GARAPH
EFFICIENT GPU-ACCELERATED GRAPH PROCESSING ON A SINGLE MACHINE WITH BALANCED REPLICATION

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Presented by Brian Wheatman

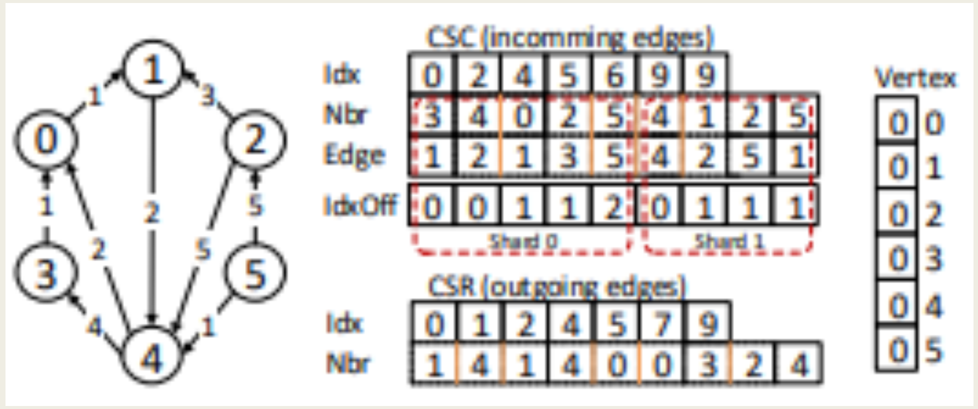
Goals of Garaph

- Use all resources of machines
  - *Large Memory*
  - *Fast Secondary Storage*
  - *CPU*
  - *GPU*
- Prior issues
  - *Skewed degree distribution*
    - Write contention
    - Work imbalance

Graph Representation

- Shards
  - *Disjoint set of vertices along with the incoming edges*
    - Increasing order of destination
  - *Sized to fit in the GPUs shared memory (about 12k vertices)*
  - *Replicated*
- Pages
  - *A set of shard for efficient movement of data*

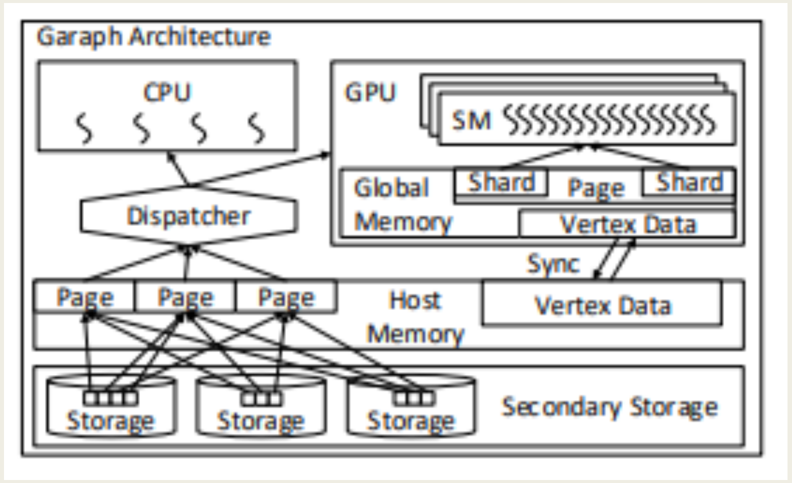
- CSC for incoming edges
  - *pull*
- CSR for outgoing edges
  - *Poor behavior on GPUs*
  - *Notify pull*
    - Only neighbors of the active set pull



