**Government of Russian Federation**

**Federal State Autonomous Educational Institution of High Professional**

**Education**

**«National Research University Higher School of Economics»**

National Research University

Higher School of Economics

Faculty of Computer Science

**Syllabus for the course**

 **«Network Science»**

 (Анализ сетевых структур)

010402 «Applied Mathematics and Informatics»,

«**Data Science**» Master program

Authors:

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Approved by: Head of Data Analysis and Artificial Intelligence Department, Sergey O. Kuznetsov

Recommended by:

Moscow, 2015

**1. Teachers**

**Author, lecturer**: Leonid Zhukov, National Research University Higher School ofEconomics, Department of Data Analysis and Artificial Intelligence, professor

**Tutor:** Ilya Makarov, National Research University Higher School ofEconomics, Department of Data Analysis and Artificial Intelligence, senior lecturer, deputy head

**2. Scope of Use**

The present program establishes minimum demands of students’ knowledge and skills, and determines content of the course.

The present syllabus is aimed at department teaching the course, their teaching assistants, and students of the Master of Science program 010402 «Data Sciences»,

This syllabus meets the standards required by:

* + Educational standards of National Research University Higher School of Economics;
	+ Educational program «Data Science» of Federal Master’s Degree Program 010402 «Applied Mathematics and Informatics», 2015;
	+ University curriculum of the Master’s program in «Data Science» for 2015.
1. **Summary**

The course “Network Science” introduces students to new and actively evolving interdisciplinary field of network science. Started as a study of social networks by sociologists, it attracted attention of physicists, computer scientists, economists, computational biologists, linguists and others and become a truly interdisciplinary field of study. In spite of the variety of processes that form networks, and objects and relationships that serves as nodes and edges in these networks, all networks poses common statistical and structural properties. The interplay between order and disorder creates complex network structures that are the focus of the study. In the course we will consider methods of statistical and structural analysis of the networks, models of network formation and evolution and processes developing on network. Special attention will be given to the hands-on practical analysis and visualization of the real world networks using available software tools and modern programming languages and libraries.

**4. Learning Objectives**

Learning objectives of the course “Network Science” are to familiarize students with a new rapidly evolving filed of network science, and provide practical knowledge experience in analysis of real world network data.

**5. Learning outcomes**

After completing the study of the discipline “Network Science”, the student should:

* Know basic notions and terminology used in network science
* Understand fundamental principles of network structure and evolution
* Learn to develop mathematical models of network processes
* Be capable of analyzing real world network data

