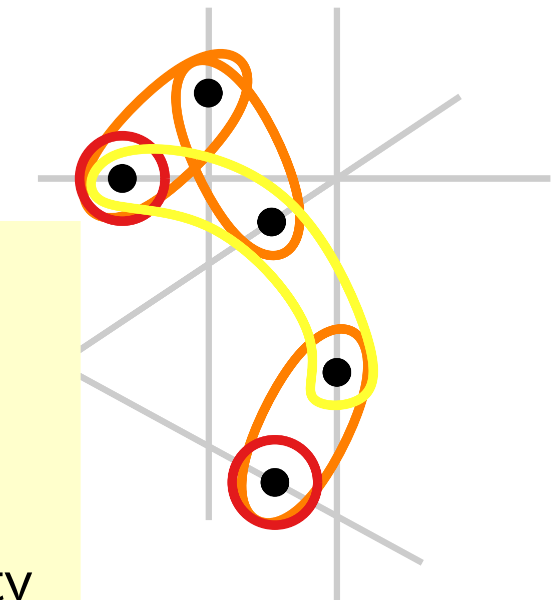
set of lines

Hypergraph representation





intersection property
does not hold



point line cover instances $\subset$ general hypergraphs

Point Line Cover – Motivation

set of points P in 2D

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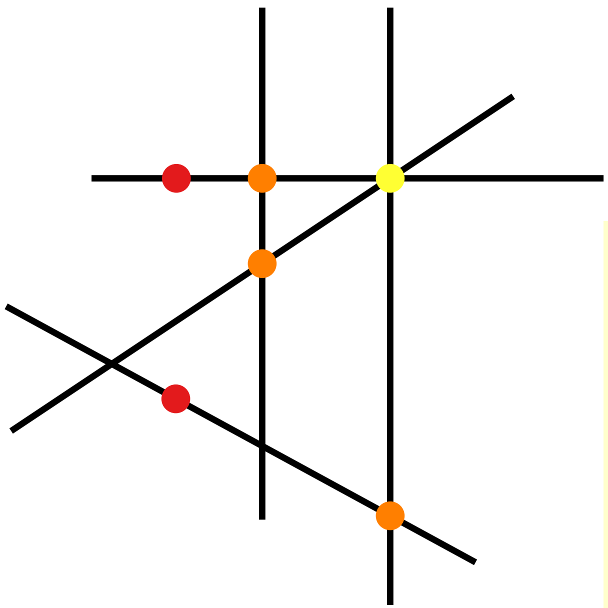
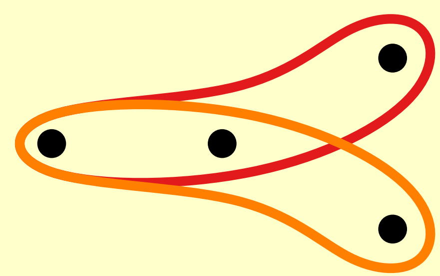
Hypergraph representation





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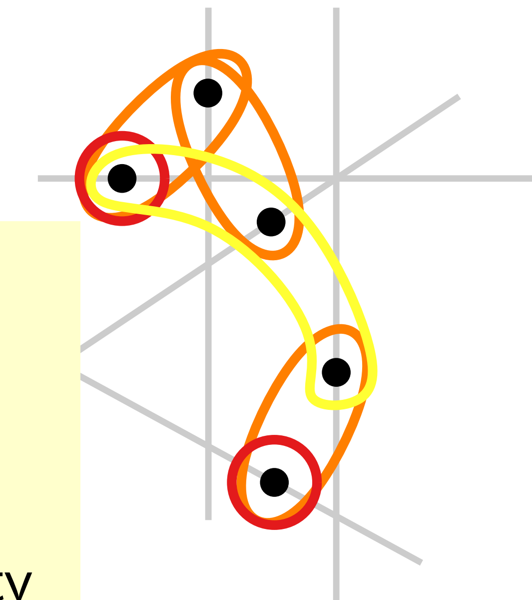
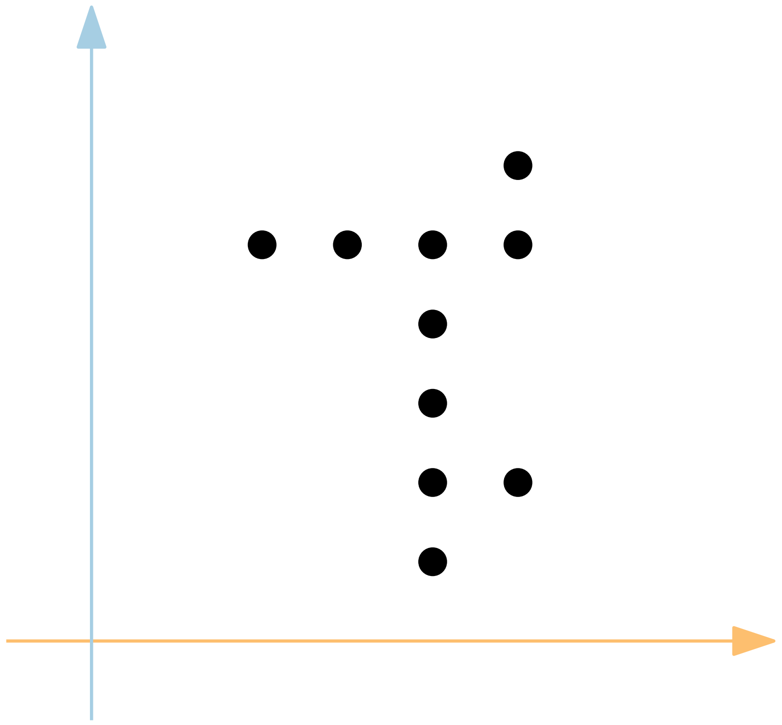


point line cover instances $\subset$ general hypergraphs

Is there a simple combinatorial characterization?

Open Q.
[Kumar, Ramesh, *ICALP* 2000]

Axis-Aligned Point Line Cover in 2D



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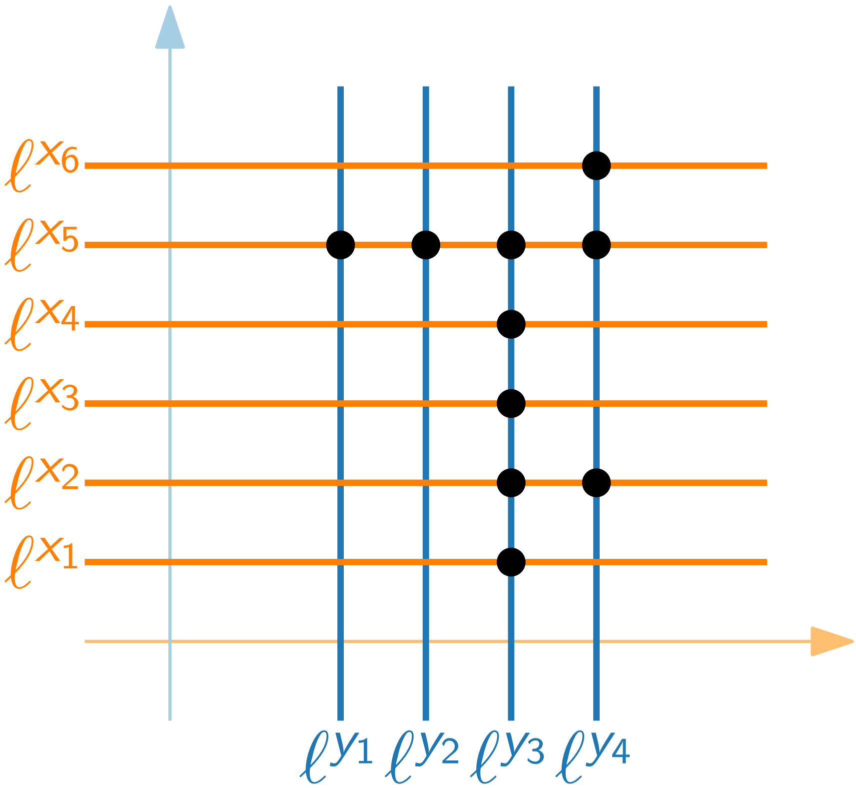

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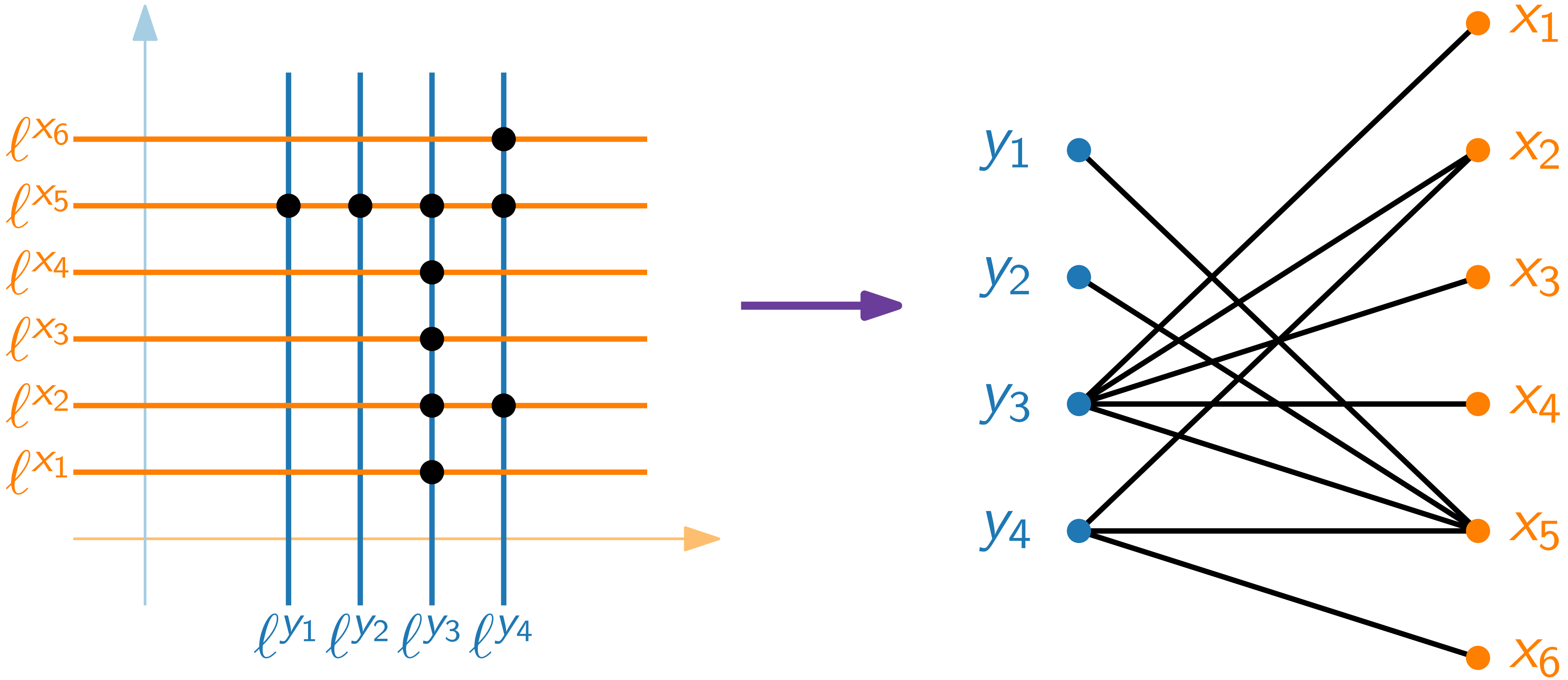

