A Language Designer's Perspective on Benchmarking Suites and Competitions

Brad Chamberlain
Chapel Team, Cray Inc.
June 2, 2017

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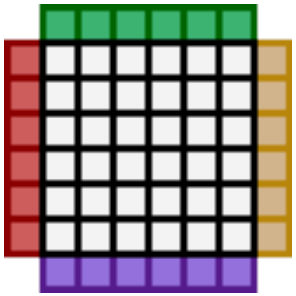
My Background

Education:

UNIVERSITY OF WASHINGTON
Computer Science & Engineering



- Earned Ph.D. from University of Washington CSE in 2001
  - worked on the ZPL data-parallel array language
- Remain associated with UW CSE as an Affiliate Professor

Industry R&D: CRAY

- Currently a Principal Engineer at Cray Inc.
- Technical lead and founding member of the Chapel language project

CRAY CHAPEL

What is Chapel?

Chapel: A productive parallel programming language

- portable
- open-source
- a collaborative effort

Goals:

- Support general parallel programming
- Make parallel programming at scale far more productive

Motivation for Chapel

Q: Can a single language be…

…as programmable as Python?
…as fast as Fortran?
…as portable as C?
…as scalable as MPI?
…as generic and meta- as C++? (but using simpler notation?)
…as fun as <your favorite language here>?

A: We believe so.

Q: So why don't we have such languages already?

A: Due to a lack of…

…long-term efforts
…resources
…community will
…developer/user co-design
…patience

Chapel is our attempt to change this

A few terminology notes for this talk…

Benchmark **= benchmarks, kernels, proxy apps, mini-apps, …**

- I don't want to get caught up in that terminological debate

Language **= any parallel programming model**

- whether a true language, an extension, a library, a pragma notation, …

"So you're designing an HPC language… how?"

- **Do something modest?**
  - challenging to create a sea change
    - likely to either result in hybrid programming models (e.g., MPI+X+Y)
    - or to not present an enticing cost::benefit ratio for switching (e.g., UPC?)
- **Do something big?**
  - potential for greater impact, but almost certain to take more time
- **closed-source or open-source?**
  - if closed, how to get co-design feedback early and often?
  - if open, how to keep audience's attention during development?
- **Chapel took the "go big (in the open) or go home" route**
  - currently suffers from "I knew you as an awkward kid" syndrome

Chapel Headlines: Which were you aware of?

- **Chapel is open-source and freely available**
- **Chapel is portable** (recent adds: AWS EC2, Docker, Windows 10, …)
- **Chapel has 14 full-time employees working on it at Cray**
  - and many other collaborators/contributors in the community
- **Chapel performance can now compete with, or beat, MPI and SHMEM**
- **Chapel has closed all major known compiler-introduced memory leaks**
- **Chapel now supports MPI+X execution**
- **Chapel supports unified access to MCDRAM on Intel Xeon Phi ("KNL")**
- **Chapel has nearly 200 webpages of modern, online documentation**
- **Chapel has a rich, growing library** (FFTW, BLAS, LAPACK, BigInt, …)
- **CHIUW, Chapel's 4th annual implementer and user workshop is today**

EMBRACE's theme and languages like Chapel

Getting Chapel's message out is clearly our challenge…

…but benchmarks play a big role in our ability to do so

Chapel Headlines (directly related to benchmarks)

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Benchmarks permit us (and users) to evaluate our progress

- relative to the status quo
- relative to other competing technologies

If you care about language innovation and adoption, you should care about benchmarks

And in addition, arenas for benchmark comparisons

What do I mean by an “arena”?

- **Essentially, a place for benchmark comparisons**
  - cross-language, cross-implementation, cross-architecture
- **Think of the top-500 as a performance-centric arena**
  - how can we expand this notion to include productivity, other concerns?
- **I’ll build on this definition as we go…**

Outline

- ✓ **Context**
  - ✓ Who I am
  - ✓ What Chapel is
  - ✓ Why I'm here
- ➢ **Survey of benchmark suites with which I have experience**
  - NPB, HPCC, DOE proxy apps, CLBG, PRK
    - What they are
    - What I've appreciated about them
    - Where they could be improved
- **Summary:** If I had resources to throw at benchmark suites…

Disclaimers

All of the following characterizations are my personal opinions—yours will likely differ.

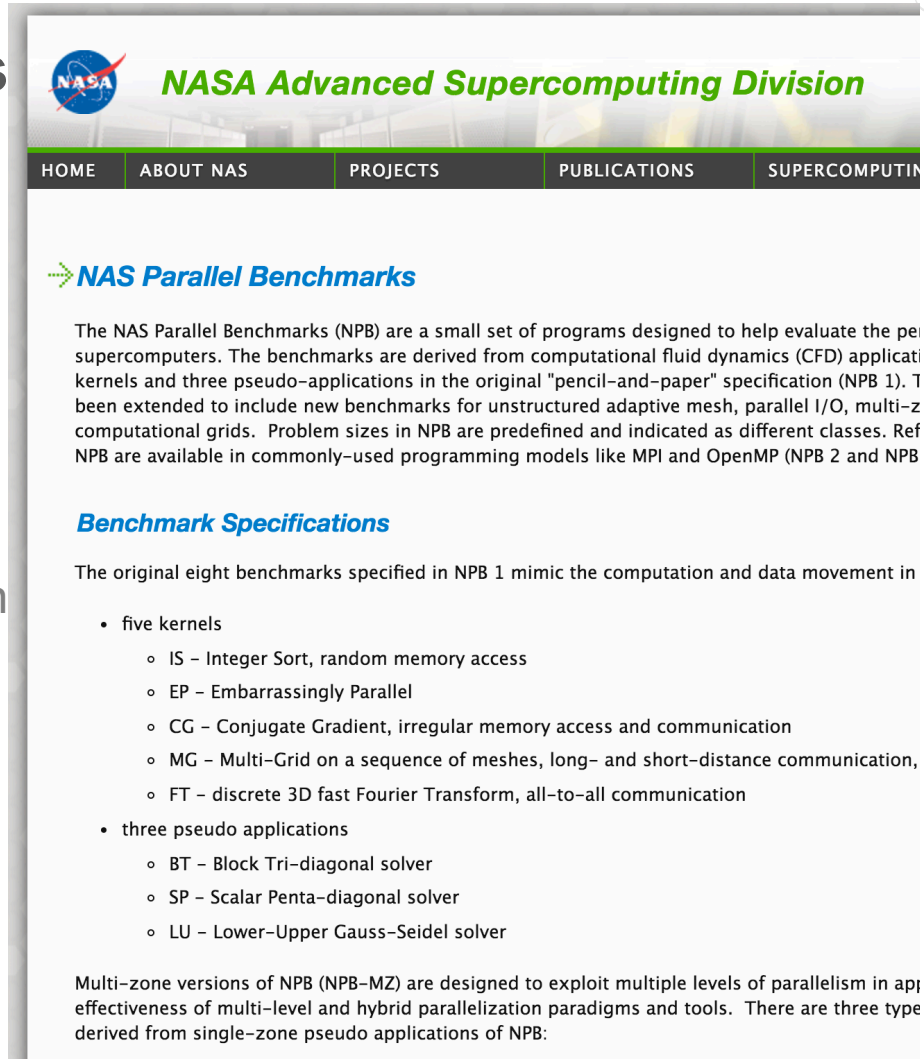
Also, my own opinions may be based on incomplete / incorrect information (for which I apologize).

The NAS Parallel Benchmark Suite (NPB)

(circa mid-to-late 1990's)

NPB: What it is

- 8 CFD-oriented benchmarks
  - paper-and-pencil descriptions
  - MPI, OpenMP implementations
    - (and others as well…)
  - Capture common HPC patterns
    - pleasingly parallel computations
    - data transpose
    - sparse mat-vect multiplication
    - stencils on hierarchical grids
    - bucket-exchange communication
    - …



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NAS Parallel Benchmarks

The NAS Parallel Benchmarks (NPB) are a small set of programs designed to help evaluate the pe supercomputers. The benchmarks are derived from computational fluid dynamics (CFD) applicat kernels and three pseudo-applications in the original "pencil-and-paper" specification (NPB 1). T been extended to include new benchmarks for unstructured adaptive mesh, parallel I/O, multi-z computational grids. Problem sizes in NPB are predefined and indicated as different classes. Ref NPB are available in commonly-used programming models like MPI and OpenMP (NPB 2 and NPB

Benchmark Specifications

The original eight benchmarks specified in NPB 1 mimic the computation and data movement in

- five kernels
  - IS - Integer Sort, random memory access
  - EP - Embarrassingly Parallel
  - CG - Conjugate Gradient, irregular memory access and communication
  - MG - Multi-Grid on a sequence of meshes, long- and short-distance communication,
  - FT - discrete 3D fast Fourier Transform, all-to-all communication
- three pseudo applications
  - BT - Block Tri-diagonal solver
  - SP - Scalar Penta-diagonal solver
  - LU - Lower-Upper Gauss-Seidel solver

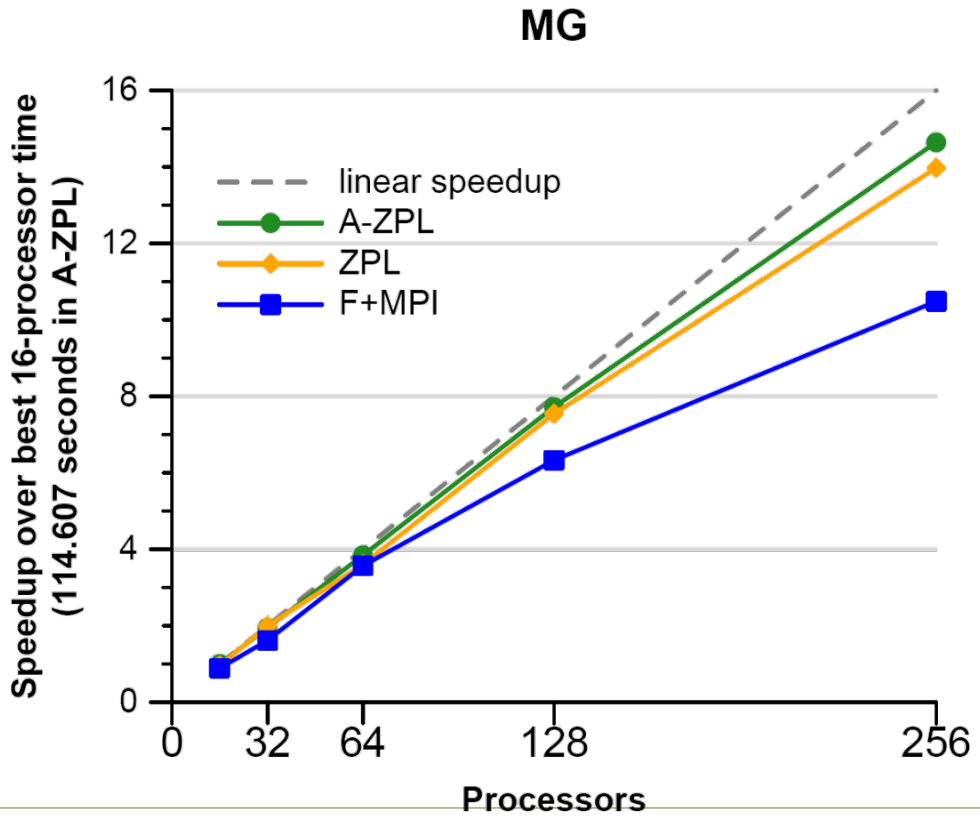
Multi-zone versions of NPB (NPB-MZ) are designed to exploit multiple levels of parallelism in app effectiveness of multi-level and hybrid parallelization paradigms and tools. There are three type derived from single-zone pseudo applications of NPB:

NPB: What it did well

- **Early example of what an HPC benchmark suite should be**
  - Well-designed and implemented
  - Reasonably well-documented
  - The basis for many evaluations of languages, systems, compilers

NPB: What it did well

- **Helped me graduate:**
  - supported comparison between ZPL and MPI for interesting patterns
  - sufficiently approachable for a graduate student to be successful with



Rating Benchmark Suites (on a 7-point scale)

- **Would HPC Application Developers care about this?**
  - **key:** 1 = no; 4 = eh…; 7 = yes!
- **Does a (clear) paper and pencil description exist?**
  - **key:** 1 = no or completely unclear; 7 = yes, and it's crystal clear
    - Ideally, a paper and pencil description should not assume the reader can translate from math equations into HPC code
    - rather, it should talk in terms of data structures and access patterns
- **Does the suite include a fast reference version?**
- **Does the suite include a clear reference version?**
  - **key:** 1 = no, or it's not; 7 = yes and it is

Rating Benchmark Suites (on a 7-point scale)

