Tree Path Labeling of Path Hypergraphs

Generalization of the Consecutive-ones Property

Anju Srinivasan

as part of **M. S.** by Research
advised by **Dr. N. S. Narayanaswamy**
CSE, IITM, Chennai - 36

25 March 2013

An Illustration

- To introduce the combinatorial problem of TPL.

Study Group Accommodation problem

- A set of n **students** arrive for a summer course, say $\{a, b, c, d, e, f, g, h, i, j, k\}$, $n = 11$.

Study Group Accommodation problem

- A set of n **students** arrive for a summer course, say $\{a, b, c, d, e, f, g, h, i, j, k\}$, $n = 11$.
- They form m **study groups**, say $\{R, B, O, G\}$, $m = 4$

Study Group Accommodation problem

- A set of n **students** arrive for a summer course, say $\{a, b, c, d, e, f, g, h, i, j, k\}$, $n = 11$.
- They form m **study groups**, say $\{R, B, O, G\}$, $m = 4$
- A student may be in more than one study group but *will* be in at least one, say $R = \{g, h, i, j, k\}$, $B = \{a, b, e, g\}$, $O = \{c, b, d\}$, $G = \{e, f, g, i\}$

Study Group Accommodation problem

- A set of n **students** arrive for a summer course, say $\{a, b, c, d, e, f, g, h, i, j, k\}$, $n = 11$.
- They form m **study groups**, say $\{R, B, O, G\}$, $m = 4$
- A student may be in more than one study group but *will* be in at least one, say $R = \{g, h, i, j, k\}$, $B = \{a, b, e, g\}$, $O = \{c, b, d\}$, $G = \{e, f, g, i\}$
- There are n single occupancy **apartments** in the university campus for their accommodation.

Study Group Accommodation problem

- A set of n **students** arrive for a summer course, say $\{a, b, c, d, e, f, g, h, i, j, k\}$, $n = 11$.
- They form m **study groups**, say $\{R, B, O, G\}$, $m = 4$
- A student may be in more than one study group but *will* be in at least one, say $R = \{g, h, i, j, k\}$, $B = \{a, b, e, g\}$, $O = \{c, b, d\}$, $G = \{e, f, g, i\}$
- There are n single occupancy **apartments** in the university campus for their accommodation.
- All these apartments are placed such that streets connecting them do not form loops - **streets form a tree**

Study Group Accommodation problem

The problem

How should the students be allocated apartments such that:

- students of each study group are neighbours?

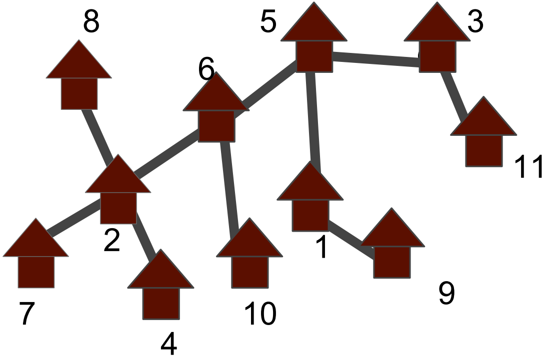
Study Group Accommodation problem

The problem

How should the students be allocated apartments such that:

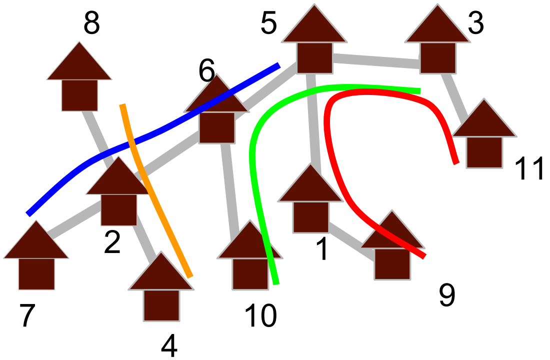
- students of each study group are neighbours?
- i.e. a study group forms **a path in the tree**.