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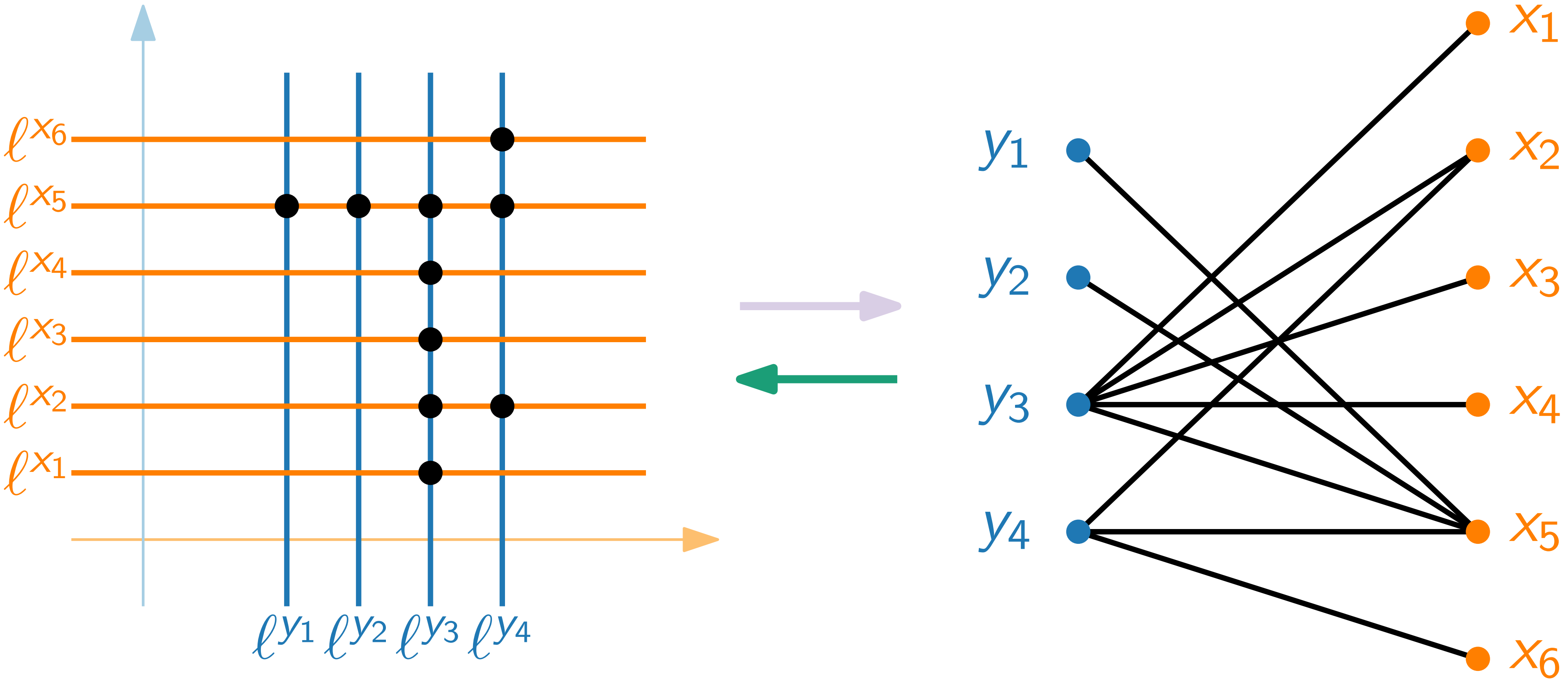

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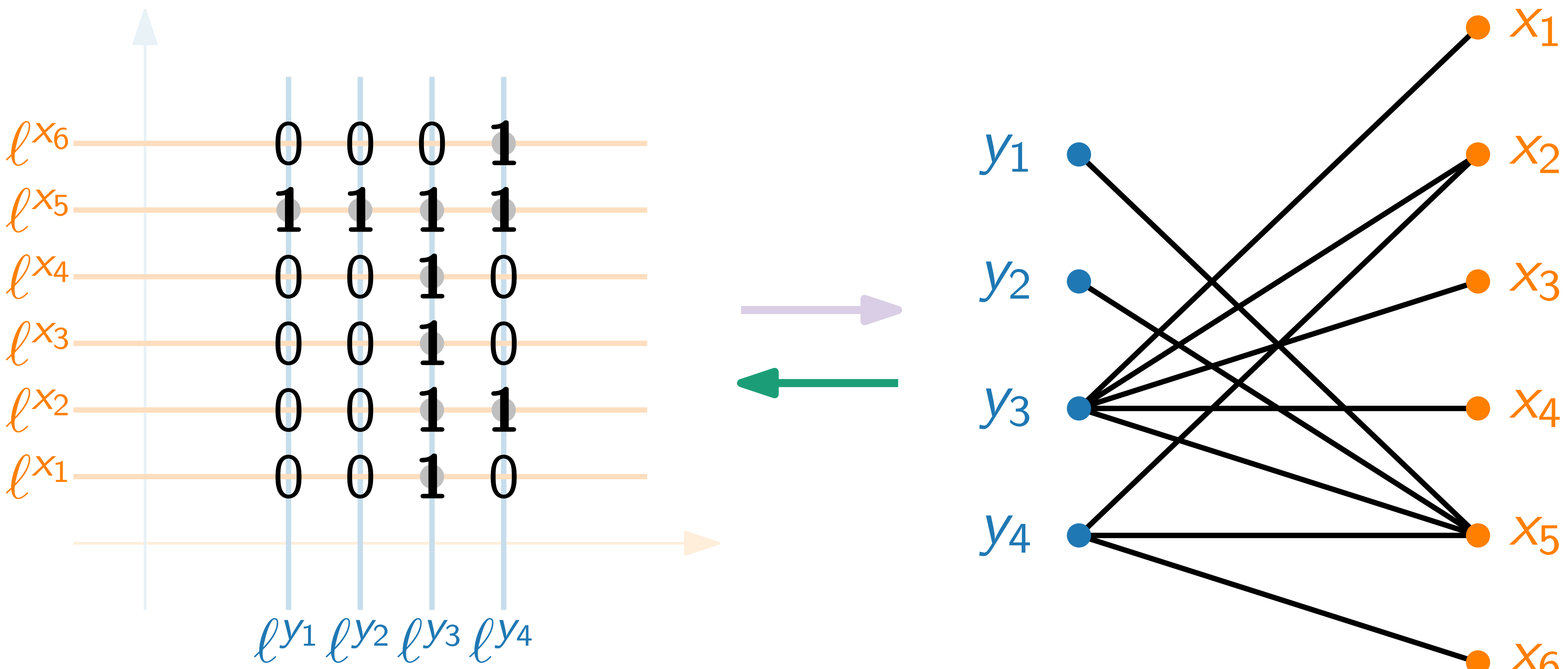
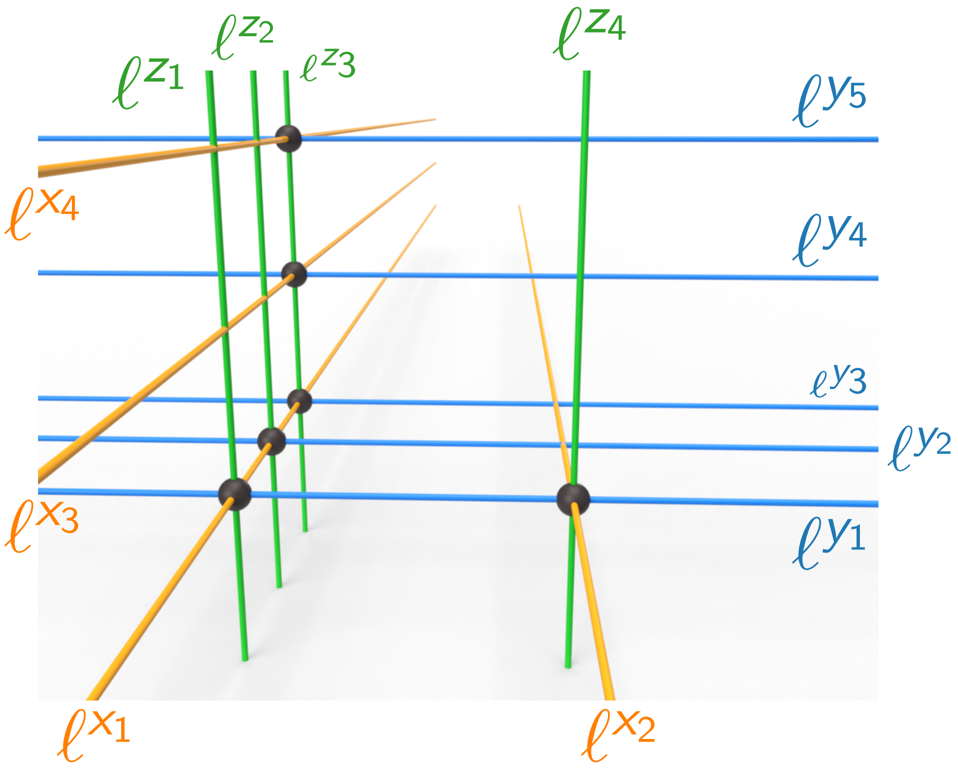
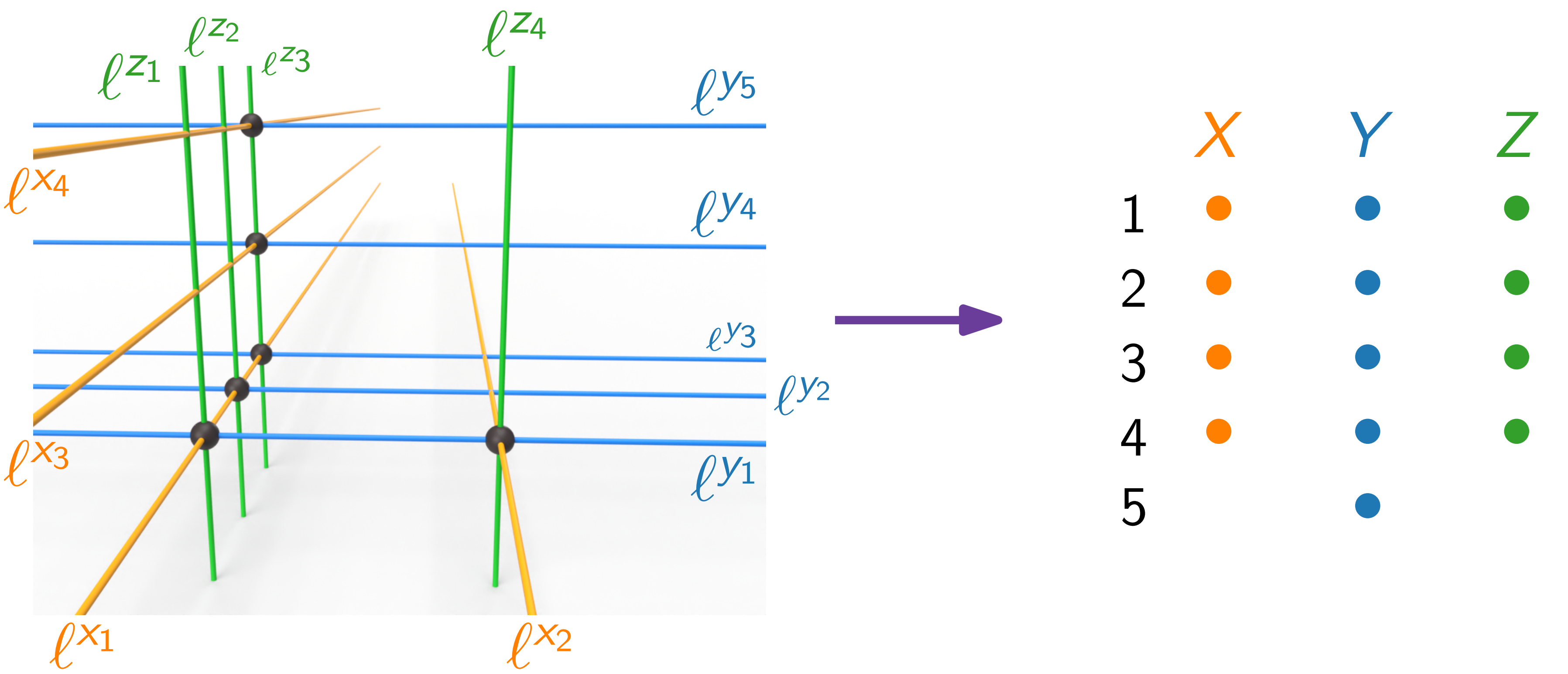


Axis-Aligned Point Line Cover in 3D



Axis-Aligned Point Line Cover in 3D



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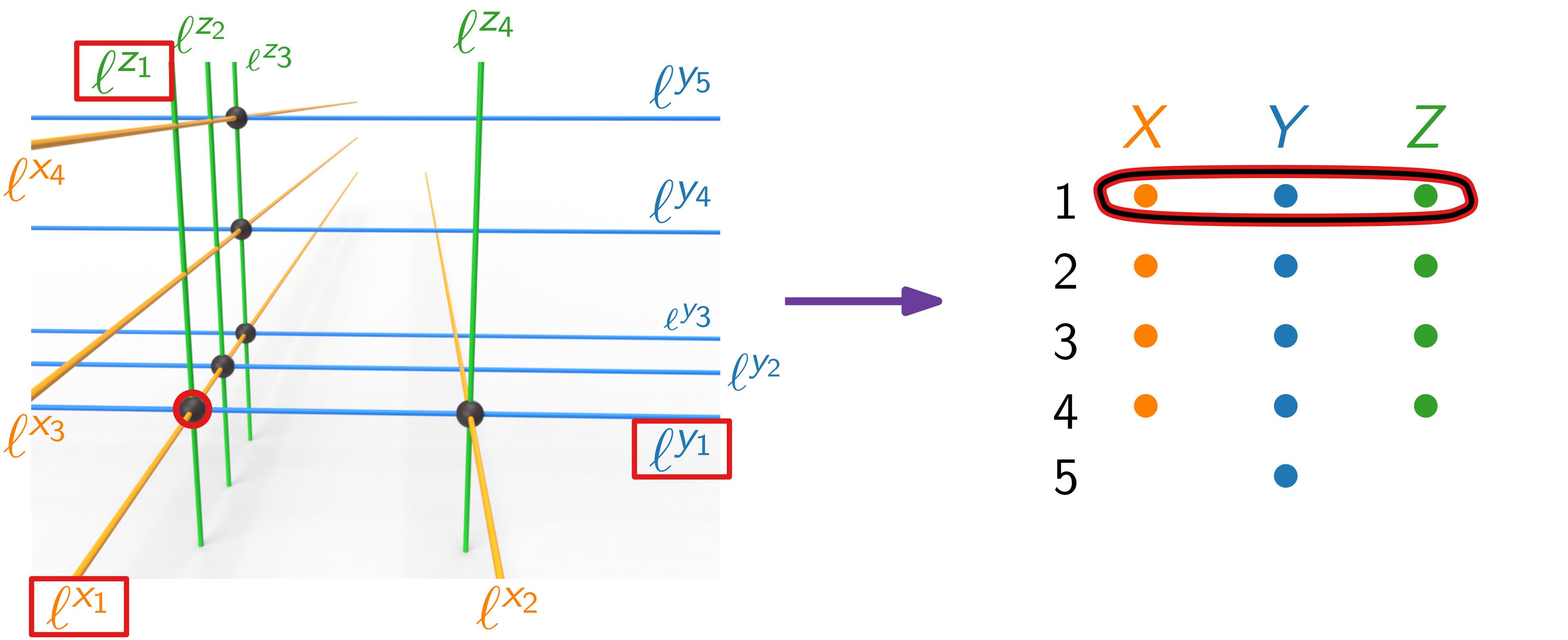