After completing the study of the discipline “Network Science” the student should have the following competences:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  | **Descriptors (indicators** | **Educative forms and methods** |
| **Competence** | **Code** | **Code (UC)** | **of achievement of the** | **aimed at generation and** |
|  |  |  |  |  |  |  |  | **result)** |  |  |  | **development of the competence** |
| The ability to | SC-1 | SC-М1 | The student is able to |  | Lectures | and | tutorials, | group |
| reflect developed |  |  | reflect developed |  |  | discussions, presentations, paper |
| methods |  |  | of |  |  | mathematical methods | reviews. |  |  |  |
| activity. |  |  |  |  |  | to network sciences |  |  |  |  |  |
| The ability to | SC-2 | SC-М2 | The student is able to | Classes, home works. |  |
| propose | a | model |  |  | improve | and | develop |  |  |  |  |
| to invent and test |  |  | research | methods | of |  |  |  |  |
| methods |  |  | and |  |  | linear |  | optimization, |  |  |  |  |
| tools |  |  | of |  |  | approximation |  | and |  |  |  |  |
| professional |  |  |  | computational | problem |  |  |  |  |
| activity |  |  |  |  |  | solvation. |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Capability |  | of | SC-3 | SC-М3 | The | student |  | obtain | Home tasks, paper reviews, |
| development | of |  |  | necessary | knowledge |  |  |  |  |
| new | research |  |  | in network | science, |  |  |  |  |
| methods, | change |  |  | which | is | sufficient | to |  |  |  |  |
| of | scientific | and |  |  | develop new | methods |  |  |  |  |
| industrial | profile |  |  | on other sciences |  |  |  |  |  |  |
| of self-activities |  |  |  |  |  |  |  |  |  |  |  |  |
| The ability to | PC-5 | IC- | The student is able to | Lectures | and | tutorials, | group |
| describe |  |  |  |  | M5.3\_5. | describe |  | network | discussions, presentations, paper |
| problems |  | and |  | 4\_5.6\_2. | problems | problems | in | reviews. |  |  |  |
| situations |  | of |  | 4.1 | terms of computational |  |  |  |  |
| professional |  |  |  | mathematics. |  |  |  |  |  |  |  |
| activity | in | terms |  |  |  |  |  |  |  |  |  |  |  |  |
| of | humanitarian, |  |  |  |  |  |  |  |  |  |  |  |  |
| economic |  | and |  |  |  |  |  |  |  |  |  |  |  |  |
| social sciences to |  |  |  |  |  |  |  |  |  |  |  |  |
| solve | problems |  |  |  |  |  |  |  |  |  |  |  |  |
| which |  | occur |  |  |  |  |  |  |  |  |  |  |  |  |
| across | sciences, |  |  |  |  |  |  |  |  |  |  |  |  |
| in |  |  | allied |  |  |  |  |  |  |  |  |  |  |  |  |
| professional |  |  |  |  |  |  |  |  |  |  |  |  |  |
| fields. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| The ability to | PC-8 | SPC-M3 | The student is able to | Discussion of paper reviews; |
| detect, | transmit |  |  | identify | mathematical | cross discipline lectures |  |
| common goals in |  |  | aspect |  | in | network |  |  |  |  |
| the | professional |  |  | research |  | evaluate |  |  |  |  |
| and |  |  | social |  |  | correctness of the used |  |  |  |  |
| activities |  |  |  |  | methods, | and | their |  |  |  |  |
|  |  |  |  |  |  |  | applicability | in | each |  |  |  |  |
|  |  |  |  |  |  |  | current situation |  |  |  |  |  |  |

**6. Place of the discipline in the Master’s program structure**

The course “Network Science” is a course taught in the first year of the Master’s program 010402 “Data Sciences” and is a base course for specialization “Intelligent Systems and Structural Analysis”

**Prerequisites**

The course is based on knowledge and understanding of

* Discrete mathematics
* Algorithms and data structures
* Linear algebra
* Theory of probability and statistical analysis

It also requires some programming experience in one of programming languages:

* + Python
	+ Matlab
	+ R
1. **Schedule**

One pair consists of 1 academic hour for lecture and 1 academic hour for classes after lecture.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  | **Contact hours** |  |  |
| **№** | **Topic** | **Total hours** |  |  | **Self-study** |  |
| **Lectures** | **Seminars** |  |
|  |  |  |  |  |
|  |  |  |  |  |  |  |
| 1 | Introduction to network science | 9 | 3 | 2 | 4 |  |
|  |  |  |  |  |  |  |
| 2 | Power laws | 13 | 3 | 2 | 8 |  |
|  |  |  |  |  |  |  |
| 3 | Models of network formation | 15 | 3 | 4 | 8 |  |
|  |  |  |  |  |  |  |
| 4 | Structure, nodes and links analysis | 17 | 3 | 6 | 8 |  |
|  |  |  |  |  |  |  |
| 5 | Network communities | 17 | 3 | 6 | 8 |  |
|  |  |  |  |  |  |  |
| 6 | Diffusion and epidemics on networks | 15 | 3 | 4 | 8 |  |
|  |  |  |  |  |  |  |
| 7 | Influence propagation | 17 | 3 | 6 | 8 |  |
|  |  |  |  |  |  |  |
| 8 | Information cascades | 15 | 3 | 4 | 8 |  |
|  |  |  |  |  |  |  |
| 9 | Evolving networks and link prediction | 17 | 3 | 6 | 8 |  |
|  |  |  |  |  |  |  |
| 10 | Network visualization | 17 | 3 | 6 | 8 |  |
|  |  |  |  |  |  |  |
|  | Total | 152 | 30 | 46 | 76 |  |

