Post-graduate Admissions Summer 2022: Syllabus and Resources

**Post-graduate Admissions Summer 2022: Syllabus and Study Material**

This document lists the syllabus and study material for the Summer 2022 PG admissions test, which will be held May 2, 2022.

**Streams and Panels**

Topics are placed under three high-level *streams*: namely Computing Systems, Intelligent Systems, and Theoretical Systems. Each stream has 2-3 *panels*, as listed below.

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| **Stream** | **Panel** |
| Computing Systems | Software Engineering, Compilers, Programming Languages |
| Systems Software |
| Hardware and Security |
| Intelligent Systems | AI/ML (NLP, Speech, Text) |
| AI/ML (Representation, Learning, Agents) |
| Visual Computing |
| Theoretical Systems | Algorithms, Complexity, Cryptography |
| Formal methods |
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**Test Format**

The test will comprise a set of questions from each of the eight panels. The next section specifies the modules included under each panel.

Each panel will have a set of 8 or more questions. There will be at least 1 question (and possibly more) from each module in this set.

Each question will carry 10 marks. Applicants may answer up to 8 questions (for a total of 80 marks) in each panel that they attempt. If they answer more than 8 questions, any 8 will be selected for evaluation (and the rest ignored).

Students applying to the Ph.D. programme must only answer questions from the *panels* (either one or two) that they have selected in their application. Answers to questions from any other panels will not be evaluated. Their score from each panel (out of 80) will be taken into account towards shortlisting for that panel.

Students applying to the M.S. programme must only answer questions from the *stream* that they have selected in their application. Answers to questions from any other streams will not be evaluated. Within the chosen stream, M.S. applicants may answer up to 12 questions (for a total of 120 marks), subject to answering at most 8 questions from each constituent panel. For example, an M.S. applicant for the Computing Systems stream may answer 6, 2, and 4 questions from its constituent panels. If they answer more than 12 questions, any 12 will be selected for evaluation (and the rest ignored). Their score from the stream (out of 120) will be taken into account towards shortlisting.

**Topics and Study Material**

This section specifies the modules listed under each panel, along with associated topics. Questions will test the applicants’ conceptual understanding of these topics. Study material is provided to help the applicants’ preparation. It is to be treated as a collection of relevant references, and *not* as the definitive syllabus for the test. Applicants are free to prepare for each module using alternative material that may be considered equivalent to the resources provided.

**Computing Systems::Software Engineering, Compilers, Programming Languages**

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| **Module** | **Topics** | **Study Material** |
| Compilers and Programming Languages | Lexical analysis, Syntax analysis, Static semantics, Runtime support, Spim assembly language | *Compilers: Principles, Techniques, and Tools*, Alfred V. Aho, Monica S. Lam, Ravi Sethi, and Jeffrey D. Ullman, 2006 (2nd edition): Sections 1.1, 1.2, 1.6, 3.1, 3,2, 3.4.4, 3.5, 3.6, 3.8.1, 3.8.3, 4.1, 4.2, 4.3, 4.4, 4.5,4.6, 5.1, 5.2, 5.3, 5.4, 6.1, 6.2, 6.3, 6.4, 6.5.1, 6.5.2, 6.9, 7.1, 7.2.2, 7.2.3.  [SPIM: A MIPS32 Simulator](https://www.google.com/url?q=http://spimsimulator.sourceforge.net/&sa=D&source=editors&ust=1650864326540036&usg=AOvVaw2m1wNGisDWXqvbwZhfRpJ5). |
| Software Engineering | Research article comprehension, Discrete structures, Logic and automata, Programming, Program comprehension in C/C++, Model comprehension for models in notations such as ER diagrams, flowcharts, and UML. | *The C++ Programming Language*, Bjarne Stoustrup, 2013 (4th edition).  *Mathematics : A Discrete Introduction*, Edward R. Scheinerman, 2012 (3rd edition).  *Towards a method of programming with assertions*, David S. Rosenblum, In Proceedings of the 14th International Conference on Software Engineering (ISCE ‘92), pages 92-104, ACM, 1992. [On-line version](https://www.google.com/url?q=https://dl.acm.org/doi/10.1145/143062.143098&sa=D&source=editors&ust=1650864326541858&usg=AOvVaw1YlqFpjyUF_pjH2xLSpycE).  *Writing Good Software Engineering Research Papers*, Mary Shaw, In Proceedings of the 25th International Conference on Software Engineering (ISCE ‘03), pages 726-736, IEEE, 2003. [On-line version](https://www.google.com/url?q=https://www.cs.cmu.edu/~Compose/shaw-icse03.pdf&sa=D&source=editors&ust=1650864326542463&usg=AOvVaw1Y3VNQIWaDGsDQUMC_K3Ad).  *Applying Design by Contract*, Bertrand Meyer, IEEE Computer 25(10): 40-51, 1992. [On-line version](https://www.google.com/url?q=http://se.ethz.ch/~meyer/publications/computer/contract.pdf&sa=D&source=editors&ust=1650864326543005&usg=AOvVaw1btK5vboQagj9o2r523u44).  *State Charts: A visual formalism for complex systems*, David Harrel, Science of Computer Programming 8(3): 231-274, 1987. [On-line version](https://www.google.com/url?q=https://www.wisdom.weizmann.ac.il/~harel/SCANNED.PAPERS/Statecharts.pdf&sa=D&source=editors&ust=1650864326543560&usg=AOvVaw2-Jg-dl7xypvgZaQ6MiL4w).  [OMG UML Specification](https://www.google.com/url?q=http://www.omg.org&sa=D&source=editors&ust=1650864326544041&usg=AOvVaw3faAheBEpT9yXHiQXOmeVy), 2015. |