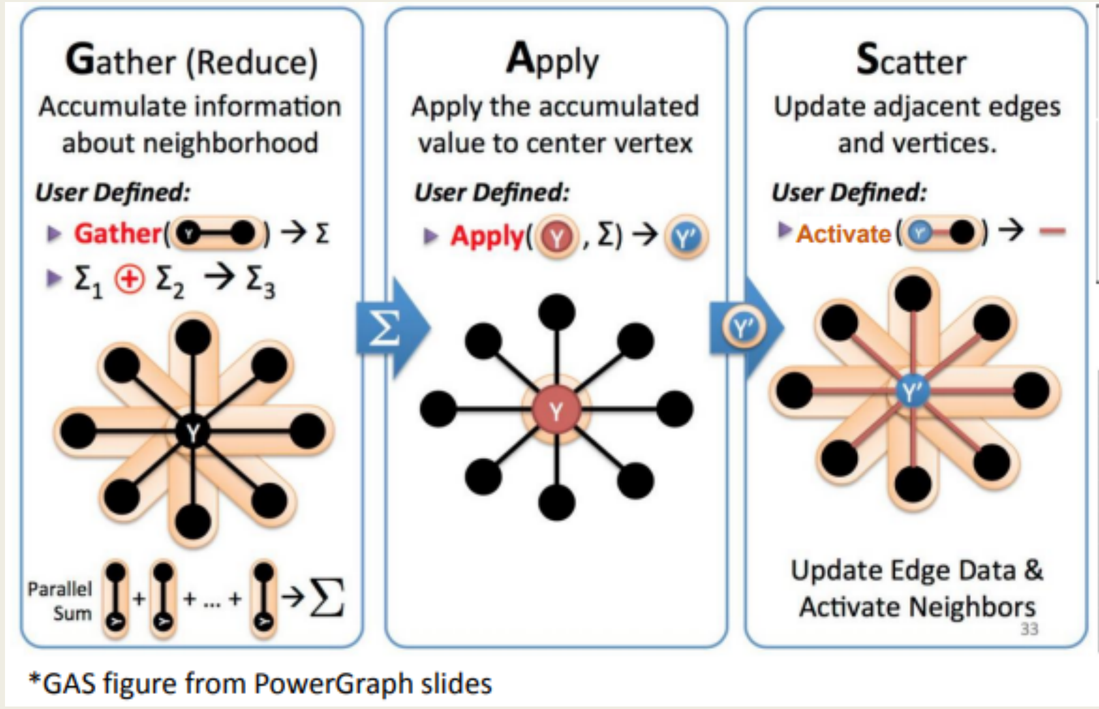
System Architecture

- Dispatcher
  - Loading graph
  - Distributing computation
  - Distribute data onto multiple SSDs

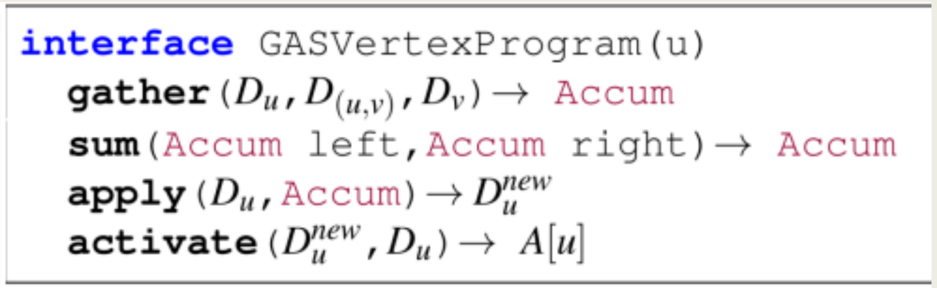
- GPU/CPU computation kernel
  - All blocks processed in parallel
  - Only pull on GPU
  - Both pull and notify pull on CPU
  - Can run either synchronously or asynchronously
    - When asynchronous updates are immediately visible
- Fault Tolerance
  - Periodically writes state to secondary storage



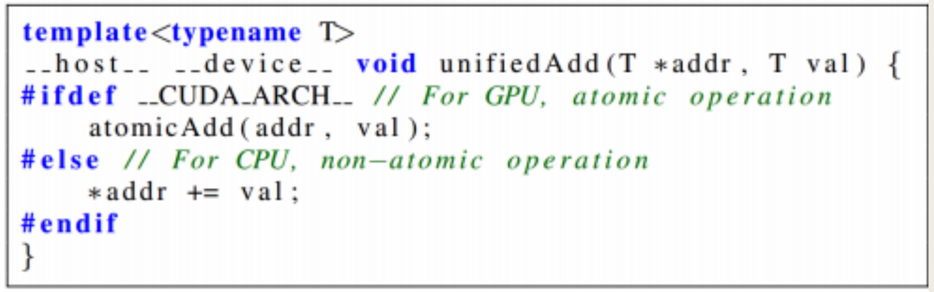
Programming API's


Gather (Reduce)
Accumulate information about neighborhood
User Defined:
Gather( ) → Σ
Σ1 ⊕ Σ2 → Σ3
Parallel Sum
Apply
Apply the accumulated value to center vertex
User Defined:
Apply(Y , Σ) → Y'
Scatter
Update adjacent edges and vertices.
User Defined:
Activate( ) →
Update Edge Data & Activate Neighbors
33

