Gemini: A Computation-Centric Distributed Graph Processing System

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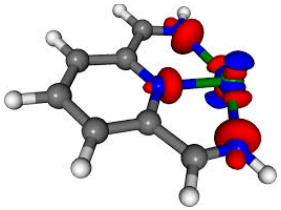
Graphs, Platforms, and Systems



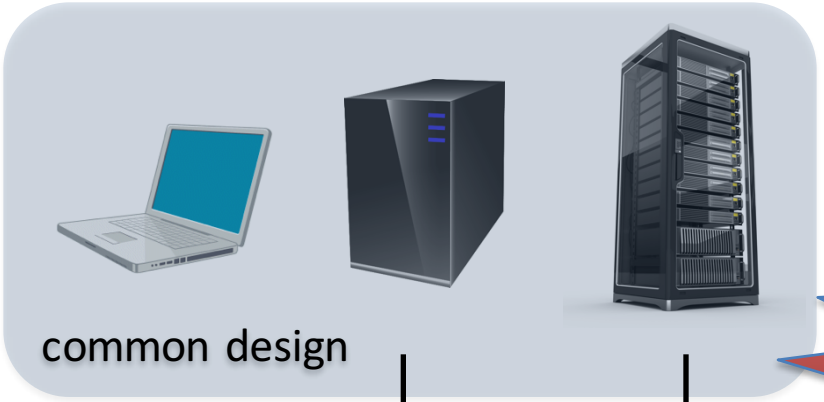





Shared-memory
Ligra[PPoPP '13], Galois[SOSP '13]
Efficiency☺ Scalability☹

Distributed
PowerGraph[OSDI '12], GraphX[OSDI '14]
Efficiency☹ Scalability☺

Connecting Shared-Memory and Distributed



Bottleneck in computation!

Profiling existing systems

Nodes System	1 Galois	8 PowerLyra[EuroSys '15]
Runtime (s)	19.3	26.9
Instructions	Distributed overhead	
Memory references		
Communication (GB)	-	38.1
Instructions per cycle	0.414	0.655
L3 cache miss rate	Sub-optimal computation	
CPU utilization		

Far from saturated for IB EDR (100Gbps) (38.1*8/2/26.9/8=**0.708**Gbps)

More instructions and memory traffic

Poorer access locality

Lower multi-core utilization

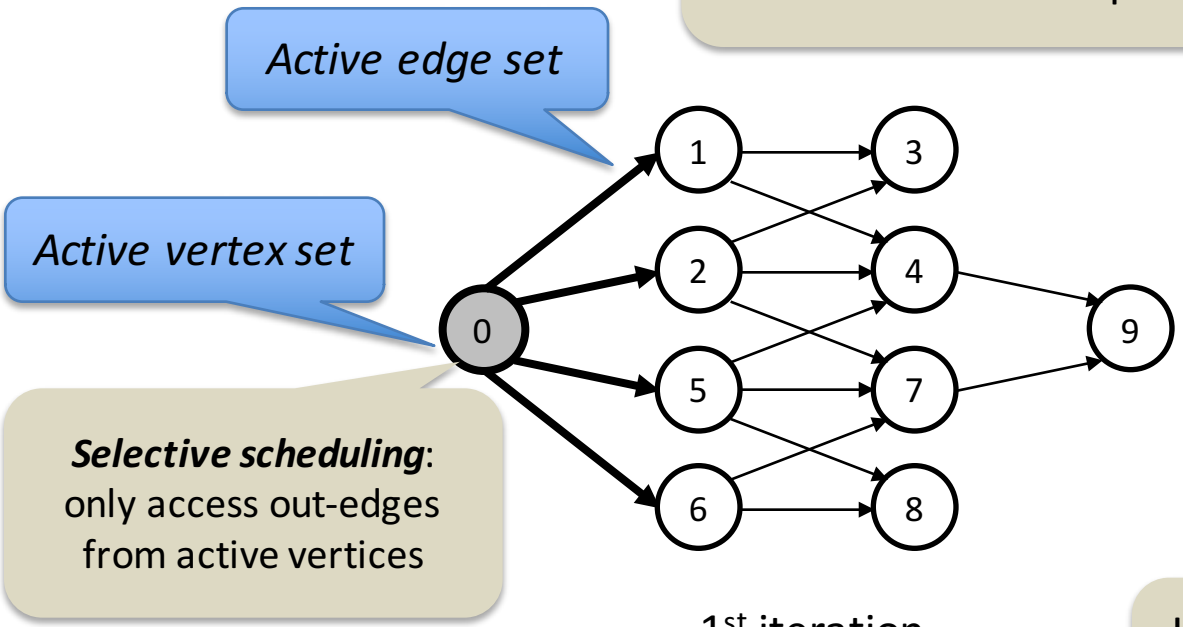
20 iterations of PageRank on twitter-2010 (41.7M vertices, 1.47B edges)

We Propose: ***Gemini***

- Build **scalability** on top of **efficiency**
  - Avoid unnecessary "distributed" side-effects
  - Optimize computation on partitioned sub-graphs
- Shift of design focus
  - Designed for distributed, but **computation-centric**
    - Modern clusters have fast interconnects
    - Computation-communication overlap in place
- Major optimizations
  - Efficiency
    - Adaptive push-/pull-style computation
    - Hierarchical chunk-based partitioning
  - Scalability
    - Locality-aware chunking
    - Chunk-based work-stealing

