**Annual Report for Period:** 10/2011 - 09/2012
**Submitted on:** 09/26/2012
**Principal Investigator:** Sayama, Hiroki .
**Award ID:** 1027752
**Organization:** SUNY Binghamton
**Submitted By:**
Sayama, Hiroki - Principal Investigator
**Title:**
CDI-Type I: Modeling and Predicting State-Topology Coevolution of Complex Adaptive Networks

## Project Participants

**Senior Personnel**

**Name:** Sayama, Hiroki
**Worked for more than 160 Hours:** Yes
**Contribution to Project:**

**Post-doc**

**Graduate Student**

**Name:** Schmidt, Jeffrey
**Worked for more than 160 Hours:** Yes
**Contribution to Project:**
Jeff worked as a primary developer of the software system this project aims to produce. He also worked with Ben on the implementation of computer simulation models of adaptive networks. He presented one abstract at ICCS 2011 and gave an oral presentation about the software at the internal CoCo seminar. He participated in the overseas research collaboration with Dr. Thilo Gross at the Max Planck Institute for the Physics of Complex Systems in Dresden, Germany, over the summer of 2011, as well as at the University of Bristol, UK, over the summer of 2012.

**Name:** Bush, Benjamin
**Worked for more than 160 Hours:** Yes
**Contribution to Project:**
Ben worked on computer simulation models of evolving social networks as an application of the adaptive network framework that this project is proposing. He also worked with Jeff on the development of adaptive networks modeling and analysis software. He presented one abstract at ICCS 2011, and participated in the overseas research collaboration with Dr. Thilo Gross at the Max Planck Institute for the Physics of Complex Systems in Dresden, Germany, over the summer of 2011, as well as at the University of Bristol, UK, over the summer of 2012.

In Year 2011-2012, Ben actively participated in the NetSci High high school research competition program as a co-supervisor of the two student teams at Maine-Endwell High School, Endwell, NY. He also played the leading role in developing those students' posters.

**Undergraduate Student**

**Name:** Krell, Steven
**Worked for more than 160 Hours:** No

**Contribution to Project:**
Steve helped the PI organize the STCAN 2011 workshop and the ICCS 2011 conference as a student administrative assistant. He was able to attend the workshop/conference and learned a lot about complex systems and network sciences.

**Name:** Wong, Chun

**Worked for more than 160 Hours:** No

**Contribution to Project:**
Chun helped developing the simulation software for the collaboration project with Dr. Irene Pestov at DRDC-CORA.

**Name:** Hantman, Alex

**Worked for more than 160 Hours:** No

**Contribution to Project:**
Alex helped writing prototype codes for the collaboration project with Dr. Zhirong Bao over the summer 2012.

**Technician, Programmer**

**Other Participant**

**Research Experience for Undergraduates**

## Organizational Partners

**Max Planck Inst. Phys. Complex Systems**
Dr. Thilo Gross at the Max Planck Institute for the Physics of Complex Systems (MPI-PKS) has been collaborating with the PI. In Summer 2011, Gross arranged a visiting scholar program at MPI-PKS for the PI and the two graduate students to stay at the Institute and conduct collaborative research. Accommodation and local allowance costs were covered by the Visitors Program of the Institute. The PI and the students were given access to various facilities, including the library and computational resources.

**Maine-Endwell High School**
The PI, Bush and Akaishi worked with Mrs. Julie Gallagher, Principal of the Maine-Endwell High School, Mr. John Endress, the School's IT specialist, and two student teams (seven female high school students) on their research projects. This was part of the NetSci-High high school research competition program, which was created and run as part of this grant. The research culminated in two poster presentations that were presented at the 2011 International Conference on Network Science (NetSci 2011) in Budapest, Hungary, as well as at the Eighth International Conference on Complex Systems (ICCS 2011) in Boston, MA. One of the teams continued their research under supervision of the PI and presented another poster at the 2012 International Conference on Network Science (NetSci 2012) in Evanston, IL.

**New York Hall of Science**
The PI collaborated with Dr. Stephen Uzzo, Ms. Tara Chudoba and Ms. Catherine Cramer at the New York Hall of Science (NYSci) to organize and run the NetSci-High high school student research program, which was part of this grant. The PI visited NYSci a few times for meetings and hosting an initial teachers' workshop there. The PI's institution provided funding to NYSci as a participant's cost to fund

the NetSci-High program. In 2011, Chudoba and the PI traveled to Budapest, Hungary, to run the high school students' poster session collaboratively. In 2012, Uzzo, Cramer and the PI traveled to Evanston, IL, to run the high school students' poster session collaboratively, as well as to organize the NetSciEd satellite symposium.

**University of Connecticut**

The PI collaborated with Dr. Junichi Yamanoi, a former Ph.D. student in the University of Connecticut Business School, to develop a computer simulation model of corporate merger processes represented as an adaptive network. The result was presented at the 2011 International Conference on Network Science (NetSci 2011) in Budapest, Hungary, and also at the Eighth International Conference on Complex Systems (ICCS 2011) in Boston, MA. This collaboration resulted in a few other presentations and a journal article publication.

**DRDC CORA**

The PI worked with DRDC CORA (Defence Research and Development Canada Centre for Operational Research and Analysis, Ottawa, ON, Canada) under a contract to develop a simulation software that applies the adaptive networks framework to the modeling and analysis of their operational networks for Arctic Search and Rescue (SAR) incidents. This collaboration resulted in one conference paper. A journal article was also written and is currently under review.

**Memorial Sloan-Kettering Cancer Center**

We have started a collaboration research project with Dr. Zhirong Bao at MSKCC, on the adaptive network modeling of C. elegans embryogenesis. This will be a valuable test case of our software.

**Chuo University**

Our collaborator Junichi Yamanoi has moved from the University of Connecticut to Chuo University, Tokyo, Japan.

**Boston University**

The PI collaborated with H. Eugene Stanley and Paul Trunfio at Boston University to organize and run the NetSciEd symposium as part of NetSci 2012.

**University of Bristol**

Dr. Thilo Gross moved from Max Planck Institute to the University of Bristol, so the PI and his graduate students visited the University of Bristol for research collaboration in Summer 2012.

## Other Collaborators or Contacts

## Activities and Findings

**Research and Education Activities:**

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Activities in Year 2010-2011:

[[[Research]]]

[Developing and implementing core algorithms for automatic discovery of
network rewriting rules]

In Year 2010-2011, we have designed and developed a preliminary version of the Generative Network Automata (GNA) framework in Python using the NetworkX module. The development is being done using SourceForge.net, a widely used open-source software development website, where all source code is publicly available for free.

The preliminary version of the GNA framework has the following capabilities:

(a) Input/output interface of network evolution data. Our framework can read network evolution data from a file in a graph ML format. Graph ML is an XML-based graph mark-up language that can represent multiple graphs in a single file, which we adopted as a general data format to represent time series of networks. Our framework can also output network time series into a graph ML file.