*GAS figure from PowerGraph slides



```
interface GASVertexProgram(u)
  gather(D_u, D_(u,v), D_v) → Accum
  sum(Accum left, Accum right) → Accum
  apply(D_u, Accum) → D_u^new
  activate(D_u^new, D_u) → A[u]
```



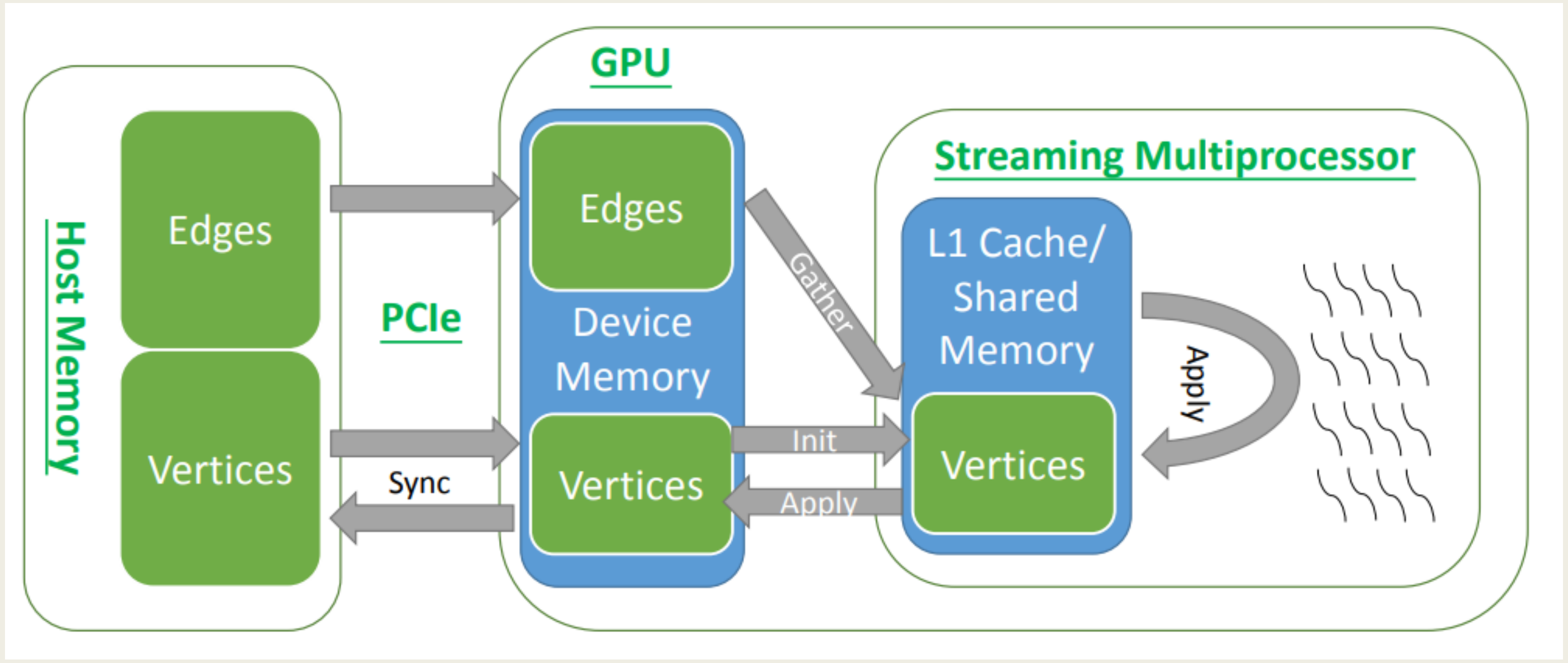
```
template<typename T>
__host__ __device__ void unifiedAdd(T *addr, T val) {
#ifdef __CUDA_ARCH__ // For GPU, atomic operation
    atomicAdd(addr, val);
#else  // For CPU, non-atomic operation
    *addr += val;
#endif
}
```

