Control of Complex Systems Initiative

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Control of Complex Systems:
An Integrated Perspective on Modern Power Grid Control

Submodular Optimization for Discovery of Key Entities in Complex Systems

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U.S. DEPARTMENT OF ENERGY

Outline

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- Project Objectives
- Background: Submodular optimization
- Spatial system: Sensor placement
  - Scalable algorithms for sensor placement in large spatial domains
- Networked system: Influence Maximization
  - Influence Maximization with Intrinsic Nodal Activation
- Looking forward

Objectives and Motivation

- Development of scalable submodular optimization approaches to address observability and controllability in large complex systems via discovery of key entities

Motivation scenarios:

- Placement of sensors across a given large geographical area
- Placement of PMUs in a power network for maximizing observability
- Joint observability-controllability optimization to localize the spread of power outage via defensive islanding
- Observing nodes on social media to monitor opinions on a topic and identifying influential nodes to incentivize towards adoption of a specific behavior.

Submodular Functions

Consider a set of entities *V*. Let $S \subseteq V$. Let $f : 2^V \rightarrow \mathcal{R}$, be a mapping that associates every such *S* with a real number. f is submodular provided it satisfies the following.

For every $S \subseteq T \subseteq V$ and any $v \in V$, $v \notin T$ we have

$$\boldsymbol{f(S \cup \{v\}) - f(S) \geq f(T \cup \{v\}) - f(T)}$$

A function $f : 2^V \rightarrow \mathcal{R}$ is monotone provided, for any $S \subseteq T$, $f(S) \leq f(T)$

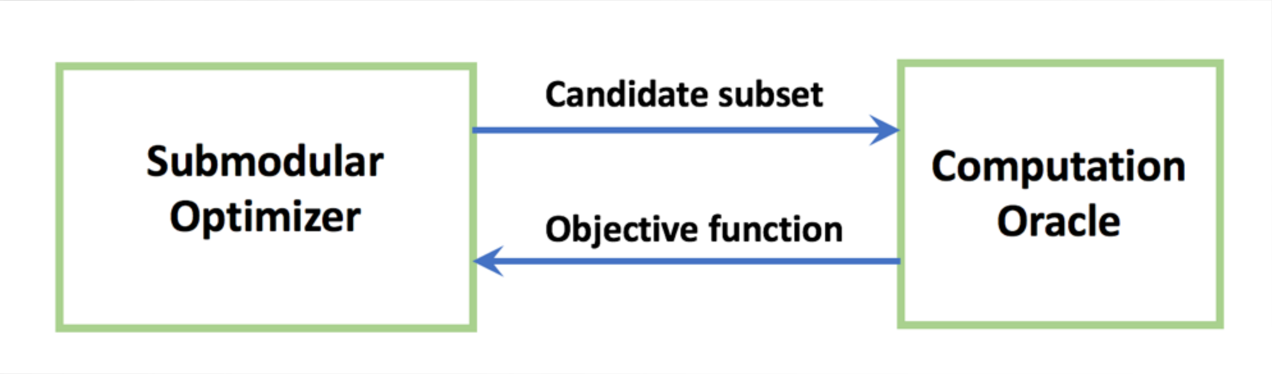
We want to select the optimal subset called the seed set S such that $f(S)$ is maximized under a constraint on the cardinality of the seed set *S i.e* $|S| \leq k$.

