Control of Complex Systems Initiative NEWSLETTER

Pacific Northwest NATIONAL LABORATORY

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CCSI
Control of Complex Systems Initiative

The Control of Complex Systems Initiative is a Pacific Northwest National Laboratory investment to build advanced controls capabilities for large-scale, complex infrastructures, particularly the power grid, buildings and buildings-grid integration. The five-year initiative was launched in fiscal year 2014.

CCSI Leadership

Initiative Lead: Michael Brambley
Co-Lead/Chief Scientist: Hong Wang
Theory Lead: Draguna Vrabie
Tools Lead: Thomas Edgar
Test Bed Lead: Mark Rice
Demonstrations Lead: Jason Fuller
Control Comm. Outreach: Karan Kalsi
Project Coordinator:

April 2017

Mike's Perspective
Michael Brambley, Initiative Lead

Welcome to the CCSI Newsletter. I look forward to keeping you posted regularly on the progress of this Pacific Northwest National Laboratory (PNNL) initiative, which is now in its fourth year.

The past year brought changes in leadership, including my new role as Initiative Lead. I'm honored to have the opportunity to shepherd CCSI and work with many talented individuals in pursuit of initiative objectives.

We recently examined the direction of CCSI and made important decisions about the future. Primary among them was to maintain our overall application foci on the electric power grid, buildings, and building-grid integration, while increasing our attention to the complexity of the systems addressed.

Sherry Kowalski
Transition Lead: Jenn Lee
Communications: Tim Ledbetter
Contact Us

PNNL Builds Capabilities for Emerging Needs Through CCSI, Other Initiatives

The Control of Complex Systems Initiative is part of Pacific Northwest National Laboratory's ongoing effort to build and/or renew the science and technology capabilities the nation will need to meet the challenges of the future.

CCSI is a PNNL internally-funded effort, one of ten current initiatives addressing capability needs in areas ranging from CCSI's focus on advanced controls to chemical imaging and nuclear process science. Through these types of initiatives, PNNL ensures that it is prepared to address and deliver solutions for new and emerging science and technology challenges.

To establish CCSI, PNNL research leaders looked into the future, identified emerging issues and

Our research progress continues to be strong. Seven projects successfully concluded at the end of fiscal year 2016, and we launched five new ones this past fall, for a total of 14 active projects.

Looking ahead, we're working in earnest to organize our annual workshop, which will be held in conjunction with the 2017 American Control Conference in Seattle, May 22-23, at the Sheraton Seattle Hotel (see more info in article below).

We'll also continue to explore and develop new collaborative relationships with industry and other partners. And, external communications, through instruments such as this newsletter and a planned web site, will underpin efforts to share information on PNNL's research and development in controls for complex systems with a broader audience.

I look forward to keeping you updated on CCSI progress in future issues of this newsletter.

Mike

Caltech's Richard Murray Kicks Off CCSI-sponsored Lecture Series

The Control of Complex Systems Lecture Series' inaugural event held February 21 at PNNL featured **Dr. Richard Murray**, a professor at the California Institute of Technology and leading researcher in control. More than 80 people attended.

associated capability needs, consulted with external experts in a workshop, mapped a detailed research plan, and then proposed a focused, five-year effort to explore control for complex systems and develop essential capabilities. The plan was then rigorously evaluated in a multi-step process.

Once approved by PNNL leadership, CCSI was funded and launched as an initiative, and subsequently has undergone regular reviews by an advisory committee composed of experts in the field. The reviews help to ensure that the initiative benefits from guidance from leading experts and is on track to achieve its intended outcomes.

CCSI-developed Arion Now Publicly Available to Users

Arion, CCSI's high-level modeling language and library, is now available as open source software for download on PNNL's [Github site](#).

Arion enables users to model the system and use cases in which they want to evaluate a control naturally. Arion provides a tool to convert the model into the languages of domain-specific simulators so that researchers don't need to rely on domain experts to start their experiment,

Dr. Murray spoke on, "Specification and Synthesis of Complex, Networked Control Systems with Applications in Physical, Biological and Computational Sciences."

He is the Thomas E. and Doris Everhart Professor of Control and Dynamical Systems and Bioengineering at Caltech and an elected member of the National Academy of Engineering (2013). He also serves as a member of CCSI's Advisory Committee.

The Lecture Series is designed to bring leading experts to PNNL to share some of the latest advances in the controls field and to raise visibility of CCSI's research.

CCSI Annual Workshop Set for May 22-23 at ACC in Seattle

CCSI will hold its annual workshop in conjunction with the 2017 American Control Conference in Seattle, May 22-23, at the conference venue, the Sheraton Seattle Hotel.

The workshop is the third in the series, and first to be held as an ACC workshop. "We believe the ACC provides our workshop with an outstanding opportunity to bring leading experts together to discuss the technical obstacles and potential solutions for unlocking the true potential of next generation power grids," says CCSI Theory Focus Area Lead **Draguna Vrabie**, who is

improving overall efficiency and reducing resource needs.