Dual Mode: BFS Example (1)

$|Active\ edge\ set| / |E| < threshold$
⇒ ***Sparse*** *mode*
⇒ ***Push*** operations



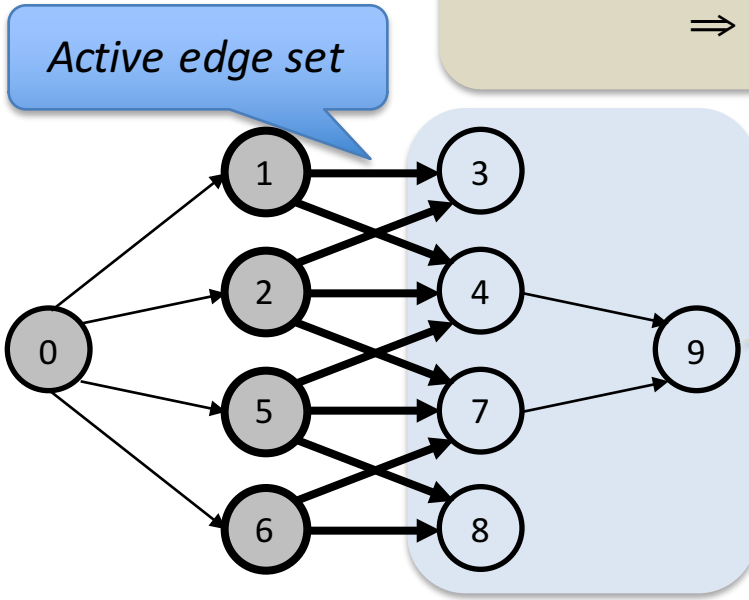
Selective scheduling:
only access out-edges
from active vertices

1st iteration

Locks/atomic operations
required for correctness
of concurrent updates

Dual Mode: BFS Example (2)

$|Active\ edge\ set| / |E| > threshold$
⇒ ***Dense*** *mode*
⇒ ***Pull*** operations

