Network Science or Applied Graph Theory? Examining the network of indirect collaboration in a Department of Mathematics

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جامعة نيويورك أبوظبي
NYU ABU DHABI

NYUAD Mathematics Colloquium
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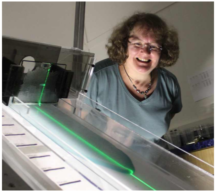
I. Networks in/and Mathematics

Examples of Mathematics Departments offering Networks Courses

- UCLA Mathematics (**Andrea Bertozzi, Mason Porter**)
- University of North Carolina Mathematics (**Peter Mucha**)
- University of Vermont Mathematics & Statistics (**Peter Dodds**)
- Queen Mary University of London Mathematical Sciences & Statistics (**Ginestra Bianconi**)
- Oxford Mathematical Institute (UK) (**Sam Howison**)
- University of Namur (Belgium) Mathematics (**Renaud Lambiotte**)
- University of Limerick (Ireland) Mathematics & Statistics (**James Gleeson**)
- Stockholm University (Sweden) Statistics (**Ove Frank**)
- Chalmers Gothenburg (Sweden) Mathematical Sciences
- Caltech Computing & Mathematical Sciences
- US Military Academy West Point
- University of Chicago Mathematics
- Dartmouth Mathematics
- University of Texas Austin Simons Center on Network Mathematics
- Bar-Ilan University (Israel) Mathematics



Andrea Bertozzi (UCLA)

Mason Porter (UCLA)

Peter Mucha (UNC)

Peter Dodds (UVM)

Ginestra Bianconi (QMU)

Sam Howison (Oxford)

Renaud Lambiotte (Namur)

James Gleeson (Limerick)

Networks in Mathematics Subject Classification (MSC2010)

05-xx Combinatorics
- **05Cxx** Graph theory
  - **05C82** Small world graphs, complex networks

35-xx Partial differential equations
- **35Rxx** Miscellaneous topics
  - **35R02** Partial differential equations on graphs and networks (ramified or polygonal spaces)

68-xx Computer science
- **68Mxx** Computer system organization
  - **68M10** Network design and communication

90-xx Operations research, mathematical programming
- **90Bxx** Operations research and management science
  - **90B10, 15** Network models, deterministic, stochastic
- **90Cxx** Mathematical programming
  - **90C35** Programming involving graphs or networks

91-xx Game theory, economics, social and behavioral sciences
- **91Dxx** Mathematical sociology (including anthropology)
  - **91D30** Social networks

94-xx Information and communication, circuits
- **94Cxx** Circuits, networks
  - **94C15** Applications of graph theory

From Numerical Mathematics

SIAM J. ALG. DISC. METH.
Vol. 6, No. 4, October 1985

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GRAPH THEORY AND FLUID DYNAMICS*

KARL GUSTAFSON† AND ROBERT HARTMAN‡

Abstract. We describe recent applications of network-theoretic graph theory to the analysis of certain discretizations of fluid flow. Also given are a natural extension to elliptic equations of divergence form and a computation of a sparseness matrix previously inaccessible due to lack of a general basis method.

AMS(MOS) subject classifications. 65N30, 68E10, 35Q10, 76D05

1. Introduction. Consider a viscous incompressible liquid in a vessel Ω in Euclidean space. Let the velocity and pressure be given by $\mathbf{u}(x, t)$ and $p(x, t)$, where a scale has been chosen so that the density equals one. Then the *Navier–Stokes equations* describing the motion of the liquid are (in three dimensions):

$$u_t - \gamma\Delta u + \sum_{k=1}^{3} u_k \mathbf{u}_{x_k} = -\text{grad } p + \mathbf{f}, \qquad x \in \Omega, \quad t > 0, \tag{1.1}$$

$$\text{div } \mathbf{u} = 0, \qquad x \in \Omega, \quad t > 0, \tag{1.2}$$

$$\mathbf{u}(x, t) = 0, \qquad x \in \partial\Omega, \quad t > 0, \tag{1.3}$$

$$\mathbf{u}(x, 0) = \mathbf{a}(x) \qquad x \in \Omega, \quad t = 0. \tag{1.4}$$

Equations (1.1) and (1.2) are coupled partial differential equations called the momentum equation and continuity equation. The boundary condition (1.3) is called the noslip condition, (1.4) is the known initial condition, $\mathbf{f}$ represents known external forces, $\gamma = 1/R$ is the viscosity, R is the Reynolds number.

It is generally accepted that for smooth known $\mathbf{f}$ and $\mathbf{a}$ the problem (1.1)–(1.4) is *well-posed* for all $t \geqq 0$. This means that the equations possess a unique solution stable under small changes of data and regular for all time. This has been shown for two dimensions and has been a longstanding open problem, which we will not discuss, in three dimensions. We shall instead look at the construction of approximate solutions following [1], [2], [3], [4].

To Mathematics of Data Science

II. Domination in Wikipedia Graphs

Wikipedia graphs

Definition

A **Wikipedia graph** is a directed graph $G = (V, E)$ such that

- nodes $v \in V$ represent **webpages** from the **Wikipedia** (Internet) domain, from now on, called **Wikipedia pages** or just **pages**, and
- edges $e = (u, v) \in E$ represent **hyperlinks** directed (or pointing) from page u to page v.

Moreover, for two pages u, v in the Wikipedia graph $G = (V, E)$ (i.e., for $u, v \in V$),

- if page v is hyperlinked (pointed) by page u (i.e., if $(u, v) \in E$), we say that page u **dominates** page v (or page v **is dominated by** page u or page v is a **dominant** of page u), and
- if page u both dominates and is dominated by page v (i.e., if (u, v) and $(v, u) \in E$), we say that pages u, v are **equi–dominant**.

