WCGT 2014–The 3rd Midwest Workshop on Control and Game Theory

April 26-27, 2014

Sponsored by Department of Electrical and Computer Engineering
College of Engineering, The Ohio State University

Contents

1 Overview

The workshop aims to bring together researchers, students and faculty from the midwest region of the United States, who develop and apply game and control theory to analyze, design and assess complex systems. It was previously held at the University of Illinois at Urbana-Champaign in 2012 and at the University of Notre Dame in 2013. We hope to provide an annual forum to highlight synergies between various related research areas, encourage discussions and facilitate collaborations on new game and control theoretic methodologies.

Topics of interest include, but are not limited to:

- Dynamic games and applications; Stochastic games; Learning and adaptive games; Evolutionary games; Cooperative games; Theory of optimal control and dynamic games; Stochastic optimization theory; Optimal and robust control designs; Adaptive and nonlinear control theory; Hybrid and switched systems; Real-time control problems; Control of multi-agent systems; Networked control systems; Control over networks; Control of energy systems; Large scale optimization problems; Quantification of uncertainty.
- Applications: telecommunications, transportation, smart grids, security, energy and resource management, economic dynamics, finance, management, environment, epidemiology, social sciences, system biology, among others.

Location:Pfahl 140, The Blackwell Inn and Conference Center, 2110 Tuttle Park Place, Columbus OH, 43210

Workshop Dates: 8:30am - 6pm on April 26 (Saturday), and 8:30am - 12pm on April 27 (Sunday)

Internet Access: WIFI@OSU is a unsecured guest network that provides users with an average 20mbps download speed that is accessible campus-wide. Users need simply to connect to the network and open their browsers to reach an authentication page that will prompt them to accept the terms and conditions of use to establish an connection. Once they have done this, they are given a 12 hour connection window. To reconnect after this period of time they will simply be prompted to re-accept the terms. The network is designed to handle high traffic and has been proven to be very stable.

Acknowledgement: Financial and logistic support provided by the College of Engineering and the Department of Electrical and Computer Engineering of the Ohio State University is gratefully acknowledged.

2 Committee Members

Organizing Committee

- **Chair:** Ümit Özgüner (Ohio State University)
- Wei Zhang (Ohio State University)
- Panos J. Antsaklis (University of Notre Dame)
- Michael Lemmon (University of Notre Dame)
- Tamer Başar (Univ. of Illinois at Urbana-Champaign)
- Daniel Liberzon (Univ. of Illinois at Urbana-Champaign)
- Ian A. Hiskens (University of Michigan)
- Kenneth A. Loparo (Case Western Reserve University)
- David W. Casbeer (Air Force Research Lab)
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- **Chair:** Wei Zhang (Ohio State University)
- Hooshang Hemami (Ohio State University)
- Kevin M. Passino (Ohio State University)
- Andrea Serrani (Ohio State University)
- Vadim I. Utkin (Ohio State University)
- Krishna Kalyanam (Air Force Research Lab)

3 Program Schedule

Workshop Program

Saturday, April 26, 2014 — Pfahl 140, The Blackwell Inn

7:30 - 16:00	**Registration**
8:15 - 8:30	**Opening Remarks**
8:30 - 10:20	**Session I: Nonlinear and Multiagent Systems** (Chair: Andrea Serrani)
8:30 - 9:00	*Coupled Oscillator Models in Estimation and Control*, Prashant Mehta (University of Illinois at Urbana Champaign)
9:00 - 9:30	*A Distributed Algorithm for Network Localization Using Angle-Of-Arrival Information*, Jianghai Hu (Purdue University)
9:30 - 10:00	*Resilience in Networked Cyber-Robotic Systems*, Sourabh Bhattacharya (Iowa State University)
10:00 - 10:20	*Cooperative Aircraft Defense from an Attacking Missile*, Eloy Garcia (Air Force Research Laboratory)
10:20 - 10:35	**Coffee Break**
10:35 - 12:00	**Session II: Energy Systems** (Chair: Wei Zhang)
10:35 - 11:05	*Generation Investment Equilibria with Strategic Producers*, Antonio J. Conejo (Ohio State University)
11:05 - 11:35	*Modelling and Control of Highly Distributed Loads*, Ian Hiskens (University of Michigan)
11:35 - 12:00	*Control of Thermostatic Loads Using Moving Horizon Estimation of Individual Load States*, Johanna Mathieu (University of Michigan)
12:00 - 13:30	**Lunch/Poster Session** (Chair: Chin-Yao Chang) Pfahl Hall-2nd Floor Foyer and Pfahl 240
	Real-Time Energy Market Price Volatility Analysis and Control, Zhao Wang (University of Notre Dame)
	On Passivity Analysis and Passivation of Feedback Interconnected Systems Using Passivity Indices, Feng Zhu (University of Notre Dame)
	Linear-Quadratic Risk-Sensitive Mean Field Games, Jun Moon (University of Illinois at Urbana Champaign)
	Electricity Pooling Markets with Strategic Producers Possessing Asymmetric Information, Mohammad Rasouli (University of Michigan)
	Sliding Mode Boundary Control of Uncertain Distributed Parameter Dynamic Systems, Meng-Bi Cheng (Ohio Stste University)
	Optimal Velocity Profile using Model Predictive Control Based on V2V Technology, Junbo Jing (Ohio State University)
	Scaled Down Testing and Autonomous Parking, Guchan Ozbilgin (Ohio State University)

	On Market-Based Coordination of Thermostatically Controlled Loads With User Preference, Sen Li (Ohio State University)
	Hierarchical Design for Demand-Side Primary Frequency Control, Christian Moya (Ohio State University)
	Control of Over-Actuated Constrained Systems with Application to High-efficiency Internal Combustion Engines, Junqiang Zhou (Ohio State University)
13:30 - 15:00	**Session III: Nonlinear Control** (Chair: Umit Ozguner)
13:30 - 14:00	*The Geometry of Over-Actuated Systems: Application to Dynamic Control Allocation*, Andrea Serrani (Ohio State University)
14:00 - 14:30	*New Results on Global Stabilization of a Class of Nonminimum-Phase Nonlinear Systems by Output Feedback*, Wei Lin (Case Western Reserve University)
14:30 - 15:00	*Stability of Sparse Systems: Theory and Algorithms*, Mohamed Ali Belabbas (University of Illinois at Urbana-Champaign)
15:00 - 15:15	**Coffee Break**
15:15 - 16:15	**Student Session I: Economics and Game Theory** (Chair: Tavafighi Hamidreza)
15:15 - 15:30	*Complexity of Equilibrium for Diffusion Game Over Social Networks*, Seyed Rasoul Etesami (University of Illinois at Urbana-Champaign)
15:30 - 15:45	*Can Carriers Make More Profit While Users Save Money*, John Tadrous (Ohio State University)
15:45 - 16:00	*Robust Toll Design: Influencing Selfish Behavior in Congestion Games with Unknown Price-Sensitive Users*, Philip Brown (University of Colorado - Boulder)
16:00 - 16:15	*User Participation in Monopolistic Cyber-Insurance Markets*, Parinaz Naghizadeh (University of Michigan)
16:15 - 16:25	**Coffee Break**
16:25 - 17:25	**Student Session II: Nonlinear and Stochastic Systems** (Chair: Arda Kurt)
16:25 - 16:40	*Stability and Control of Infection Diffusion Dynamics Over Arbitrary Networks*, Ali Khanafer (University of Illinois at Urbana-Champaign)
16:40 - 16:55	*Passivity and Dissipativity Analysis of a System and its Approximation*, Meng Xia (University of Norte Dame)
16:55 - 17:10	*Bayesian Traffic Light Parameter Tracking Based on Semi Hidden Markov Models*, Engin Ozatay (Ohio State University)
17:10 - 17:25	*Large-Scale Dissipative and Passive Control Systems and the Role of Symmetry*, Vahideh Ghanbari (University of Notre Dame)
18:45 - 21:00	**Dinner (by special registration)** Hunan House: 2305 E Dublin Granville Rd Columbus, OH 43229