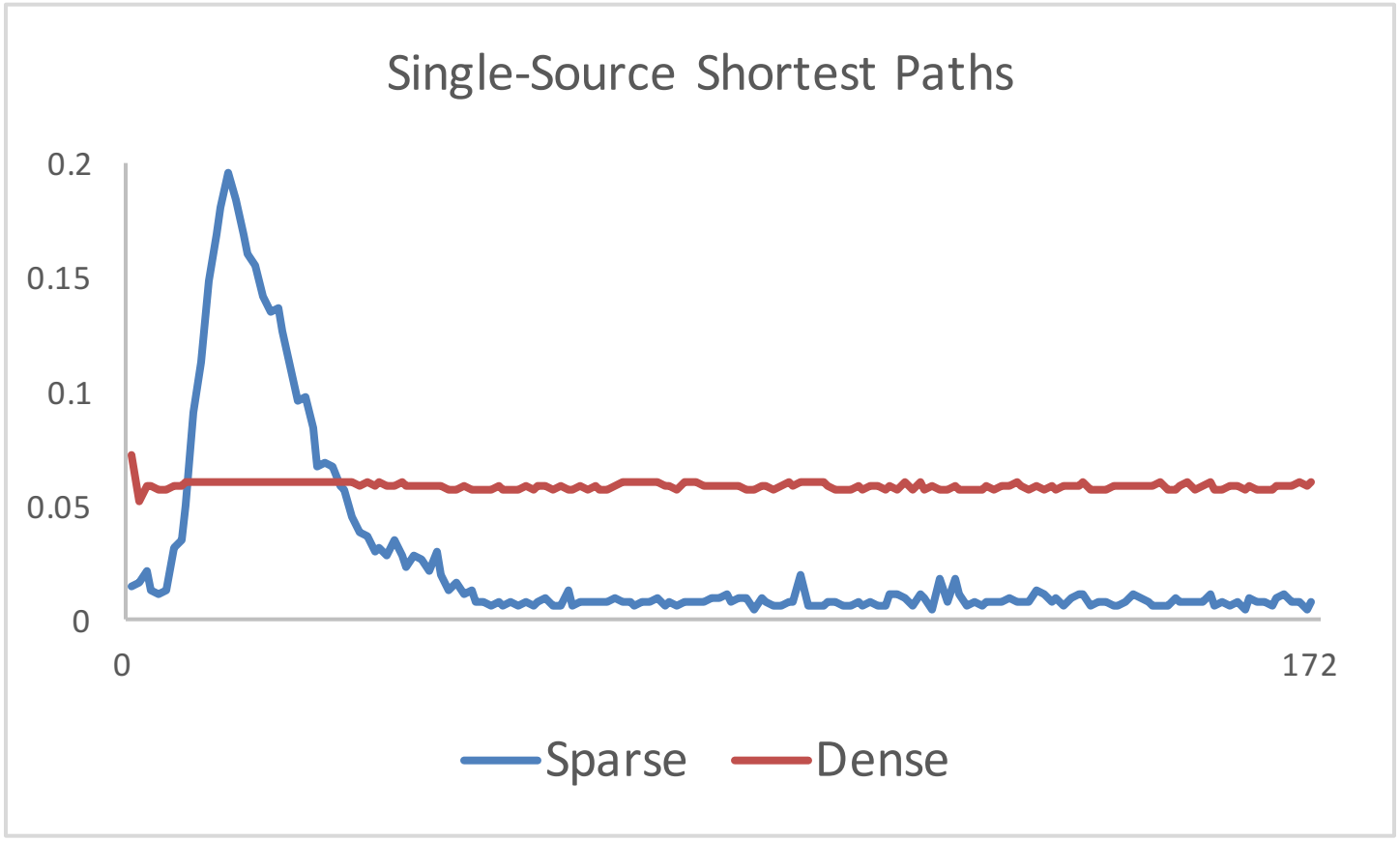


Useless computation

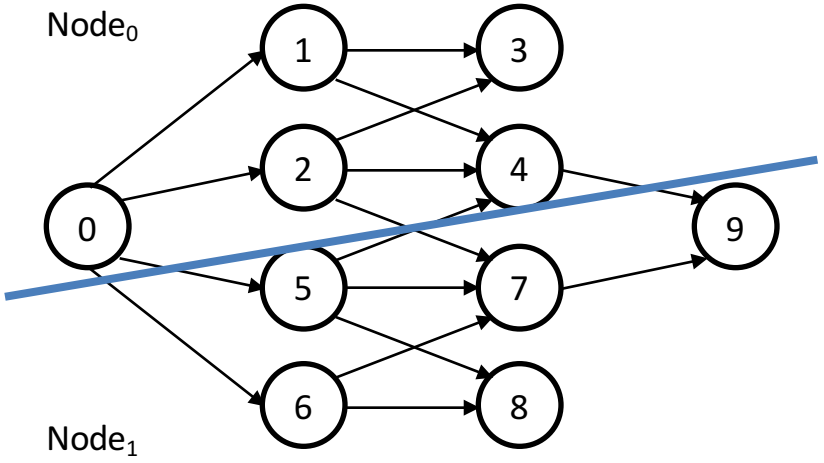
2nd iteration

Vertices pulling along in-edges
Contention-free updating