**Computing Systems::Systems Software**

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| **Module** | **Topics** | **Study Material** |
| Operating Systems | Processes, System calls and interrupts, CPU scheduling, Memory management via paging and demand paging, Threads and concurrency, Condition variables and semaphores for synchronization, I/O and filesystems. | [Lectures on Operating Systems](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~mythili/os/&sa=D&source=editors&ust=1650864326546430&usg=AOvVaw2gD6CVi0jmF6N7NVcVsCA2) by Mythili Vutukuru.  *Operating Systems: Three Easy Pieces*, Remzi H. Arpaci-Dusseau and Andrea C. Arpaci-Dusseau, [on-line textbook](https://www.google.com/url?q=https://pages.cs.wisc.edu/~remzi/OSTEP/&sa=D&source=editors&ust=1650864326547012&usg=AOvVaw0I6B1lAYBf3YZLwlhxp2EZ). |
| C/C++ Programming and Data structures | Programming in C/C++, Recursion, Arrays, Stacks, Queues, Linked lists, Trees, Binary search trees, Binary heaps, Graphs, Searching, Sorting, Hashing. | *Introduction to Programming through C++:*[*NPTEL course*](https://www.google.com/url?q=https://www.youtube.com/playlist?list%3DPLOzRYVm0a65eklyMDXGSWObRA-7lCdkSm&sa=D&source=editors&ust=1650864326548079&usg=AOvVaw2gHYhF31KTSybUPHg0WYap)*by Abhiram Ranade.*[*Companion textbook*](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~ranade/book.html&sa=D&source=editors&ust=1650864326548303&usg=AOvVaw3ykNZH9Qx1kjCmcGoLnyG7)*.*  *Data Structures and Algorithms,*[*NPTEL course*](https://www.google.com/url?q=https://www.youtube.com/playlist?list%3DPLBF3763AF2E1C572F&sa=D&source=editors&ust=1650864326548866&usg=AOvVaw3tG35MEIACTJxKOxpqZrDU)*by Naveen Garg.* |
| Computer Networks | Layering, Packet switching, Application layer protocols (HTTP, DNS, etc.), Transport layer protocols (TCP, UDP), IP addressing, Routing and forwarding, Medium Access Control, Data link layer, Physical layer. | [Lectures on Computer Networks](https://www.google.com/url?q=https://www.youtube.com/channel/UC9KOS69Po018NGKJsR2RgrA/playlists?view%3D50%26sort%3Ddd%26shelf_id%3D2&sa=D&source=editors&ust=1650864326549886&usg=AOvVaw0skBLXCG7gFEP0o0Xw4aOk) by Kameswari Chebrolu. |
| Computer Architecture | ISA vs. microarchitecture, Instruction pipelining, Pipeline hazards and mitigations, Branch prediction, Interrupt/exception handling, Memory hierarchy, Caches: mapping techniques, types of misses, design trade-offs (line-size, associativity, cache size), virtual caches, cache optimizations, Superscalar and out-of-order processors, Amdahl’s law and its implications. | [*Computer Architecture*](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~biswa/courses/CS305/schedule.html&sa=D&source=editors&ust=1650864326550990&usg=AOvVaw1D7H5tvln1_YEFP5E3mrJ9)*course offered by Biswabandan Panda: Lectures*9-27 and 30-36.  *Computer Organization and Design*, David A. Patterson and John L. Hennessy, 5th edition (2014): Chapters/sections 1.6-1.10, 2.10, 2.17-2.19, 4.1-4.10, 5.1-5.4, 5.7, 5.8.  *Computer Architecture: A Quantitative Approach*, John L. Hennessy and David A. Patterson, 6th edition (2018): Chapters/sections 2.3, 3.3. |
| Databases | ER-model, Relational model: relational algebra, tuple calculus, SQL, Integrity constraints, Normal forms, File organization, Indexing (e.g., B and B+ trees), Transactions and concurrency control. | *Database System Concepts*, Avi Silberschatz, Henry F. Korth and S. Sudarshan, 7th edition (2019). |

