Shared Memory HPC Programming: Past, Present, and Future

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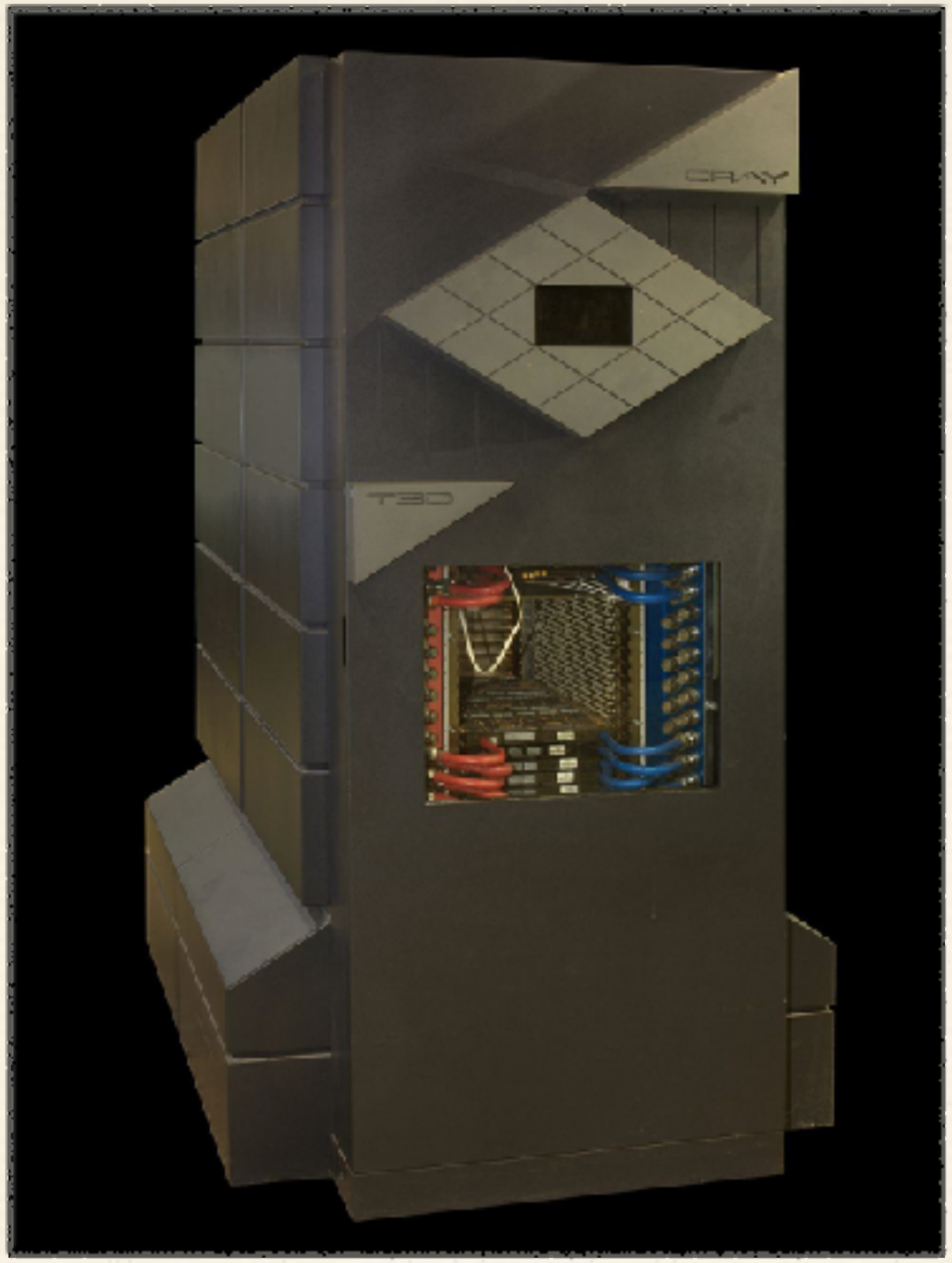


Our Problem in 1993

How do we program this? And get good performance?