Sunday, April 27, 2014 — Pfahl 140, The Blackwell Inn

8:30 - 9:50	**Session IV: Networked Control Systems** (Chair: Panos Antsaklis)
8:30 - 9:00	*Forecasting Regime Shifts in Networked Dynamical Systems with Applications to the Development of Sustainable Infrastructure*, Michael Lemmon (University of Notre Dame)
9:00 - 9:30	*On the Security of Cyber-Physical Systems*, Bruno Sinopoli (Carnegie Mellon University)
9:30 - 9:50	*Networked Control over Non-Deterministic Channels*, Vincenzo Liberatore (Case Western Reserve University)
9:50 - 10:00	**Coffee Break**
10:00 - 11:10	**Session V: Optimization and Optimal Control** (Chair: Jianghai Hu)
10:00 - 10:30	*Distributed Optimization over Directed Graphs*, Angelia Nedich (University of Illinois at Urbana-Champaign)
10:30 - 10:50	*Decision Making Algorithms for Unmanned Vehicles with Resource Constraints*, Sivakumar Rathinam (Texas A&M University, College Station)
10:50 - 11:10	*A Duality Framework for Stochastic Optimal Control of Complex Systems*, Andreas Malikopoulos (Oak Ridge National Laboratory)
11:10 - 11:55	**Student Session III: Game Theory and Applications** (Chair: Ali Khanafer)
11:10 - 11:25	*Common Information based Markov Perfect Equilibria for Linear-Quadratic-Gaussian (LQG) Games with Asymmetric Information*, Abhishek Gupta (University of Illinois at Urbana-Champaign)
11:25 - 11:40	*Learning Efficient Correlated Equilibria*, Holly Borowski (University of Corolado - Boulder)
11:40 - 11:55	*Optimal Energy Procurement from a Strategic Seller with Private Renewable and Conventional Generation*, Tavafoghi Hamidreza (University of Michigan)
11:55 - 12:00	**Closing Remarks**

Social Program

Saturday, April 26, 2014

10:20 - 10:35	**Coffee Break**
15:00 - 15:15	**Coffee Break**
12:00 - 13:30	**Lunch** (Pfahl Hall-2nd Floor Foyer)
16:15 - 16:25	**Coffee Break**
18:45 - 21:00	**Dinner -(by special registration)** Hunan House: 2305 E Dublin Granville Rd Columbus, OH 43229

Sunday, April 27, 2014

9:50 - 10:00	**Coffee Break**

4 Presentation Abstracts

Session I: Nonlinear and Multiagent Systems (Saturday, April 26, 8:30 - 10:20)

Title: **Coupled Oscillator Models in Estimation and Control**

Author: **Prashant Mehta**
(University of Illinois at Urbana Champaign, mehtapg@illinois.edu)

Abstract: Inference (prediction) is believed to be a fundamentally important computational function for biological sensory systems. For example, the Bayesian model of sensory (e.g., visual) signal processing postulates that the cortical networks in the brain encode a probabilistic belief about reality. The belief state (modeled as a posterior distribution in the Bayes' formalism) is updated based on comparison between the novel stimuli (from senses) and the internal prediction.

A natural question to ask then is whether there is a rigorous methodology (and algorithms) to implement complex forms of prediction (via Bayes theorem) at the level of neurons - the computing elements of the brain? In this talk I will provide a qualified answer to this question based on a coupled oscillator feedback particle filter model. A single oscillator is a simplified model of a single spiking neuron, and the coupled oscillator model solves an inference problem. The methodology will be described with the aid of an activity recognition demonstration. Time permitting, some applications to robotic locomotion will also be discussed.

This work is the result of collaboration with Professor Sean Meyn, and with several students at the University of Illinois.

Title: **A Distributed Algorithm for Network Localization Using Angle-Of-Arrival Information**

Author: **Jianghai Hu** (Purdue University, jianghai@purdue.edu)

Abstract: The focus of this talk is the AOA network localization problem, namely, localizing network nodes based on the angles-of-arrival measurements between certain neighboring network nodes together with the absolute locations of some anchor nodes. We propose the concepts of stiffness matrix and fixability for the anchored formation graphs modeling the networks and show that they provide a complete characterization of the AOA localizability as well as an explicit formula for the localization result. Moreover, a distributed continuous-time algorithm is proposed that converges globally to the correct localization result on fixable formation graphs. Performances of the proposed algorithm, e.g., convergence rate and robustness to com-

munication delay, are characterized. Sensitivities of the localization results with respect to errors in AOA measurements and anchor nodes positions will also be discussed.

Title: **Resilience in Networked Cyber-Robotic Systems**

Author: **Sourabh Bhattacharya** (Iowa State University, sbhattac@iastate.edu)

Abstract: Robots play an important role in tasks related to surveillance. Teams of mobile robots and autonomous vehicles are often deployed in civil as well as military scenarios for intrusion detection and monitoring purposes. In this talk, I will present scenarios of adversarial intrusion and persistent surveillance in teams of autonomous vehicles. I will present some recent results in persistent visual tracking for mobile robots based on pursuit and evasion games.

Title: **Cooperative Aircraft Defense from an Attacking Missile**

Author: **Eloy Garcia**
(Air Force Research Laboratory, eloy.garcia.1.ctr@us.af.mil)

Abstract: A three-body pursuit-evasion scenario will be addressed. In this scenario an Attacker missile using Command to Line of Sight guidance pursues a Target aircraft and a Defender missile launched by a wingman aims at intercepting the Attacker before it reaches the aircraft. A cooperative optimal control problem is posed which captures the goal of the Target-Defender team, namely, to maximize the separation between Target and Attacker at the instant of capture of the Attacker by the Defender. The optimal control law provides the heading angles for the Target and the Defender team. Similar scenarios are explored, using a game theoretical approach, which characterize different objectives and capabilities of the Attacker and the Target-Defender team.

Session II: Energy Systems (Saturday, April 26, 10:35 - 12:00)

Title: **Generation Investment Equilibria with Strategic Producers**

Author: **Antonio J. Conejo** (Ohio State University, conejonavarro.1@osu.edu)

Abstract: This presentation describes a methodology to characterize generation investment equilibria in an electricity market with strategic producers. To this end, the investment problem of each producer is represented using a Stackelberg game, whose upper-level problem determines the optimal investment and offers of the producer to maximize its profit, and whose lower-level problems represent different market clearing conditions. This model can be transformed into a mathematical program with equilibrium constraint, MPEC. The joint consideration of all producer MPECs, one per producer, which constitutes a set to interdependent Stackelberg games, is an equilibrium problem with equilibrium constraints. To identify the solutions of this equilibrium problem, each MPEC is replaced by its KKT conditions. The resulting mixed-integer system of equalities and inequalities allows determining the EPEC equilibria through an auxiliary MILP problem.