(b) Identification of network rewriting events and compression of network evolution data. Our framework can scan a given graph ML file and sequentially detect differences between two consecutive snapshots of networks, and then utilize this information to compress the network evolution data. When the network differences are identified, several statistical measurements associated with the differences are also recorded, which will be used for estimation of extraction mechanisms in (c) described below.

(c) Automatic discovery of subgraph extraction rules. When multiple candidate models of subgraph extraction mechanisms are given, our framework can calculate the likelihood of each mechanism based on the compressed network evolution data. This likelihood calculation algorithm was newly developed over the past year (i.e., not described in our original proposal), whose details will be disclosed in a conference or journal publication shortly. The calculated likelihood values can be presented back to the user, then either the user can choose the plausible extraction mechanism by assessing those values, or the software can automatically select the mechanism with the largest likelihood value.

(d) Automatic discovery of subgraph rewriting rules and reconstruction of network evolution. Our framework can use the collection of network changes generated in (b) above as a set of subgraph rewriting rules and perform network rewritings so as to reconstruct network evolutionary processes from an initial configuration (i.e., simulation of network evolution).

All of the above capabilities have already been implemented and are

working in our software. There is still much room to make each capability more reliable and computationally more efficient. We will continue to work on the improvement of our software.

[Testing algorithms with abstract network models]

We have tested the implemented algorithms for automatic rule discovery using artificially generated network evolution data. Specifically, we have used several different network growth models, including (a) degree-based preferential attachment, (b) state-based preferential attachment, (c) degree-based preferential attachment applied to nodes with a specific state only, and (d) pure random attachment, among others. We have applied our software to these data and confirmed that in most cases the correct model was identified with the largest likelihood values. There are still some cases when our software gives wrong answers. Possible causes of such wrong estimations are being investigated and will be fixed.

Our software can also reconstruct (i.e., simulate) network evolution using the automatically discovered extraction/rewriting rules. We are currently evaluating the quality of the reconstruction results by comparing them with the original network evolution data.

[Collecting real-world social network data]

Real-world network evolution data are necessary for future evaluation of our framework. Through the process of searching, we realized a fundamental lack of such data of network evolution over time. To address this problem, we have developed an original web search engine based method for collecting approximated historical data of temporally changing social adaptive networks. In our method, a search query string is combined with additional keywords that specify the inclusion/exclusion of specific years to limit the search results to a particular time point. Using the proposed method, we reconstructed the temporal evolution of a social network from 2005 to 2009 of 93 individuals who are important in the US economy as a test case.

We also used this method to reconstruct a network that represents the relatedness between scientists and their peers as well as various research topics. We characterized each individual scientist's most notable research topics (expertise) by measuring a 'visibility boost', defined as the increase of the scientist's visibility resulting from focusing on a particular research topic. We analyzed the correlation between scientists' expertise and their interdisciplinary nature. The interdisciplinarity of a scientist was characterized in two different ways: (a) diversity in their expertise (i.e., how many research topics they are associated with), and (b) their betweenness centrality in the scientists' network (i.e., how much they connect multiple scientific communities). While this research did not consider the dynamical nature of the network (yet), it did demonstrate the effectiveness of our data collection method.

We plan to apply this method to collect more data of real-world social network evolution, which will be used in the evaluation of our modeling framework at a later stage of the project.

[Expanding domains of application]

Several applications of adaptive networks for biological and social systems modeling have been initiated, including:

(a) Adaptive network models of social network evolution. We have developed an adaptive network model of idea-exchanging social networks to investigate the relationship between individual behavior and network position. Our individual agents divide their time into three distinct actions: thinking about and reconciling one's own ideas, disseminating ideas to others, and listening to ideas from one's peers. Each individual is host to a local population of ideas, some of which are fixed, while others can be replaced as a result of social interaction. Individuals evaluate ideas based on their local idea population, and these evaluations are used to update the (directed) link weights whenever ideas are exchanged. Using this model, we calculated the distribution of network centrality and other measurements over the space of all possible individual behaviors.

(b) Adaptive network models of corporate merger. In collaboration with Junichi Yamanoi at the University of Connecticut Business School, we have developed an adaptive network model of cultural integration in merging firms, represented as a network initially made of two communities. Nodes receive information from their neighbors and update their cultural states, while the link weights also change so that links between nodes with similar/different cultural states are encouraged/discouraged. We explored two experimental parameters that determine initial link distributions: how concentrated the information sources of within-firm social ties are on a small number of key individuals, and how concentrated the between-firm links are on information sources of each firm. Model implementation and Monte Carlo simulations were conducted in Python using the NetworkX module.

(c) Adaptive network based models of collective behavior of swarms. In collaboration with Thilo Gross at the Max Planck Institute for the Physics of Complex Systems, we have started using adaptive networks to represent interaction networks of marching locust swarms that may switch the direction of motion between left and right. Gross's recent work considered phase transitions in a homogeneous swarm. We have extended their model to heterogeneous swarms made of multiple types. To facilitate analytical work, we have developed a computer program that automatically generates all the network rewriting rules from a smaller set of model assumptions, and also a set of dynamical equations that describe dynamical change of network motif densities using a technique called 'moment closure'. This program may eventually be integrated into our Python-based GNA framework in the future.

(d) Incorporation of GNA into network models of joint systems. We have recently made a research contract with Defence Research and Development Canada Centre for Operational Research and Analysis (DRDC-CORA) to develop GNA-based computer simulation models and analysis tools of the behavior of dynamical operational networks made of heterogeneous specialized agents, each working in distinct environmental domains. A target problem is the SAR (Search and Rescue) operational network for the Canadian Arctic. This project will be the

first instance of real-world applications of our GNA framework used in non-academic domains.

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[[[Dissemination]]]

[Publications]

During Year 2010-2011, we have published seven conference proceedings publications listed below (two full papers and five short abstracts) on general overviews of GNA framework and/or technical details of automatic rule discovery and data collection methods. Of particular note is that the PI's presentation at the IPSJ SIG Mathematical Modelling and Problem Solving (2010-MPS-81) won the Best Presentation Award. See the attached supplementary documents for details.

* Hiroki Sayama, Adaptive networks: An emerging research theme on state-topology coevolution in complex networks, in Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam, eds., Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011), New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, 2011, p.416.

* Jeffrey Schmidt, Benjamin James Bush, and Hiroki Sayama, A Python implementation of generative network automata, in Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam, eds., Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011), New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, 2011, pp.439-440.

* Hiroki Sayama and Junichi Yamanoi, An adaptive network model of cultural integration in corporate merger, in Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam, eds., Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011), New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, 2011, pp.435-436.

* Benjamin James Bush, Jeffrey Schmidt, and Hiroki Sayama, Behavior and centrality in idea exchanging adaptive social networks, in Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam, eds., Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011), New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, 2011, pp.437-438.

