



# Convex Algebraic Geometry and Polynomial Optimization

Bridging Real Algebraic Geometry & Semidefinite Programming

|         |                                               |           |                                                               |
|---------|-----------------------------------------------|-----------|---------------------------------------------------------------|
| Dates:  | February 1 – February 5, 2027                 | Venue:    | IIT Kharagpur, West Bengal, India                             |
| Format: | 20 Hours Lectures + 5 Lab Sessions (10 Hours) | Audience: | Graduate Students & Researchers in Control, Optimization & ML |

## 01. WORKSHOP OVERVIEW

This intensive workshop bridges classical real algebraic geometry with modern computational semidefinite programming (SDP). Designed for graduate students and researchers in Control Engineering, Optimization, and Machine Learning, it covers theoretical guarantees of positivity certificates and demonstrates how to exploit algebraic structures to bypass traditional computational scaling barriers.

## 02. RESOURCE PERSONS & SPEAKERS

### MAIN SPEAKER

**Prof. Harish Pillai**

Dept. of Electrical Engineering  
IIT Bombay

### CO-ORGANIZER & LECTURER

**Dr. Swanand R. Khare**

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### CO-ORGANIZER & LECTURER

**Dr. Mousumi Mandal**

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## 03. LECTURE SCHEDULE & COMPREHENSIVE SYLLABUS

| Part 1: Real-World Applications & Positivity Foundations (7 Hours)     |                                        |                                                                                |
|------------------------------------------------------------------------|----------------------------------------|--------------------------------------------------------------------------------|
| Hour                                                                   | Module / Topic                         | Detailed Contents & Key Concepts                                               |
| Hours 1-2                                                              | PMO Gallery & Semialgebraic Geometry   | Case studies in control/ML; global optimization & NP-hardness.                 |
| Hours 3-4                                                              | SOS Certificates & 1D/2D Hand-Solving  | SOS polynomials, Hilbert's 1888 theorem, Gram SDPs & Sylvester criterion.      |
| Hours 5-6                                                              | Basis Reduction & SOS Factorization    | Newton Polytope basis pruning & Cholesky factorization of Gram matrices.       |
| Hour 7                                                                 | Matrix-Valued SOS Constraints          | Transitioning to matrix polynomials and non-linear LMIs.                       |
| Part 2: The Dual Universe & The Moment Problem (6 Hours)               |                                        |                                                                                |
| Hour                                                                   | Module / Topic                         | Detailed Contents & Key Concepts                                               |
| Hours 8-9                                                              | Riesz Functionals & Moment Matrix      | Moment sequences, Hankel-structured moment matrices & cone duality.            |
| Hours 10-11                                                            | Putinar's Theorem & Lasserre Hierarchy | Localizing matrices, Archimedean property & primal-dual relaxations.           |
| Hour 12                                                                | Dual Point Extraction                  | Curto-Fialkow flat extension theorem & Henrion-Lasserre algorithm.             |
| Part 3: Advanced Coordinate Rings & Rekha Thomas's Framework (7 Hours) |                                        |                                                                                |
| Hour                                                                   | Module / Topic                         | Detailed Contents & Key Concepts                                               |
| Hours 13-15                                                            | Obstructions & Theta Bodies $TH_k(I)$  | Odd-degree stalls, spectrahedra, and constructing first Theta Body $TH_1(I)$ . |
| Hours 16-17                                                            | Facial Topology & Semidefinite Lifting | Extreme rays, determinantal varieties & symbolic null-space matrix systems.    |
| Hours 18-20                                                            | Sparsity, Symmetry & Future Horizons   | Chordal decomposition, symmetry reduction, non-commutative SOS & DRO.          |

## 04. HANDS-ON LABORATORY SYLLABUS (5 SESSIONS)

| Session        | Lab Focus & Title                 | Practical Scope & Software Tools                                                            |
|----------------|-----------------------------------|---------------------------------------------------------------------------------------------|
| Lab 1 & 2 (4h) | Setup, Verification & ROA Control | YALMIP/SOSTOOLS/MOSEK toolchain & Lyapunov function synthesis for non-linear control.       |
| Lab 3 & 4 (4h) | Theta Bodies & Neural Net Safety  | Determinantal variety lifting & structured matrix approximations for deep net verification. |
| Lab 5 (2h)     | Large-Scale Scalability           | Chordal graph decomposition & block-diagonal symmetry reduction for high-dim systems.       |

### Registration & Contact Information

Registration is open to graduate students, researchers, and professionals in Control, Optimization, and Machine Learning.  
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