Polynomial Optimization (401-3908-21G)

Adam Kurpisz

ETH Zürich

ONLINE LECTURES - SET UP

- Lectures via Zoom, link on Moodle (problems—restart).
- Lectures are recorded, recordings on Moodle.
- You are muted, unmuting $\Rightarrow$ agreement to be on recording.
- Chat function, set to private mode, asking question anonymous.

ONLINE LECTURES - SET UP

- Lectures via Zoom, link on Moodle (problems—restart).
- Lectures are recorded, recordings on Moodle.
- You are muted, unmuting $\Rightarrow$ agreement to be on recording.
- Chat function, set to private mode, asking question anonymous.

ONLINE LECTURES - SET UP

- Lectures via Zoom, link on Moodle (problems—restart).
- Lectures are recorded, recordings on Moodle.
- You are muted, unmuting $\Rightarrow$ agreement to be on recording.
- Chat function, set to private mode, asking question anonymous.

ONLINE LECTURES - SET UP

- Lectures via Zoom, link on Moodle (problems—restart).
- Lectures are recorded, recordings on Moodle.
- You are muted, unmuting $\Rightarrow$ agreement to be on recording.
- Chat function, set to private mode, asking question anonymous.

DATES AND TIMES

Volume: 3h/week—type G

Wednesday, 16-18 — lectures

Friday, 13-14 — exercise sessions, Federica Cecchetto

Office hours,16-18 — office hours, please register one day before

- 10 minutes break, if you do not agree please complain now.
- Type G— single group in exercise sessions.
- Any deviation will be communicated: Friday 26.02 — lecture

DATES AND TIMES

Volume: 3h/week—type G

Wednesday, 16-18 — lectures

Friday, 13-14 — exercise sessions, Federica Cecchetto

Office hours,16-18 — office hours, please register one day before

- 10 minutes break, if you do not agree please complain now.
- Type G— single group in exercise sessions.
- Any deviation will be communicated: Friday 26.02 — lecture

Dates and times

Volume: 3h/week—type G

Wednesday, 16-18 — lectures

Friday, 13-14 — exercise sessions, Federica Cecchetto

Office hours,16-18 — office hours, please register one day before

- 10 minutes break, if you do not agree please complain now.
- Type G— single group in exercise sessions.
- Any deviation will be communicated: Friday 26.02 — lecture

Dates and times

Volume: 3h/week—type G

Wednesday, 16-18 — lectures

Friday, 13-14 — exercise sessions, Federica Cecchetto

Office hours,16-18 — office hours, please register one day before

- 10 minutes break, if you do not agree please complain now.
- Type G— single group in exercise sessions.
- Any deviation will be communicated: Friday 26.02 — lecture

Dates and times

Volume: 3h/week—type G

Wednesday, 16-18 — lectures

Friday, 13-14 — exercise sessions, Federica Cecchetto

Office hours,16-18 — office hours, please register one day before

- 10 minutes break, if you do not agree please complain now.
- Type G— single group in exercise sessions.
- Any deviation will be communicated: Friday 26.02 — lecture

PERFORMANCE ASSESSMENT

Type: end-of-semester examination

- Exam will take place between Monday, May 24 (calendar week 21) up until and including Friday, June 18 (calendar week 24)

Repetition of the exam:

- Possible to repeat without having to re-enroll in a course.
- A repetition date, in first two weeks of the Fall semester.
- The repetition may not be used as alternative for the first attempt.
- Students must register for such a repetition date using myStudies.
- Possible once the result of their first try has been officially announced.

Legal basis: `https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/end-of-semester-examinations.pdf`

Performance assessment

Type: end-of-semester examination

- Exam will take place between Monday, May 24 (calendar week 21) up until and including Friday, June 18 (calendar week 24)

Repetition of the exam:

- Possible to repeat without having to re-enroll in a course.
- A repetition date, in first two weeks of the Fall semester.
- The repetition may not be used as alternative for the first attempt.
- Students must register for such a repetition date using myStudies.
- Possible once the result of their first try has been officially announced.

Legal basis: `https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/end-of-semester-examinations.pdf`

Performance assessment

Type: end-of-semester examination

- Exam will take place between Monday, May 24 (calendar week 21) up until and including Friday, June 18 (calendar week 24)

Repetition of the exam:

- Possible to repeat without having to re-enroll in a course.
- A repetition date, in first two weeks of the Fall semester.
- The repetition may not be used as alternative for the first attempt.
- Students must register for such a repetition date using myStudies.
- Possible once the result of their first try has been officially announced.