AC for the Cray T3D

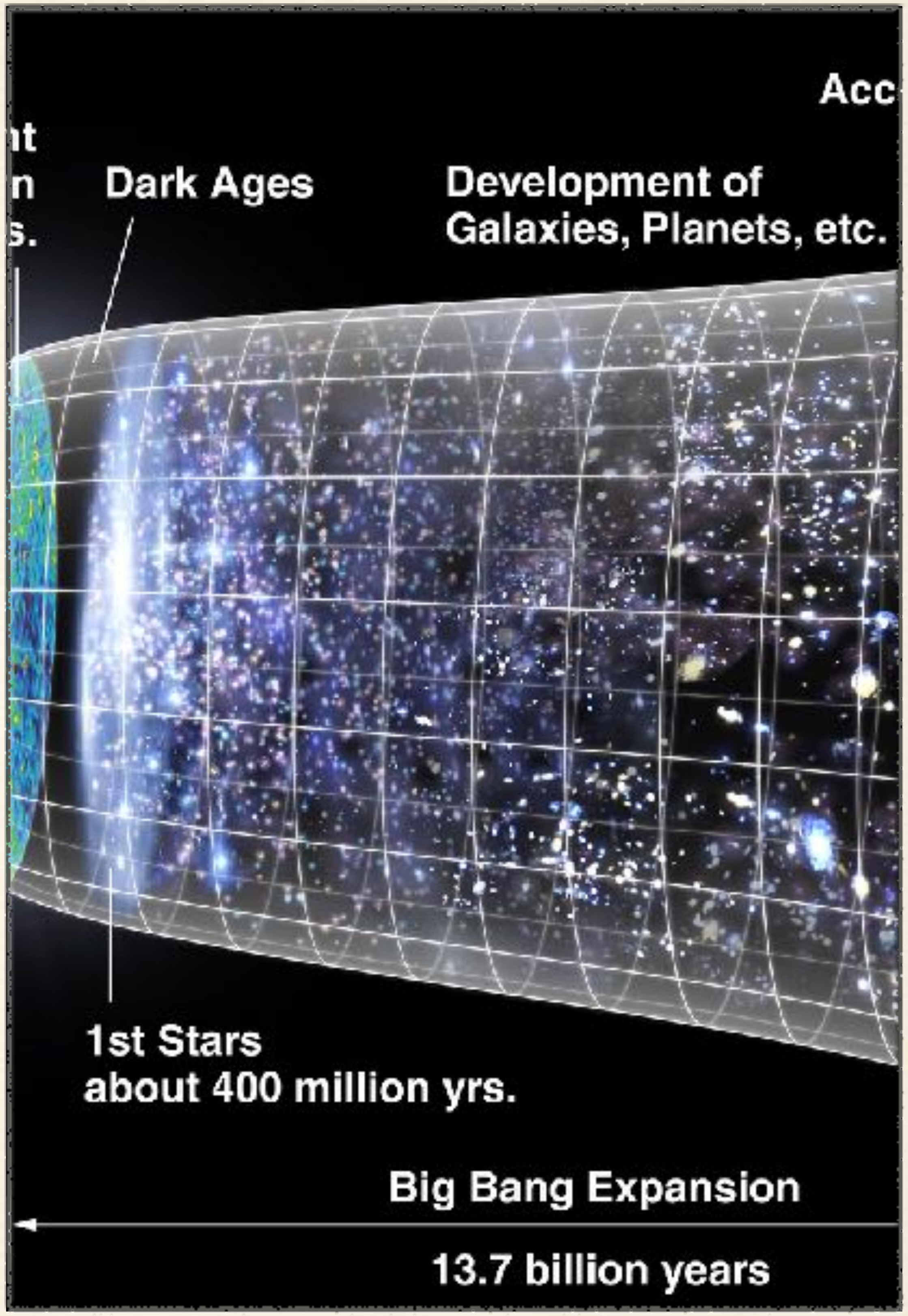
- An outgrowth of our work on CM5
- Shared memory on a distributed memory machine
    - “dist” keyword is the only syntax change
    - Performance high from special hardware on T3D
    - Faster than “shmem” library, due to low overhead

UPC = AC + Split-C + PCP

- Collaboration with UC Berkeley and LLNL
  - Takes “shared” from AC’s “dist”
  - “strict” and “relaxed” shared memory semantics
  - Split barriers: “notify/wait”
  - Locks
  - Adds several data distributions

PGAS: Expanding the collaboration

- SHMEM Library
- CoArray Fortran
- Global Arrays
- Titanium



DARPA HPCS Program
3 New PGAS Languages!

