# Motivation and Goal

- graph processing becomes increasingly important in academic and industrial environments
- many problems modeled with graphs, e. g., machine learning and data mining
- many business models are based on graphs, e. g., viral marketing or Google's search engine
- graph sizes increase to several billion edges

→ performance, parallelism and distribution of graph algorithms becomes more important

Main Goal: *Comparison of five graph processing systems in their performance on different graphs and algorithms.*

# Overview

1. Preliminaries
   - Basics
   - Computation Styles
   - Hugepages
2. Frameworks
3. Evaluation
   - Research vs. Production Case
   - Results
4. Conclusion and Outlook

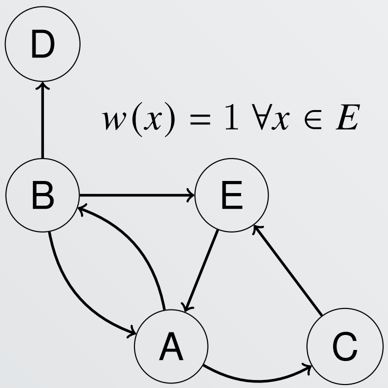
# Preliminaries

## Graphs

A *weighted, directed graph* is the tuple $G = (V, E, w)$ where the *vertex set* is $V \subseteq \mathbb{N}$ and the $E$ is the *edge set* with

$$E \subseteq \{(x, y) \mid x, y \in V, x \neq y\}$$

and $w : E \to \mathbb{R}$ is a mapping of edge to a weight.



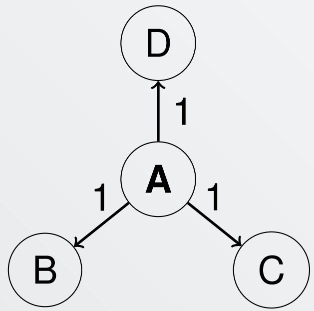

## Algorithms

**Single-Source Shortest-Paths (SSSP):** find the shortest path from a starting vertex to every other vertex

**Breadth-first search (BFS):** find a node outgoing from a starting vertex, by increasing maximum hop count step-wise

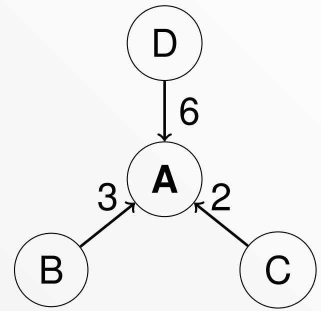
**PageRank (PR):** link analysis algorithm; weighs vertices, measuring their relative importance

## Push Style




- reads active vertex, writes neighborhood
- more efficient, if only few active vertices at the same time
- more efficient, if neighborhoods of active vertices do not overlap

## Pull Style




- reads neighborhood, writes active vertex

$\rightarrow$ only one write and many read operations

- less synchronization in parallel implementations needed
- more efficient, if many vertices active at the same time

# Hugepages

- most systems use virtual memory management
  - represents an abstraction to hardware memory
  - virtual memory is organized in pages
  - translations of virtual memory to physical memory are cached, because every translation takes time
- typically, memory pages are 4 KiB in size
- **hugepages** can be several MiB in size → reduce number of cache misses
- especially noticeable in very memory intensive applications

# Frameworks

| Framework | Version | NUMA | Dist. | Features | Notes |
|---|---|---|---|---|---|
| **Galois** | 29.06.2020 | ✓ | (✓) | general purpose library designed for parallel programming, Hugepage support | distributed using Gluon |
| **Gemini** | 02.11.2016 | ✓ | ✓ | distributed message-based approach from scratch | version contains bugs that had to be fixed |
| **Giraph** | 08.05.2020 | X | ✓ | built on Apache Hadoop | BFS is not natively supported |
| **Ligra** | 14.08.2019 | ✓ | X | dynamically switches between push and pull style | |
| **Polymer** | 28.08.2018 | ✓ | X | optimizes data layout and memory access strategies | |

