HPC Graph Analytics on the OneGraph Model

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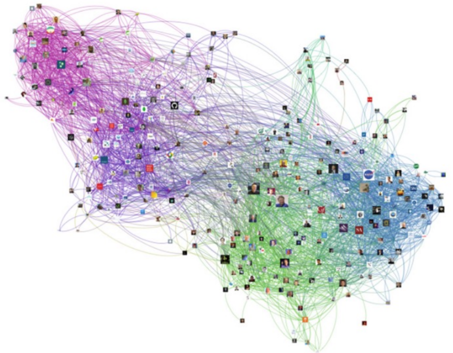
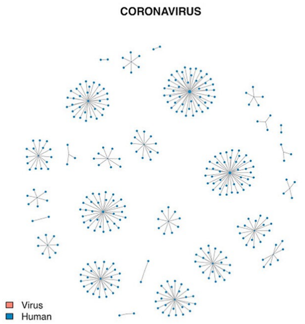
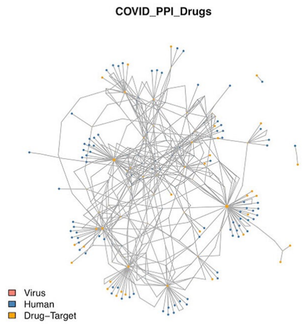
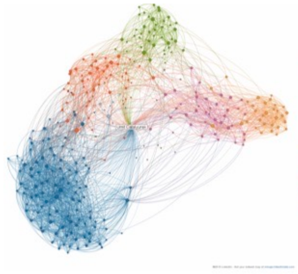
Graphs are Ubiquitous and Fun!

