Application

2015-03-31

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Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): Decision making on networked systems in presence of antagonistic interactions

Project start: 2016-01-01

Project end: 2019-12-31

Review panel applied for: NT-14

Classification code: 20202. Reglerteknik

Keywords: Signed Graphs, Dynamics of Complex Networks, Networked Control Systems, Consensus

Funds applied for

Year:	2016	2017	2018	2019
Amount:	1,000,000	1,000,000	1,000,000	1,000,000

Descriptive data

Project info

Project title (Swedish)*

Beslutsfattande i nätverk av system med antagonistiska kopplingar

Project title (English)*

Decision making on networked systems in presence of antagonistic interactions

Abstract (English)*

The aim of this project is to investigate the dynamical behavior and the strategies for control of complex networked systems in which cooperative and antagonistic interactions coexist. Antagonistic interactions, represented by edges with negative weights, appear naturally in a number of applicative contexts. The dynamics of a system on the resulting signed graph is normally richer and more complicated to predict than on its purely cooperative counterpart. Also the control problems become significantly more challenging when antagonism is present in a network.

In this project, qualitative and quantitative models of interconnected systems will be developed. Qualitative models are needed when the network has poorly characterized dynamical interactions, while quantitative models deal with cases in which the functional form of the interactions is well-known or can be specified by the designer, as in networked control systems. The two paradigms make use of different methodologies to investigate the collective dynamics of a complex system. In both cases, system-theoretical properties of the networked systems will be investigated, as well as techniques to encode distributed decision making processes on the dynamics of the signed networks.

For instance we plan to extend to signed graphs the existing graphical test for checking controllability, observability and decoupling, and to apply them to the large-scale signed networks available in the literature. When dealing with quantitative models, problems that will be investigated include the predictability of opinion forming processes and their influenceability through external inputs or through stubborn agents. For both paradigms we plan to develop algorithms for controlling the collective dynamical behavior of the signed networks.

Popular scientific description (Swedish)*

Ett komplext nätverk kan vanligtvis representeras med en graf där noderna är ``agenter'' med utförandeförmågor, och kanterna motsvarar kopplingar eller informationsutbyten mellan noderna. Detta paradigm används över ett brett spektrum av vetenskapliga discipliner, från biologi till samhällsvetenskap, teknik till ingenjörsvetenskap. Det har fått en anmärkningsvärd uppmärksamhet under senare år då de nyss nämnda disciplinerna visat att många naturligt förekommande såväl som konstruerade system verkligen är strukturerade på detta sätt. Exempelvis ett nätverk av gener som representerar kopplingar mellan de ~20000 generna i en cell är ett distribuerat system i bemärkelsen att de styrande kopplingarna mellan generna sker utan något behov av en centraliserad bestlutsenhet. Likaså i ett socialt nätverk av personer, där varje nod är en beslutsfattare och betsluten som en nod kan tänkas ta vanligtvis är påverkade (men inte bestämda) av angränsande noder. Även konstruerade system kan byggas enligt decentraliserade principer. Ta till exempel en grupp robotar som koordinerar sitt agerande utan att vara beroende av en gemensam basstation.

I dessa och liknande uppställningar görs det gemensamma antagandet litteraturen att agenterna samarbetar för att uppnå ett gemensamt mål. Detta antagande är rimligt i många fall, exempelvis för en grupp robotar utplacerade för att utföra en viss uppgift, men det kan vara restriktivt i andra fall. I exempelvis ett nätverk av gener, där kopplingar mellan gener kan verka aktiverande (en kant representerad med ett positivt tecken) eller hämmande (kant med negativt tecken). Likaså i ett socialt nätverk, där personer kan ha positiva (vänskapliga) eller negativa (ovänliga) relationer. Även i fallet med grupper av robotar som tävlar mot varandra är en modell baserad på enbart samarbeten inte lämplig.

Detta projekt fokuserar på förståelsen av beteendet hos komplexa nätverk där både samarbeten och antagonism samexisterar. Dynamiken som kommer ur denna samexistens är vanligtvis rikare och svårare att förutse än dess motpart med endast samarbete. Också reglerproblem får ytterligare en svårighetsgrad när antagonism finns med. Målet med projektet är att utveckla modeller som förmår förbättra vår förståelse av dynamiken i komplexa nätverk med såväl positiva som negativa kopplingar, och algoritmer som kan reglera deras beteende.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*	2. Teknik > 202. Elektroteknik och elektronik > 20202. Reglerteknik

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Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

Signed Graphs

Keyword 2*

Dynamics of Complex Networks

Keyword 3*

Networked Control Systems

Keyword 4

Consensus

Keyword 5

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

None

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Research Program
Claudio Altafini (690106-0696)

1 Purpose and aims

The main purpose of this proposal is to investigate how the presence of antagonistic interactions in complex networked systems affects its collective dynamical behavior and its control.

For a network of interacting agents, a common assumption in the literature is that the agents collaborate to achieve a common goal. In many real-world scenarios, however, it is more natural to assume that cooperative and antagonistic interactions coexist. Depending on the application one has in mind, these two terms refer to trust/mistrust, friend/foe, alliance/competition, activation/inhibition, etc., see Fig. 1 for a few examples. In interconnected systems, passing from cooperation to cooperation plus antagonism widens the range of possible dynamical behaviors, and renders the control design more complex. We have shown recently that some of the theoretical tools and concepts normally used for cooperative networked systems, such as for example the Perron-Frobenius theorem [5] and the notion of consensus [3], can be used with profit also in this more complex scenario.

