# Machine Learning for Drug Overdose Surveillance

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A portion of this work was performed at NYU's **Center for Urban Science and Progress**. We gratefully acknowledge funding support from **NSF** (IIS-0953330, GRFP DGE-1252522) and the **NCSU Laboratory for Analytical Sciences**. Thanks to **Eric Hulsey** (Allegheny County DHS) for feedback on discovered clusters.

# Drug overdoses

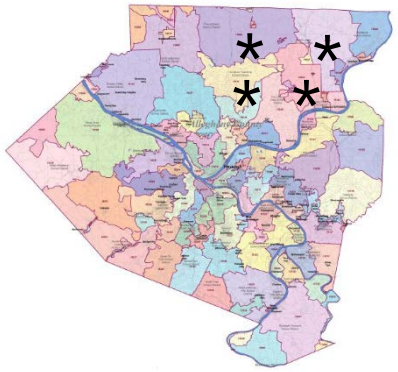
- Drug overdoses are an increasingly serious problem in the United States and worldwide.
  - The CDC estimates that 47,055 drug overdose deaths occurred in the United States in 2014, 61% of which involved opioids.
- These statistics motivate public health to identify emerging trends in overdoses, including geographic, demographic, and behavioral patterns (which combinations of drugs are involved).

# Drug overdoses

- Machine learning has potential to **save lives** by:
  - **Integrating** multiple data sources across space, time, and subpopulations
  - **Detecting** subtle, emerging patterns of overdoses in the early stages
  - **Targeting** an effective public health response (treatment, education, naloxone distribution, etc.)
  - **Informing** prevention by quantifying effects of legislative and policy changes
- Here we present two new machine learning methods for early detection and accurate characterization of overdose trends.
  - Challenging problems in public policy can inspire new, general ML methods!

# Case study 1: overdoses in Allegheny County

- Collaboration with Allegheny County, PA, Department of Human Services, including retrospective analysis (2008-2015) and plans for a prospective surveillance tool.
- ~2000 cases: for each overdose victim, we have date, zip code, age, gender, race, and which drugs present (~30 dimensions plus space and time)
- We developed a novel pattern detection method, **multidimensional tensor scan**, to detect emerging geographic, demographic, and behavioral patterns.
  - **Earlier detection** of emerging overdose clusters - daily surveillance.
  - Better characterization of **where** and **who** is affected.



X

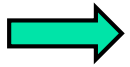
white males aged 20-49

X

# Multidimensional Tensor Scan

- In a nutshell: we identify **subspaces** of the attribute space (a subset of values for each attribute) with higher than expected numbers of recent case counts.
  - Spatial area (subset of locations) and time window
  - Affected genders, races, age ranges, and which drugs involved.
- We use a novel tensor decomposition approach to estimate how many counts we expect for each combination of attributes, while maintaining computational efficiency.
- Iterative conditional optimization: we optimize over all subsets of values for each attribute conditional on the current subsets of values for all other attributes.
- Each conditional optimization step can be performed efficiently (without exhaustive search over subsets) using the linear-time subset scanning (LTSS) property.

Exhaustive search:
$O(2^N)$ subsets
= millions of years!



Fast subset scan:
O(N) subsets
= milliseconds!

# MDTS Overdose Results (1)


**Fentanyl** is a dangerous drug which has been a huge problem in western PA.

It is often mixed with white powder heroin, or sold disguised as heroin.

January 16-25, 2014:
14 deaths county-wide from fentanyl-laced heroin.

March 27 to April 21, 2015:
26 deaths county-wide from fentanyl, heroin only present in 11.

January 10 to February 7, 2015:

Cluster of 11 fentanyl-related deaths, mainly black males over 58 years of age, centered in Pittsburgh's downtown Hill District.

Very unusual demographic: common dealer / shooting gallery?

Started in the SE suburbs of Pittsburgh, including a cluster of five geographically and demographically similar cases between March 27 and April 8. Our method could have detected this pattern as early as March 29th.

Fentanyl, heroin, and combined deaths remained high through end of June (>100).

# MDTS Overdose Results (2)

Another set of discovered overdose clusters involved a combination of Methadone and Xanax.

Methadone: an opioid used for chronic pain relief and to treat heroin addiction, but also addictive and risk of OD.


Xanax (alprazolam): a benzodiazepine prescribed for panic and anxiety disorders.

The combination produces a strong high but can be deadly (~30% of methadone fatal ODs).

From 2008-2012: multiple M&X OD clusters, 3-7 cases each, localized in space and time.

From 2013-2015: no M&X overdose clusters; 33% and 47% drops in yearly methadone and M&X deaths respectively.

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Increased state oversight of methadone clinics and prescribing physicians after passage of the Methadone Death and Incident Review Act (Oct 2012).