- **Would HPC Application Developers care about this?**
  - **key:** 1 = no; 4 = eh…; 7 = yes!
  - NPB: 6-7 when written, 5-6 now?
- **Does a (clear) paper and pencil description exist?**
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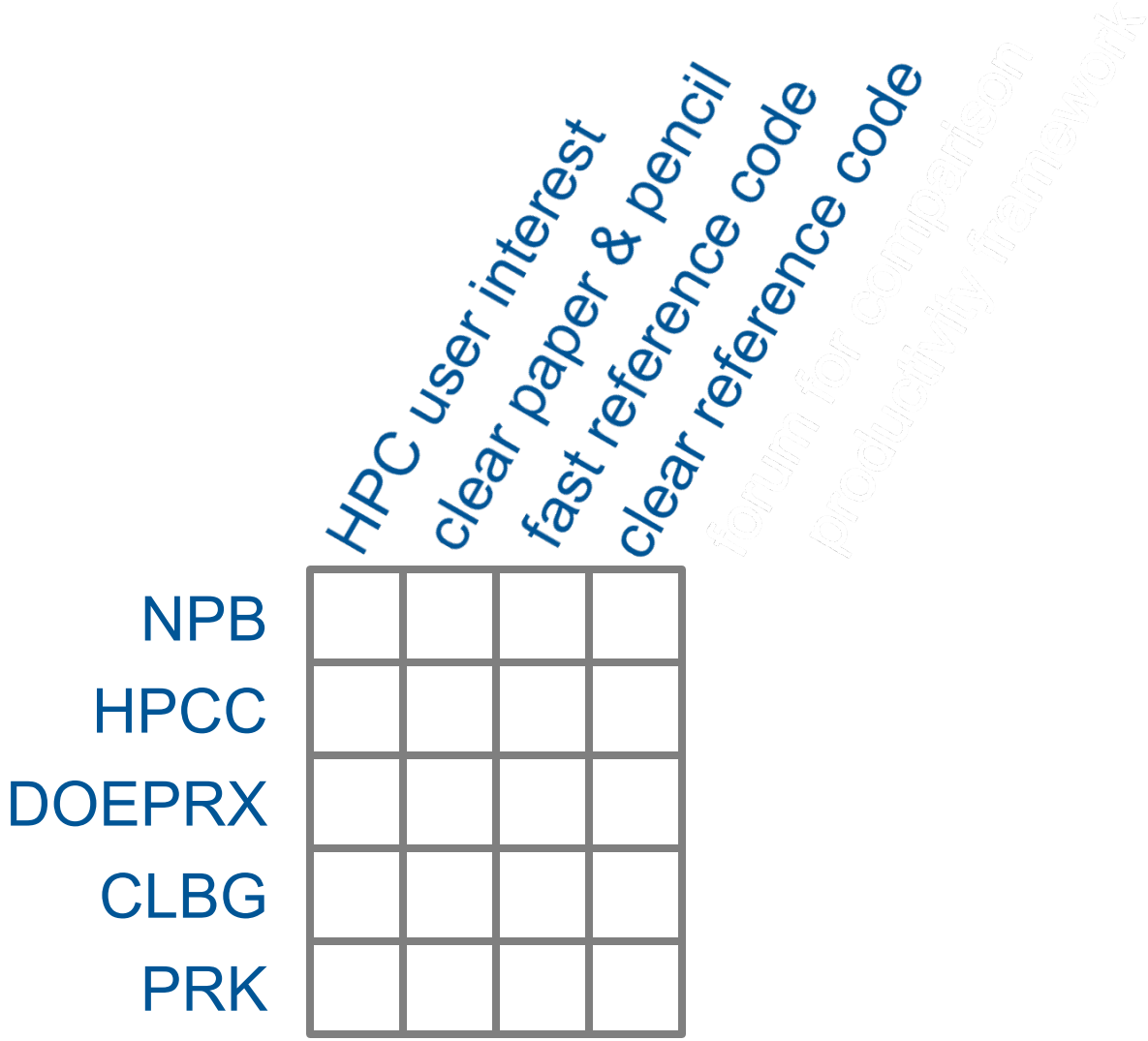
    - Ideally, a paper and pencil description should not assume the reader can translate from math equations into HPC code
    - rather, it should talk in terms of data structures and access patterns
  - NPB: 3 (too many equations, not enough data structures / CS)
- **Does the suite include a fast reference version?**
  - NPB: 7
- **Does the suite include a clear reference version?**
  - **key:** 1 = no, or it's not; 7 = yes and it is
  - NPB: 3 (it's not terrible, but also not particularly instructive)

Benchmark Suite Scorecard

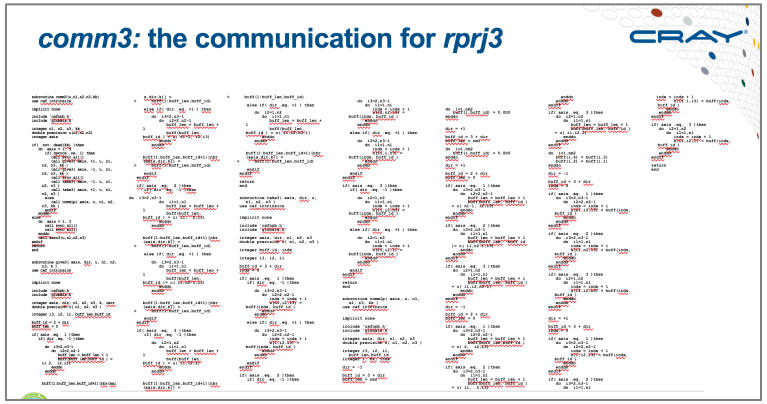


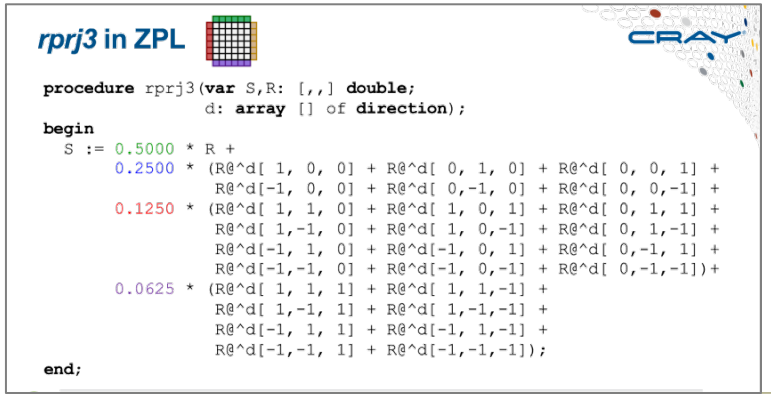
Benchmark Suite Scorecard

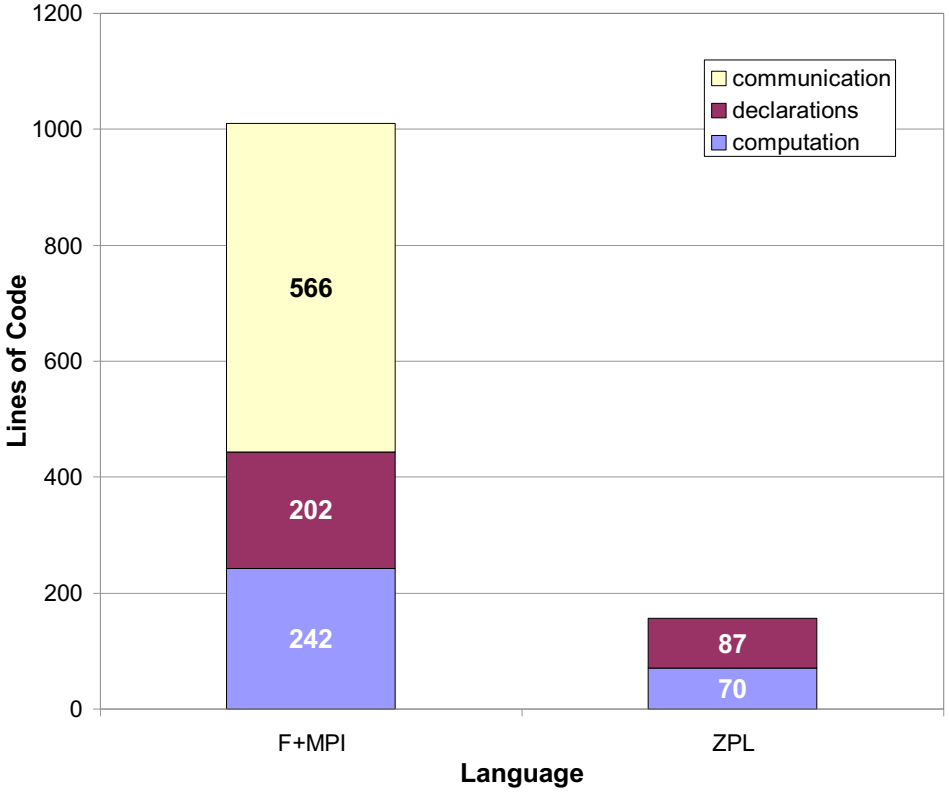
	HPC user interest	clear paper & pencil	fast reference code	clear reference code	forum for comparison	productivity framework
NPB	✓	~	✓	~		
HPCC						
DOEPRX						
CLBG						
PRK						

NPB: Where it fell short

- No established competition for comparing performance
- No prescribed basis for comparing elegance / productivity
  - neither is a big surprise given its timing and HPC's performance focus







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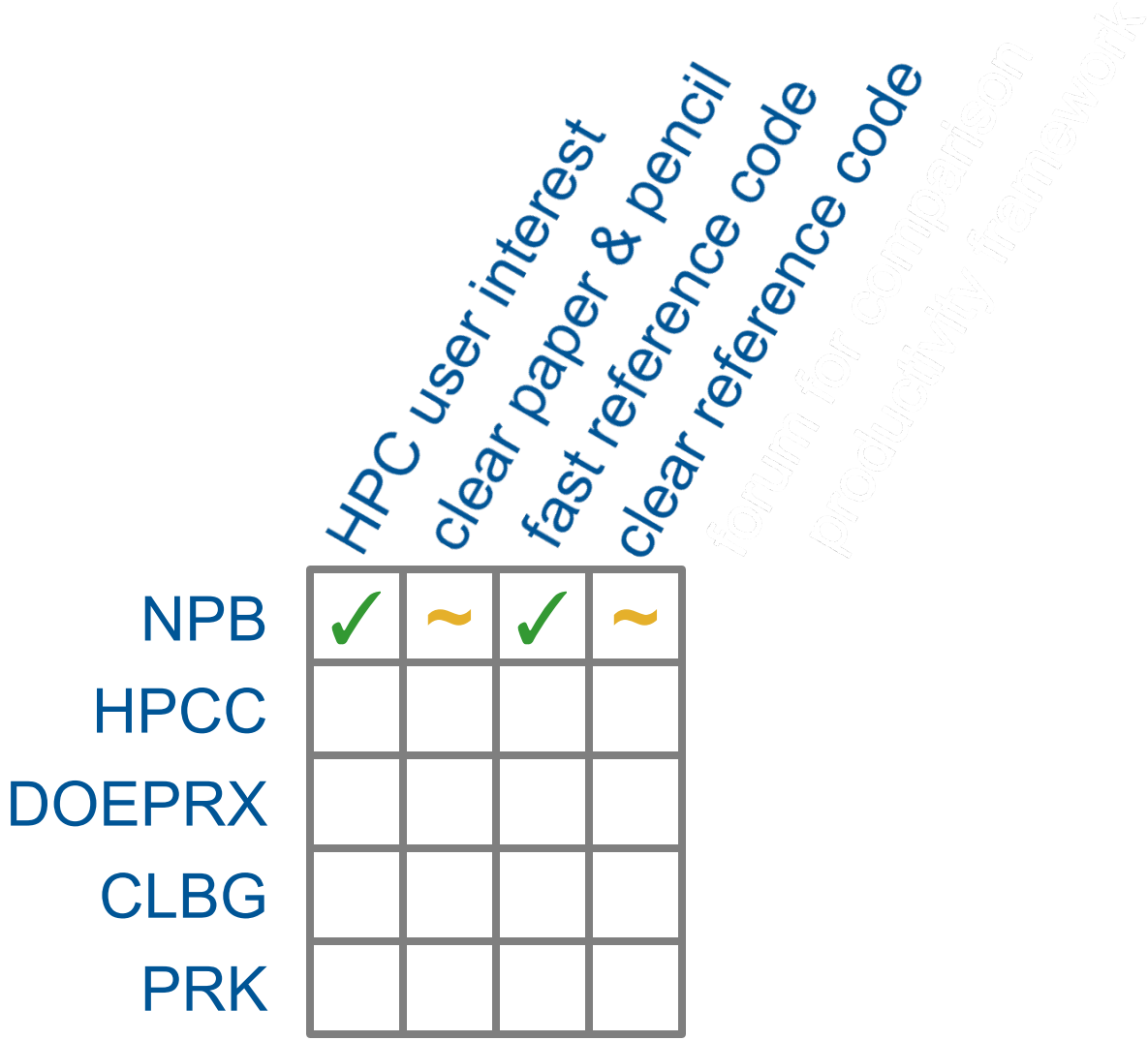