* Hiroki Sayama, Adaptive networks: An emerging research theme on state-topology coevolution in complex networks, IPSJ SIG Mathematical Modelling and Problem Solving Technical Report 2010-MPS-081, no. 28, Fukuoka, Japan, December 16-17, 2010. (Won the Best Presentation Award)

* Hiroki Sayama, An algorithm for automatically discovering dynamical

rules of adaptive network evolution from empirical data, Proceedings of the 5th International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (BIONETICS 2010), Boston, MA, December 1-3, 2010, Springer.

* Jin Akaishi, Hiroki Sayama, Shelley D. Dionne, Xiujian Chen, Alka Gupta, Chanyu Hao, Andra Serban, Benjamin James Bush, Hadassah J. Head, and Francis J. Yammarino, Reconstructing history of social network evolution using web search engines, Proceedings of the 5th International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (BIONETICS 2010), Boston, MA, December 1-3, 2010, Springer.

[Developing project websites]

We have developed the project website at http://coco.binghamton.edu/NSF-CDI.html. Our GNA framework source codes are also available from http://gnaframework.sourceforge.net/.

[Organizing academic meetings]

We have organized the following meetings on adaptive network research during Year 2010-2011:

* STCAN 2010: Special Track on State-Topology Coevolution in Adaptive Networks. This track was held as part of the Fifth International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (BIONETICS 2010), Boston, MA, on December 1-3, 2010. The track consisted of seven peer-reviewed full papers on various topics relevant to adaptive networks. Thilo Gross (collaborator for this project) helped organizing this special track as a co-chair, and planned to give a keynote talk. Unfortunately his travel was canceled because of the inclement weather in Europe.

* STCAN 2011: Workshop on State-Topology Coevolution in Adaptive Networks. This workshop was held as part of the Eighth International Conference on Complex Systems (ICCS 2011), Boston, MA, on June 27, 2011. The workshop hosted seven presentations selected based on abstract reviews. Compared to STCAN 2010, a broader range of application research areas was represented in this workshop, such as management and organizational sciences.

* NetSci High: International High School Student Poster Competition on Network Science. This new educational outreach program was developed in collaboration with the New York Hall of Science. Two poster sessions were organized: one in the 2011 International School and Conference on Network Science (NetSci 2011), on June 6-10, 2011, Budapest, Hungary, and the other in the Eighth International Conference on Complex Systems (ICCS 2011), Boston, MA, on June 26-July 1, 2011. More details will be provided in the Educational Outreach section of this annual report.

[Other dissemination activities]

We also made several oral and poster presentations about the research outcomes of this project, as listed below:

* Hiroki Sayama, Adaptive networks: An emerging research theme on state-topology coevolution in complex networks, invited talk at Electrical & Computer Engineering Research Seminar Series, Binghamton University, Binghamton, NY, September 20, 2011.

* Hiroki Sayama, Spatial artificial chemistries: Recent developments, a tutorial talk at the Artificial Chemical Computing Systems Tutorial at the Eleventh European Conference on Artificial Life (ECAL 2011), Paris, France, 2011.

* Hiroki Sayama and Jin Akaishi, Characterizing interdisciplinarity of scientists and research topics using web search engines, presented as a talk at NetSci 2011: International School and Conference on Network Science, June 6-10, 2011, Budapest, Hungary.

* Hiroki Sayama and Junichi Yamanoi, An adaptive network model of cultural integration in corporate merger, presented as a talk at NetSci 2011: International School and Conference on Network Science, June 6-10, 2011, Budapest, Hungary.

* Cara Boothroyd, Brianna Benson, Deanna Blansky, Christina Kavanaugh, Julie Gallagher, John Endress, Benjamin James Bush, and Hiroki Sayama, Academic achievement and personal satisfaction in high school social networks, presented as a poster at the NetSci High: International High School Student Poster Competition on Network Science, in NetSci 2011: International School and Conference on Network Science, June 6-10, 2011, Budapest, Hungary.

* Jessica Calderone, Emma Valentine, Josie Trichka, Julie Gallagher, Benjamin James Bush, Jin Akaishi, and Hiroki Sayama, A comparative study on the social networks of fictional characters, presented as a poster at the NetSci High: International High School Student Poster Competition on Network Science, in NetSci 2011: International School and Conference on Network Science, June 6-10, 2011, Budapest, Hungary.

* Hiroki Sayama, Computational approaches to adaptive network modeling, invited talk at the Adaptive Network Dynamics minisymposium in SIAM Conference on Applications of Dynamical Systems (DS11), Snowbird, UT, May 22-26, 2011.

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[[[Education]]]

[Course development]

The PI proposed a new graduate-level course 'BME-523X: Dynamics of Complex Networks', which has been approved by the Binghamton University Graduate Studies Committee and will officially run in Spring 2012. This course will provide students with concepts and mathematical/computational tools of network science, for modeling, analyzing and simulating the dynamics of various complex adaptive

networks. Specific topics to be introduced in this course will include: Graphs, complex networks (random networks, small-world networks, scale-free networks), network analysis techniques (diameter and density measures, degree distribution, centrality measures, community identification, modularity, motifs), scaling and power laws, dynamical networks, adaptive networks, robustness and vulnerability of networks, and applications to biological, ecological, social and engineered systems. Python and NetworkX will be used for modeling and analysis of complex networks. The GNA framework will be integrated in the course materials.

[Graduate student training]

Two graduate research assistants (Benjamin James Bush and Jeffrey Schmidt) were hired and trained in this project. Bush joined in Fall 2010 and has been working on the application of adaptive networks to social network modeling and analysis. Schmidt joined in Spring 2011 and has been working on the implementation of the GNA framework in Python/NetworkX. They gave oral presentations on their respective research results at the Eighth International Conference on Complex Systems (ICCS 2011) in June 2011. Both of them traveled to the Max Planck Institute for the Physics of Complex Systems in Dresden, Germany, in July/August 2011, and participated in research collaboration with Thilo Gross and his staff/students.

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Activities in Year 2011-2012:

[[[Research]]]

[Developing and implementing core algorithms for automatic discovery of
network rewriting rules]

In Year 2011-2012, we have made substantial progresses in all aspects of the Generative Network Automata (GNA) framework software, which is now named 'PyGNA'. The first fully functional version of the software was completed over the summer of 2012 and has been officially released to public as an alpha test version (ver. 0.6) on SourceForget.net (http://gnaframework.sourceforge.net/).

The current version of PyGNA has implemented major developments and improvements in all of the following four features:

(a) Input/output interface of network evolution data in a graph ML format.
(b) Identification of network rewriting events and compression of network evolution data.
(c) Automatic discovery of subgraph extraction rules based on the likelihood calculation method over given multiple candidate models of subgraph extraction mechanisms.
(d) Automatic discovery of subgraph rewriting rules and reconstruction of network evolution.

In addition to the above, the most recent version of PyGNA also has the following new features:

(e) Simple scripting language (following the Python syntax) in which the users can write their own likelihood calculation models that PyGNA will use for model estimation.
(f) Quantitative evaluation and comparison of multiple models for the extraction mechanism using logarithms of subgraph extraction probabilities.
(g) Online tutorial written as an executable Python code.