Wikipedia graphs stemming from fixed pages

Definition

Let $W = \{w_1, \dots, w_k\}$ be a finite collection of k (distinct) Wikipedia pages. A Wikipedia graph $G = (V, E)$ is said to be a **graph of Wikipedia pages stemming from** W, whenever

- $V = W \cup Z$, where $W \cap Z = \varnothing$ and $|Z| > 0$,
- every page $z \in Z$ is dominated by (at least) one page $w \in W$, there is no page in W without any dominant pages in Z, and
- if there exists a hyperlink $(z, y) \in E$ such that $z \in Z$ and $y \in V$, then either $y \in W$, in which case pages z, y are equi–dominant, or $y \in Z$, in which case page z dominates or is dominated by page y.

Using the terminology of **ego–centric networks** (or **ego–nets**), pages in W are called **egos** and pages in Z are called **alters**. Moreover, a hyperlink $(u, v) \in E$ is called **reciprocating** if $(v, u) \in E$ (i.e., if u, v are equi–dominant).

Wikipedia graphs stemming from the pages of `Graph theory`, `Network science` and `Complex network`

Let $G = (V, E)$ be the Wikipedia graph stemming from

$$W = \{\texttt{Graph theory}, \texttt{Network science}, \texttt{Complex network}\},$$

- G is composed of 733 pages and 31,435 hyperlinks,
- the density of G is 0.059,
- the density of reciprocating hyperlinks is 0.391,
- G is weakly connected,
- G is not strongly connected and it has 11 strongly connected components,
- denoting by G_{lscc} the largest strongly connected component of G, then:
  - G_{lscc} is composed of 722 pages and 31,277 hyperlinks,
  - the density of G_{lscc} is 0.06,
  - the density of reciprocating hyperlinks is 0.393,
  - the diameter of G_{lscc} is 8.

Domination number

Definition

Let S be a set of dominating pages in the Wikipedia graph G. S is called a **minimum dominating set** if the cardinality of S is minimum among the cardinalities of any other dominating set on G. The cardinality of a minimum dominating set is called the **domination number** of graph G and is denoted by $\gamma(G)$.

Apparently, the domination number of the Wikipedia graph stemming from W is

$$\gamma(G) = |W| = 3$$

. However, if the relationship of domination was defined conversely (i.e., for a hyperlinh $(u, v) \in E$, v would be called **conversely dominating** u), then the **converse domination number** of the Wikipedia graph stemming from W would have found to be

$$\gamma_{\text{converse}}(G) = 61.$$

A categorical attribute on pages

For every page $v \in V \setminus W$, let

$$A(v) = \{w \in W : w \text{ dominates } v\} \neq \varnothing.$$

If $v \in W$, by reflexivity, take $A(v) = \{v\}$. So, this association defines a set–valued mapping $A : V \to 2^W$. Now, instead of taking all possible (nonempty) subsets of W, we consider the partition of 2^W

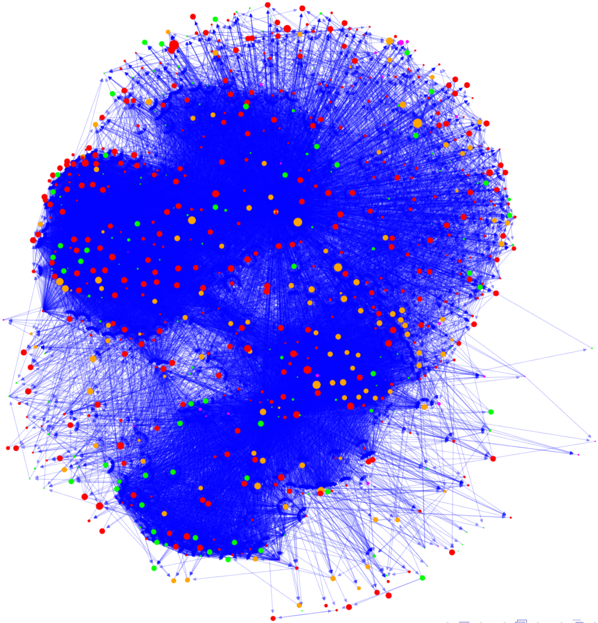
$$2^W = \mathscr{W}_1 \cup \mathscr{W}_2 \cup \mathscr{W}_3 \cup \mathscr{W}_{123}$$

into the following four disjoint subsets:

$$\begin{aligned} \mathscr{W}_1 &= \{\texttt{Graph theory}\}, \\ \mathscr{W}_2 &= \{\texttt{Network science}\}, \\ \mathscr{W}_3 &= \{\texttt{Complex network}\}, \\ \mathscr{W}_{123} &= \{A \in 2^W : |A| \geq 2\}. \end{aligned}$$

In this way, setting $\mathscr{W} = \{\mathscr{W}_1, \mathscr{W}_2, \mathscr{W}_3, \mathscr{W}_{123}\}$, a (single-valued) attribute $\alpha : V \to \mathscr{W}$ is defined on all pages stemming from W.

The graph of Wikipedia pages stemming from "Graph Theory, Network Science and Complex Network"
(red nodes are pages hyperlinked only from "Graph theory",
lime nodes are pages only hyperlinked from "Network science",
magenta nodes are pages only hyperlinked from "Complex network",
and orange nodes are pages hyperlinked by at least two of the starting pages)



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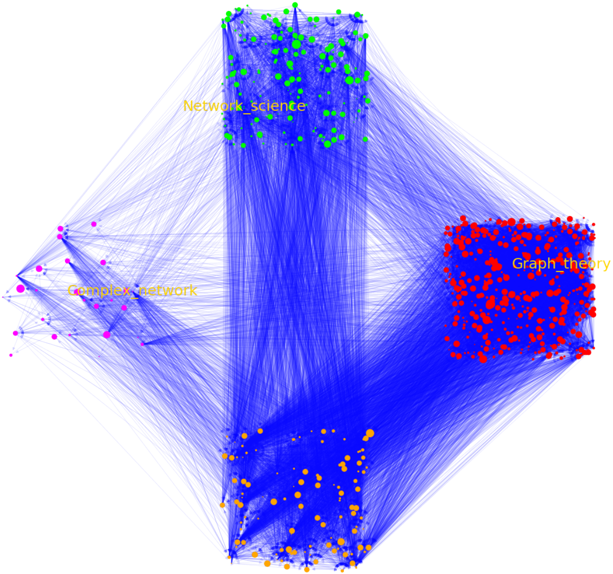