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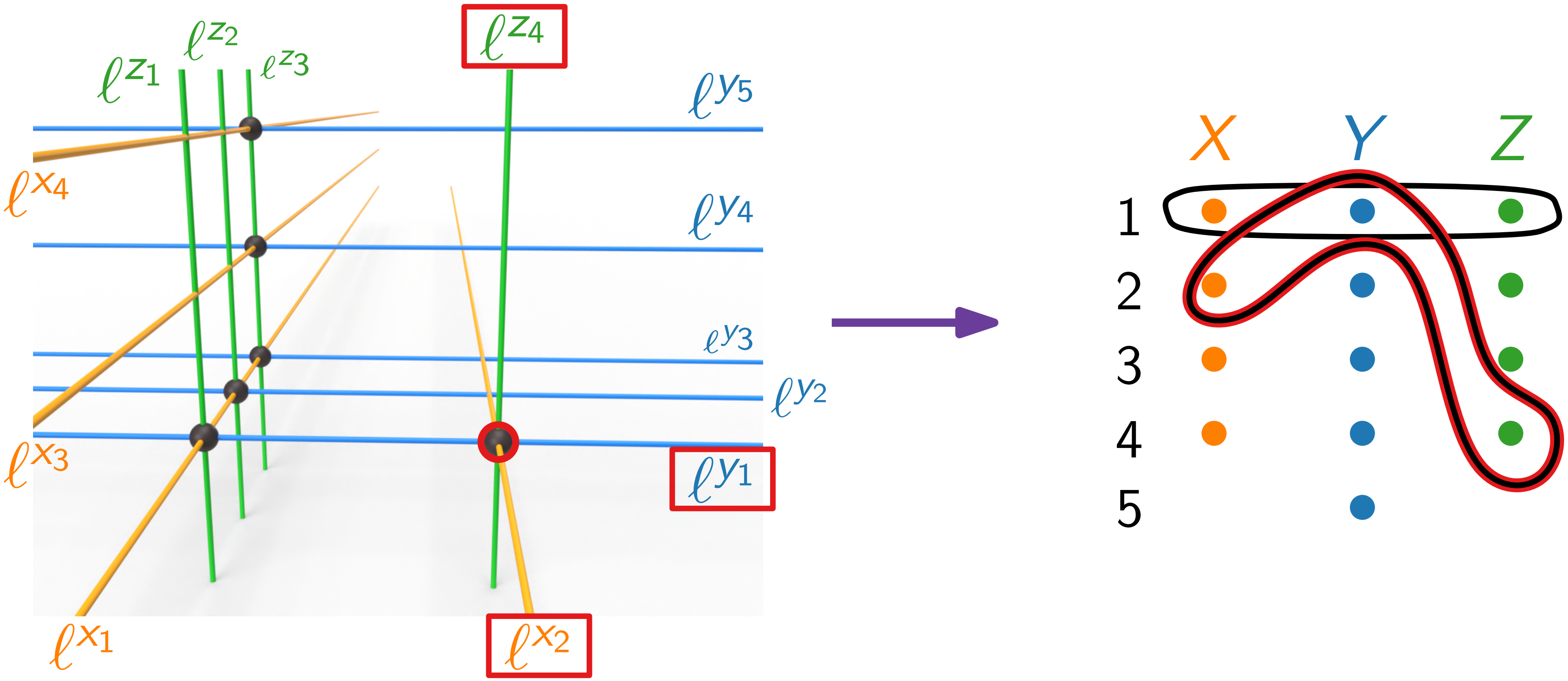
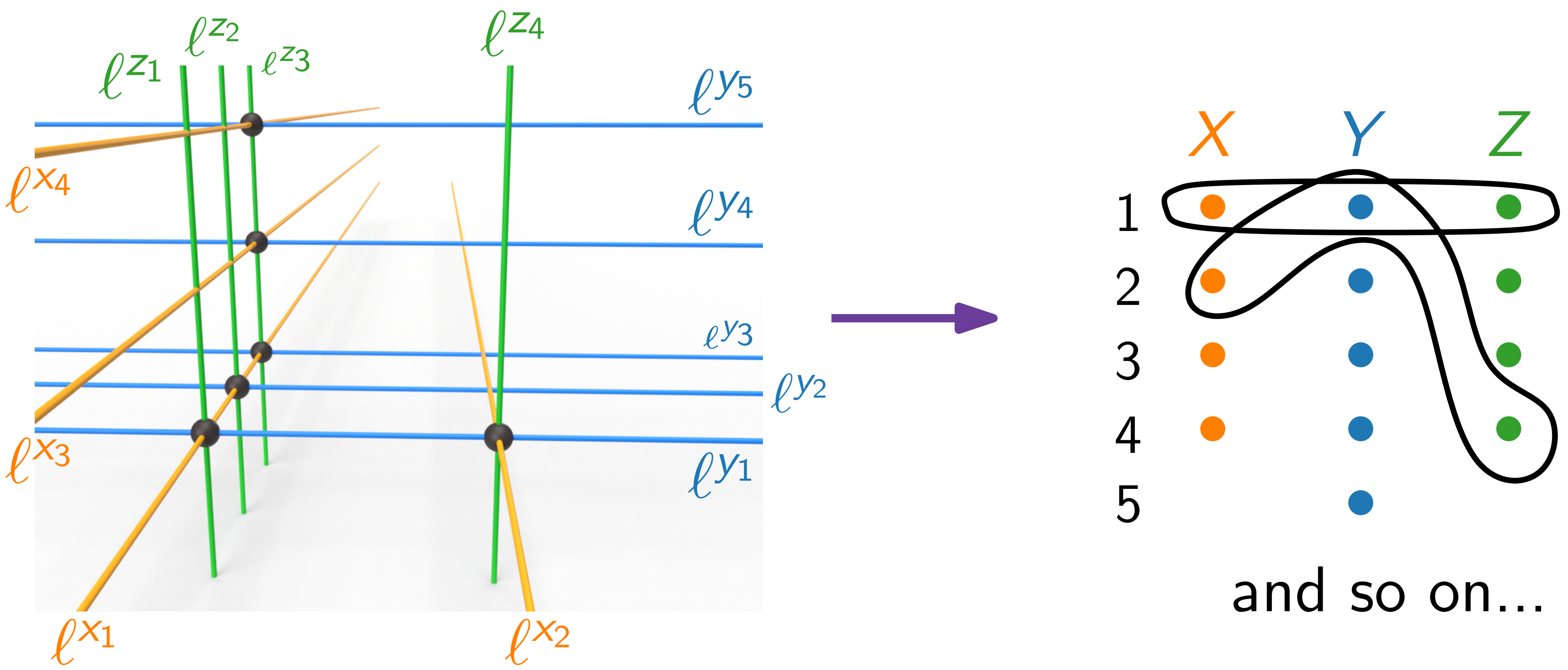


Axis-Aligned Point Line Cover in 3D



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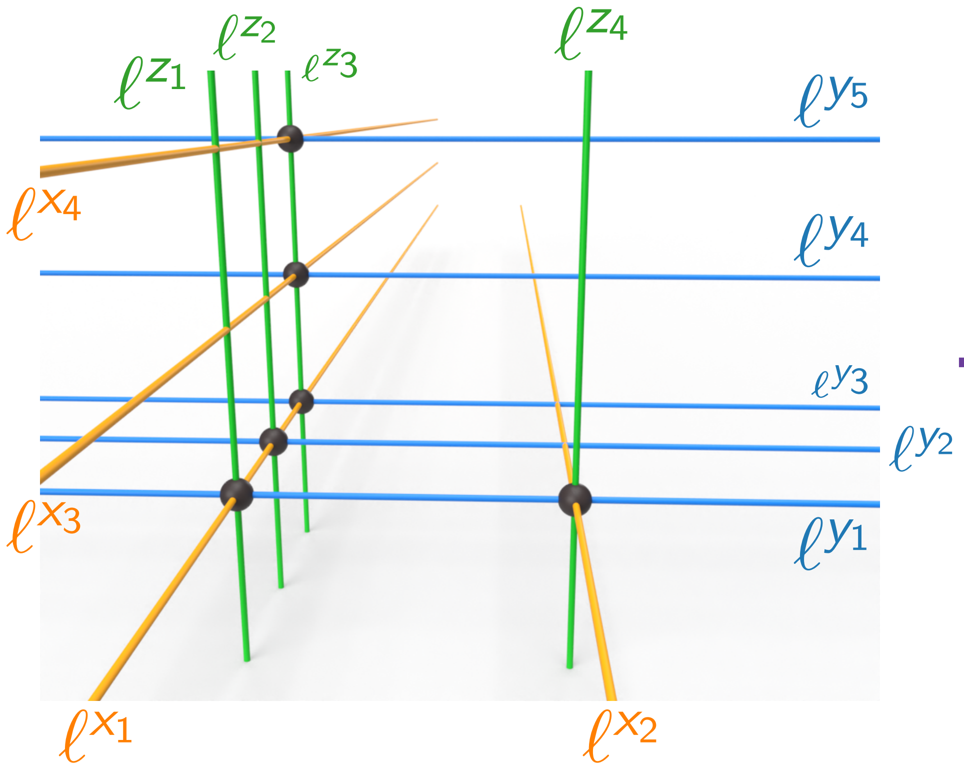
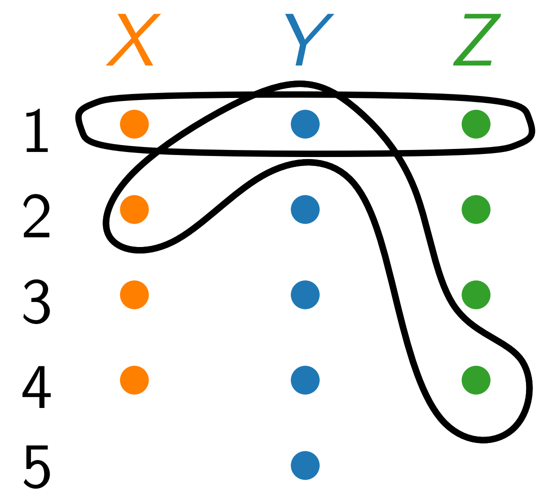




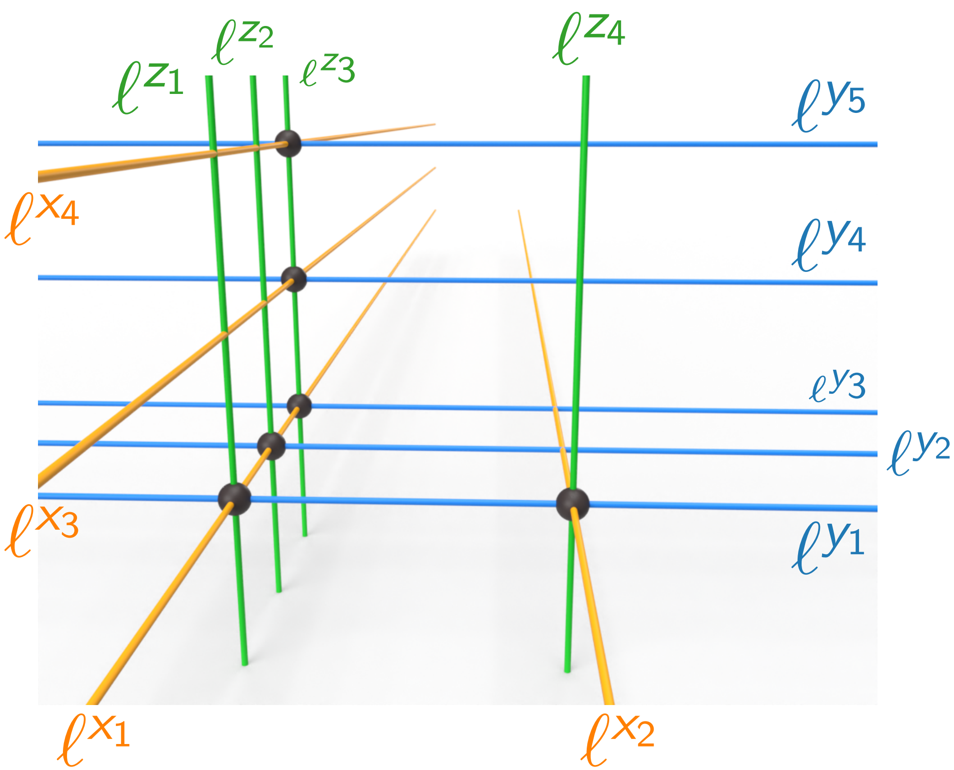
and so on...