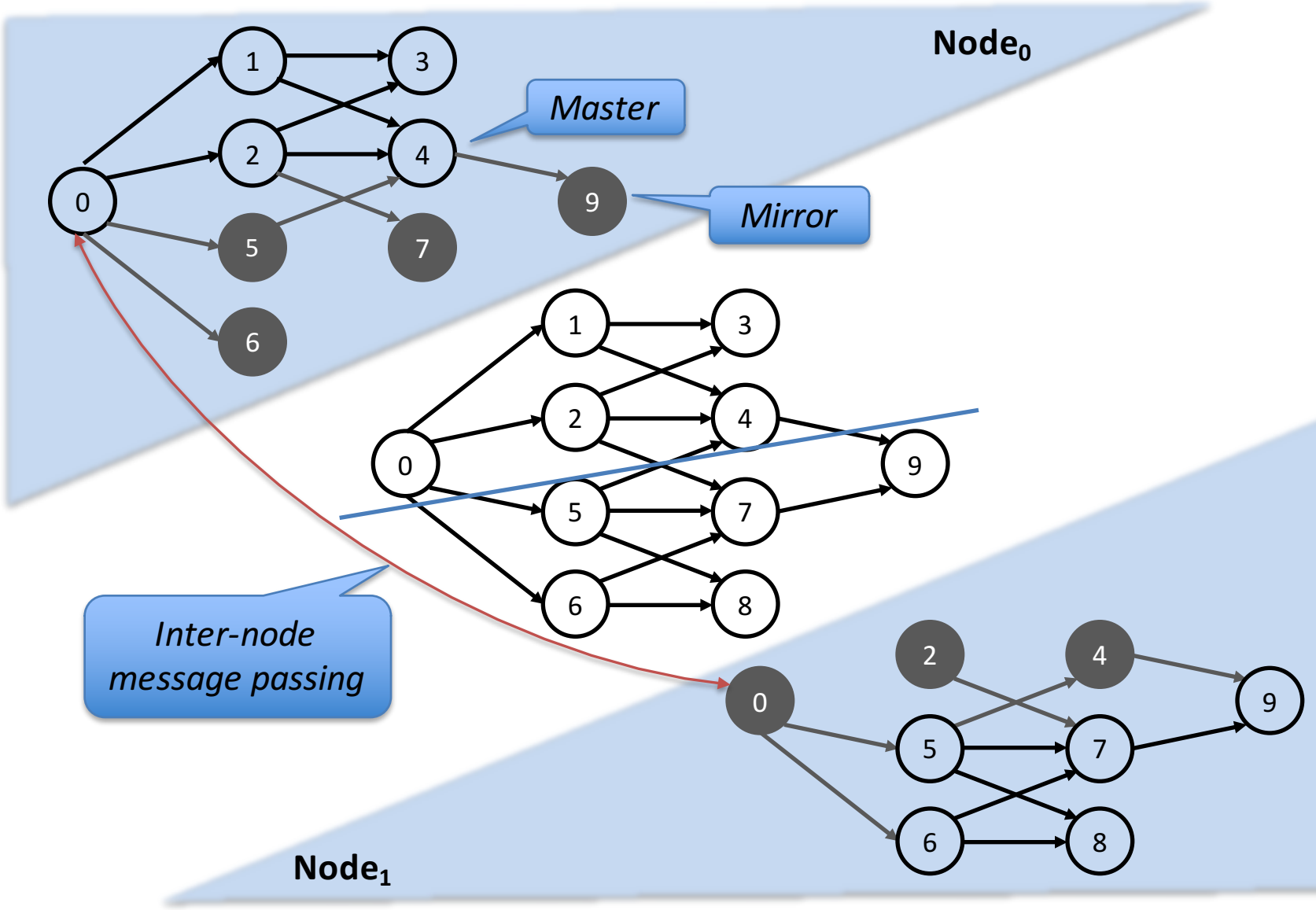
Push vs. Pull: Performance Impact



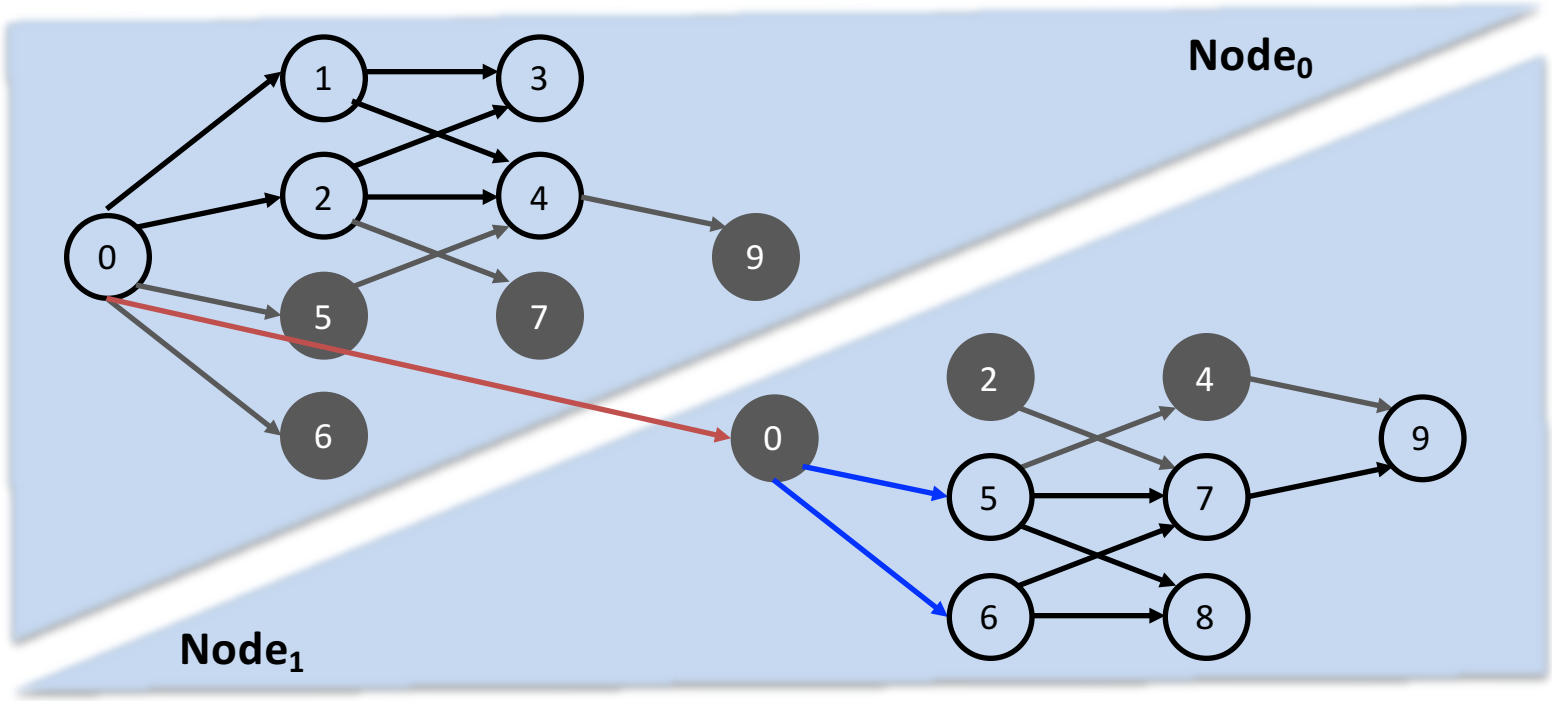
Distributed Dual-Mode Computation



When Distributed to 2 Nodes

