Topic Suggestions for SFI's Complex Systems Summer School

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The Santa Fe Institute's (SFI) *Complex Systems Summer School (CSSS)* is held each summer with a new class each year of doctoral and postdoctoral students from top universities around the world. During the last three weeks of CSSS, students work in small groups on a capstone project related to complex systems. Students self-organize to form their cross-disciplinary groups and select their topics.

MITRE, as a member of the SFI Applied Complexity Network (ACtioN) has been encouraged to suggest complexity-related topics, and associated datasets, which the students may consider.

This document contains three one-page write-ups describing suggested topics for the Summer 2016 session.

How Will Small Unmanned Aircraft Systems (sUAS) at Very Low Altitudes Fly Safely?

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There is a lot of energy going into considering how sUAS will interact with each other and with manned aircraft, at very low altitudes. NASA, through its UAS Traffic Management (UTM) Program, as well as Google and Amazon, are making considerable investments to address this problem. Most are looking at mission types as the basis – many kinds of needs for flying a sUAS, on a one-at-a-time basis. They are finding that there are a lot of issues to be addressed to be able to fly each of these missions safely.

But, how do we analyze how a number of UAS, flying a variety of missions, will perform and interact in a specific area? Two aspects of this have seen minimal exploration: 1) there have been projections of a number of UAS in an area (though not specific missions or tracks), to push the limits on number; and 2) there have been a number of detailed mission scenarios, that describe the individual tracks in detail, but only for a single or limited number of missions. The intent of the latter was not to push the limits on number of UAS in an area, in order to see how the interactions change. A thorough Modeling and Simulation (M&S) examination is required, to examine how a variety of missions (on specific tracks) in a specific area will interact with each other.

This project would be scoped to investigate how sUAS would interact just with each other (not with manned aircraft or with obstacles). A model is required that would begin by capturing simple operational characteristics for a series of UAS mission profiles. The model would fly a series of these missions in a specific area, starting with a few of each type, and incrementally increasing the number with each model run. For the first set of runs, they would not involve any conflict detection and avoidance maneuvers for any of the UAS. The model would measure how close the sUAS got to each other, and count the number of times the sUAS got within a given distance of each other.

The data from the first series of runs would be compared to chart how the number of close encounters increase, as the number of missions increases – looking for a "knee" in the curve, as it approaches grid-lock. Several aspects of this data could be explored:

1. The details of the first set of runs could be explored for details of how and where the interactions take place (are they all in one area?).
2. The variable of close separation distance could be varied, and the change in the close encounters over the same set of missions could be recalculated and re-charted, to see how gridlock is affected. These data set would feed a discussion of "how close is too close?" for these types of missions.
3. Subsequently, models of conflict detection and avoidance could be added to the series of model runs, to see if these changes in behavior by the sUAS would decrease the number of close separations. These collision detection and avoidance methods could span a range of methods, to include:
    - Simple reactions – "rules of the road" such as "see another UAS, pass on the right"
    - Central "big brain" control -- a monitor such as the ATC model, impose downward from the controlled airspace models, to direct sUAS traffic at a scale that is smaller (in aircraft size and separation) and larger (in numbers of aircraft in an area).
    - Distributed control – like a ground model with roads and stop lights, or other networked models with simple local rules
    - Other models that we haven't thought of yet – what behaviors do these model runs reveal? What might emerge as a possible solution?

How do simple rules affect an increasingly complex set of interactions? How far can congestion of sUAS in a specific area go, before you get grid-lock?

A Traffic Signal Control for Isolated Intersection in Presence of Connected Vehicles

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Presently, traffic control on a signalized road intersection is performed using one of the following three strategies:

1) fixed-time (utilizes observed traffic data to create traffic signal plans that may be different for different times of the day),
2) actuated (takes into the consideration input from infrastructure-based sensors such as loop or video detectors to adjust the length of the current phase (e.g., shortens or skips a phase if no vehicle benefiting from it is present) by applying simple logic), and
3) adaptive (takes into the consideration inputs from sensors to predict near-future traffic conditions and finds an optimal traffic signal timing for those conditions).