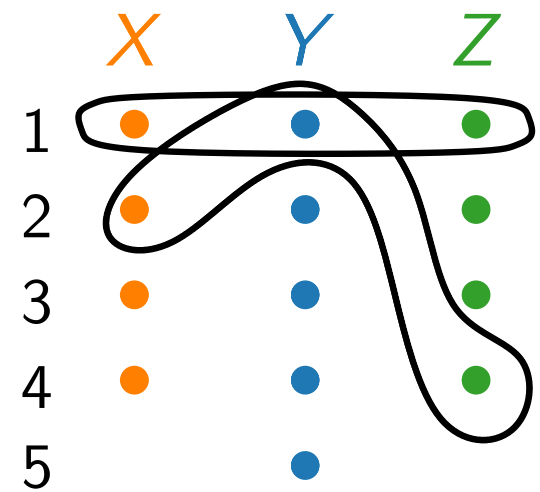
(every hyperedge has exactly 3 vertices, one from each group)

3-uniform

3-partite

Axis-Aligned Point Line Cover in 3D





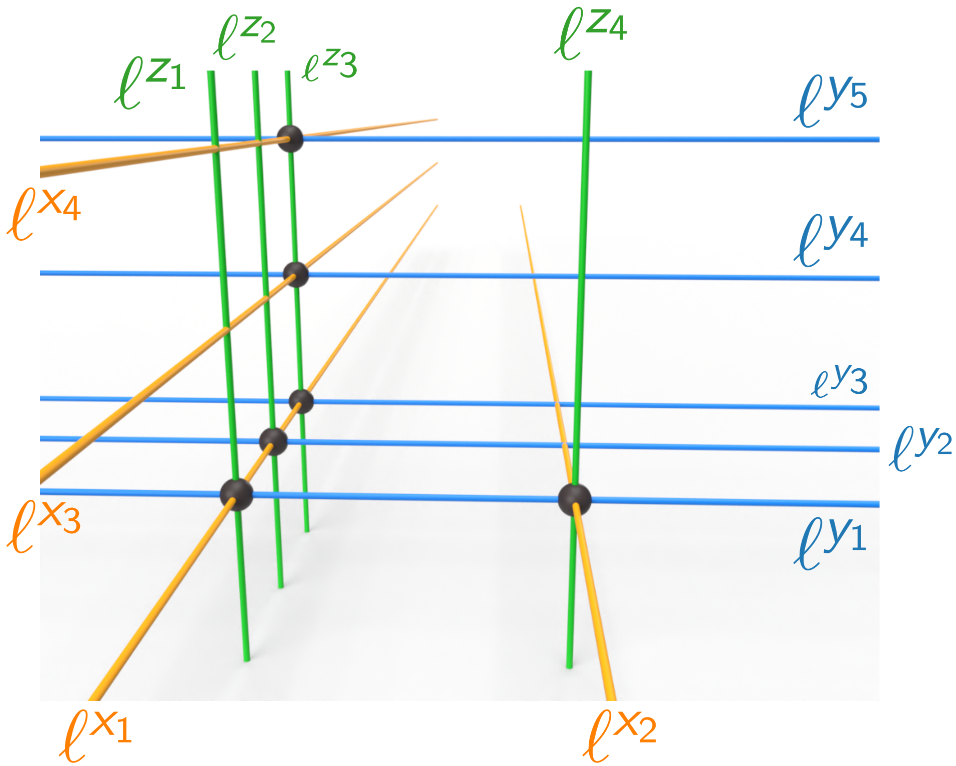
and so on...

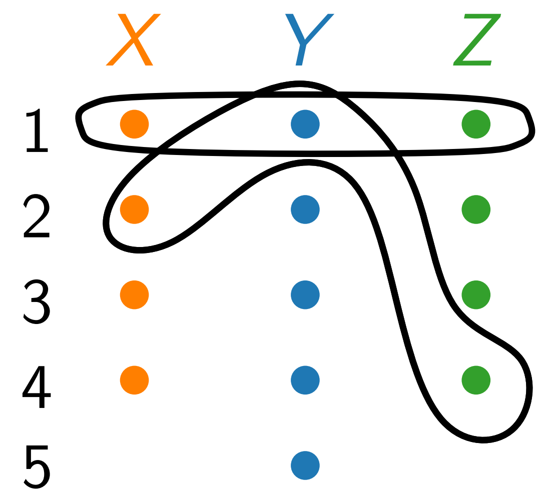
(every hyperedge has exactly 3 vertices, one from each group)

3-uniform — easy to check

3-partite — NP-hard

Axis-Aligned Point Line Cover in 3D





and so on...

(every hyperedge has exactly 3 vertices, one from each group)

3-uniform — easy to check

3-partite — NP-hard

3-hypergraph

Representable Hypergraphs

axis-aligned point line cover instance

↓

k-hypergraph

k-partite and k-uniform

Representable Hypergraphs

axis-aligned point line cover instance

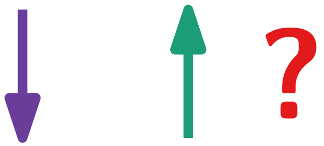
↓ ↑ ?

k-hypergraph

k-partite and k-uniform

Representable Hypergraphs

axis-aligned point line cover instance

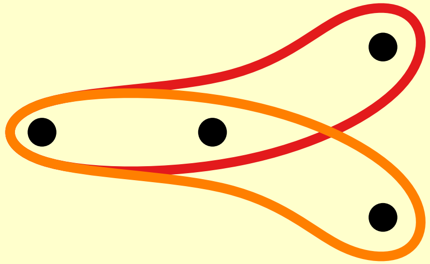


k-hypergraph

k-partite and *k*-uniform

No

exception: 2D



intersection property
does not hold

Representable Hypergraphs

axis-aligned point line cover instance

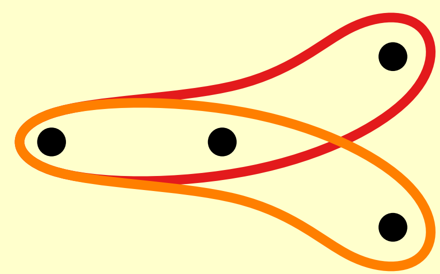
↓ ↑ **?**

k-hypergraph

k-partite and *k*-uniform

No

exception: 2D



intersection property
does not hold

Which *k*-hypergraphs can be *represented*
via axis-aligned point line cover instances?

Paths

Notation.

$[k] = \{1, \ldots, k\}$ for $k \in \mathbb{N}$

A hypergraph $G = (V, E)$

$V = V_1 \cup \ldots \cup V_k$

Paths

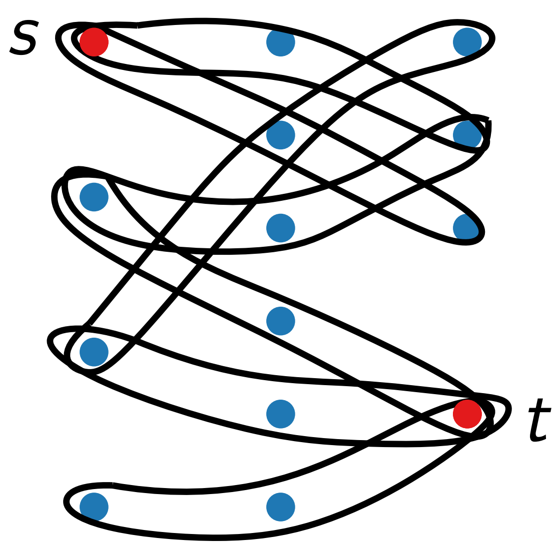
Notation.

$[k] = \{1, \ldots, k\}$ for $k \in \mathbb{N}$

A hypergraph $G = (V, E)$
$V = V_1 \cup \ldots \cup V_k$

Def.

Let $s, t \in V$. An *s-t path* is a sequence of vertices $s = v_1, \ldots, v_r = t$ such that $\forall i \in [r-1]$ v_i and v_{i+1} belong to the same edge.



Paths

Notation.

$[k] = \{1, \ldots, k\}$ for $k \in \mathbb{N}$

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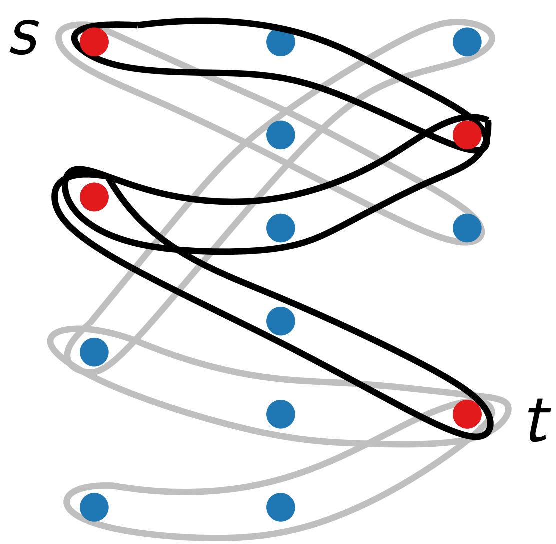


Paths

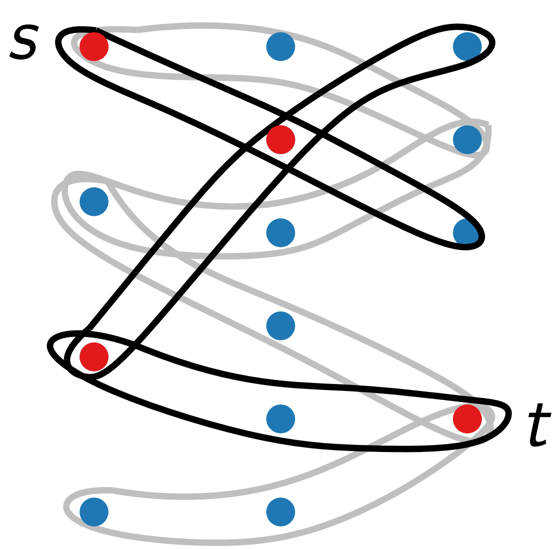
Notation.

$[k] = \{1, \ldots, k\}$ for $k \in \mathbb{N}$

A hypergraph $G = (V, E)$
$V = V_1 \cup \ldots \cup V_k$

Def.

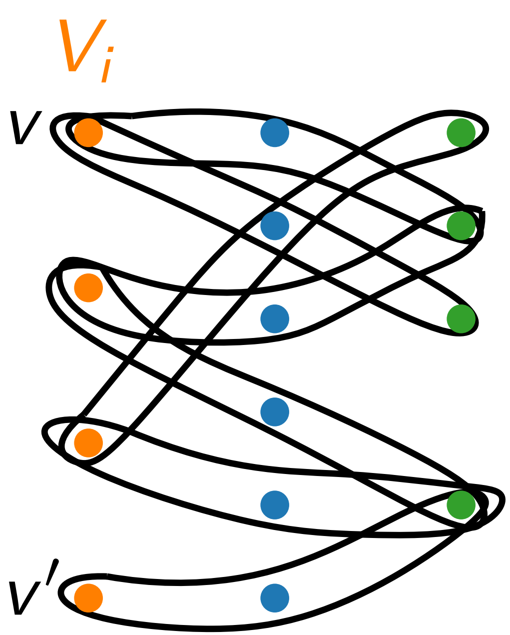
Let $s, t \in V$. An *s-t path* is a sequence of vertices $s = v_1, \ldots, v_r = t$ such that $\forall i \in [r-1]$ v_i and v_{i+1} belong to the same edge.



Separability – Key Property

Def. *Vertex separability*

For a given k-hypergraph G two distinct vertices v and v' from the same group V_i where $i \in [k]$ are *separable* if there exists $j \in [k]$ with $j \neq i$ such that every v-v' path contains a vertex in V_j.