# Evaluation

## Machines

vsflash1-5,

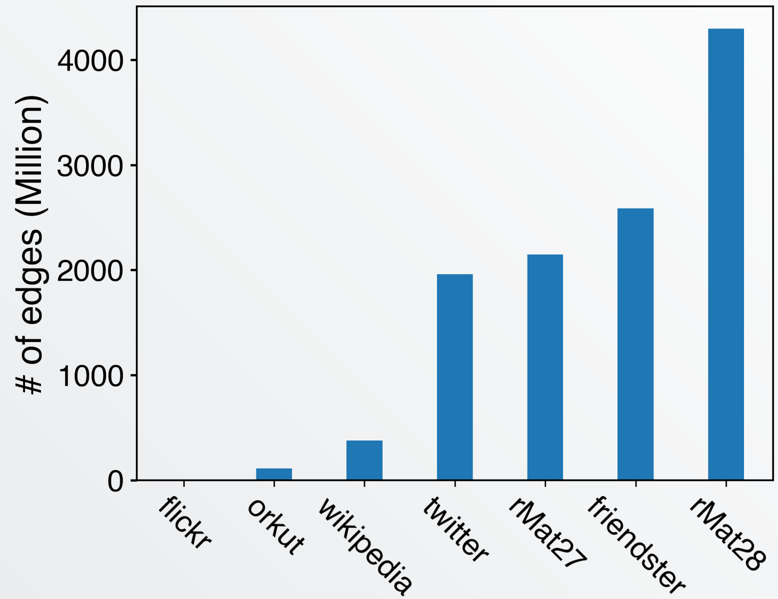
- 96 cores, of which 48 virtual
- 256 GB of RAM each[1]
- Ubuntu 18.04.2 LTS

## Measurements

- **execution time**: time from start to finish of the console command
- **calculation time**: time the framework actually executed the algorithm
- executed each test case 10 times

## Graphs

Both rMat graphs are synthetic, others are real-world data sets; Flickr: 24MB, rMat28: 76GB




[1] one machine only 128 GB

## Production Case

- running system: multiple calculations on a single graph
- graph data stays loaded between calculations

→ short calculation times should be preferred

- Not main focus of this presentation![2]

## Research Case

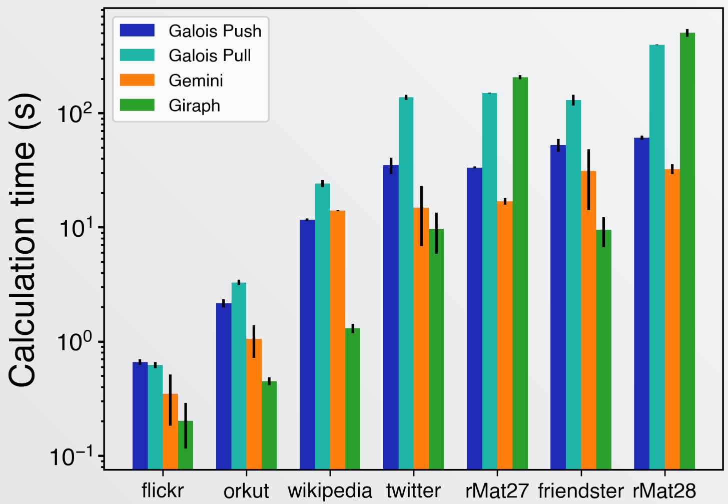
- individual calculation cases: possibly new graph for each calculation
- frequently changing algorithm