Study Group Accommodation problem



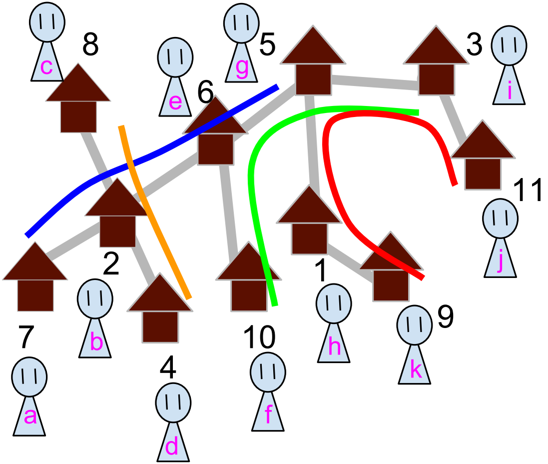
$R = \{g, h, i, j, k\}$
$B = \{a, b, e, g\}$
$O = \{c, b, d\}$
$G = \{e, f, g, i\}$

Study Group Accommodation problem



$R = \{g, h, i, j, k\}$
$\rightarrow \{9, 1, 5, 3, 11\}$
$B = \{a, b, e, g\}$
$\rightarrow \{7, 2, 6, 5\}$
$O = \{c, b, d\}$
$\rightarrow \{4, 2, 8\}$
$G = \{e, f, g, i\}$
$\rightarrow \{10, 6, 5, 3\}$

Study Group Accommodation problem



$R = \{g, h, i, j, k\}$
$\rightarrow \{9, 1, 5, 3, 11\}$
$B = \{a, b, e, g\}$
$\rightarrow \{7, 2, 6, 5\}$
$O = \{c, b, d\}$
$\rightarrow \{4, 2, 8\}$
$G = \{e, f, g, i\}$
$\rightarrow \{10, 6, 5, 3\}$

Tree Path Labeling of Path Hypergraphs

- The set of study groups $\rightarrow$ **Set system / Hypergraph**

Tree Path Labeling of Path Hypergraphs

- The set of study groups $\rightarrow$ **Set system / Hypergraph**
- The streets with apartments $\rightarrow$ **Target tree**

Tree Path Labeling of Path Hypergraphs

- The set of study groups $\rightarrow$ **Set system / Hypergraph**
- The streets with apartments $\rightarrow$ **Target tree**
- The path mapping to study groups $\rightarrow$ **Tree Path Labeling (TPL)**

Tree Path Labeling of Path Hypergraphs

- The set of study groups → **Set system / Hypergraph**
- The streets with apartments → **Target tree**
- The path mapping to study groups → **Tree Path Labeling (TPL)**
- The apartment allocation → **Path Hypergraph Isomorphism**

Tree Path Labeling of Path Hypergraphs

There *exists* an apartment allocation that "fits" the path mapping

Tree Path Labeling of Path Hypergraphs

There *exists* a hypergraph isomorphism that "fits" the TPL

Tree Path Labeling of Path Hypergraphs

There *exists* a hypergraph isomorphism that "fits" the TPL
$\Rightarrow$ the TPL is FEASIBLE

Tree Path Labeling of Path Hypergraphs

There *exists* a hypergraph isomorphism that "fits" the TPL
$\Rightarrow$ the TPL is FEASIBLE
There *exists* an apartment allocation that gives some study group path mapping

Tree Path Labeling of Path Hypergraphs

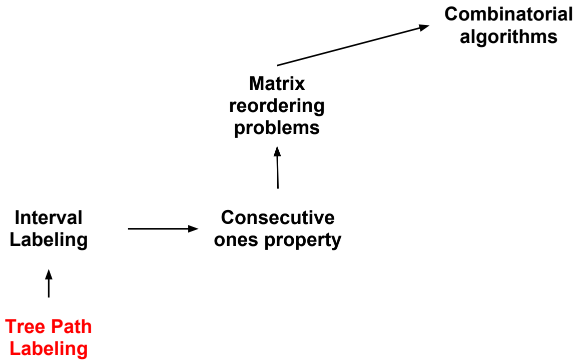
There exists a hypergraph isomorphism that "fits" the TPL
$\Rightarrow$ the TPL is FEASIBLE
There *exists* a hypergraph isomorphism that gives at least one feasible TPL

Tree Path Labeling of Path Hypergraphs

There *exists* a hypergraph isomorphism that "fits" the TPL
$\Rightarrow$ the TPL is FEASIBLE
There *exists* a hypergraph isomorphism that gives at least one feasible TPL
$\Rightarrow$ the hypergraph is a PATH HYPERGRAPH

Consecutive Ones $\rightarrow$ Path Labeling

The motivation



Compute Feasible Tree Path Labeling

`Input`	A hypergraph $\mathcal{F}$ with vertex set U and a tree T.
`Question`	Does there exist a set of paths $\mathcal{P}$ from T and a bijection $\ell : \mathcal{F} \rightarrow \mathcal{P}$, such that Feasible Tree Path Labeling returns **true** on $(\mathcal{F}, T, \ell)$.