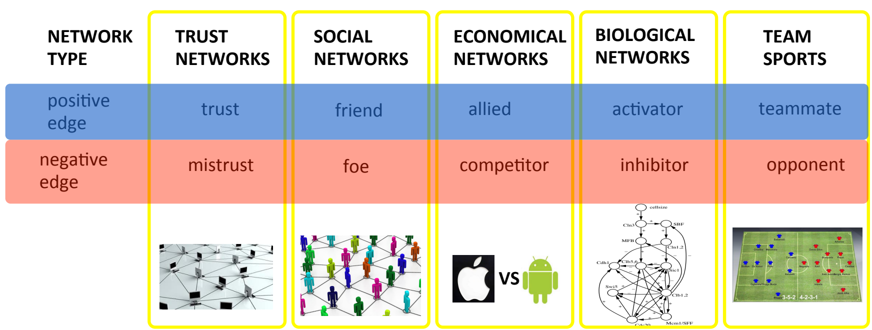

Figure 1: Examples of signed networks.

The aim of this proposal is to study in a systematic way networked systems in which cooperation and antagonism coexist, using methodological approaches tailored to the level of knowledge that we have of a network. In particular,

1. When a network is poorly known (e.g., those from social network theory or from biology), then we will apply qualitative methods that do not rely on the precise functional form of the interactions but only on the topology and on the pattern of cooperation/antagonism among agents. In this case the specific objectives of the proposal are to investigate system-theoretical properties such as controllability, observability input-output decoupling, extending to signed networks the graphical tests that exist for these properties. In particular we will try to understand how to control large-scale signed networks whose nodes are not naturally endowed with a control authority, as it is often the case for complex networks outside the sphere of control theory.

2. For networked systems in which the functional form of the interactions is known well quantitatively, we will investigate a series of dynamical problems arising from the presence of antagonism, and that have no counterpart on purely cooperative networks, such as the achievement of unanimity, the predictability of opinion forming processes (e.g. voting schemes, decision-making processes, etc.), and the use of stubborn agents to steer such opinion-forming processes. Finally for networked control systems (in which each agent has some control authority) we will study variants and generalizations of the consensus problem, tailored to the presence of antagonism but also to a series of specific, non-standard applications.

2 Survey of the field

The paradigm of complex networks, vast collections of "agents" with processing capabilities interacting with their neighbors, is widespread across a large spectrum of scientific disciplines, from Biology to Social Sciences, from Technology to Engineering. Network theory as a science dedicated to the analysis and modeling of these complex natural and man-made systems has registered in the last decade an explosive growth and an impressive number of ramifications [6, 7, 20, 25]. Regardless of the field they are drawn from, these networks have a lot in common: they are interconnected systems in which the nodes are individual decision-makers and the information that can influence the process of "decision forming" (i.e., the dynamics) is transmitted locally through first neighbors communication. They may have however also significant differences. For example, in the models used in control theory the functional forms of the interactions (and hence the dynamics) can often be chosen by the designer, suitable control inputs are available and can be used to coordinate the behavior of the system or to accomplish a certain task [20, 25]. In networks from other domains (biological networks [6, 29], social networks [13], technological networks [7, 20, 25] are all models of interest for this proposal), the interactions between the nodes are often encoded in the network and hardly accessible by the modeler, and the dynamics are poorly characterized. Sometimes all that is known is just a qualitative information such as the sign of the influence that a node exerts on another node.

Networks as signed graphs. A *signed graph* is a graph in which the edges are endowed with a sign. A positive edge indicates some form of cooperation between the nodes involved, while a negative edge indicates antagonism, see Fig. 1. In this proposal we are interested in two different levels of knowledge of the details of a signed network:

1. **Qualitative paradigm.** The graph of the network is assumed to be know but no information is available on the functional form of the interactions, other than a sign. This setting is sometimes referred to as *influence graphs*.

2. **Quantitative paradigm.** Both the topology and the functional form of the interactions are assumed to be known. These latter may still be signed, as in the previous case.

The setting of qualitative signed graphs has formal analogies with the *qualitative modeling* developed in the 1960s in Economics [24], but also with the large body of research in linear algebra [10] and in discrete dynamical systems, like Boolean Networks. It is often used in Systems Biology [30, 29]. Models of interconnected systems [18, 27], such as for instance neural networks [15, 18], can instead be classified as quantitative signed graphs, as for them the functional form of the interactions (e.g. activator/inhibitor nonlinearities) are usually specified. Consensus, robots coordination, and most other multiagent problems currently studied in control theory (surveyed in [20, 23, 25]) fall into this category.

Signed networks have been studied for a long time also in social network theory [13, 32], with particular reference to a property called *structural balance*. Structural balance theory aims to understand the structure and origin of tensions and conflicts in a network of individuals (or, for us, agents). In terms of signed networks, the potential sources of tension are the cycles of negative sign (i.e., having an odd number of negative edges), see Fig. 2 for an illustration. In particular, a signed graph is structurally balanced if and only if all its cycles are positive [32]. As such, structural balance is intrinsically a global property of the network. Computing the level of structural balance of large networks is an NP-hard problem. In [14] we have developed heuristics applicable to the large-scale signed networks currently available in the literature ($\sim 10^5$ nodes).

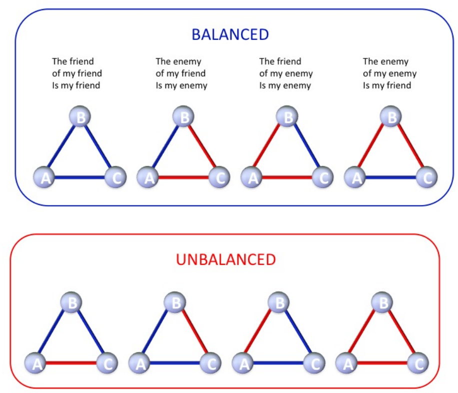

Figure 2: Structural balance on triads.