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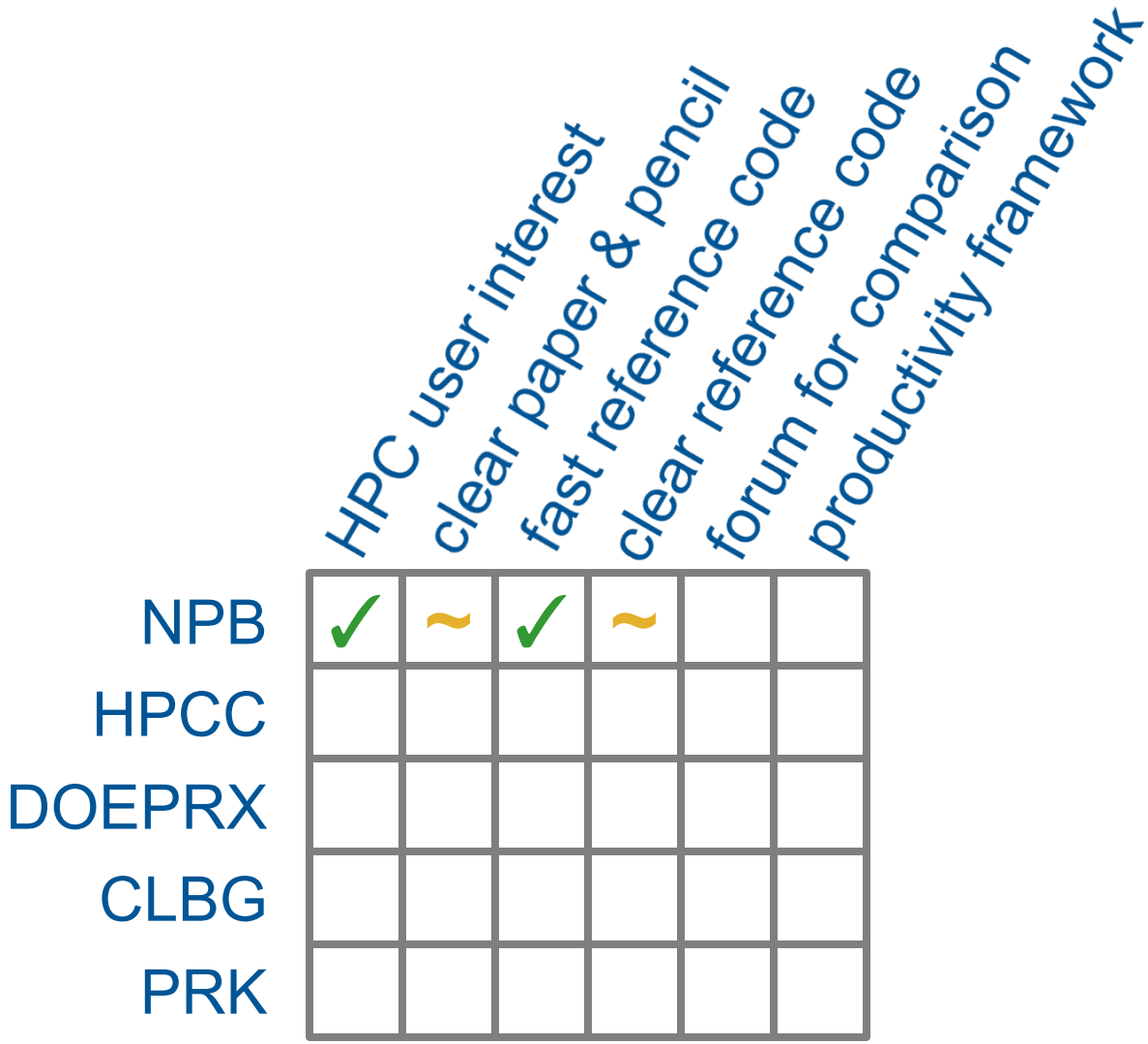

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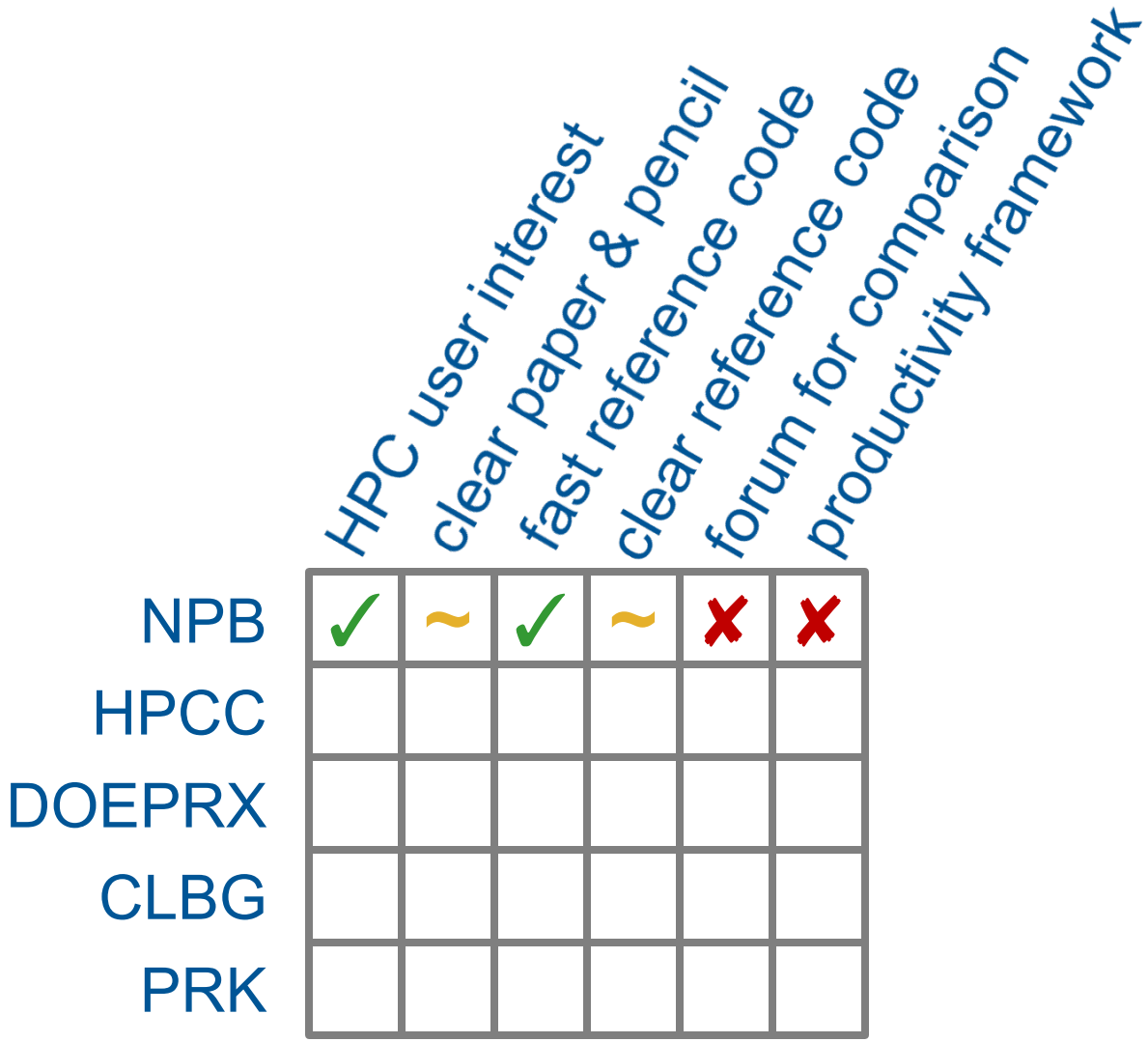


Other things one might want to rate…

- Size of codes? (effort to port to new languages)
- Arbitrarily scalable input sets?
- Self-verification of result?
- Was it designed more to measure communication (1) or computation (7)?

Other things one might want to rate…

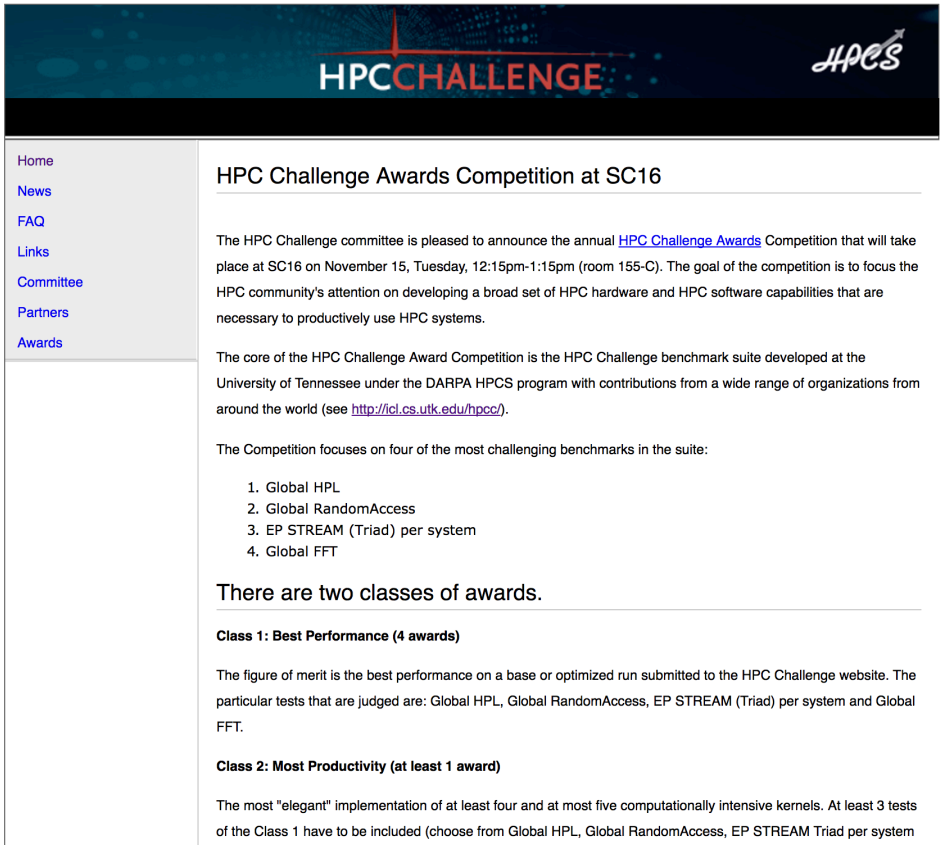
- Size of codes? (effort to port to new languages)
  - NPB: 5-6
- Arbitrarily scalable input sets?
  - NPB: 2
- Self-verification of result?
  - NPB: 7
- Was it designed more to measure communication (1) or computation (7)?
  - NPB: 5

(but I'm not as interested in these, personally, at least today)

The HPC Challenge Competition (HPCC)

HPCC: What it is

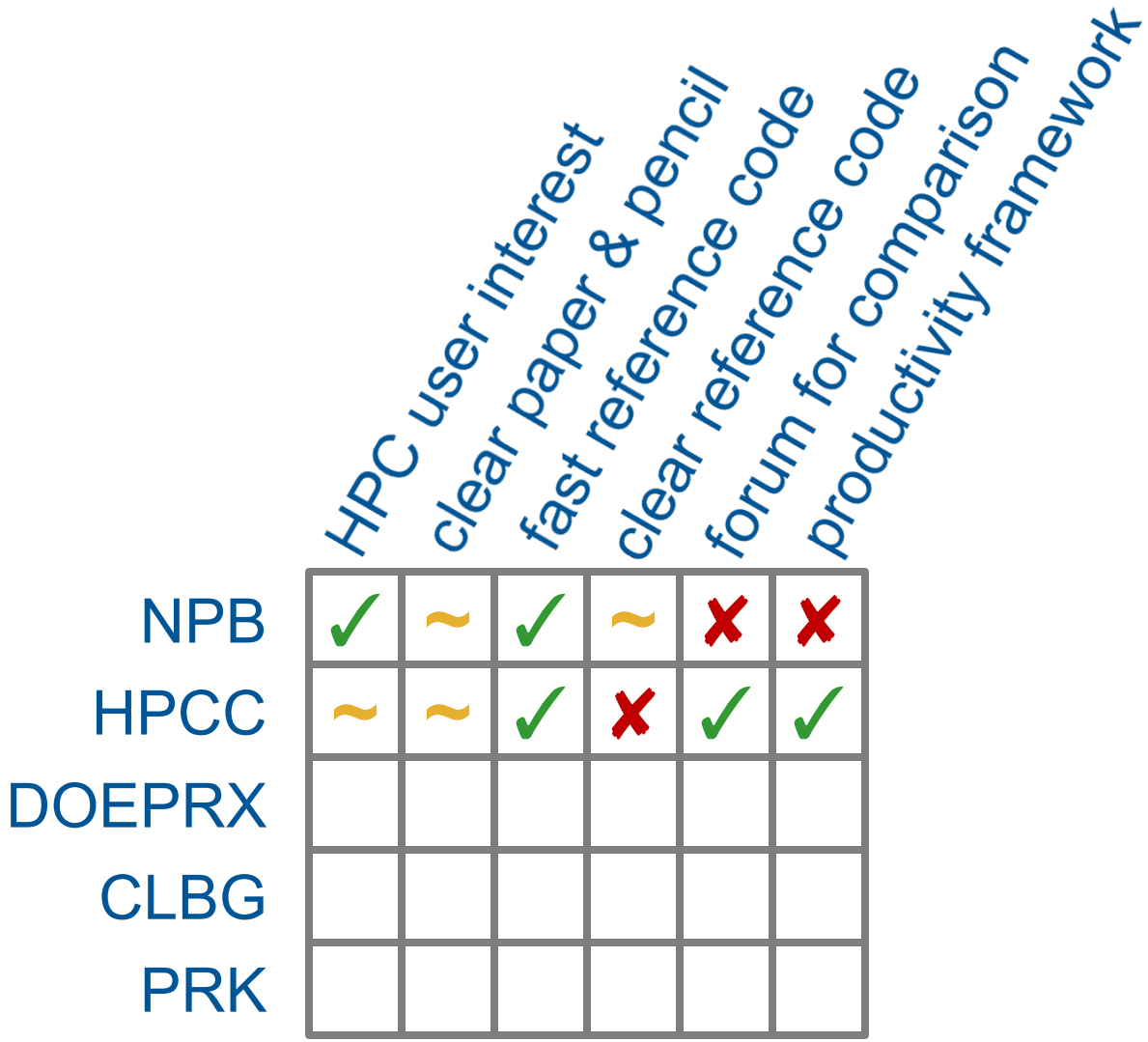
- **A benchmark suite and competition kicked off towards the start of the HPCS program**
  - class 1: perf only (boring!)
  - class 2: productivity
    - 50% performance
    - 50% elegance, judged by panel
  - 4 core computations:
    - Stream Triad (memory, EP)
    - Random Access (GUPS)
    - FFT (data transpose)
    - HPL (block-cyclic linear algebra)
  - over time, entrants could submit their own computations of interest as well…



HPCC: What it did well

- Established an annual competition for benchmarking
- Focused attention on elegance in addition to performance

Benchmark Suite Scorecard



HPCC: Numerical Scoring

- **Would HPC Application Developers care about this?**
  - HPCC: 4 (comm idioms yes, computations, less so)
- **Does a (clear) paper and pencil description exist?**
  - HPCC: 5 (some—stream, ra—were clearer than others—hpl)
- **Does the suite include a fast reference version?**
  - HPCC: 7
- **Does the suite include a clear reference version?**
  - HPCC: 2 (monolithic, difficult to detangle code; some parts inscrutable)
- **Forum for comparison?**
  - HPCC: 7
- **Framework for evaluating productivity?**
  - HPCC 7

HPCC: Where it fell short

- **Many judges seemed to not spend much time on elegance**
  - in practice, might catch glimpses of code in 5-minute presentations
    - or not…
    - even when you did, 5-minutes is not enough time to make that call well
  - admittedly, SC is a busy time of year…
- **In early years, awarded separate perf and elegance awards**
  - disregarded the tension between those concerns
- **Difficult for public to process results after the fact**
  - code was not made available in a standard way
- **Once arbitrary codes added, couldn't make comparisons**
- **Lack of continuity from year to year…**

What Trend Do these Awards Suggest?