For this problem the simple Greedy algorithm works very well

Let S^* denote the optimal solution to the problem. If *f* is monotone submodular and $f(\phi) = 0$, then due to a powerful result derived by Nemhauser et al.

$$\boldsymbol{f(S) \geq \left(1 - \frac{1}{e}\right) f(S^*)}$$

Scalability: Two Pieces to Address



Scale the greedy algorithm. Ordinary Greedy Algorithm : O(kn) oracle calls

Scale the computation oracle.
Oracle Complexity : Varies between applications.
Example : Sensor Placement :O(n^3)

General Sensor Placement

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- Assume that the quantity to be sensed can be modeled as a Gaussian Process with a given covariance function
- Given a set of ‘N’ possible sites distributed either spatially or over a network and given that the *NxN* co-variance matrix can be computed
- Given a budget of ‘k’ sensors, find the sites where the sensors need to be placed in order to maximize the observability
- Metric for the optimization: The metric that we consider is the mutual information between the sensed and the un-sensed locations
- Given a set of locations where sensors are placed, the marginal gain in MI by adding a new element y to the set A is given by

$$\frac{\sigma_y^2 - \Sigma_{y\mathcal{A}}\Sigma_{\mathcal{A}\mathcal{A}}^{-1}\Sigma_{\mathcal{A}y}}{\sigma_y^2 - \Sigma_{y\bar{\mathcal{A}}}\Sigma_{\bar{\mathcal{A}}\bar{\mathcal{A}}}^{-1}\Sigma_{\bar{\mathcal{A}}y}}$$

Initial Results

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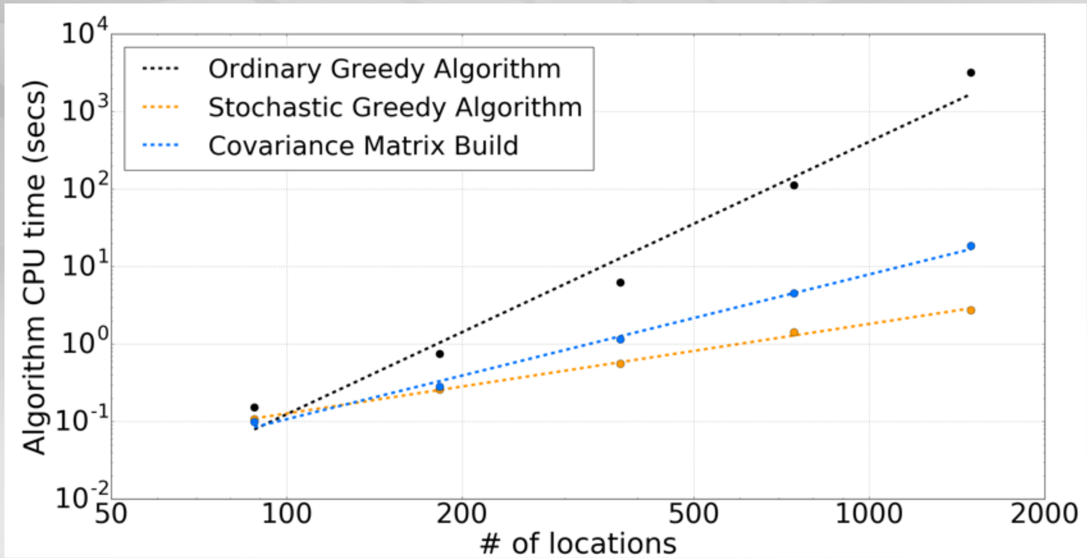
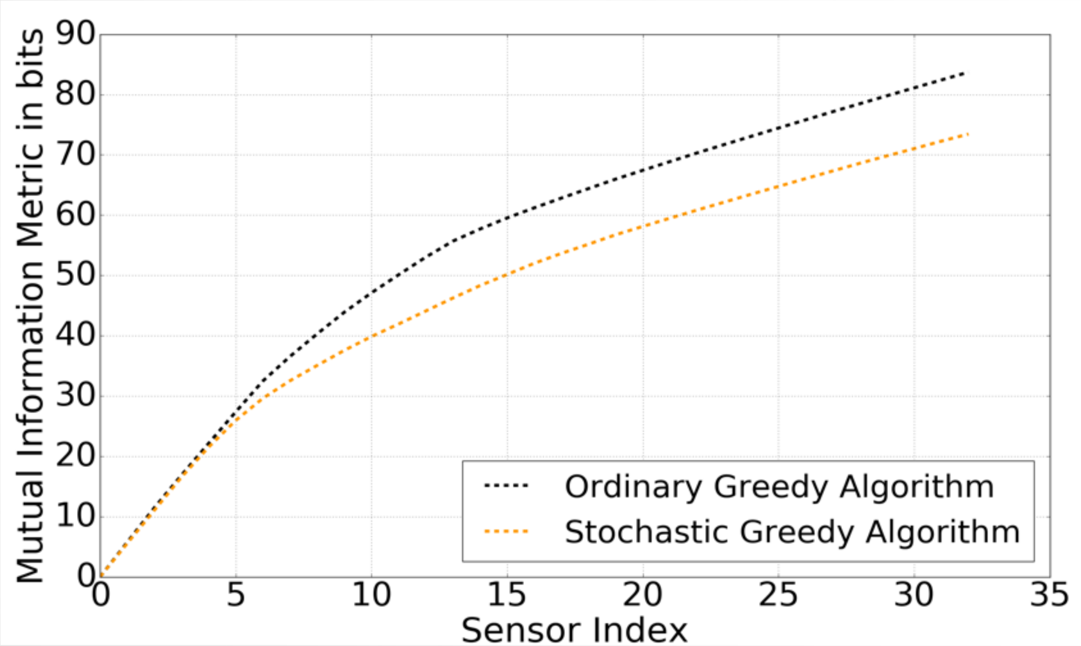