From signed topology to dynamics. From a Dynamical Systems perspective, a qualitative information such as the sign of the edges of a graph enables to some extent the investigation of a series of dynamical properties of any dynamical system having that sign pattern. These properties include counting the number of equilibria and determining their stability [24, 10], or studying the existence of oscillations [30]. Unfortunately, most of the conditions obtained are very conservative (they have to hold for any dynamical system having a certain sign pattern) and hence of little practical utility. One exception is *monotonicity* [28], property that describes the tendency of a dynamical system to have an ordered response to perturbations, avoiding oscillatory or chaotic behaviors, like in a one-dimensional system [29]. This property is important because it is a proxy for robust and predictable behavior, and as such, a monotone-like behavior is expected e.g. in biological networks. In fact, in [16] we have found that gene regulatory networks tend to be near-monotone. In [2] we have investigated the predictability of monotone dynamical processes of opinion forming on social networks, while in [14] we have shown that also currently available on-line signed social networks seem to be near-monotone.

If in addition the functional form of the interactions is known, then a broad range of dynamical properties can usually be studied in a much more efficient way. An extensive literature exists on the subject of networked systems, dealing with linear and nonlinear interconnected systems, and with their applications [18, 20, 23, 25, 27].

Control problems over qualitative networks. If the networked systems of interest in control theory are often naturally endowed with some form of actuation and some degree of control at each node, this is not true for the majority of complex networks. In a biological network, for example, control can correspond to the action of drugs. In a social network of opinions, certain nodes (driver nodes, or "opinionators") can influence the opinion of the remaining nodes, and hence drive a process of opinion forming or favor the rapid spreading of information to the whole community. For qualitative networks, criteria for choosing which nodes to "actuate" are not yet well studied. One interesting approach is proposed in [19] where a purely graphical controllability concept is used [12], particularly suitable for poorly known systems. It consists in studying the following linear time-invariant system

$$\dot{x} = Ax + Bu,$$

in which only the position of the zero entries of A and B are fixed, while the nonzero entries could be any (nonzero) number. Controllability is guaranteed generically, i.e., for almost all choices of these nonzero entries [12]. Following [19], if only the topology of a network is given (i.e., A), how do we select a *minimal set of control inputs* (i.e., B) so as to guarantee that by acting on these inputs we can reach all the nodes of the network?

Rather than the minimal number of driven nodes, other criteria for determining control inputs could be easily envisaged. For example, can we systematically investigate which nodes are not affecting an output or, more generally, the *input-output decoupling* properties of the networks? Or, can we integrate into a graphical controllability notion constraints such as positivity of the state and/or of the input? How do we extend the methods to dynamics more realistic than linear time-invariant?

Control problems on quantitative networks: from cooperation to antagonism. In a networked control system in which all nodes are independent decision-making, it is natural to assume that each agent has some control authority that can be used to accomplish a task in conjunction with the other agents. This "fully actuated" paradigm has received a huge attention in recent years, for problems like multiagent coordination, consensus and distributed decision making [20, 25]. The underlying assumption is that all agents cooperate to a common goal. When antagonism is added to the picture, then the landscape of possible behaviors is drastically more complex, and all the distributed control problems become more challenging. Furthermore, new problems arise from the coexistence of cooperation and competition, like for instance leader selection, opinion propagation or achievement of unanimity. In the purely cooperative case, these problems are either simple or do not have a direct counterpart.

Consensus and its variants. A distributed consensus problem is a control algorithm in which all agents of a network agree to converge to a common value, typically the average of their initial conditions [23]. In the linear case, the closed loop system is usually a Laplacian matrix. Diffusion-based schemes like this are used also for other tasks, like to perform dynamical load balancing among the units of a distributed computing system [11].

Extension to antagonism is possible. We have shown in [3] that a form of bipartite consensus (with states that become polarized in two opposite factions) is achievable if and only if the underlying signed graph is structurally balanced.

It is possible to think of variants of the consensus problem in which the agents are still required to reach an agreement, but rather than to a common value, to a redistribution of their initial conditions according to a certain set of weights [26]. If, as for "standard" consensus, the solution has an explicit dependence from the initial conditions, then the networked system can be used as a "computational machine" that carries out a given task in a distributed way. Non-distributed dynamical systems that implement algorithms are well-known in linear algebra. Google's PageRank (i.e., the computational of the Perron-Frobenius eigenvector through a power method [17]) is a popular example. In [4] we have shown that a continuous-time distributed dynamical systems can be used for instance to sort numbers.

3 Project description

3.1 Methodology and specific goals

For convenience, the goals of this project follow the classification in the 2 nested paradigms shown in Fig. 3, representing different levels of knowledge of the details of a network.

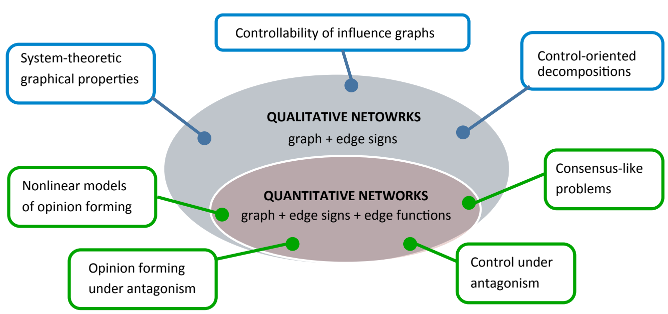

Figure 3: Classes of problems investigated in this proposal and methodological paradigms to be used.

3.1.1 Qualitative paradigm

When at most an influence graph is known for a network, the goals of the research will be the following.

Investigating system-theoretical properties of large-scale networks. The classical theory of graphical linear systems allows to investigate a number of properties of a system in which only the location of the zero entries of an adjacency matrix is available [12]. System-theoretical properties, other than controllability, that can be studied within the same framework are for instance *observability*, *invariant zeros*, *pole placement*, and *disturbance rejection*. All of them admit graph-theoretical characterizations, particularly suitable to deal with the setting of large networks, for which little is known of the dynamics. Computationally efficient algorithms will be developed for this scope.