**8. Requirements and Grading**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Type of****grading** | **Type of** |  |  | **Characteristics** |  |  |
| **work** |  |  |  |  |  |
| 3 | 4 |  |  |  |
| Homework | 4 | 4 | Solving homework tasks | and |  |
| examples. |  |  |
|  |  |  |  |  |
| Special |  |  |  |  |  |
|  |  | Independent modelling | and |  |
| homework |  |  |  |
| 1 | 1 | verification of research papers |  |
| – research |  |
|  |  | results |  |  |
| projects |  |  |  |  |
|  |  |  |  |  |
| Mid Term Exam | 1 |  |  |  |  |
| Final Exam |  | 1 | Written exam |  |  |

**9. Assessment**

*The assessment* consists of weekly classwork andhomework. Short quizzes are assigned after each lecture through the google-forms to make students pass their homeworks (otherwise the maximal grade for HW will not exceed 4 of 10).Studentshave to demonstrate their knowledge in each lecture topic concerning both theoretical facts, and practical tasks’ solving. All tasks are connected through the discipline and have increasing complexity. The two practical projects should be presented in class and graded by both, lecturers and students. The weight of a project is three times greater than the weight of each HW.

Each technical report should be made in IPython Notebook format.

Labs are to be uploaded in DataJoy Group storage.

Students obtain the following points per each condition:

* Correct data analysis – 4 points;
* Suitable visualization – 3 points;
* Report completeness and formulas’ descriptions – 2 points;
* Extra 1 point for overall report evaluation and excellent research and soft skills.

Technical details for reports and projects are placed to the corresponding technical section.

*Final assessment* is the final exam. Students have to demonstrate knowledge of theory facts,but the most of tasks would evaluate their ability to solve practical examples, present straight operation, and recognition skills to solve them.

**The grade formula:**

***The exam*** will consist of 10 problems, giving 10 points each, total 100 points for the exam

***Final course mark*** *is obtained from the following formula*:

*Оfinal = 0,6\*О cumulative+0,4\*Оexam*.

The grades are rounded in favour of examiner/lecturer with respect to regularity of class and home works. All grades, having a fractional part greater than 0.5, are rounded up.

**Table of Grade Accordance**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Ten-point** | **Five-point** |  |  |
|  | **Grading Scale** | **Grading Scale** |  |  |
|  |  |  |  |  |
| 1 | - very bad |  |  |  |
| 2 | – bad | Unsatisfactory - 2 | **FAIL** |  |
| 3 | – no pass |  |  |  |
|  |  |  |  |  |
| 4 | – pass | Satisfactory – 3 |  |  |
| 5 | – highly pass |  |  |
|  |  |  |
|  |  |  |  |  |
| 6 | – good | Good – 4 |  |  |
| 7 | – very good | **PASS** |  |
|  |  |
|  |  |  |  |  |
| 8 | – almost excellent |  |  |  |
| 9 | – excellent | Excellent – 5 |  |  |
| 10 – perfect |  |  |  |
|  |  |  |  |  |

1. **Course Description**

The following list describes main topics covered by the course with lecture order.

**Topic 1. Introduction to network science**

**Content**:

Introduction to new science of networks. Complex networks theory. Basic network properties and metrics. Networks examples.

**Recommended reading:**

* 1. Chapters 1-3 of Mark Newman. "Networks: An Introduction". Oxford University Press, 2010.
	2. Chapters 1,2 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

**Supplementary reading:**

1. Albert-Laszlo Barabasi and Eric Bonabeau. Scale Free Networks. Scientific American, p 50-59, 2003
2. Mark Newman. The physics of networks. Physics Today,2008
3. Stanley Milgram. The Small-World Problem. Psychology Today, Vol 1, No 1, pp 61-67, 1967
4. J. Travers and S. Milgram. An Experimental Study of the Small World Problem. Sociometry, vol 32, No 4, pp 425-433, 1969
5. Mark Granovetter. The strengtth of weak ties , American Journal of Sociology, 78(6):1360-1380, 1973.

**Topic 2. Power laws Content**:

Power law distribution. Scale-free networks. Pareto distribution, normalization, moments. Zipf’s law. Rank-frequency plot.