Scaling

Ordinary Greedy: 3.6
Stochastic Greedy: 1.2
Covariance Build: 2.0



Quality

Network Scenario:
Influence Maximization Problem

- A large class of natural and man-made systems with rich dynamics can be studied through the abstraction of graphs.

- Signals arrive at each node along the incoming edges, undergo (non-linear) processing at the node and the processed signal is transmitted along the out-going edges.

- Given the models for node behavior and edge interactions and the objectives we are interested in, how can we find those influential nodes which have maximal impact on the system ?

- Applications in diverse fields
  - Viral marketing for product adoption
  - Spread of content on social media
  - Spread of diseases in contact-networks
  - Keystone species in microbial communities
  - Controllability and Observability in complex systems

Our Contribution: Inclusion of Intrinsic Activation

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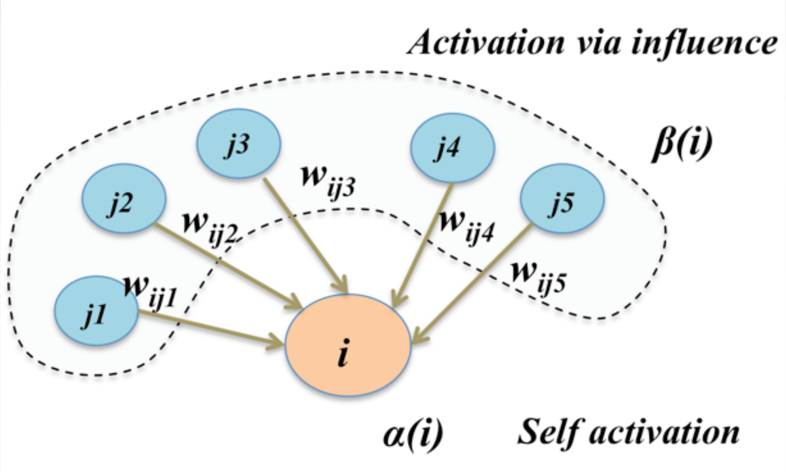
Activation at each node is split into two mechanisms to allow correspondences to real-world situations

Intrinsic activation: Activation at each node attributable to its own intrinsic mechanisms

Influenced activation: Activation originating at each node attributable to influence of the neighboring nodes

Parameterize by the tendency towards intrinsic activation denoted by α and that towards influenced activation by β