Compute Feasible Tree Path Labeling

- Is the given hypergraph $\mathcal{F}$ a path hypergraph w.r.t. target tree T?
- i.e. find at least one feasible tree path labeling $\ell : \mathcal{F} \rightarrow P$, P is a set of paths on T.
- Complexity is inconclusive for arbitrary trees, polynomial time for certain classes of trees.

Feasible Tree Path Labeling

`Input`	A hypergraph $\mathcal{F}$ with vertex set U, a tree T, a set of paths $\mathcal{P}$ from T and a bijection $\ell : \mathcal{F} \rightarrow \mathcal{P}$.
`Question`	Does there exist a bijection $\phi : U \rightarrow V(T)$ such that ϕ when applied on any hyperedge in $\mathcal{F}$ will give the path mapped to it by the given tree path labeling ℓ. i.e., $\ell(S) = \{\phi(x) \mid x \in S\}$, for every hyperedge $S \in \mathcal{F}$.

Feasible Tree Path Labeling

- Is the given TPL ℓ of hypergraph $\mathcal{F}$ on tree T feasible?
- What is the hypergraph isomorphism $\phi : U \rightarrow V(T)$?
- Solvable in polynomial time.

Compute Interval Labeling

Compute Feasible Tree Path Labeling when target tree is an interval or path P_n

Compute Interval Labeling

- Is the given hypergraph $\mathcal{F}$ an interval hypergraph [KKLV10]?
- Equivalent to consecutive ones property checking or ICPIA [NS09]
- Solvable in polynomial time.

Compute k-subdivided Star Path Labeling

Compute Feasible Tree Path Labeling when target tree is a k-subdivided star and every hyperedge in $\mathcal{F}$ is of size at most $k+2$

COMPUTE k-SUBDIVIDED STAR PATH LABELING

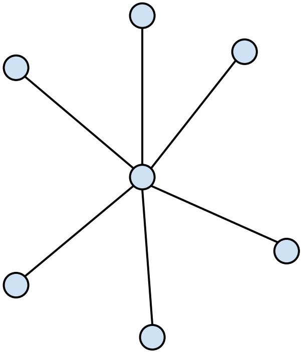
- Solvable in polynomial time.

k-subdivided star

A star with all its edges subdivided exactly k times.

k-subdivided star

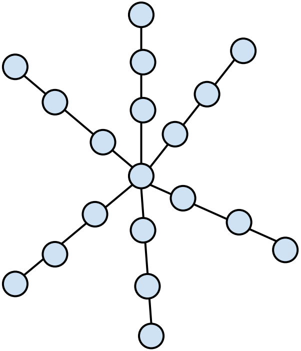
A star with all its edges subdivided exactly k times.



$k = 0$, star

k-subdivided star

A star with all its edges subdivided exactly k times.



2-subdivided star

Compute Feasible Tree Path Labeling

Input	A hypergraph $\mathcal{F}$ with vertex set U and a tree T.
Question	Does there exist a set of paths $\mathcal{P}$ from T and a bijection $\ell : \mathcal{F} \rightarrow \mathcal{P}$, such that Feasible Tree Path Labeling returns **true** on $(\mathcal{F}, T, \ell)$.