Attribute assortativity coefficient

Following Mark Newman (2003), the (normalized) **enumerative attribute assortativity** (or **discrete assortativity**) **coefficient** of attribute α is defined as:

$$r_\alpha = \frac{\operatorname{tr}\mathbf{M}_\alpha - ||\mathbf{M}_\alpha^2||}{1 - ||\mathbf{M}_\alpha^2||},$$

where $\mathbf{M}_\alpha$ is the $|\mathscr{W}| \times |\mathscr{W}|$ (normalized) **mixing matrix** of the values (or catefories) of attribute α on edges of G. Equivalently:

$$r_\alpha = \frac{\sum_{i,j \in V}(A_{ij} - \frac{k_i k_j}{2m})\delta(\alpha(i), \alpha(j))}{2m - \sum_{i,j \in V}(\frac{k_i k_j}{2m})\delta(\alpha(i), \alpha(j))},$$

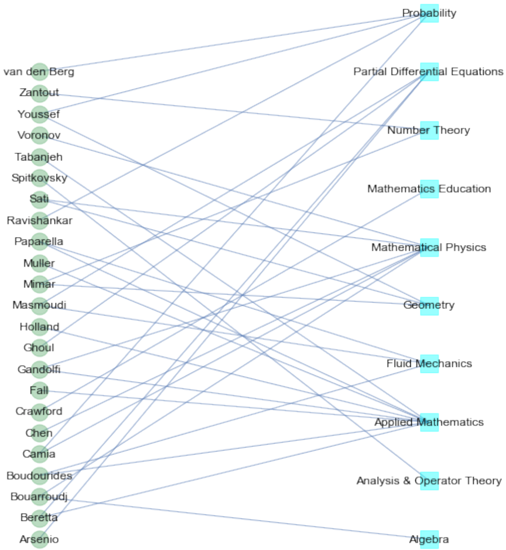
where A_{ij} is the adjacency matrix of graph G, m is the total number of edges of G, k_i is the degree of vertex i and $\delta(x, y)$ is the Kronecker delta. Here, we find that

$$r_\alpha = 0.473$$

implying that the Wikipedia graph stemming from W is moderately assortative for the previously defined attribute α.

III. Math Faculty and Research Areas

The bipartite graph of faculty members and research areas in the NYUAD Math Faculty Network



The basics of Formal Cocept Analysis (FCA)

Definition

- A **formal context** is a triple (G, M, I), where G is a set of **objects**, M is a set of **attributes**, and I is a **relation** between G and M, in which we read $(g, m) \in I$ as "object g has attribute m."
- For $A \subseteq G$, the **prime derivation operator on sets of objects** is defined as $A' = \{m \in M : \forall g \in A, (g, m) \in I\}$.
- For $B \subseteq M$, the **prime derivation operator on sets of attributes** is defined as $B' = \{g \in G : \forall m \in B, (g, m) \in I\}$.

Properties:

For $A, A_1, A_2 \subseteq G$,

- $A_1 \subseteq A_2 \Rightarrow A_2' \subseteq A_1'$,
- $A \subseteq A''$ and $A' \subseteq A'''$.

For $B, B_1, B_2 \subseteq M$,

- $B_1 \subseteq B_2 \Rightarrow B_2' \subseteq B_1'$,
- $B \subseteq B''$ and $B' \subseteq B'''$.

Definition

A **formal concept** is a pair (A, B), where $A \subseteq G$ and $B \subseteq M$, such that $A' = B$ and $B' = A$. A is called the **extent** and B the **intent** of the concept (A, B).

Lemma

For $A \subseteq G$ and $B \subseteq M$, (A, B) is a formal concept if and only if A and B are both maximal with respect to $A \times B \subseteq I$, meaning that every concept corresponds to a maximal rectangle in the relation I.

An ordering on concepts:
$(A_1, B_1) \leq (A_2, B_2) \Leftrightarrow A_1 \subseteq A_2 (\Leftrightarrow B_1 \subseteq B_2)$.

Definition

The set of all concepts $\mathfrak{B}(G, M, I)$ together with the partial order $\leq$ is the **concept lattice** of the context (G, M, I) and it is denoted as $\underline{\mathfrak{B}}(G, M, I)$.

Definition

An **implication** $X \longrightarrow Y$ is said to hold in a context, if every object that has all attributes from X also has all attributes from Y.

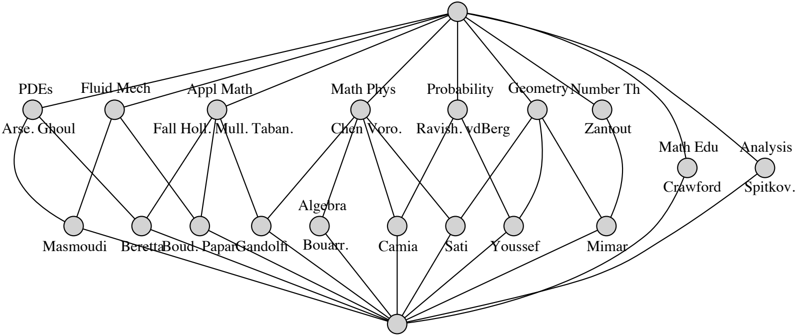
Definition

Let (G, M, I) be a context. Then (M, G, I^{-1}) is the **dual context** of (G, M, I), with the understanding that $(m, g) \in I^{-1} \iff (g, m) \in I$.