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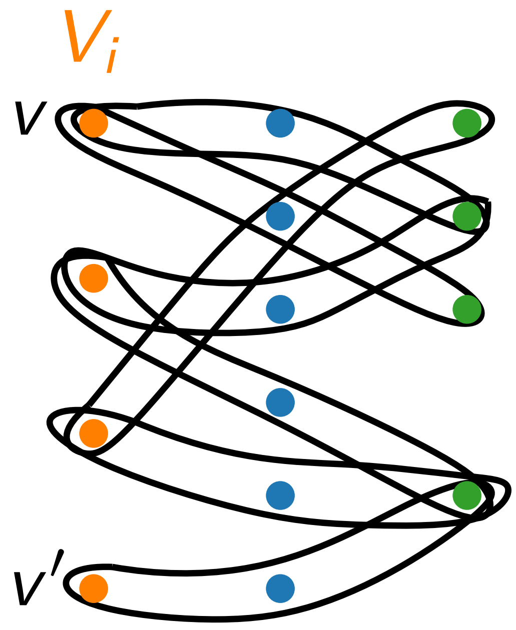

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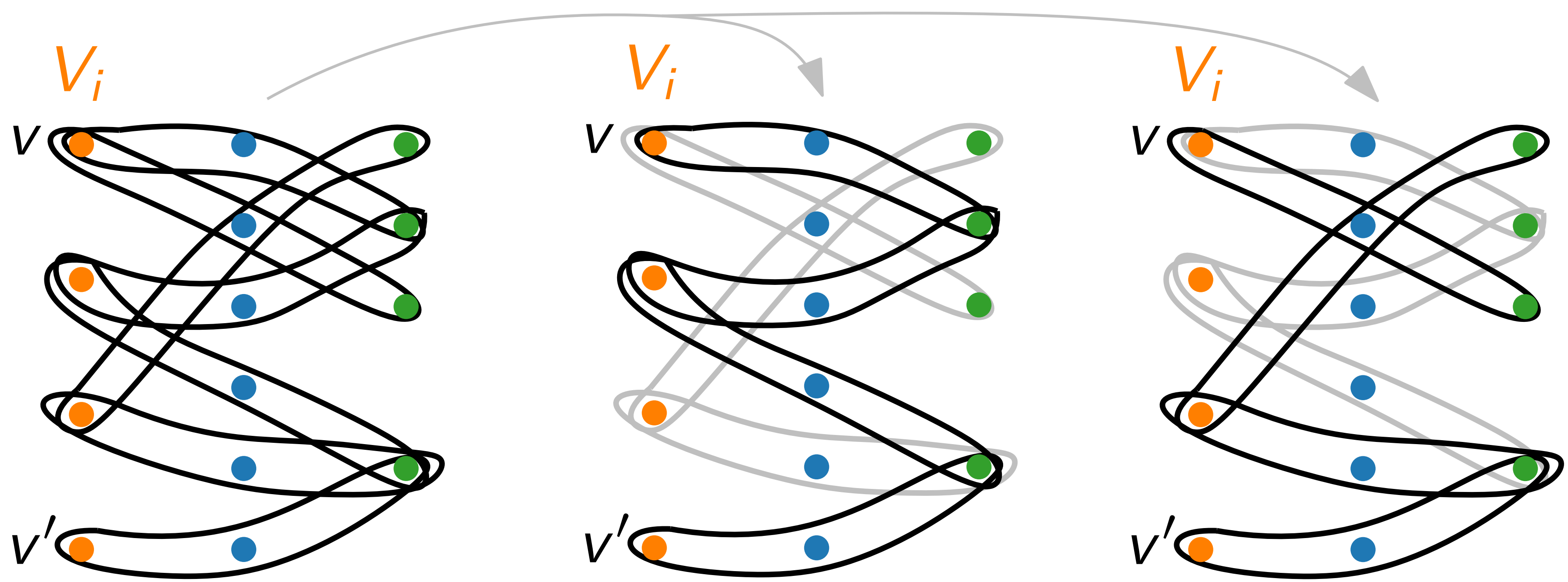

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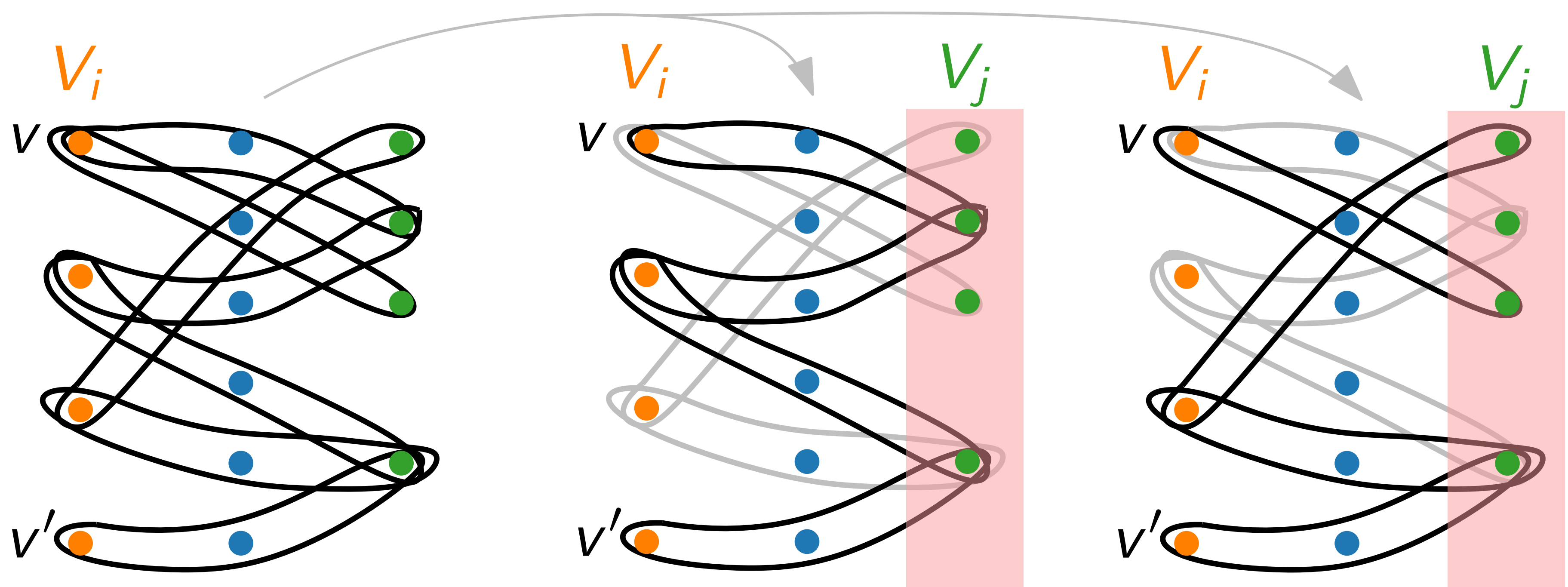

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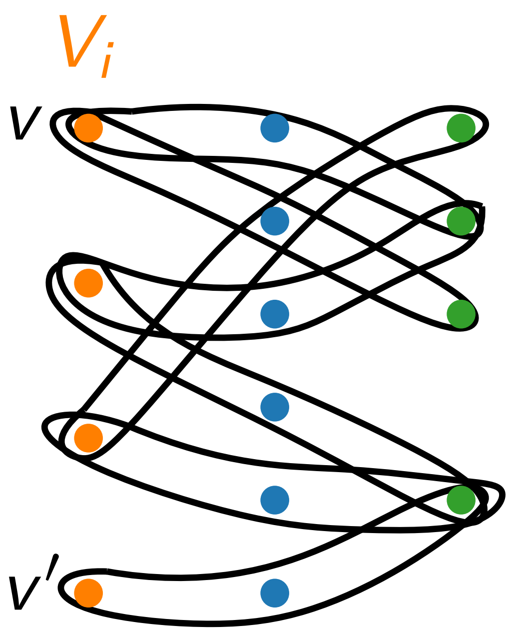

A k-hypergraph is called *vertex separable* if every two vertices from the same group are separable.

Main Result

Theorem

A k-hypergraph G is representable if and only if it is vertex separable.

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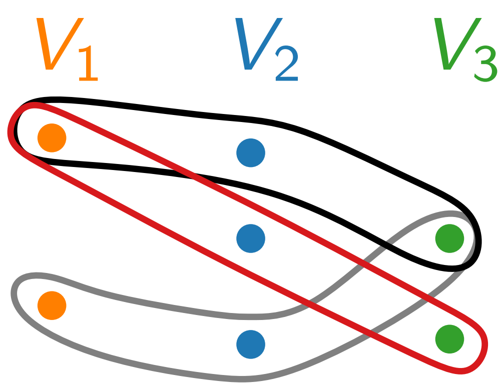

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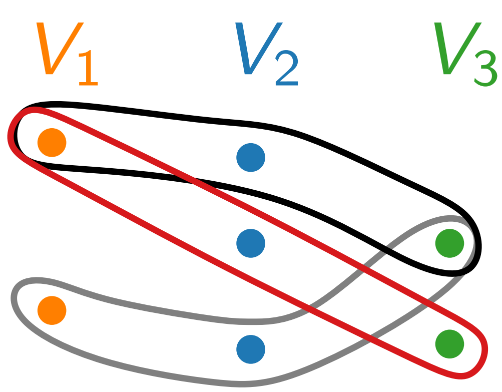

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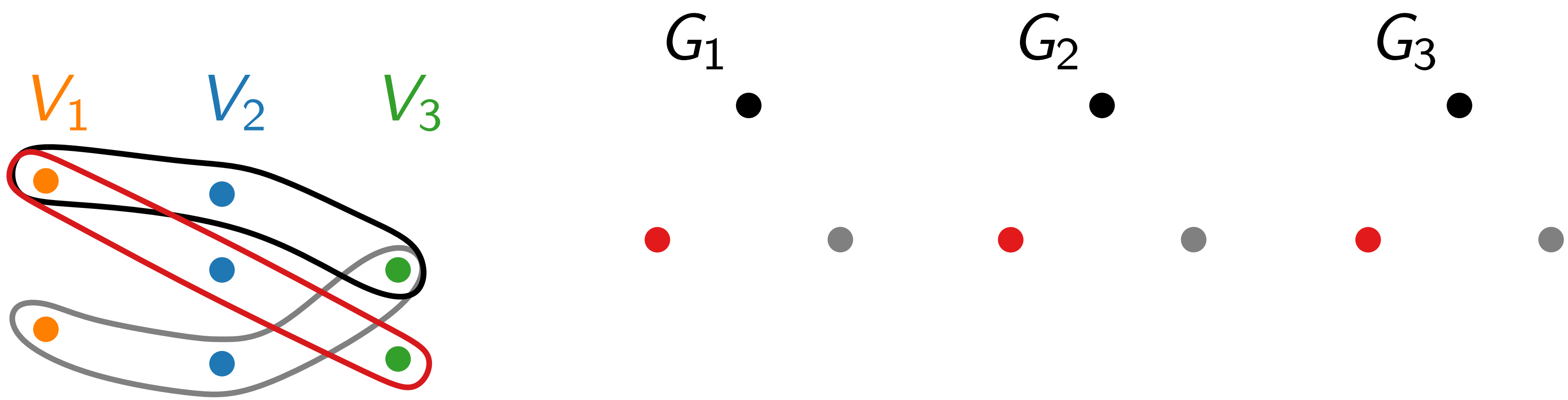

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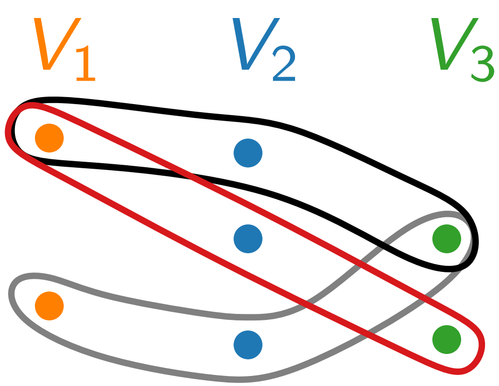

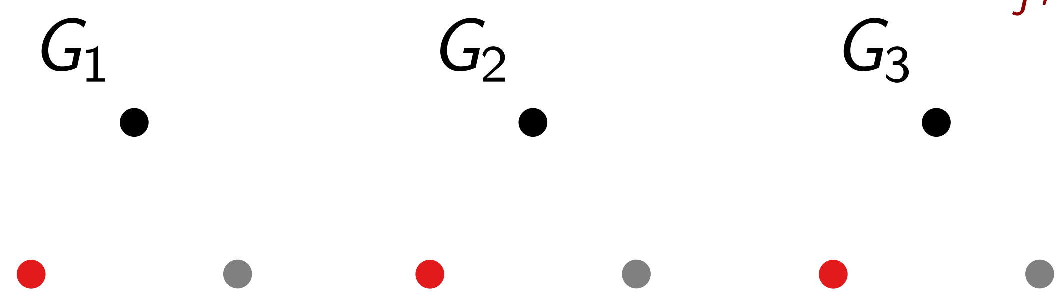

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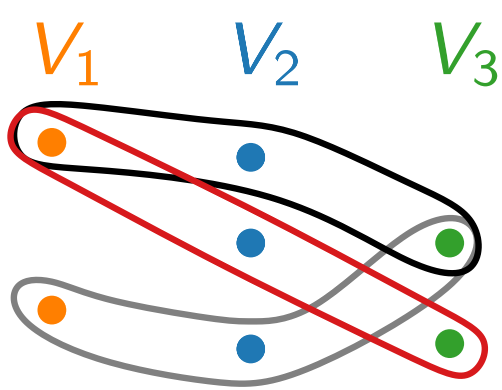