→ framework should be relatively fast on different algorithms

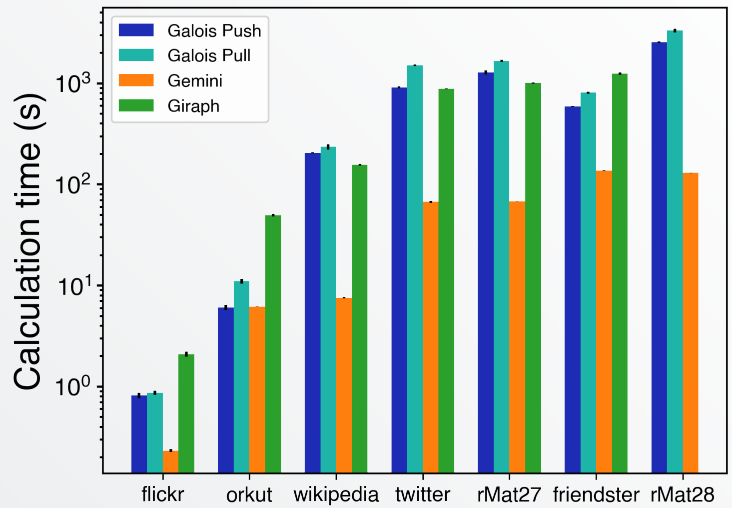
→ overall small execution times should be preferred

[2] see paper for details

# Production Case Distributed



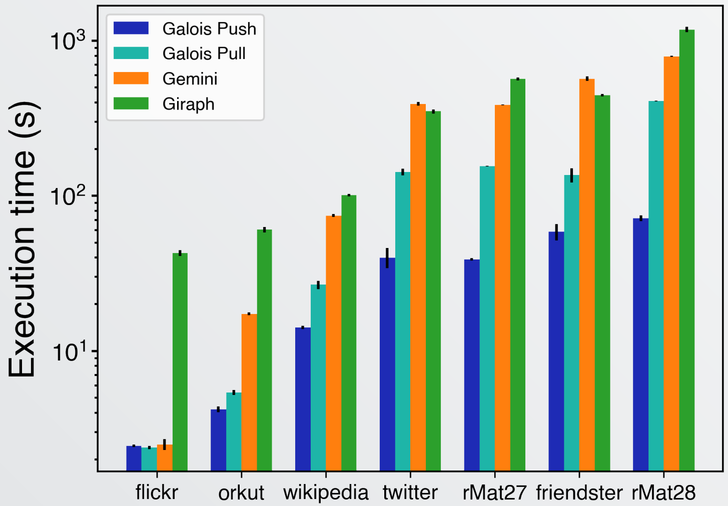
(a) SSSP



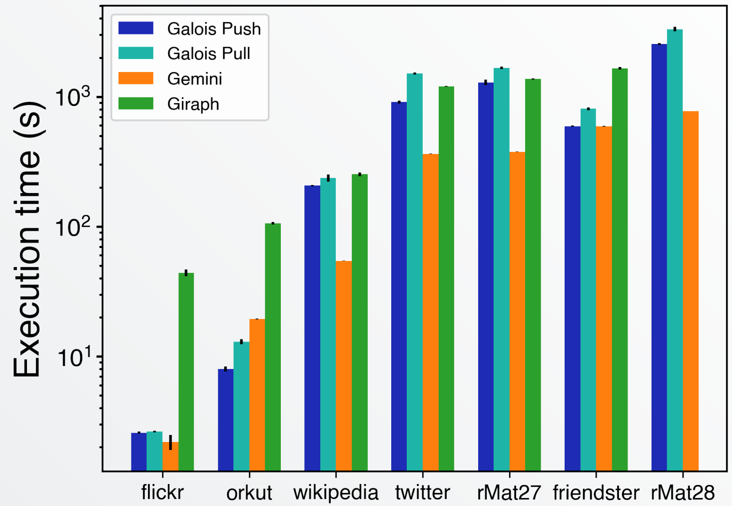
(b) PR

- Giraph is fastest on SSSP and BFS on the real world graphs
- Giraph has problems with synthetic graphs
- Gemini is fastest on PR, with Giraph on second place