2006: Cilk wins "Best overall productivity"

Chapel and X10 take honorable mentions

2007: X10 and Python/Star-P win "most productive" awards

2008: Chapel, UPC+X10, Parallel Matlab tie for "most productive"

2009: Chapel wins "most productive"

2010: UPC+X10 win "most productive system"

CAF wins "most productive language"

2011: Chapel wins "most elegant language"

2012: Chapel wins "most elegant language"

2013: XcalableMP wins class 2

2014: PCJ wins "most elegant"

Ratings for Suites Supporting Comparisons

- **Is the approach prescribed / constrained (7) or not (1)?**
  - Why? Want to evaluate technologies over algorithmic cleverness
- **Is the competition open to anyone who wants to enter?**
- **Does the competition maintain continuity?**
  - Imagine if the top-500 required everyone to re-run every six months…
- **Does the competition use apples-to-apples comparisons?**
- **Can community members surf the results conveniently?**
  - In order to draw their own conclusions, make their own visualizations
- **Does the suite trivially support running it yourself?**
  - In order to reproduce results or obtain than on different systems

Benchmark Suite Scorecard

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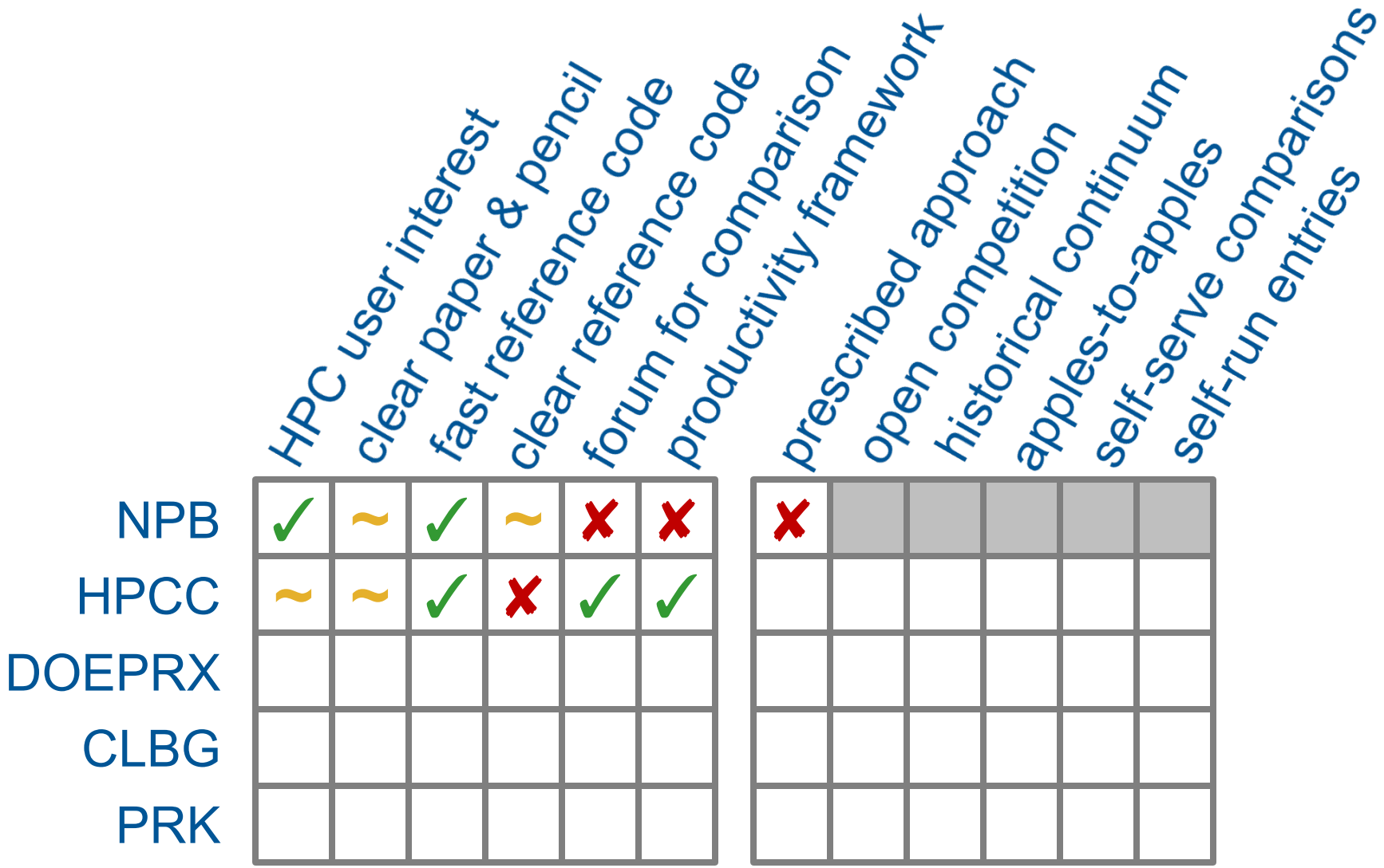

Benchmark Suite Scorecard

Comparison Ratings for HPCC

- Is the approach prescribed / constrained (7) or not (1)?
  - HPCC: 3
- Is the competition open to anyone who wants to enter?
  - HPCC: 7
- Does the competition maintain continuity?
  - HPCC: 1
- Does the competition use apples-to-apples comparisons?
  - HPCC: 2
- Can community members surf the results conveniently?
  - HPCC: 2
- Does the suite trivially support running it yourself?
  - HPCC: 1

Thoughts on improving the HPCC competition

- **Have entries carry over from year-to-year like top-500**
  - Or, run competition continually in real-time like the CLBG
- **Have judges devote time offline to evaluating elegance**
- **Re-unify set of benchmarks to study**
  - Perhaps introduce a new benchmark each year, retiring an old one?
- **Maintain submitted codes and results in a unified manner**

DOE Proxy Applications (DOEPRX)

DOE Proxy Apps: What they are

- **Benchmarks that are…**
  …large enough and realistic enough that experts value their results
  …yet tractable enough that non-experts can tackle them
- **Where's the screenshot?**
  - This is not a well-defined benchmark suite per se
  - More a style of benchmark that has been in vogue in recent years
  - As a result, no central repository (as far as I'm aware of…)

DOE Proxy Apps: What they do well

- As intended: Create tractable codes that matter

DOE Proxy Apps: Where they fall short

- **They present something of a moving target:**
  - There are *lots* of them, including *apparent* redundant instances
  - Many seem to go through phases of being more or less fashionable
  - Each requires a fair amount of effort to port and tune
  - **The challenge:** How is a modest-sized team to invest its time?
- **Aforementioned lack of centralized suite**
  - Keeping tabs on several / all of them requires lots of effort
- **No established forums for comparison**

Benchmark Suite Scorecard

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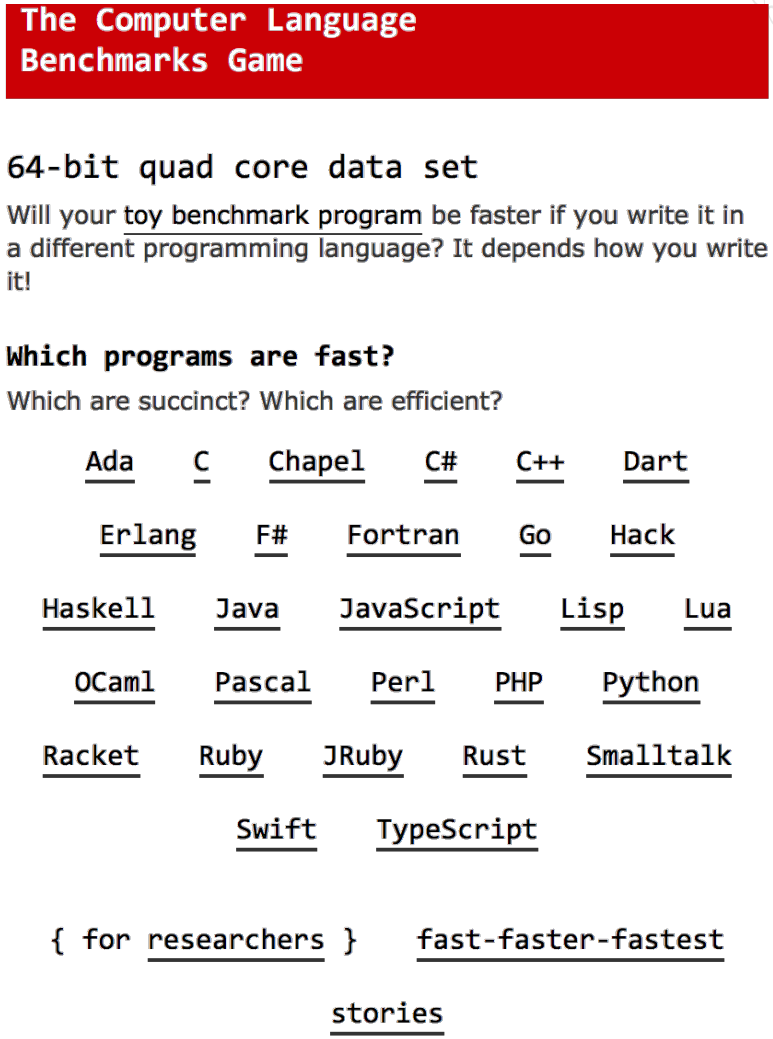
The Computer Language Benchmarks Game (CLBG)

CLBG: What it is

- **A suite of 13 "toy" benchmarks**
  - single-node
  - serial, vectorizable, or multicore parallel
  - exercise key features like…
    …memory management
    …tasking and synchronization
    …arbitrary-precision math
    …vectorization
    …strings and regular expressions
- **Imagine a 3D ragged matrix:**
  - with 13 benchmarks
    x ~28 languages
    x as many impls as are interesting
  - each entry contains:
    - source code
    - performance information
    - "code size"



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    x g
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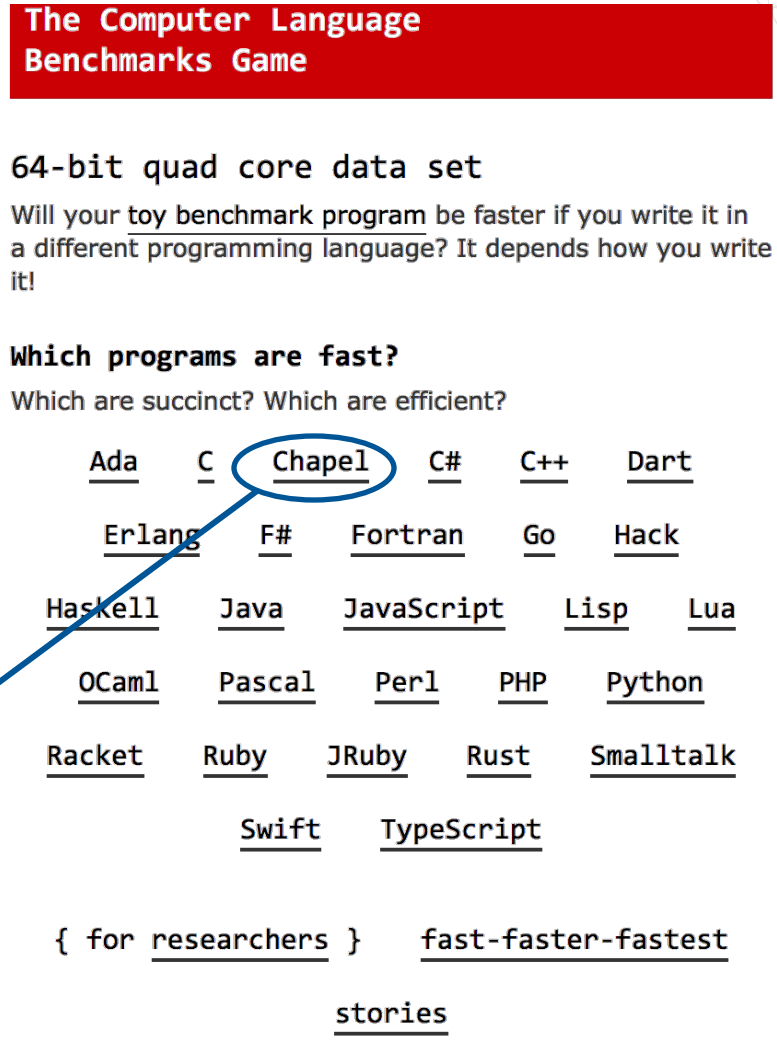
Chapel entries have been accepted since ~IPDPS 2016