**Computing Systems::Hardware and Security**

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| **Module** | **Topics** | **Study Material** |
| C/C++ Programming and Data structures | Programming in C/C++, Recursion, Arrays, Stacks, Queues, Linked lists, Trees, Binary search trees, Binary heaps, Graphs, Searching, Sorting, hashing. | *Introduction to Programming through C++:*[*NPTEL course*](https://www.google.com/url?q=https://www.youtube.com/playlist?list%3DPLOzRYVm0a65eklyMDXGSWObRA-7lCdkSm&sa=D&source=editors&ust=1650864326555149&usg=AOvVaw3PgUt86Cb59kP8jE6Tud3e)*by Abhiram Ranade.*[*Companion textbook*](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~ranade/book.html&sa=D&source=editors&ust=1650864326555444&usg=AOvVaw3FuPt5L28LkRPCRIt9p0c4)*.*  *Data Structures and Algorithms,*[*NPTEL course*](https://www.google.com/url?q=https://www.youtube.com/playlist?list%3DPLBF3763AF2E1C572F&sa=D&source=editors&ust=1650864326555977&usg=AOvVaw3Io8aYDDnSzOoNn1qCGvCO)*by Naveen Garg.* |
| Computer Architecture and Operating Systems | CPU interrupt/exception handling, Privileged instructions, Handling function calls: stack and frame pointers, Branch predictors, Branch target buffers, Caches, Cache hierarchy optimizations, Virtual memory, Address translation, Paging, OS rings of protection, System call handling, Confidentiality, integrity, and availability properties, Timing channels (side/covert), Flush-based attack. | [*Computer Architecture*](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~biswa/courses/CS305/schedule.html&sa=D&source=editors&ust=1650864326557047&usg=AOvVaw1Ts4UOmD464tUVQnyDq8Hg)*course offered by Biswabandan Panda: Lectures 6, 24-27, 30-34.*  [*Computer Architecture for Performance and Security*](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~biswa/courses/CS773/schedule.html&sa=D&source=editors&ust=1650864326557591&usg=AOvVaw3_K72GPcytw1huuHEJVjE7) course offered by Biswabandan Panda: Lecture 3.  [A Survey of Microarchitectural Timing Attacks and Countermeasures on Contemporary Hardware](https://www.google.com/url?q=https://eprint.iacr.org/2016/613.pdf&sa=D&source=editors&ust=1650864326558113&usg=AOvVaw1m2IwLw6A52_y_irak2qNq), Qian Ge, Yuval Yarom, David Cock, and Gernot Heiser, 2016: pages 1-3.  *Operating Systems: Three Easy Pieces*, Remzi H. Arpaci-Dusseau and Andrea C. Arpaci-Dusseau, [on-line textbook](https://www.google.com/url?q=https://pages.cs.wisc.edu/~remzi/OSTEP/&sa=D&source=editors&ust=1650864326558657&usg=AOvVaw0kfGUbi6YGnT45HOvpQnSg): Chapters 6, 13, 15, 18, 53.  [Lectures on Operating Systems](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~mythili/os/&sa=D&source=editors&ust=1650864326559151&usg=AOvVaw2fp6a4I2FowfSq_hWbVCKM) by Mythili Vutukuru: Lectures 3, 7-9.  *Computer Organization and Design*, David A. Patterson and John L. Hennessy, 5th edition (2014): Chapters/sections 2, 4.8-4.10, 5.3, 5.4, 5.7, A.3-A.7.  *Computer Architecture: A Quantitative Approach*, John L. Hennessy and David A. Patterson, 6th edition (2018): Section 3.3. |
| Computer Network Security | Basics and case studies of symmetric key (AES) and asymmetric key (RSA) cryptography, Cryptographic hash functions and their uses, Message authentication codes (MAC), Digital signatures and digital certificates, Basic authentication and key exchange protocols including Diffie-Hellman key exchange and SSL/TLS. | [Online lectures on Network Security](https://www.google.com/url?q=https://www.youtube.com/channel/UC9KOS69Po018NGKJsR2RgrA/playlists?view%3D50%26sort%3Ddd%26shelf_id%3D1&sa=D&source=editors&ust=1650864326560878&usg=AOvVaw2iyi6pfByR7AZwfgnyvinN) by Kameswari Chebrolu. |
| Blockchains | Proof-of-work consensus, Attacks on proof-of-work blockchains such as double spend and selfish mining. | [*Introduction to Blockchains*](https://www.google.com/url?q=https://www.youtube.com/playlist?list%3DPLfmqK5mMBWj9dEmo91RBJd3xHx4TQi8bA&sa=D&source=editors&ust=1650864326561907&usg=AOvVaw0AgCpb-WjbvdOPTrm3Riif)*course offered by Vinay Ribeiro: Lectures*1-11.  *Bitcoin and Cryptocurrency Technologies*, Arvind Narayanan, Joseph Bonneau, Edward Felten, Andrew Miller, and Steven Goldfeder, 2016: Chapters 1, 2, 3, 5. [Book a web page](https://www.google.com/url?q=https://bitcoinbook.cs.princeton.edu/&sa=D&source=editors&ust=1650864326562481&usg=AOvVaw12Hvv0cu-3g4AIf9aFvg_J) with links to corresponding lectures 1, 2, 3, 5. |
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**Intelligent Systems::AI/ML (NLP/Speech/Text)**