Approval of generic suboxone (buprenorphine + naloxone) in early 2013 lowered cost of suboxone treatment as an alternative to methadone clinics.

Why did these deaths cluster, when methadone and methadone + other benzo deaths did not?

What factors could explain the dramatic reduction in M&X overdose clusters?

# Case study 2: overdoses in New York

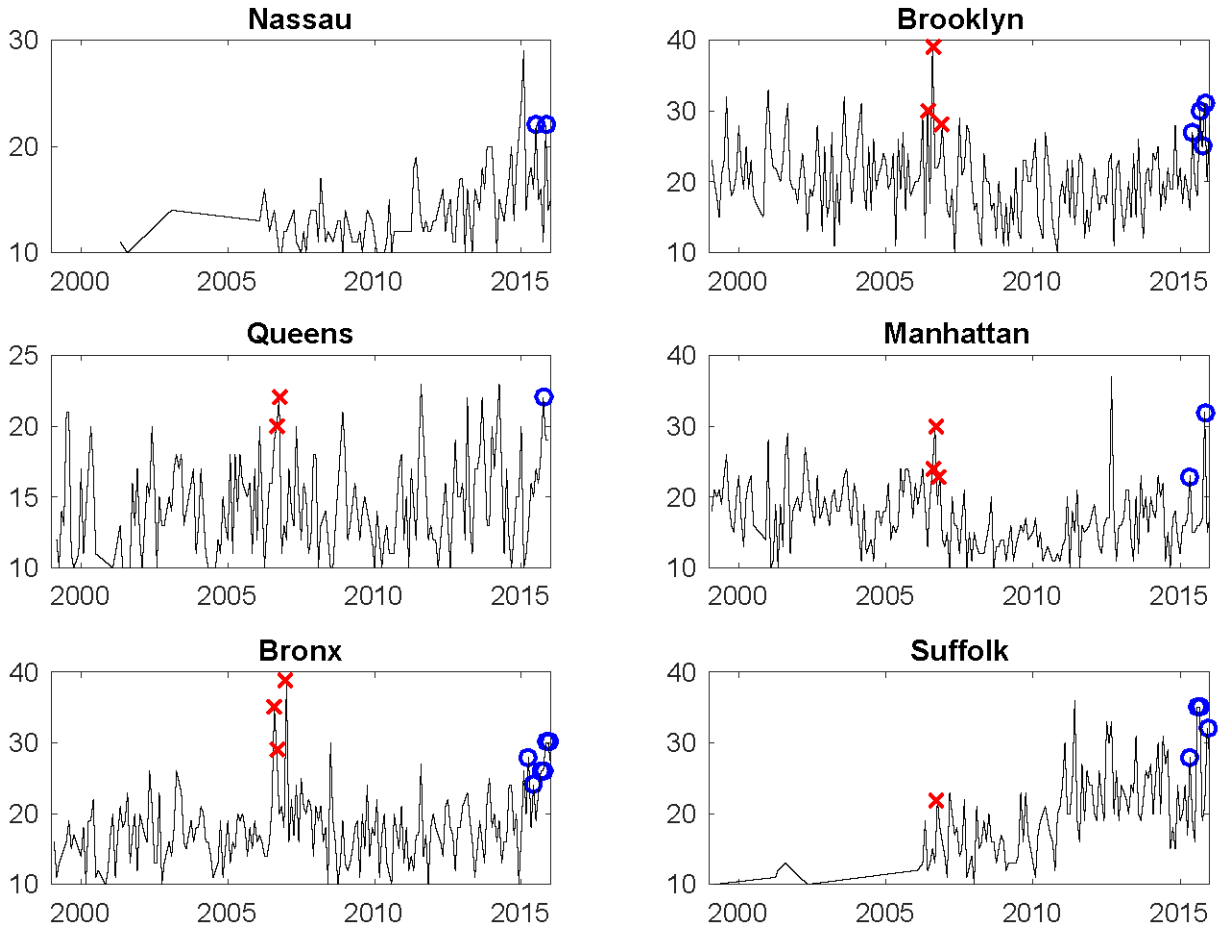
- For this case study we did not have victim-level data, but **aggregate monthly counts** of fatal opioid overdoses for six New York counties from 1999-2015.
- Main goals: to estimate “typical” overdose trends, and identify anomalous spikes in overdose deaths.
- Challenge for accurate estimation: data points are **correlated** in space and time.
- We developed a new approach which combines **Gaussian processes** (to model correlations) and **subset scan** (to identify the most anomalous space-time regions).