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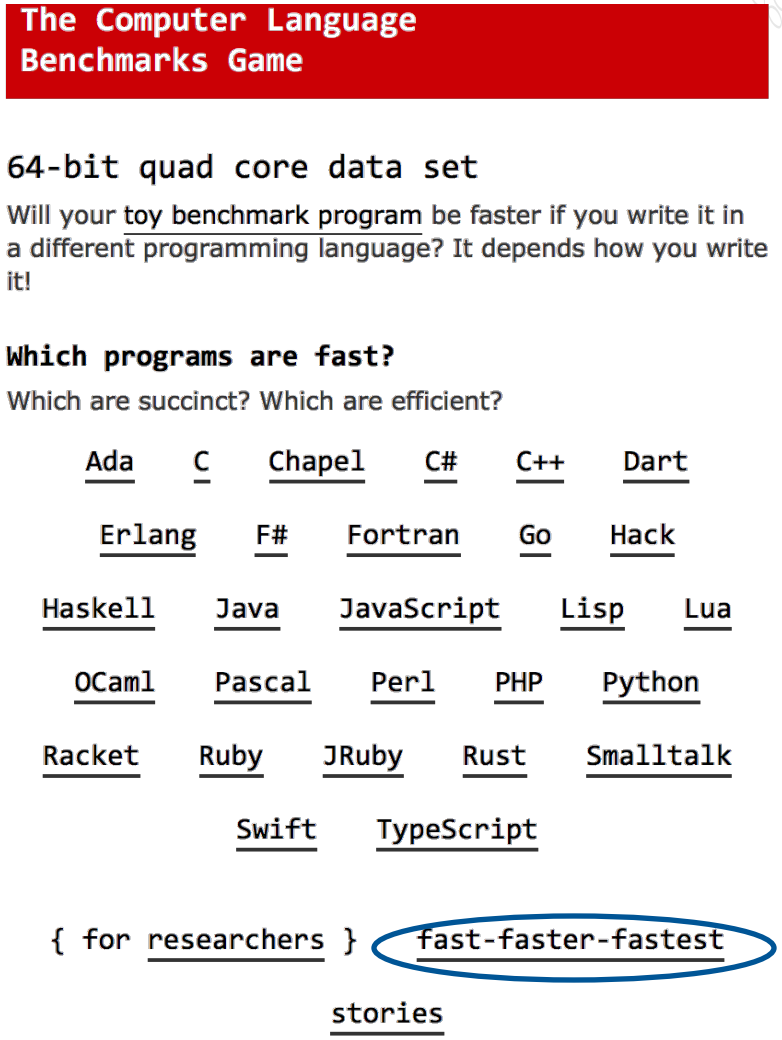
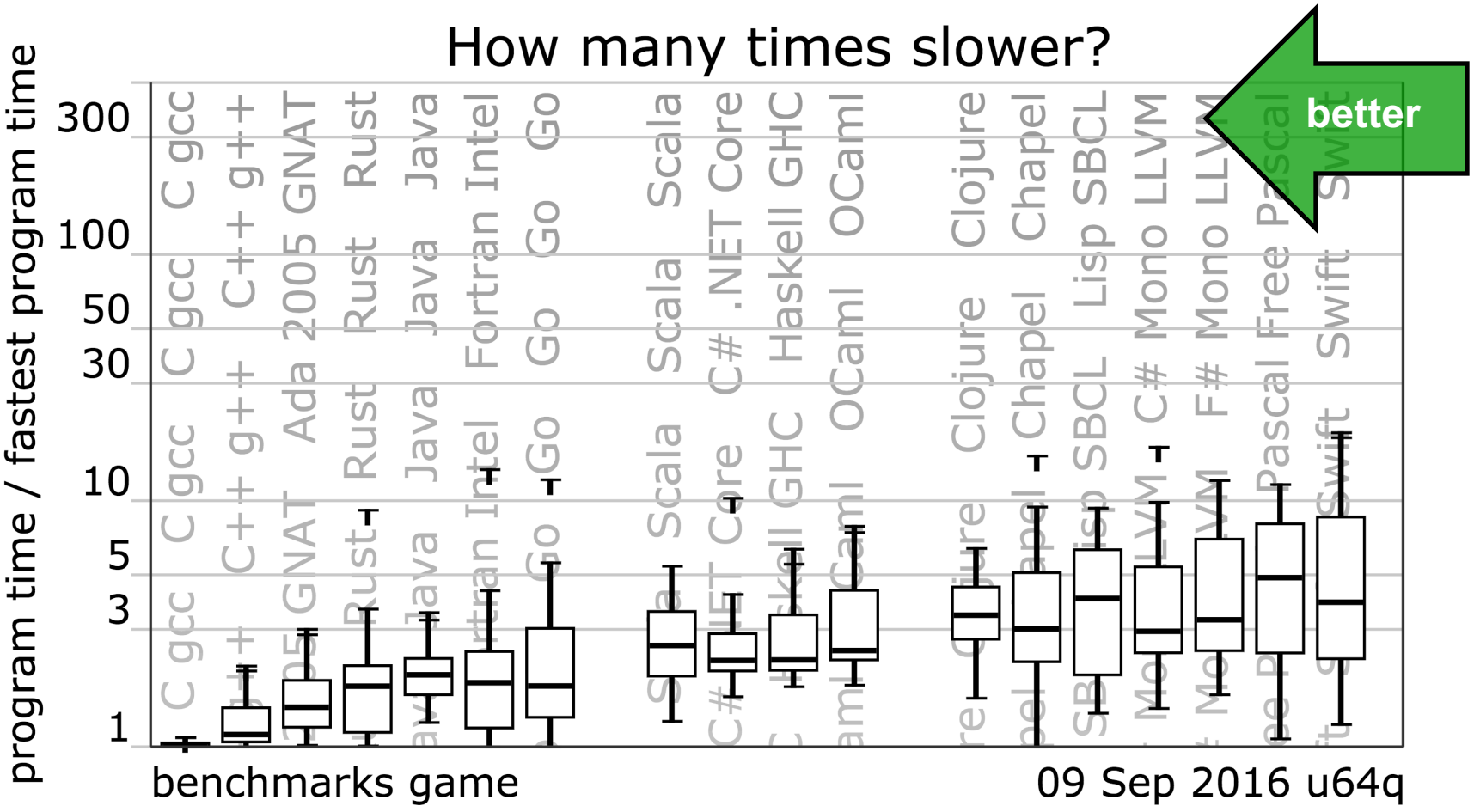


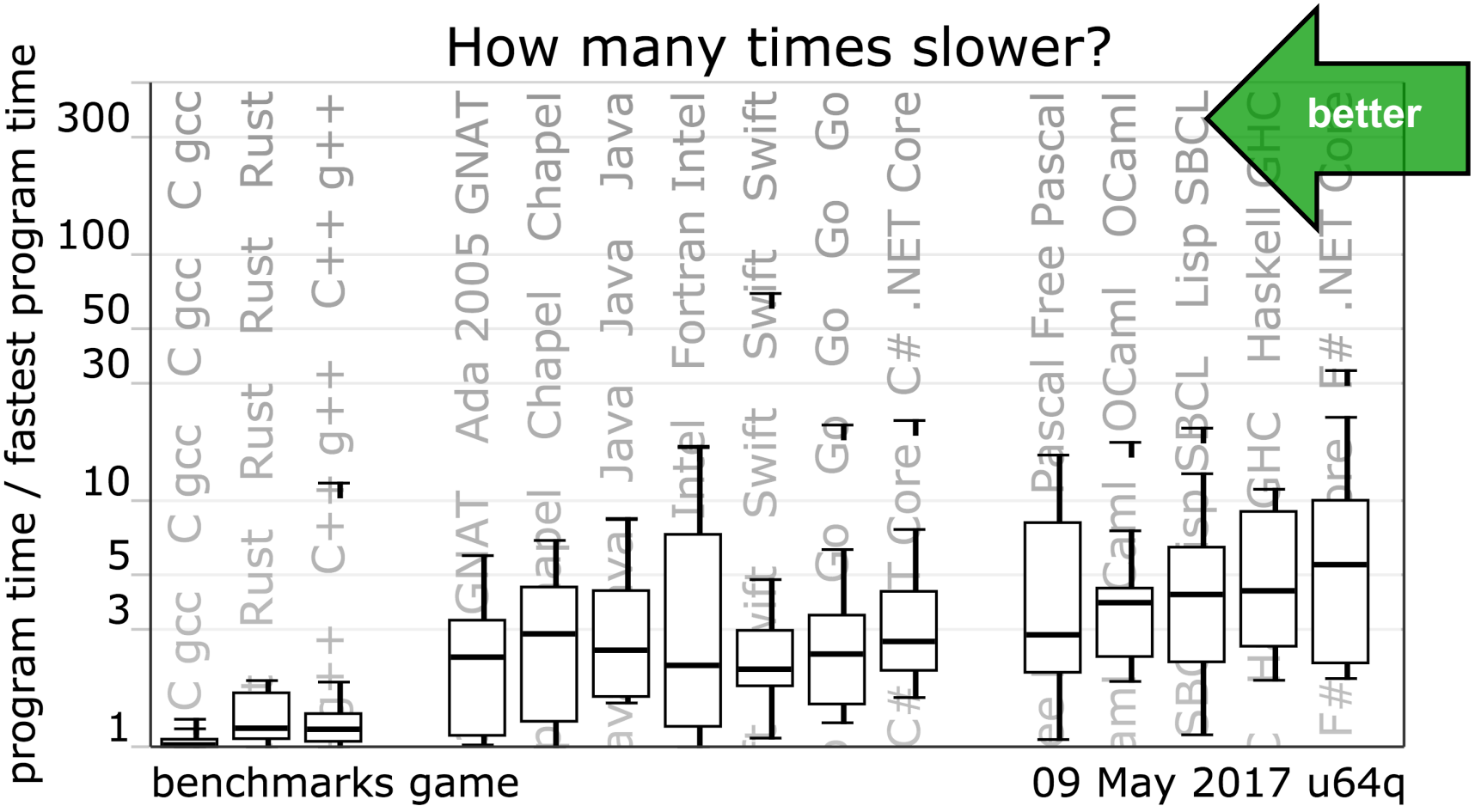
CLBG: Fast-faster-fastest graph (Sep 2016)

Site summary: relative performance (sorted by geometric mean)



CLBG: Fast-faster-fastest graph (May 2017)

Site summary: relative performance (sorted by geometric mean)



CLBG: Sorting Results

Can sort results by execution time, code size, memory or CPU use:

The Computer Language Benchmarks Game

chameneos-redux

description

program source code, command-line and measurements

×	source	secs	mem	gz	cpu	cpu load
1.0	**C** gcc #5	**0.60**	820	2863	2.37	100% 100% 98% 100%
1.2	**C++** g++ #5	**0.70**	3,356	1994	2.65	100% 100% 91% 92%
1.7	**Lisp** SBCL #3	**1.01**	55,604	2907	3.93	97% 96% 99% 99%
2.3	**Chapel** #2	**1.39**	76,564	1210	5.43	99% 99% 98% 99%
3.3	**Rust** #2	**2.01**	56,936	2882	7.81	97% 98% 98% 98%
5.6	C++ g++ #2	3.40	1,880	2016	11.88	100% 51% 100% 100%
6.8	Chapel	4.09	66,584	1199	16.25	100% 100% 100% 100%
8.0	**Java** #4	**4.82**	37,132	1607	16.73	98% 98% 54% 99%
8.5	**Haskell** GHC	**5.15**	8,596	989	9.26	79% 100% 2% 2%
10	Java	6.13	53,760	1770	8.78	42% 45% 41% 16%
10	Haskell GHC #4	6.34	6,908	989	12.67	99% 100% 2% 1%
11	**C#** .NET Core	**6.59**	86,076	1400	22.96	99% 82% 78% 91%
11	**Go**	**6.90**	832	1167	24.19	100% 96% 56% 100%
13	Go #2	7.59	1,384	1408	27.65	91% 99% 99% 78%
13	Java #3	7.94	53,232	1267	26.86	54% 96% 98% 94%

The Computer Language Benchmarks Game

chameneos-redux

description

program source code, command-line and measurements

×	source	secs	mem	gz	cpu	cpu load
1.0	**Erlang**	58.90	28,668	**734**	131.19	62% 60% 51% 53%
1.0	**Erlang** HiPE	59.39	25,784	**734**	131.58	60% 56% 56% 54%
1.1	**Perl** #4	5 min	14,084	**785**	7 min	40% 40% 29% 28%
1.1	**Racket**	5 min	132,120	**791**	5 min	1% 0% 0% 100%
1.1	Racket #2	175.88	116,488	842	175.78	100% 1% 1% 0%
1.2	**Python 3** #2	236.84	7,908	**866**	5 min	24% 48% 27% 45%
1.3	**Ruby**	90.52	9,396	**920**	137.53	35% 35% 35% 34%
1.3	**Ruby** JRuby	48.78	628,968	**928**	112.15	65% 60% 49% 58%
1.3	**Go** #5	11.05	832	**957**	32.48	75% 74% 75% 73%
1.3	**Haskell** GHC #4	6.34	6,908	**989**	12.67	99% 100% 2% 1%
1.3	Haskell GHC	5.15	8,596	989	9.26	79% 100% 2% 2%
1.6	**OCaml** #3					32% 38% 37% 39%
1.6	Go					100% 96% 56% 100%
1.6	**Chapel**					0% 100% 100% 100%
1.6	Chapel #2					99% 99% 98% 99%

gz == code size metric
strip comments and extra whitespace, then gzip

CLBG: Comparing Pairs of Languages

Can also compare languages pair-wise (performance only):