Legal basis: `https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/end-of-semester-examinations.pdf`

Performance assessment

Type: end-of-semester examination

- Exam will take place between Monday, May 24 (calendar week 21) up until and including Friday, June 18 (calendar week 24)

Repetition of the exam:

- Possible to repeat without having to re-enroll in a course.
- A repetition date, in first two weeks of the Fall semester.
- The repetition may not be used as alternative for the first attempt.
- Students must register for such a repetition date using myStudies.
- Possible once the result of their first try has been officially announced.

Legal basis: `https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/end-of-semester-examinations.pdf`

PERFORMANCE ASSESSMENT

Type: end-of-semester examination

- Exam will take place between Monday, May 24 (calendar week 21) up until and including Friday, June 18 (calendar week 24)

Repetition of the exam:

- Possible to repeat without having to re-enroll in a course.
- A repetition date, in first two weeks of the Fall semester.
- The repetition may not be used as alternative for the first attempt.
- Students must register for such a repetition date using myStudies.
- Possible once the result of their first try has been officially announced.

Legal basis: https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/end-of-semester-examinations.pdf

Performance assessment

Type: end-of-semester examination

- Exam will take place between Monday, May 24 (calendar week 21) up until and including Friday, June 18 (calendar week 24)

Repetition of the exam:

- Possible to repeat without having to re-enroll in a course.
- A repetition date, in first two weeks of the Fall semester.
- The repetition may not be used as alternative for the first attempt.
- Students must register for such a repetition date using myStudies.
- Possible once the result of their first try has been officially announced.

Legal basis: `https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/end-of-semester-examinations.pdf`

PERFORMANCE ASSESSMENT

Type: end-of-semester examination

- Exam will take place between Monday, May 24 (calendar week 21) up until and including Friday, June 18 (calendar week 24)

Repetition of the exam:

- Possible to repeat without having to re-enroll in a course.
- A repetition date, in first two weeks of the Fall semester.
- The repetition may not be used as alternative for the first attempt.
- Students must register for such a repetition date using myStudies.
- Possible once the result of their first try has been officially announced.

Legal basis: `https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/end-of-semester-examinations.pdf`

EXAM

Exam:

- Written 120-180 minutes.
- Similar to problem sets/exercises in the script.
- The course is taught for the first time—no previous exams.
- Mock exam will be published two weeks before end of the semester.
- No coding exercises on the exam.

EXAM

Exam:

- Written 120-180 minutes.
- Similar to problem sets/exercises in the script.
- The course is taught for the first time—no previous exams.
- Mock exam will be published two weeks before end of the semester.
- No coding exercises on the exam.

EXAM

Exam:

- Written 120-180 minutes.
- Similar to problem sets/exercises in the script.
- The course is taught for the first time—no previous exams.
- Mock exam will be published two weeks before end of the semester.
- No coding exercises on the exam.

Exam

Exam:

- Written 120-180 minutes.
- Similar to problem sets/exercises in the script.
- The course is taught for the first time—no previous exams.
- Mock exam will be published two weeks before end of the semester.
- No coding exercises on the exam.

Exam

Exam:

- Written 120-180 minutes.
- Similar to problem sets/exercises in the script.
- The course is taught for the first time—no previous exams.
- Mock exam will be published two weeks before end of the semester.
- No coding exercises on the exam.

Continuous performance assessment

Type: c. Learning tasks

- Not mandatory, possible grade upgrade.

Exercise session:

- Volunteers can present solutions in the exercise sessions.
- Can improve the total course unit grade by up to 0.25 grade points.
- Students can still achieve the maximum grade of 6 with the exam only.
- 2 smaller or 1 big exercise is enough.

- Solutions to exercises can be uploaded and corrected, but no grade bonus is offered.

Legal basis: `https://www.ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/directive-continuous-performance-assessment.pdf`

Continuous performance assessment

Type: c. Learning tasks

- Not mandatory, possible grade upgrade.

Exercise session:

- Volunteers can present solutions in the exercise sessions.
- Can improve the total course unit grade by up to 0.25 grade points.
- Students can still achieve the maximum grade of 6 with the exam only.
- 2 smaller or 1 big exercise is enough.

- Solutions to exercises can be uploaded and corrected, but no grade bonus is offered.

Legal basis: `https://www.ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/directive-continuous-performance-assessment.pdf`

CONTINUOUS PERFORMANCE ASSESSMENT

Type: c. Learning tasks

- Not mandatory, possible grade upgrade.