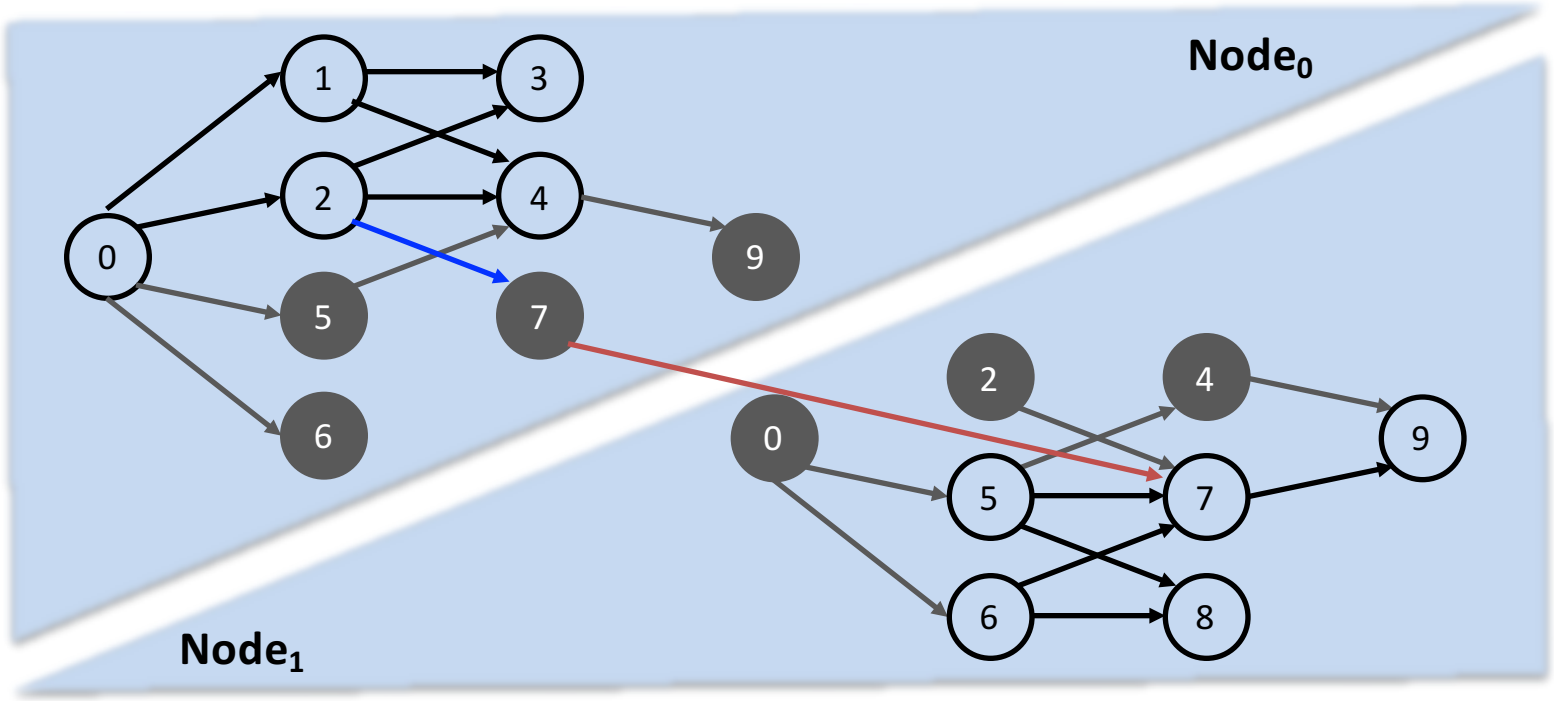


Gemini's Distributed Push



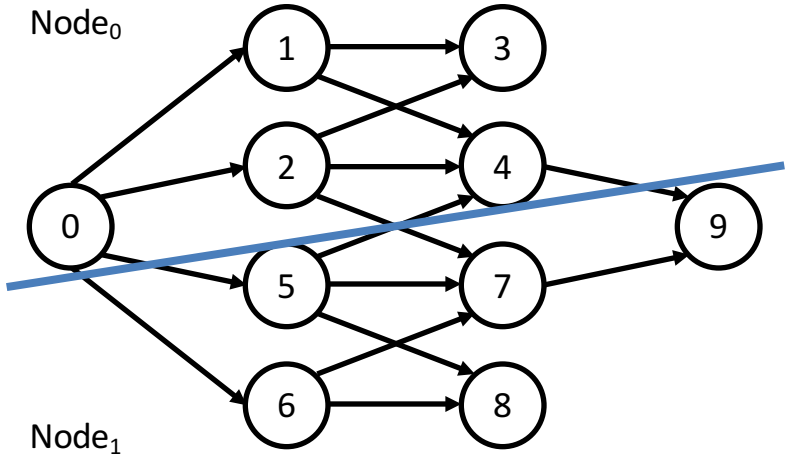
Masters message mirrors, who update their local neighbors