Title: **Modelling and Control of Highly Distributed Loads**

Author: **Ian Hiskens** (University of Michigan, hiskens@umich.edu)

Abstract: Responsive load control offers a particularly effective approach to compensating for the variability inherent in large-scale renewable generation, and mitigating the effects of generation and transmission outages. Furthermore, as plug-in electric vehicles grow in popularity, scheduling their charging load will become vitally important to prevent local overloads, and to ensure optimal use of generation resources. The presentation will discuss various control strategies that achieve coordinated response of large numbers of highly distributed and diverse loads. Designing and analysing the dynamic behaviour of load control schemes is reliant upon models that capture both the inherent characteristics of loads together with their response to control signals. The presentation will consider load models which fulfill these requirements.

Title: **Control of Thermostatic Loads Using Moving Horizon Estimation of Individual Load States**

Author: **Johanna Mathieu** (University of Michigan, jlmath@umich.edu)

Abstract: Electric power systems with high penetrations of intermittent and uncertain renewable energy sources will require additional reserve capacity. Recent research has shown that thermostatically controlled loads (TCLs) can

provide reserves to power systems. However, a key challenge is to achieve coordinated control of large populations of resources using existing communication and control infrastructure or with minimal addition of new infrastructure. In this talk, I will describe how we can use state estimation to improve our ability to control an aggregation of TCLs to track power system signals. Past work has focused on estimating the states of aggregate system models, such as Markov models and PDE models. Our new work investigates the possibility of estimating the states of individual TCLs, modeled as stochastic hybrid systems, using measurements/estimates obtained from existing equipment, for example, data transmitted from residential smart meters at low frequency (e.g., every 15 minutes) and real-time estimates of the aggregate power consumption of an aggregation of TCLs computed from distribution substation power measurements. We develop a moving horizon state estimator (MHSE) and benchmark it against a simpler model-based predictor. We also propose a scalable closed-loop control structure that uses the MHSE to provide frequency control with TCL populations. We demonstrate our results via a number of case studies with different TCL aggregations, process and measurement noise characteristics, and controller forcing levels. Our simulations show that the MHSE usually provides accurate state estimates and improves the controller tracking performance, but the results are dependent upon the noise and forcing levels.

Lunch/Poster Session (Saturday, April 26, 12:00 - 13:30)

Title: **Real-Time Energy Market Price Volatility Analysis and Control**

Author: **Zhao Wang** (University of Notre Dame, zwang6@nd.edu)

Abstract: Real-time dispatching operations, among other operations in different time scales, are organized in deregulated energy markets. Besides traditional generators, novel service providers, such as renewable energy resources, provide services responding to real-time dispatching signals. Uncertain outputs of these novel service providers may influence the underlying real-time energy market, in particular resulting in price volatility. Outputs of uncertain service providers are modeled as Markov processes whose transitions depend on external conditions. We then build market dynamic models to analyze the impacts of unfulfilled services with realistic marginal cost curves. Furthermore, we propose a bidding strategy for uncertain service providers to reduce the impact of uncertainty on market price volatility and improve their expected profits.

Title: **On Passivity Analysis and Passivation of Feedback Interconnected Systems Using Passivity Indices**

Author: **Feng Zhu** (University of Notre Dame, fzhu1@nd.edu)

Abstract: Passivity indices (levels) are used to measure the excess or shortage of passivity. While most of the work in the literature focuses on stability conditions for interconnected systems using passivity indices (levels), here we focus on passivity and passivation of the feedback interconnection of two input feed-forward output-feedback (IF-OF) passive systems.

Although it is well known that the negative feedback interconnection of two passive systems is still passive, the quantitative characterization of passivity for the closed-loop system has not been addressed previously. In our work, the conditions are given to determine passivity indices (levels) in feedback interconnected systems. The results can be viewed as the extension of the well-known compositional property of passivity. We also consider the passivation problem which can be used to render a non-passive plant passive using a feedback interconnected passive controller. The passivity indices (levels) of the passivated system are also determined. The results derived do not require linearity of the systems as it is commonly assumed in the literature.

Moreover, passivity and passivation problems for event-triggered feedback interconnected systems are also addressed. The results are extensions of the previous results by considering, in addition, the effect of event-triggered samplers in the feedback path. In this work, we consider passivity in two event-triggered control schemes based on the location of the event-triggered samplers: sampler at plant output and sampler at controller output. For both schemes, we first derive the conditions to characterize passivity indices (levels) for the interconnected systems. The event-triggering condition proposed guarantees that these indices (levels) can be achieved. Then the passivation problem is considered and passivation conditions are provided. The passivation conditions depend on the passivity indices (levels) of the plant and controller and also the event-triggering condition, which reveals the trade off between desired passivity levels and communication resource utilization.

Title: **Linear-Quadratic Risk-Sensitive Mean Field Games**

Author: **Jun Moon**
(University of Illinois at Urbana Champaign, junmoon2@illinois.edu)

Abstract: In this paper, we consider linear-quadratic risk-sensitive mean field games (LQRSMFGs). Each agent strives to minimize an exponentiated integral quadratic cost or risk-sensitive cost function, which is coupled with other agents via a mean field term. By invoking the Nash certainty equivalence principle, we first obtain a robust decentralized control law for each agent to construct a mean field system. We then provide appropriate conditions under which the mean field system admits a unique deterministic function

that approximates the mean field term with arbitrarily small error when the number of agents, say N, goes to infinity. We also show the closed-loop system stability, and prove that the set of N robust decentralized control laws possesses an epsilon-Nash equilibrium property. Moreover, it is shown that epsilon can be taken to be arbitrarily close to zero as N goes to infinity, but our epsilon bound is weaker than its linear-quadratic mean field game (LQMFG) counterpart due to risk-sensitivity in the present case. We also discuss the partial equivalence between the LQRSMFG and the LQ robust mean field game. Finally, we discuss two different limiting cases, and show that one of these is equivalent to the corresponding LQMFG.

Title: **Electricity Pooling Markets with Strategic Producers Possessing Asymmetric Information**

Author: **Mohammad Rasouli** (University of Michigan, junmoon2@illinois.edu)

Abstract: In the restructured electricity industry, electricity pooling markets are an oligopoly with strategic producers possessing private information (private production cost function). We focus on pooling markets where aggregate demand is represented by a non-strategic agent. We consider demand to be elastic.

We propose a market mechanism that has the following features.

- It is individually rational.
- It is budget balanced.
- It is price efficient, that is, at equilibrium the price of electricity is equal to the marginal cost of production.
- The energy production profile corresponding to every non-zero Nash equilibrium of the game induced by the mechanism is a solution of the corresponding centralized problem where the objective is the maximization of the sum of the producers' and consumers' utilities.

We identify some open problems associated with our approach to electricity pooling markets.