Exercise session:

- Volunteers can present solutions in the exercise sessions.
- Can improve the total course unit grade by up to 0.25 grade points.
- Students can still achieve the maximum grade of 6 with the exam only.
- 2 smaller or 1 big exercise is enough.

- Solutions to exercises can be uploaded and corrected, but no grade bonus is offered.

Legal basis: `https://www.ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/directive-continuous-performance-assessment.pdf`

CONTINUOUS PERFORMANCE ASSESSMENT

Type: c. Learning tasks

- Not mandatory, possible grade upgrade.

Exercise session:

- Volunteers can present solutions in the exercise sessions.
- Can improve the total course unit grade by up to 0.25 grade points.
- Students can still achieve the maximum grade of 6 with the exam only.
- 2 smaller or 1 big exercise is enough.

- Solutions to exercises can be uploaded and corrected, but no grade bonus is offered.

Legal basis: `https://www.ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/directive-continuous-performance-assessment.pdf`

CONTINUOUS PERFORMANCE ASSESSMENT

Type: c. Learning tasks

- Not mandatory, possible grade upgrade.

Exercise session:

- Volunteers can present solutions in the exercise sessions.
- Can improve the total course unit grade by up to 0.25 grade points.
- Students can still achieve the maximum grade of 6 with the exam only.
- 2 smaller or 1 big exercise is enough.

- Solutions to exercises can be uploaded and corrected, but no grade bonus is offered.

Legal basis: `https://www.ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/directive-continuous-performance-assessment.pdf`

CONTINUOUS PERFORMANCE ASSESSMENT

Type: c. Learning tasks

- Not mandatory, possible grade upgrade.

Exercise session:

- Volunteers can present solutions in the exercise sessions.
- Can improve the total course unit grade by up to 0.25 grade points.
- Students can still achieve the maximum grade of 6 with the exam only.
- 2 smaller or 1 big exercise is enough.

- Solutions to exercises can be uploaded and corrected, but no grade bonus is offered.

Legal basis: `https://www.ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-en/directive-continuous-performance-assessment.pdf`

MATERIALS

Script:

- New chapter of the script is updated on Friday evening. Available on Moodle.

Notes:

- After every lecture, the handwritten notes will be uploaded.

Templates:

- Before every lecture, a template to do your own notes will be published.

Solutions:

- Problems that will be solved during the problem set sessions are listed in the script under the environment ”Exercise”.
- Problems will be solved during the exercise sessions and also available in the script after solving them in the exercise sessions.

Recordings:

- After every lecture, the lecture videos will be uploaded.

MATERIALS

Script:

- New chapter of the script is updated on Friday evening. Available on Moodle.

Notes:

- After every lecture, the handwritten notes will be uploaded.

Templates:

- Before every lecture, a template to do your own notes will be published.

Solutions:

- Problems that will be solved during the problem set sessions are listed in the script under the environment "Exercise".
- Problems will be solved during the exercise sessions and also available in the script after solving them in the exercise sessions.

Recordings:

- After every lecture, the lecture videos will be uploaded.

MATERIALS

Script:

- New chapter of the script is updated on Friday evening. Available on Moodle.

Notes:

- After every lecture, the handwritten notes will be uploaded.

Templates:

- Before every lecture, a template to do your own notes will be published.

Solutions:

- Problems that will be solved during the problem set sessions are listed in the script under the environment "Exercise".
- Problems will be solved during the exercise sessions and also available in the script after solving them in the exercise sessions.

Recordings:

- After every lecture, the lecture videos will be uploaded.

MATERIALS

Script:

- New chapter of the script is updated on Friday evening. Available on Moodle.

Notes:

- After every lecture, the handwritten notes will be uploaded.

Templates:

- Before every lecture, a template to do your own notes will be published.

Solutions:

- Problems that will be solved during the problem set sessions are listed in the script under the environment ”Exercise”.
- Problems will be solved during the exercise sessions and also available in the script after solving them in the exercise sessions.

Recordings:

- After every lecture, the lecture videos will be uploaded.

MATERIALS

Script:

- New chapter of the script is updated on Friday evening. Available on Moodle.

Notes:

- After every lecture, the handwritten notes will be uploaded.

Templates:

- Before every lecture, a template to do your own notes will be published.

Solutions:

- Problems that will be solved during the problem set sessions are listed in the script under the environment ”Exercise”.
- Problems will be solved during the exercise sessions and also available in the script after solving them in the exercise sessions.