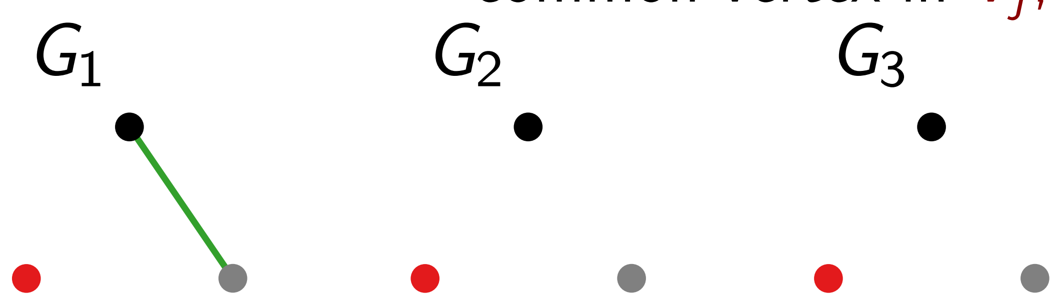

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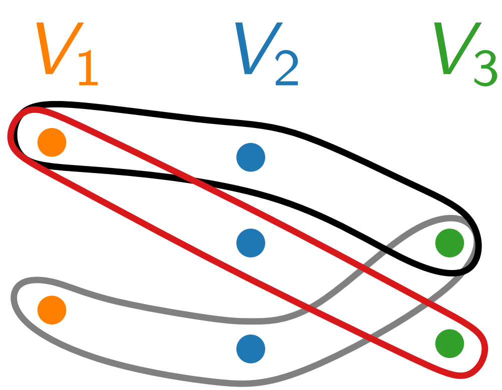

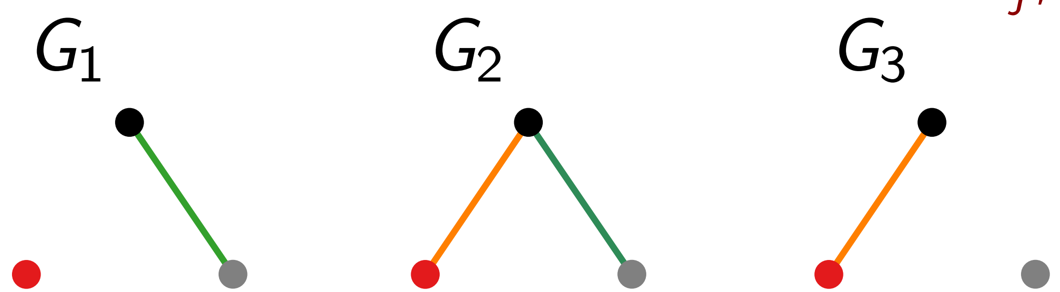

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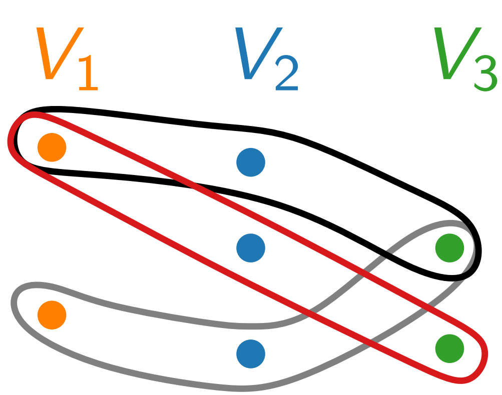

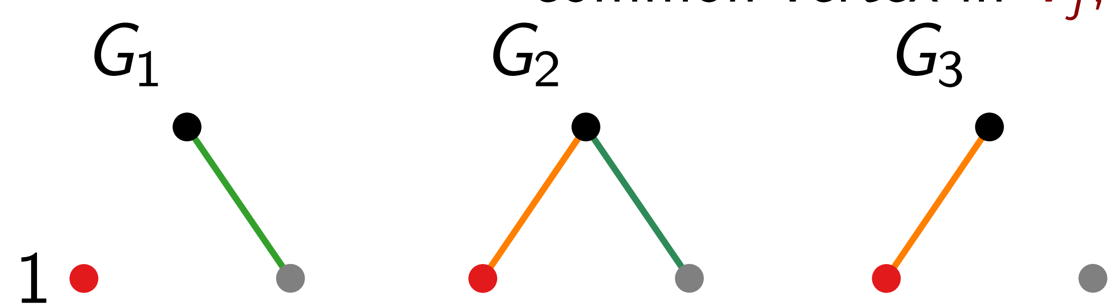

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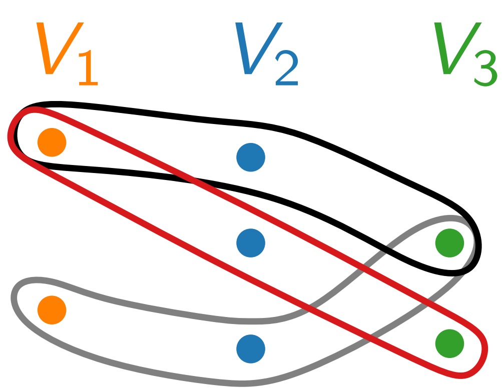

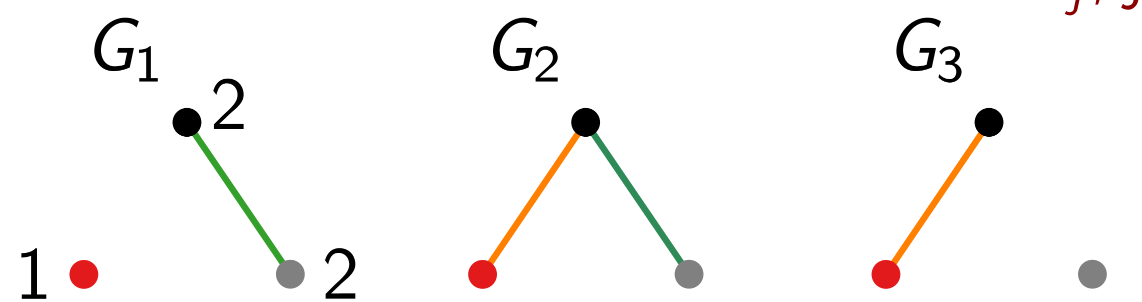

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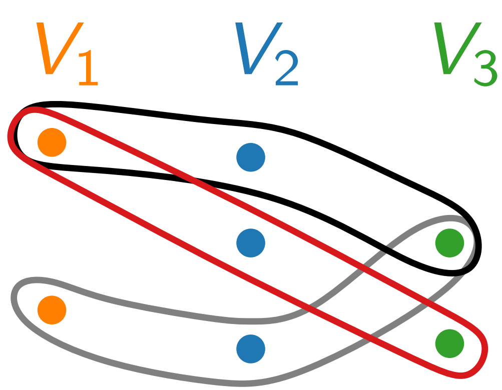

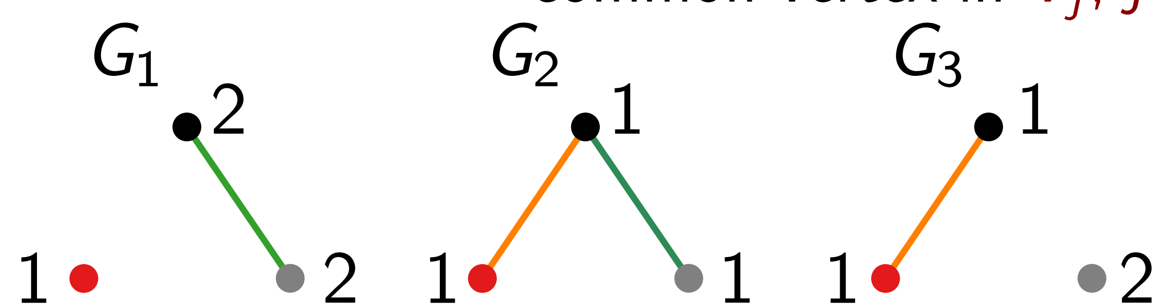

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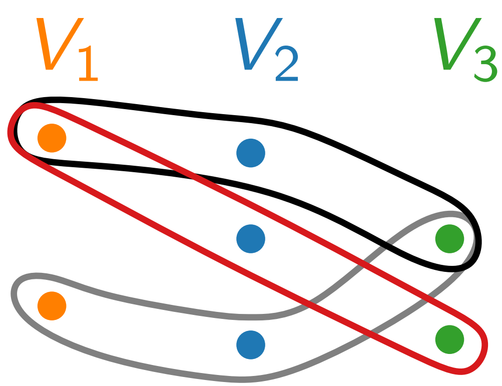

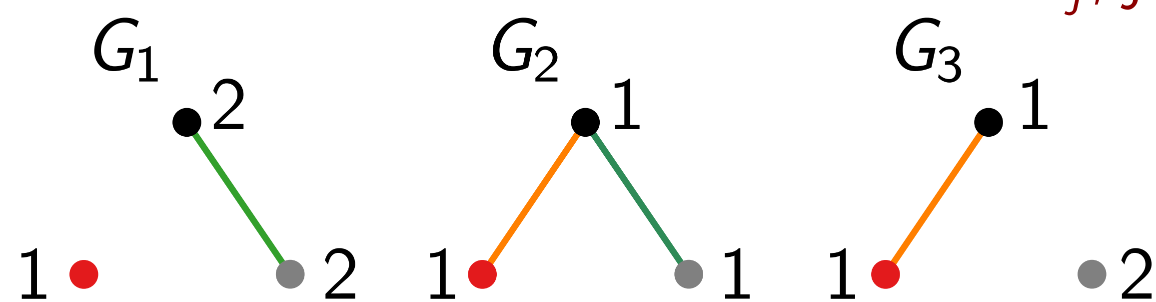

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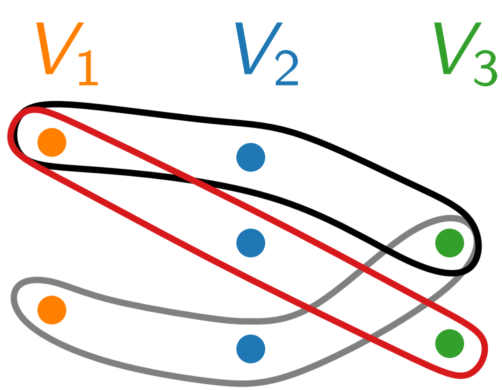

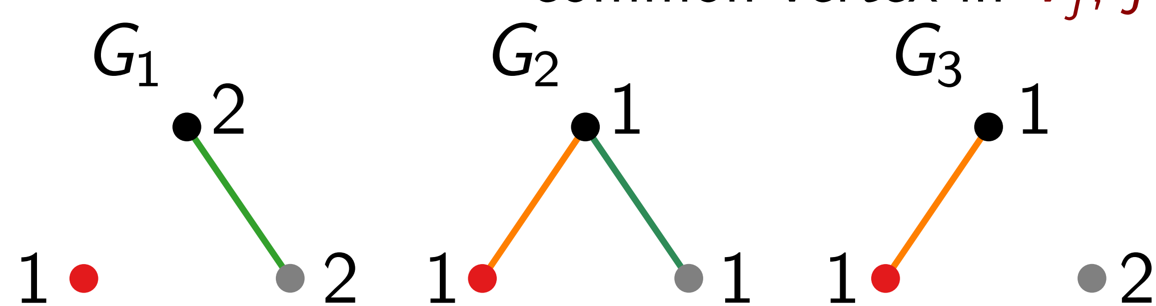

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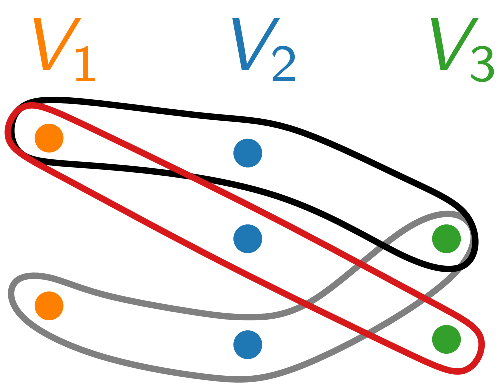

