

# Introducing ESCAPE, Gunrock and Pluros

## Groundbreaking Performance through Algorithms, Hardware and Abstractions



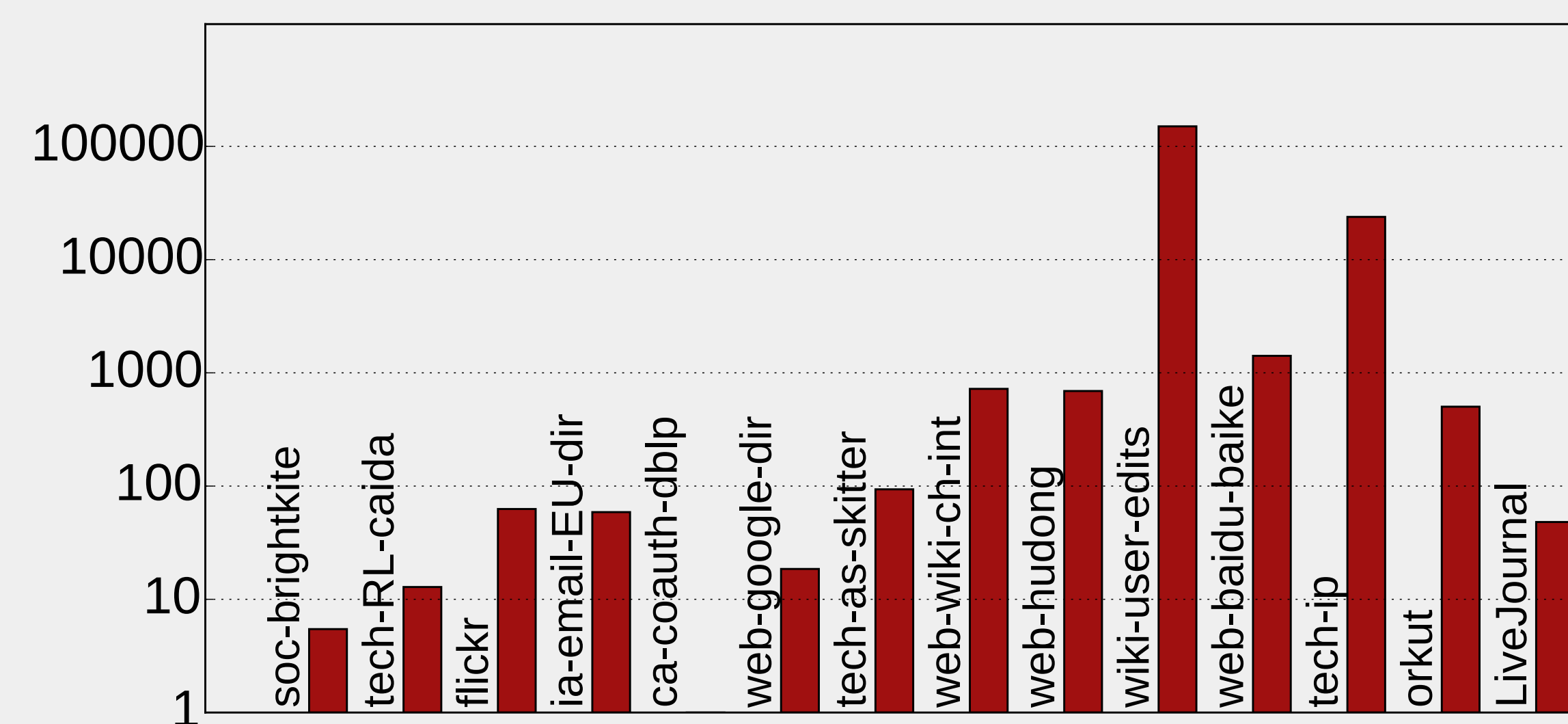