Recordings:

- After every lecture, the lecture videos will be uploaded.

PREREQUISITES

Formally no prerequisites.

Desirable: background in

- linear programming
- integer programming

PREREQUISITES

Formally no prerequisites.

Desirable: background in

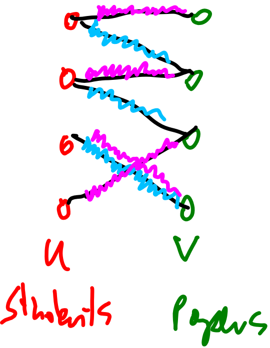
- linear programming
- integer programming

LP

LP is a very a powerful technique.

Input: $G(U \cup V, E)$

Output: max cardinality matching



WHAT?

Question: *Is there life beyond LP methods?*

WHAT?

Question: *Is there life beyond LP methods?*

Goal: Broad exposition to mathematical optimization methods.

WHAT?

Question: *Is there life beyond LP methods?*

Goal: Broad exposition to mathematical optimization methods.

LP

Mathematical Optimization

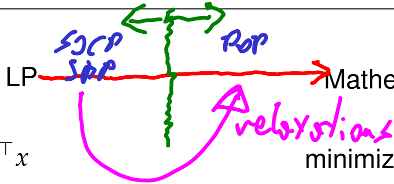
minimize $c^\top x$

subject to $a_i^\top x \leqslant b_i$ for $i \in [m]$

WHAT?

Question: *Is there life beyond LP methods?*

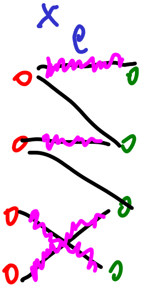
Goal: Broad exposition to mathematical optimization methods.



minimize $c^\top x$
subject to $a_i^\top x \leqslant b_i$ for $i \in [m]$

minimize $f_0(x)$
subject to $f_i(x) \leqslant b_i$ for $i \in [m]$

for $f_0, f_i : \mathbb{R}^n \to \mathbb{R}$



Why?

$$\max \sum_{e \in E} x_e$$

$$\sum_{e \in \delta(v)} x_e \leq 1 \quad \forall v \in V$$

$$x_e \in \{0,1\} \quad \forall e \in E$$

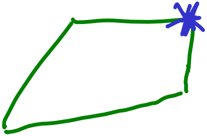
$$x_e \in [0,1] \quad \forall e \in E$$

$Ax \leq b$

TU

Challenges for LP

- LP relaxation might not be tight
- Problems might just have nonlinear nature



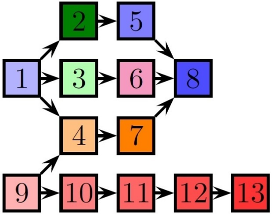
WHY?

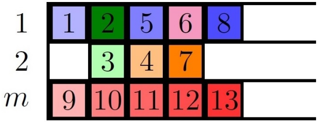
Challenges for LP

- LP relaxation might not be tight
- Problems might just have nonlinear nature

WHY?

Scheduling with precedence constraints.



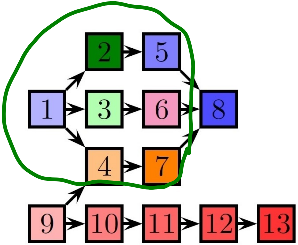


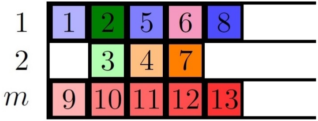
- Garey, Johnson **OPEN8**
- Greedy

https://sites.math.washington.edu/~rothvoss/publications.html

WHY?

Scheduling with precedence constraints.



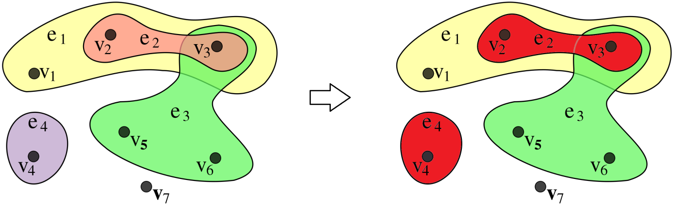


- Garey, Johnson **OPEN8**
- Greedy

https://sites.math.washington.edu/~rothvoss/publications.html

WHY?