GPU-Based Graph Processing

- Graph Processing Engine
- Replication-Based Gather

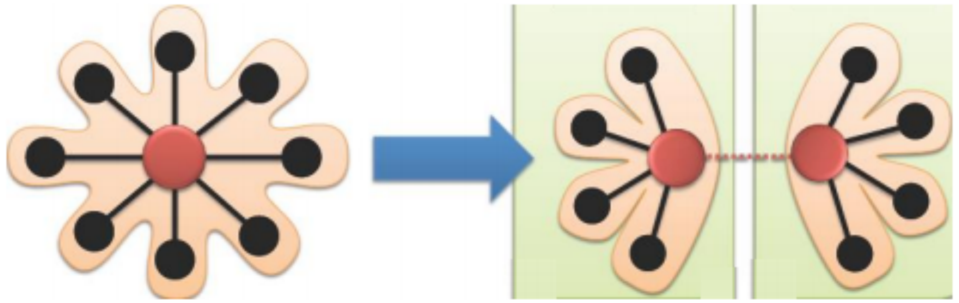
Graph Processing Engine

- Vertices stored in GPU global memory
- Each SM has a local copy of the vertices of the shard
  - Gather by reading from global memory updating the local copy
  - Then written back to global memory on GPU
  - After round GPU global memory synchronized with host memory

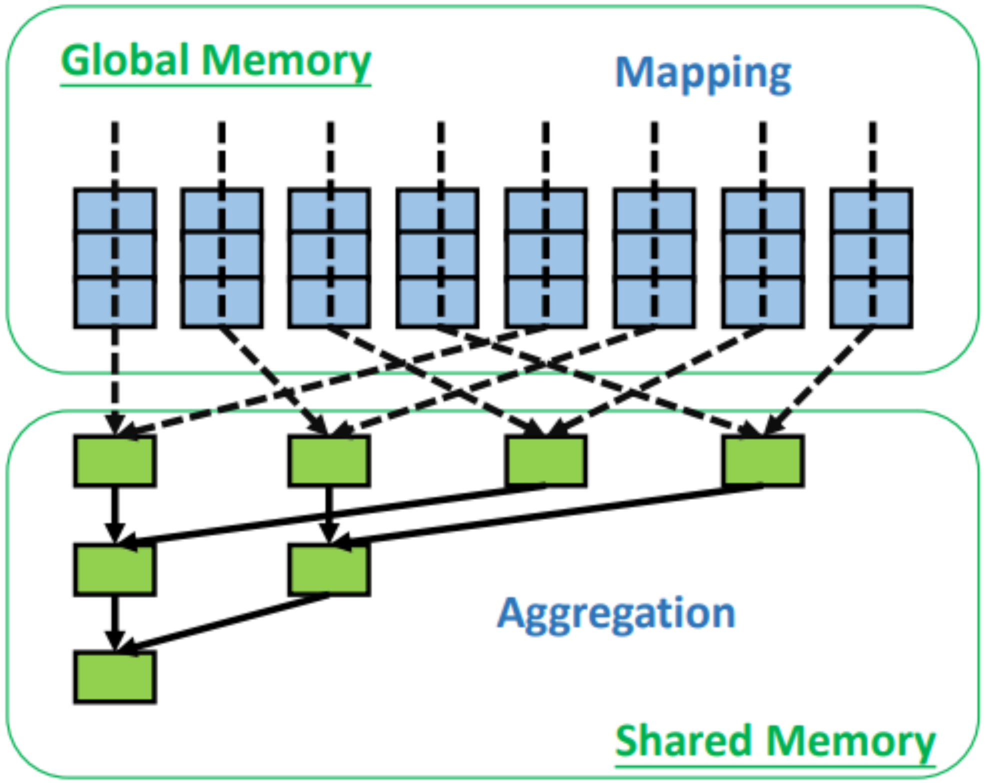


Replication-Based Gather

- To avoid write contention
  - *Within a shard lots of edges going to the same node*
    - Made worse by natural graphs power law distribution
  - *Replicate the node data and sum up partial values then accumulate*