[Testing algorithms with abstract network models]

We conducted experiments applying PyGNA to data generated by abstract adaptive network models, in order to test if it could correctly identify the actual network generation mechanisms used to reproduce the input data. The following four abstract network models were used as inputs to PyGNA:

(a) Barabasi-Albert network, grown using the standard degree-based preferential attachment method.
(b) 'Degree-state' network, grown by degree-based preferential attachment applied only to the subset of nodes that have a particular state. Each newly added node is assigned with a randomly selected state.
(c) 'State-based' network, grown by random attachment only to nodes that have a particular state. Again, each newly added node is assigned with a randomly selected state.
(d) 'Forest fire' network, generated by the method proposed in the literature.

We also quantified the accuracy of the reconstructed network models by measuring the distance of probability distributions of extracted subgraphs between original and simulated networks. Specifically, for the original input data and the reconstructed network simulation results, we counted how many times each of the different kinds of subgraphs was selected for graph rewriting events, and then computed the Bhattacharyya distance between the two distributions.

The results were reported in a manuscript that was submitted to Computers & Mathematics with Applications, which is currently under review.

[Collecting real-world network data]

We have written and published two journal articles on the web search engine-based method of real-world social network data collection that we developed last year.

We are currently working with our collaborators to obtain other types of real-world adaptive network data (Dr. Zhirong Bao at Memorial Sloan-Kettering Cancer Center for the data of spatial cellular network evolution over the embryogenesis of C. elegans, and Dr. Junichi Yamanoi at Chuo University for the data of social/business network

evolution in Japanese industries).

[Expanding domains of application]

We have continued working on the applications of adaptive network modeling for biological and social systems. The progress of each project is summarized below:

(a) Adaptive network models of social network evolution. We completed building the agent-based simulation model and have designed an exhaustive parameter sweep experiment. We also implemented a parallel simulation platform based on a server-client architecture for this experiment, since the amount of computation required to complete it would be large. We conducted test simulation runs using this parallel simulation system, but it was recognized that the speed of each simulation run was not fast enough in order to complete the whole set of simulations within a reasonable length of time. We are currently analyzing and optimizing the simulator code to drastically speed up the simulations.

(b) Adaptive network models of corporate merger. In collaboration with Dr. Junichi Yamanoi now at Chuo University in Tokyo, Japan, we have developed an adaptive network model of cultural integration in merging firms, represented as a network initially made of two communities. We investigated the impact of network structures within and between two merging firms on post-merger cultural integration and organizational dysfunctions---individual turnover, interpersonal conflict and organizational communication ineffectiveness---that arise from insufficient cultural integration. This result has been accepted for publication in Computational and Mathematical Organization Theory.

(c) Adaptive network based models of collective behavior of swarms. In collaboration with Dr. Thilo Gross now at the University of Bristol, UK, we have completed and revised the software that automatically generates a set of differential equations that approximate the dynamics of motif densities using the moment closure method. We have applied it to analyze the dynamics of collective movements of heterogeneous swarms made of two types. So far, the results we obtained are rather trivial, without much to claim scientific/mathematical novelty. We will continue this subproject to study other models of collective behavior.

(d) Incorporation of GNA into network models of joint systems. In collaboration with Dr. Irene Pestov at the Defence Research and Development Canada Centre for Operational Research and Analysis (DRDC-CORA), we have developed OpNetSim, an adaptive network-based computer simulation model of the behavior of dynamical operational networks made of heterogeneous specialized agents, each working in distinct environmental domains. The final simulator software and its user's manual were produced and delivered to DRDC-CORA as specified in our contract. The results were published in one conference paper (MSV '12) as well as included in the journal article submitted to Computers & Mathematics with Applications (currently under review).

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[[[Dissemination]]]

[Publications]

During Year 2011-2012, we have published three journal articles and two full-paper conference proceedings publications listed below. In addition to these, there are two journal articles currently under review. See the attached supplementary documents for details.

* Junichi Yamanoi and Hiroki Sayama, Post-merger cultural integration from a social network perspective: A computational modeling approach, Computational and Mathematical Organization Theory, in press.

* Hiroki Sayama and Jin Akaishi, Characterizing interdisciplinarity of researchers and research topics using web search engines, PLoS ONE, 7(6): e38747, 2012.

* Shelley D. Dionne, Jin Akaishi, Xiujian Chen, Alka Gupta, Hiroki Sayama, Francis J. Yammarino, Andra Serban, Chanyu Hao, Hadassah J. Head and Benjamin James Bush, Retrospective relatedness reconstruction: Applications to adaptive social networks and social sentiment, Organizational Research Methods, 15: 663-692, 2012.

* Hiroki Sayama, Modeling co-evolution of states and topologies of adaptive networks, Proceedings of EvoNet2012: ALIFE 13 Workshop on Evolving Networks, from Systems/Synthetic Biology to Computational Neuroscience, pp.3-6.

* Irene Pestov, Hiroki Sayama and Chun Wong, Modeling discrete distributed heterogeneous systems, Proceedings of the Ninth International Conference on Modeling, Simulation and Visualization Methods (MSV'12), Las Vegas, NV, 2012.

Also, the following two conference papers have finally been published in print in the post-conference proceedings:

* Hiroki Sayama, An algorithm for automatically discovering dynamical rules of adaptive network evolution from empirical data, Proceedings of the 5th International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (BIONETICS 2010 -- Boston, MA, December 1-3, 2010), Jun Suzuki and Tadashi Nakano, eds., LNICST 87, pp.497-504, 2012. Springer.

* Jin Akaishi, Hiroki Sayama, Shelley D. Dionne, Xiujian Chen, Alka Gupta, Chanyu Hao, Andra Serban, Benjamin James Bush, Hadassah J. Head, and Francis J. Yammarino, Reconstructing history of social network evolution using web search engines, Proceedings of the 5th International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (BIONETICS 2010 -- Boston, MA, December 1-3, 2010), Jun Suzuki and Tadashi Nakano, eds., LNICST 87, pp.155-162, 2012. Springer.

[Organizing academic meetings]

Because we already organized two international meetings on adaptive networks in the previous academic year, we decided not to organize another one during Year 2011-2012. This decision was made so that we could focus more on the core research activities.

We are currently planning to organize a next symposium on the State-Topology Coevolution in Adaptive Networks (STCAN 2013) as a satellite symposium of the 2013 International School and Conference on Network Science (NetSci 2013), which will be held in Copenhagen, Denmark, in June 2013 (http://netsci2013.net/).

Regarding the educational component of this project, we have organized the following two meetings. More details will be provided in the Educational Outreach section of this annual report.