- Fortress: Implicit Parallelism, Strong Types
  - Cool look: like math in both ASCII and Unicode
  - Effort ended in 2012
- X10: Java-like syntax, asynchrony, locales
  - Going strong but, not much "HPC"
- Chapel: Separate Parallelism and Locality
  - Annual Conference, open source distribution

Post-HPCS PGAS

- Habenaro C and UPC++ (Rice)
- UPC++ (Berkeley)
- CoArray C++ (Cray, EPCC)
- HPX (C++/11,14, LSU, FAU)
- XcalableMP (Tskuba)
- GASPI (Fraunhofer)
- OpenSHMEM
- More every time one looks

HPC at a Crossroads

- Path to Exascale is underway:
  - System complexity increasing
  - Huge increase in OPs
  - Lesser increases in memory and communication performance
- Application development is getting harder, not easier

PGAS at a Crossroads

- Many implementations exist of PGAS techniques, essentially all platforms
- Provide a wealth of programming metaphors
- Performance has been shown to be very good
  - A number of cases which exceed best message passing code
    - Because you have a wider choice of algorithms and synchronization
- Programmer "base" is
  - (somewhat) small, and
  - (somewhat) static

Our Problem in 2017

How do we program this? And get good performance?

Key problem: Random Communication

- Many PGAS apps access shared memory randomly
  - Problematic on modern systems, due to relatively high cost of message initiation
- We have an approach called “exstack/Conveyors”:
  - Generate many more accesses than threads
  - Sort them locally, send in batches
  - Take received messages, process locally
  - Repeat until done
  - Several synchronization styles supported

exstack/Conveyors Analysis

- Performance surprisingly good for most apps
  - Most have plenty of parallelism in their accesses
  - Most tolerate the significant added latency
- Programability is a complete mess
  - Ugly, lengthy, complex looping structures in code
  - Have to packetize work by hand
- We want better, much like our previous "AC" work
  - We have tried to improve this and not found key
  - Aware of related efforts, we don't see key there either
  - Yet!

Thought Questions for Today

- How important is HPC performance?
  - And what does “performance” mean?
- How important is HPC programability?
  - And what does “programability” mean?
- How can we deal with HPC system complexity?
- Should we expand the PGAS horizons beyond HPC?

HPC Performance

- Performance has always been *critical* to HPC
  - By definition. If not, why go to the trouble. What matters:
    - Application results per unit time (e.g., day)
    - Application results per unit cost (e.g., $, Watt)
- Ways to improve application performance
  - Understand performance limiters, then
    - Write new code which gets around limiters
      - Includes both tweaks and new algorithms
    - Use new systems which address limiters
      - Hardware, Compilers, OS, etc, etc.

HPC Programability

- Programability has always been *debated* in HPC
  - By definition: Performance is *critical*. What matters:
    - Application performance achieved per unit cost
- Ways to improve programability
  - Apply more or better programmers
  - Apply more or better tools for programmers
  - Apply different programming techniques
- Debate is always about mix and extent of efforts

“An unwritten program has ZERO performance”

–Me

Key HPC Complexity
Multi-Level Parallelism

- Hardware is becoming increasingly hierarchical
  - Start with SMP “nodes” in distributed machines
  - Add threads within cores within processors
    - GPUs and other accelerators only add to the complexity
- Two distinct issues:
  - What is shared among threads on a “node”? But not globally?
  - What controls the parallel activity on a node?

Multi-Level Parallelism?

- Some programming models urge multi-level
  - SHMEM + pthreads or OpenMP
  - Programmers then write two levels of control flow, one for across nodes, one for on nodes
- UPC supports only local and shared
  - PGAS thread per hardware thread seems about right
  - An extension was made to allow shared allocation on node

Is “HPC” the only PGAS “market”?

- Mostly yes
  - Pointless to “partition” a tiny system
- But maybe not!
  - No widely-useful model for programing SMP processors
    - Most restricted to concurrency (e.g., go)
  - PGAS could provide a path to scalable apps
  - PGAS can be powerful metaphor in progammer education

PGAS Future?

- Stay the Course?
- Another Unification?
- New Approach?