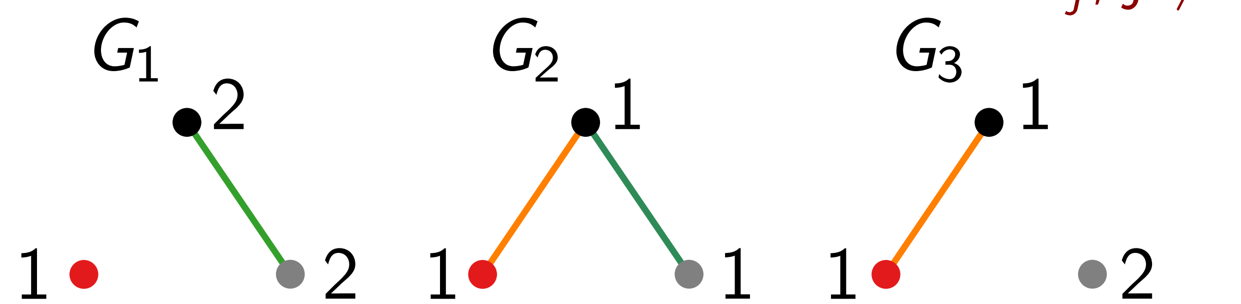

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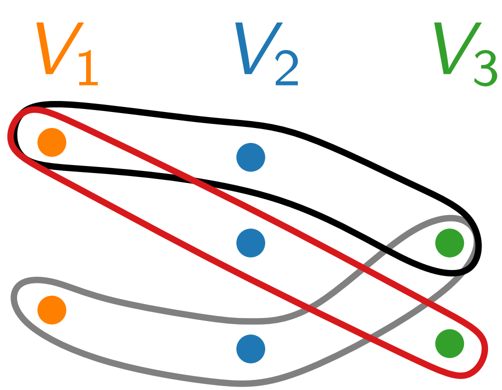

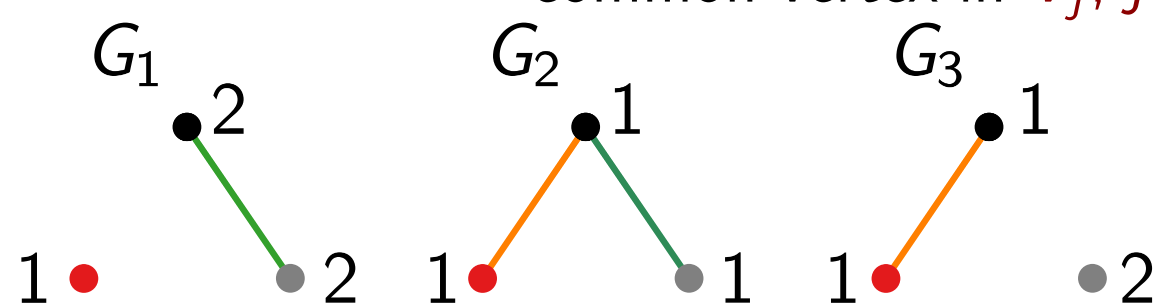

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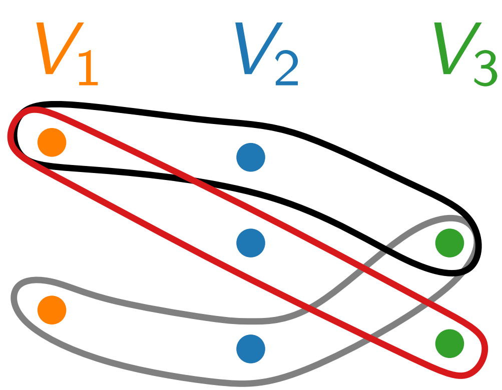

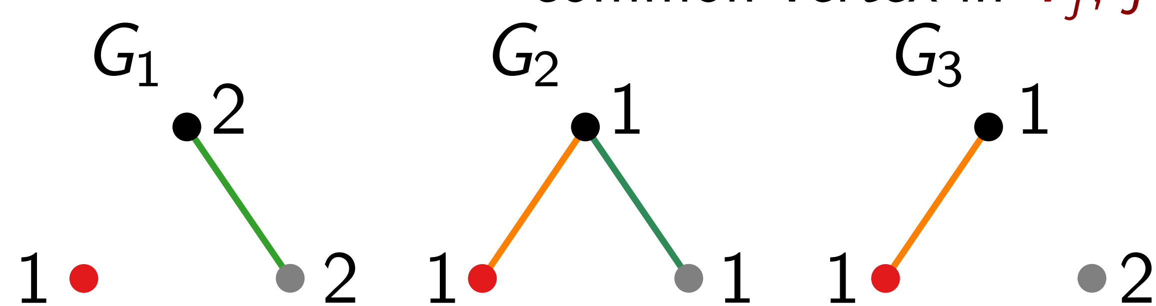

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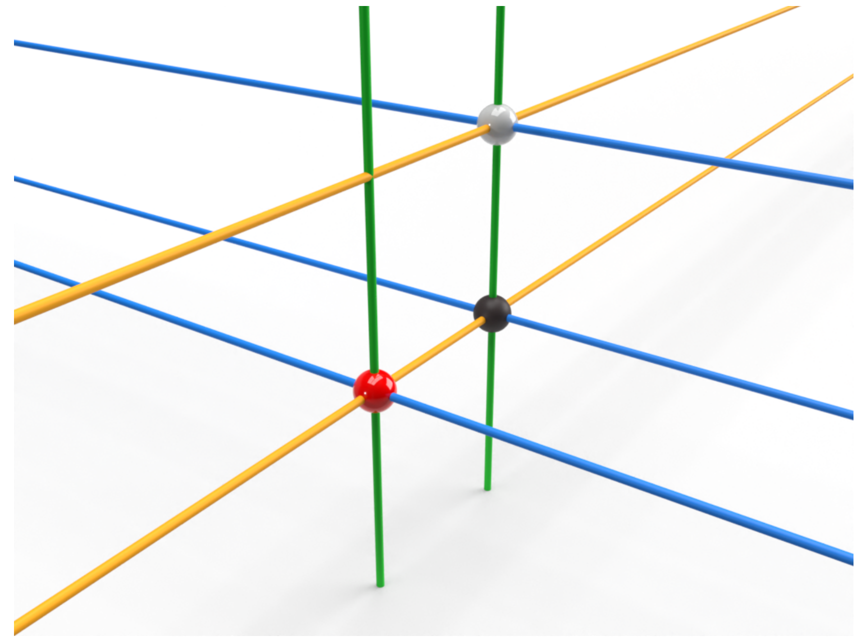

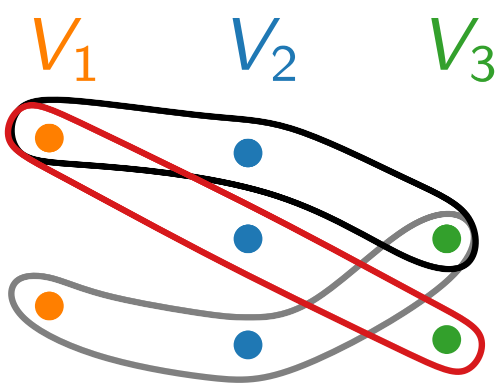

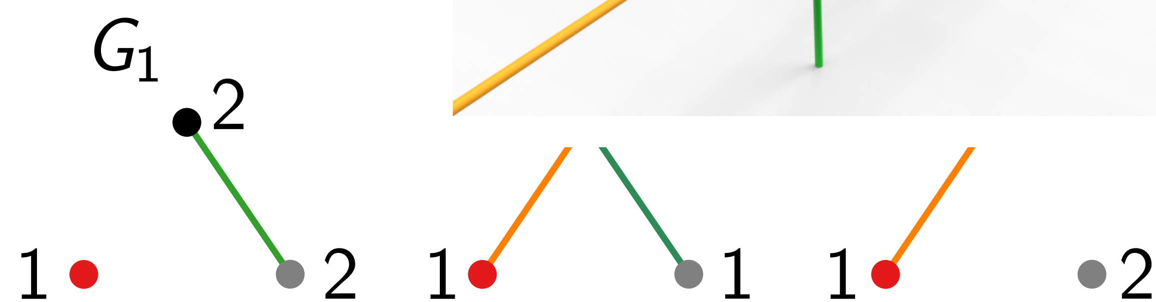

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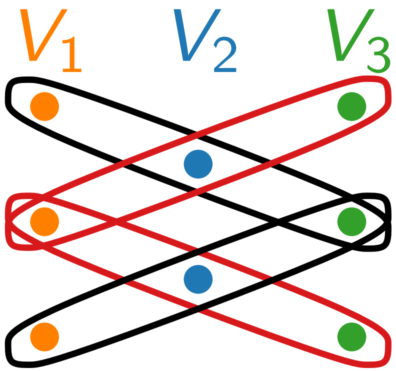

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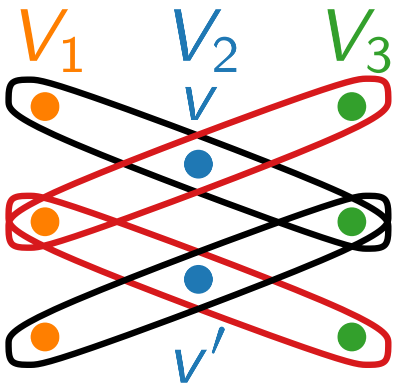

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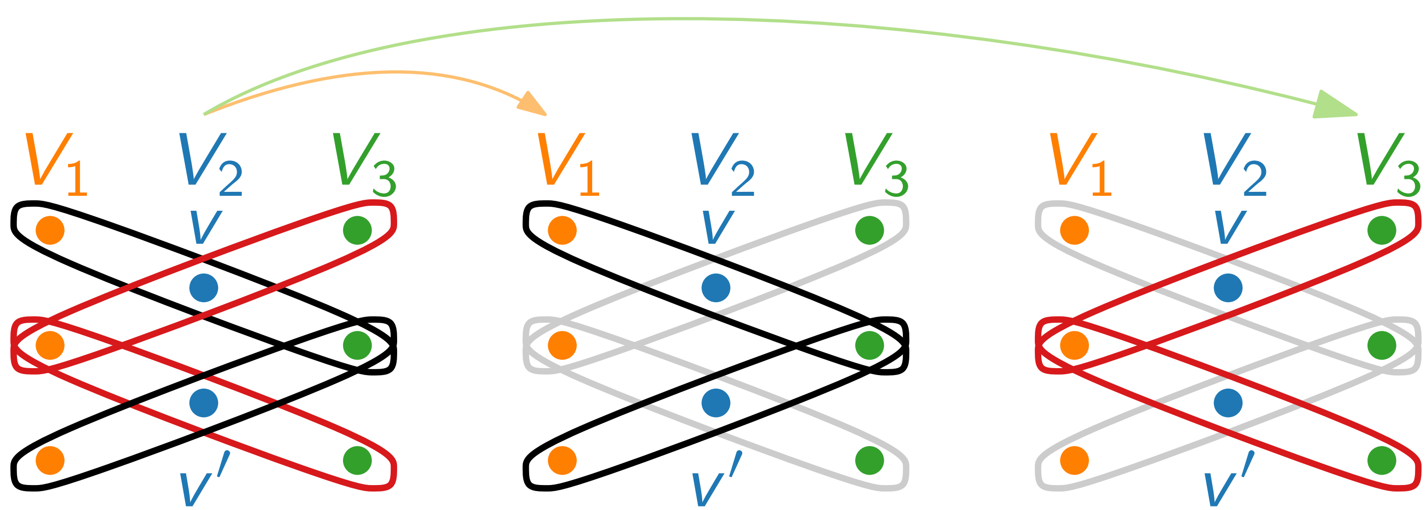