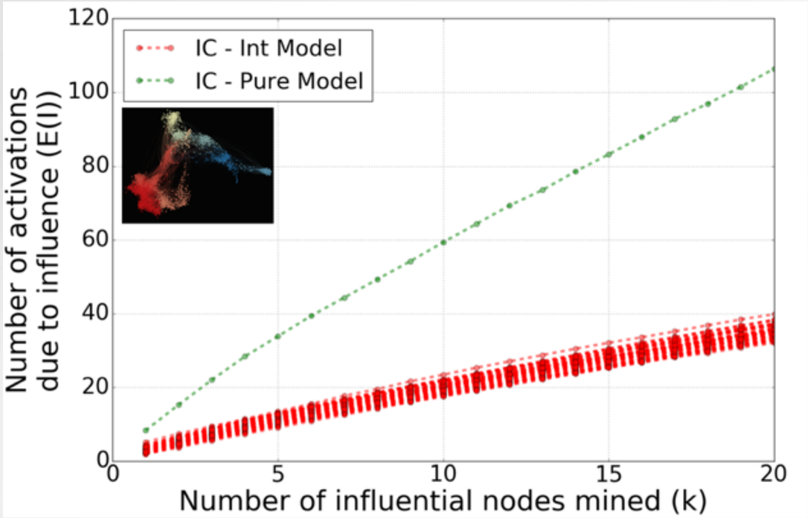


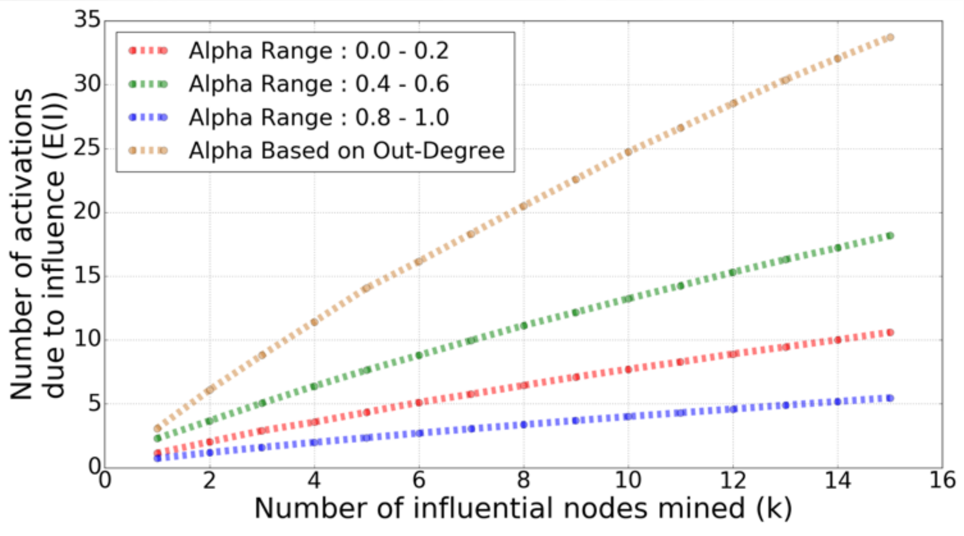
Arun V. Sathanur and Mahantesh Halappanavar, "Influence Maximization on Complex Networks with Intrinsic Nodal Activation," Social Informatics, Bellevue, WA, Nov 2016

Experiments on the Twitter network

Independent Cascade model over-estimates the number of activations

Ran the algorithm with three different alpha ranges and finally the scenario where the alpha values were set to be proportional to the node out-degree. The last one maximizes engagement.





Looking forward

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- Distributed submodular optimization algorithms for even larger problems
- Online submodular optimization for real-time applications
- Working with domain experts to apply the algorithms to power grid applications at scale :
  - PMU placement
  - Controlled Islanding
  - Synchronization
- Scalable algorithms for influence maximization

Thank You

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