10:00–10:20  Me: *High-Performance Analysis of Streaming Graphs*


10:50–11:10  Anand Iyer and Ion Stoica, *Time-Evolving Graph Processing on Commodity Clusters*

11:15–11:35  Srikanta Tirthapura, *et al., Parallel and Streaming Methods for Real-Time Analysis of Dense Structures from Graphs*

Continued in MS226 this afternoon, 2:15pm–3:50pm.
Continuation of MS200:

2:15–2:35  Elisabetta Bergamini and Henning Meyerhenke, *On Betweenness Centrality Problems in Dynamic Graphs*

2:40–3:00  Sriram Srinivasan and Sanjukta Bhowmick, *Predicting Movement of Vertices Across Communities in Dynamic Networks*

3:05–3:25  Keita Iwabuchi, *et al.*, *Large-Scale Dynamic Graph Processing on HPC Systems*

3:30–3:50  Anita Zakrzewska, *Creating Dynamic Graphs from Temporal Data*

Some slides to be posted at [http://graphanalysis.org](http://graphanalysis.org).
High-Performance Analysis of Streaming Graphs

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School of Computational Science and Engineering
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SIAM CSE, 2 March 2017
Outline

Motivation and Applications

Current and Future STINGER Models

Extracting Interesting Subgraphs

GPUs for Streaming Graphs?

Closing
Motivation and Applications
Cyber-security  Identify anomalies, malicious actors
Health care    Finding outbreaks, population epidemiology
Social networks Advertising, searching, grouping
Intelligence   Decisions at scale, regulating markets, smart & sustainable cities
Systems biology Understanding interactions, drug design
Power grid     Disruptions, conservation
Simulation     Discrete events, cracking meshes

Changes are important. Cannot stop the world...
Why Graphs?

Another tool, like dense and sparse linear algebra.

- Combine *things* with *pairwise relationships*
- Smaller, more generic than raw data.
- Taught (roughly) to all CS students...
- Semantic attributions can capture essential *relationships*.
- Traversals can be faster than filtering DB joins.
- Provide clear phrasing for queries about *relationships*.
Potential Applications

• Social Networks
  • Identify *communities*, influences, bridges, trends, anomalies (trends *before* they happen)...
  • Potential to help social sciences, city planning, and others with large-scale data.

• Cybersecurity
  • Determine if new connections can access a device or represent new threat in < 5ms...
  • Is the transfer by a virus / persistent threat?

• Bioinformatics, health
  • Construct gene sequences, analyze protein interactions, map brain interactions
  • Credit fraud forensics ⇒ detection ⇒ monitoring
  • Real-time integration of all the customer’s data
Streaming graph data

Network data rates:

- Gigabit ethernet: 81k – 1.5M packets per second
- Over 130,000 flows per second on 10 GigE (< 7.7 μs)

Person-level data rates:

- 500M posts per day on Twitter (6k / sec)\(^1\)
- 3M posts per minute on Facebook (50k / sec)\(^2\)

But often analyze only changes and not entire graph.

Throughput & latency trade off and expose different levels of concurrency.

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\(^1\) [www.internetlivestats.com/twitter-statistics/](http://www.internetlivestats.com/twitter-statistics/)
Streaming graph analysis

Terminology, will go into more details:

- **Streaming** changes into a massive, evolving graph
- Will compare models later...
- Need to handle *deletions* as well as insertions

Previous STINGER performance results (x86-64):

**Data ingest**  >2M upd/sec [Ediger, McColl, Poovey, Campbell, & Bader 2014]

**Clustering coefficients**  >100K upd/sec [R, Meyerhenke, B, E, & Mattson 2012]

**Connected comp.**  >1M upd/sec [McColl, Green, & B 2013]

**Community clustering**  >100K upd/sec* [R & B 2013]

**PageRank**  Up to 40× latency improvement [R 2016]
Current and Future STINGER Models
STINGER: Framework for streaming graphs

- OpenMP + sufficiently POSIX-ish
- Multiple processes for resilience
Current STINGER model

**Pre-process batch:**
Sort by source vertex, reconcile ins/del.

**Pre-change hook**

**Alter graph (may “age off” old edges)**

**Post-change hook**

**Batch of insertions / deletions**

**Affected vertices**

**Change in metric**
Is STINGER’s current model good enough?

Data ingest rates, R-MAT into R-MAT, scales 24 & 30

Want to add analysis clients **without slowing data ingest!**

Note that scale 30 starts with 1.1B vertices, 17B edges...

(Different STINGER internal parameters.)

Streaming Graphs — SIAM CSE MS200, 2 Mar 2017
What if we don’t hold up changes?

**Additional STINGER model**

Analyze concurrently with the graph changes, and produce a result correct for the starting graph and some subset of concurrent changes.³

**Sample of other models**

- Evolving: Sample, accurate w/high-prob.
- Classical: dynamic algorithms, versioned data

³Chunxing Yin, Riedy, Bader. “Validity of Graph Algorithms on Streaming Data.” January 2017. (in submission)
Algorithm validity in our model: Example.

Can you compute degrees in an undirected graph (no self loops) concurrently with changes?

Algorithm: Iterate over vertices, count the number of neighbors.

1. Compute $\text{deg}(v_1)$
2. Compute $\text{deg}(v_2)$

Cannot correspond to an undirected graph plus any subset of concurrent changes.

Valid for our model? No!