A characterization of feasible TPL

Intersection Cardinality Preserving Path Labeling (ICPPL)

A path labeling $(\mathcal{F}, \ell)$ on the given tree T s.t.

$$|S_1 \cap S_2 \cap S_3| = |\ell(S_1) \cap \ell(S_2) \cap \ell(S_3)|$$

for all not necessarily distinct $S_1, S_2, S_3 \in \mathcal{F}$

A characterization of feasible TPL

Intersection Cardinality Preserving Path Labeling (ICPPL)

A path labeling $(\mathcal{F}, \ell)$ on the given tree T s.t.

$$|S_1 \cap S_2 \cap S_3| = |\ell(S_1) \cap \ell(S_2) \cap \ell(S_3)|$$

for all not necessarily distinct $S_1, S_2, S_3 \in \mathcal{F}$

Theorem

A path labeling $(\mathcal{F}, \ell)$ on tree T is feasible iff it is an ICPPL.

Finding path hypergraph isomorphism ϕ

Given an ICPPL $(\mathcal{F}, \ell)$ on tree T

- Uses two filters to refine $(\mathcal{F}, \ell)$

Finding path hypergraph isomorphism ϕ

Given an ICPPL $(\mathcal{F}, \ell)$ on tree T

- Uses two filters to refine $(\mathcal{F}, \ell)$
- `filter common leaf` - ensures that the resulting ICPPL has no two path labels sharing a leaf.

Finding path hypergraph isomorphism ϕ

Given an ICPPL $(\mathcal{F}, \ell)$ on tree T

- Uses two filters to refine $(\mathcal{F}, \ell)$
- `filter common leaf` - ensures that the resulting ICPPL has no two path labels sharing a leaf.
- `filter fix leaf` - finds the pre-image of each leaf in T.

Finding path hypergraph isomorphism ϕ

Given an ICPPL $(\mathcal{F}, \ell)$ on tree T

- Uses two filters to refine $(\mathcal{F}, \ell)$
- `filter common leaf` - ensures that the resulting ICPPL has no two path labels sharing a leaf.
- `filter fix leaf` - finds the pre-image of each leaf in T.
- Remove leaves from T and their preimages from $\mathcal{F}$. Repeat filters until T becomes a path.

Finding path hypergraph isomorphism ϕ

Given an ICPPL $(\mathcal{F}, \ell)$ on tree T

- Uses two filters to refine $(\mathcal{F}, \ell)$
- `filter common leaf` - ensures that the resulting ICPPL has no two path labels sharing a leaf.
- `filter fix leaf` - finds the pre-image of each leaf in T.
- Remove leaves from T and their preimages from $\mathcal{F}$. Repeat filters until T becomes a path.
- When T is a path, problem becomes interval assignment. Use ICPIA [NS09]

Finding path hypergraph isomorphism ϕ

`filter common leaf` $(\mathcal{F}, \ell)$

- Pick any two paths P_1, P_2 in $(\mathcal{F}, \ell)$ that share a leaf. Let $\ell(S_i) = P_i$ for all $S_i \in \mathcal{F}$.

Finding path hypergraph isomorphism ϕ

`filter common leaf` $(\mathcal{F}, \ell)$

- Pick any two paths P_1, P_2 in $(\mathcal{F}, \ell)$ that share a leaf. Let $\ell(S_i) = P_i$ for all $S_i \in \mathcal{F}$.
- Remove S_1, S_2, P_1, P_2 from $(\mathcal{F}, \ell)$

Finding path hypergraph isomorphism ϕ

`filter common leaf` $(\mathcal{F}, \ell)$

- Pick any two paths P_1, P_2 in $(\mathcal{F}, \ell)$ that share a leaf. Let $\ell(S_i) = P_i$ for all $S_i \in \mathcal{F}$.
- Remove S_1, S_2, P_1, P_2 from $(\mathcal{F}, \ell)$
- Add to $(\mathcal{F}, \ell)$:
  $\ell(S_1 \setminus S_2) = P_1 \setminus P_2$
  $\ell(S_2 \setminus S_1) = P_2 \setminus P_1$
  $\ell(S_1 \cap S_2) = P_1 \cap P_2$

Finding path hypergraph isomorphism ϕ

`filter common leaf` $(\mathcal{F}, \ell)$

- Pick any two paths P_1, P_2 in $(\mathcal{F}, \ell)$ that share a leaf. Let $\ell(S_i) = P_i$ for all $S_i \in \mathcal{F}$.
- Remove S_1, S_2, P_1, P_2 from $(\mathcal{F}, \ell)$
- Add to $(\mathcal{F}, \ell)$:
  $\ell(S_1 \setminus S_2) = P_1 \setminus P_2$
  $\ell(S_2 \setminus S_1) = P_2 \setminus P_1$
  $\ell(S_1 \cap S_2) = P_1 \cap P_2$
- Repeat till no two paths share a leaf.