Controllability of influence graphs. What happens to a graphical controllability test if we also know the signs of the nonzero entries as in an influence graph? Having the sign of the influences available restricts the ranges of the nonzero entries of the adjacency matrix, but should not alter drastically the genericity of controllability, unless constraints are present also on the state or control inputs. In contexts like biology, for example, this is normally the case, as state variables represent concentrations of molecular species, and "inputs" are associated e.g. to the action of drugs, which is usually single-mode (activatory or inhibitory on a target, not both). In the project we will seek methods to combine the theory of influence graphs with the framework of linear systems with constrained control inputs [9], developing algorithms applicable to large-scale networks.

Control-oriented decompositions of a signed network. When studying controllability for graphical linear systems, criteria other than those mentioned in [19] can be considered for selecting a set of driver nodes. This is particularly true for influence networks, or when controls and states are constrained. An approach could be to maximize the control range, i.e., the (generic) dimension of the controllable subspace of each chosen input. Another to optimize the output-nulling invariant subspace of certain nodes of interest (the outputs), or, more generally, to study the *signed input-output decoupling* problem in a systematic way. All of these approaches provide control-oriented methodologies for decomposing large-scale networks, implementable through graphical tests.

3.1.2 Quantitative paradigm.

When a more detailed model is available for a networked system, then a more thorough investigation of its dynamical behavior is possible. In the proposal the focus will be on networks combining cooperation and antagonism.

The problem of achieving unanimity in presence of antagonism. When a network has antagonistic interactions, then it is expected that a negative tie between two agents stimulates divergence in the corresponding states, rather than approaching them as in the case of cooperating agents. This increases our difficulty in predicting the outcome of e.g. a distributed process of opinion forming on such networks. Problems like understanding when a group of agents may achieve an unanimous opinion (i.e., all opinions that converge to the positive orthant or all to the negative orthant [2]) in spite of the presence of unfriendly ties become important. In [5] we have shown that for linear dynamics unanimity can be achieved provided that the adjacency matrix is eventually positive (i.e., it becomes positive after a certain power [22]). A field in which this problem is of relevance is opinion dynamics on social networks [1]. Another is distributed voting schemes, or more generally, distributed decision-making systems. This setting has analogies with game theory, analogies which will be investigated during the project.

Extension to nonlinear opinion dynamics. We plan to investigate the existence of conditions similar to [5] for nonlinear signed networks. In particular, this entails the search for classes of models more realistic than the linear time-invariant models used so far. Invariant cones (used in [5]) have been extensively studied for linear control systems [8], because they allow to handle state and input constraints. We are not aware of significant extensions to nonlinear systems, although we believe that a systematic analysis is possible, combining the insight given by Perron-Frobenius theorem with the theory of monotone systems and with concepts such as eventual positivity of adjacency matrices [5]. For models of influence propagation on social networks, the existence of such cones would help considerably in predicting the outcome of "realistic" opinion forming processes (or of voting schemes, or of distributed decision-making algorithms) in presence of antagonism. For example, we expect that an invariant cone "built around" an eventually positive adjacency matrix will be enough to guarantee unanimity if the class of monotone systems has some extra property, such as concavity or subhomogeneity [31].

Control through stubborn agents. An agent that can influence the other agents without being itself influenceable is called stubborn [1]. Stubborn agents behave like leaders (driver nodes, or "opinionators") in a process of opinion forming. When antagonism is present, choosing the leaders according to their influence pattern on the other nodes is a difficult task, which in the linear case can be formulated as a cone-invariance problem in presence of persistent disturbances [5]. In the project we intend to investigate the systematic use of stubborn agents as control authority in more general models of opinion forming.

Weighted consensus-like problems. Mathematically, the consensus problem consists in setting up a distributed feedback law rendering the closed loop marginally (but not asymptotically) stable. In the linear case, the eigenspace corresponding to the zero eigenvalue consists of vectors with all equal entries, and convergence for all agents is therefore to a common value which depends on the initial conditions. The resulting closed loop matrix in this case is a Laplacian matrix [23, 20]. Consider a consensus-like problem in which the eigenspace relative to the zero eigenvalue is not a vector of all equal entries, but it is "titled" according to a certain set of weights. Then the initial conditions of the agents of the network will be redistributed unevenly, according to the weights of the nodes. A class of algorithms accomplishing this task is the so-called generalized diffusion algorithms [26]. If in a consensus scheme the state values transmitted to the neighbors are reweighted by the numbers assigned to the agents, then the resulting right weighted Laplacian converges to a state proportional to these weights [4]. Applications of this concept, such as load balance with uneven capacities, clustering consensus and secure-communication schemes will be studied within this project.

3.2 Time table and implementation

The research in the two methodological paradigms described above can be carried out in parallel. The various tasks described are sufficiently independent from each other, meaning that the time schedule of the project can be quite flexible. The main constraints we foresee are in the qualitative studies, where the theoretical analysis has to be followed by the development of computational tools, and by their application to large-scale datasets. A time horizon of 4 years should be enough to carry out such a plan.

In the perspective of the present proposal, the expertise of the PI in nonlinear control and in complex networks (including those of biological/social type) will be combined with the competences in systems and control theory existing in the Department of Electrical Engineering of Linköping University. However, since the themes proposed will constitute a novel axis of research for the Department, there is a need to have a person (PhD student) fully dedicated to them. Hence the request for a PhD fellowship, which constitutes the core financial request of this proposal. Potential applicative contexts which may involve other members of the Department include for instance multivehicle coordination (Daniel Axelhill), wireless network control (Fredrik Gustafsson, Fredrik Gunnarsson), distributed optimization (Anders Hansson).