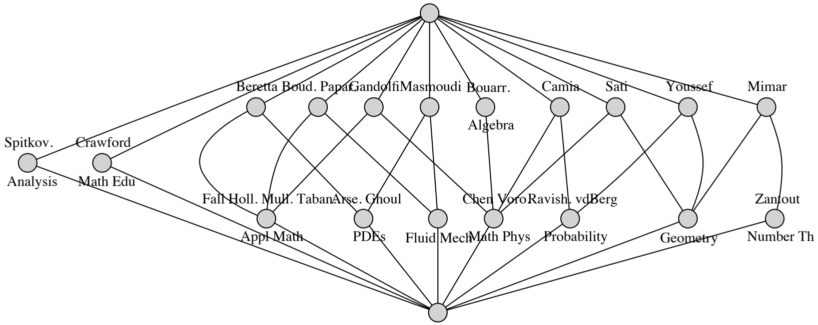
Theorem

The concept lattice of the dual context is isomporphic to the concept lattice of a context.

The concept lattice of the context of Math Faculty and Research Areas



The dual concept lattice of the context of Math Faculty and Research Areas



IV. Math Faculty Collaboration Network

The AMS MathSciNet tool to find collaboration distances among any two authors of Math publications

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AMERICAN MATHEMATICAL SOCIETY
MATHSCINET
MATHEMATICAL REVIEWS

New York Univ, Courant Inst

Search MSC | Collaboration Distance | Current Journals | Current Publications

ISSN 2167-5163

MR Collaboration Distance = 3

Federico Camia	coauthored with	Sandro Graffi	MR1627552
Sandro Graffi	coauthored with	Barry Simon	MR0332068
Barry Simon	coauthored with	Ilya Matvey Spitkovsky	MR3735507

Change First Author | Change Second Author | New Search

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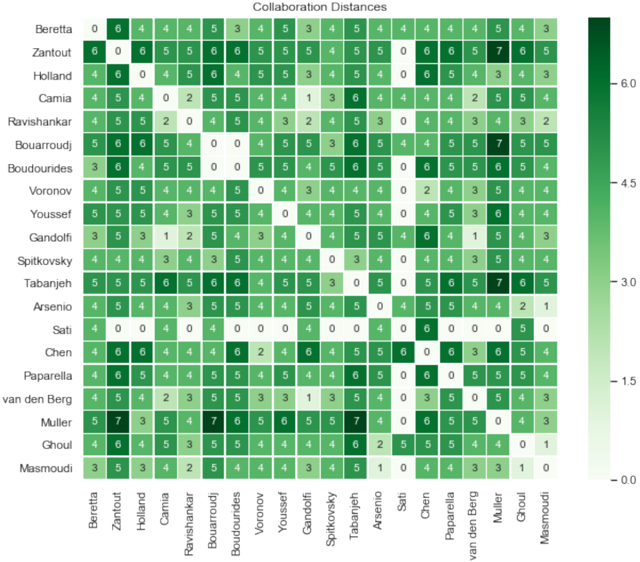
AMS AMERICAN MATHEMATICAL SOCIETY

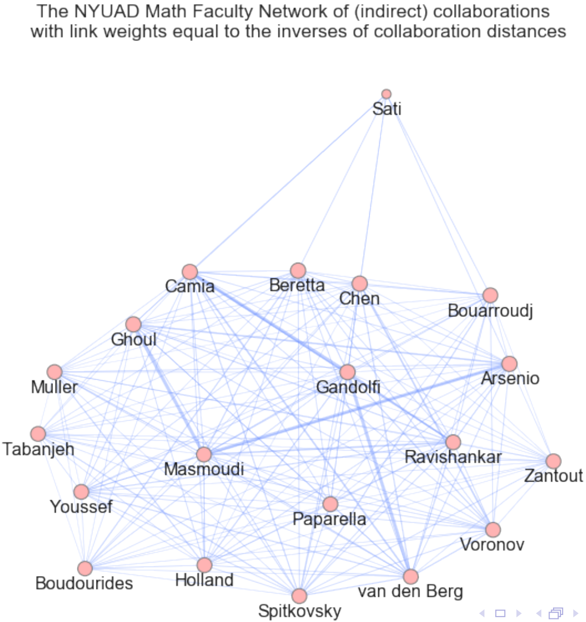
Collaboration distances among any two members of the NYUAD Math Faculty



The mean value of all collaboration distances is 3.98

	mean
Masmoudi	3.10
Ravishankar	3.30
van den Berg	3.35
Spitkovsky	3.50
Gandolfi	3.55
Voronov	3.60
Camia	3.75
Arsenio	3.85
Youssef	3.95
Beretta	3.95
Ghoul	4.00
Holland	4.00
Boudourides	4.20
Paparella	4.30
Bouarroudj	4.45
Chen	4.50
Muller	4.60
Tabanjeh	4.70
Zantout	4.90

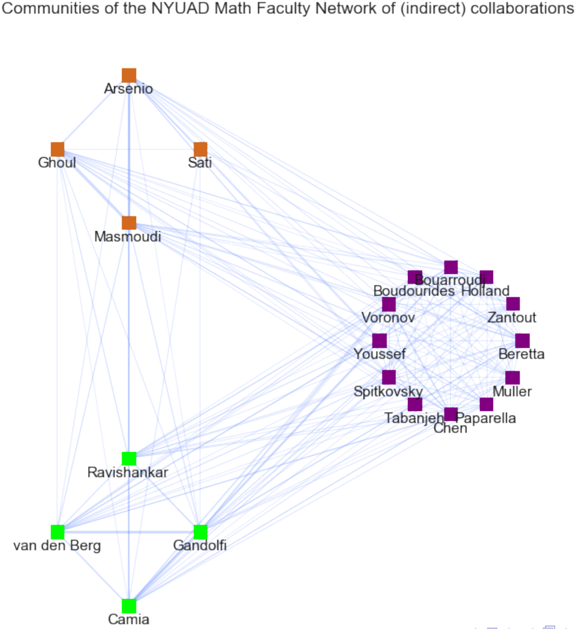
The network of (indirect) collaboration among Math Faculty



