Leveraging Graph Theory and High-Performance Computing to Improve Resiliency of Cyber-Physical Systems by Minimizing Recovery Time Incurred by a Disruption

About ERDC-ITL:

The U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi, is the premier research and development laboratory complex for the Corps of Engineers, engaged in creating and applying advanced information technology to support the Warfighter and the nation. ERDC-ITL develop revolutionary products, processes, and methods to address a wide range of engineering and scientific challenges.

R**ESEARCH LOCATION:** Vicksburg, MS

PROJECT DESCRIPTION:

The rise in connectivity and embedding of cyber systems in operational infrastructure lends itself to improved performance, efficiency, and availability. However, these systems have also seen an increase in disruption and outages both from natural events and targeted attacks. Recovery time improvements and minimizing downtime is often overlooked for investigations into resilience bolstering and system design. Though system design aids in minimizing the possibility of outages, this work aims to prioritize strategies to recover in instances of disruption. Methodologies and techniques by using recovery time as a metric will be implemented through the lens of network and graph theory. This research will utilize parallelization and high-performance computing resources to optimize mean time to recovery.

This research effort poses the recoverability of complex network infrastructure as a network-theoretic and graph-theoretic problem using highly parallel algorithms instantiated on high-performance computing resources to solve the problems. Specifically, the performance of a dynamical network process (e.g. the damping of a power system's swing dynamics, or the congestion/delay imposed by a communication network) can be distilled into a set of graph-derived metrics (e.g., the Fiedler eigenvalue of the graph's Laplacian), which are degraded by disruptions that modify the network. Network recovery can then be viewed as a graph design problem, where node and edge resources must be allocated on a limited time budget to optimally improve the degraded metrics. Conversely, the problem can be posed as an optimization of the recovery time, subject to a bound that the metrics must achieve.

The research in this project will focus on developing algorithmic and structural solutions to these graph optimization problems, and then pursuing parallelization to permit solutions for realistic-scale systems (100's-1000's of nodes, 100's of heterogeneous recovery resources).

Interns will develop research skills in their entirety:

- Formulate the basic research problem.
- Develop and deepen understanding of the process of literature reviews and surveys and will objectively define established and existing research in the specific topic area and related fields.
- Understand how to develop novel, noteworthy techniques that differentiates itself from prior investigations.
- Perform mathematical, computational, and/or engineering research.
- Create test-cases and experimental setups.
- Objectively analyze and report on findings.
- Develop technical writing skills through creating manuscripts, identifying topical venues, and learning the manuscript submission process.

Interns will develop personal and professional skills:

- Collaborate with Cyber R&D Team.
- Develop weekly debriefing and presentation skills.
- Develop capabilities for division of research, tag-teaming, co-teaming, and independence and be responsible for timeliness and communication.
- Develop an understanding of research laboratories through tours of ITL and conversational overviews of division, branch, and team projects and capabilities.

ANTICIPATED START DATE:

May 2025 – Exact start dates will be determined at the time of selection and in coordination with the selected candidate.

QUALIFICATIONS:

The scope and depth of the proposed project lends itself to see success from contributions from collegiate-level interns.

The ideal candidate should be pursuing their bachelor's, master's, or doctoral degree. Desired skills would include familiarity in network controls and anomaly detection problems for infrastructures (computing systems, power-grid controls, resiliency), high-performance computing and graph algorithms, and prior research in power-grid resilience to cyber threats or resilience of cyber-physical systems (namely communications-enabled power and energy systems).

ACADEMIC LEVEL:
Degree received within the last 60 months or currently pursuing:

- Bachelor's
- Master's
- Doctoral

DISCIPLINE NEEDED:

- Computer, Information, and Data Science
- Engineering
- Science & Engineering-related