External collaborations include Andrea De Martino (CNR / La Sapienza, Rome, Italy) and Daniel Remondini (Univ. of Bologna, Italy) for what concerns biological networks, Roberto Mulet (Havana University, Cuba) and Ginestra Bianconi (Queen Mary University, London UK) for what concerns general complex networks. In order to favor these international collaborations, we are currently submitting an application to a "Research and Innovation Staff Exchange (RISE) Marie-Skłodowska-Curie Action" (call of April 2015). This grant is limited to exchange of personnel, not to new recruitments. If approved, it will be used to host students in Linköping and to allow the recruited PhD student to take courses in the partner institutes (notably in subjects such as Statistical Physics and Biophysics).

4 Significance with respect to the state of the art

In many fields outside those normally considered by control theory, the amount of data available for complex interconnected systems is steadily growing. Often times these datasets cannot be directly transformed into dynamical models because our knowledge is still too fragmented (think for example of most biological networks involving genes and proteins, or of the logbooks describing the actions of the users of on-line media). Even more often it is unclear if and how these networks can be controlled. By targeting networks described as influence graphs, this proposal aims at investigating the simplest class of systems for which the dynamics is poorly characterized but not completely unknown. The objective of extending a series of graphical system-theoretical properties (such as controllability, observability, decoupling, etc.) to signed graphs is novel and it has the potential of providing more appropriate information on how to control these systems than their purely graphical counterparts. It is a strong belief of the PI that the systems and control paradigm can give an important contribution to the understanding of these complex networks from a dynamical perspective, beyond the topological aspects mostly studied nowadays.

Also for the networks for which we can make assumptions on the functional form of the interactions, the introduction of signs on the edges gives rise to a rich set of new dynamical behaviors, absent in a purely cooperating setting. These behaviors can be used to describe real-world situations. Especially if we succeed in introducing more realistic models for the interactions, they can be used to investigate complex distributed decision-making problems in various types of applications. Needless to say, also the corresponding control problems are more complex and challenging.

The two frameworks (qualitative and quantitative) that will be investigated are obviously connected, and complement each other in many aspects. The fact that the PI has already a significant experience in dealing with both [2, 3, 5, 14, 16] should constitute a good starting point for this proposal, and an indicator of the feasibility of the goals it contains.

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[29] E. D. Sontag. Monotone and near-monotone biochemical networks. *Syst. Synth. Biol.*, 1(2):59–87, 2007.

[30] R. Thomas and M. Kaufman. Multistationarity, the basis of cell differentiation and memory. I. structural conditions of multistationarity and other nontrivial behavior. *Chaos*, 11:165–179, 2001.

[31] P. Ugo Abara, F. Ticozzi, and C. Altafini. Existence, uniqueness and stability properties of positive equilibria for a class of nonlinear cooperative systems. In *submitted*, 2015.

[32] S. Wasserman and K. Faust. *Social Network Analysis: methods and applications*. Cambridge Univ. Press, 1994.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Claudio Altafini	20
2	Other personnel without doctoral degree	To be recruited	80

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Claudio Altafini	20	257,040	257,040	257,040	257,040	1,028,160
2	Other personnel without doctoral degree	To be recruited	80	440,640	440,640	440,640	440,640	1,762,560
	Total			697,680	697,680	697,680	697,680	2,790,720

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Travel and publication costs	58,132	58,132	58,132	58,132	232,528
	Total	58,132	58,132	58,132	58,132	232,528

Running Costs

Running Cost	Description	2016	2017	2018	2019

Depreciation costs

Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	697,680	697,680	697,680	697,680	2,790,720		2,790,720
Running costs					0		0
Depreciation costs					0		0
Premises	58,132	58,132	58,132	58,132	232,528		232,528
Subtotal	755,812	755,812	755,812	755,812	3,023,248	0	3,023,248
Indirect costs	244,188	244,188	244,188	244,188	976,752		976,752
Total project cost	1,000,000	1,000,000	1,000,000	1,000,000	4,000,000	0	4,000,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Model

The basic funding concerns one PhD student. A simple budget model is applied. The yearly salary cost for a PhD student, assuming 80% funding, with 53% LKP is $30000 \cdot 1.53 \cdot 0.8 \cdot 12 = 440{,}640$ SEK. Overheads (listed in indirect costs) are 35%, that is 154,224 SEK / year, meaning that the total becomes 594,864 SEK / year.

A similar calculation applied to the salary of the PI, assuming a 20% funding, leads to 257,040 SEK / year, plus an overhead of 89,964 SEK / year, for a total of 347,004 SEK / year.

Tavel and publication costs are 58,132 SEK / year.

The indirect costs (overheads) are 244,188 SEK / year.

The total requested is therefore 1,000,000 SEK / year.

Recruitment process

Students with background in Systems and Control or a closely related discipline are suitable candidates for this project. A call for applications will be issued if the project is approved.

Current grants / grant applications

The research of this proposal is not currently funded by any grant. A similar topic is the subject of a grant application within the ``Research and Innovation Staff Exchange (RISE) Marie-Sklodowska-Curie Action" (call of April 2015), together with Andrea De Martino (CNR / La Sapienza, Rome, Italy) and Roberto Mulet (Havana University, Cuba). This type of grant is limited to exchange of personnel, not to new recruitments.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

	Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019	Total
1	EU Marie-Curie Action	Andrea De Martino (CNR, Rome, Italy)	RISE (Research and Innovation Staff Exchange)	to be submitted in April	100,000	100,000	100,000		300,000
	Total				100,000	100,000	100,000	0	300,000

CV and publications

CV

Curriculum vitæ
Claudio Altafini (690106-0696)

Education

23/05/2001 **PhD** in Optimization and Systems Theory, Royal Institute of Technology (KTH), Stockholm, Sweden. Main supervisor: Anders Lindquist.