"We're pleased that Arion is now publicly available, where it can begin benefitting those who need to define complex models in scale and across multiple industry/domains for controls-related research," says **Thomas Edgar**, one of the technology's developers and lead for CCSI's Tools Focus Area.

Abramson to Chair Initiative's Advisory Committee;
New Member Joins

Alexis Abramson of Case Western Reserve University, a current member of the CCSI Advisory Committee, has agreed to take on chair duties.

Dr. Abramson is the Milton and Tamar Maltz Professor of Energy Innovation in Mechanical and Aerospace Engineering at CWRU and Director of the Great Lakes Energy Institute.

She assumes the chair role from **Paul Ehrlich**, who accepted a position at Pacific Northwest National Laboratory in September. Ehrlich comes to PNNL from Building Intelligence Group LLC, a consulting firm he founded. He will remain on the committee as an internal PNNL representative.

organizing the workshop with colleague **Krishnamurthy Dvijotham**.

Titled "Control of Complex Systems: An Integrated Perspective on Modern Power Grid Control," the workshop will emphasize the interactions between three technical areas as they relate to modernization of the electric power grid:

- Dynamics and Control
- Analytics and Optimization
- Economics and Market Design.

The event is open to anyone interested in the subject matter. Past workshop participants have included leading researchers in the control community, U.S. Department of Energy stakeholders, grid regulators, utility engineers, building scientists, building controls and equipment vendors, professors, and students.

The event will include "tutorial" sessions on the three technical areas by leading researchers. It also will feature presentations on research at the forefront of this field by academic researchers, and presentations by industry representatives discussing needs, challenges, and opportunities for applying advanced controls, analytics, and optimization to future power grids.

The workshop also will feature a special "lightning" session of brief, 10-minute presentations that will allow a selected group of attending researchers and students to share information about their respective research and development projects. Interested individuals (graduate students, postdocs, professors, industry and laboratory researchers, and others) should send a title and half-page abstract to Draguna Vrabie and Michael Brambley by no later than May 6, 2017, for consideration.

Also, **Ralph Kappelhoff** has joined the advisory committee. He is an Executive Software Development Leader at General Electric and has worked in leadership roles for several other companies, including Alstom, Areva, and Rockwell Automation.

In addition to Abramson, Ehrlich and Kappelhoff, current committee members are:

Magnus Egerstedt, Georgia Tech
Richard Murray, Caltech
Rob Pratt, PNNL.

The advisory committee regularly reviews CCSI progress and provides advice on future directions.

Alexis Abramson (left), talks with researcher Jeff Daily during the 2016 CCSI Annual Review's poster session.

All-Hands Meeting Serves as Kick-Off to Fiscal Year 2017

The PNNL Events website offers [more workshop details and registration information](#). Additionally, the [ACC Registration Login](#) site is available for those who are ready to register (requires a PIN and password--directions are provided). Please note: ACC registration requires a separate payment. Workshop questions? Contact [Sherry Kowalski](#).

Craig Miller of the National Rural Electric Cooperative Association speaks at the March 2016 CCSI Workshop.

Spotlight on CCSI Staff
Researcher Wants to Make Real-World Impact

Krishnamurthy Dvijotham, who goes by "Dj," joined Pacific Northwest National Laboratory in August 2016 from the California Institute of Technology, where he served as a postdoctoral fellow in Caltech's Center for Mathematics of Information. In CCSI, Dj leads a new project,

CCSI leadership, principal investigators and research staff gathered on November 2 for a meeting to discuss the initiative's status and future plans, and to get better acquainted with staff new to CCSI. "I wanted to bring everyone together to talk about our efforts going forward, ensure that we are coordinated and integrated, and build team enthusiasm," says Initiative Lead **Michael Brambley**. "It was exciting to see everyone and to discuss CCSI goals, priorities for Fiscal Year 2017, and our new projects. We have a great team."

Recent and Upcoming CCSI Publications

Journal Papers

Wu D., T. Yang, A.A. Stoorvogel, and J. Stoustrup. 2017. "Distributed Optimal Coordination for Distributed Energy Resources in Power Systems." *IEEE Transactions on*

"Scalable Verification Methodologies for Complex Infrastructure Networks," which is within the Initiative's Theory Focus Area. In the following interview, Dj talks about his CCSI project, research interests, aspirations and hobbies.

Question: Why did you decide to join PNNL?

Dj: I enjoyed CalTech's environment focused on the scientific aspects of research, asking new scientific questions, and finding answers from a fundamental research perspective. But I also want to take scientific ideas and bring them to fruition in real-world problems, and impact the way things work in society. I felt being at a national laboratory would provide the resources to work on problems at a larger scale.

Question: What will your CCSI project help achieve?

Dj: We're trying to develop algorithms that will be capable of certifying that the power grid will operate safely even in the presence of significant uncertainty. Say you forecasted there would be 100 megawatts of wind energy available today, but you know it might be off by 10 megawatts, up or down. You want to make sure that even if you're off by up to 10 megawatts, everything on the grid will be o.k.; voltages will be within limits, the current will be within limits, those kinds of things. We're working to modify robust optimization techniques to address challenges and to apply directly to systems like the grid.