Gemini's Distributed Pull

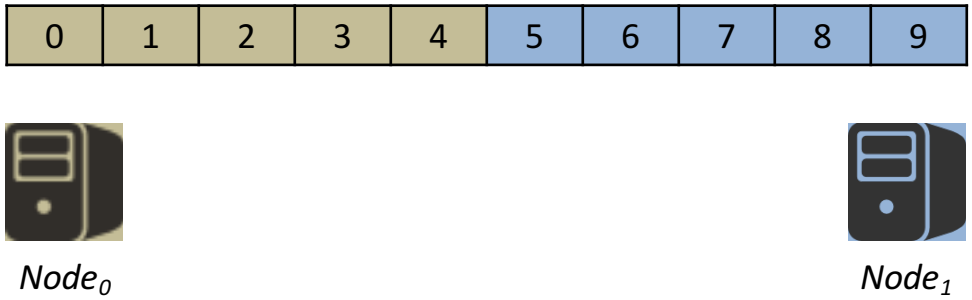


Mirrors pull updates from neighbors, then message masters

Gemini's Choice of Graph Partitioning



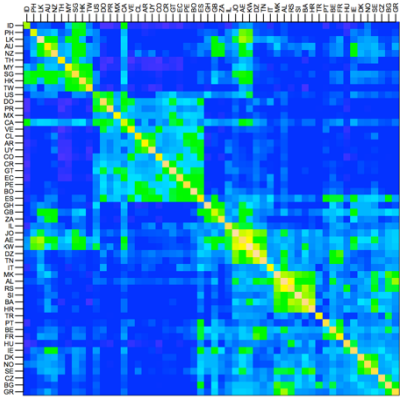
- Chunking
  - Divide vertex set ***V*** into ***p*** **contiguous** chunks



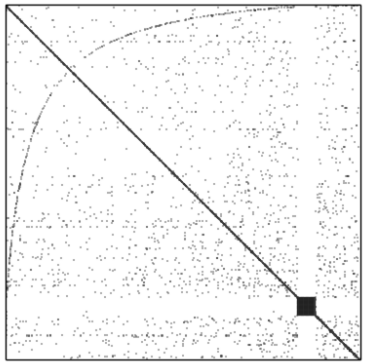
  - Dual-mode edge data distributed accordingly

Why Chunk-Based Partitioning?

- It preserves locality!
  - Fact: **locality** exists in many real-world graphs
    - Vertices "semantically" ordered



Facebook Country Adjacency Matrix[1]



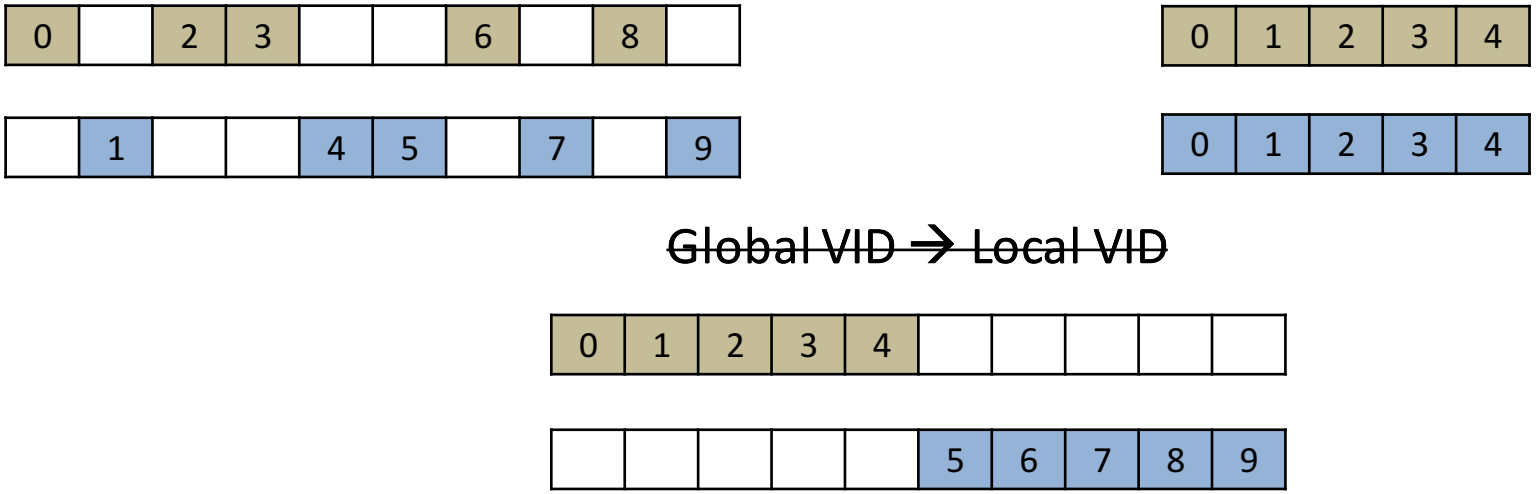
UK Web (2005) Adjacency Matrix

  - Preprocessing affordable when vertices unordered
    - E.g., BFS[Algorithms 09], LLP[WWW '11]