Title: **Sliding Mode Boundary Control of Uncertain Distributed Parameter Dynamic Systems**

Author: **Meng-Bi Cheng** (Ohio Stste University, chengmengbi@gmail.com)

Abstract: This talk considers the boundary stabilization problems of distributed parameter systems subjected to boundary disturbance. These systems including heat systems, wave systems, delay systems, Burgers equations, and

Schrodinger equations, which are particularly utilized to describe the dynamic behavior of these engineering process: heat conduction processes, mechanical vibrations, time-delay plants, traffic dynamics, and quantum control, respectively. Their system dynamic are governed by partial differential equation (PDE) with different forms or even with complex values. To deal with the system instability, we apply the integral transformation to convert the original PDE system into a target PDE when an appropriate backstopping boundary control input is applied. The associated Lyapunov function can then be used for designing an infinite-dimensional sliding surface for each plant, on which the system exhibits exponential stability, invariant of the bounded matched disturbance. This sliding surface holds the property of one relative order with respect to the control input, such that the conventional or continuous sliding-mode control can be directly applied to achieve the control goal. Simulation results are provided to demonstrate the feasibility of the proposed control scheme.

Title: **Optimal Velocity Profile using Model Predictive Control Based on V2V Technology**

Author: **Junbo Jing** (Ohio Stste University, `jing.71@osu.edu`)

Abstract: Vehicles' fuel economy is strongly influenced by the drivers driving habits and judgments. Properly planned velocity profile can effectively reduce the vehicles fuel consumption in various scenarios. However, restricted by the drivers experience and limited traffic information obtained, the drivers can hardly plan precisely for the aim of saving energy. Our research focuses on minimizing the vehicles fuel consumption in the car-following scenario on highways by providing optimal velocity profiles. The system obtains the traffic information needed from on-board sensors and V2V Technology. The on-board sensors measure the positions of the front vehicle, and V2V communications provide over-the- horizon awareness of the changes in traffic flow. Based on the information obtained, Gibbs model is adopted to fit the parameters of the front vehicles driving style using genetic optimization, and the front vehicles future velocity profile is predicted for a horizon of seconds. Intelligent Driver Model and Markov Model is deployed to further increase the prediction horizon. With the predicted velocities of the front vehicle, the ego vehicles velocity is determined by using model predictive control. Apart from the aim of optimized fuel economy, driving safety is enforced and ride comfort is cared. Results show that this algorithm can save up to 9% of fuel, and can help to form traffic platoons if widely adopted.

Title: **Scaled Down Testing and Autonomous Parking**

Author: **Guchan Ozbilgin**

(Ohio Stste University, ozbilgin.1@buckeyemail.osu.edu)

Abstract: This study illustrates a methodology to reduce the time and effort spent on full-scale Intelligent Transportation System testing, through the use of small- scale testbeds. Scaled down testing platforms enable the researchers to implement, compare, and assess different architectures for intelligent transportation by deploying hardware-in-the-loop (HIL) simulation and testing, giving strong indications on the performance and high-level behavior of such systems at full scale. The performance of the scaled down testing is illustrated using a specific example based on an autonomous parking. The approach is demonstrated on intelligent transportation system testbed in The Ohio State University Control and Intelligent Transportation Research Laboratory. The detailed experimental results show the applicability and robustness of the proposed system.

Title: **On Market-Based Coordination of Thermostatically Controlled Loads With User Preference**

Author: **Sen Li** (Ohio Stste University, li.2886@buckeyemail.osu.edu)

Abstract: We focus on the transactive control framework for a group of autonomous Thermostatically Controlled Loads (TCL) to achieve system-level objectives with price incentives. The problem is formulated as maximizing the social welfare subject to a feeder power constraint. It allows the coordinator to affect the aggregated power of a group of dynamical systems, and creates an interactive market where the users and the coordinator cooperatively determine the optimal energy allocation and energy price. The optimal pricing strategy is derived, which maximizes social welfare while respecting the feeder power constraint. The bidding strategy is also proposed, along with the estimation framework for the users to derive bidding in real time with unknown model parameters and partially measureable system state. The simulation results demonstrate that the proposed approach can effectively maximize the social welfare and reduce power congestion at key times.

Title: **Hierarchical Design for Demand-Side Primary Frequency Control**

Author: **Christian Moya** (Ohio Stste University, moya.10@osu.edu)

Abstract: A novel hierarchical decentralized framework is proposed for demand-side primary frequency control based on the structure preserving power system model. The proposed framework involves two decision layers and enables the systematic design of load controllers that can effectively increase the system damping. At the supervisory layer, the control gain is determined to specify the desired aggregate load response if frequency deviates. This

gain is periodically updated by taking into account the time-varying availability of end-use responsive loads and the system oscillatory modes. At the device layer, each end-use load changes its operating mode independently with certain probability that is calculated based on a Markov-Chain model, the received control gain, and local frequency measurement. This probability is calculated such that the actual aggregate load response can match the desired one required by the supervisory layer. Simulation results demonstrate the efficacy of the proposed load control strategy.

Title: **Control of Over-Actuated Constrained Systems with Application to High-efficiency Internal Combustion Engines**

Author: **Junqiang Zhou** (Ohio Stste University, zhou.412@osu.edu)

Abstract: Modern engines for passenger vehicles are characterized with various advanced technologies with an increased number of actuators, to improve the engine performance such as fuel economy, emission and drivability. However, an innovative control approach is not available to integrate the advanced technologies in its entirety to meet desired system-level performance. This research is motivated by the need to develop a systematic methodology to simultaneously control and optimize over-actuated engine systems. The proposed control methodology relies upon the characterization in geometric terms of the state-space redundancy, which is exploited based on inverse model allocation to shape transient response by optimizing on-line a given cost function. A case study on a Diesel engine shows the effectiveness of the proposed control strategy.

Session III: Nonlinear Control (Saturday, April 26, 13:30 - 15:00)

Title: **The Geometry of Over-Actuated Systems: Application to Dynamic Control Allocation**

Author: **Andrea Serrani** (Ohio State University, serrani@ece.osu.edu)

Abstract: Input redundancy in a control system is typically resolved by means of (static) control allocation strategies, where the standing assumption prescribes that a virtual control input can be defined, which has the same dimensionality of the regulated output. A control strategy designed on the basis of this virtual input is then "distributed" across the redundant set of actuators via on-line optimization. Essentially, this implies that the redundancy is confined to the null-space of the input operator, which can be factored out by projection. On the other hand, the elusive case of input redundancy with full-rank input operators constitutes an "intrinsic" redundancy in the system, as multiple independently controllable state-trajectories exist that are compatible with a given reference output. In this talk, we give a geometric characterization of intrinsically redundant linear systems, in the context of the full-information output regulation problem. It is shown that intrinsic input redundancy can be exploited in the inverse system towards the definition of novel dynamic control allocation strategies. In the proposed scheme, the steady-state behavior of the system is shaped through dynamic optimization of selected performance criteria penalizing both the control input and the state trajectory, while maintaining invariance of the error-zeroing subspace. An illustrative example on a low-order model of a fighter jet is presented to elucidate the applicability of the method.

Title: **New Results on Global Stabilization of a Class of Nonminimum-Phase Nonlinear Systems by Output Feedback**

Author: **Wei Lin** (Case Western Reserve University, linwei@cwru.edu)

Abstract: This talk will present some new results on global stabilization by output feedback for nonminimum-phase nonlinear systems. The class of nonlinear systems under consideration has a cascade configuration that consists of a driven system, also known as the inverse dynamics, and a driving system. It is proved that although the zero dynamics may be unstable, there is an output feedback controller, globally stabilizing the nonlinear system if both the driven and driving systems have a lower-triangular form and satisfy a global Lipschitz-like condition,and the inverse dynamics satisfy the input-to-state stabilizability condition. A design procedure is provided for the construction of an n-dimensional dynamic output feedback compensator. Two examples and simulations are also presented to validate the effectiveness of the proposed output feedback control scheme.