Various centrality indices (sorted by PageRank)

	page	degree	closeness	betweenness	eigenvector	HITS	Katz	PageRank	load	communicability	current flow
6	Gandolfi	1.000000	1.000000	0.010508	0.232639	0.071479	0.232361	0.068262	0.010508	0.626138	0.493149
9	Masmoudi	0.947368	0.950000	0.000344	0.227933	0.072013	0.227461	0.067978	0.000344	0.605377	0.478942
4	Camia	1.000000	1.000000	0.010508	0.232639	0.063661	0.232361	0.061309	0.010508	0.626138	0.493149
19	van den Berg	0.947368	0.950000	0.000344	0.227933	0.064667	0.227461	0.060270	0.000344	0.605377	0.478942
0	Arsenio	1.000000	1.000000	0.010508	0.232639	0.060384	0.232361	0.058861	0.010508	0.626138	0.493149
7	Ghoul	1.000000	1.000000	0.010508	0.232639	0.059814	0.232361	0.057614	0.010508	0.626138	0.493149
12	Ravishankar	0.947368	0.950000	0.000344	0.227933	0.060391	0.227461	0.057418	0.000344	0.605377	0.478942
1	Beretta	1.000000	1.000000	0.010508	0.232639	0.049723	0.232361	0.052006	0.010508	0.626138	0.493149
14	Spitkovsky	0.947368	0.950000	0.000344	0.227933	0.050632	0.227461	0.051684	0.000344	0.605377	0.478942
16	Voronov	0.947368	0.950000	0.000344	0.227933	0.050922	0.227461	0.051460	0.000344	0.605377	0.478942
5	Chen	1.000000	1.000000	0.010508	0.232639	0.046118	0.232361	0.048374	0.010508	0.626138	0.493149
8	Holland	0.947368	0.950000	0.000344	0.227933	0.046733	0.227461	0.047013	0.000344	0.605377	0.478942
17	Youssef	0.947368	0.950000	0.000344	0.227933	0.046543	0.227461	0.046839	0.000344	0.605377	0.478942
11	Paparella	0.947368	0.950000	0.000344	0.227933	0.042163	0.227461	0.043292	0.000344	0.605377	0.478942
2	Bouarroudj	0.947368	0.950000	0.009190	0.221280	0.039808	0.222033	0.043165	0.009190	0.586469	0.479956
10	Muller	0.947368	0.950000	0.000344	0.227933	0.041567	0.227461	0.042240	0.000344	0.605377	0.478942
15	Tabanjeh	0.947368	0.950000	0.000344	0.227933	0.038576	0.227461	0.040619	0.000344	0.605377	0.478942
3	Boudourides	0.894737	0.904762	0.000000	0.216313	0.039364	0.216888	0.040422	0.000000	0.563833	0.464990
18	Zantout	0.947368	0.950000	0.000344	0.227933	0.036717	0.227461	0.038723	0.000344	0.605377	0.478942
13	Sati	0.368421	0.612903	0.000000	0.089623	0.018724	0.102886	0.022451	0.000000	0.127093	0.267151

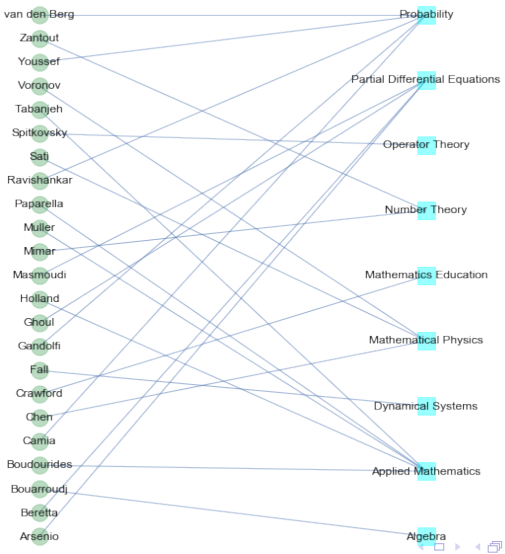
Community partitioning



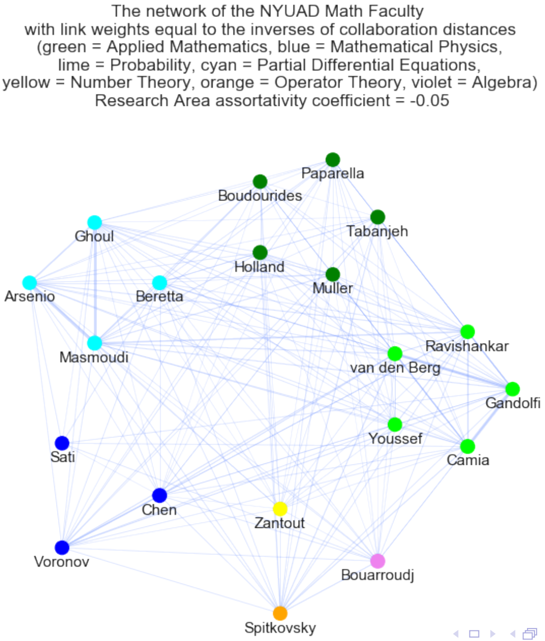
V. Assortativity of Research Areas in the Collaboration Network