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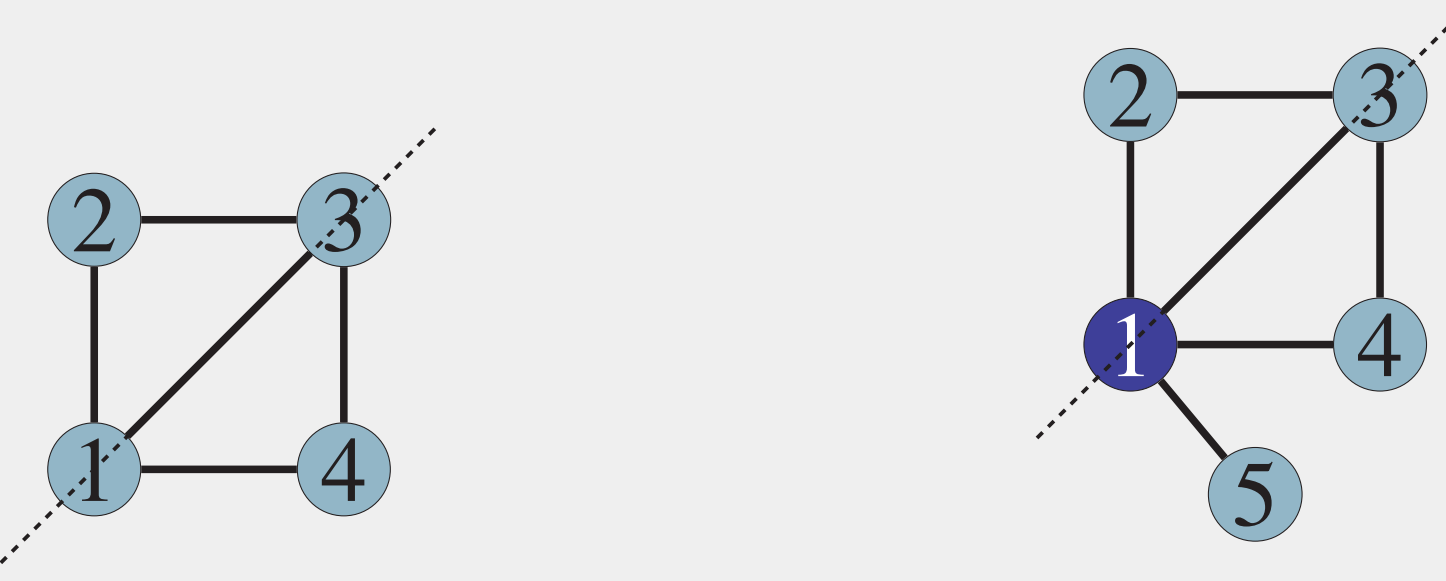
### Exact 5-vertex counts in minutes with ESCAPE