Title: **Stability of Sparse Systems: Theory and Algorithms**

Author: **Mohamed Ali Belabbas**
(University of Illinois at Urbana-Champaign,
belabbas@illinois.edu)

Abstract: Many problems of practical and theoretical nature in control, biology and communications are described by an underlying graph encoding which interactions between a group of agents are allowed. It is thus interest to know whether this underlying graph is such that systems defined over it are stabilizable. In this lecture, we present results characterizing such graphs and algorithms to create them in polynomial time.

Student Session I: Economics and Game Theory (Saturday, April 26, 15:15 - 16:15)

Title: **Complexity of Equilibrium for Diffusion Game Over Social Networks**

Author: **Seyed Rasoul Etesami**
(University of Illinois at Urbana-Champaign, etesami1@illinois.edu)

Abstract: We revisit the competitive diffusion game on undirected connected graphs and study the complexity of the existence of pure Nash equilibrium for such game. We first characterize the utility of each player based on the location of its initial seed placements. Using this characterization, we show that the utility of the each player is a sub modular function of its initial seed set. Following this, a simple greedy algorithm provides an initial seed placement within a constant factor of optimal solution. We show the NP-hardness of the decision about existence of the pure Nash equilibrium for general networks. Finally we provide some necessary conditions for a given profile to be a Nash equilibrium and prove a lower bound for the maximum social welfare of the game with two players.

Title: **Can Carriers Make More Profit While Users Save Money**

Author: **John Tadrous** (Ohio State University, tadrous.1@osu.edu)

Abstract: In this work, we investigate the profit maximization problem for wireless network carriers and payment minimization for end users. Motivated by our recent findings on proactive resource allocation, we focus on the scenario whereby end users harness predictable demand and WiFi connectivity in proactive data downloads, to minimize their expected payments. Carriers, on the other hand, utilize smart pricing schemes to differentiate between the off-peak and peak hour prices so as to reduce peak costs and maximize their profit. We formulate the tension between the carrier and end user as a

two-player Stackelberg game in which the carrier assigns prices first, then the end user responds with optimized proactive downloads. We explore the equilibrium points under maximum and average price constraints, and study the impact of WiFi availability on the system's performance. In particular, we compare the new equilibria with the baseline scenario of flat pricing and no proactive downloads. Despite the potential uncertainty about future demand, and the freshness of proactively downloaded content, we characterize new equilibria points that yield win-win situation with respect to the baseline equilibrium.

Title: **Robust Toll Design: Influencing Selfish Behavior in Congestion Games with Unknown Price-Sensitive Users**

Author: **Philip Brown**
(University of Colorado at Boulder, philip.brown@colorado.edu)

Abstract: We focus on the derivation of taxation mechanisms for improving system-level behavior in congestion games with unknown price-sensitive users. Here, a taxation mechanism represents a general rule for assigning local taxation functions to edges in a given network, e.g., Pigovian taxes or marginal-cost taxes. Recent results have identified taxation mechanisms that lead to optimal system-level behavior for the considered class of games; however, these mechanisms require that a system-designer has a complete characterization of network structure and the users' sensitivities. Furthermore, the robustness of these mechanisms to mis-characterization in this information is unknown. With these issues in mind, we focus on the derivation of robust taxation mechanisms - that is, taxation mechanisms that provide strong efficiency guarantees irrespective of the underlying network or user characteristics. With this goal in mind, we define a scaled marginal-cost taxation mechanism in which the edge taxation functions are derived without explicit knowledge of the network structure or the users' sensitivities. We then derive the optimal scaled marginal-cost taxation mechanism that limits worst-case inefficiencies over these uncertainties for the class of parallel-network congestion games with affine latency functions. In other words, we derive the scaled marginal-cost taxation mechanism that optimizes the price of anarchy. Note that viewing the price of anarchy as a design objective represents a significant departure from traditional price of anarchy results in the existing literature.

Title: **User Participation in Monopolistic Cyber-Insurance Markets**

Author: **Parinaz Naghizadeh** (University of Michigan, naghizad@umich.edu)

Abstract: A user's investment in security in an interdependent system affects the security standing of other entities interacting with it as well, by reducing the probability of an indirect attack initiated from the protected user.

The interactions of strategic users in such setting is often modeled as an interdependent security (IDS) game. The Nash equilibria of these game are in general inefficient, as users ignore the externality of their actions on others, and may in addition free-ride on other users' efforts. To improve the overall security at the equilibrium state of these games, the literature has proposed cyber-insurance as a potential mechanism, using which users are incentivized to improve their investments in security. In particular, existing work has shown that, under a binary investment model, a monopolist insurer can design cyber-insurance contracts so as to induce socially optimal security investments.

In this talk, we first present a new insurance design mechanism by a monopolist insurer for a continuous investment decision model, which implements the socially optimal equilibrium of the corresponding IDS game. We then study users' participation incentives in this monopolistic market. These constraints have not been specifically addressed in the literature on monopolistic cyber-insurance, as the existing works have assumed mandatory insurance. We show that due to the non-excludable nature of security, there may exist scenarios in which it is impossible to guarantee that users voluntarily purchase insurance from the market, irrespective of how the insurer designs the contracts. We discuss the implication of this impossibility and possible ways to circumvent it.

Student Session II: Nonlinear and Stochastic Systems (Saturday, April 26, 16:25 - 17:25)

Title: **Stability and Control of Infection Diffusion Dynamics Over Arbitrary Networks**

Author: **Ali Khanafer**
(University of Illinois at Urbana-Champaign, khanafe2@illinois.edu)

Abstract: In this work, we analyze the stability properties of a susceptible-infected-susceptible (SIS) diffusion model over arbitrary networks. Similar to the majority of infection spread dynamics, this model exhibits a threshold phenomenon. When the curing rates in the network are high enough, the all-healthy state is globally asymptotically stable. Otherwise, a strictly positive endemic state arises and the entire network could become infected. We show that this model can be viewed as a concave game among the nodes. This characterization allows us to provide a simple condition, that can be checked in a distributed fashion, for stabilizing the origin. Using notions from positive systems theory, we prove that the endemic state is globally asymptotically stable in connected undirected graphs as well as strongly connected digraphs. We also show that for these networks, the endemic state is locally exponentially stable. For a weakly connected digraph, we

provide conditions for the existence, uniqueness, and global stability of a strictly positive endemic state. Further, we identify scenarios in which only a strongly connected component can be infected, while the remaining nodes in the network remain healthy. Finally, when the curing rates are viewed as controllers, we propose a framework for reducing the residual infection in arbitrary networks using a limited number of control nodes. Several simulations illustrate our results.This work is in collaboration with Tamer Basar and Bahman Gharesifard.

