Modeling Civil Conflict and Aid Delivery in Uganda

Peter J. Bull
Institute for Applied Computational Science
Harvard University
52 Oxford Street
Cambridge, MA 02139
bull@fas.harvard.edu

Isaac M. Slavitt
Institute for Applied Computational Science
Harvard University
52 Oxford Street
Cambridge, MA 02139
slavitt@fas.harvard.edu

Abstract

Using MCMC techniques, we model civil conflict in Uganda and optimize the limited relief aid that can be provided in these scenarios. We describe a method to simulate civil conflict events in space and time given historical data about these events. We also optimize the distribution of limited aid resources to refugees from these crises. Modeling aid delivery as a combination of the traveling salesman problem and the knapsack algorithm — two NP-hard problems — we find acceptable solutions using stochaastic metaheuristics.

1 The Data

The data comes from ACLED (Armed Conflict Location and Event Data Project), which is a dataset with locations, dates, fatalities, motivation, actors involved, and other information about civil conflicts in Africa. Their collection of data on Uganda covers 1997-2013, and they have a real-time tracker of events reported in 2014.[1] The need for an understanding of these patterns of conflict is clear, as ACLED notes:

> This dataset codes the dates and locations of all reported political violence events in over 50 developing countries. Political violence includes events that occur within civil wars or periods of instability. Although civil war occurrence is decreasing across African countries, new forms of political violence are becoming more common.

For Uganda, the dataset contains around 4,500 observations of civil violence. Each observation includes the data, location, an quantified estimate for how precise these measures are, a number of fatalities for the event, and the actors involved.

2 Modeling Civil Conflict Events

We will use a bayesian monte-carlo model to simulate drawing samples (civil conflict events) from their underlying distribution. After creating a grid for the country, we will assume that for a given square i, j a civil conflict event:

$$Y_{i,j} \sim \text{Poi}(\mu_{i,j}) \tag{1}$$

We can then place a prior on our rate $\mu_{i,j}$ given our knowledge about other conflicts and other regions (so as to not use the data we are training and testing on to create our prior). In a poisson model, the rate parameter is equal to the mean $\lambda_{i,j} = \mu_{i,j}$. This rate parameter is connected to a linear combination of the predictors $\mathbf{X}$ as follows where β is a set of weighting coefficients:

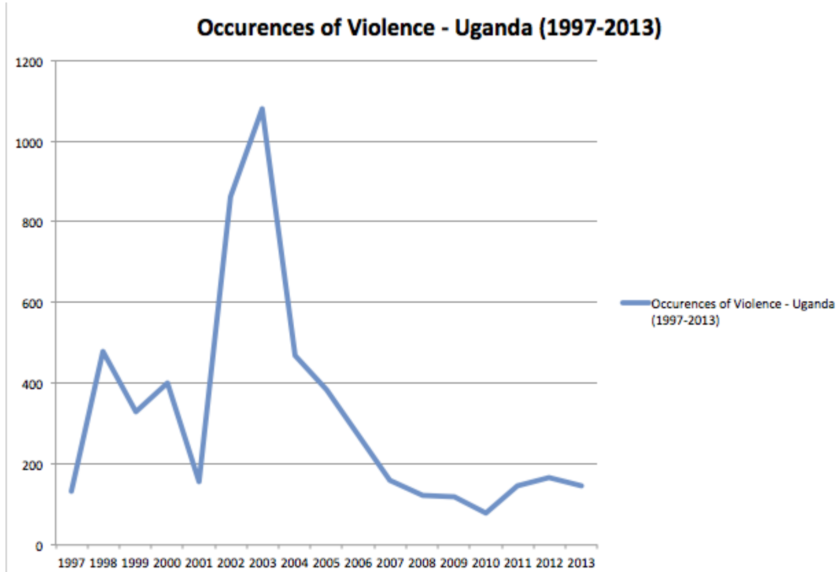

Figure 1: Civil conflict per year in Uganda 1997-2013. [2]

$$\lambda_{i,j} = \exp(x_{i,j}\beta) \tag{2}$$

This becomes bayesian when we start to consider a prior distribution over these coefficients, β. In practice, the prior is given by the multivariate normal [3]:

$$\beta \sim \mathcal{N}(b_0, B_0^{-1}) \tag{3}$$

where b_0 is the vector of means of the explanatory variables and B_0 is the precision matrix for the explanatory variables.

We can then sample potential future conflicts to get an idea of how these conflicts occur within a region. We will then use the samples from this distribution to generate test cases for the optimization problem that we are concerned with.

3 Optimizing Resource Placement and Allocation

Traveling Salesman Problem

Problem statement

One question of particular interest that we can tackle using techniques from the class is how to route emergency aid to locations where it is needed. It is all well and good to use our *predictive* methods to anticipate where conflicts may occur, but decision makers in a real world scenario would also desire *prescriptive* tools to help carry out their mission. For concreteness, let's postulate a Red Cross medical or food supply caravan that originates from the organization's in-country headquarters. This caravan wishes to visit all n emergent locations in order to deliver needed supplies. They wish to do so in the most efficient manner possible.