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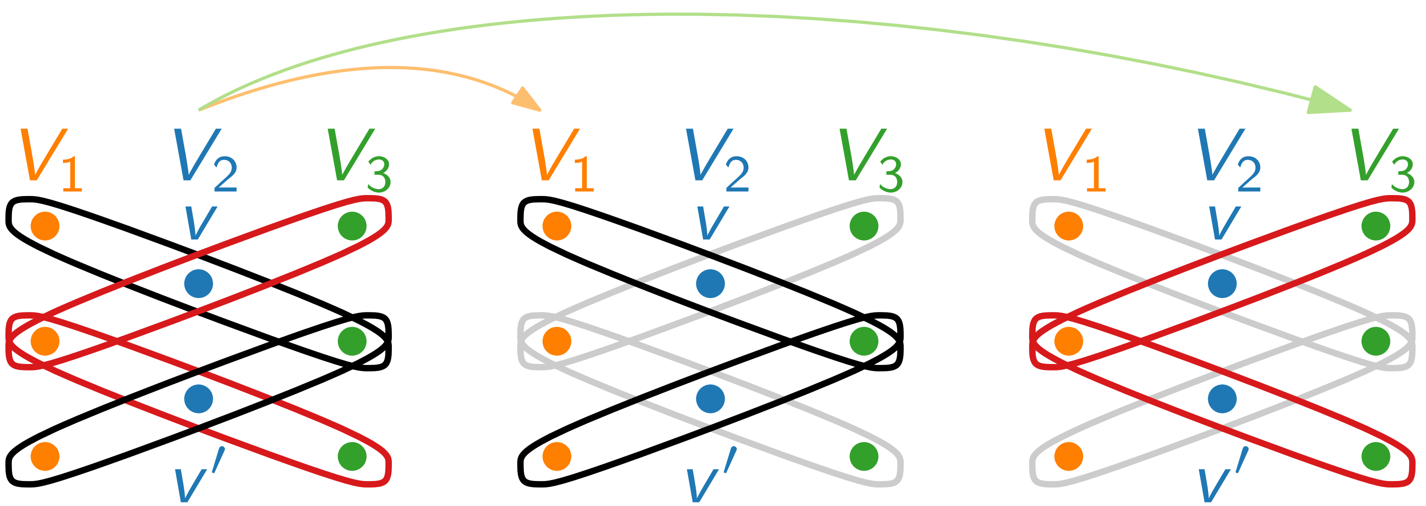

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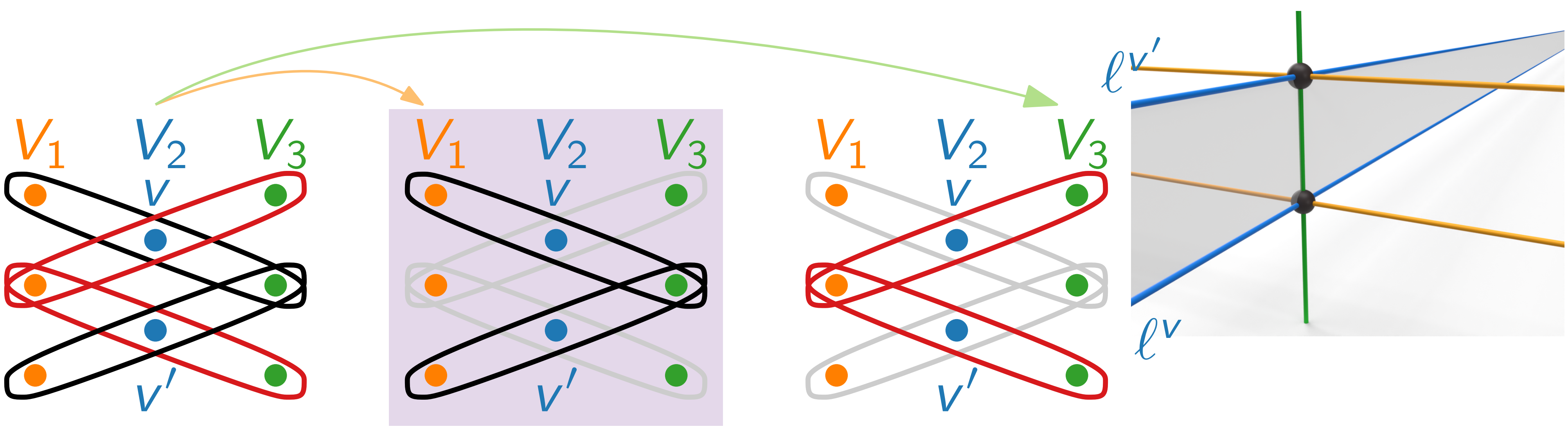

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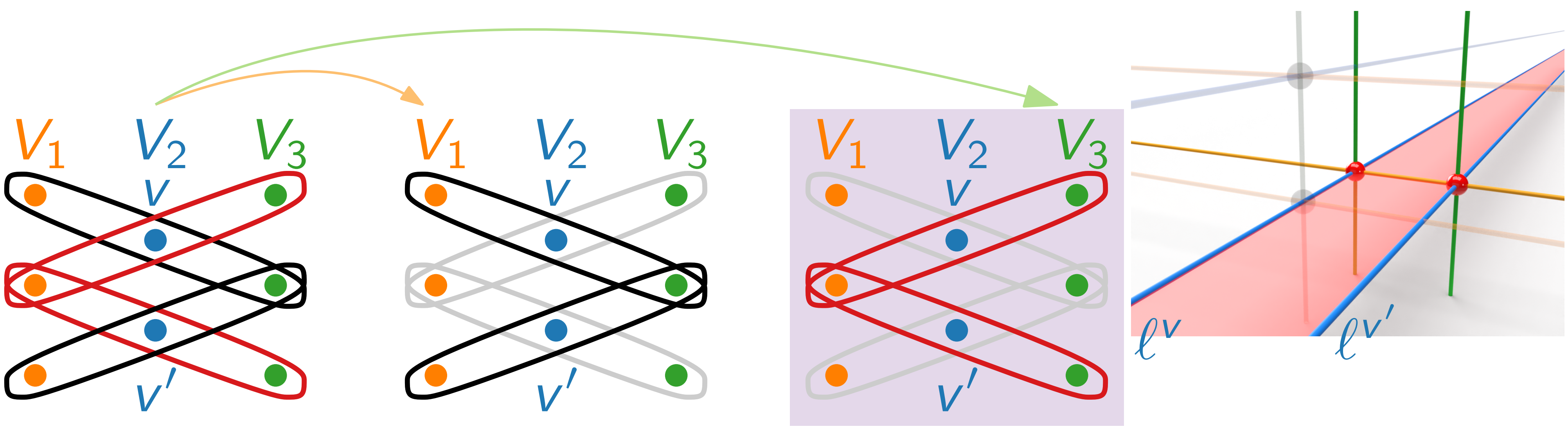

Proof – Part 2

vertex separable $\Leftarrow$ there is a representation

Assume that G is not vertex separable but it has a point line cover representation.

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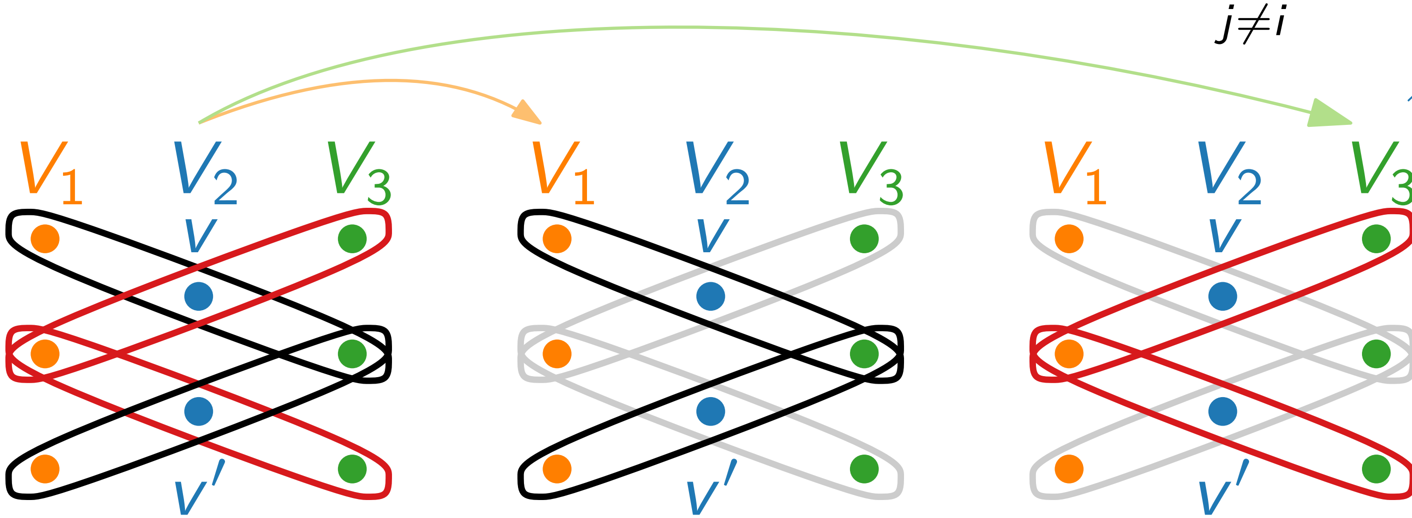

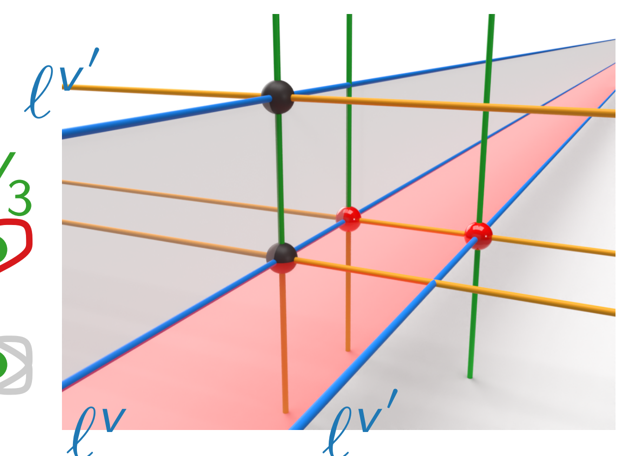

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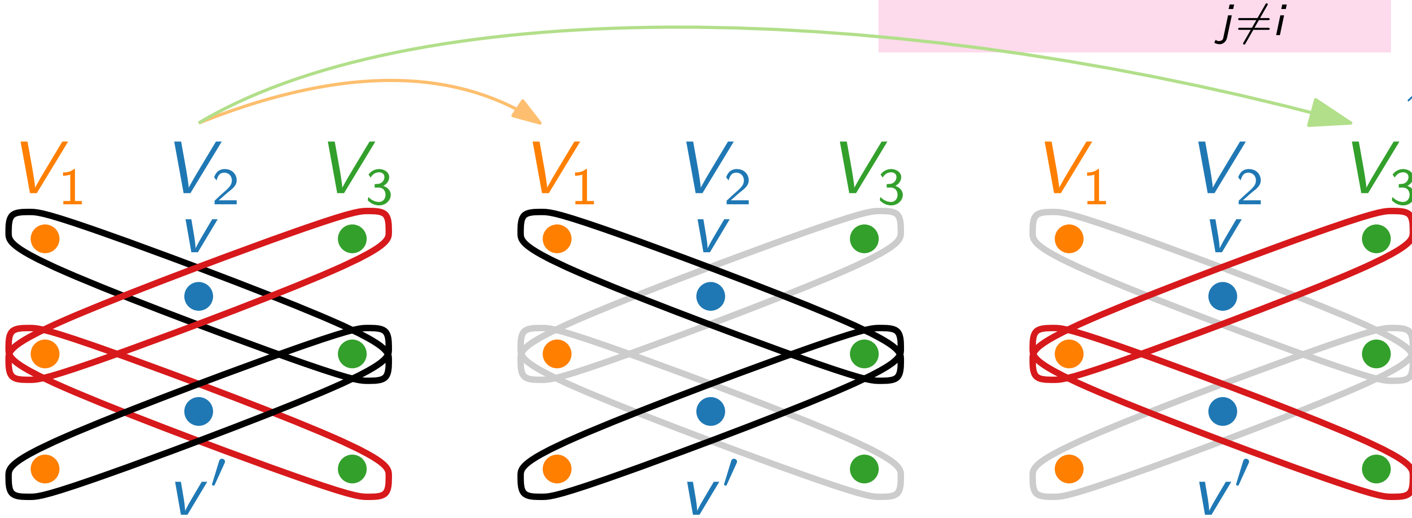
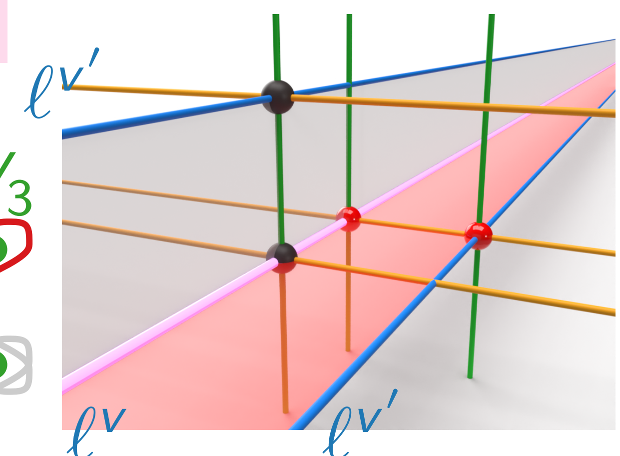
↯





□

Further Results & Open Questions

- Generalization to ℓ-dimensional subspace, $\ell < d$

Further Results & Open Questions

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Space	d-dimensional
Covering objects	lines
Representable hypergraphs	vertex separable

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Further Results & Open Questions

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similar to representation of bipartite graphs in 2D

Further Results & Open Questions

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- Design *improved* algorithms for vertex separable hypergraphs (e.g vertex cover, matching) parameterized by ℓ and d

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