Title: **Passivity and Dissipativity Analysis of a System and its Approximation**

Author: **Meng Xia** (University of Notre Dame, mxia@nd.edu)

Abstract: We consider the following problem: what passivity properties can be inferred for a system by studying only an approximate mathematical model for it. Our results show that an excess of passivity (whether in the form of input strictly passive, output strictly passive or very strictly passive) in the approximate model guarantees a certain passivity index for the system, provided that the norm of the error between the approximate and the true models is sufficiently small in a suitably defined sense. Further, we consider $(Q; S; R)$-dissipative systems and show that $(Q; S; R)$-dissipativity has a similar robustness property, even though the supply rates for the system and its approximation may be different. These results may be particularly useful if either the approximate model is much easier to analyze, or if the accurate system model is unknown precisely.

Title: **Bayesian Traffic Light Parameter Tracking Based on Semi Hidden Markov Models**

Author: **Engin Ozatay** (Ohio State University, ozatay.1@osu.edu)

Abstract: The previous studies have shown that the optimization of the driving velocity profiles and route selection based on the availability of the traffic lights' operation information in a traffic network can significantly reduce the individual and cumulative energy consumption of the on road vehicles for the urban drivings. In this work we propose an accurate and precise stochastic online estimation method of the parameters of the traffic lights operating at a piece-wise constant period. In our work we first model the traffic lights with a Semi Hidden Markov Model (SHMM) and then develop the period measurement model governed by an unique noise model specific to the indirect traffic light period measurements. The proposed method solves the estimation problem in two stages: in the first stage we determine the sequence of Markovian States maximizing the probability given the measurements and the SHMM parameters, the in the second stage we update

the period and state duration estimates based on the Bayesian Tracking given the corresponding latest measurements. The simulation and real vehicle data results prove that the proposed method can accurately estimate the switching times and the period of the piece-wise fixed period traffic lights.

Title: **Large-Scale Dissipative and Passive Control Systems and the Role of Symmetry**

Author: **Vahideh Ghanbari** (University of Notre Dame, vghanbar@nd.edu)

Abstract: In this study, stability conditions for large-scale systems are derived by categorizing agents into symmetry groups and applying local control laws under limited interconnections with neighbors. Stability for dissipative and passive systems is considered and conditions are derived for the maximum number of subsystems that may be added while preserving stability. There may exist an upper bound on the number of subsystems so to guarantee stability, depending on the structure of symmetric interconnection. Three kinds of symmetries are studied: star-shaped symmetry, cyclic symmetry and chain symmetry. Also, approximate symmetry with respect to interconnections are represented.

Session IV: Networked Control Systems (Sunday, April 27,8:30 - 9:50)

Title: **Forecasting Regime Shifts in Networked Dynamical Systems with Applications to the Development of Sustainable Infrastructure**

Author: **Michael Lemmon** (University of Notre Dame, lemmon@nd.edu)

Abstract: A regime shift occurs when a dynamical system "flips" from a nominal operating state to an alternative operating state. Regime shifts can be catastrophic for users who have grown accustomed to the quality of services provided by the system prior to this shift. This talk will discuss methods for assessing a dynamical system's susceptibility to catastrophic regime shifts using sum-of-squares relaxations to bound the system's so-called "distance to bifurcation" and "first passage time" probabilities. The methods will be used to assess the susceptibility of aquatic ecosystems to regime shifts.

Title: **On the Security of Cyber-Physical Systems**

Author: **Bruno Sinopoli** (Carnegie Mellon University, brunos@ece.cmu.edu)

Abstract: Cyber Physical Systems (CPS) refer to the embedding of widespread sensing, computation, communication, and control into physical spaces. Appli-

cation areas are as diverse as aerospace, chemical processes, civil infrastructure, energy, manufacturing and transportation, most of which are safety-critical. The availability of cheap communication technologies such as the internet makes such infrastructures susceptible to cyber security threats, which may affect national security as some of them, such as the power grid, are vital to the normal operation of our society. Any successful attack may significantly hamper the economy, the environment or may even lead to loss of human life. As a result, security is of primary importance to guarantee safe operation of CPS. In an offensive perspective, attacks of this sort can be carried out to disrupt the functionality of the enemy's critical infrastructures without destroying it or even be directly identified. Stuxnet, the malware at the root of the destruction of centrifuges employed to enrich uranium in Iran's nuclear facilities, is a clear example of how strategically important is to gain a deep understanding of CPS security. In this talk I will provide an introduction to CPS security, give an overview of recent results from our research group as well as directions for future work.

Title: **Networked Control over Non-Deterministic Channels**

Author: **Vincenzo Liberatore** (Case Western Reserve University, `vl@case.edu`)

Abstract: Networked Control Systems (NCSs) involve the remote control of a plant that is connected to a controller via a communication network.
In this talk, we will start by reviewing established research results in Distributed Algorithms and Internet Measurement: for example, clocks can be synchronized only to within a round-trip time, and packet losses must be assumed to follow an arbitrary non-deterministic pattern. These facts imply a novel approach for the analysis of NCSs, which will be exemplified by playback buffers. Playback buffers turn network delays into time-invariant quantities, but at the potential expense of increased packet losses and delays. We will describe a class of controllers for buffered NCS that is stable under arbitrary packet losses.

Session V: Optimization and Optimal Control (Sunday, April 27, 10:00 - 11:10)

Title: **Distributed Optimization over Directed Graphs**

Author: **Angelia Nedich**
(University of Illinois at Urbana-Champaign, `angelia@illinois.edu`)

Abstract: Recent advances in wired and wireless technology necessitate the development of theory, models and tools to cope with new challenges posed by large-scale networks and various problems arising in current and anticipated applications over such networks. In this talk, optimization problems

and algorithms for distributed multi-agent networked systems will be discussed. The distributed nature of the problem is reflected in agents having their own local (private) information while they have a common goal to optimize the sum of their objectives through some limited information exchange. The inherent lack of a central coordinator is compensated through the use of network to communicate certain estimates and the use of appropriate local-aggregation schemes. The overall approach allows agents to achieve the desired optimization goal without sharing the explicit form of their locally known objective functions. However, the agents are willing to cooperate with each other locally to solve the problem by exchanging some estimates of relevant information. Distributed algorithms will be discussed for directed graphs with their basic convergence properties.

Title: **Decision Making Algorithms for Unmanned Vehicles with Resource Constraints**

Author: **Sivakumar Rathinam** (Texas A&M University, srathinam@tamu.edu)

Abstract: Small, heterogeneous, unmanned vehicles are being used increasingly in civil and military applications for monitoring a group of targets. In this work, I consider a path planning problem involving multiple, heterogeneous vehicles starting from distinct depots. The objective of the path planning problem is to find a path for each vehicle so that each of the targets is visited at least once by a vehicle, the motion constraints of the vehicles are satisfied, and the sum of the travel times of all the vehicles is minimized. By exploiting the structure of the problem, I will present the algorithms developed by our research group, which are currently the best known for this path planning problem.

Joint work with Dr. Swaroop Darbha and students at Texas A & M.

Title: **A Duality Framework for Stochastic Optimal Control of Complex Systems**

Author: **Andreas Malikopoulos**
(Oak Ridge National Laboratory, andreas@ornl.gov)

Abstract: In this talk, we present a model for the analysis and stochastic optimization of a system consisting of interactive subsystems and address the problem of minimizing the system's long-run expected average cost. We treat the stochastic control problem as a multiobjective optimization problem of the one-stage expected costs of the subsystems and we develop a duality framework to prove that the control policy yielding the Pareto optimal solution minimizes the average cost criterion of the system. We provide the conditions of existence and a geometric interpretation of the solution. For

practical situations with constraints consistent to those studied here, our results imply that the Pareto control policy may be of value in deriving online an optimal control policy in complex systems.