Hypergraph matching

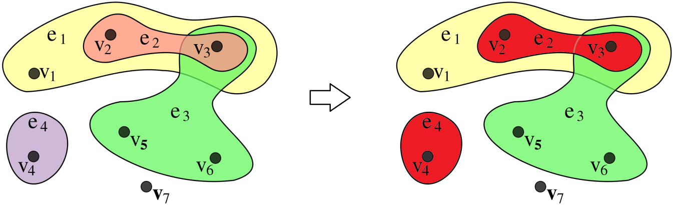


- $\frac{k+1+\epsilon}{3}$-approximation
- Local Search

https://en.wikipedia.org/wiki/Hypergraph

Why?

Hypergraph matching



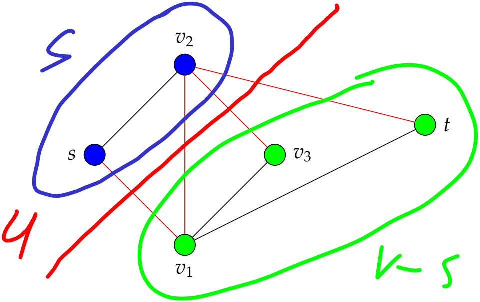
- $\frac{k+1+\epsilon}{3}$-approximation
- Local Search

$\frac{k+1}{2}$

https://en.wikipedia.org/wiki/Hypergraph

WHY?

Max-Cut problem

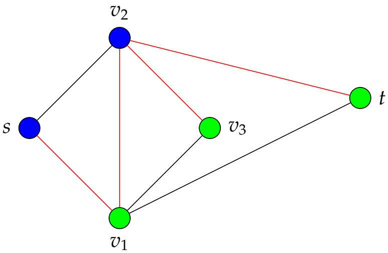


Input: G(V,E)
Output:
S ⊆ V:
cut (S, V-S)
is max.

- ≈ 0.878-approximation
- Mathematical Programming

WHY?

Max-Cut problem

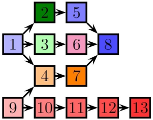


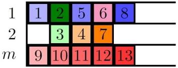
- ≈ 0.878-approximation   SDP
- Mathematical Programming

WHY?

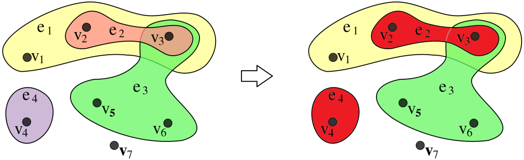
Do we really need LP and mathematical optimization methods?

OPTIMIZATION PROBLEMS

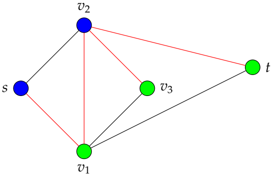




- Garey, Johnson **OPEN8**
- Greedy



- $\frac{k+1+\epsilon}{3}$-approximation
- Local Search



- ≈ 0.878-approximation
- Math. Prog.

OPTIMIZATION PROBLEMS

Garey, Johnson **OPEN8**

Greedy

$\frac{k+1+\epsilon}{3}$ approximation

Local Search

$\approx$ 0.878-approximation

Math. Prog.

WHY?

Do we really need LP and mathematical optimization methods?

WHY?

Do we really need LP and mathematical optimization methods?

They are much easier to use than tailor made algorithms.

WHY?

Do we really need LP and mathematical optimization methods?

They are much easier to use than tailor made algorithms.

	Single User	Floating	Server Single Socket	Server Dual Socket	Server Quad Socket
AMPL	**$4000**	**$6000**	**$8000**	**$14000**	**$24000**
Linear-quadratic solvers:					
CPLEX	$9500	$14500	*Contact us for details*		
Gurobi *	$10000	$20000	*Contact us for details*		
Xpress	$8000	$12000	$16000	$32000	$64000

WHAT?

LP/CP

⇓

SOCP

⇓

SDP

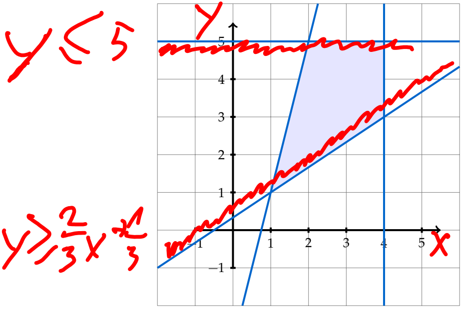
⇓

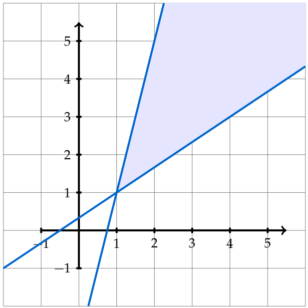
POP $\leftrightarrow$ Nonnegativity

⇓

Convex relaxations
(SOCP, SDP)