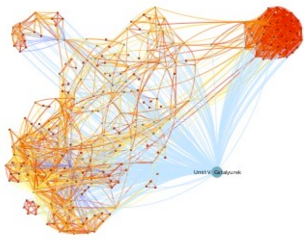




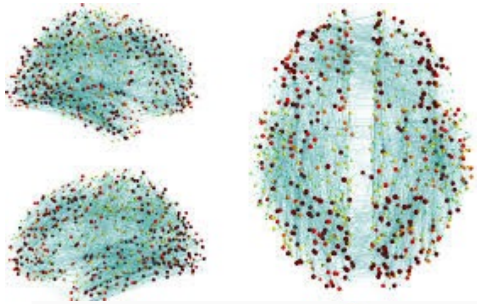




Linkedin Ego-Net



DBLP Ego-Net



They are growing. Up to billions of vertices and edges

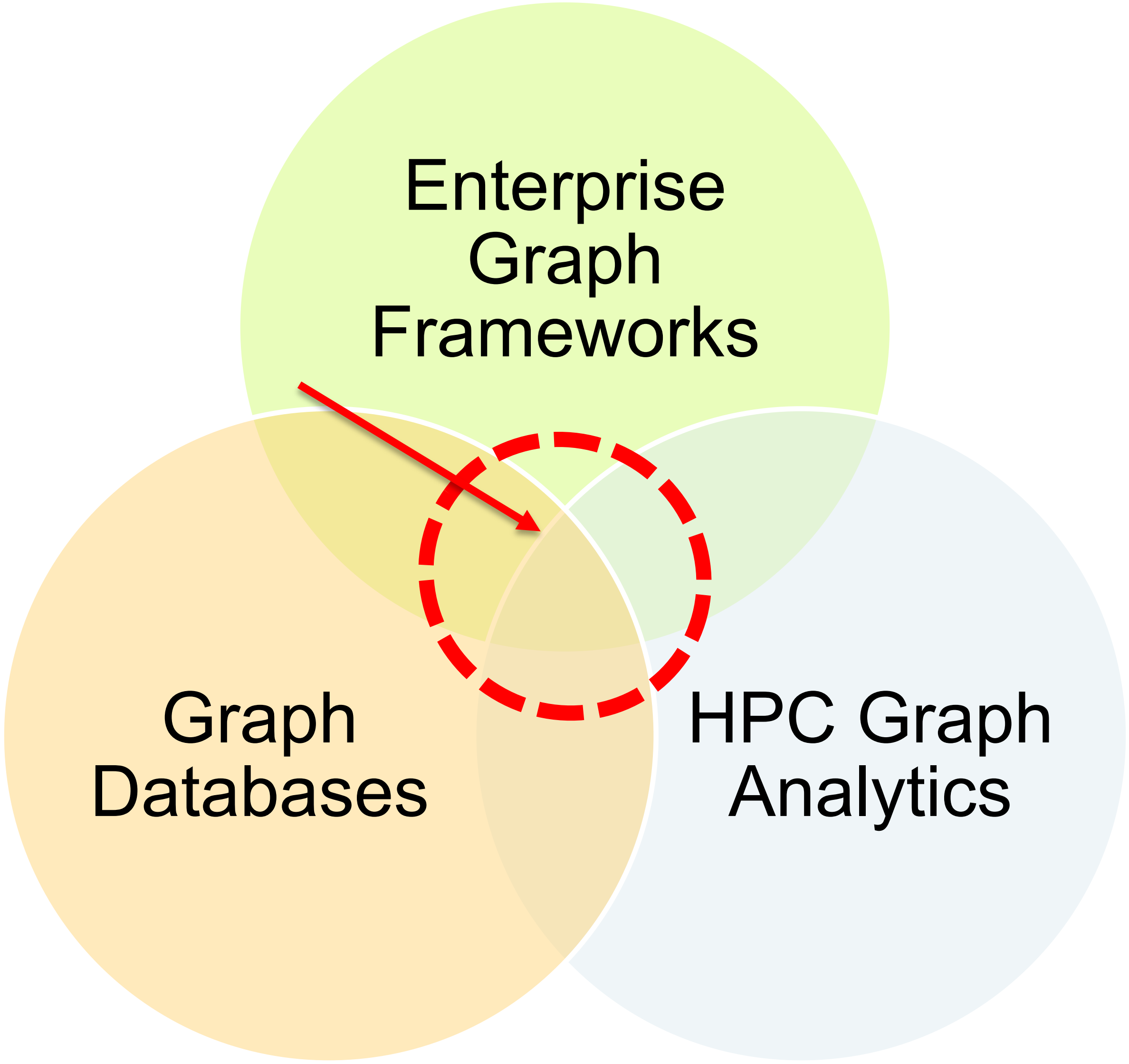
Fast, efficient analysis is important and pervasive

Many graph processing frameworks, and databases, have been proposed/developed

Image credits:

Jenn Caulfield, Social network vector illustration, 2018
Gerhard et al., Frontiers in Neuroinformatics 5(3), 2011
Albert-László Barabási/BarabasiLab 2019
Caleb Jonson, How to Visualize Your Twitter Network, 2014

Landscape of current “Graph World”



Scalability

Our goal is to have a performance that is in **small-constant factor** from HPC / State-of-the-art Graph Analytics, yet provide easy to maintain and productive development environment.

- F. McSherry, M. Isard, and D. G. Murray, “Scalability! But at what COST?” HotOS, 2015.
- N. Satish, N. Sundaram, M. M. A. Patwary, J. Seo, J. Park, M. A. Hassaan, S. Sengupta, Z. Yin, and P. Dubey, “Navigating the maze of graph analytics frameworks using massive graph datasets”. SIGMOD 2014.

Graph Data Models

LPG: Labeled Property Graphs

Vertices

Nodes: Label/ID + *Properties* (set of key-value pairs)