Finding path hypergraph isomorphism ϕ

`filter common leaf` $(\mathcal{F}, \ell)$

Lemma

Let $(\mathcal{F}', \ell')$ be the resulting labeling after applying `filter common leaf` *to TPL $(\mathcal{F}, \ell)$. If $(\mathcal{F}, \ell)$ is an ICPPL, $(\mathcal{F}', \ell')$ is also an ICPPL.*

Finding path hypergraph isomorphism ϕ

`filter common leaf` $(\mathcal{F}, \ell)$

Lemma

Let $(\mathcal{F}', \ell')$ be the resulting labeling after applying `filter common leaf` *to TPL $(\mathcal{F}, \ell)$. If $(\mathcal{F}, \ell)$ is an ICPPL, $(\mathcal{F}', \ell')$ is also an ICPPL.*

Proof.

- Induction on iteration of the filter.
- Invariants: $\ell_j(S)$ is a path, ℓ_j maintains ICPPL's intersection cardinality equations.
- ICPPL also preserves 4-way intersection cardinalities.

$\square$

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

- A leaf is unique to a path

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

- A leaf is unique to a path
- Pick a leaf v, let it be on path P. Let $\ell(S) = P$

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

- A leaf is unique to a path
- Pick a leaf v, let it be on path P. Let $\ell(S) = P$
- Pick an element x from S which is not present in any other set. i.e. $x \in S \setminus \cup_{S_i \neq S} S_i$

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

- A leaf is unique to a path
- Pick a leaf v, let it be on path P. Let $\ell(S) = P$
- Pick an element x from S which is not present in any other set. i.e. $x \in S \setminus \cup_{S_i \neq S} S_i$
- Remove S, P from $(\mathcal{F}, \ell)$

Finding path hypergraph isomorphism ϕ

filter fix leaf $(\mathcal{F}, \ell)$

- A leaf is unique to a path
- Pick a leaf v, let it be on path P. Let $\ell(S) = P$
- Pick an element x from S which is not present in any other set. i.e. $x \in S \setminus \cup_{S_i \neq S} S_i$
- Remove S, P from $(\mathcal{F}, \ell)$
- Add $\ell(S \setminus x) = P \setminus v$. Define $\phi(x) = v$

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

- A leaf is unique to a path
- Pick a leaf v, let it be on path P. Let $\ell(S) = P$
- Pick an element x from S which is not present in any other set. i.e. $x \in S \setminus \cup_{S_i \neq S} S_i$
- Remove S, P from $(\mathcal{F}, \ell)$
- Add $\ell(S \setminus x) = P \setminus v$. Define $\phi(x) = v$
- Remove leaf v from T

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

- A leaf is unique to a path
- Pick a leaf v, let it be on path P. Let $\ell(S) = P$
- Pick an element x from S which is not present in any other set. i.e. $x \in S \setminus \cup_{S_i \neq S} S_i$
- Remove S, P from $(\mathcal{F}, \ell)$
- Add $\ell(S \setminus x) = P \setminus v$. Define $\phi(x) = v$
- Remove leaf v from T
- Repeat till there are no more unique paths for leaves. Call `filter common leaf` .

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

- A leaf is unique to a path
- Pick a leaf v, let it be on path P. Let $\ell(S) = P$
- Pick an element x from S which is not present in any other set. i.e. $x \in S \setminus \cup_{S_i \neq S} S_i$
- Remove S, P from $(\mathcal{F}, \ell)$
- Add $\ell(S \setminus x) = P \setminus v$. Define $\phi(x) = v$
- Remove leaf v from T
- Repeat till there are no more unique paths for leaves. Call `filter common leaf` .
- End if T is empty

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

Critical part is finding $x \in S \setminus \cup_{S_i \neq S} S_i$

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

Critical part is finding $x \in S \setminus \cup_{S_i \neq S} S_i$

Lemma

If $\ell(S)$ uniquely has a leaf, S_{priv} is non-empty where $S_{priv} = S \setminus \cup_{S_i \neq S} S_i$.