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| **Module** | **Topics** | **Study Material** |
| Calculus | Differentiation, Integration, Partial derivatives, Nested integration, Polar coordinates, etc. | *Calculus*, Gilbert Strang, 2nd edition (2010): Chapters 1-15. [Companion web resource](https://www.google.com/url?q=https://ocwnext-rc.odl.mit.edu/courses/res-18-001-calculus-online-textbook-spring-2005/pages/textbook/&sa=D&source=editors&ust=1650864326566999&usg=AOvVaw3yKoAqIhDZxgqQyS_5kfd9). |
| Linear algebra | Vectors, Linear equations, Vector spaces and subspaces, Orthogonality, Determinants, Eigenvalues and eigenvectors. | *Introduction to Linear Algebra*, Gilbert Strang, 3rd edition (2003): Chapters 1-6. [Related web resource](https://www.google.com/url?q=https://ocw.mit.edu/courses/mathematics/18-06-linear-algebra-spring-2010/&sa=D&source=editors&ust=1650864326568406&usg=AOvVaw3HBqSGkQ2Uoe0mk_JA5bWw). |
| Probability | Basic probability, Random variables, Sampling, Parameter estimation, Regression. | *Introduction to Probability and Statistics for Engineers and Scientists*, Sheldon M. Ross, 5th edition (2014): Chapters 3, 4, 6, 7, 9. |
| Algorithms | Algorithms, Asymptotic notation, Divide and conquer, Sorting, Searching. | *Introduction to Algorithms*, Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, 3rd edition (2009): Chapters 1, 2, 3, 4, 6, 7, 12. |
| Machine Learning basics | Machine learning tasks, Overfitting, Parameter estimation, Gradient descent, etc. | Deep Learning, Ian Goodfellow, Yoshua Bengio, Aaron Courville, 2016: Chapter 5. [On-line version](https://www.google.com/url?q=https://www.deeplearningbook.org/&sa=D&source=editors&ust=1650864326570950&usg=AOvVaw3c303fVU_YmtIlzKwY1hHF). |
| Speech and Language Processing | N-gram language models, Naive Bayes and sentiment classification, Logistic regression, Hidden Markov Models, Word Sense and Wordnet, Automatic Speech Recognition and Text-to-Speech. | Speech and Language Processing, Daniel Jurafsky and James H. Martin, 3rd edition (2020): Chapters/sections: 3, 4, 5, 18, 26.1, 26.2, 26.3, Appendix A. [On-line version](https://www.google.com/url?q=https://web.stanford.edu/~jurafsky/slp3/&sa=D&source=editors&ust=1650864326572175&usg=AOvVaw2A5EtEA9bd1av5gTD-Vs5_). |
| Neural Natural Language Processing | Word vector representations, Recurrent neural networks and language models), Gated recurrent units and further topics in NMT, Dynamic neural networks for question answering. | *Natural Language Processing with Deep Learning,*Winter 2017 course offered by Chris Manning at Stanford University: Lectures 2, 8, 11, 16. [Videos of course lectures](https://www.google.com/url?q=https://www.youtube.com/playlist?list%3DPL3FW7Lu3i5Jsnh1rnUwq_TcylNr7EkRe6&sa=D&source=editors&ust=1650864326573387&usg=AOvVaw3a4212IIICCjW2xPrxPVlt). |