Path Forward One: Keep Pressing

- Our current languages and libraries are good!
- Our current programmers are good!
- We are growing friends all the time
- To Do List:
    - Implement github-scale sharing of PGAS utilities
    - Start work on new application areas
    - Develop curriculum

Path Forward Two: New Unification

- UPC took three smaller, locally used languages
  - And made something better than sum of parts
- Several areas to consider
  - Many C++ based PGAS efforts are underway
  - PGAS Multi-treading and asynchrony
    - Including efforts that don’t know they are PGAS, yet :)
- But gaining branding and adoption is always hard

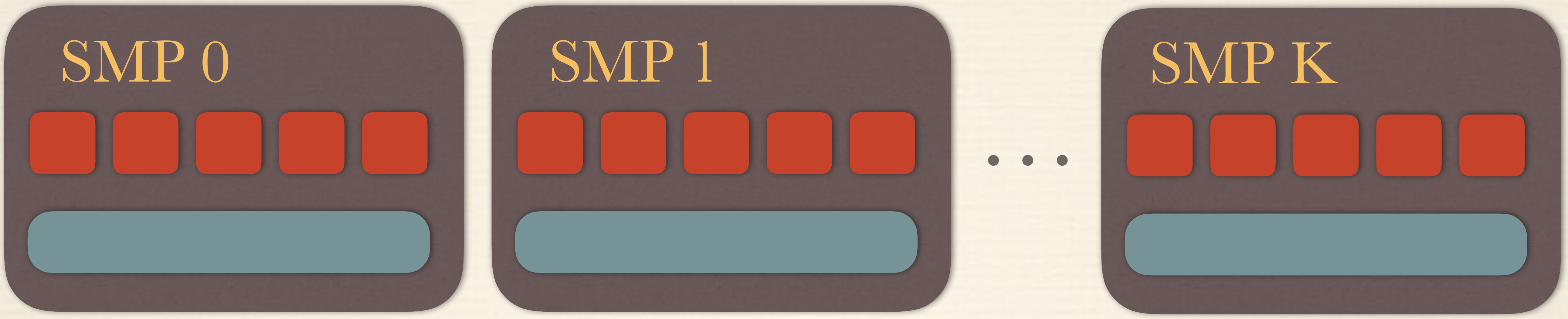
Path Forward Three: New Approach

- What's all this about Python (and friends) then?
  - No need to change the language to change programming models
  - Abundant local computation means we can (maybe) afford the overhead
    - And maybe call "native" code when needed
  - Can us any good communication system
- Why is there no "PGAS" for Python?
  - There is (or was), google "Python PGAS"
  - It was a good thought but never got supported

Consider: JavaScript and Node.js

- Node.js is a JavaScript engine based on Chrome's V8. All I/O is event driven and non-blocking
- Performance: See "Benchmarksgame"
  - JavaScript is about10x Python, 1x go,java, 0.1x C
- Interesting model
  - Every piece of JavaScript is sequential
  - But much parallelism based on event driven "I/O"
  - Which provides good mechanisms to deal with parallelism
- My attempt is to "PGAS" this where performance penalty is acceptable

PGAS Node.js



UPC/PGAS Process: started by SLURM

- Fixed program for inter-node accesses and synchronization

Node.js Process: `fork()/exec()` by UPC/PGAS

- User program, use `mmap()` communication with

PGAS Shared Objects

- All shared data derived from a root shared object
  - Data stored in PGAS program
  - Methods are something like get(), put(), action()
  - Access to shared mediated by PGAS program
  - Completion through callbacks, “promises”
  - May provide the programability and performance