[1] The Anatomy of the Facebook Social Graph

More Benefits of Chunking

- Low-overhead distributed designs

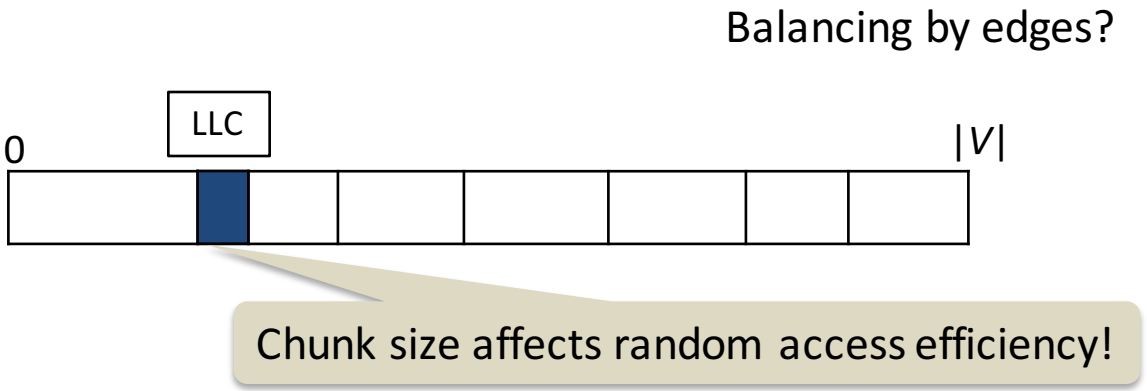


- Applied recursively at different levels
  - More on this later

Challenges with Distributed Chunking

- When scaling out
  - CSR/CSC vertex indices can become very **sparse**
  - *Solution:* **compress** vertex indices
- Modern servers built upon NUMA architecture
  - **Interleaved** layout sub-optimal
  - *Solution:* apply inter-socket **sub-partitioning**
- Chunking as vertex-centric (edge-cut) scheme
  - Vertex-centric solutions are not good at **load balancing** natural graphs
  - *Solution:* balancing workload in **locality**-aware manner

Locality-Aware Chunking



- Gemini considers both vertex and edge
  - Edge: the amount of work to be processed
  - Vertex: the processing speed of work (locality)
  - Hybrid metric: $\alpha \cdot |V_i| + |E_i|$

Chunking, Chunking All the Way

Per-node partition

cluster

Per-socket partition w. NUMA-aware placement

node

Data partitioning till socket-level

Per-core work chunk

socket

core

Mini-chunk for work-stealing

Work partitioning within socket

Locality-aware

Fine grain (64-vertex)

Evaluation

- Platform: 8-node cluster
  -  Intel Xeon E5-2670 v3 (12-core CPU), 30MB L3 cache
  -  2 sockets sharing 128 GB RAM (DDR4 2133MHz)
  -  Network: Mellanox Infiniband EDR 100Gbps

- Applications
  - PageRank (PR) (20 iterations)
  - Connected Components (CC)
  - Single-Source Shortest Paths (SSSP)
  - Breadth-First Search (BFS)
  - Betweenness Centrality (BC)

- Input graphs

Graph	|V|	|E|
enwiki-2013	4,206,785	101,355,853
twitter-2010	41,652,330	1,468,365,182
uk-2007-05	105,896,555	3,738,733,648
weibo-2013	72,393,453	6,431,150,494
clueweb-12	978,048,098	42,574,107,469

Single-Node Efficiency

Application	Ligra	Galois	Gemini
PR	21.2	19.3	**12.7**
CC	6.51	**3.59***	4.93
SSSP	**2.81**	3.33	3.29
BFS	**0.347**	0.528	0.468
BC	2.45	3.94*	**1.88**

Runtime in seconds (twitter-2010)

More iterations

More instructions

NUMA-aware memory accesses

System	Ligra	Gemini
Remote access ratio	50.1%	9.10%
L3 cache miss rate	52.6%	40.1%
Average access latency	183ns	125ns

Memory performance (BC)

"*" uses different algorithms.

Multi-Node Scalability: Larger Graphs

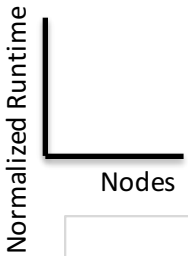
Graph	|V|	|E|
enwiki-2013	4,206,785	101,355,853
twitter-2010	41,652,330	1,468,365,182
uk-2007-05	105,896,555	3,738,733,648
weibo-2013	72,393,453	6,431,150,494
clueweb-12	**978,048,098**	**42,574,107,469**