12/02/1996 **M. Sc. ("Laurea")** in Electrical Engineering, University of Padova, Italy.

Employment

2014- **Full Professor** in Automatic Control, Linköping University, Linköping, Sweden.

2005-2013 **Assistant Professor** (**"Ricercatore"**, tenured), Applied Mathematics, SISSA, International School for Advanced Studies, Trieste, Italy.

2001-2004 **Research Associate**, Applied Mathematics, SISSA.

1997-2001 **Graduate student**, KTH, Dept. of Math. and Center for Autonomous Syst.

1996-1997 **Process Control Engineer**, Cerestar Italia SpA.

1995-1996 **Control Engineer**, ABB Industrial Systems AB, Västerås, Sweden.

Invited visits, seminars and lectures

- I have spent periods as visiting scientist in Technion, Haifa (6 months in 1997), Caltech (5 months in 2000), MIT (2 months in 2005), IMA, Minneapolis (2 months in 2008), IHES, Paris (2 months in 2010).
- more than 20 invited seminars abroad (including Caltech, MIT, Berkeley, IMA) and more than 20 invited lectures at international meetings/workshops.

Research interests

- **Modeling and Control of Complex Networks.** Dynamical properties of large-scale complex systems from biological, technological and social sciences; consensus and coordination problems over networks.
- **Systems Biology.** Data mining and modeling from high throughput data; reverse engineering of gene networks; nonlinear models of biological processes; metabolic networks.
- **Control Theory and Applications.** Nonlinear and geometric control; positive systems; robot control; control of quantum mechanical systems.

Supervision of students

- **Primary supervisor of 5 PhD students**, all from SISSA (PhD year, current affiliation): Giuseppe Facchetti (2013, Norwich University, UK); Giovanna De Palo (2012, Imperial College, UK); Giovanni Iacono (2012, Radbound University, NL); Mattia Zampieri (2010, ETH Zurich, CH); Nicola Soranzo (2009, CRS4 - Center for Advanced Studies, Research and Development in Sardinia, IT).

- **Current PhD students:** Gustav Lindmark (2015-on, Linköping).
- **1 Post-doc** (SISSA): Gabriele Lini (2012-13, Magneti Marelli, Torino, IT).
- $\sim$ 10 **M. Sc. theses** (KTH, SISSA, ENSTA, ICTP, Padova, Linköping).

Teaching experience

- Graduate courses
  - **Linköping**: Modeling and simulation (2014).
  - **MIT**: Feedback control for NMR systems (2005).
- PhD courses
  - **Linköping**: Network dynamical systems: models and applications (2015).
  - **SISSA**: Geometric Control & Applications (2002, '03, '05); Bioinformatics/Biostatistics (2006-13); Dynamical Models in Biology (2007-13).
  - **Padova**: Dyn. Models in Biology (2009, '11); Bilinear Control Syst. (2010).

Organization of scientific activities

Research group. In the years 2005-13 in SISSA I have lead an independent research group, composed on average by three PhD students and a post-doc, under my direct supervision. I am now forming my research group in Linköping.

Workshops/schools, etc.

- coordinator of the course in Systems Biology, Italian summer school for Ph.D. Students in Automatic Control, July 2013.
- director of 3 international summer schools in Bioinformatics, Trieste (2011, '12, '13).
- organizer of many workshops/schools and of invited sessions at international conferences.

Editorial & evaluation activities

- Associate Editor of the *IEEE Transactions on Automatic Control* (since 2012).
- Corresponding Guest Editor for a special issue on "Control of Quantum Mechanical Systems" for the *IEEE Trans. on Automatic Control*, (2010-11).
- Member of the Conf. Editorial Board of the IEEE Control Systems Society (2009-13), of the Conf. Editorial Board of the European Control Association (2013-on), of the IPC of the IEEE Multi-Conference on Systems and Control (2014-on), of the IEEE International Conference on Control, Measurement and Instrumentation (2015);
- Member of the Proposal Evaluation Panel for the French Nat. Cancer Inst., 2009-11;
- Opponent/Member of PhD Committees In SISSA, Padova, Grenoble, MINES-ParisTech and Linköping.

Publication list

Publication list 2007-14
Claudio Altafini (690106-0696)

(all papers are dowloadable from http://users.isy.liu.se/en/rt/claal20/)
(citation data: Google Scholar, 03/2015)

Journal papers

[J32 (*)] C. Altafini and G. Lini. Predictable dynamics of opinion forming for networks with antagonistic interactions. *IEEE Trans. on Automatic Control*, 60(2):342-357, 2015.
Number of citations: 0

[J31 (*)] C. Altafini. Consensus problems on networks with antagonistic interactions. *IEEE Trans. on Automatic Control*, 58(4):935-946, 2013.
Number of citations: 61

[J30] C. Altafini. Stability analysis of diagonally equipotent matrices. *Automatica*, 49(9):2780-2785, 2013.
Number of citations: 0

[J29] F. Ticozzi, K. Nishio and C. Altafini. Stabilization of stochastic quantum dynamics via open and closed loop control. *IEEE Trans. on Automatic Control*, 58(1):74-85, 2013.
Number of citations: 12

[J28] G. De Palo, G. Facchetti, M. Mazzolini, A Menini, V. Torre and C. Altafini. Common dynamical features of sensory adaptation in photoreceptors and olfactory sensory neurons. *Nature Sci. Rep.*, 3:1251, 2013.
Number of citations: 6

[J27] G. Facchetti and C. Altafini. Partial inhibition and bilevel optimization in Flux Balance Analysis. *BMC Bioinformatics*, 14:344, 2013.
Number of citations: 0

[J26] G. Iacono, C. Altafini and V. Torre. Early phase of plasticity-related gene regulation and SRF dependent transcription in the hippocampus. *PLoS ONE*, 8(7): e68078, 2013.
Number of citations: 1