Assigning unique Research Area to each Math Faculty

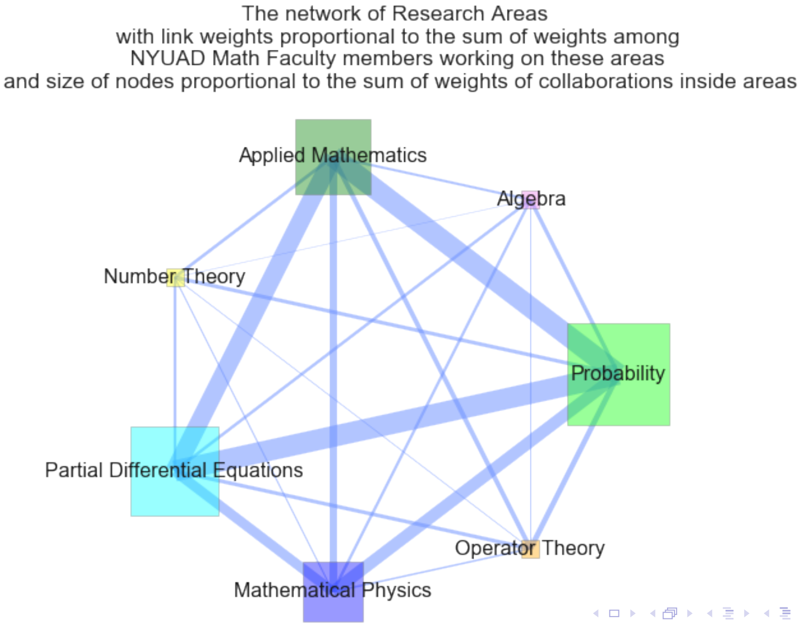
The bipartite graph of NYUAD Math Faculty and unique Research Areas



The network of Math Faculty collaboration assorted in Research Areas



The Network of Research Areas of the Math Faculty



VI. A Model of a Social Influence Process

The Friedkin–Johnsen Model of Social Influence on Graph

- Let $G = (V, E)$ be a (weakly) connected **graph** with n **nodes** representing **persons**. Given two persons (nodes) $i, j \in V$, one denotes by $i \sim j$ that i, j are **adjacent** (i.e., i, j are **neighbors** to each other). Let $\mathbf{A}$ denote the **adjacency matrix** of G.
- For each person (node) $i \in V$ and each time step $k = 0, 1, 2, \ldots$, the **opinion** of i (with regards to a certain issue) at time k is denoted by $x_i^{(k)} \in \mathbb{R}$.
- The opinion of i at time k is updated at the subsequent time step $k + 1$ according to the following iterative scheme of the **Friedkin–Johnsen Social Influence Model**:

$$x_i^{(k+1)} = s_i \, N \, x_i^{(k)} + (1 - s_i) \, x_i^{(0)},$$

  - where $N \, x_i^{(k)}$ is the *average* opinion held by i's neighbors at time step k, $x_i^{(0)}$ is the initial opinion of i and
  - the scalar parameter $s_i \in [0, 1]$ is called **susceptibility coefficient** of person (node) i.

Solving the Friedkin–Johnsen system of equations

- Disregarding the time exponent (k), $N\,x_i$ is defined as:

$$N\,x_i = \frac{1}{k_i}\sum_{j\sim i} x_j,$$

where k_i denotes the degree of i. In other words, $\mathbf{N}$ is a **random walk matrix** on G:

$$\mathbf{N} = \mathbf{D}^{-1}\mathbf{A},$$

where $\mathbf{D}$ denotes the diagonal matrix of degrees of G.

- As $\mathbf{N}$ is a *row–stochastic* matrix, $\mathbf{I} - \mathbf{S}\,\mathbf{N}$ becomes *diagonally dominant*, where $\mathbf{S}$ denotes the the diagonal matrix of susceptibility coefficients of persons (nodes).
- Therefore, the solution to this problem converges (relatively fast, depending on $\mathbf{S}$) to the vector $\bar{\mathbf{x}} = \bar{\mathbf{x}}(\mathbf{S};\mathbf{x}^{(0)})$ of equilibrium (steady state) opinions of persons (nodes) of G:

$$\bar{\mathbf{x}} = (\mathbf{I} - \mathbf{S}\,\mathbf{N})^{-1}(\mathbf{I} - \mathbf{S})\,\mathbf{x}^{(0)}.$$

Remarks on on influence susceptibility coefficients

- When $s_i = 0$, i's opinion does not change ($x_i^{(k)} = x_i^{(0)}$, for every time iteration $k = 1, 2, \ldots$). Such a person (node) is called **persistent** or **stubborn** in holding the same opinion without being influenced by anybody else.
- When $s_i = 1$, i is always adopting the average neighbors' opinion $N\, x_i^{(k)}$ without taking into account the initial opinion $x_i^{(0)}$. Such a person (node) is called **malleable** or fully **conforming** to the neighbors' influences.
- When $0 < s_i < 1$, i's opinion is interpolated in between the average neighbors' opinion $N\, x_i^{(k)}$ and the initial opinion $x_i^{(0)}$, in such a way that the exact position of the resulting i's opinion is weighted as a convex combination through s_i.

Boundary conditions

We partition the set of nodes (persons) of the Friedkin–Johnsen social influence system as follows:

$$V = \Omega \cup \partial\Omega \quad (\Omega \cap \partial\Omega = \varnothing),$$

where:

- $\Omega = \{i \in V : s_i > 0\}$ is the domain of the Friedkin–Johnsen social influence system composed *exclusively* of nonpersistent persons (nodes).
- $\partial\Omega = \{i \in V : s_i = 0\}$ is the **boundary** of the domain of the social influence system composed *exclusively* of persistent persons (nodes).

Furthermore, we assume that:

- $|\partial\Omega| < n$.
- $\forall j \in \partial\Omega, \exists i \in \Omega, i \sim j$.

The Initial Boundary Value Friedkin–Johnsen Problem

- When $\partial\Omega \neq \emptyset$, any person (node) on the social influence boundary $\partial\Omega$ is called **source of a boundary stimulation** or just a **persistent source**. Moreover, we use the notation $\partial\Omega = \{j_a\}_{a=1,\ldots,|\partial\Omega|}$.
- Thus, the **Initial Boundary Value Problem** (**IBVP**) of the Friedkin–Johnsen social influence system is the following:

$$
\begin{aligned}
x_i^{(k+1)} &= s_i\, N\, x_i^{(k)} + (1 - s_i) x_i^{(0)}, \text{ for all } i \in \Omega, k = 0, 1, \ldots, \\
x_{j_a}^{(k)} &= 1, \text{ for all } j_a \in \partial\Omega, k = 0, 1, \ldots, \\
x_i^{(0)} &= \phi_i, \text{ for all } i \in \Omega,
\end{aligned}
$$

where ϕ_i is the initial opinion of person/node $i \in \Omega$.