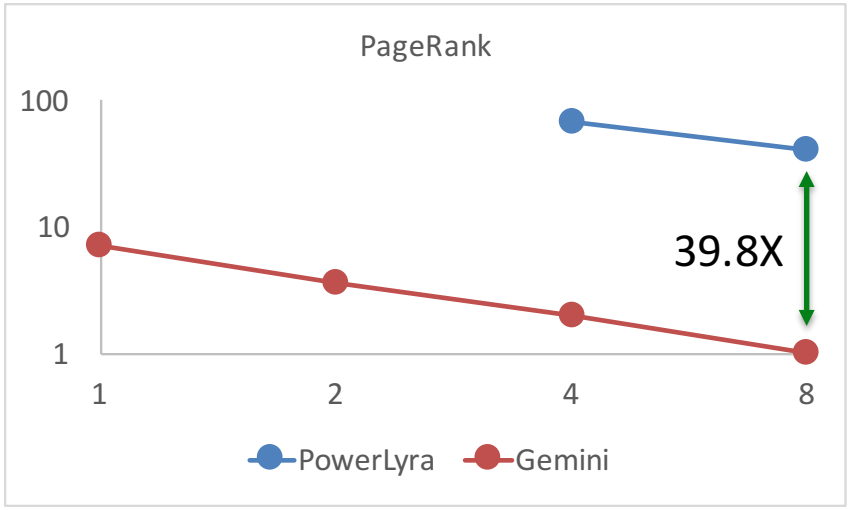
318GB input graph

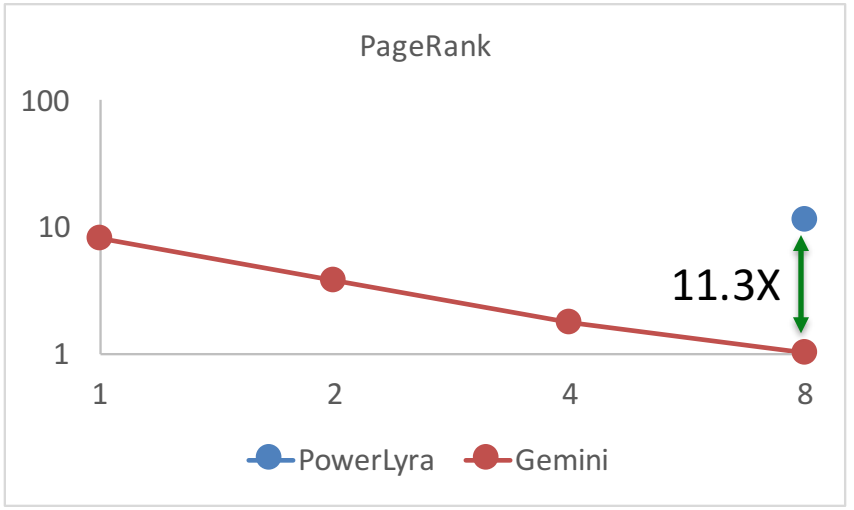
Application	PowerLyra	Gemini
PR	Out of memory	31.1
CC		25.7
SSSP		56.9
BFS		10.2
BC		45.3

Runtime in seconds (clueweb-12)

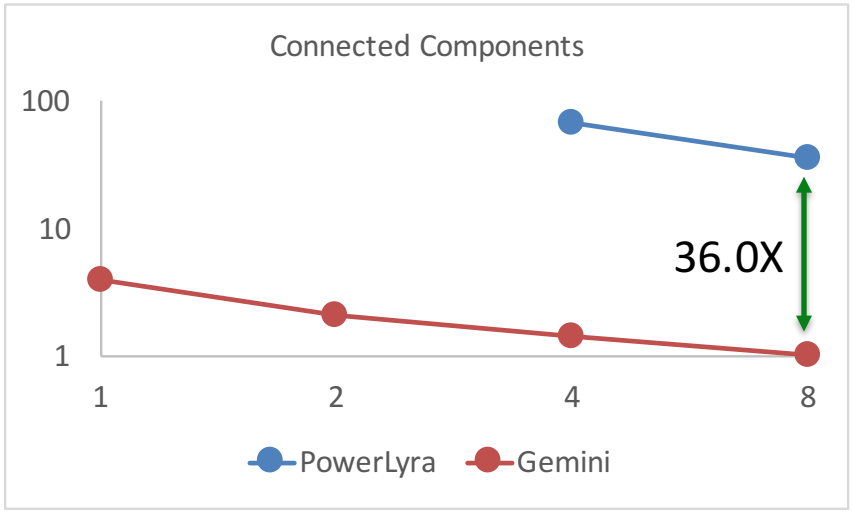
Multi-Node Scalability: Faster Speeds



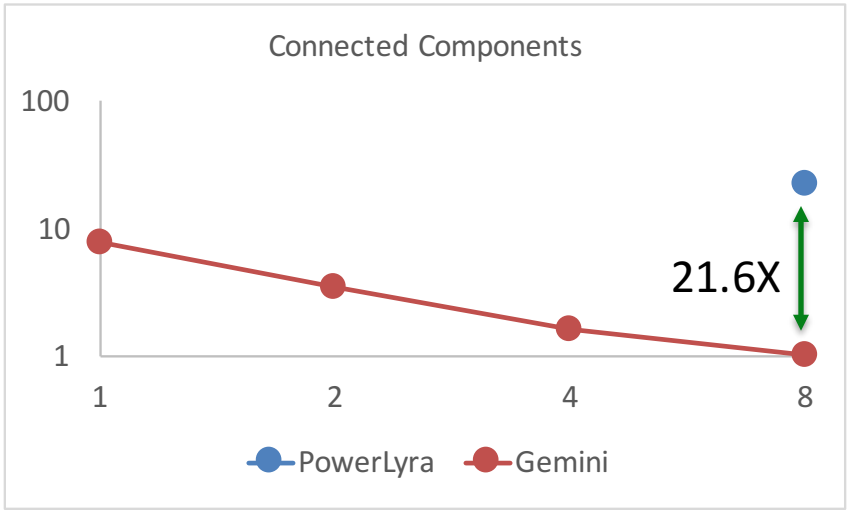




uk-2007-05



weibo-2013



Closing Remarks

Search **GeminiGraph** on Github

- What have we learned
  - Computation efficiency highlighted by fast network
    - Existing guidelines may not apply
  - **Chunking works!**
    - Multi-fold benefits
    - Enables series of optimizations

Thanks!

Q & A