Finding path hypergraph isomorphism ϕ

`filter fix leaf` $(\mathcal{F}, \ell)$

Critical part is finding $x \in S \setminus \cup_{S_i \neq S} S_i$

Lemma

If $\ell(S)$ uniquely has a leaf, S_{priv} is non-empty where $S_{priv} = S \setminus \cup_{S_i \neq S} S_i$.

Proof.

- Let $\mathcal{F}' = S \cap S_i$ and $\ell'(S \cap S_i) = P \cap P_i$ for all $S_i \in \mathcal{F}$, $\ell(S_i) = P_i$.
- $S_{two} = supp(\mathcal{F}'), P_{two} = supp(\ell')$
- $(\mathcal{F}', \ell')$ is an ICPIA. Therefore $|S_{two}| = |P_{two}|$. Hence $|S_{priv}| = |P_{priv}|$. We know P has at least a leaf.

Compute k-subdivided Star Path Labeling

Compute Feasible Tree Path Labeling when target tree is a k-subdivided star and every hyperedge in $\mathcal{F}$ is of size at most $k+2$

Why k-subdivided star?

- When the root vertex is removed, we get disjoint paths.

Why k-subdivided star?

- When the root vertex is removed, we get disjoint paths.
- Super marginal sets are assigned an arbitrary ray not considered yet.

Why k-subdivided star?

- When the root vertex is removed, we get disjoint paths.
- Super marginal sets are assigned an arbitrary ray not considered yet.
- Sets that overlap with the super marginal set are considered just like in ICPIA algorithm [NS09] until a path containing root vertex is assigned.

Compute TPL for k-subdivided star

- – summarize algorithm

Compute TPL for k-subdivided star

- – summarize algorithm
- – complexity

Theory of prime submatrices

- – Mention the two subproblems

Theory of prime submatrices

- – Mention the two subproblems
- – diagrams

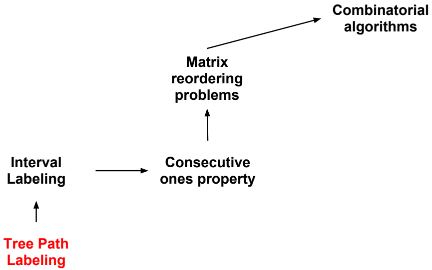
TBD

...

– more slides will come here –

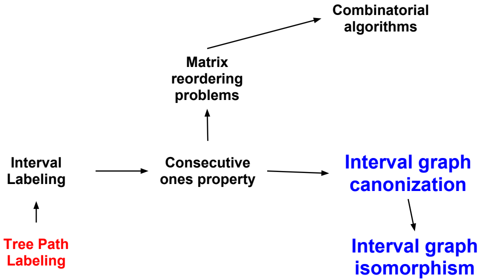
Path Labeling → Graph Isomorphism

Application



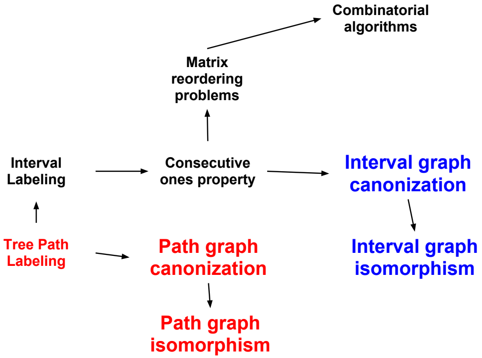
Path Labeling → Graph Isomorphism

Application



Path Labeling → Graph Isomorphism

Application



References I

Martin Charles Golumbic.
Algorithmic graph theory and perfect graphs, volume 57 of *Annals of Discrete Mathematics*.
Elsevier Science B.V., 2004.
Second Edition.

Johannes Köbler, Sebastian Kuhnert, Bastian Laubner, and Oleg Verbitsky.
Interval graphs: Canonical representation in logspace.
Electronic Colloquium on Computational Complexity (ECCC), 17:43, 2010.

N. S. Narayanaswamy and R. Subashini.
A new characterization of matrices with the consecutive ones property.
Discrete Applied Mathematics, 157(18):3721–3727, 2009.

Thank you

Questions?