- ▶ Counting small subgraphs is of fundamental importance in bioinformatics, social science, infrastructure networks and many other domains.
- ▶ A  $10^7$  edge graph can have  $10^{12}$  4-vertex and  $10^{17}$  5-vertex patterns!
- ▶ ESCAPE counts up to 5-vertex patterns *exactly* in minutes on a single core.
- ▶ 10–1000x faster than previous state-of-the-art for 4-vertex counting.
- ▶ First practical solution for exact 5-vertex counts for graphs of this size.

Speedup over PGD



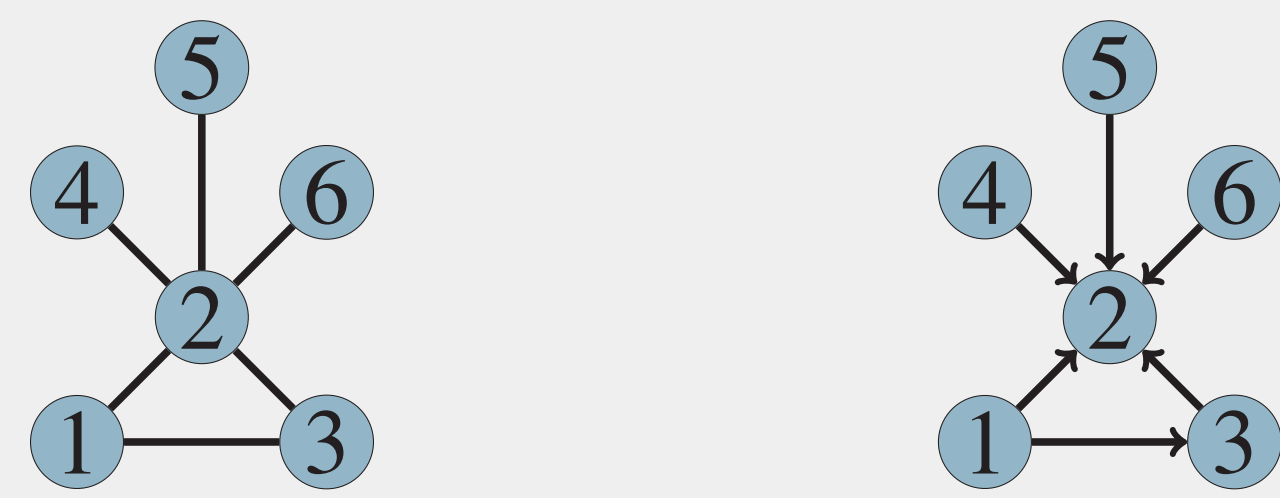
**Key idea 1:** split larger patterns into smaller ones by vertices or edges and then use a simple combinatorial formula. For example, the triangle count associated with an edge ( $\Delta_{1,3}$ ) can be used to count the 4 and 5-vertex patterns shown without actually discovering each instance of the larger pattern.