The term "connected vehicles" refers to vehicles equipped with wireless communication devices that enable transfer of messages to other vehicle (vehicle-to-vehicle communication (V2V)) or to infrastructure (vehicle-to-infrastructure communication (V2I)). Among the other devices, infrastructure includes traffic signal controllers. To reduce latency, safety critical messages are expected to be transmitted using Dedicated Short Range Communication (DSRC). Non-safety critical messages could be transmitted using cellular communication technologies (e.g., 3G, 4G, 5G, LTE). The Society of Automotive Engineers (SAE) has established standards pertaining to the message content for V2V and V2I communications. Among others, the message set includes: Basic Safety Message (BSM), MAP Message (MAP), Signal Status Message (SSM), Signal Request Message (SRM), and Signal Phasing and Timing Message (SPaT).

Drivers of connected vehicles are expected to have improved situational awareness, as the V2V communication accommodates alerting on sudden changes in the state vector of the leading vehicle (e.g., abrupt speed reduction). Similarly, the infrastructure (in this case, the intersection traffic signal controller) will be able to collect information about vehicles in its vicinity and adjust the signal timing accordingly (e.g., reduce delays of vehicles traversing intersection, provide right of way to priority eligible vehicles). For benefits to be realized, not all vehicles will need to be connected. In fact, in several current and past pilot programs, only a fraction of observed vehicles were connected.

In light of improved data sharing (states of the vehicles and infrastructure are shared) how should traffic be optimized on an isolated intersection using the adaptive control method? If DSRC is assumed as a means of communication, how does its limited range (up to 300 meters; could be parameterized) influence the quality of the results (e.g., efficiency)? How to determine location of the vehicles that are not connected? How to model priority eligible vehicles (the objective is to design a realistic controller which will take into consideration safety (e.g., yellow lights may be needed), priorities, and delays)? If all vehicles are connected, is the intersection controller based on traffic lights needed? If not, what could be the alternative control strategies?

Methods for Determining Optimal Location of Spaceports

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The number of commercial space launches per year is expected to increase dramatically in the near future. Each such space launch includes phases during which space vehicles pass through airspace normally used by other aircraft with dramatically different performance characteristics, such as air carrier flights. To provide for the safety of aircraft operations, current procedures block large sections of airspace from use by other aircraft during launch and re-entry of space vehicles. Aircraft operators (such as air carrier operators) must route flights around the blocked airspace, at significant cost in terms of fuel and time. Thus, aircraft traffic density in the vicinity of spaceports influences the cost associated with commercial space operations. In addition, operation of space vehicles may be highly affected by meteorological conditions. Thus, when considering potential locations of spaceports, it is necessary to consider prevalent weather conditions expected (or observed) at any considered location.

There is a set of FAA-licensed commercial spaceports including[1]:

California Spaceport, California
Cape Canaveral Spaceport, Florida
Cecil Field Spaceport, Florida
Kodiak Launch Complex, Alaska
Mid-Atlantic Regional Spaceport, Virginia
Mojave Air and Space Port, California
Oklahoma Spaceport, Oklahoma
Spaceport America, New Mexico
Cape Canaveral Air Force Station, Florida
Ronald Reagan Ballistic Missile Defense Test Site, Kwajalein Atoll
Vandenberg Air Force Base, California
Wallops Flight Facility, Virginia

What are the other factors that need to be considered while determining spaceport location? How can the problem of optimal spaceport location be formalized mathematically for any number (N) of spaceports? What are the objective functions and constraints (e.g., geographic proximity of spaceports to airports and each other) that should apply to the optimization? In terms of the selected criteria, how do the current spaceport locations compare to the "optimal" locations for the same number of spaceports? Can the spaceport location optimization problem be extended to address multiple stakeholders involved with or affected by space operations, each of whom may have costs and benefits (e.g., a more realistic case involving multiple operators)? What approaches could be used to ensure fairness among the stakeholders?

[1] FAA, 2011 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies and Spaceports, 2011

MITRE-SFI Challenge Problems

1. Sentinel Power Grid Analytics

(POCs: Creighton Hager, chager@mitre.org ; David Slater, dslater@mitre.org)

Can we detect small deviations in sets of geo-located high fidelity data streams that potentially indicate a larger disturbance is coming?

A transient is defined as a fast, short duration burst of energy in a system. The Sentinel capability monitors the AC voltage of the North American Electrical Interconnects at a rate of 50,000 samples per second. With a bandwidth of 14 kHz we are able to observe transients that have durations of less than 100 µs. Analyzing transients and electric grid metadata, such as phase or frequency, may provide the ability to potentially identify predictors/precursors for electric grid disturbances both locally and regionally.