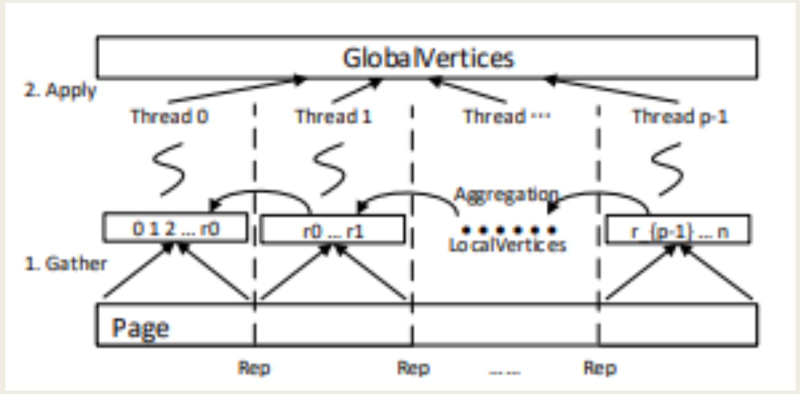


- Customized replication
  - O(N) -> O(logN), N≤32
  - Modeling: balance profits and costs
  - $R_i = 2^{\min\left\{\left\lceil \log \frac{|E_i|}{|V_i|} - 0.5\right\rceil, 5\right\}}$.



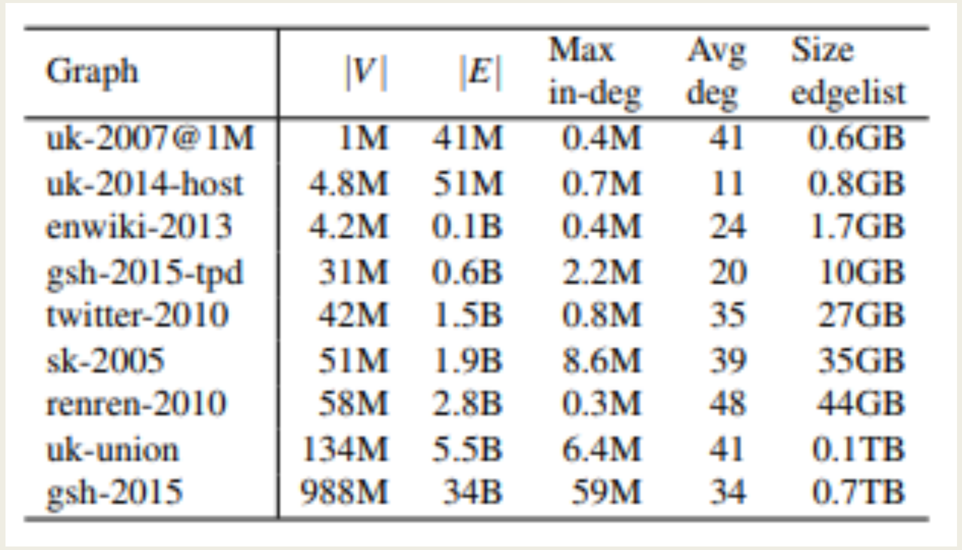
CPU-Based Graph Processing

- Processing with Edge Partitions
  - *Edges or split up equally into different partitions*
  - *Vertexes split are duplicated*
    - Later aggregated to obtain value
- Dual-Mode Processing Engine