The Computer Language Benchmarks Game

Chapel programs versus Go

all other Chapel programs & measurements

by benchmark task performance

regex-redux

source	secs	mem	gz	cpu	cpu load
Chapel	**10.02**	1,022,052	477	19.68	99% 72% 14% 12%
Go	29.51	352,804	798	61.51	77% 49% 43% 40%

binary-trees

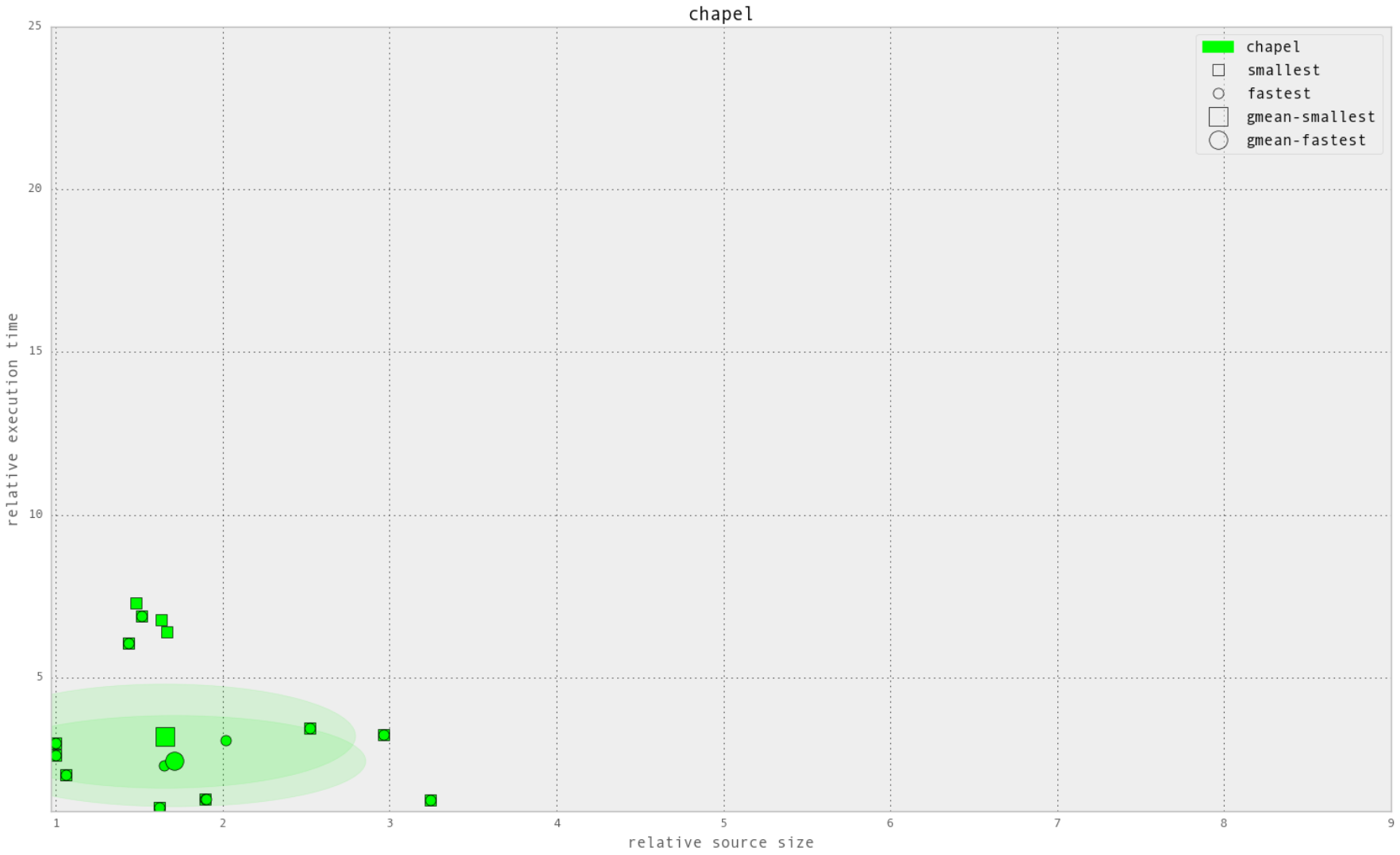
source	secs	mem	gz	cpu	cpu load
Chapel	**14.32**	324,660	484	44.15	100% 58% 78% 75%
Go	34.77	269,068	654	132.04	95% 97% 95% 95%

fannkuch-redux

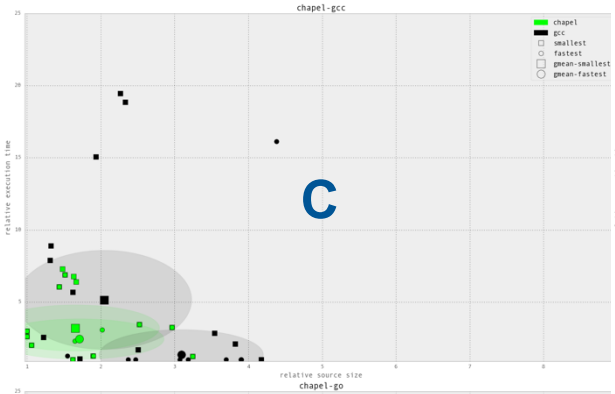
source	secs	mem	gz	cpu	cpu load
Chapel	**11.38**	46,056	728	45.18	100% 99% 99% 100%

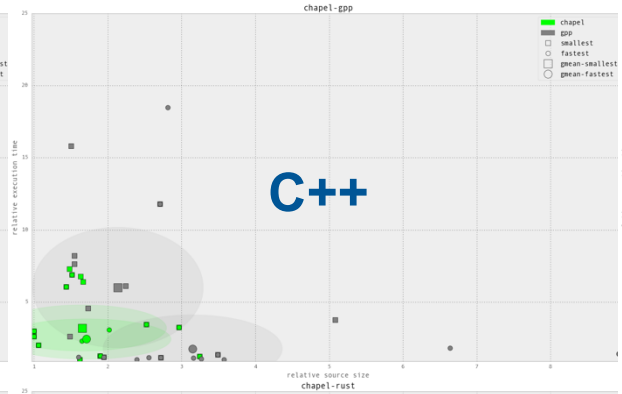
But happily, all the data is open source!

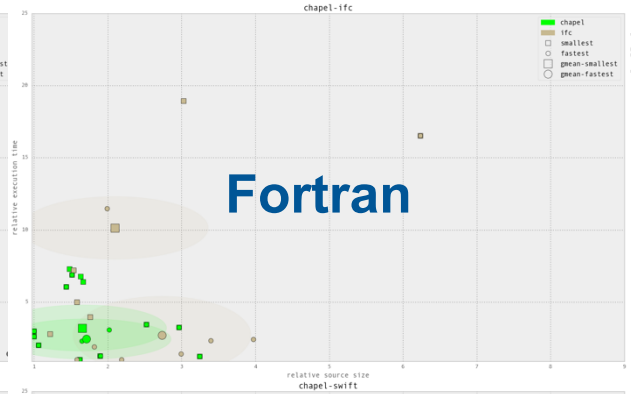
Chapel entries: normalized perf & size (Apr 2017)