# Research Case Distributed



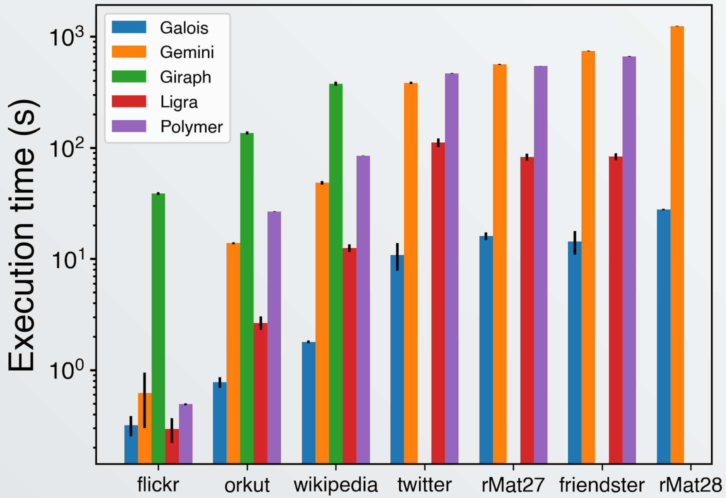

(a) SSSP



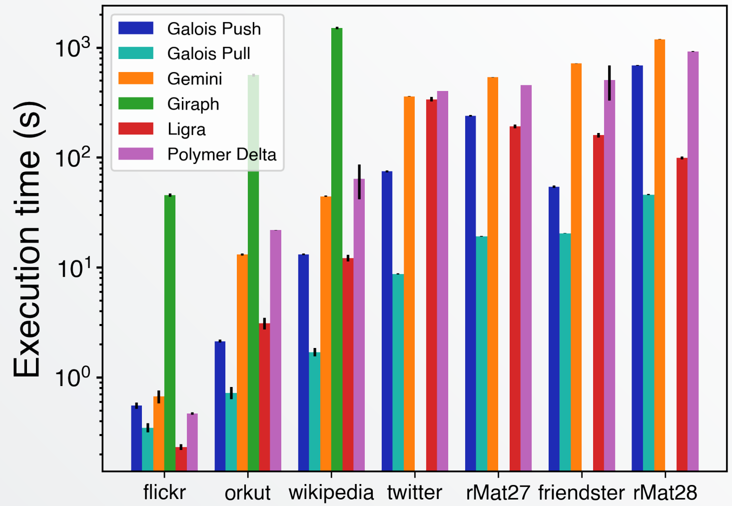

(b) PR

- Galois Push is faster than Pull in all cases
- Both Galois implementations fastest on SSSP or BFS
- Gemini is fastest on PR in almost all cases

# Research Case Single Node




(a) SSSP




(b) PR

- Giraph is either slowest or requires too much RAM (>256 GB)
- Galois is fastest in almost all cases, second fastest is Ligra
- Gemini and Polymer are comparably slow

# Galois With Hugepages

| | Calc Time (s) | | Exec Time (s) | |
|---|---|---|---|---|
| **Graph** | w/o | w/ | w/o | w/ |
| flickr | 0.01 | **0.01** | 0.3 | **0.2** |
| orkut | 0.10 | **0.02** | 0.8 | **0.5** |
| wikipedia | 0.38 | **0.11** | 1.8 | **1.1** |
| twitter | 2.47 | **0.94** | 10.8 | **5.1** |
| rMat27 | 4.50 | **1.39** | 16.0 | **6.4** |
| friendster | 4.70 | **1.78** | 14.4 | **7.5** |
| rMat28 | 9.77 | **3.34** | 27.8 | **13.1** |