Evaluation

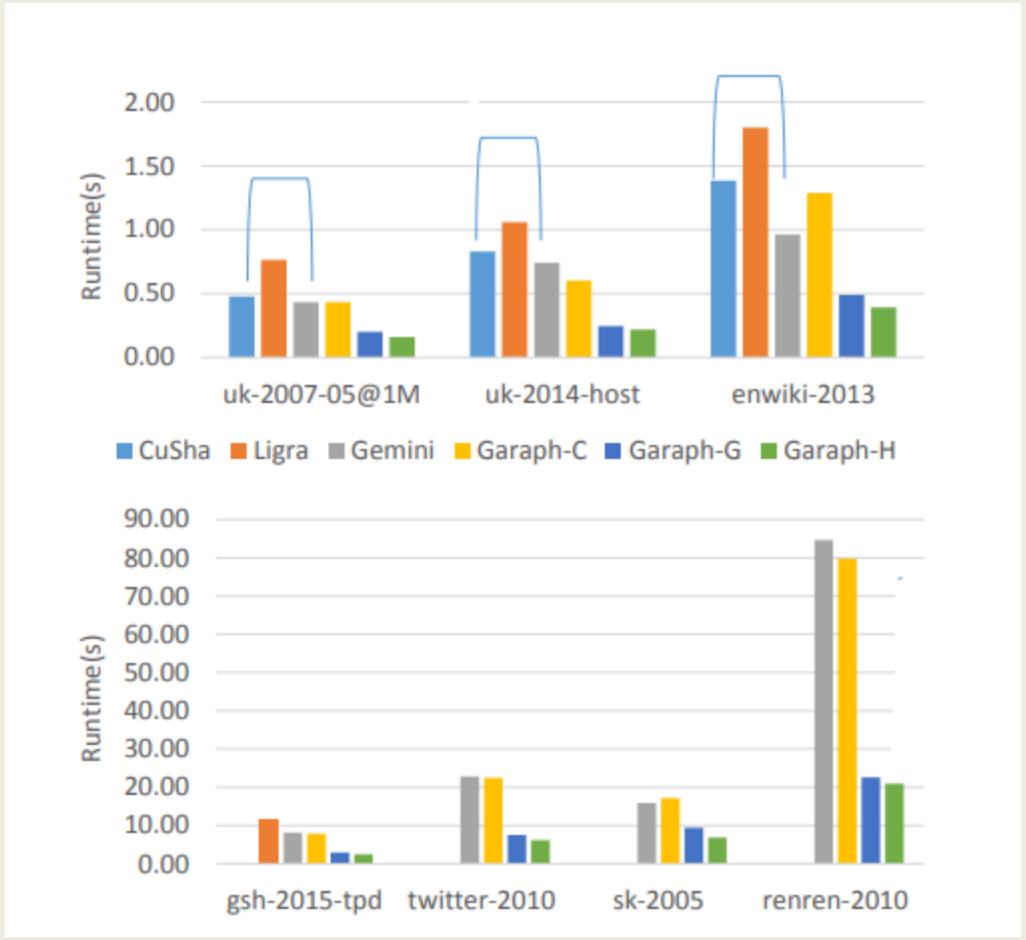
- Comparison with Other Systems
- Customized Replication
- Dual Modes of the CPU Kernel
- Hybrid CPU-GPU Scheduling



Graph	$\lvert V \rvert$	$\lvert E \rvert$	Max in-deg	Avg deg	Size edgelist
uk-2007@1M	1M	41M	0.4M	41	0.6GB
uk-2014-host	4.8M	51M	0.7M	11	0.8GB
enwiki-2013	4.2M	0.1B	0.4M	24	1.7GB
gsh-2015-tpd	31M	0.6B	2.2M	20	10GB
twitter-2010	42M	1.5B	0.8M	35	27GB
sk-2005	51M	1.9B	8.6M	39	35GB
renren-2010	58M	2.8B	0.3M	48	44GB
uk-union	134M	5.5B	6.4M	41	0.1TB
gsh-2015	988M	34B	59M	34	0.7TB