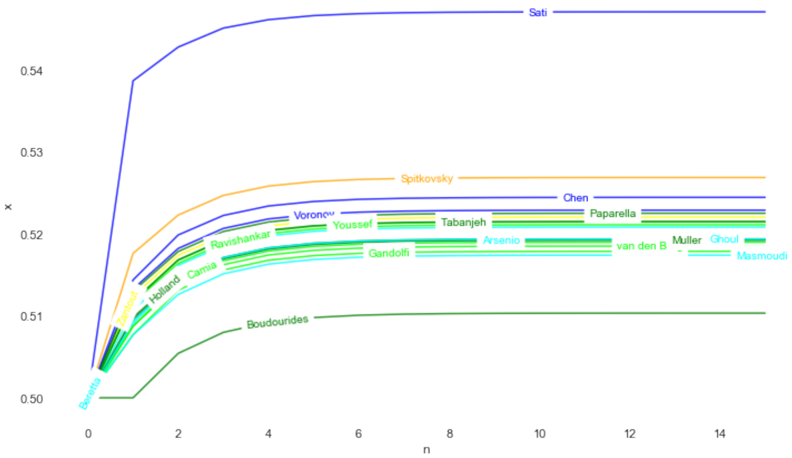
Solving the Initial Boundary Value Friedkin–Johnsen Problem on a Math Faculty collaboration network with Research Areas as sources of boundary simulation

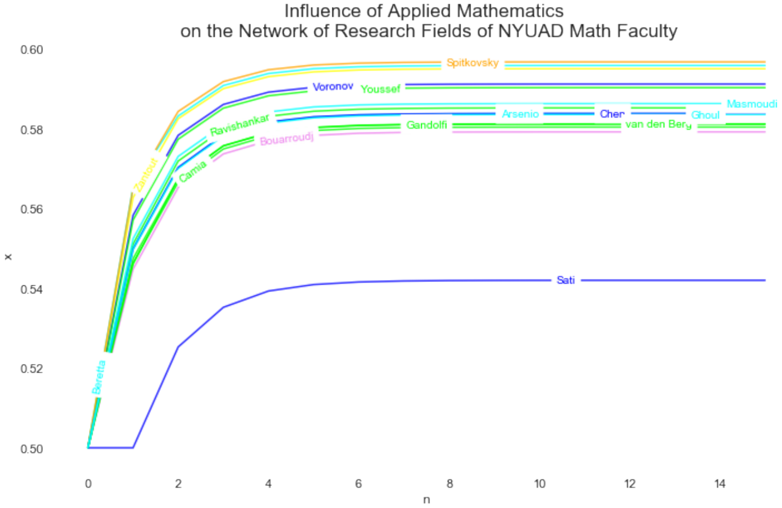
Now, let G be the network of (indirect) collaboration among Math Faculty and let $\mathscr{R}$ denote the 7 Research Areas to a (unique) of which each Faculty member is involved:

$$\begin{aligned}\mathscr{R} = \{&\texttt{Algebra},\ \texttt{Applied Mathematics},\ \texttt{Mathematical Physics},\\ &\texttt{Number Theory},\ \texttt{Operator Theory},\\ &\texttt{Partial Differential Equations},\ \texttt{Probability}\}.\end{aligned}$$

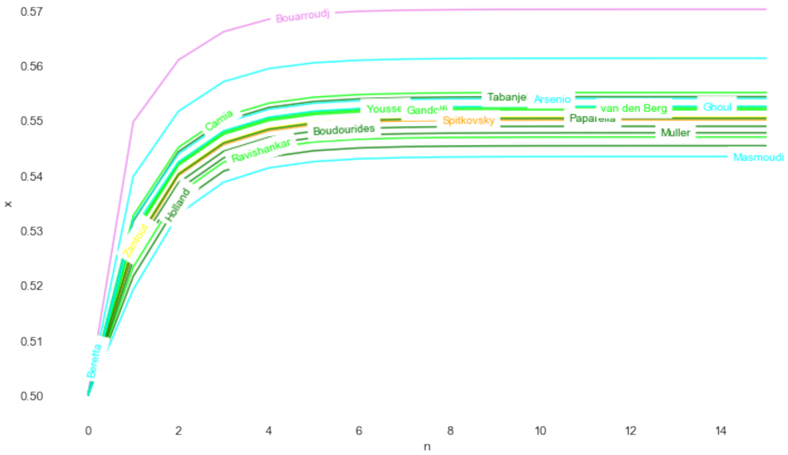
In what follows, for each Research Area in $\mathscr{R}$, the Math Faculty working on this Research Area will be taken as a source of boundary simulation to the remaining Math Faculty involved in all other Research Areas and the influence exerted by the former to the latter will be plotted time (iteration step).