**Intelligent Systems::AI/ML (Representation/Learning/Agents)**

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| Module | Topics | Study Material |
| Calculus | Differentiation, Integration, Partial derivatives, Nested integration, Polar coordinates, etc. | *Calculus*, Gilbert Strang, 2nd edition (2010): Chapters 1-15. [Companion web resource](https://www.google.com/url?q=https://ocwnext-rc.odl.mit.edu/courses/res-18-001-calculus-online-textbook-spring-2005/pages/textbook/&sa=D&source=editors&ust=1650864326576080&usg=AOvVaw2wvRDD51LmHaG32bnbEHWP). |
| Linear algebra | Vectors, Linear equations, Vector spaces and subspaces, Orthogonality, Determinants, Eigenvalues and eigenvectors. | *Introduction to Linear Algebra*, Gilbert Strang, 3rd edition (2003): Chapters 1-6. [Related web resource](https://www.google.com/url?q=https://ocw.mit.edu/courses/mathematics/18-06-linear-algebra-spring-2010/&sa=D&source=editors&ust=1650864326577217&usg=AOvVaw13oheXlf5Qy9Xg2nPMbbeI). |
| Probability | Basic probability, Random variables, Sampling, Parameter estimation, Regression. | *Introduction to Probability and Statistics for Engineers and Scientists*, Sheldon M. Ross, 5th edition (2014): Chapters 3, 4, 6, 7, 9. |
| Algorithms | Algorithms, Asymptotic notation, Divide and conquer, Sorting, Searching. | *Introduction to Algorithms*, Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, 3rd edition (2009): Chapters 1, 2, 3, 4, 6, 7, 12. |
| Learning with Graphs | Link prediction, Social networks. | [Link to reading material](https://www.google.com/url?q=https://drive.google.com/drive/folders/1F13dv3RdJKQ-HnYB2vqvDxQpQh9zWBB3?usp%3Dsharing&sa=D&source=editors&ust=1650864326580103&usg=AOvVaw0-OnTNIQecdKs9nowfYYXs) (see README). |
| Stochastic Multi-armed Bandits | Bandits, Regret, Sampling algorithms (epsilon-greedy, UCB, Thompson Sampling), Hoeffding’s Inequality. | *Foundations of Intelligent and Learning Agents*, Autumn 2021 course at IIT Bombay: Lectures from weeks 1 ([video](https://www.google.com/url?q=https://drive.google.com/file/d/1MQtCsms-BLEnIqEpdCpg1ERtt0IgMBYF/view&sa=D&source=editors&ust=1650864326581349&usg=AOvVaw0cM9o2l97mKkzSNP5_BmO4), [slides](https://www.google.com/url?q=https://drive.google.com/file/d/1GLZl9CIceTgUJVS7RtYsALm28YYt0ltf/view&sa=D&source=editors&ust=1650864326581585&usg=AOvVaw0OJi6x8HxJs-piPcRgDWpt)), 2 ([video](https://www.google.com/url?q=https://drive.google.com/file/d/1_Ko5Mfg8DpXcpZVOa7fDBR-N0DIBaJ0s/view&sa=D&source=editors&ust=1650864326581849&usg=AOvVaw00ic4cpLsclPYirqw6haXr), [slides](https://www.google.com/url?q=https://drive.google.com/file/d/1rDMXVSgdcXbtayd4x8npm_qs-r4kFlTA/view&sa=D&source=editors&ust=1650864326582072&usg=AOvVaw3DtYPePZqg8PVTEs2iDazF)), 3 ([video](https://www.google.com/url?q=https://drive.google.com/file/d/1-ibXb2lpBJ9LRPn_PIqV8z-SOI68aUVc/view&sa=D&source=editors&ust=1650864326582294&usg=AOvVaw0WYbRE9AnMAsFTxznHMpoY), [slides](https://www.google.com/url?q=https://drive.google.com/file/d/1WTJW97ymsgwt20iY7h6a1iiQPwmOaQuL/view&sa=D&source=editors&ust=1650864326582518&usg=AOvVaw1VmIPWSUptP5wwDi_J1h90)). Solved questions based on the material are provided in exam papers and assignments linked from the course pages from the [2017](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~shivaram/teaching/old/cs747-a2017/index.html&sa=D&source=editors&ust=1650864326582770&usg=AOvVaw0sl50QAYYFSYZaI-3m4MA-), [2018](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~shivaram/teaching/old/cs747-a2018/index.html&sa=D&source=editors&ust=1650864326582999&usg=AOvVaw2t5enyaL7P2EPL5p9EUy8i), [2019](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~shivaram/teaching/old/cs747-a2019/index.html&sa=D&source=editors&ust=1650864326583216&usg=AOvVaw1rgyiuiSIcDZ7CxIG-J3fr), [2020](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~shivaram/teaching/old/cs747-a2020/index.html&sa=D&source=editors&ust=1650864326583438&usg=AOvVaw1YJctyWRbl7OUJiKAFODsm), and [2021](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~shivaram/teaching/old/cs747-a2021/index.html&sa=D&source=editors&ust=1650864326583653&usg=AOvVaw2AW7Z5vUg_nL6wwqH99cYi) offerings. |
| Strategic Multi-agent Systems | General tenets of game theory, Normal form games, Perfect information extensive form games. | [Lecture notes](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~swaprava/courses/cs711/lecnotes.pdf&sa=D&source=editors&ust=1650864326584685&usg=AOvVaw2e7f8gaCEJvhzsE2aKIy1s): Lectures 2-8.3. Modules 1-22 from this [video playlist](https://www.google.com/url?q=https://www.youtube.com/watch?v%3DUne_8S0YRxA%26list%3DPL3eEm6KzZ3lF2TlVOnPyJHyGWJhUogn-D%26index%3D3&sa=D&source=editors&ust=1650864326585034&usg=AOvVaw19MmJnt0ZSJqeL4R1G-hoe) provide detailed explanations of the concepts along with the boardwork. |
| Learning for Structured Output Spaces | Directed graphical models, Undirected graphical models | *Probabilistic Graphical Models: Principles and Techniques*, Daphne Koller and Nir Friedman, 2009: Chapters 3, 4. |