* NetSci High: High School Student Research Program on Network Science. This was a continuation of the NetSci High poster competition organized in the previous year. It was again organized in collaboration with the New York Hall of Science (Dr. Stephen Uzzo and Ms. Catherine Cramer). This year, the program was run in the form of scholarships offered to participating high school student teams. Two student teams participated from the Binghamton area. Those teams were offered a scholarship to attend the NetSci 2012 conference in Evanston, IL, on June 18-22, 2012, and presented their posters. One of the students was also invited to give a short oral presentation at the NetSciEd symposium described below. This year, we also received a corporate donation to this program from BAE Systems. This program was very well received by the network science community, and will be followed by an NSF ITEST project 'Network Science for the Next Generation', run by Boston University and the New York Hall of Science. The PI will continue to participate in the ITEST project as a consultant.

* NetSciEd Satellite Symposium on Education @ NetSci2012: Infuse Network Science into K-12 and Undergraduate Education. This symposium was also organized and hosted in collaboration with the New York Hall of Science. Nine presentations were made by invited speakers who work on the intersection between network science and education. The PI also gave a presentation on his own experience supervising high school students' research projects on networks.

[Developing project websites]

In addition to the project website and the GNA framework website on SourceForge.net, we have developed the following two websites for educational activities:

* NetSci High website:
  https://sites.google.com/a/binghamton.edu/netsci-high-2011-2012/

* NetSciEd Symposium website:
  https://sites.google.com/a/binghamton.edu/netscied12/

[Other dissemination activities]

We also made several oral and poster presentations about the research and education outcomes of this project, as listed below:

* Hiroki Sayama, Computer programming for adaptive network modeling, a one-day seminar given at Defence Research and Development Canada Centre for Operational Research and Analysis, September 30, 2012, Ottawa, ON, Canada.

* Jeffrey Schmidt, GNApy: A Python implementation of generative network automata, Collective Dynamics of Complex Systems (CoCo) Seminar, Binghamton University, Binghamton, NY, October 5, 2011. http://vimeo.com/30110300

* Junichi Yamanoi and Hiroki Sayama, Post-merger cultural integration from a social network perspective: A computational modeling approach, presented at the Fifth Intra-Organizational Network Conference (ION 5), April 14-15, 2012, Lexington, KY.

* Hiroki Sayama, Introducing network science to high schools: Merits, issues, and tips, from a professor's perspective, to be presented at NetSciEd Satellite Symposium at NetSci2012: Education -- Infuse Network Science into K-12 and Undergraduate Education, June 18, 2012, Evanston, IL.

* Deanna Blansky, Christina Kavanaugh, Cara Boothroyd, Brianna Benson, Julie Gallagher, John Endress, and Hiroki Sayama, A possible spread of academic success in a high school social network: A two-year study, presented as a poster at NetSci 2012: International School and Conference on Network Science, June 18-22, 2012, Evanston, IL.

* Hiroki Sayama, An informal seminar talk about adaptive networks and generative network automata, given to graduate students at the Institute for Complex Systems Simulation of the University of Southampton, UK, August 7, 2012, Southampton, UK.

* Junichi Yamanoi and Hiroki Sayama, Post-merger cultural integration from a social network perspective: A computational modeling approach, Collective Dynamics of Complex Systems (CoCo) Seminar, Binghamton University, Binghamton, NY, September 19, 2012. http://vimeo.com/49806141

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[[[Education]]]

[Course development]

The PI has offered the new graduate-level course 'BME-523X: Dynamics of Complex Networks' for the first time in Spring 2012. See the attached course syllabus for more details. The course was received very positively by the students and has recently been approved to be a permanent graduate course by the Watson School's Graduate Studies Committee, currently awaiting final approval by the Binghamton University Graduate Curriculum Committee and the Graduate Council. It is planned to be offered again in Spring 2013.

[Graduate student training]

Two graduate research assistants (Jeffrey Schmidt and Benjamin James Bush) were hired continuously and trained in this project. Schmidt has been the main software developer of PyGNA, working on the implementation of the GNA framework in Python/NetworkX. Bush has been working on the application of adaptive networks to social network modeling and analysis, and also helps Schmidt in the software development. Schmidt gave an oral presentation about his work at the CoCo seminar in Fall 2011, and is currently writing his Master's thesis on the adaptive network models. Both of the students traveled to the University of Bristol, UK, in July/August 2012, and participated in research collaboration with Dr. Thilo Gross and his staff/students.

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**Findings:**

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Findings in Year 2010-2011:

[Testing algorithms with abstract network models]

Testing the implemented algorithms for automatic rule discovery using artificially generated network evolution data produced the following outcomes:

* Experiments with data generated by (1) degree-based preferential attachment ('degree only') and (2) degree-based preferential attachment applied to a specific state only ('degree-state') produced correct results.

* Experiments with data generated by (3) state-based preferential attachment ('state only') gave wrong results. Specifically, our algorithms estimated that the data should be generated using 'degree-state' mechanisms, instead of what was actually used ('state only').

We are currently investigating into potential causes of the problem above. One possibility is that even if the true mechanism of data generation used information about node states only, the resulting network growth process may actually have shown some degree correlation as an emergent property. If this is the case, that would mean our algorithms did correctly identify observed correlations in the data.

Another issue that was realized through the software development process is how to handle subgraph rewriting cases that did not occur in the given network evolution data. This problem is particularly crucial when one tries to simulate network evolution based on a relatively small set of empirical data. To address this issue, we are currently implementing an option to simulate network evolution stochastically by measuring the distances between the extracted subgraph and the actual subgraph rewriting events, and by using the measured distances as probabilities of rule selection.

[Collecting real-world social network data]

Using our web search engine-based data collection method, we reconstructed the temporal evolution of a social network from 2005 to 2009 of 93 individuals who are important in the US economy. We measured centralities of those individuals for every year and found several illustrative cases where the temporal change of centrality of an individual correctly captured the actual events that are related to him/her over this time period. These results indicate the effectiveness of the proposed method.

We also used our data collection method to reconstruct a network that represents the relatedness between scientists and their peers as well as various research topics. Analysis of the results revealed several distinct classes of research topics with regards to the interdisciplinarity metrics. Topics in 'classic' science tend to correlate positively with diversity of the scientist's expertise, but negatively with his/her betweenness centrality, while topics that are more common terms tend to correlate in an opposite way. Interestingly, topics such as 'complex network' and 'complex system' tend to sit between these two classes. These results demonstrate a novel way of characterizing the interdisciplinarity of scientists and their research topics. We are currently conducting more detailed analysis of the obtained data, with one journal article manuscript in preparation.

[Expanding domains of application]

(a) Adaptive network models of social network evolution. Preliminary results of computer simulation showed that the centrality of individuals were affected by their behavioral propensity, though the implications of results differed significantly for different experimental conditions. We are currently checking the simulation code and also revising the data analysis code to calculate the probability for each individual to be the origin of the ideas being discussed in the society.

(b) Adaptive network models of corporate merger. Using an adaptive network model, we investigated the impact of network structures within and between two merging firms on cultural integration and organizational dysfunctions that are derived from cultural distance. The simulation results demonstrated that the highest cultural integration was achieved when the network structure is more centralized within the merging firms while connections between the merging firms are less concentrated to central individuals.