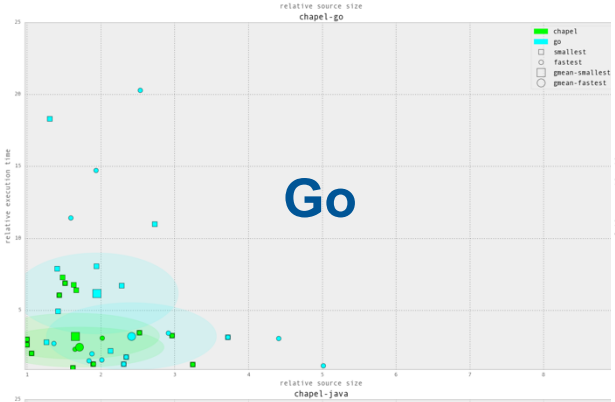


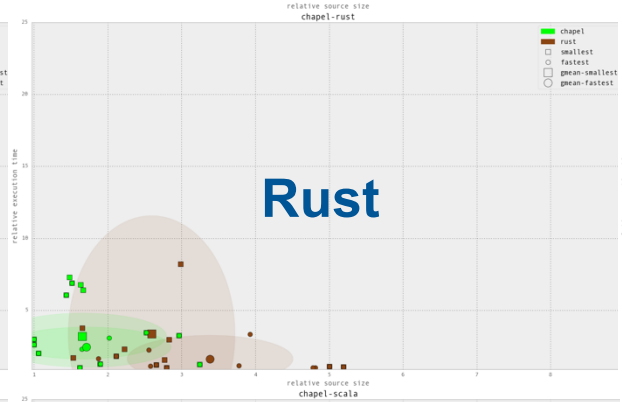
Chapel vs. 9 other languages

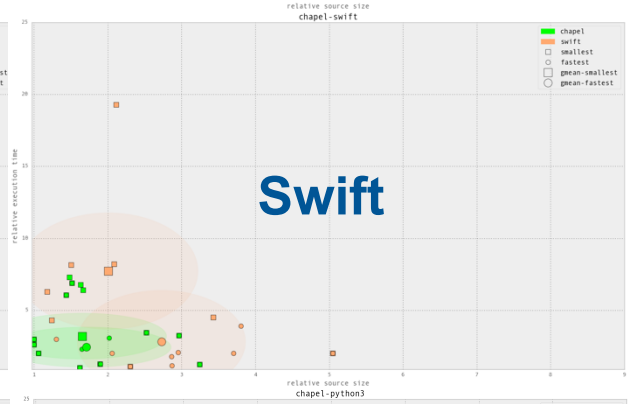


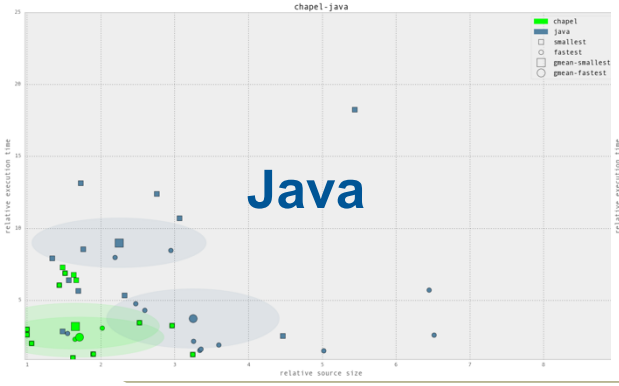


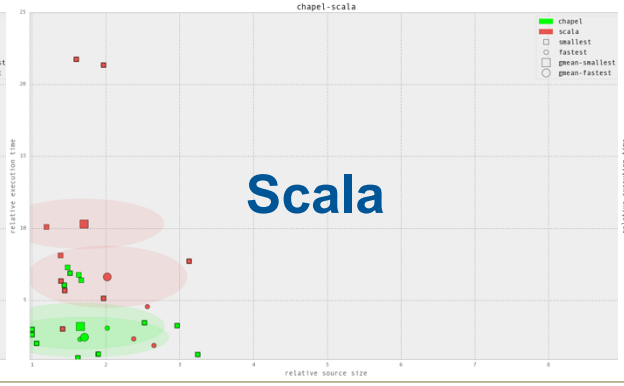


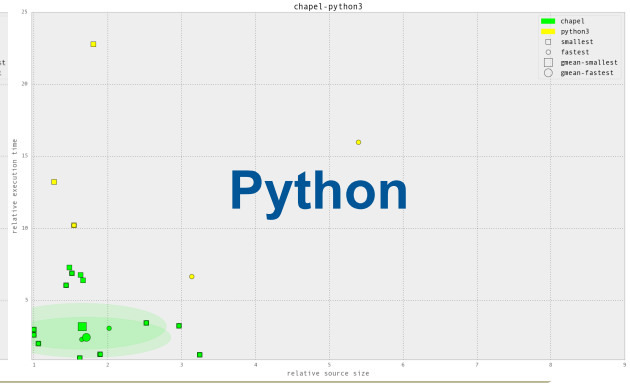




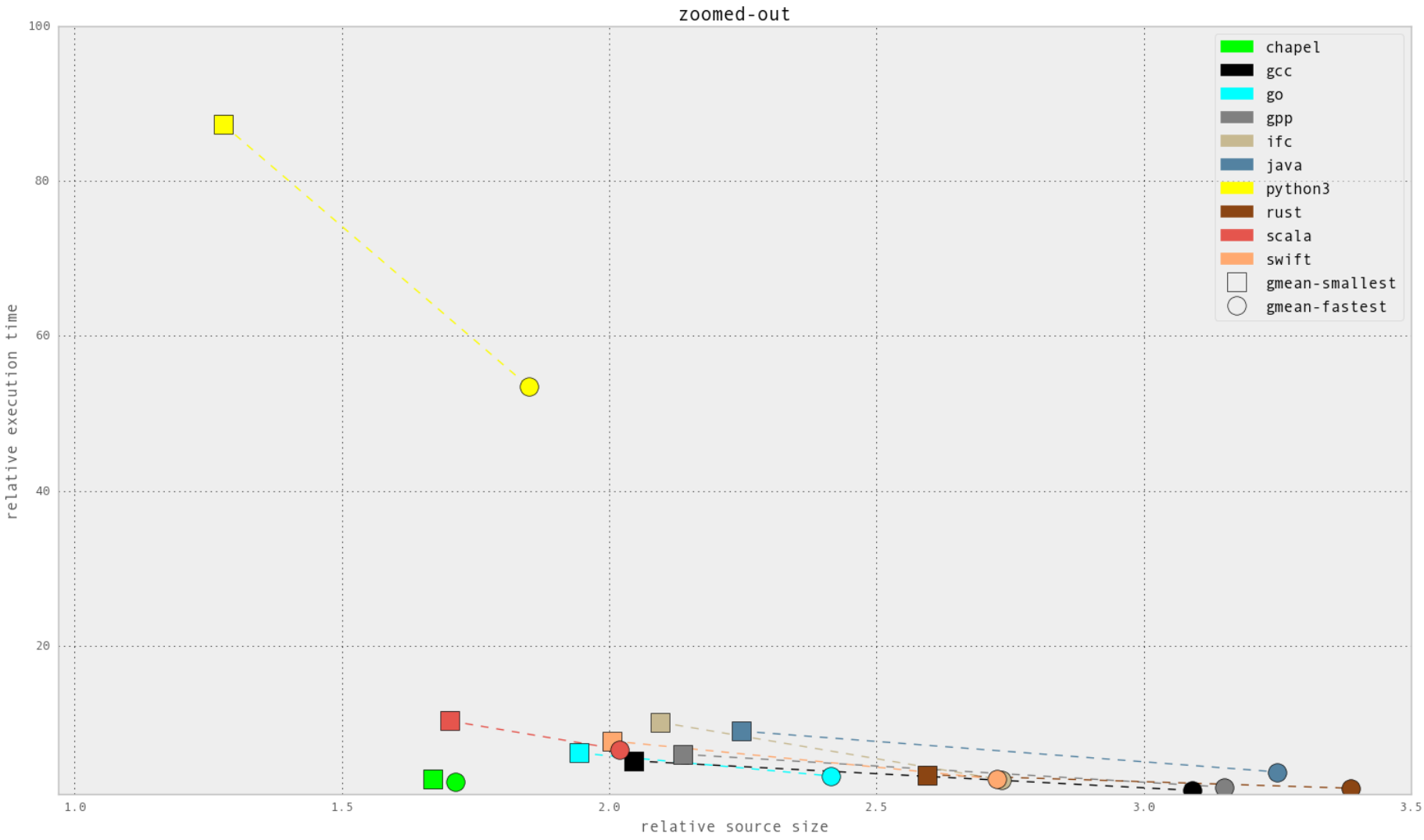




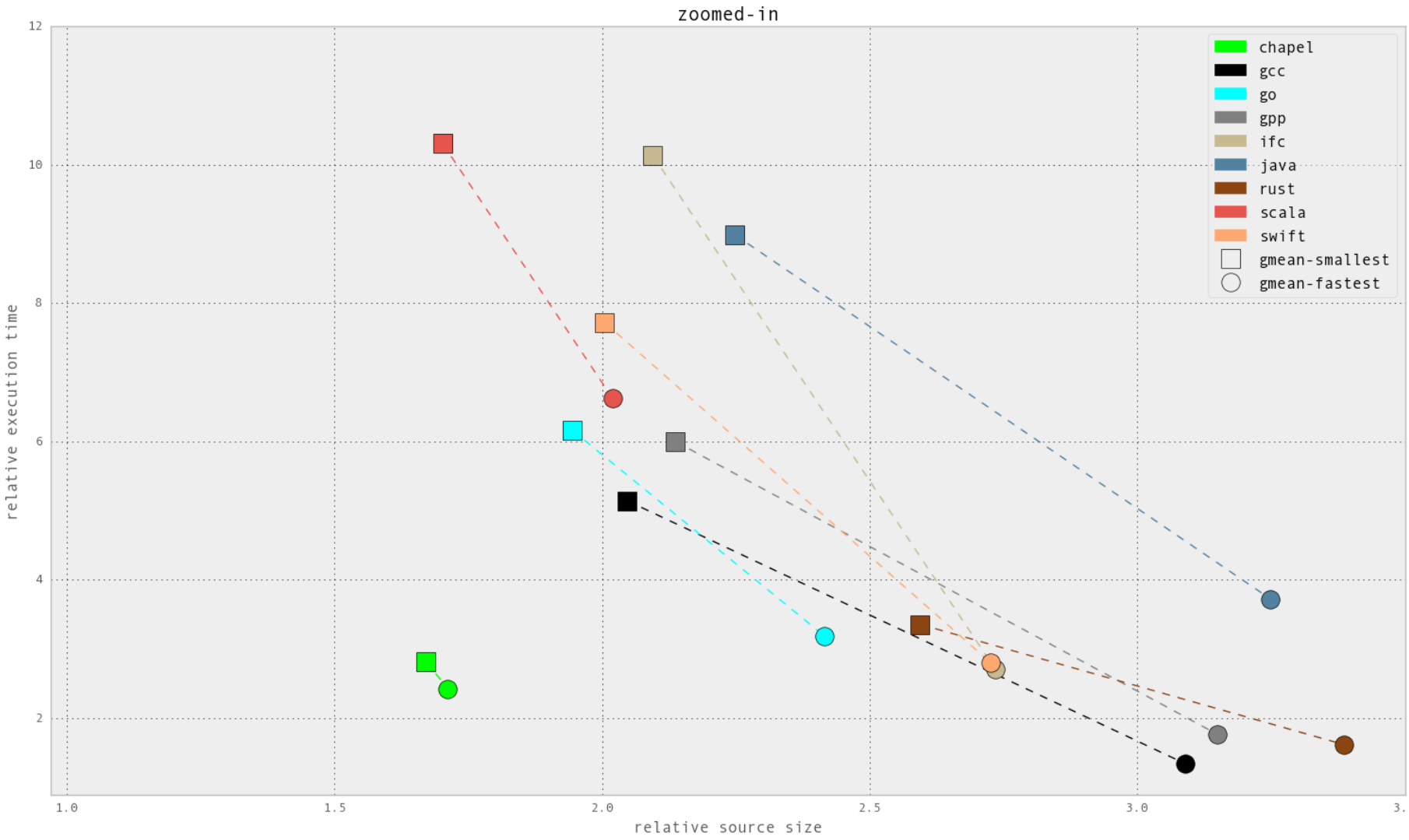




Cross-Language Summary



Cross-Language Summary (no Python)



CLBG: Website

Can also browse program source code (but this requires actual thought):

```
proc main() {
  printColorEquations();

  const group1 = [i in 1..popSize1] new Chameneos(i, ((i-1)%3):Color);
  const group2 = [i in 1..popSize2] new Chameneos(i, colors10[i]);

  cobegin {
    holdMeetings(group1, n);
    holdMeetings(group2, n);
  }

  print(group1);
  print(group2);

  for c in group1 do delete c;
  for c in group2 do delete c;
}


//
// Print the results of getNewColor() for all color pairs.
//
proc printColorEquations() {
  for c1 in Color do
    for c2 in Color do
      writeln(c1, " + ", c2, " -> ", getNewColor(c1, c2));
  writeln();
}


//
// Hold meetings among the population by creating a shared meeting
// place, and then creating per-chameneos tasks to have meetings.
//
proc holdMeetings(population, numMeetings) {
  const place = new MeetingPlace(numMeetings);

  coforall c in population do           // create a task per chameneos
    c.haveMeetings(place, population);

  delete place;
}
```

excerpt from 1210 gz Chapel #2 entry

```
void get_affinity(int* is_smp, cpu_set_t* affinity1, cpu_set_t* affinity2)
{
    cpu_set_t                   active_cpus;
    FILE*                       f;
    char                        buf [2048];
    char const*                 pos;
    int                         cpu_idx;
    int                         physical_id;
    int                         core_id;
    int                         cpu_cores;
    int                         apic_id;
    size_t                      cpu_count;
    size_t                      i;

    char const*                 processor_str       = "processor";
    size_t                      processor_str_len   = strlen(processor_str);
    char const*                 physical_id_str     = "physical id";
    size_t                      physical_id_str_len = strlen(physical_id_str);
    char const*                 core_id_str         = "core id";
    size_t                      core_id_str_len     = strlen(core_id_str);
    char const*                 cpu_cores_str       = "cpu cores";
    size_t                      cpu_cores_str_len   = strlen(cpu_cores_str);

    CPU_ZERO(&active_cpus);
    sched_getaffinity(0, sizeof(active_cpus), &active_cpus);
    cpu_count = 0;
    for (i = 0; i != CPU_SETSIZE; i += 1)
    {
        if (CPU_ISSET(i, &active_cpus))
        {
            cpu_count += 1;
        }
    }

    if (cpu_count == 1)
    {
        is_smp[0] = 0;
        return;
    }

    is_smp[0] = 1;
    CPU_ZERO(affinity1);
```

excerpt from 2863 gz C gcc #5 entry

CLBG: What it does well

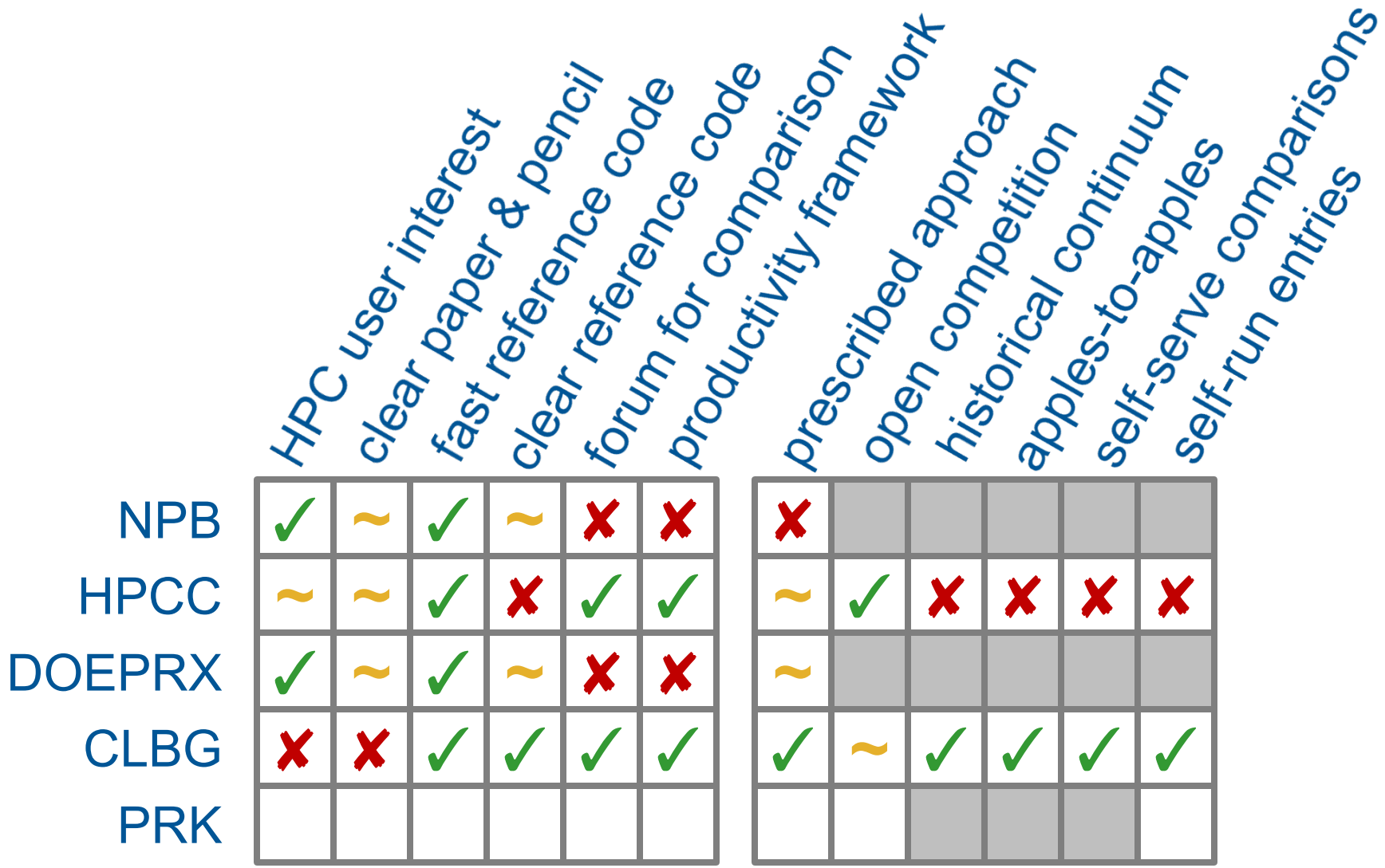
- Engages the community, drives interest and chatter
- Incredibly active in terms of steady stream of submissions

CLBG: Where it falls short (for HPC)

- Single-node only
- Only some overlap with HPC computational idioms

Benchmark Suite Scorecard

Benchmark Suite Scorecard



CLBG: Summary

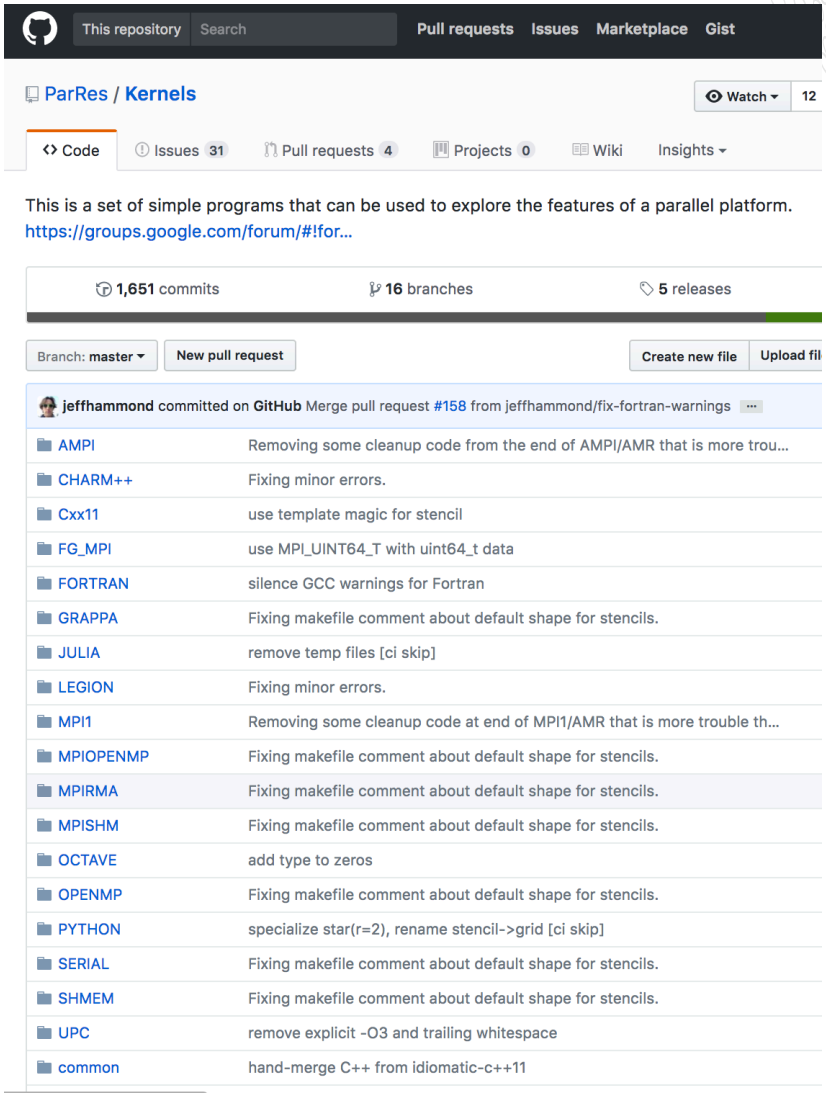
- **HPC would benefit greatly from something like the CLBG**
  - a good, engaging challenge to encourage innovation
  - online, continual, open, surfable
- **This would be far from trivial, though…**
  - what system(s) would be used for the evaluation?
  - what benchmarks?
  - need a reasonably neutral party to arbitrate questions
    - e.g., “Does doing xyz violate the prescribed approach?”
  - level of effort required to keep all the necessary software up-to-date
  - …
- **Yet, doing something would beat doing nothing**
  - top-500 and CLBG as examples of this
    - neither is perfect, yet each contributes something of value to the community