Chordal 4-cycle: Edge (1,3) cuts the pattern, count is  $\binom{\Delta_{1,3}}{2}$

Pattern 5-11: Edge (1,3) and vertex 1 cut the pattern, count is  $\binom{\Delta_{1,3}}{2}(d_1 - 3)$

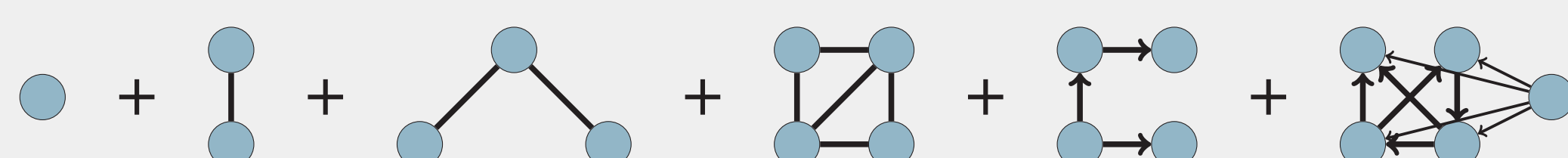
**Key idea 2:** orient the graph by degree-order and enumerate directed versions of a pattern to reduce combinatorial explosion.



Original undirected graph  
Vertex 2 is expensive

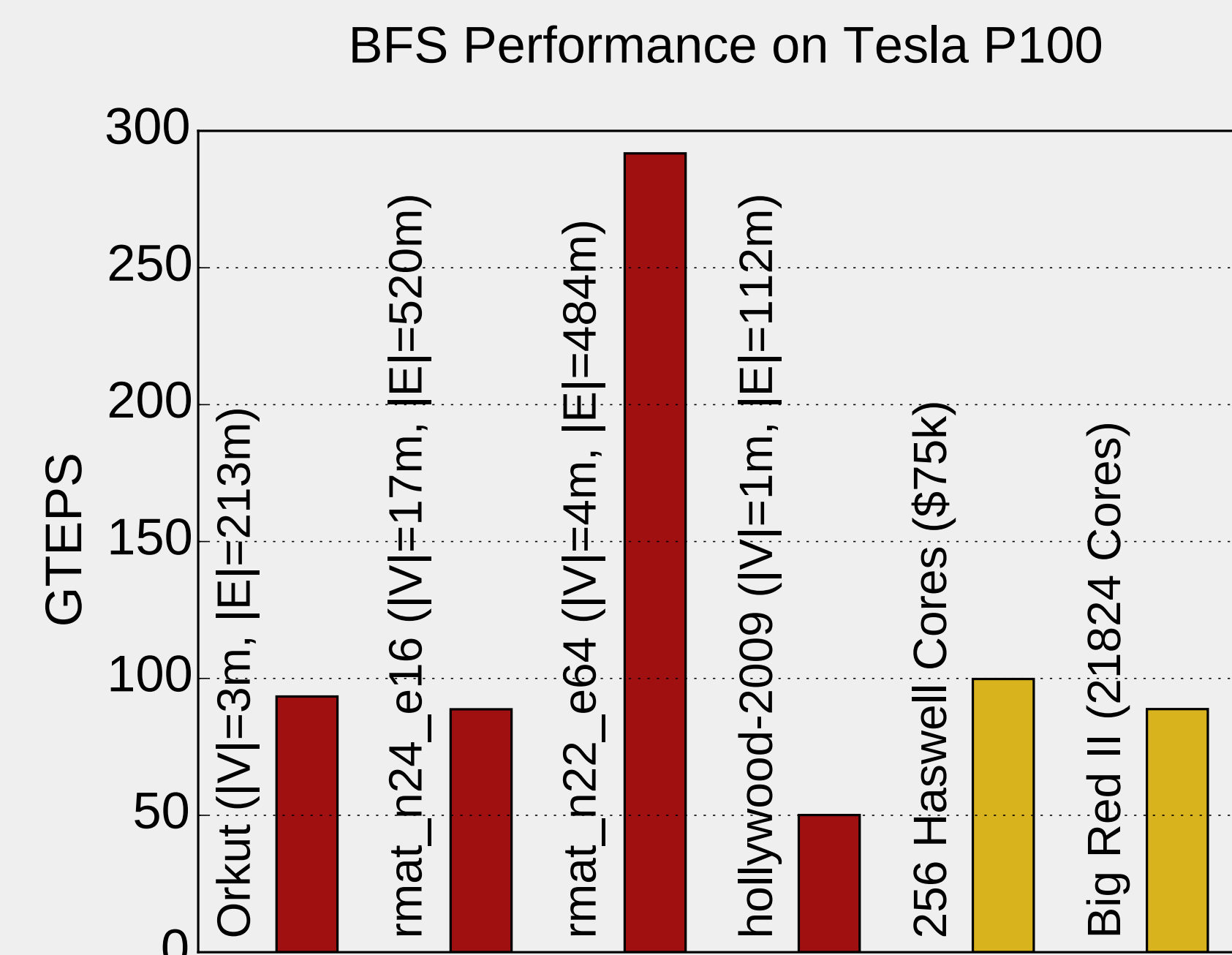
Oriented by degree  
Only Vertex 1 has an out-out pair

**Provable complexity:** expressed in counts of specific patterns



### Nearing 100 GTEPS on 1 GPU with Gunrock

- ▶ GPUs offer tremendous power, but challenging to leverage for graphs.
- ▶ Gunrock enables GPU implementations in just tens of lines of C++.
- ▶ Supercomputing performance with commodity GPUs!
- ▶ Gunrock currently scales to 4-6 GPUs in a box.