We present two examples of transients below: (1) transients isolated from the raw full voltage waveform and (2) transients isolated from the voltage metadata. In the first case, the data set comprises one hour of raw full voltage data and associated timing metadata of a power disturbance in McLean, VA. Can you find exactly when the local power disturbance occurred? Can you find the transients or other precursors that indicate the approach of a disturbance? In the second case, the data set is a day of metadata (extracted frequency values) collected from four cities in the Eastern Interconnect during the Boston snowstorm. Can you find transients or precursors locally and regionally? Can you find any relationships spatially, temporally, or otherwise within the data set?

Data available from SFI and MITRE

Full voltage waveform of the 2014-03-26 17-00-00 UTC hour at McLean; data recorded at 50,000 samples per second with timing metadata.

Frequency metadata of the 2013-02-09 UTC day at Bedford, McLean, St. Louis, and Tampa; data extracted at 1 sample per second.

Frequency metadata for the months of May, June, and July 2013 from the following locations: Bedford, McLean, St. Louis, and Tampa.

2. Network Geo-Location (Polish Power Grid)

(POCs: David Slater, dslater@mitre.org; Garry Jacyna gjacyna@mitre.org)

Many networks exist both in network space (nodes and edges) and physical space. Given general location information and network details, can we determine where in physical space the nodes and edges exist?

As part of the Matpower MATLAB package[1], several snapshots of the network connectivity for the Polish power grid between 1999 and 2007 are publically available. This network consists of generators and substations (nodes) and power lines (edges). Although connectivity information is available, the physical locations are not. Given this information as well as any other information publically available, can you infer the physical location of the nodes of this network? Can you characterize how the network changes over time?

Data

Matpower can be obtained here: http://www.pserc.cornell.edu/matpower/
The Polish grid can be found in the files: case2383wp.m, case2736sp.m, case2737sop.m, case 2746wop.m, csae2746wp.m, case3012wp.m, case3120sp.m, and case3375wp.m

3. Predicting Cascade Size

(POCs: Matt Koehler, mkoehler@mitre.org; David Slater, dslater@mitre.org)

Can we use simulation and history to predict the size of cascading events in the future?

The dynamics of Self-Organized Critical (SOC) Systems are, by their very nature, very difficult to predict. The overall distribution of event sizes appears stationary but predicting the size of any given event is very difficult. For example, the canonical Bak Sandpile model shows a power law distribution for the sizes of sand avalanches. Although that distribution is stable, predicting the size of a given avalanche is very difficult (impossible?). Some have said that our critical infrastructure and financial markets are SOC systems. Others have claimed that they can predict the dynamics of these systems, especially financial markets. Does this make sense?

[1] http://www.pserc.cornell.edu/matpower/

Can you take the Bak sandpile model and make any statements about future avalanche sizes based upon history? This prediction need not be specific, but could take the form of probabilities of larger or smaller avalanches occurring. Look broadly at the dynamics; for example, Sornette has found it useful to look at "draw-ups" and "draw-downs" or consecutive movements in the same direction (avalanches of increasing or decreasing size).

Does this boil down to a sampling problem? If you had a time series of avalanches *and* some sense of the current state of the Bak sandpile could you do a better job of predicting the size of the next avalanche? If so, how accurate does your knowledge of the system need to be, does it need to include some information about where the next sand grain was likely to fall?

Data

A NetLogo and C++ implementations of the Bak sandpile model are available

Financial market data can be found here: http://finance.yahoo.com/market-overview/

4. The "Viscosity" of Labor (POC: Matt Koehler, mkoehler@mitre.org)

Given US Census collected data can we find relationships between labor and urban scale?

Using US Census data (and other sources) a number of interesting scaling laws have been discovered that relate to the dynamics of urban human social systems. These scaling law relate to such things as the generation of intellectual property, income, tax revenue, crime, and so on. What about labor? Does the scaling seen in income come from new or shifting categories of labor or simply increasing the income within an existing (static?) distribution of labor categories? Is there a spatial component? Does the spatial distribution change with the scale of the urban area?

Data

Data on labor types for the US can be found at the US Census: http://www.census.gov/data.html

5. DOTA 2 (POC: David Slater, dslater@mitre.org)

Given high resolution data from a set of games, can we determine when a team changes strategies within a single game or between games?

DOTA 2 is a 5 v 5 battle game. Recently, high resolution data from many (tens of thousands) of games has been made available. The data includes movement, activities, camera views, and other key stroke-level actions. Can data from game play be used to determine coherent strategies and when these strategies change? How do you define strategy in this context? How do you define a change of strategy? How big does the change need to be to be detectable?

This large dataset can be obtained directly from SFI or MITRE.