Mathematical specification

This is fundamentally an optimization problem, and one that is well known. Here is the traditional convex optimization specification of the problem:

$$
\begin{aligned}
&\min \sum_{i=0}^{n} \sum_{j \neq i, j=0}^{n} c_{ij} x_{ij} \\
&\text{s.t.} \\
&\quad x_{ij} \in \{0,1\} && i,j = 0, \cdots, n \\
&\quad \sum_{i=0, i \neq j}^{n} x_{ij} = 1 && j = 0, \cdots, n \\
&\quad \sum_{j=0, j \neq i}^{n} x_{ij} = 1 && i = 0, \cdots, n \\
&\quad u_i - u_j + n x_{ij} \leq n - 1 && 1 \leq i \neq j \leq n
\end{aligned}
$$

This should be immediately recognizable as the traveling salesman problem (TSP), an integer linear program (ILP) where:

- x_{ij} is a binary decision variable indicating whether we go from location i to location j.
- c_{ij} is the distance between location i and location j.
- The objective function is the sum of the distances for routes that we decide to take.
- The constraints ensure that all locations are visited once and only once.

The problem, of course, is that brute force solution of the TSP is $\mathcal{O}(n!)$. Traditional, deterministic algorithm approaches such as branch-and-bound or branch-and-cut are still impractical for larger numbers of nodes. In many cases, exhaustive search for global optimality is not even particularly helpful as long as the solution found is good enough. We will use simulated annealing (SA) to get acceptable solutions to the TSP (c.f. the class lectures and homework problem).

Proposed approach (*The Prestige*)

Hold on to your butts, that's not all. Because we did something similar in class, we will complicate this problem a bit. Consider a mash-up of two NP-hard problems: the traveling salesman problem and the knapsack problem. "What? You guys are crazy." Maybe, but we're doing it live.

We will make the problem double-plus-NP-hard by making this a multi-objective optimization problem where *the contents of the aid trucks* also have an optimization component. Therein lies the knapsack problem: subject to a volume or weight constraint, and given that different locations might have very different needs such as food, vaccinations, or emergent medical supplies, *which supplies do we pack on the trucks*? This may be a toy problem, but if so it is an inherently unsafe toy like a BB gun — you could put your eye out.

Here's the unbounded[1] version of the knapsack problem:

$$
\begin{aligned}
&\max \sum_{i=1}^{n} v_i x_i \\
&\text{s.t.} \\
&\quad x_i \in \mathbb{Z} \\
&\quad x_i \geq 0 \\
&\quad \sum_{i=1}^{n} w_i x_i \leq W
\end{aligned}
$$

In this formulation:

[1]Often, this problem is formulated such that you can only bring one of each item, but that doesn't make sense here. We want to be able to bring as many types of each type of aid as we think necessary, and we'll assume that as many as desired are available to load on the trucks before starting out from HQ.

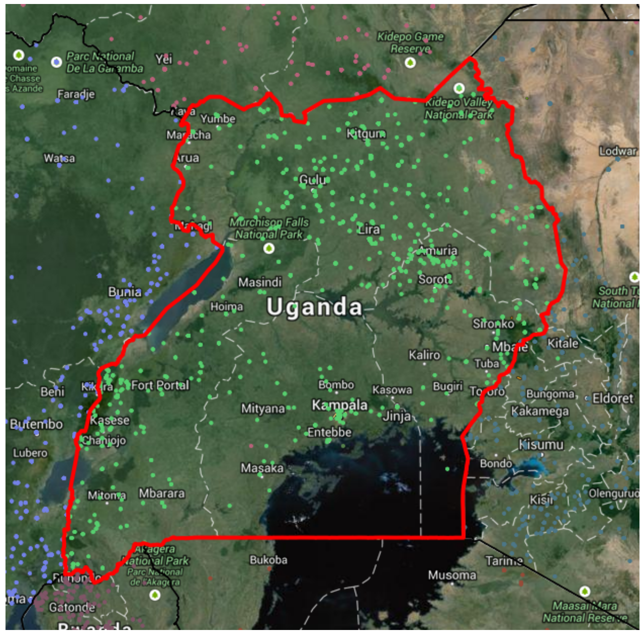

Figure 2: Civil conflicts in Uganda 1997-2013.

- x_i is a zero or positive integer decision variable indicating how many units of item i we load on the truck.
- v_i is the utility we get from bringing along item i.
- w_i is the weight of item i.
- W is the maximum weight the truck can carry.

References

[1] C. Raleigh, A. Linke, H. Hegre, and J. Karlsen, "Introducing ACLED-armed conflict location and event data," *Journal of Peace Research*, vol. 47, no. 5, pp. 1–10, 2010.