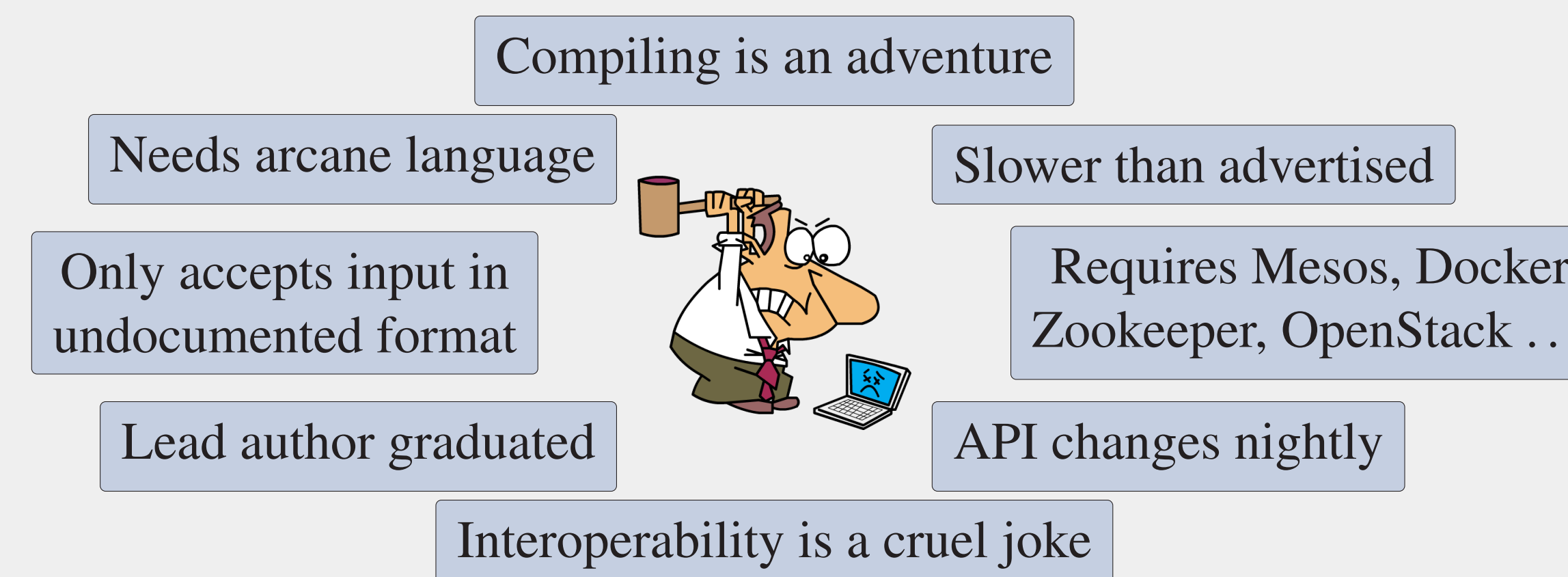


Gunrock uses sophisticated load balancing combined with memory and cache-friendly data layout, hidden behind a few customizable operators:

- ▶ **advance:** generate a new frontier by visiting neighbors
- ▶ **filter:** remove elements from a frontier based on a predicate
- ▶ **compute:** apply per-vertex or per-edge operations
- ▶ **intersect:** get intersection of two frontiers

Gunrock comes with applications like SSSP, Page Rank, Betweenness-Centrality, Connected Components, SALSA, HITS, Twitter ‘who to follow’ and more. Gunrock can be used with C, C++ and Python.

### A better way to use the cutting-edge?

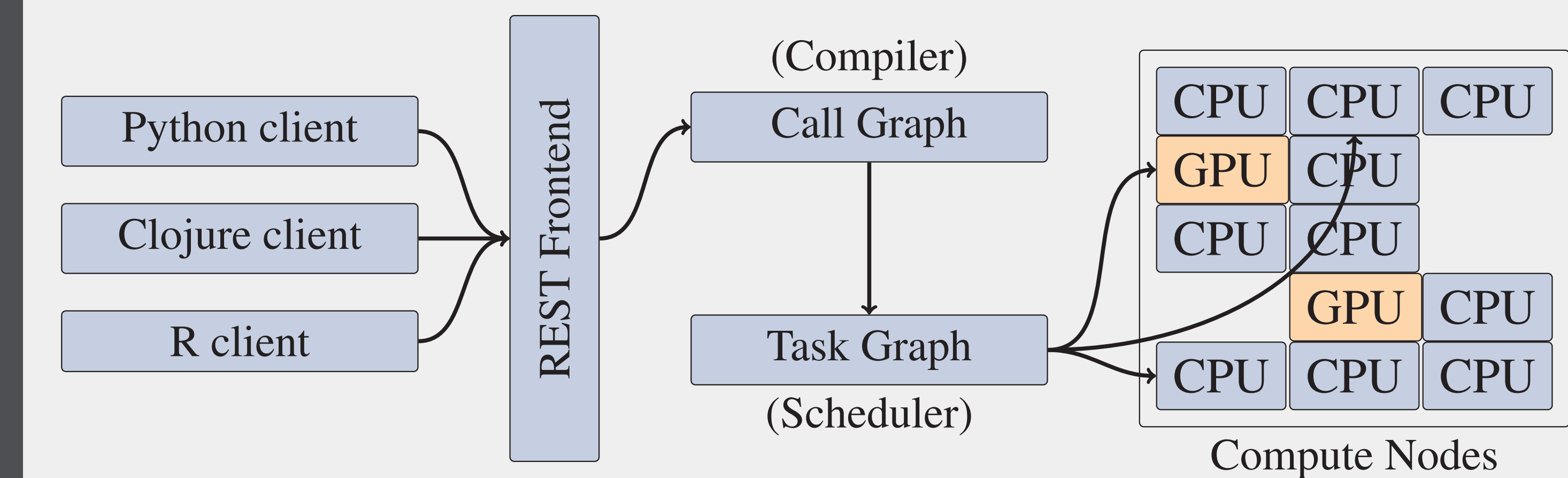


Can we build a system that offers all our favorite HPC tools with:

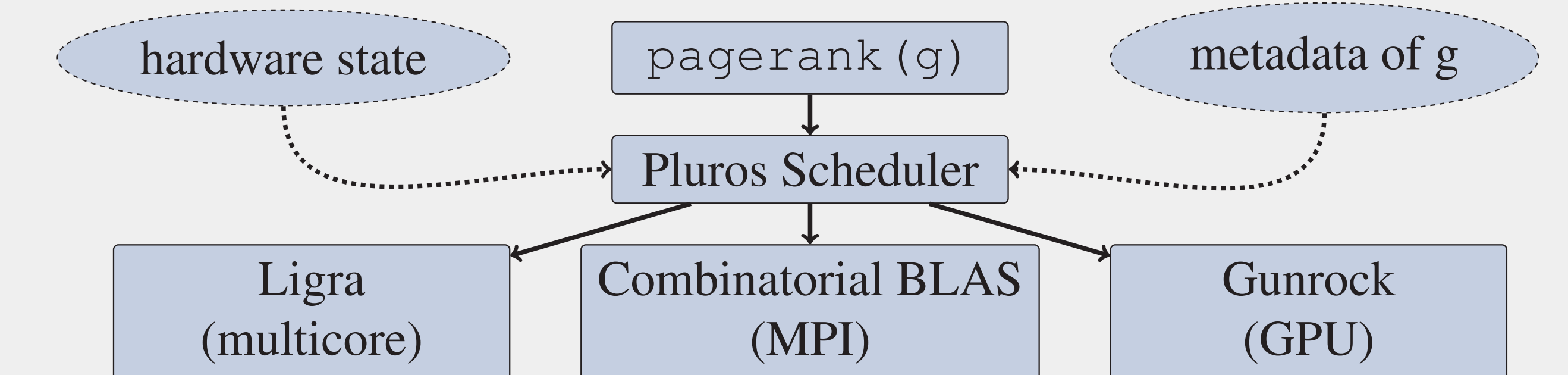
- ▶ a simple, seamless API in any modern language,
- ▶ transparent scaling with problem size, hardware, users,
- ▶ isolation from software and hardware hassles,
- ▶ **without compromising on performance?**

### Pluros: a scalable black box full of HPC goodies

- ▶ Encapsulates a scalable collection of compute elements as a service.
- ▶ Lets you compose data-flow programs that get optimally mapped to heterogenous hardware.



- ▶ Incorporates disparate and competing HPC solutions with minimal or no modification and exposes them with a unified API.
- ▶ Self-learning scheduler determines the right software and hardware for a specific problem.
- ▶ Silently handles all details of scalability and interoperability.



- ▶ Graph API powered by ESCAPE, Gunrock, NVGraph, Combinatorial BLAS, Ligra, Galois, Stinger, PowerGraph and many others.
- ▶ Seamlessly composable with data cleanup, feature engineering, machine learning, deep learning, image processing and other APIs.
- ▶ Supports distributed data ingestion and low-latency streaming.
- ▶ Open source, to be released in Summer 2017.

### Credits

Partially funded by DARPA awards D14PC00023, D15PC00010, D15PC00106 and WN11NF16C0020, in collaboration with Royal Caliber, LLC. and Onu Technology, Inc. ESCAPE development is led by Prof. C. Seshadhri at U.C. Santa Cruz and Dr. Ali Pinar at Sandia National Labs. Gunrock development is led by Prof. John Owens at U.C. Davis.

### Additional information

| Project | Information              | Source code                    |
|---------|--------------------------|--------------------------------|
| ESCAPE  | arxiv.org/abs/1610.09411 | bitbucket.org/seshadhri/escape |
| Gunrock | arxiv.org/abs/1791.01170 | github.com/gunrock/gunrock     |
| Pluros  | pluros.io                | To be released Summer 2017     |