Question: What benefits do you see from your involvement in CCSI?

Dj: What I'm looking forward to most is interacting with a group of people working on similar problems, feeding off of each other,

Automation Science and Engineering. 14(2):414-424. DOI: 10.1109/TASE.2016.2627006.

Tiam B., Z. Zuo, X. Yan, and H. Wang. 2017. "A Fixed-time Output Feedback Control Scheme for Double Integrator Systems." *Automatica*. 80:17-24. DOI: 10.1016/j.automatica.2017.01.007.

Zhou P., H. Song, H. Wang, and T.Y. Chai. 2017. "Data-driven Nonlinear Subspace Modeling for Prediction and Control of Molten Iron Quality Indices in Blast Furnace Ironmaking." *IEEE Transactions on Control Systems Technology*. (Available online; in press).

Conference Papers

Chang C.Y., and W. Zhang. 2016. "On Exact and Near Optimal Power Flow Solutions for Microgrid Applications." *Proceedings of 55th IEEE Conference on Decision and Control*, pp. 4950-4956, Las Vegas, NV, Dec. 12-14, 2016. DOI: 10.1109/CDC.2016.7799026

Fang H., D. Wu and T. Yang. "Cooperative Management of a Lithium-ion Battery Energy Storage Network: A Distributed MPC Approach." *Proceedings of 55th IEEE Conference on Decision and Control*, pp. 4226-4232, Las Vegas, NV, Dec. 12-14, 2016. DOI: 10.1109/CDC.2016.7798911.

Li. S, W. Zhang, L. Zhao, J. Lian, and K. Kalsi. 2016. "On Social Optima of Non-Cooperative Mean Field Games." *Proceedings of 55th IEEE Conference on Decision and Control*, pp. 3584-3590, Las Vegas, NV, Dec. 12-14, 2016. DOI: 10.1109/CDC.2016.7798808

and hopefully building something much bigger than we might've been able to do individually. Within the Theory focus area, we're trying to meet regularly, discuss our projects, and benefit from that information.

Question: What are activities you enjoy in your spare time?

Dj: I have studied Indian classical music, vocal performance, for a while. I studied with a teacher when I lived in Seattle, and more recently have been studying remotely. I also enjoy outdoor activities, such as hiking and running.

Project Highlight
Co-Simulation Capability Enables Control Solutions

The modernized grid will require control systems that concurrently coordinate everything from operation of building management systems and temperature set points in homes, to electric vehicle charging. Such coordination makes it possible to not only optimize existing energy resources, but reduce consumer costs.

The CCSI project, "Co-Simulation Platform for Rapid Prototyping of Control Algorithms," is helping to enable this vision by providing a co-simulation framework that will make it possible to more quickly prototype, validate and deploy algorithms that carry out actions such as building system coordination.

Lu Y., C.Y. Chang, W. Zhang, L.D. Marinovici, and A. Conejo. 2016. "On Resilience Analysis and Quantification for Wide-Area Control of Power Systems." *Proceedings of 55th IEEE Conference on Decision and Control*, pp. 5799-5804, Las Vegas, NV, Dec. 12-14, 2016. DOI: 10.1109/CDC.2016.7799161.

The three-year project concludes in September. "Last year, one of our efforts focused on doing hardware-in-the-loop through a connection to VOLTTRON™ (a distributed control and sensing software platform). That allowed us to do simulations of physical water heaters in conjunction with simulated water heaters, as well as the ability to simulate a building on the Pacific Northwest National Laboratory campus," says **Jeff Daily**, the project's principal investigator. "The goal this year is to scale up these simulation capabilities from thousands of simulations to tens of thousands--a scale that would be unprecedented in the energy sector."

The project leverages the Framework for Network Co-Simulation (or FNCS, which is pronounced "phoenix"), an open source software tool developed by PNNL's Future Power Grid Initiative several years ago. FNCS makes it possible to bring together and synchronize multiple simulations to better understand how a control system will work. Daily, a FNCS developer, is pleased to see the tool expanding its impact. "PNNL was at the front of the co-simulation wave, and we continue to be relevant and innovate," he explains, noting that PNNL is now leading a nine-laboratory collaboration to build the next generation of open-source co-simulation tools, funded through the Department of Energy's Grid Modernization Initiative.

FNCS also is viewed as a linchpin technology for establishing CCSI's test bed capability, and has been a key component of the initiative's annual integrated demonstrations that showcase CCSI tools working together.

In addition to the GMLC, FNCS is being used in various projects for federal agencies, including the Department of Energy's Advanced Research Projects Agency-Energy and the Department of Defense's Defense Advanced Research Projects Agency. "It's an enabling technology that has allowed PNNL and others to move into research domains that were not possible before," Daily says.

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Pacific Northwest National Laboratory

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