Influence of Algebra on the Network of Research Fields of NYUAD Math Faculty

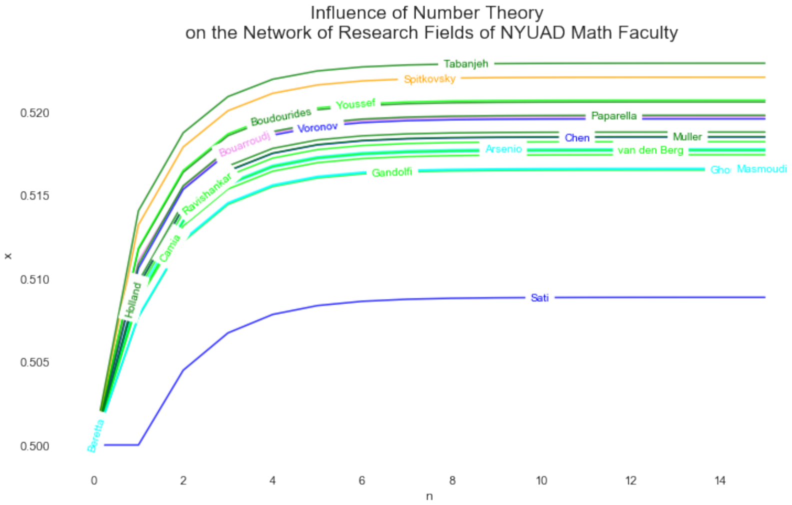



Influence of Applied Mathematics
on the Network of Research Fields of NYUAD Math Faculty
0.60
0.58
0.56
0.54
0.52
0.50
x
0
2
4
6
8
10
12
14
n
Spitkovsky
Voronov
Youssef
Masmoudi
Arsenio
Cher
Ghoul
Ravishankar
Gandolfi
van den Berg
Bouarroudj
Zantout
Camia
Beretta
Sati

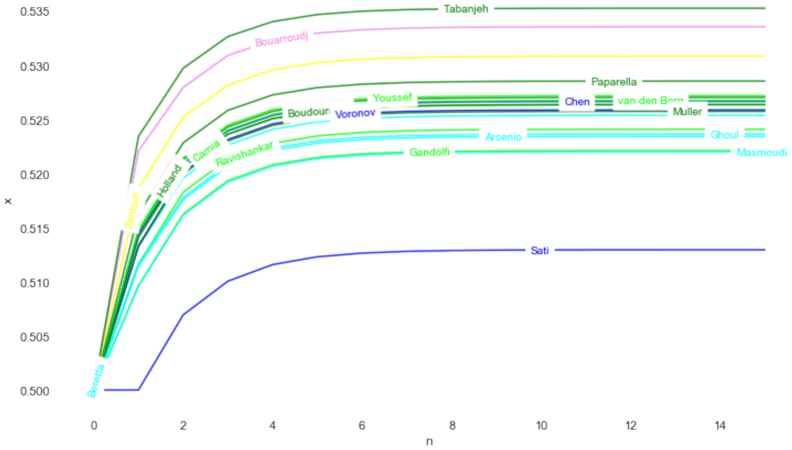
Influence of Mathematical Physics
on the Network of Research Fields of NYUAD Math Faculty

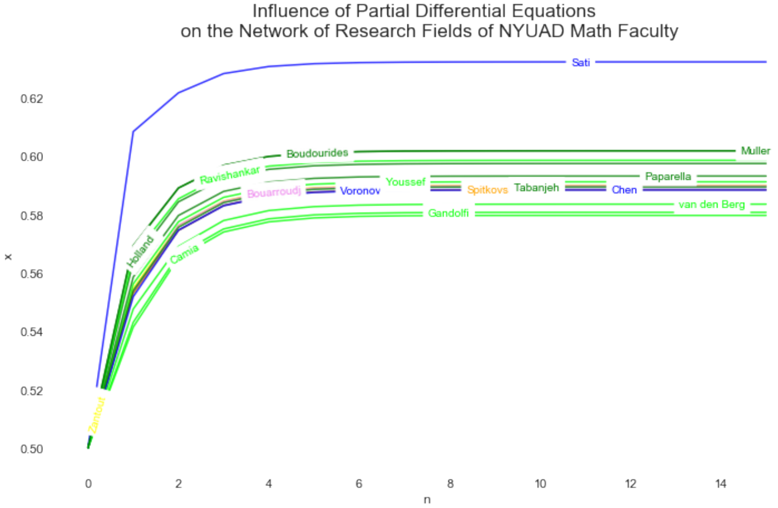


Influence of Number Theory on the Network of Research Fields of NYUAD Math Faculty

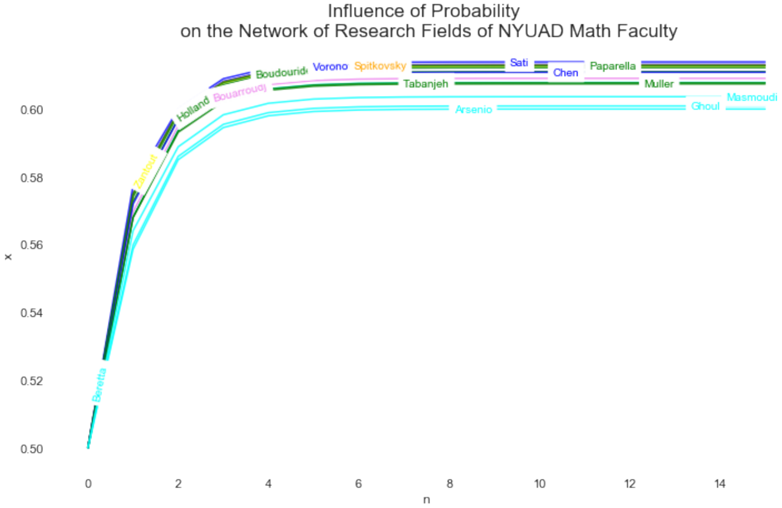


Influence of Operator Theory
on the Network of Research Fields of NYUAD Math Faculty





Influence of Partial Differential Equations
on the Network of Research Fields of NYUAD Math Faculty
Sati
Boudourides
Muller
Ravishankar
Paparella
Youssef
Bouarroudj
Voronov
Spitkovs
Tabanjeh
Chen
van den Berg
Gandolfi
Holland
Camia
Zantout
x
0.50
0.52
0.54
0.56
0.58
0.60
0.62
n
0
2
4
6
8
10
12
14



Influence of Probability
on the Network of Research Fields of NYUAD Math Faculty
x
n
0.50
0.52
0.54
0.56
0.58
0.60
0
2
4
6
8
10
12
14
Beretta
Zantout
Holland
Bouarroudj
Boudourid
Vorono
Spitkovsky
Sati
Chen
Paparella
Tabanjeh
Muller
Masmoudi
Ghoul
Arsenio