INEQUALITY VS VERTEX REPRESENTATION

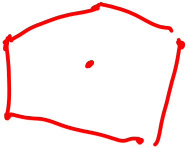




Inequality representation

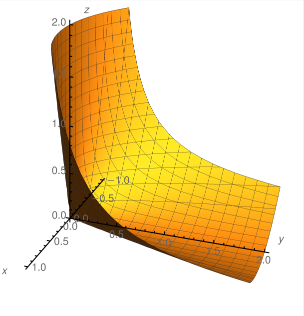
Vertex representation

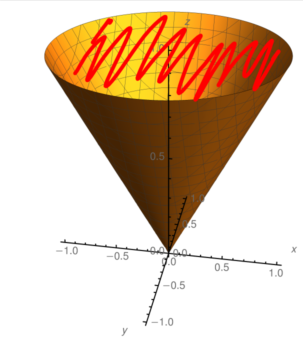
$$\begin{array}{ll} \text{minimize} & c^\top x \\ \text{subject to} & a_i^\top x \leqslant b_i \text{ for } i \in [m] \end{array}$$



SoCP

Lorentz cone.





APPLICATION

Markowitz portfolio optimization

Input: n assets, budget B, predicted change in price $p \in \mathbb{R}^n$.
Output: Portfolio of assets maximizing the profit.

$p_i = 2$

$\max p^T x$

$\mathbb{1}^T x = B \quad \sum_{i \in [n]} x_i = B$

$x_i \geq 0 \quad \forall i \in [n]$

$x_i \leq \frac{B}{10}$

Input: n assets, budget B, predicted mean change in price $\overline{p} \in \mathbb{R}^n$, covariance matrix Σ.
Output: Portfolio of assets minimizing the risk (variance), for expected profit at least r.

APPLICATION

Markowitz portfolio optimization

Input: n assets, budget B, predicted change in price $p \in \mathbb{R}^n$.
Output: Portfolio of assets maximizing the profit.

Input: n assets, budget B, predicted mean change in price $\bar{p} \in \mathbb{R}^n$, covariance matrix Σ.
Output: Portfolio of assets minimizing the risk (variance), for expected profit at least r.

$$\min \; x^T \Sigma x$$

$$\bar{p} x \geq r$$

$$\mathbb{1}^T x = B$$

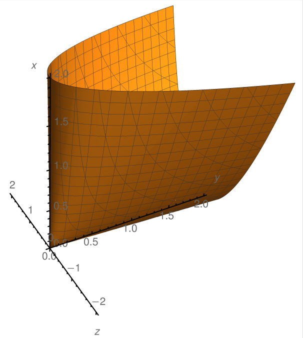
$$x_i \geq 0 \quad \forall i \in [n]$$

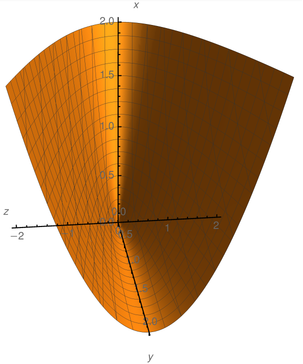
QP

SOCP

SDP

Cone of PSD matrices.

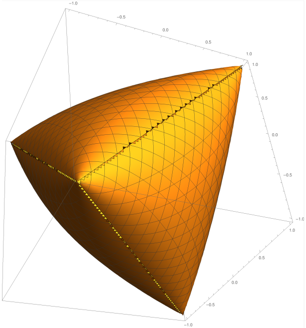


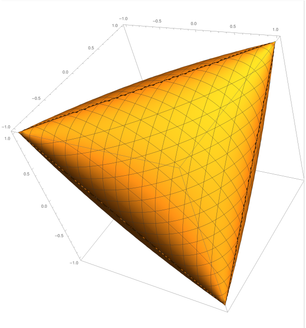


$$\left\{ (x,y,z) \in \mathbb{R}^3 : \begin{bmatrix} x & z \\ z & y \end{bmatrix} \succeq 0 \right\}$$