Student Session III: Game Theory and Applications (Sunday, April 27, 11:10 - 11:55)

Title: **Common Information based Markov Perfect Equilibria for Linear-Quadratic-Gaussian (LQG) Games with Asymmetric Information**

Author: **Abhishek Gupta**
(University of Illinois at Urbana-Champaign, gupta54@illinois.edu)

Abstract: We consider a class of two-player dynamic stochastic LQG nonzero-sum games. Each controller acquires possibly different dynamic information about the state process and the other controller's past actions and observations. This leads to a dynamic LQG game of asymmetric information among the controllers. In this talk, we present a novel refinement concept for Nash equilibrium in dynamic LQG games with asymmetric information, called common information based Markov perfect equilibrium. We prove that in a dynamic LQG game, under certain conditions, a unique common information based Markov perfect equilibrium exists. Furthermore, this equilibrium can be computed by solving a sequence of linear equations.

Title: **Learning Efficient Correlated Equilibria**

Author: **Holly Borowski**
(University of Corolado at Boulder, holly.borowski@colorado.edu)

Abstract: The vast majority of the literature in distributed learning focuses on attaining convergence to Nash equilibria. Correlated equilibria, on the other hand, can often characterize collective behavior that is far more efficient than even the best Nash equilibrium. However, there are no distributed learning algorithms in the existing literature that coverage to specific correlated equilibria. We provide one such algorithm. In particular, the proposed algorithm guarantees that the agents? collective joint strategy will constitute an efficient correlated equilibrium with high probability. The key to attaining efficient correlated behavior as the result of a distributed learning process is incorporating a common random signal into the learning environment.

Title: **Optimal Energy Procurement from a Strategic Seller with Private Renewable and Conventional Generation**

Author: **Tavafoghi Hamidreza** (University of Michigan, tavaf@umich.edu)

Abstract: We consider a mechanism design problem for energy procurement, when there is one buyer and one seller, and the buyer is the mechanism designer. The seller can generate energy from conventional (deterministic) and renewable (random) plants, and has multi-dimensional private information which determines her production cost. The objective is to maximize the buyer's utility under the constraint that the seller voluntarily participates in the energy procurement process. We show that the optimal mechanism is a menu of contracts (nonlinear pricing) that the buyer offers to the seller, and the seller chooses one based on her private information.

5 Alphabetical List of Participants

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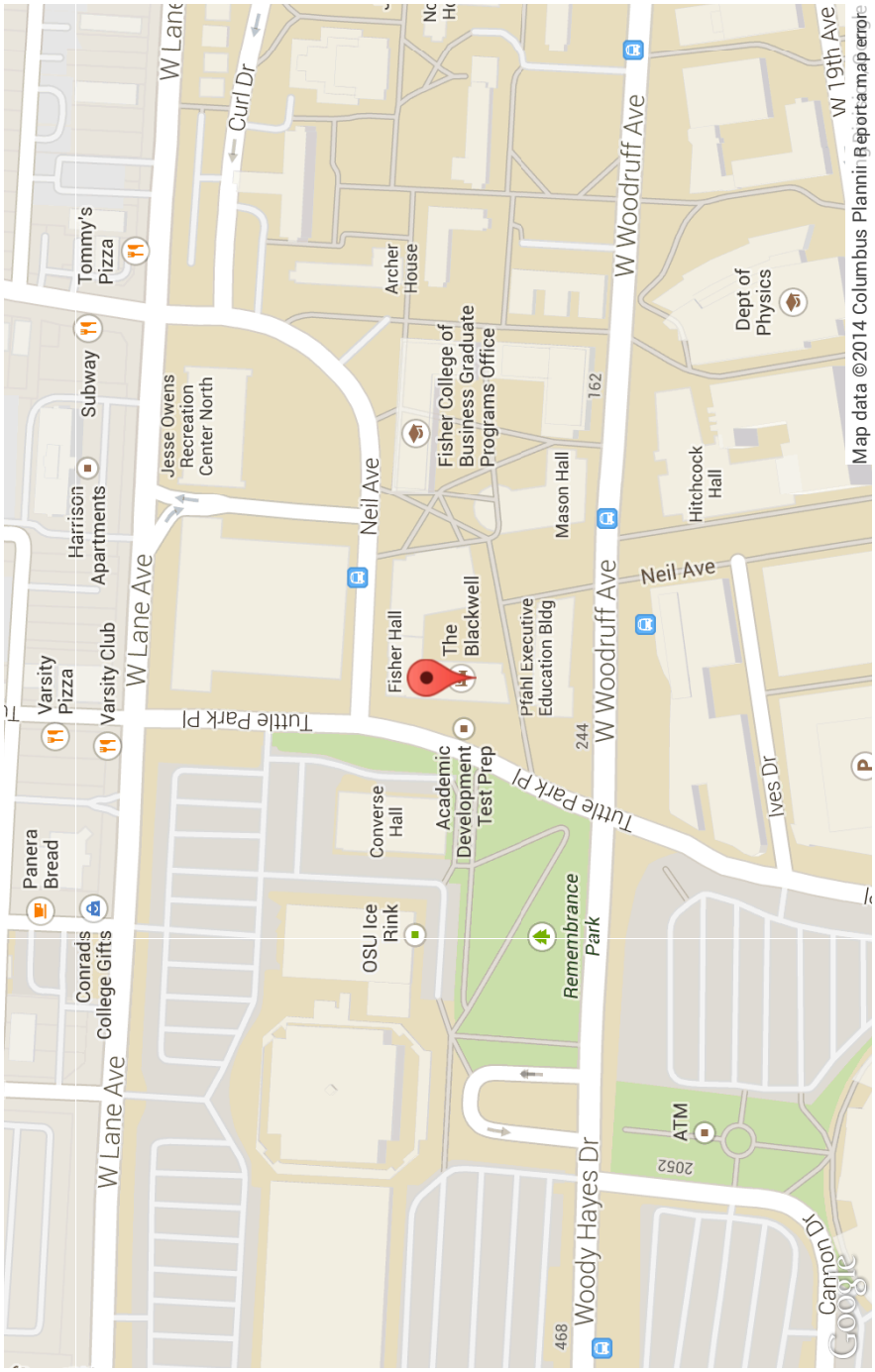
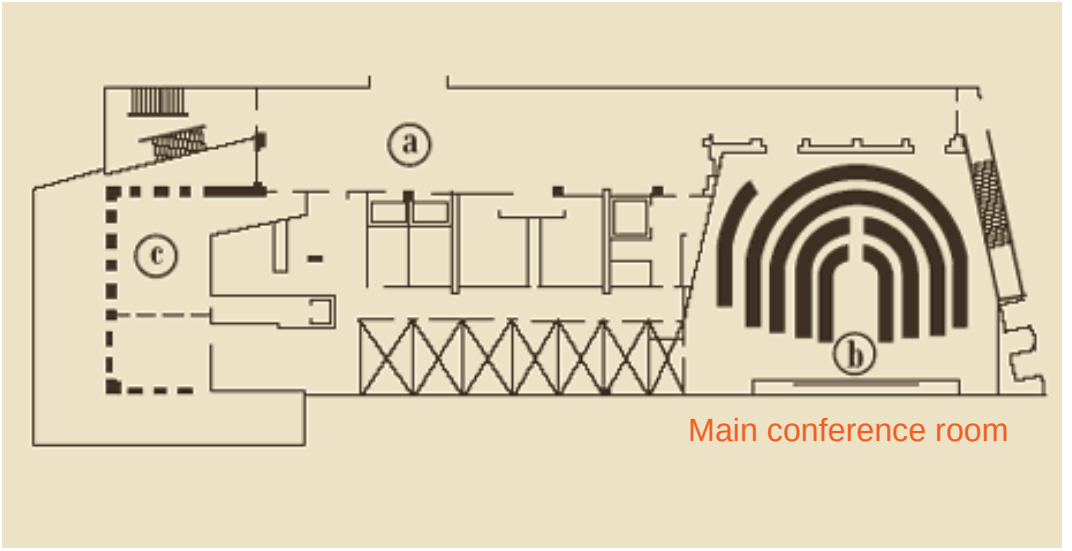
6 Maps