**Recommended reading:**

1. Chapter 8 of Mark Newman. "Networks: An Introduction". Oxford University Press, 2010.
2. Chapter 18 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

**Supplementary reading**:

1. M. E. J. Newman. Power laws, Pareto distributions and Zipf’s law. Contemporary Physics 46(5), 323-351, 2005
2. Clauset, C.R. Shalizi, M.E.J. Newman. Power-law distributions in empirical data. SIAM Review 51(4), 661-703, 2009
3. M. Mitzenmacher. A brief history of generative models for power law and lognormal distributions. Internet Mathematics, vol 1, No. 2, pp. 226-251, 2004
4. M.L. Goldstein, S.A. Morris, and G.G. Yen. Problems with fitting to the power-law distribution, Eur. Phys. J. B 41, pp 255–258, 2004.

**Topic 3. Models of network formation**

**Content**:

Erdos-Reni random graph model. Poisson and Bernulli distributions. Distribution of node degrees. Phase transition, gigantic connected component. Diameter and cluster coefficient. Configuration model. Barabasi-Albert model. Preferential attachment. Equation in continues approximation. Time evolution of node degrees. Node degree distribution. Average path length and clustering coefficient. Small world model. Watts-Strogats model. Transition from regular to random. changes in clustering coefficient and average path length.

**Recommended reading:**

1. Chapters 12, 14 of Mark Newman. "Networks: An Introduction". Oxford University Press, 2010.
2. Chapter 20 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

**Supplementary reading:**

1. P. Erdos and A. Renyi. On random graphs I. Publ. Math. Debrecen, 1959.
2. P. Erdos and A. Renyi. On the evolution of random graphs. Magyar Tud. Akad. Mat. Kutato Int. Koezl., 1960.
3. Duncan J. Watts and Steven H. Strogatz. Collective dynamics of ‘small-world’ networks. . Nature 393:440-42, 1998.
4. AL Barabasi and R. Albert. Emergence of Scaling in Random Networks. Science, 286, 1999

**Topic 4. Structure, nodes and links analysis**

**Content**:

Node centrality metrics, degree centrality, closeness centrality, betweenness centrality, eigenvector centrality. Graph structure based metrics. PageRank, stochastic metric and Perron-Frobenius theorem. Power iterations. Hubs and Authorities. HITS algorithm. Kendall-Tau ranking distance. Structural equivalency metrics. Euclidean and Hamming distance. Correlation coefficient. Cosine similarity. Assortative mixing and homophily. Modularity. Mixing by degree.

**Recommended reading:**

1. Chapter 7 of Mark Newman. "Networks: An Introduction". Oxford University Press, 2010.
2. Chapter 14 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

**Supplementary reading:**

1. Linton C. Freeman. Centrality in Social Networks. Conceptual Clarification. Social Networks, Vol 1, pp 215-239, 1978
2. Phillip Bonacich. Power and Centrality: A Family of Measures. American journal of sociology, Vol.92, pp 1170-1182, 1987.
3. S. Brin, L. Page. The PageRank Citation Ranknig: Bringing Order to the Web.
4. John M. Kleinberg. Authoritative Sources in a Hyperlinked Environment. Proc. 9th ACM-SIAM Symposium on Discrete Algorithms, 1998.
5. M. Newman. Mixing patterns in networks. Phys. Rev. E, Vol. 67, p 026126, 200

**Topic 5. Network communities**

**Content**:

Network communities. Graph density. Graph pertitioning. Min-cut, quotent and normalized cuts metrics. Divisive and agglomerative algorithms. Repeated bisection. Correlation matrix. Clustering. Edge Betweenness. Newman-Girvin algorithm. Spectral methods. Modularity maximization algorithm (Newman). Approximation algorithms. Randomized min-cut (Karges's algorithm). Probability of finding min-cut. Multilevel paradigm. Multilevel algorithm for power law graphs. Local clustering. Conductance. Nibble Algorithms. Graph motiffs, k-cores, diad and triad census