Not incorrect, just not valid for our model.
Algorithm validity in our model

• What is valid?
  • Typical BFS and follow-ons (betweenness centrality)
  • Shiloach-Vishkin connected components
  • PageRank? (hm.)
  • Saved decisions...

• What is invalid?
  • Making a decision twice in implementations.
    • $\Delta$-stepping SSSP: Decrease a weight below $\Delta$
    • Degree optimization: Cross threshold, miss vertex
  • Applying old information.
    • Labeling in S. Kahan’s components alg.
Fun properties

Due to Chunxing Yin, under sensible assumptions:

- You can produce a single-change stream to demonstrate invalidity.
- Algorithms that produce a subgraph of their input cannot be guaranteed to run concurrently with changes and always produce snapshot outputs.

In progress:

- Validity for streaming! Apply an algorithm valid for our model. Also collect the changes during execution. Now update the result for those changes while more changes accumulate. Repeat.
- Algorithms like PageRank... Actually nearby to graph + subset?
- Verification for debugging, etc.
Extracting Interesting Subgraphs
Graphs: Big, nasty hairballs

Yifan Hu’s (AT&T) visualization of the in-2004 data set
http://www2.research.att.com/~yifanhu/gallery.html
But no shortage of structure...

- Locally, there are clusters or communities.
- There are methods for global community detection.
- Also need local communities around seeds for queries and targeted analysis.
Seed set expansion

- Seed set expansion finds the “best” subgraph or communities for a set of vertices of interest
  - Many quality criteria: Modularity, conductance-ish, etc.
- Want to produce smaller expansions for viz. as well as larger communities for deeper analysis.
- Dynamic agglomerative / modularity algorithms update larger communities faster than recomputation [Zakrzewska & Bader]
Both PageRank and Katz centrality recover blocks in artificial stochastic block model graphs.

Working on *updating* the expanded sets using incremental iterations:

Updating PageRank [R]:

\[
\Delta x^{(k+1)} = \alpha A^T \Delta D^{-1} \Delta x^{(k)} + \\
\alpha (A^T D^{-1} - A^T D^{-1}) x + r|_{\Delta x^{(k+1)}}
\]

Updating Katz:

\[
\Delta x^{(k+1)} = \\
\alpha A \Delta x^{(k)} + (r - \alpha \Delta Ax)|_{\Delta x^{(k+1)}}
\]
Streaming seed set expansion

- Work in progress!
- Which seed set expansion methods provide subgraphs useful for further analysis? How do the results compare to global analysis?
- We do not want to maintain the entire $|V|$ PR or Katz vector, only around $|S|$ where $S$ is the output.
- Can we continue applying earlier stopping criteria\(^4\) for top-$K$ separation?

\(^4\)Eisha Nathan, Geoffrey Sanders, James Fairbanks, Van Emden Henson, David A. Bader. “Graph Ranking Guarantees for Numerical Approximations to Katz Centrality,” Jan 2017. (in submission, Wed. CSE poster)
GPUs for Streaming Graphs?
So... Now what?

- Maintain these communities / subgraphs on or near accelerators!
- Sending changes may help with the connection bandwidth problem.
- cuSTINGER [Green & Bader]
  - A variant of STINGER for NVIDIA GPUs
  - Ingest at rates over $10^7$ updates / sec
  - Ingest & triangle count updates at up to $2 \times 10^6$ upd/s (*higher in prep!*)
  - Amenable to existing high-performance static analysis kernels like betweenness centrality.
- [https://github.com/cuStinger](https://github.com/cuStinger)
So... Now what?

- Maintain these communities / subgraphs on or near accelerators!
- Sending changes may help with the connection bandwidth problem.
- Micron Automata (in progress with Aluru, Roy, and Srivatsava)
  - Hardware implementation of non-deterministic finite automata
  - Can be adapted to tackle graph problems!
So... Now what?

- Maintain these communities / subgraphs on or near *accelerators*!
- Sending *changes* may help with the connection bandwidth problem.
- Others?
  - Examining FPGA + HMC combinations to move closer to memory (with Young).
  - Interest in others?
Closing
Future directions

- Of course, continue developing streaming / dynamic / incremental algorithms.
  - For massive graphs, computing small changes is always a win.
  - Improving approximations or replacing expensive metrics like betweenness centrality would be great.
- Include more external and semantic data.
  - If vertices are documents or data records, many more measures of similarity.
  - Only now being exploited in concert with static graph algorithms.

STINGER represents only some approaches! There are others.
HPC Lab People

Faculty:
- David A. Bader
- Jason Riedy
- Oded Green*

Included here:
- Chunxing Lin
- Eisha Nathan
- Anita Zakrzewska

STINGER:
- Robert McColl,
- James Fairbanks* (GTRI),
- Adam McLaughlin*,
- David Ediger* (GTRI),
- Jason Poovey (GTRI),
- Daniel Henderson†,
- Karl Jiang†, and
- feedback from users in industry, government, academia

Support: DoD, DoE, NSF, Intel, IBM, Oracle, NVIDIA

* Ph.D. related to STINGER. † Other previous students.
STINGER: Where do you get it?

Home: www.cc.gatech.edu/stinger/
Code: git.cc.gatech.edu/git/project/stinger.git/
Gateway to

• code,
• development,
• documentation,
• presentations...

Remember: Academic code, but maturing with contributions.

Users / contributors / questioners:
Georgia Tech, PNNL, CMU, Berkeley, Intel, Cray, NVIDIA, IBM, Federal Government, Ionic Security, Citi, Accenture, ...