If interested in more, see my 4:20pm talk at CHIUW today

The Intel ParRes Kernels (PRK)

PRK: What it is

- **A suite of ~12 parallel kernels**
  - designed to expose perf bottlenecks
  - example kernels:
    - …stencil
    - …sparse matrix-vector
    - …particle-in-cell pattern
    - …wavefront-style computation
    - …transpose
    - …dgemm
  - serial, parallel, and distrib. versions
  - hosted on GitHub
    - ~18 languages represented
    - uses Travis to preserve quality



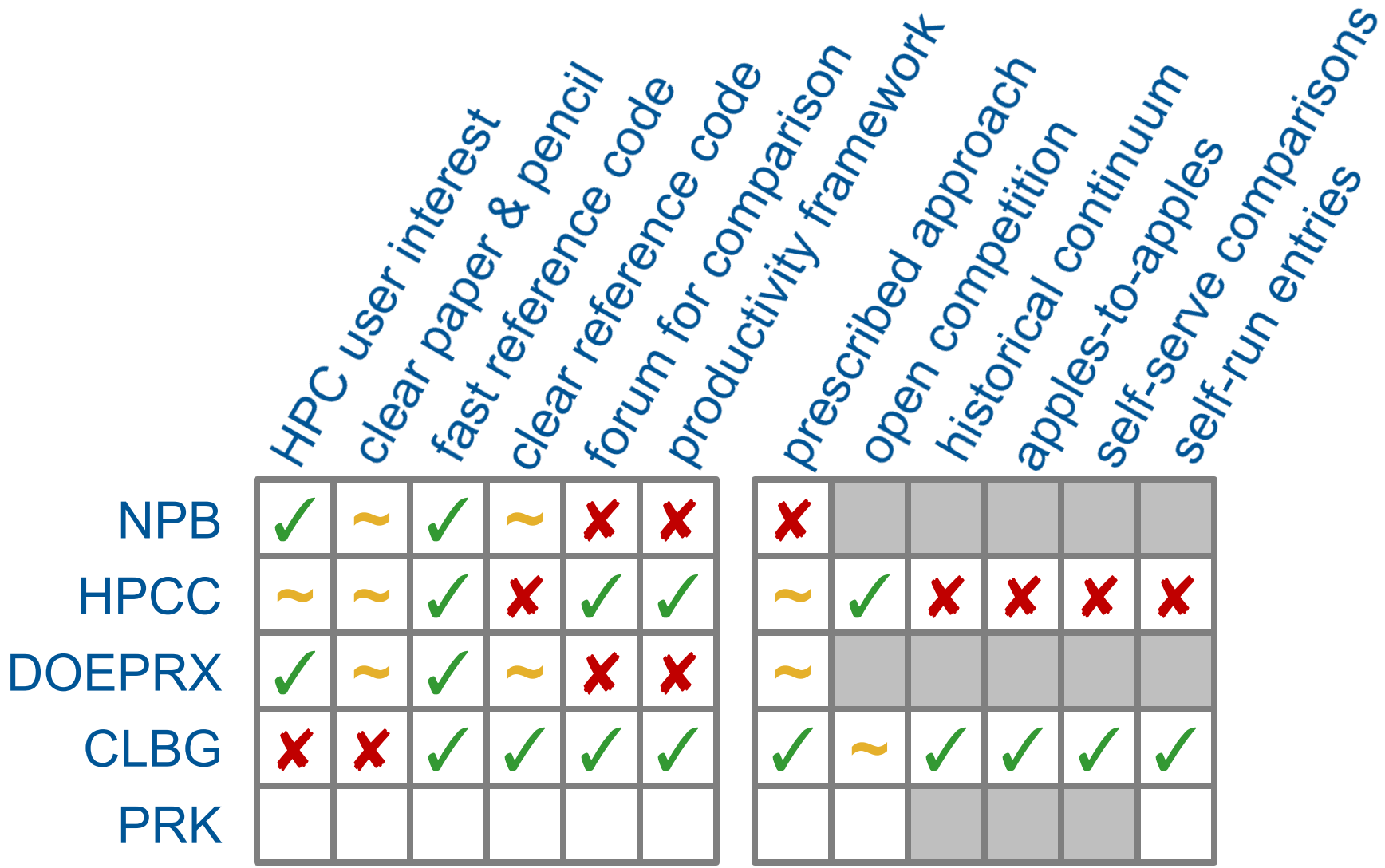
PRK: What it does well

- Establishes a set of basis vectors for real applications

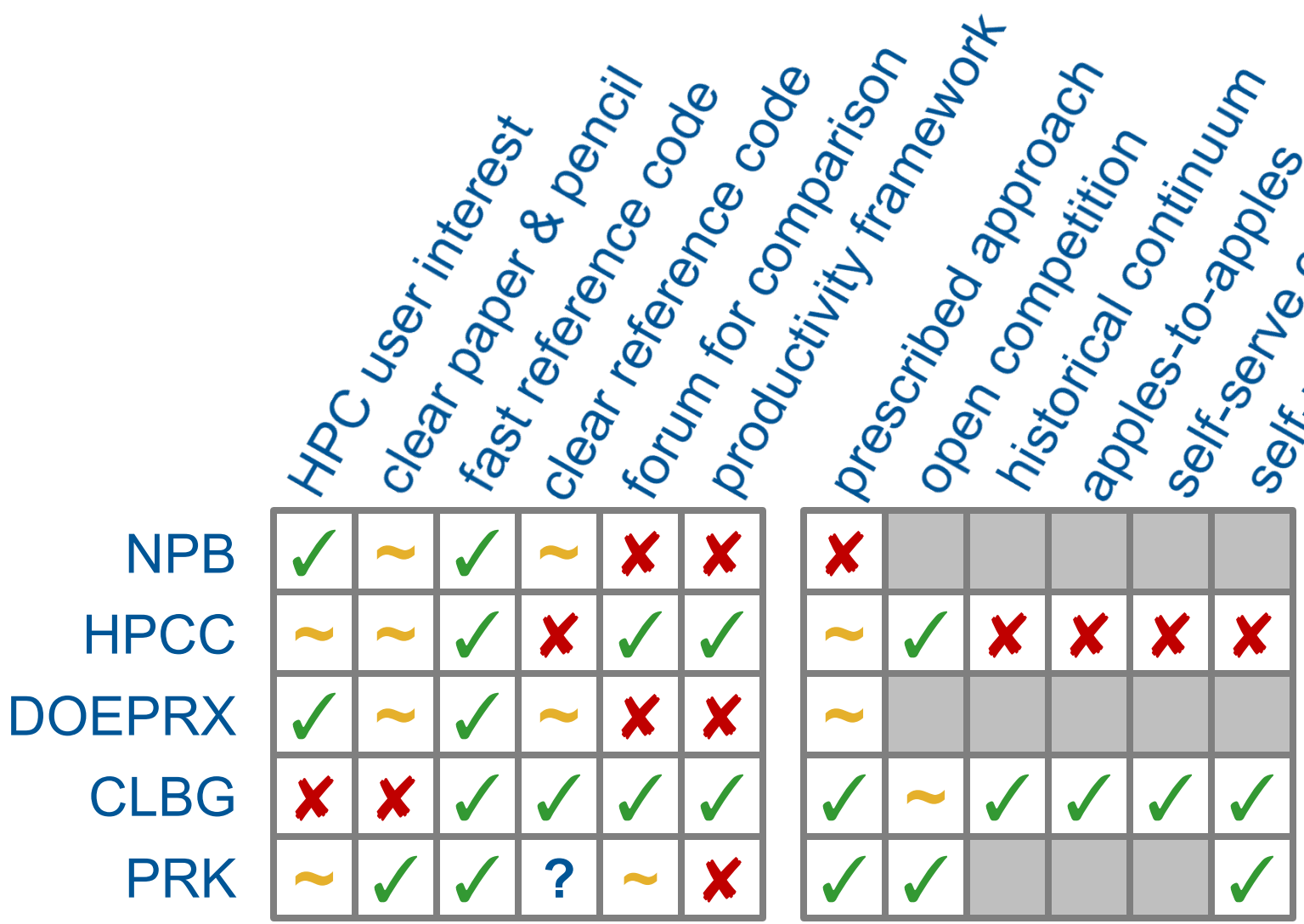
PRK: Where it falls short (at present)

- **Not a lot of uptake or interest as of yet**
  - Not for lack of interest among its curators
- **No formal competition or arena**
  - Yet, framework exists for running codes automatically

Benchmark Suite Scorecard



Benchmark Suite Scorecard



Wrap-up

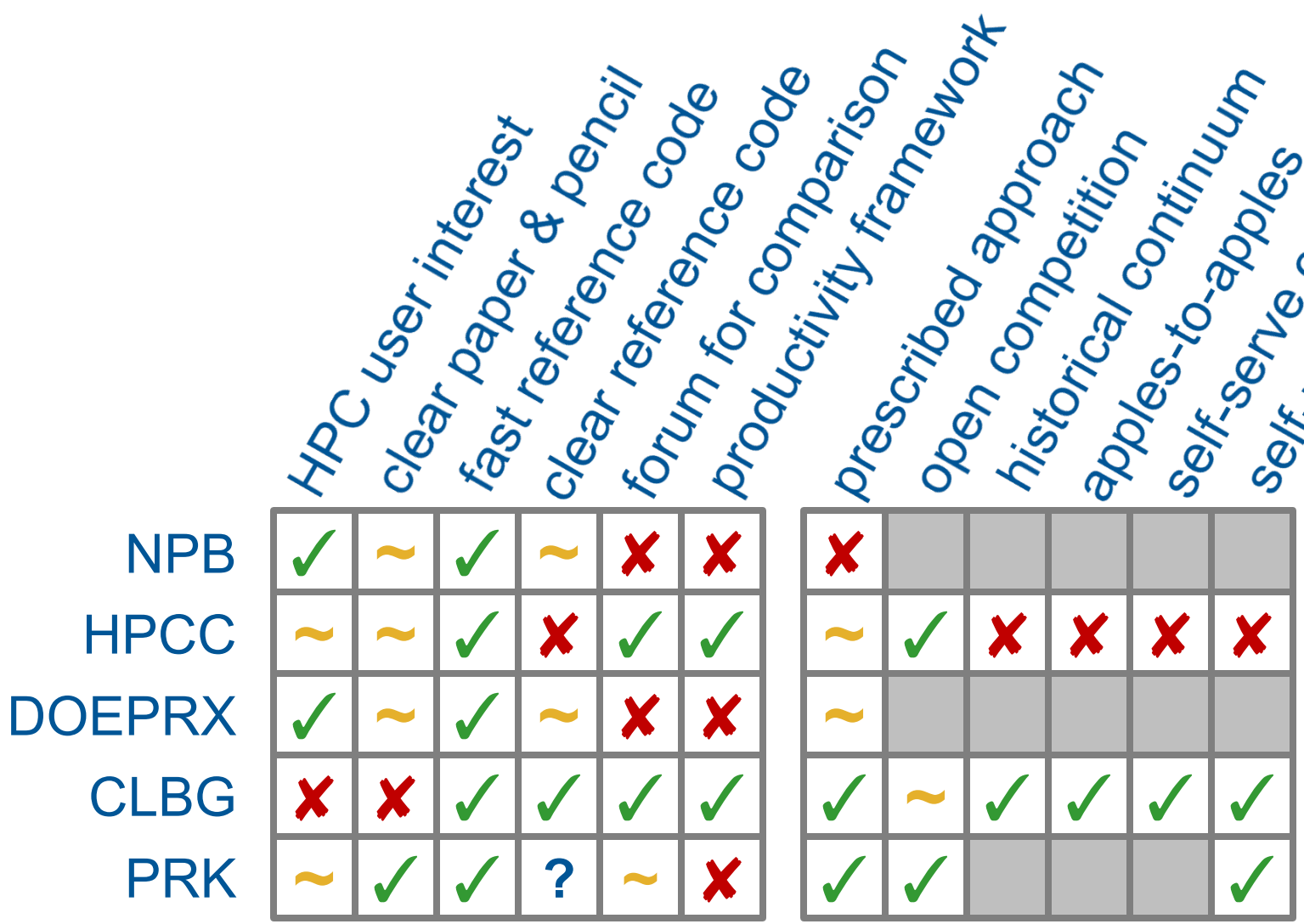
In Summary

Scoring existing HPC benchmark suites, each has a distinct approach and set of characteristics…

A Proposal:

- Create a group to curate a CLBG-style arena for the PRK
  - e.g., a DOE lab with access to supercomputer resources
  - or an academic group granted time on DOE resources
- Can we create something as viral and engaging for HPC as the CLBG is for mainstream programmers?

Benchmark Suite Scorecard



Questions?

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