**Recommended reading:**

1. Chapter 11 of Mark Newman. "Networks: An Introduction". Oxford University Press, 2010.

**Supplementary reading:**

1. M.E.J. Newman, M. Girvan. Finding and evaluating community structure in networks. Phys. Rev. E 69, 026113, 2004.
2. M.E.J. Newman. Modularity and community structure in networks. PNAS Vol. 103, N 23, pp 8577-8582, 2006
3. S. E. Schaeffer. Graph clustering. Comp. Sci. Rev., Vol. 1, p 27-64, 2007
4. D.R. Karger. Global min-cuts in RNC, and other ramifications of a simple min-cut algorithm. Proceedings SODA '93, p. 21-30, 1993
5. A. Abou-rjeili, G. Karypis. Multilevel algorithms for partitioning power-law graphs. In Proceedings IPDPS '06, p 10, 2006
6. G.Karypis and V. Kumar. A fast and high quality multilevel scheme for partitioning irregular graphs. SIAM J. on Sci. Comp., Vol. 20, p 359-392, 1998.
7. Daniel A. Spielman, Shang-Hua Teng. A Local Clustering Algorithm for Massive Graphs and Its Application to Nearly Linear Time Graph Partitioning. SIAM Journal on computing, Vol. 42, p. 1-26, 2013
8. R. Andersen, F. Chung, K. Lang. Local graph partitioning using pagerank vectors. In Proc. FOCS, 2006.
9. S. Fortunato. Community detection in graphs . Physics Reports, Vol. 486, pp. 75-174, 2010
10. V. Batagelj, M. Zaversnik. An O(m) Algorithms for Cores Decomposition of Networks. 2003
11. L. da F. Costa, F. A. Rodrigues, et. al. Characterization of complex networks: A survey of measurements.Advances in Physics, Vol. 56, pp. 167-242, 2007
12. R. Milo, S. Shen-Orr, S. Itzkovitz et al. Network motifs: simple building blocks of complex networks. Science 298 (5594): 824–827, 2002

**Topic 6. Diffusion and epidemics on networks**

**Content**:

Physical diffusion. Diffusion equation. Diffusion on networks. Discrete Laplace operator, Laplace matrix. Solution of the diffusion equation. Random walks on graph. Epidemic models SI, SIS, SIR. Solution of diff. equations. Limiting cases. Modeling of infection propagation

**Recommended reading:**

1. Chapters 6, 17 of Mark Newman. "Networks: An Introduction". Oxford University Press, 2010.
2. Chapter 21 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

**Supplementary reading:**

1. Lovasz, L. Random walks on graphs: a survey. In Combinatorics, Paul Erdos is eighty. pp. 353 – 397. Budapest: Janos Bolyai Math. Soc., 1993
2. Chung, Fan R.K. Spectral graph theory (2ed.). Providence, RI: American Math. Soc., 1997
3. H.W. Hethcote. The Mathematics of Infections Diseases. SIAM Review, Vol. 42, No. 4, pp. 599-653, 2000
4. Matt. J. Keeling and Ken.T.D. Eames. Networks and Epidemics models Journal R. Soc. Interface, Vol 2, pp 295-307, 2005
5. G. Witten and G. Poulter Simulations of infections diseases on networks Computers in Biology and Medicine, Vol 37, No. 2, pp 195-205, 2007
6. M. Kuperman and G. Abramson Small World Effect in an Epidemiological Model., Phys. Rev. Lett., Vol 86, No 13, pp 2909-2912, 2001

**Topic 7. Influence propagation**

**Content**:

Social diffusion. Granovetter's Threshold model of Collective behavior. Most influential nodes in network. Cascades in networks. Basic cascade model. Cascade capacity.