SDP

Eliptop



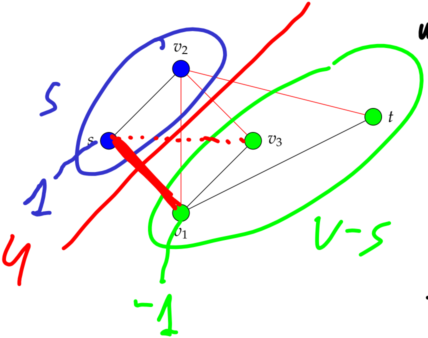


$$\left\{ X \in \mathbb{R}^6 : \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{12} & x_{22} & x_{23} \\ x_{13} & x_{23} & x_{33} \end{bmatrix} \succeq 0,\ x_{11} = x_{22} = x_{33} = 1 \right\}$$

APPLICATION

Max-Cut problem

Input: Undirected graph $G(V, E)$.
Output : Cut $S \in V$ that maximizes size of the cut $S, V \setminus S$.



$$\sum_{u,v:(u,v)\in E} \frac{1}{2}(1 - x_u x_v)$$

1 if $(u,v) \in (S, V-S)$
0 o.w.

$$x_v \in \{-1, 1\} \quad \forall v \in V$$

SDP → 0.878

LP → 0.5

POP

Polynomial Optimization

$$\begin{array}{ll} \text{minimize} & f_0(x) \\ \text{subject to} & f_i(x) \leqslant b_i \text{ for } i \in [m] \end{array}$$

for $f_0, f_i \in \mathbb{R}[x_1, \ldots, x_n]$

Captures:

- All the combinatorial problems listed above.
- SOCP
- SDP
- Many others

POP

Polynomial Optimization

$$\begin{aligned} \text{minimize} \quad & f_0(x) \\ \text{subject to} \quad & f_i(x) \leqslant b_i \text{ for } i \in [m] \end{aligned}$$

for $f_0, f_i \in \mathbb{R}[x_1, \ldots, x_n]$

Captures:

- All the combinatorial problems listed above.
- SOCP
- SDP
- Many others

$x_i \in \{0, 1\}$

$x_i^2 - x_i \geq 0$, $x_i^2 - x_i \leq 0$ $\Rightarrow$ $x_i^2 - x_i = 0$

$x_i = 1 \quad x_i = 0$

POP

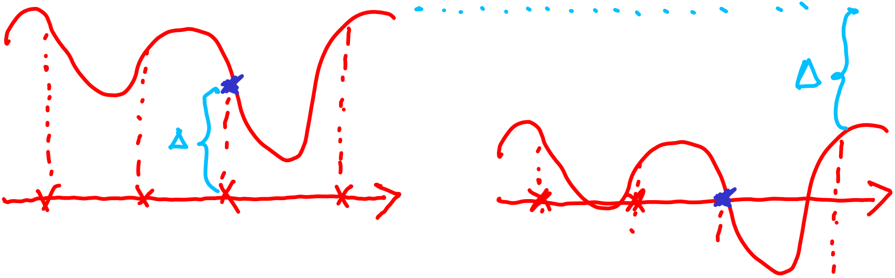
Where is a catch?

It is not convex.

POP

Where is a catch?

It is not convex.