Edges

Relationships: Label/ID + Type + Properties

RDF: Resources Description Framework

Vertices

Resources: URIs

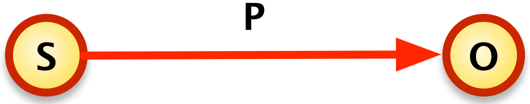
Attribute Values: Literals

Edges

Relationships: URIs

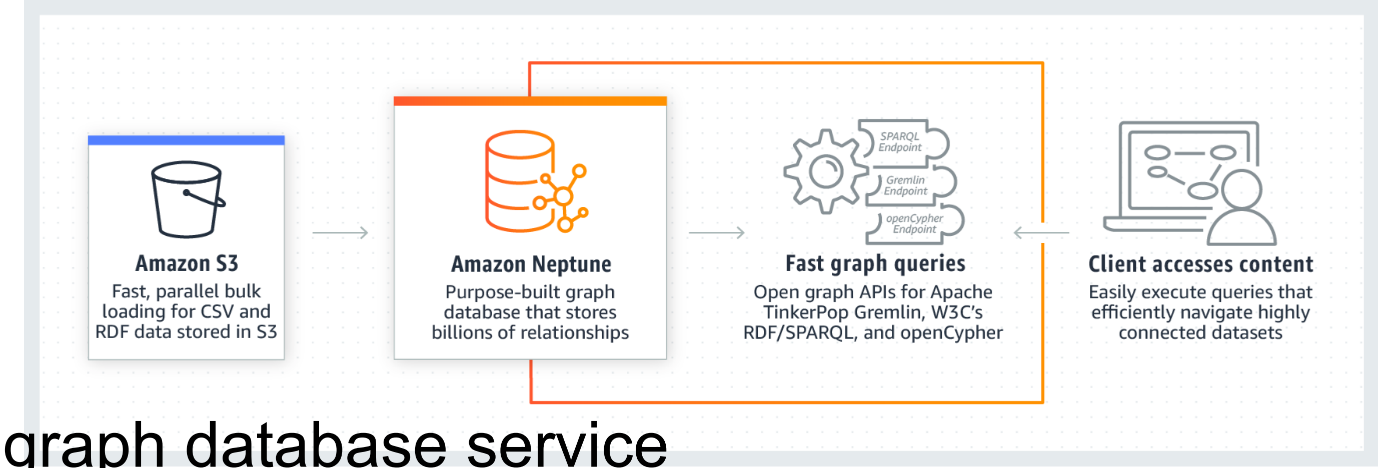
RDF Triple: **S**ubject-**P**redicate-**O**bject

(SPO)



There is no internal structure for nodes and edges

Graph interoperability



- Amazon Neptune
  - managed, cloud-based graph database service
  - supports RDF (SPARQL) and LPG (Gremlin & openCypher)
- User has to choose either RDF or LPG
  - this choice also determines which query languages are available
  - the choice is not always easy, and is hard to reverse later
- RDF vs. LPG
  - RDF offers a formal model, LPG not so much
  - RDF is “sometimes seen as academic”, and developers tend to prefer LPG
  - different strengths and weaknesses

Graph interoperability

- What if we did not have to choose between RDF and LPG?
- What if we could use Gremlin over RDF, or SPARQL over LPG?
- Interoperability: single graph (meta)model, free use of any query language
  - we are not interested in “qualified” interoperability where one meta-model is *implemented* using the other
- RDF-star is a step towards having LPG features in RDF
- 1G model (“one graph to rule them all”)
  - "Graph? Yes! Which one? Help!", O. Lassila, M. Schmidt, B. Bebee, D. Bechberger, W. Broekema, A. Khandelwal, K. Lawrence, R. Sharda, B. Thompson, arXiv:2110.13348v1, 2021.

Storage Challenges: Interoperability

- Interoperability: serve both RDF and LPG
- 1G Graph Storage
  - Three kinds of relations
    - Dictionaries: URIs/Literals → IDs
    - Graph Structure: Topologies – relations between (S)ubject and (O)bject, in other words between “vertices”
    - Graph Data: Values – properties of vertices and edges
  - In 1G, Edges/Properties (of vertices and edges) can become “vertices”
- Relations are partitioned (sharded)
  - 1D: Dictionaries, Vertex Properties etc.
  - 2D: Topology and properties of edges (collocated for performance)

Storage Challenges: Dynamic Partitioned Data

- Graph is not static (well, obviously!)
  - Many HPC Graph Analytics kernels assumes graph is not changing.
  - Even dynamic ones conveniently *ignores* deletion.
- How to (dynamically) distribute data?
- System generated IDs are uniform random
  - Notice that graph comes as vertices as URIs
  - Load-balanced partitioning (declustering) is favored against locality for initial load
  - Graph-aware re-ordering/re-labeling can be done after graph is loaded
- Sharding options: Node partition (1D) vs Edge partition (fine-grain 2D) vs Blocked partition (coarse-grain 2D)
  - Blocked partition is used as a sweet spot between performance and architecture agnostic algorithm development [1] (more on next slide)