**Recommended reading:**

1. Chapter 19 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

**Supplementary reading:**

1. Mark S. Granovetter. Threshold Models of Collective Behavior. American Journal of Sociology Vol. 83, No. 6, pp. 1420-1443, 1978.
2. H. Peyton Young. The Diffusion of Innovations in Social Networks. In L. E. Blume and S. N. Durlauf (eds.), The Economy as an Evolving Complex System III (2003)
3. D. Kempe, J. Kleinberg, E. Tardos. Maximizing the Spread of Influence through a Social Network. In Proc. KDD 2003.
4. D. Watts. A simple model of global cascades on random networks. Proc. Natl. Acad. Sci., vol. 99 no. 9, 5766-5771, 2002.
5. D. Kempe, J. Kleinberg, E. Tardos. Influential Nodes in a Diffusion Model for Social Networks. Lecture Notes in Computer Science, Eds C. Luis, I.Giuseppe et.al, 2005
6. S. Morris. Contagion. Review of Economic Studies 67, 57-78, 2000.
7. L.Backstrom, D. Huttenlocher, J. Kleinbrg, X. Lan, Group Formation in Large Social Networks: Membership, Growth and Evolution, In Proc. KDD 2006.
8. J.L. Iribarren, E. Moro, Impact of Human Activity Patterns on the Dynamics of Information Diffusion, Phys. Rev. Letters, Vol 103, 038702, 2009
9. J. Leskovec, L. Adamic, B. Huberman, The Dynamics of Viral Marketing, EC 2006

**Topic 8. Information cascades**

**Content**:

Observational learning. Information cascades.

**Recommended reading:**

1. Chapter 16 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

**Supplementary reading:**

1. Chapter 19 of David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.
2. A. V. Banerjee. A Simple Model of Herd Behavior. The Quarterly Journal of Economics, Vol. 107, No. 3, pp. 797-817, 1992.
3. S. Bikhchandani, D Hirshleifer and I.Welch. A Theory of Fads, Fashion, Custom, and Cultural Change as Information Cascades. Journal of Political Economy. Vol. 100, pp. 992-1026, 1992.
4. S. Bikhchandani, D Hirshleifer and I.Welch. Learning from the Behavior of Others: Conformity, Fads, and Informational Cascades
5. L. Anderson and C. Halt. Information Cascades in the Laboratory. The American Economic Review, Vol. 87, No. 5 (Dec., 1997), pp. 847-862
6. Pierre Lemieux. Following the Herd . Regulation, Winter 2003-2004

**Topic 9. Evolving networks and link prediction**

**Content**:

Network growth. Shrinking diameter. Link reciprocity. Link prediction problem. Supervised learning for prediction.

**Recommended reading:**

1. L. Backstrom, J. Leskovec. Supervised Random Walks: Predicting and Recommending Links in Social Networks. In Proc. WSDM, 2011
2. D. Liben-Nowell, J. Kleinberg. The Link Prediction Problem for Social Networks. Proc. CIKM, 2003.
3. J. Leskovec, L. Backstrom, R. Kumar, A. Tomkins. Microscopic Evolution of Social Networks. In Proc. KDD 2008.
4. J. Leskovec, J. Kleinberg, C. Faloutsos. Graph Evolution: Densification and Shrinking Diameters. ACM TKDD, 2007.

**Supplementary reading:**

1. P. D’haeseleer, S. Liang, R. Somogyi. Genetic network inference: from co-expression clustering to reverse engineering. Bioinformatics, vol. 16, 2000.
2. G. Kossinets, D.J. Watts. Empirical Analysis of an Evolving Social Network. Science, 2006.
3. R. Kumar, J. Novak, A. Tomkins. Structure and evolution of online social networks. In Proc. KDD, 2006.

**Topic 10. Network visualization Content**:

Visual exploration. Graph layouts: radial, force directed, spectral. Matrix visualization.

**Recommended reading:**

1. “Handbook of Graph Drawing and Visualization”, Eds Roberto Tamassia, CRC Press, 2013
2. Brandes, Ulrik, and Dorothea Wagner. "Analysis and visualization of social networks." Graph drawing software. Springer Berlin Heidelberg, 2004. 321-340.
3. Nathalie Henry and Jean-daniel Fekete. “MatrixExplorer: a Dual-Representation System to Explore Social Networks, IEEE Transactions on Visualization and Computer Graphics, 2006. v12 , pp 677-684.