The following application subprojects have just started recently, so there is no substantial finding to be reported at this point.

(c) Adaptive network based models of collective behavior of swarms
(d) Incorporation of GNA into network models of joint systems

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Findings in Year 2011-2012:

[Testing algorithms with abstract network models]

The reconstructed networks produced by PyGNA were first compared to the original input networks generated according to the aforementioned four network growth mechanisms. For the Barabasi-Albert (a), degree-state (b) and state-based (c) networks, both input and reconstructed networks have visually similar structures. For the forest fire network (d), however, PyGNA failed to capture the unique topological characteristics of the original input network, probably because of the complexity in the original network generation method. Also notable is that PyGNA mistakenly concluded that the state-based network (c) evolved based on the degree-based preferential attachment mechanism, and yet successfully reproduced network evolution that is very similar to the original. While this was not what we originally expected, we find this result intriguing because it illustrates the fact that certain network evolution may be explained effectively by multiple models and also that our software can be used to automatically discover and compare such alternative models.

Then, the accuracy of the reconstructed network models was characterized by measuring the Bhattacharyya distance (BD) of probability distributions of extracted subgraphs between original and reconstructed networks. For the Barabasi-Albert network (a), the low BD value indicates that the simulated network is indeed very close to the original input network. In the meantime, the high BD value for the degree-state network (b) shows that the extraction mechanism selected by PyGNA is having difficulty matching the distribution of extracted subgraphs seen in the input network. Results for the state-based network (c) present an interesting case; even though the extraction mechanism selected by PyGNA is different from what was actually used to generate the original input data, the distributions of extracted subgraphs are very similar with very low BD. Finally, for the forest fire network, the extraction mechanism selected by PyGNA is over-choosing certain subgraphs and is unable to generate 3 of the subgraphs seen in the input data, resulting in the apparent topological difference. Meanwhile, the BD value for this case is reasonably good, given the complexity of the original network dynamics.

These preliminary results tells us that the current algorithm in PyGNA is effective for certain types of networks while still limited for the analysis of others, especially those that involve pure randomness and/or mesoscopic topological structures such as motifs. We are currently revising and expanding our algorithm by addressing these issues in order to improve the performance of PyGNA. One promising extension of the extraction algorithm (which was realized through intensive discussions with Dr. Gross during our stay at the University of Bristol) is to use a motif-based likelihood calculation, instead of a node-based one that is currently adopted in our current algorithm. We plan to implement this in the future versions of PyGNA. We also plan to implement evolutionary algorithms to automatically search for effective likelihood functions.

[Collecting real-world network data]

We have conducted more detailed, systematic analyses on the real-world social network data collected with web search engines. In particular, through the reconstruction of researchers' network, it was found that researchers who had high 'visibility boosts' by the same research topic tended to be close to each other in their network. We calculated correlations between visibility boosts by research topics and researchers' interdisciplinarity at the individual level (diversity of topics related to the researcher) and at the social level (his/her centrality in the researchers' network). We found that visibility boosts by certain research topics were positively correlated with researchers' individual-level interdisciplinarity despite their negative correlations with the general popularity of researchers. It was also found that visibility boosts by network-related topics had positive correlations with researchers' social-level interdisciplinarity. Research topics' correlations with researchers' individual- and social-level interdisciplinarities were found to be nearly independent from each other. These findings suggest that the notion of 'interdisciplinarity' of a researcher should be understood as a multi-dimensional concept that should be evaluated using multiple assessment means.

The results above was published in PLoS One. The other work on the reconstruction of social networks among 93 individuals who are important in the US economy was also published in Organizational Research Methods.

[Expanding domains of application]

(b) Adaptive network models of corporate merger. Using an agent-based model, we investigate the impact of network structures within and between two merging firms on post-merger cultural integration and organizational dysfunctions---individual turnover, interpersonal conflict and organizational communication ineffectiveness---that arise from insufficient cultural integration. The simulation results demonstrate that the highest level of cultural integration is achieved when social ties are more centralized within each merging firm and the social ties between the merging firms are less concentrated on central individuals. Additionally, the results show that within-firm and between-firm network structures significantly affect individual turnover, interpersonal conflict and organizational communication ineffectiveness, and that these three outcome measurements do not vary in tandem.

The results above were recently accepted for publication in Computational and Mathematical Organization Theory.

(d) Incorporation of GNA into network models of joint systems. We analyzed and modeled a real SAR incident in the Arctic that occurred in December 2008. We examined the actual log of inter-agent communications during this SAR incident, and manually reconstructed the rewriting rules that drove the operational network formation. OpNetSim, our simulator software, was then used to simulate the temporal development of the operational network under several hypothetical scenarios. Since the simulation algorithm involves stochasticity, the topology of the simulated network does not exactly

match the actual one, but the general trend of increasing agent heterogeneity and concentration on the Search Master node were correctly represented in this model.

The results above were included in a manuscript that was submitted to Computers & Mathematics with Applications and is currently under review.

We did not spend much time or resource to make significant progresses in the following application subprojects over the last year, so there is no substantial finding to be reported for those at this point.

(a) Adaptive network models of social network evolution.
(c) Adaptive network based models of collective behavior of swarms.

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**Training and Development:**

Through collaboration with Dr. Thilo Gross at the University of Bristol (formerly at the Max Planck Institute for the Physics of Complex Systems), the PI has acquired mathematical knowledge and skills for analytical study of adaptive network dynamics using moment closure techniques, as well as many creative ideas and insights into how one could effectively represent and analyze various dynamics of adaptive networks.

We have hired two graduate research assistants for this project: Jeffrey Schmidt and Benjamin James Bush. Bush is from an underrepresented group (Hispanic). They both enrolled in the Ph.D. program in Systems Science at Binghamton University, and the PI supervises their work. Both students took a graduate course on computational modeling taught by the PI. They gave oral presentations on their work on adaptive networks at the Eighth International Conference on Complex Systems (ICCS 2011) in June 2011. Schmidt also gave a talk on PyGNA at an internal seminar at Binghamton University in Fall 2011. Both students went to the Max Planck Institute (in summer 2011) and to the University of Bristol (in summer 2012), to accompany the PI for the collaboration with Dr. Gross. Their reflections on these international research experiences are attached to this annual report. Schmidt also accompanied the PI in his visit to DRDC-CORA in Ottawa, Canada, in September 2011, and participated in the initial stage of the collaboration with DRDC-CORA.

In addition, the PI, Bush and Jin Akaishi (collaborator) participated in the supervision of local high school student teams during the Fall 2010/Spring 2011 semesters. They had weekly meetings with two student teams on a regular basis to discuss research progresses, tasks and directions. They all gained valuable educational experiences through these outreach activities. The PI continued supervising one of those student teams during 2011-2012.