Histogram in JavaScript

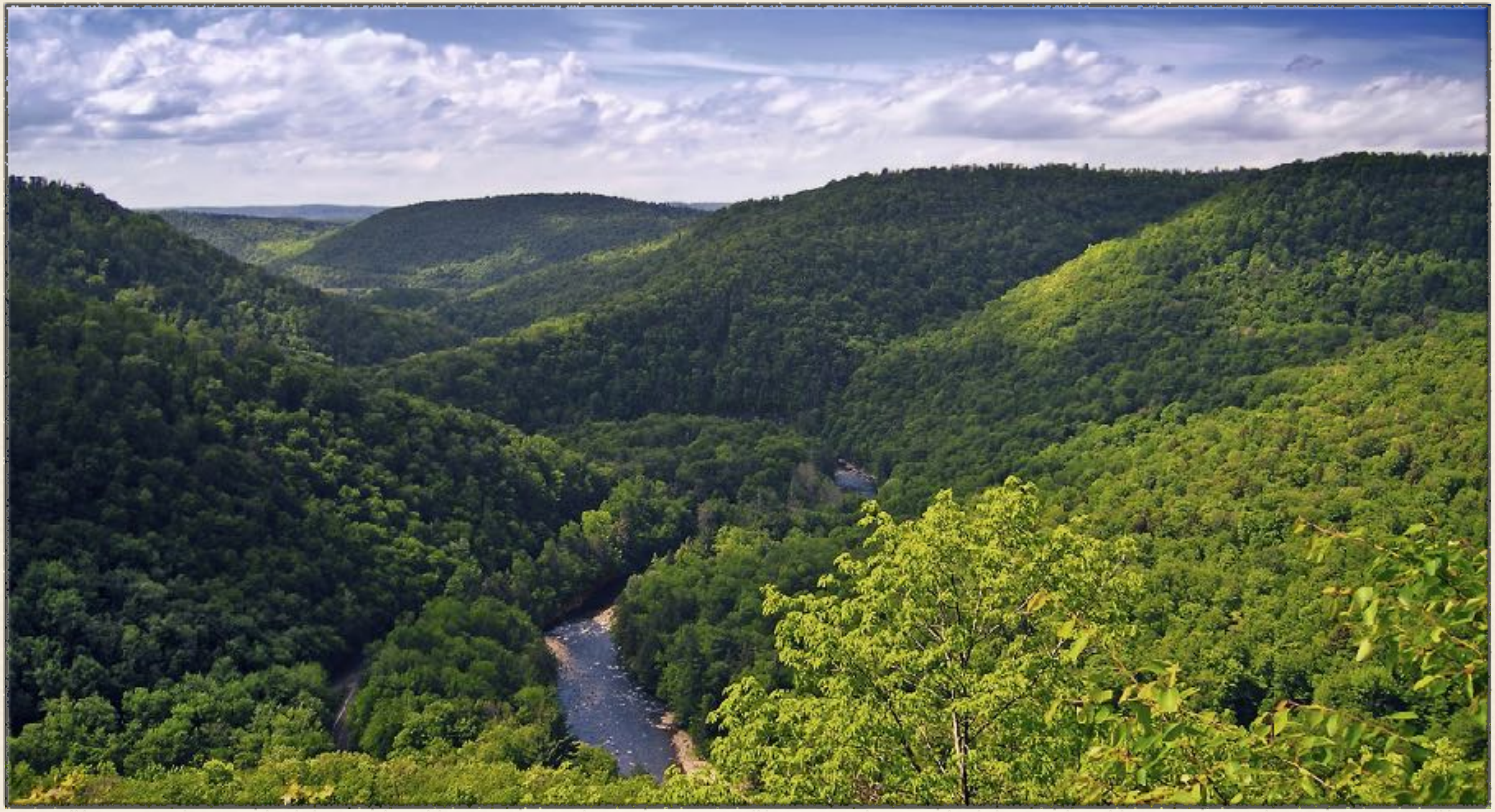
```
let num_per = 2457;
let span = par.num_proc*num_per;

Histogram(par, num_per, function(h) {
 for (let i = 0; i < 12345*par.num_proc; i++) {
  h.update(Math.random()*span));
 }).then(h => print h.histo[0]);
```

- `par` is an object which holds parallel context, from
- `Histogram` is a specialization of `ParallelUpdater`
  - update() parallel communication
  - Callback parallelizes allocation
  - Promise ".then()" handles completion
- Really just starting here, but I'm excited!

Closing Thoughts

- PGAS has developed a significant history
- Currently at a crossroads:
  - Concepts have proved useful in HPC
  - Struggling with current architectures
  - Adapt new approaches
- All future paths are interesting
  - But JavaScript is fun for me now, but happy to help with others!



Future Vistas for PGAS

The fun has only begun

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Backup Slides

DARPA's HPCS Program

- High ***Productivity*** Computing Systems
- Productivity: Output per unit of Input
  - Output is problems solved
  - Input is money, energy, people time
- Goal: Increase productivity of HPC by 10x:
  - Systems performance 10x for many metrics
  - Algorithm and Software developers 10x effective in making good code
  - System operators spend 1/10 effort to manage system

New Uses for HPC/PGAS

- A lot of emphasis on "Big Data"
  - How about an awesomely fast PGAS key-value store
- Machine "Deep" "learning"
  - Can PGAS allow real advances in this field
- Previously "Abandoned" HPC applications
  - Industrial uses in manufacturing
- My assertions:
  - PGAS approaches could help add new application areas
  - These are not using HPC (much) because it is too hard to program

Complexity of Next Gen HPC?

- Strong forces for higher complexity
  - Need to control energy leads to specialization
    - Accelerators like GPUs
    - Small, specialized memories
    - Communication at a distance is always limited by cost
  - ExaScale goals are pushing for large performance gains
- Some trends to lower complexity
  - Many applications can fit "on a node" or small segment of system
  - Communication bound algorithms might ignore complex parts of system