**Intelligent Systems::Visual Computing**

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| **Module** | **Topics** | **Study Material** |
| Calculus | Differentiation, Integration, Partial derivatives, Nested integration, Polar coordinates, etc. | *Calculus*, Gilbert Strang, 2nd edition (2010): Chapters 1-15. [Companion web resource](https://www.google.com/url?q=https://ocwnext-rc.odl.mit.edu/courses/res-18-001-calculus-online-textbook-spring-2005/pages/textbook/&sa=D&source=editors&ust=1650864326588550&usg=AOvVaw01xn9uyuZATcrzIU7RwBvs). |
| Linear algebra | Vectors, Linear equations, Vector spaces and subspaces, Orthogonality, Determinants, Eigenvalues and eigenvectors. | *Introduction to Linear Algebra*, Gilbert Strang, 3rd edition (2003): Chapters 1-6. [Related web resource](https://www.google.com/url?q=https://ocw.mit.edu/courses/mathematics/18-06-linear-algebra-spring-2010/&sa=D&source=editors&ust=1650864326589733&usg=AOvVaw1kWF9ENnkXKMcnZkJNR3ZA). |
| Probability | Basic probability, Random variables, Sampling, Parameter estimation, Regression. | *Introduction to Probability and Statistics for Engineers and Scientists*, Sheldon M. Ross, 5th edition (2014): Chapters 3, 4, 6, 7, 9. |
| Algorithms | Algorithms, Asymptotic notation, Divide and conquer, Sorting, Searching. | *Introduction to Algorithms*, Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, 3rd edition (2009): Chapters 1, 2, 3, 4, 6, 7, 12. |
| Image Processing | Fourier transforms (discrete and continuous, 1D and 2D), Image filtering in the spatial and frequency domains, Image restoration, Convolution and correlation, Image enhancement, histogram equalization, Image derivatives and edge detection, Basic image compression: steps of the JPEG standard, discrete cosine transforms. | *Digital Image Processing*, Rafael C. Gonzalez and Richard E. Woods, 3rd edition (2007): Chapters/sections 3, 4, 5.1-5.8, 8.2.1, 8.2.8. |
| Computer Graphics | Transformation Matrices (2D, 3D Linear transformations, Translation, Affine transformations, Inverses of transformation matrices, Coordinate transformations),  Viewing (Viewing transformations, projective transformations, Perspective projection, Properties of the perspective transform). | *Fundamentals of Computer Graphics*, Steve Marschner and Peter Shirley, 4th edition (2018): Chapters 6, 7. |