[J25] G. Facchetti, G. Iacono, G. De Palo and C. Altafini. A rate-distortion theory for gene regulatory networks and its application to logic gate consistency. *Bioinformatics*, 29(9):1166-1173, 2013.
Number of citations: 0

[J24 (*)] C. Altafini. Dynamics of opinion forming in structurally balanced social networks. *PLoS ONE*, 7(6): e38135, 2012.
Number of citations: 28

[J23] G. Facchetti, G. Iacono and C. Altafini. Exploring the low-energy landscape of large-scale signed social networks. *Phys. Rev. E*, 86:036116, 2012.
Number of citations: 8

[J22] G. Facchetti, M. Zampieri and C. Altafini. Predicting and characterizing selective multiple drug treatments for metabolic diseases and cancer. *BMC Systems Biology*,

6:115, 2012.
Number of citations: 9

[J21] Q. K. Beg, M. Zampieri, N. Klitgord, S. B. Collins, C. Altafini, M. H. Serres, D. Segrè. Detection of transcriptional triggers in the dynamics of microbial growth: application to the respiratorily versatile bacterium Shewanella Oneidensis. *Nucleic Acids Research*, 40(15):7132-7149, 2012.
Number of citations: 6

[J20] G. De Palo, A. Boccaccio, A. Miri, A. Menini and C. Altafini. A dynamical feedback model for adaptation in the olfactory transduction pathway. *Biophysical J.*, 102(12): 2677-2686, 2012.
Number of citations: 5

[J19] N. Soranzo, F. Ramezani, G. Iacono and C. Altafini. Decompositions of large-scale biological systems based on dynamical properties. *Bioinformatics*, 28(1):76-83, 2012
Number of citations: 3

[J18 (*)] G. Facchetti, G. Iacono and C. Altafini. Computing global structural balance in large-scale signed social networks. *Proc. Nat. Ac. Sci.*, 108(52):20953-8, 2011.
Number of citations: 61

[J17] M. Zampieri, G. Legname, D. Segrè and C. Altafini. A system-level approach for deciphering the transcriptional response to prion infection. *Bioinformatics*, 27(24):3407-3414, 2011.
Number of citations: 8

[J16] G. De Palo, F. Eduati, M. Zampieri, B. Di Camillo, G. Toffolo and C. Altafini. Adaptation as a genome-wide autoregulatory principle in the stress response of yeast. *IET Systems Biology*, 5(4):269-283, 2011.
Number of citations: 1

[J15] C. Altafini, P. Cappellaro and D. Cory. Feedback schemes for radiation damping suppression in NMR: a control-theoretical perspective. *Systems Control Letters*, 59 (12):782–786, 2010.
Number of citations: 4

[J14] G. Iacono and C. Altafini. Monotonicity, frustration, and ordered response: an analysis of the energy landscape of perturbed large-scale biological networks. *BMC Systems Biology*, 4:83, 2010.
Number of citations: 13

[J13 (*)] G. Iacono, F. Ramezani, N. Soranzo and C. Altafini. Determining the distance to monotonicity of a biological network: a graph-theoretical approach. *IET Systems Biology*, 4(3):223–235, 2010.
Number of citations: 17

[J12] J. Coatléven and C. Altafini. A kinetic mechanism inducing oscillations in simple chemical reactions networks. *Mathematical Biosciences and Engineering*, 7(2):303–314, 2010.
Number of citations: 3

[J11] S. Pegoraro, F. D. Broccard, M. E. Ruaro, D. Bianchini, D. Avossa, G. Pastore, G. Bisson, C. Altafini and V Torre. Sequential steps underlying neuronal plasticity

induced by a transient exposure to gabazine. *J. Cell. Physiol.*, 222(3):713-728, 2009.
Number of citations: 6

[J10] N. Soranzo and C. Altafini. ERNEST: a toolbox for chemical reaction network theory. *Bioinformatics*, 25(21):2853-2854, 2009.
Number of citations: 17

[J9] M. Zampieri G. Legname and C. Altafini. Investigating the conformational stability of prion strains through a kinetic replication model. *PLoS Computational Biology*, 5(7): e1000420, 2009.
Number of citations: 8

[J8] N. Soranzo, M. Zampieri, L. Farina and C. Altafini. mRNA stability and the unfolding of gene expression in the long-period yeast metabolic cycle. *BMC Systems Biology*, 3:18, 2009.
Number of citations: 6

[J7] F. D. Broccard, S. Pegoraro, M. E. Ruaro, C. Altafini and V Torre. Characterization of the time course of changes of the evoked electrical activity in a model of a chemically-induced neuronal plasticity. *BMC Research Notes*, 2:13, 2009.
Number of citations: 6

[J6] C. Altafini. Controllability and simultaneous controllability of isospectral bilinear control systems on complex flag manifolds. *Systems and Controls Letters*, 58:213-16, 2009.
Number of citations: 11

[J5] M. Zampieri, N. Soranzo, D. Bianchini and C. Altafini. Origin of co-expression patterns in E.coli and S.cerevisiae emerging from reverse engineering algorithms. *PLoS ONE*, 3(8):e2981, 2008.
Number of citations: 8

[J4] M. Zampieri, N. Soranzo and C. Altafini. Discerning static and causal interactions in genome-wide reverse engineering problems. *Bioinformatics*, 24(13):1510-1515, 2008.
Number of citations: 25

[J3] N. Soranzo, G. Bianconi and C. Altafini. Comparing association network algorithms for reverse engineering of large scale gene regulatory networks: synthetic vs real data. *Bioinformatics*, 23(13):1640-1647, 2007.
Number of citations: 104

[J2] C. Altafini. Feedback stabilization of isospectral control systems on complex flag manifolds: application to quantum ensembles. *IEEE Transactions on Automatic Control*, 52(11):2019-2028 2007.
Number of citations: 55

[J1] C. Altafini. Feedback control of spin systems. *Quantum Information Processing*, 6(1):9-36, 2007.
Number of citations: 39

International Conferences

[C16] C. Altafini. A continuous-time dynamical system that can sort agents through distributed protocols. *2014 IEEE Multi-conference on Systems and Control*, Antibes, France, October 2014.