[1] **PGAbB: A Block-Based Graph Processing Framework for Heterogeneous Platforms**
Abdurrahman Yasar, Sivasankaran Rajamanickam, Jonathan W. Berry, Umit V. Catalyurek
https://arxiv.org/abs/2209.04541

Why 2D?: PGAbB Results on Selected Graphs [1]

- Power9 (2 x 16 x 4) CPUs & Volta100 GPU.
  - 320 GB Host Memory. 32 GB Device Memory.
  - CPU-GPU bandwidth: ~60GB/s
- PGAbB: Kokkos at the backend with OpenMP (Host) and Cuda (Device)
- All wormalized wrt GAPBS

	Number of			
Graph	**Vertices**	**Edges**	**Triangles**	**CC**
Twitter7	41.6 M	1.2 B	34.8 B	0.001
Com-Orkut	3 M	117 M	627 M	0.041
Sk-2005	50.6 M	1.8 B	84.9 B	0.002
Kmer_V1r	214 M	232 M	49	0.000
Europe-OSM	50.9 M	54.1 M	61 K	0.003
Myciel.19	393 K	451 M	0	0
Kron-Scale21	2.1 M	91 M	8.8 B	0.044

		Social		Web	Gene	Road	Synthetic	
		twitter7	Orkut	sk-2005	kmer_V1r	eu_osm	myciel19	kron21
Galois	PR	0.83	1.01	1.01	0.89	1.03	6.96	0.78
	SV/LP	8.40	1.71	1.68	2.29	1.81	1.25	1.12
	CC	0.84	1.56	0.98	0.64	0.64	2.94	0.81
	BFS	0.26	0.59	0.46	0.34	2.14	0.39	0.18
	TC	0.69	1.06	0.63	0.90	1.21	0.44	0.40
Ligra	PR	0.39	0.60	0.99	0.43	0.53	2.59	0.72
	SV/LP	1.24	0.70	1.05	0.18	0.02	0.58	0.66
	CC	0.02	0.04	0.00	0.02	0.01	0.03	0.02
	BFS	0.61	0.67	0.93	0.68	0.16	1.37	0.82
	TC	0.31	0.35	0.12	0.30	0.17	0.43	0.69
LAGraph	PR	0.75	0.98	0.60	0.75	0.65	3.21	0.71
	SV/LP	14.24	1.64	0.89	0.30	0.13	7.70	0.92
	CC	0.17	0.21	0.12	0.14	0.05	0.27	0.09
	BFS	0.79	0.33	0.77	0.27	0.33	0.75	0.30
	TC	0.38	0.87	0.66	0.29	0.16	0.52	0.37
Galois-GPU	PR	0.00	2.72	0.00	1.01	1.49	12.12	1.62
	SV/LP	0.00	3.67	0.00	2.43	2.71	2.65	1.57
	CC	0.00	0.46	0.00	1.16	0.99	0.09	0.15
	BFS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TC	1.03	0.85	0.90	0.00	0.00	0.38	0.65
Gunrock	PR	0.00	1.28	0.00	1.44	1.34	5.42	0.97
	SV/LP	0.00	1.88	0.00	3.18	1.22	3.90	0.97
	CC	0.00	0.24	0.00	1.51	0.44	0.14	0.09
	BFS	4.61	1.48	0.00	3.59	0.80	3.45	5.73
	TC	0.00	0.74	0.00	0.04	0.02	0.29	0.23
PGAbB-GPU	PR	4.20	4.72	0.74	0.53	0.64	13.60	2.30
	SV/LP	19.19	9.96	3.16	6.45	3.63	9.21	3.85
	CC	1.68	1.08	5.52	3.56	1.37	0.64	0.31
	BFS	0.18	0.85	0.97	0.28	0.32	1.06	0.27
	TC	3.09	3.39	2.34	0.52	0.32	2.87	2.33
PGAbB	PR	4.64	4.67	0.80	0.53	0.64	10.76	1.79
	SV/LP	18.02	5.95	1.90	5.73	2.95	7.70	1.98
	CC	1.25	1.53	2.14	1.91	0.96	2.40	0.87
	BFS	0.16	0.89	0.77	0.90	0.33	1.00	0.29
	TC	3.02	3.01	1.69	1.11	3.91	5.39	3.48