# Case study 2: overdoses in New York

- We compared our new **Gaussian Process Subset Scan** method to typical anomaly detection approaches on real and synthetic datasets.
  1) GP+SS > individual anomaly detection (SVM, GP)
     → Nearby points matter for subtle anomalies
  2) GP+SS > SS alone
     → Covariance structure matters for correlated data
  3) Flexible detection matters for complex patterns (e.g., irregularly-shaped regions)

# Opioid overdose deaths in New York

- Two statistically significant anomalies.




✖ Mid 2006. Just before naloxone programs.

⭘ End of 2015. Recent surge due to fentanyl.

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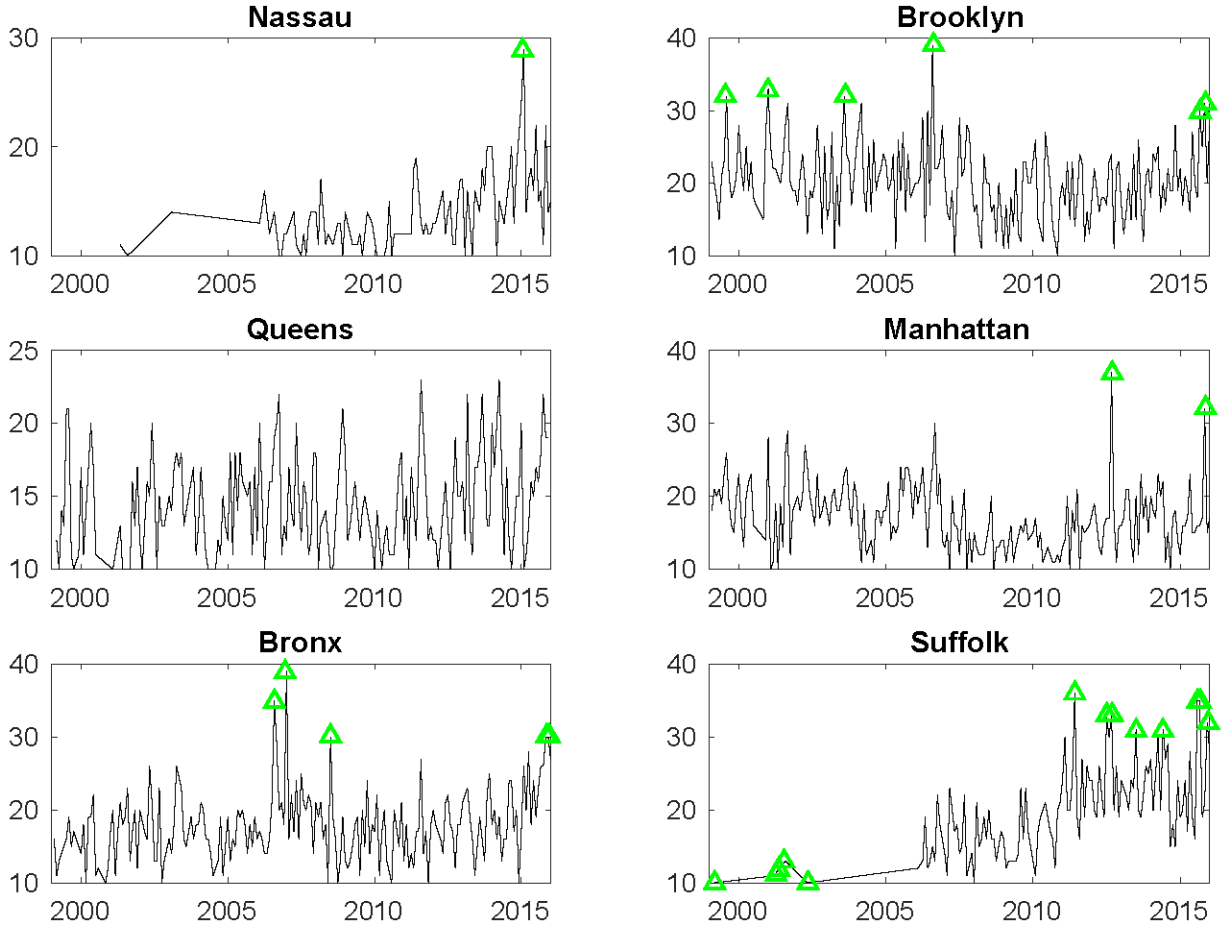


Standard anomaly detection methods (one-class SVM, GP model-based anomaly detection) fail to capture the significant trends.

# Conclusions

Our retrospective analysis of overdose data from PA and NY suggests high potential utility for a **prospective** drug overdose surveillance system, to facilitate targeted and effective interventions.

Our approach can be applied to many other tasks, such as surveillance of sexually transmitted illness, where patterns of interest may have demographic, geographic, and behavioral components.

Thanks for listening!

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