(a) SSSP

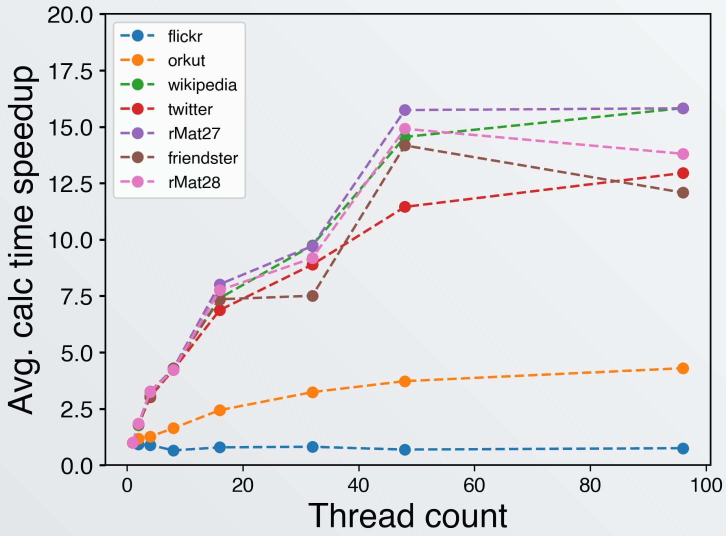
| | Calc Time (s) | | Exec Time (s) | |
|---|---|---|---|---|
| **Graph** | w/o | w/ | w/o | w/ |
| flickr | 0.01 | **0.01** | 0.3 | **0.2** |
| orkut | 0.06 | **0.02** | 0.7 | **0.6** |
| wikipedia | 0.17 | **0.03** | 1.7 | **1.4** |
| twitter | 0.77 | **0.11** | **8.7** | 9.3 |
| rMat27 | 0.65 | **0.13** | 19.2 | **8.1** |
| friendster | 1.01 | **0.14** | 20.4 | **13.1** |
| rMat28 | 1.15 | **0.24** | 46.0 | **16.4** |

(b) PR Pull

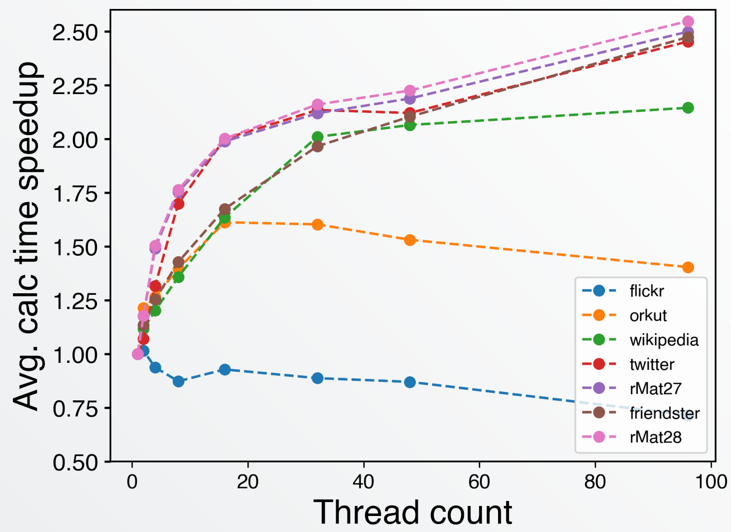
- Hugepages reduce both calculation and execution time on all algorithms

$\rightarrow$ Execution times can be up to 3$\times$ shorter

# Multithreaded Speedup of Galois




(a) SSSP with Hugepages




(b) PR Pull with Hugepages

- Speedups can be significant, with and without hugepages
- Speedup of PR not to the same degree as on SSSP (2.5× vs. 15×)

# Conclusion and Outlook

Generally: 1) performance highly dependent on the framework, algorithm and data set
2) single node almost always preferrable, as long as RAM is sufficient

## Production Case

- Giraph is very fast on distributed systems (especially SSSP and BFS)
- Gemini is fast for distributed PR
- Gemini and Ligra are good options for single node

## Research Case

- Galois is fastest in almost all cases; further improvements with hugepages possible

## Outlook

→ incorporate new frameworks and new algorithms

→ explore range of settings and other implementations

→ repeat similar tests in the future: frameworks are updated and new ones are introduced