This project also involved several undergraduate assistants. Steven Krell (Bioengineering junior) was hired to assist the PI in organizing the STCAN 2011 workshop and the ICCS 2011 conference itself (for which the PI served as a Program Chair). While he did not conduct any

research, Krell was able to attend the workshop/conference as a staff member and learned a lot about complex systems and network sciences. For research, Chun Wong (Bioengineering senior) was hired during Spring 2012 to help the PI develop the simulation software for the collaboration project with DRDC-CORA. He accompanied the PI and Schmidt in their visit to DRDC-CORA in Ottawa, Canada, in September 2011. Finally, Alex Hantman (Bioengineering junior) helped writing prototype codes for the collaboration project with Dr. Zhirong Bao during summer 2012.

**Outreach Activities:**

We have developed NetSci High: High School Student Research on Network Science, a pilot educational outreach program organized and run in close collaboration with Dr. Stephen Uzzo, Ms. Tara Chudoba and Ms. Catherine Cramer at the New York Hall of Science. This program aims to infuse network science, an emerging interdisciplinary field of study on complex networks, into K-12 education by connecting high school students and teachers to university research labs and letting them work on current network science research for several months, culminating in a poster presentation at NetSci conferences.

In early Fall 2010, we organized initial teachers' workshops at three locations (New York City, Boston, and Binghamton) to recruit high school science/math teachers and students to this program. The PI attended the New York City workshop and also hosted the Binghamton workshop. As a result, seven student teams and their teachers participated in the program during 2010-2011 and worked with their local research laboratories. In Binghamton, the PI, Bush and Akaishi collaboratively supervised two student teams (seven female students) in Maine-Endwell high school in Endwell, NY, in close collaboration with Mrs. Julie Gallagher, Assistant Principal of the school.

Each of the seven participating teams worked on its own research project in network science and submitted a poster electronically by mid-April, 2011. The submissions were then reviewed by a scientific committee made of leading network scientists, who selected two winning posters. As a result, four high school students and their teachers (three of them, each representing a different school) traveled to Hungary, Budapest, in June 2011, to participate in the 2011 International Conference on Network Science (NetSci 2011) and present their work there in person. The travel costs were covered by this grant. All of the seven posters were printed and put up at NetSci 2011. Unfortunately none of the Binghamton student teams were selected as winners. The PI later arranged another poster session at the Eighth International Conference on Complex Systems (ICCS 2011) in Boston, MA, for which he served as a Program Chair. Some of the students who could not go to NetSci 2011 were able to come and present their work at ICCS 2011 on their own. At each poster session, the audience was asked to fill in a comment sheet to give encouragement and feedback to the students and teachers who participated in this program.

The second year of the NetSci High program was run as scholarships offered to participating high school student teams. Two student teams participated from the Binghamton area. Due to the shortage of time for program preparation, we could not recruit teams from other areas. The PI supervised one team from Maine-Endwell High School, while another

professor in Computer Science at Binghamton University supervised another team from Vestal High School. Those teams were offered a scholarship to attend the NetSci 2012 conference in Evanston, IL, on June 18-22, 2012, and presented their posters to international audience. For the second year of the program, we also received a corporate donation from BAE Systems.

We also organized a satellite symposium on education (NetSciEd) at the NetSci 2012 conference. This symposium aimed to address how network science will transform STEM education in the coming years, in anticipation of preparing the next generation of network scientists, as well as addressing the urgent needs in improving STEM education overall. Topics discussed at this event included:

* Network Science in K-16 Practice and Policy
* Network Science in Informal Education
* New Directions in Learning Science
* Developing Metrics for Effective Educational Collaboration Networks

Nine presentations were made by invited speakers who work on the intersection between network science and education. All the presentations are made available publicly on the symposium website. The PI also gave a presentation on his own experience supervising high school students' research projects on networks. At the end of the symposium, a highly active panel discussion was held to determine directions in support of research and practice in the use of network science to improve education.

Selected comments from participating students, as well as some photos taken at these conferences, are attached to this annual report. They are also available on the NetSci High/NetSciEd websites:

https://sites.google.com/a/binghamton.edu/netsci-high-2011-2012/
https://sites.google.com/a/binghamton.edu/netscied12/

After the initial two-year pilot period, NetSci High is going to expand further as the NSF ITEST project 'Network Science for the Next Generation', run by Boston University and the New York Hall of Science. The PI continues to participate in the ITEST project as a consultant. More information can be found at http://www.bu.edu/networks/.

## Journal Publications

Hiroki Sayama, Irene Pestov, Jeffrey Schmidt, Chun Wong, Junichi Yamanoi, and Thilo Gross, "Adaptive networks as models of complex systems", Computers and Mathematics with Applications, p. , vol. , (2012). Submitted,

Deanna Blansky, Christina Kavanaugh, Cara Boothroyd, Brianna Benson, Julie Gallagher, John Endress, and Hiroki Sayama, "Spread of academic success in a high school social network", PLOS ONE, p. , vol. , (2012). Submitted,

Junichi Yamanoi and Hiroki Sayama, "Post-merger cultural integration from a social network perspective: A computational modeling approach", Computational and Mathematical Organization Theory, p. , vol. , (2012). Accepted,

Hiroki Sayama and Jin Akaishi, "Characterizing interdisciplinarity of researchers and research topics using web search engines", PLoS ONE, p. e38747, vol. 7(6), (2012). Published, 10.1371/journal.pone.0038747

Shelley D. Dionne, Jin Akaishi, Xiujian Chen, Alka Gupta, Hiroki Sayama, Francis J. Yammarino, Andra Serban, Chanyu Hao, Hadassah J. Head and Benjamin James Bush, "Retrospective relatedness reconstruction: Applications to adaptive social networks and social sentiment", Organizational Research Methods, p. , vol. , (2012). Accepted, 10.1177/1094428112442572

**Books or Other One-time Publications**

Hiroki Sayama, "Adaptive networks: An emerging research theme on state-topology coevolution in complex networks", (2011). Conference Proceedings, Published
Editor(s): Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam
Collection: Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011)
Bibliography: New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, p.416

Jeffrey Schmidt, Benjamin James Bush, and Hiroki Sayama, "A Python implementation of generative network automata", (2011). Conference proceedings, Published
Editor(s): Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam
Collection: Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011)
Bibliography: New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, pp.439-440.

Hiroki Sayama and Junichi Yamanoi, "An adaptive network model of cultural integration in corporate merger", (2011). Conference proceedings, Published
Editor(s): Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam
Collection: Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011)
Bibliography: New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, pp.435-436.

Benjamin James Bush, Jeffrey Schmidt, and Hiroki Sayama, "Behavior and centrality in idea exchanging adaptive social networks", (2011). Conference proceedings, Published
Editor(s): Hiroki Sayama, Ali A. Minai, Dan Braha, and Yaneer Bar-Yam
Collection: Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems (ICCS 2011)
Bibliography: New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, pp.437-438.