**Theoretical Systems::Algorithms, Complexity, Cryptography**

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| **Module** | **Topics** | **Study Material** |
| Algorithms | Sorting, Searching, Graph traversal, Shortest paths, Minimum spanning tree, Algorithms for computational questions in algebra and number theory (e.g. Karatsuba’s algorithm for fast integer multiplication), Strassen’s algorithm for fast matrix multiplication, Fast polynomial multiplication via the Fast Fourier Transform, Algorithm for computing the greatest common divisor (GCD) of natural numbers/univariate polynomials, Standard algorithm design techniques like greedy, divide and conquer, dynamic programming, Basic data structures (arrays, trees, heaps), Analysis of running time of algorithms, Proof of correctness of algorithms. | *Introduction to Algorithms*, Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, 3rd edition (2009): Chapters 1, 2, 3, 4, 6, 7, 12.  Algorithm Design, Jon Kleinberg and Eva Tardos, 2005 (1st edition).  [Tim Roughgarden lectures](https://www.google.com/url?q=https://www.youtube.com/channel/UCcH4Ga14Y4ELFKrEYM1vXCg/playlists&sa=D&source=editors&ust=1650864326597218&usg=AOvVaw1OGWZt7LCQCY-AaWCNAsJp) (*Algorithms Illuminated*, 4 parts) |
| Discrete math | Counting, Permutations and combinations, Sets and relations, Solving recurrence relations, Proofs via mathematical induction, Basics of generating functions, | *Discrete Mathematics and Its Applications*,  Kenneth H. Rosen, 2017 (7th edition). |
| Graph Theory | Connectivity, Reachability, Matchings, Colorings. | *Mathematics for Computer Science,  Eric Lehman, F. Thomson Leighton, and Alberty R. Meyer: Chapters 9, 10, 11.*[*On-line version*](https://www.google.com/url?q=https://eng.libretexts.org/Bookshelves/Computer_Science/Programming_and_Computation_Fundamentals/Mathematics_for_Computer_Science_(Lehman_Leighton_and_Meyer)&sa=D&source=editors&ust=1650864326599669&usg=AOvVaw17F3Sn1bpcGvkDQTlIHWeH). |
| Linear Algebra | Matrices and determinants, Solving linear system of equations, Eigenvalues and eigenvectors. | *Introduction to Linear Algebra*, Gilbert Strang, 3rd edition (2003). [Related web resource](https://www.google.com/url?q=https://ocw.mit.edu/courses/mathematics/18-06-linear-algebra-spring-2010/&sa=D&source=editors&ust=1650864326601141&usg=AOvVaw2x0_n3dFXjRC62DsXpz7fX). |
| Probability | Conditional probability, Linearity of expectation, Union bound, Inclusion-exclusion. | *Mathematics for Computer Science,  Eric Lehman, F. Thomson Leighton, and Alberty R. Meyer: Part 4.*[*On-line version*](https://www.google.com/url?q=https://eng.libretexts.org/Bookshelves/Computer_Science/Programming_and_Computation_Fundamentals/Mathematics_for_Computer_Science_(Lehman_Leighton_and_Meyer)&sa=D&source=editors&ust=1650864326602850&usg=AOvVaw1oPNfM74Try-2ecYWaXXcL). |