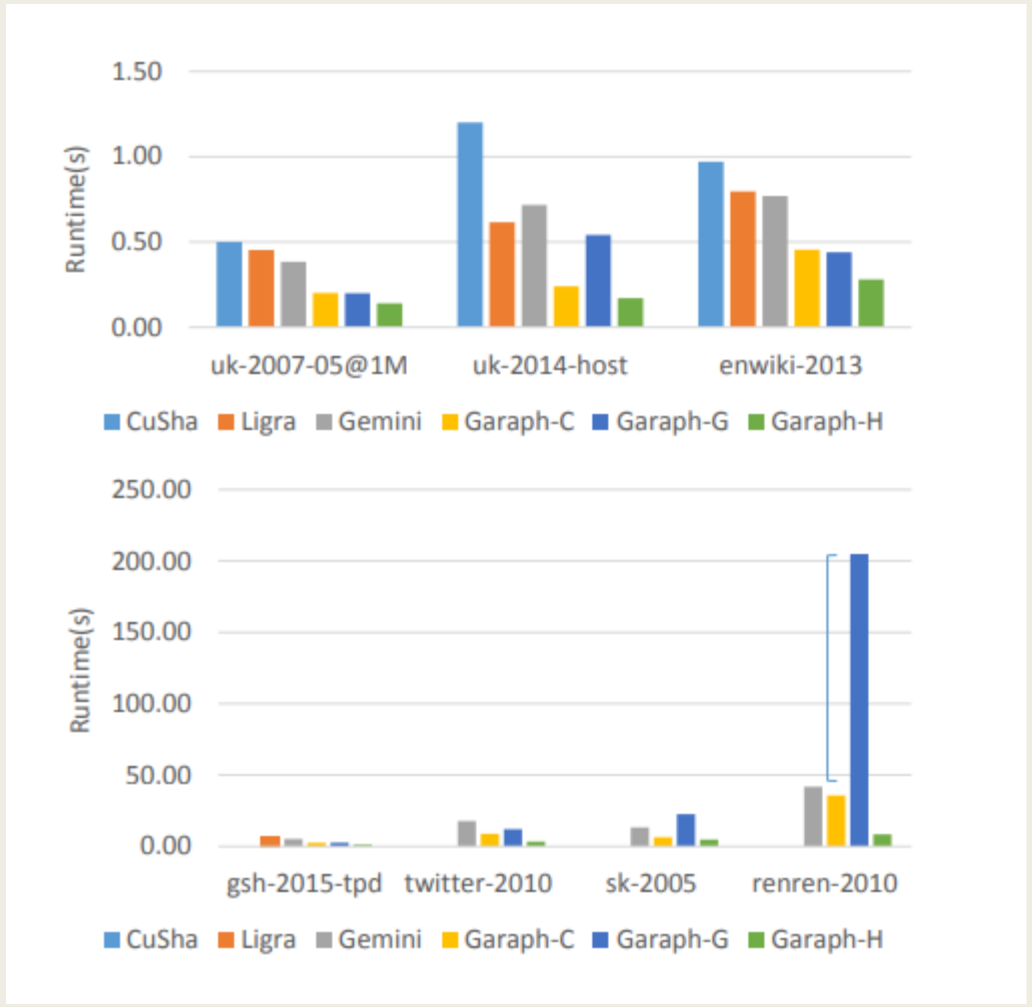
Comparison with Other Systems

- 10 iterations Pagerank



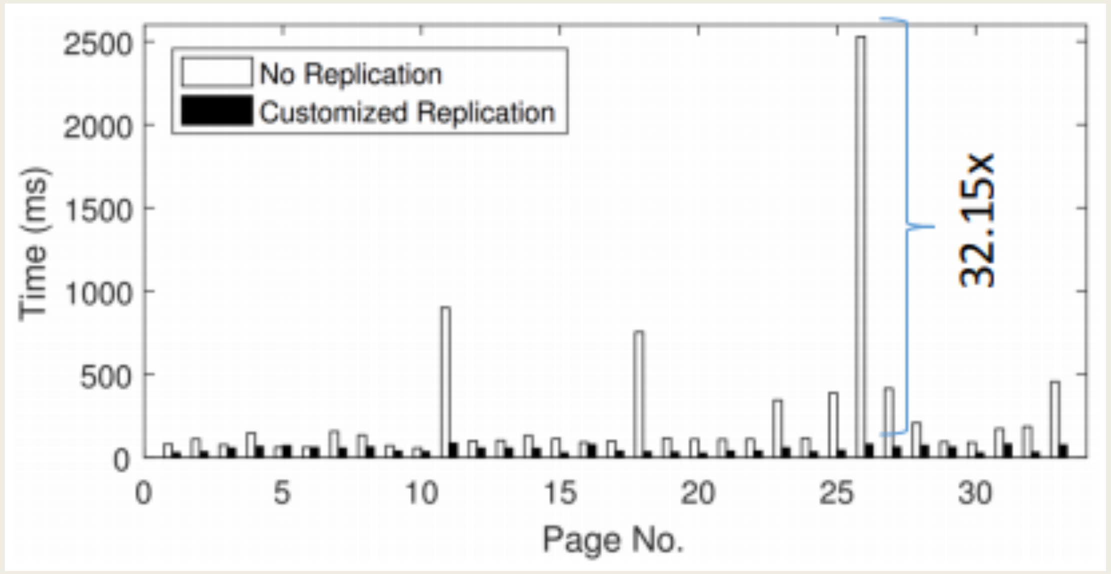
Comparison with Other Systems

- Connected components
- Until convergence
- GPU can be much slower



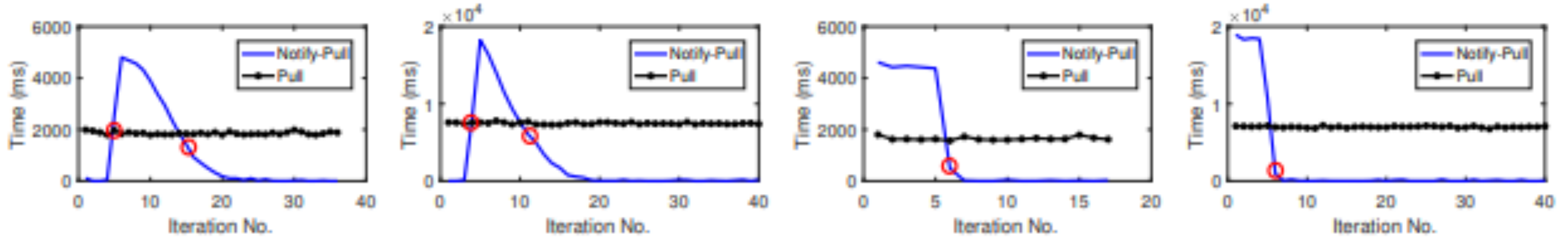
Customized Replication

- Helps some pages dramatically



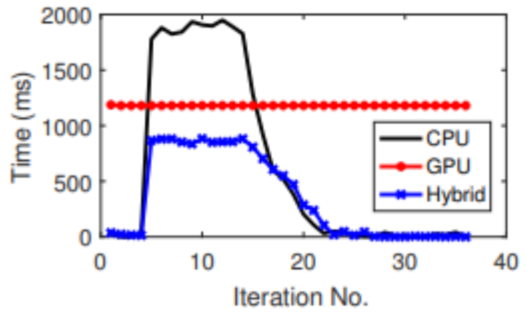