[C15] C. Altafini and G. Lini. Achieving unanimous opinions in signed social networks. *Proc. of the European Control Conf.*, Strasbourg, France, June 2014.

[C14] C. Altafini. Achieving consensus on networks with antagonistic interactions. *Proc. of the 51st IEEE Conf. on Decision and Control*, Maui, Hawaii, December 2012.

[C13] C. Altafini. Dynamics of opinion forming in structurally balanced social networks. *Proc. of the 51st IEEE Conf. on Decision and Control*, Maui, Hawaii, December 2012.

[C12] F. Ticozzi, K. Nishio and C. Altafini. Environment-assisted and feedback-assisted stabilization of quantum stochastic evolutions. *Proc. of the 51st IEEE Conf. on Decision and Control*, Maui, Hawaii, December 2012.

[C11] G. Facchetti and C. Altafini. Dose-dependent drug synergism in flux balance analysis. *9th International Workshop on Computational Systems Biology*, Ulm, June 2012.

[C10] G. Iacono and C. Altafini. Average frustration and phase transition in large-scale biological networks: a statistical physics approach. *8th IFAC Symposium "Nonlinear Control Systems"*, Bologna, 2010.

[C9] C. Altafini, P. Cappellaro and D. Cory. Feedback schemes for radiation damping suppression in NMR: a control-theoretical perspective. *Proc. of the 48th IEEE Conf. on Decision and Control*, p. 1445-1450, Shanghai, China, December 2009.

[C8] G. De Palo, A. Boccaccio, A. Menini and C. Altafini. Short- and long-term adaptation in olfactory transduction as a leaky integral feedback. *Proc. of the 48th IEEE Conf. on Decision and Control*, p. 4578-4583, Shanghai, China, December 2009.

[C7] F. Ramezani, G. Iacono, N. Soranzo and C. Altafini. On the distance to monotonicity of a biological network: a graph-theoretical approach. *Proc. of European Control Conf.*, Budapest, 2009.

[C6] M. Zampieri G. Legname and C. Altafini. Prion kinetic replication models and strain-dependent stability (to denaturation). *Proc. of European Control Conf.*, Budapest, 2009.

[C5] M. Zampieri N. Soranzo and C. Altafini. Modeling the genome-wide transient response to stimuli in yeast: adaptation through integral feedback. *Proc. of the 47th IEEE Conf. on Decision and Control*, p. 167-172, Cancun, Mexico, December 2008.

[C4] J. Coatléven and C. Altafini. A kinetic mechanism inducing oscillations in simple chemical reactions networks. *Proc. of the 47th IEEE Conf. on Decision and Control*, p. 1771-1776, Cancun, Mexico, December 2008.

[C3] N. Soranzo, M. Zampieri, D. Bianchini and C. Altafini. Network inference from gene expression profiles: what "physical" network are we seeing? FOSBE, Stuttgart 2007.

[C2] N. Soranzo, G. Bianconi, C. Altafini. Linear and nonlinear methods for gene regulatory network inference. *7th IFAC Symposium "Nonlinear Control Systems"*, p. 533-538, Pretoria, South Africa, 2007.

[C1] C. Altafini. Controllability of isospectral bilinear control systems on complex flag manifolds. *7th IFAC Symposium "Nonlinear Control Systems"*, p. 894-897, Pretoria, South Africa, 2007.

Review articles

[R1] C. Altafini and F. Ticozzi. Modeling and Control of Quantum Systems: An Introduction. Special Issue on Quantum Control of the *IEEE Trans. on Automatic Control*, 57(8):1898-1917, 2012.
Number of citations: 54

Other journal publications

[O1] C. Altafini, A. M. Bloch, M. R. James, A. Loria and P. Rouchon. Guest Editorial: Special Issue on Control of Quantum Mechanical Systems. *IEEE Trans. on Automatic Control*, 57(8):1893-1895, 2012.

Open-access software tools

[S1] N. Soranzo and C. Altafini, ERNEST: a toolbox for chemical reaction network theory. Matlab toolbox for the evaluation of the number of equilibria in a chemical reaction network. Freely available at the web-site http://people.sissa.it/∼altafini/papers/SoAl09/.

Popular science publications

[V1] C. Altafini. Internet, l'Eden del conformista, *la Stampa*, 4/1/2012.

Bibliographic data and outreach

Total number of citations of my publications. (Google Scholar, 03/2015): ∼ 1540

Media coverage of my research. My research in social networks has received media coverage at national level (Il Sole 24 Ore, La Stampa, Corriere della Sera, Panorama, Wired, Le Scienze).

CV

Name: Claudio Altafini	**Doctorial degree:** 2001-05-23
Birthdate: 19690106	**Academic title:** Professor
Gender: Male	**Employer:** Linköpings universitet

Research education

Dissertation title (swe)
Geometric Control Methods for Nonlinear Systems and Robotic Applications

Dissertation title (en)
Geometric Control Methods for Nonlinear Systems and Robotic Applications

Organisation	Unit	Supervisor
Kungliga Tekniska Högskolan, Sweden Sweden - Higher education Institutes	Institutionen för Matematik	Anders Lindquist

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20202. Reglerteknik		2001-05-23

Publications

Name: Claudio Altafini	**Doctorial degree:** 2001-05-23
Birthdate: 19690106	**Academic title:** Professor
Gender: Male	**Employer:** Linköpings universitet

Altafini, Claudio has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.