Location of the Blackwell Hotel

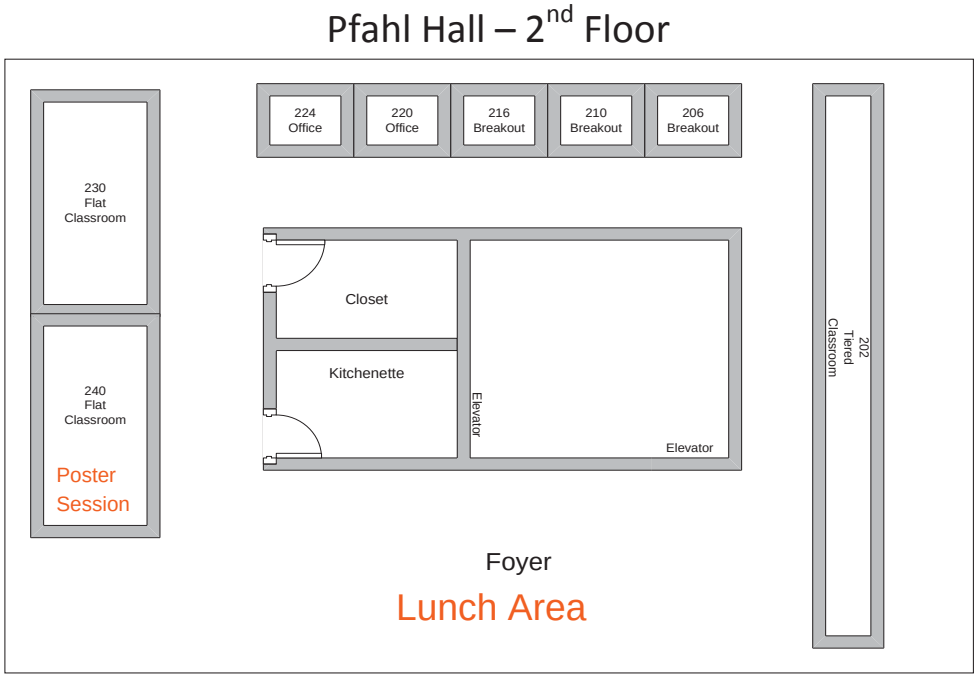
Address: 2110 Tuttle Park Place, Columbus, Ohio 43210. Phone: 614-247-4000

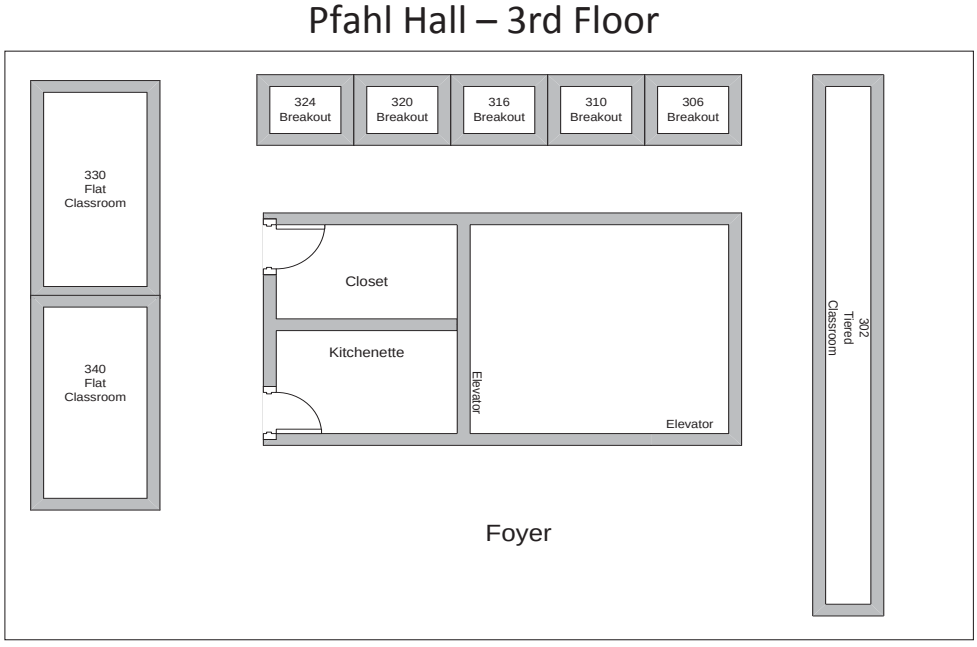
Floor Plan of Blackwell Hotel



Phfal Conference Center 1st Floor Floor Plan

(a) First Floor Break Area, Registration/Reception
(b) Pfahl 140, Large Tiered Classroom
(c) Executive Boardroom





Phfal Hall 2nd-3rd Floor Plan (lunch and breakout room)

7 About Columbus

COLUMBUS ATTRACTIONS: Downtown Columbus and the surrounding area are home to many unique cultural and natural attractions. On the north side of downtown Columbus, is the Short North Arts District, a popular gallery, dining, and nightspot. If you prefer sports or concerts to galleries, then head to the Arena District, where you will find multiple sports and concert venues. The Columbus Zoo and Aquarium, named the Number One Zoo in America by USA Travel Guide in 2009, and the Center of Science and Industry are popular attractions, as are the Columbus Whetstone Park of Roses and the Franklin Park Conservatory. The Central Ohio Greenway Trail System connects Columbus and outlying areas. Also among your choices are BalletMet, Broadway Across America-Columbus, the Columbus Jazz Orchestra, The Columbus Symphony and the Contemporary American Theatre Company. See world-class visual art at the Columbus Museum of Art, The King Arts Complex and Franklin Park Conservatory and Botanical Gardens, the only botanical garden in the world with a permanent collection of glass artwork by Dale Chihuly.

OHIO STATE CAMPUS AREA: There are a wide variety of attractions just a short walk from the Blackwell hotel, such as the Ohio Stadium, the Thompson Library, the Oval, and the OSU recreational facility (RPAC), a resort-level gym/spa that is one of the largest at any university. Visitor pass for RPAC can be purchased at the font desk of Blackwell. A longer walk from the hotel can bring you to the Wexner Center for the Arts, the Ohio Union, and the Mirror Lake.