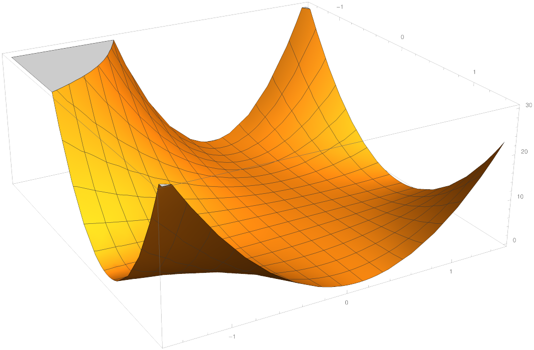


CONNECTION TO NONNEGATIVITY

Is $9x^2y^2 - 6x^2y + x^2 - 6xy^2 + 8xy - 2x + y^2 - 2y + 1$ *nonnegative?*

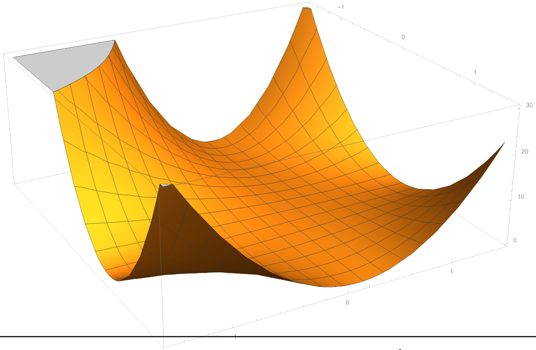
CONNECTION TO NONNEGATIVITY

Is $9x^2y^2 - 6x^2y + x^2 - 6xy^2 + 8xy - 2x + y^2 - 2y + 1$ *nonnegative?*



Connection to nonnegativity

Is $9x^2y^2 - 6x^2y + x^2 - 6xy^2 + 8xy - 2x + y^2 - 2y + 1$ *nonnegative?*



$$(-3xy + x + y - 1)^2 \geq 0 \quad \forall x, y \in \mathbb{R}$$

HILBERT'S 17TH QUESTION

Is every nonnegative polynomial an SoS polynomial?

Motzkin: $M(x,y) := x^4y^2 + x^2y^4 - 3x^2y^2 + 1$

Is every nonnegative polynomial an SoS of rational functions?

HILBERT'S 17TH QUESTION

Is every nonnegative polynomial an SoS polynomial? NO

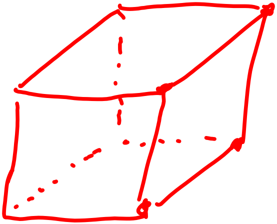
Motzkin: $M(x,y) := x^4y^2 + x^2y^4 - 3x^2y^2 + 1$

Is every nonnegative polynomial an SoS of rational functions? YES

Artin 27'

POSITIVESTELLENSATZ

Good news: Every polynomial nonnegative on a "nice" subset of $\mathbb{R}^n$ has SoS certificate of nonnegativity.



$x_i \in \{0, 1\}$

Moreover: It can be found efficiently using Semidefinite programming.

POSITIVESTELLENSATZ

Good news: Every polynomial nonnegative on a “nice” subset of $\mathbb{R}^n$ has SoS certificate of nonnegativity.

Moreover: It can be found efficiently using Semidefinite programming.

OTHER CERTIFICATES

Is SoS the only option?

We will look for other families of nonnegative polynomials such that:

- Efficient optimization over their cone is possible
- Provide “tight” relaxations for Polynomial Optimization Problems.

Polýa Positivestellensatz: Optimization free technique.

OTHER CERTIFICATES

Is SoS the only option?

We will look for other families of nonnegative polynomials such that:

- Efficient optimization over their cone is possible
- Provide “tight” relaxations for Polynomial Optimization Problems.

Polýa Positivestellensatz: Optimization free technique.

OTHER CERTIFICATES

Is SoS the only option?

We will look for other families of nonnegative polynomials such that:

- Efficient optimization over their cone is possible
- Provide “tight” relaxations for Polynomial Optimization Problems.

Polýa Positivestellensatz: Optimization free technique.

APPLICATIONS

Applications:

Combinatorial optimization

- Min $s-t$ Cut
- Max Cut
- scheduling with precedence constraints

Control Theory

- Stability criteria

Finance

- Variants of Markowitz portfolio optimization

APPLICATIONS

Applications:

Combinatorial optimization

- Min $s - t$ Cut
- Max Cut
- scheduling with precedence constraints

Control Theory

- Stability criteria

Finance

- Variants of Markowitz portfolio optimization

Applications

Applications:

Combinatorial optimization

- Min $s - t$ Cut
- Max Cut
- scheduling with precedence constraints

Control Theory

- Stability criteria

Finance

- Variants of Markowitz portfolio optimization

SUMMARY

Lectures

- Have script during the lectures.
- The lectures complement the script.
- Reading additional literature recommended.

Exercise sessions and office hours

- 0.25 grade points for active participation.
- Attend, working systematically is the key to success.
- Ask for office hours to further clarify things.
- Cooperate with colleagues.

Further questions

- Talk to me or TA, directly or by email.

SUMMARY

Lectures

- Have script during the lectures.
- The lectures complement the script.
- Reading additional literature recommended.

Exercise sessions and office hours

- 0.25 grade points for active participation.
- Attend, working systematically is the key to success.
- Ask for office hours to further clarify things.
- Cooperate with colleagues.

Further questions

- Talk to me or TA, directly or by email.

SUMMARY

Lectures

- Have script during the lectures.
- The lectures complement the script.
- Reading additional literature recommended.

Exercise sessions and office hours

- 0.25 grade points for active participation.
- Attend, working systematically is the key to success.
- Ask for office hours to further clarify things.
- Cooperate with colleagues.

Further questions

- Talk to me or TA, directly or by email.

Thank you