**Supplementary reading:**

1. V. Batagelj and A. Mrvar. Pajek-analysis and visualization of large networks. Springer, 2003.
2. Bastian M., Heymann S., Jacomy M. (2009). Gephi: an open source software for exploring and manipulating networks. In Proc ICWSM 2009.

3. Henry, N.; Fekete, J.; McGuffin, M.J., "NodeTrix: a Hybrid Visualization of Social

 Networks," Visualization and Computer Graphics, IEEE Transactions on , vol.13, no.6,

 pp.1302,1309,

1. **Term Educational Technology**

The following educational technologies are used in the study process:

* + discussion and analysis of the results of the home task in the group;
	+ individual education methods, which depend on the progress of each student;
	+ analysis of skills to formulate common problem in terms of mathematics and solve it; The course is used to be in format of teleconference lectures.
1. **Recommendations for course lecturer**

Course lecturer is advised to use interactive learning methods, which allow participation of the majority of students, such as slide presentations, combined with writing materials on board, and usage interactive programming environments for demonstration purposes. The course is intended to be adaptive, but it is normal to differentiate tasks in a group if necessary, and direct fast learners to solve more complicated tasks.

**13. Recommendations for students**

The course is interactive. Lectures are combined with classes. Students are invited to ask questions and actively participate in-group discussions. There will be special office hours for students, which would like to get more precise understanding of each topic. Teaching assistant will also help you. All tutors are ready to answer your questions online by official e-mails that you can find in the “contacts” section**.**

* 1. **Sample final exam questions**
1. Some social network has an exponential destribution of node degrees, given by P(k) = Ce−ak,

where C and a are constants and a is given. Find the fraction of the network nodes that have no more than k0 neigbours. Use continues approximation kmin = 0, kmax = ∞.

1. Consider random walk on the undirected graph given below. Calculate the probability of being on the node #9 in the limit of large time.

1. Describe Zipf’s law. What is the connection between Zipf’s law and power law distributions?
2. Calculate node desgree destributions in the Barabasi-Albert model with uniform probability of

attachment P(k) = 1/(m\_0 + T)

1. Which of the graphs given below has been most likely generated form Erdos-Renyi model with N=5 and p=0.3 Why? Which one couldn’t be generated by that model?

 **15. Reading and Materials**

 **15.1 Required Reading**

* 1. Mark Newman. "Networks: An Introduction". Oxford University Press, 2010.
	2. David Easley and John Kleinberg. "Networks, Crowds, and Markets: Reasoning About a Highly Connected World." Cambridge University Press 2010.

1. **Recommended Reading**
	1. Stanley Wasserman and Katherine Faust. "Social Network Analysis. Methods and Applications." Cambridge University Press, 1994
	2. Matthew O. Jackson. "Social and Economic Networks". Princeton University Press, 2010.
2. **List of review papers**
	* 1. R. Albert and A-L. Barabasi. Statistical mechanics of complex networks. Rev. Mod. Phys, Vol. 74, p 47-97, 2002
		2. M. E. J. Newman. The Structure and Function of Complex Networks. SIAM Review, Vol. 45, p 167-256, 2003
		3. S. Boccaletti et al. Complex networks: Structure and dynamics. Phys. Reports, Vol. 424, p 175-308, 2006
		4. S. N. Dorogovtsev and J. F. F. Mendes. Evolution of Networks. Adv. Phys. Vol. 51, N 4, p 1079-1187
3. **Course telemaintenance**

All material of the discipline are posted in informational educational site at NRU HSE portal [www.cs.hse.ru/ai](http://www.cs.hse.ru/ai), <http://www.leonidzhukov.net/hse/2016/networks/>,

<https://github.com/MakarovIA/networks> and DataJoy Group.

Students are provided with links to research papers, electronic books, data and software via different cloud services and tools.

1. **Equipment**

The course requires a laptop, projector, and acoustic systems.

It also requires opportunity to install programming software, such as:

* Python
* Matlab
* R

on student personal computers.

 One of core ways is to use the service [www.getdatajoy.com](http://www.getdatajoy.com) or use installed software on Amazon Web-server.

Lecture materials, course structure and syllabus are prepared by Leonid Zhukov and Ilya Makarov