[1] PGAbB: A Block-Based Graph Processing Framework for Heterogeneous Platforms A. Yasar, S. Rajamanickam, J. W. Berry, U V. Catalyurek https://arxiv.org/abs/2209.04541

How about computational model

- Internally we provide
  - From “think like a vertex” to “think like a sub-graph (block/tile)”
  - Visitor model

- Externally:
  - Currently openCypher + with Graph API

- Ümit says
  - Low-hanging fruit: GraphBLAS

Storage Challenges: Scalability and Transactions

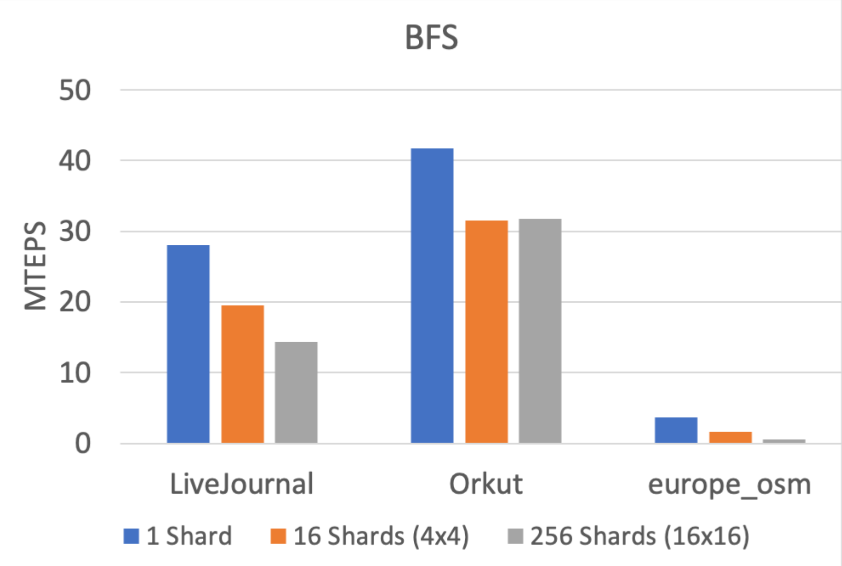
- Scalability: Scaling Up (vertical/single-node) and Scaling Out (horizontal/multi-node)
  - Read scaling is “easy”
  - Write scaling with transaction support is challenging:
    - Distributed in-memory graph storage with logging is still challenging to implement.

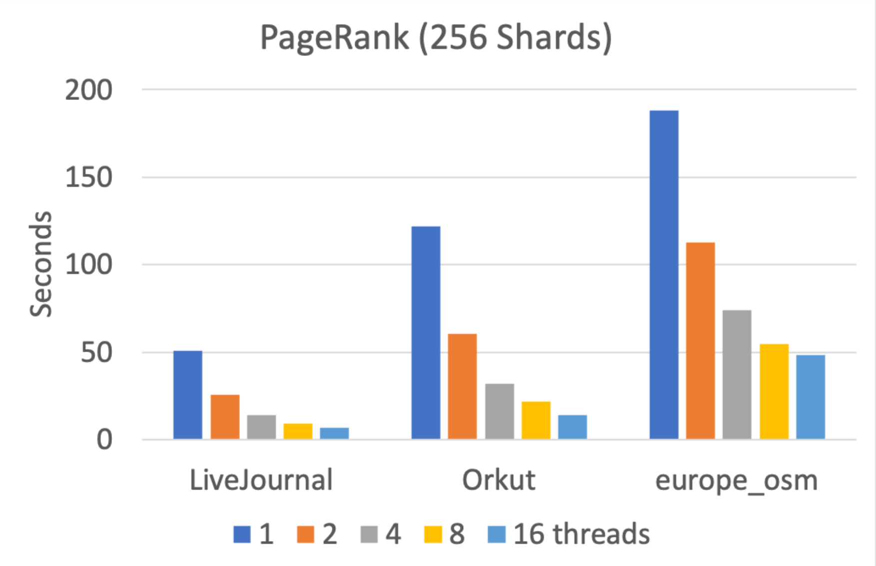
- What does it mean to provide Graph Analytics under transactional system?
  - Transaction aware reads
    - Index-driven vs Scan-based kernels and dynamic tradeoffs based on cardinality estimates
  - Dynamic creation of “Views” for multi-iteration algorithms