| Algebra and Number Theory | Elementary topics, such as following. Number of roots of a non-zero univariate polynomial, Relation between roots and coefficients, Mean value theorems, Primes and composites, Euclid’s algorithm for computing the GCD. | *Mathematics for Computer Science,  Eric Lehman, F. Thomson Leighton, and Alberty R. Meyer: Chapter 8.*[*On-line version*](https://www.google.com/url?q=https://eng.libretexts.org/Bookshelves/Computer_Science/Programming_and_Computation_Fundamentals/Mathematics_for_Computer_Science_(Lehman_Leighton_and_Meyer)&sa=D&source=editors&ust=1650864326604401&usg=AOvVaw0bOzkLXpfuHt0RIy0TIUCb). |
| Complexity Theory | P, NP, Co-NP. NP-completeness, Undecidability. | [Ryan O’Donnell’s Lecture series](https://www.google.com/url?q=https://www.youtube.com/watch?v%3DRxhpiYKFQd8%26list%3DPLm3J0oaFux3YL5vLXpzOyJiLtqLp6dCW2&sa=D&source=editors&ust=1650864326605540&usg=AOvVaw17IXs1yQSnYcDhwKzopj1_). |

**Theoretical Systems::Formal Methods**

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| **Module** | **Topics** | **Study Material** |
| Logic | Propositional and first order logics, Satisfiability, Boolean connectives, Quantifiers, Encoding problems into Boolean and first order logics, Logical equivalences and simplification. | *Logic in Computer Science*, Michael Huth and Mark Ryan, 2nd edition (2004). |
| Theory of Computation | Deterministic and non-deterministic finite automata, Automata minimization, Regular expressions and languages, Pumping lemma for regular languages, Push-down automata and context-free languages, Turing machines, Recursively enumerable languages, Decidablity. | *Introduction to Automata Theory, Languages, and Computation, John E. Hopcroft, Rajeev Motwani, and Jeffrey D. Ullman, 2013 (3rd edition).* |
| Discrete Structures | Sets, Relations, Functions, Partial orders, Mathematical induction. | *Discrete Mathematics and Its Applications*,  Kenneth H. Rosen, 2017 (7th edition). |
| Basic Algorithms | Graph and list traversal algorithms, Searching and sorting, Asymptotic time/space complexity using big-O notation. | *Introduction to Algorithms*, Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, 3rd edition (2009). |
| Programming | Functions, global vs local variables, classes, pointers, programming primitives, writing basic data structures such as lists, arrays, and trees, Handling files, parsing files. | *Introduction to Programming through C++:*[*NPTEL course*](https://www.google.com/url?q=https://www.youtube.com/playlist?list%3DPLOzRYVm0a65eklyMDXGSWObRA-7lCdkSm&sa=D&source=editors&ust=1650864326614232&usg=AOvVaw0m7dCOW0iiwi5EHXpL71aH)*by Abhiram Ranade.*[*Companion textbook*](https://www.google.com/url?q=https://www.cse.iitb.ac.in/~ranade/book.html&sa=D&source=editors&ust=1650864326614544&usg=AOvVaw3vTbxCjpGlaU_kgO00zez-)*.* |