Dual Modes of the CPU Kernel

- On some iterations notify pull is much better

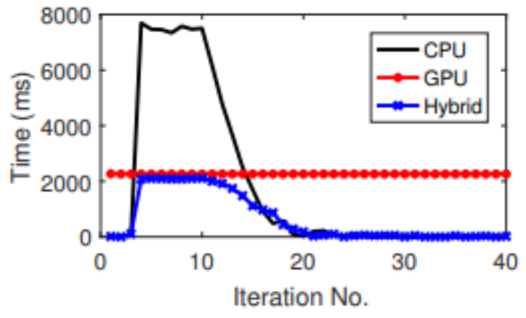


(a) SSSP: twitter-2010 (b) SSSP: renren-2010 (c) CC: twitter-2010 (d) CC: renren-2010

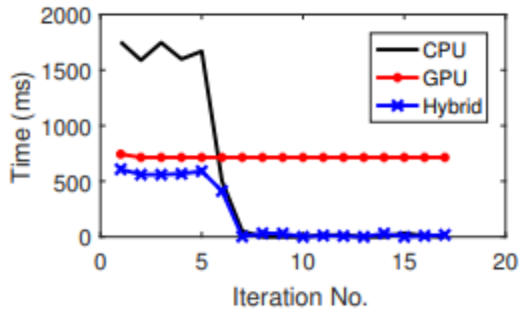
Hybrid CPU-GPU Scheduling



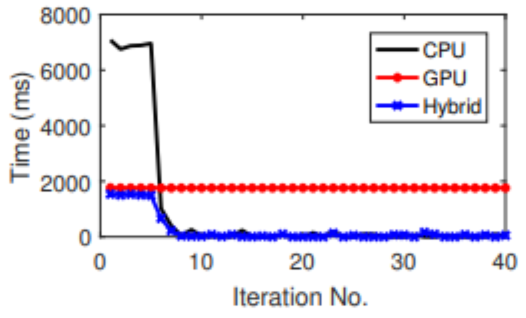
(a) SSSP: twitter-2010



(b) SSSP: renren-2010



(c) CC: twitter-2010



(d) CC: renren-2010