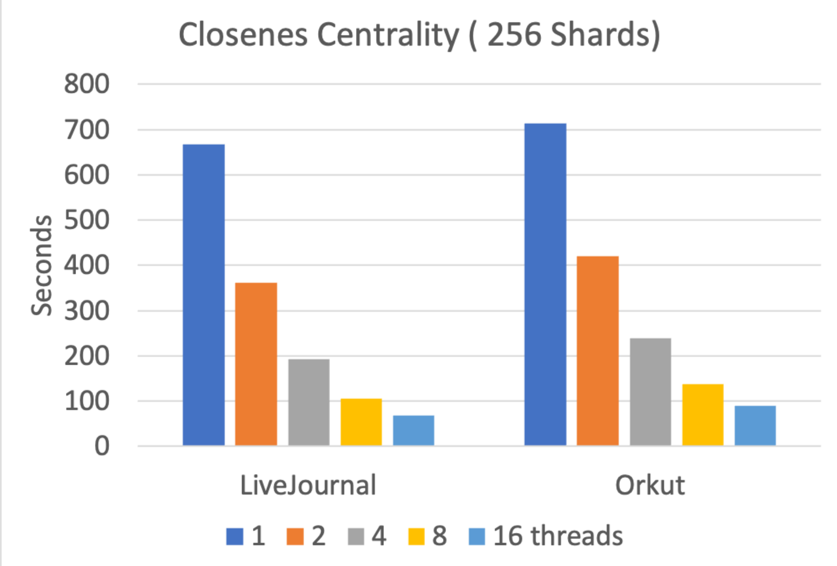
Effect of Shading to Performance

- **Early results** on a single, **old** EC2 instance
- Each shard executed sequentially (no fine-grain parallelism)
- Results show expected behavior:
  - Performance of BFS correlated with avg degree
  - 2D partitioning/sharding is not ideal for BFS, especially for very sparse data, but works well for almost all others, such as PageRank

name	#vertices	#edges (undirected)	avg degree
com-LiveJournal	3,997,962	34,681,189	17.35
com-Orkut	3,072,441	117,185,083	76.28
europe_osm	50,912,018	54,054,660	2.12







Computational Infrastructure Challenges

- Can we implement once, and run everywhere: from multi-core to multi-host with potentially accelerators?
- Yes!
  - Multi-Level Intermediate Representation (MLIR) for Graphs
  - “Coarse-grained” Labeled-Dataflow Execution
- Can we support both OLAP and OLTP graph data management?
- Yes!
  - Native Storage
  - Advanced Scan Kernels
  - State-of-the-art Transactional Model (MVCC, …)

Conclusions & Future Directions

- HTAP (i.e., Hybrid OLTP and OLAP) solutions are needed!
  - Enterprise Graph Systems gives the *illusion* of read scaling, while failing in absolute performance, and write/update scaling (they just leave that to IO system)
  - HPC Graph Analytics codes/libraries, are one-off, focused on narrow set of kernels and fail to provide end-to-end solutions
  - Existing “Real” Graph Databases, provides either OLTP or OLAP, but fails to deliver both

- Interoperability is a big challenge!
  - SPARQL, Gremlin and OpenCypher queries for both OLTP and OLAP workloads

- Graph as a Service

- **It is exciting times for Graphs!**