Hiroki Sayama, "Adaptive networks: An emerging research theme on state-topology coevolution in complex networks", (2010). Conference proceedings, Published
Bibliography: IPSJ SIG Mathematical Modelling and Problem Solving Technical Report 2010-MPS-081, no. 28, Fukuoka, Japan, December 16-17 (Won the Best Presentation Award)

Hiroki Sayama, "An algorithm for automatically discovering dynamical rules of
adaptive network evolution from empirical data", (2010). Conference proceedings, Published
Bibliography: Proc. 5th International ICST Conference on Bio-Inspired
Models of Network, Information, and Computing Systems
(BIONETICS 2010 -- Boston, MA, December 1-3, 2010), Jun
Suzuki a

Jin Akaishi, Hiroki Sayama, Shelley D. Dionne, Xiujian Chen,
Alka Gupta, Chanyu Hao, Andra Serban, Benjamin James Bush,
Hadassah J. Head, and Francis J. Yammarino, "Reconstructing history of social network evolution using web
search engines", (2010). Conference proceedings, Published

Bibliography: Proc. the 5th International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (BIONETICS 2010 -- Boston, MA, December 1-3, 2010), Jun Suzu

Irene Pestov, Hiroki Sayama and Chun Wong, "Modeling discrete distributed heterogeneous systems", (2012). Book, Published
Bibliography: Proceedings of the Ninth International Conference on Modeling, Simulation and Visualization Methods (MSV'12), Las Vegas, NV, 2012

Hiroki Sayama, "Modeling co-evolution of states and topologies of adaptive networks", (2012). Book, Published
Collection: Proceedings of EvoNet2012: ALIFE 13 Workshop on Evolving Networks, from Systems/Synthetic Biology to Computational Neuroscience
Bibliography: pp.3-6

## Web/Internet Site

**URL(s):**

http://coco.binghamton.edu/NSF-CDI.html
http://gnaframework.sourceforge.net/

**Description:**

(1) Project website
(2) Generative Network Automata framework software (PyGNA) on SourceForge.net

## Other Specific Products

**Product Type:**

**Software (or netware)**

**Product Description:**

We have developed PyGNA --- the Generative Network Automata (GNA) modeling, analysis and simulation framework implemented as a Python module. This framework allows a user to construct adaptive network models based on GNA, either based on the user's own network rewriting rules or rules that are automatically reconstructed from given network evolution data. The framework also allows dynamic simulations of network behavior.

**Sharing Information:**

The first public release version of PyGNA (ver. 0.6) has been released in September 2012. Its source codes and other information are all publicly available from our SourceForge.net site.

## Contributions

**Contributions within Discipline:**

This project will produce a novel theoretical framework and a computational toolkit that will transform the ways of studying the dynamics on and of complex networks and thereby achieve significant advances in the modeling and prediction of their self-organization.

**Contributions to Other Disciplines:**

The outcomes of this project will be useful in many cutting-edge fields, including social network science, organizational research, network ecology and epidemiology, systems biology, bioinformatics, and many others. Areas of application include social network analysis, modeling and analysis of organizational behavior, and modeling and analysis of biological network formation. The developed framework will also serve as a generalized conceptual/mathematical 'language' for modeling, analyzing and discussing the dynamics of various complex systems, which will galvanize interdisciplinary discussion and collaboration across many different areas of applications. To facilitate cross-disciplinary discourses, international workshops/special sessions have been organized at a couple of conferences.

**Contributions to Human Resource Development:**

This project involves two graduate research assistants (Jeff Schmidt and Benjamin James Bush). They are receiving multidicsiplinary research training under financial support from this NSF award, including international collaboration with Dr. Thilo Gross at the University of Bristol, UK (formerly at the Max Planck Institute for the Physics of Complex Systems in Dresden, Germany). The PI and the two students stayed in Dr. Gross's lab during the summers in 2011 and 2012 and had intensive discussions with him as well as his staff. The PI learned from this collaboration experience new analytical techniques, including automatic equation construction with moment closure. The students' reflections on their learning through these international experiences are attached to this annual report.

**Contributions to Resources for Research and Education:**

This project is producing a free software package of the GNA framework for modeling and analysis of complex adaptive networks, which will be a useful computational resource for broader research communities.

The new graduate course on complex adaptive networks produced in this project will serve as an educational resource for faculty and students at Binghamton University.

Moreover, the educational outreach program developed as part of this project, NetSci High, has come to be recognized very positively among the international network science community. It will serve as a continuing educational resource for those who want to initiate similar K-12 outreach programs that will bridge secondary education with cutting-edge scientific research labs.

**Contributions Beyond Science and Engineering:**

The proposed GNA framework may help model and understand many real-world social/organizational/operational networks, which may help better inform policy makers and business practitioners. For example, we have collaborated with DRDC CORA on GNA-based modeling of their operational networks. The outcome of this project will inform Canadian

Defence authorities about what kind of organizational improvements will help make their SAR response joint systems more efficient. Similarly, our recent work on cultural integration after corporate merger offers many valuable implications for how to make corporate M&A effective and successful.

## Conference Proceedings

## Special Requirements

**Special reporting requirements:** None

**Change in Objectives or Scope:**

We propose to change the scope of the Participant Costs portion of this award ($40,000). Its original scope was to organize the NetSci High high school student research program on Network Science and support travels of selected students and teachers to NetSci 2011 that was held in Budapest, Hungary, in June 2011. Because the actual costs of the proposed activity was less than what was originally expected, we propose to organize a second round of the NetSci High program for 2012, supporting travels of student teams to NetSci 2012 in Evanston, IL in June 2012. We also propose to host a symposium on Network Science in K-12 Education in order to invite more researchers to the discussions on this important subject and increase the awareness in both network science and educational research communities. Budgetary details are described below. Original Proposed Budget: Travel expenses for principals/teachers - $3,000; Expenses for local logistics - $2,000;Teacher stipends - $10,000;Travel support for top three projects - $20,700;Travel support for Program Coordinator - $2,300;Advertising and administrative costs - $2,000;Total=$40,000. Actual expenses: Travel expenses for principals/teachers - $1,100;Expenses for local logistics - $262;Teacher stipends - $2,500;Travel support - $19,706; Advertising, printing, administrative - $1,490. Total=$25,058. Difference: $14,942. Reasons for difference: The actual number of teachers involved in NetSci High 2011 was smaller than was originally planned. This was due to the shortage of time available to recruit them. As a result of fewer teacher participants, travel expenses were also lower than expected. Expenses for local logistics were also much lower than expected, largely because we were able to use locations available to us at no charge. Proposed use of remaining funds (shortage): NetSci High 2012(https://sites.google.com/a/binghamton.edu/netsci-high-2011-2012/): Travel scholarships for student teams - $6,000; NetSciEd Symposium (https://sites.google.com/a/binghamton.edu/netscied12/): Travel expenses for speakers - $8,540; Expenses for local logistics - $400. Total = $14,940

**Animal, Human Subjects, Biohazards:** None

## Categories for which nothing is reported:

Any Conference