HiHAT: A Way Forward to Perf Portability with Retargetable Infrastructure

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OUTLINE

- Perspective: performance portability
- Challenges: More heterogeneity in HW platforms, SW interfaces
- Solutions: Common retargetable infrastructure - hierarchical hetero async tasking

HETEROGENEITY AND RETARGETABILITY

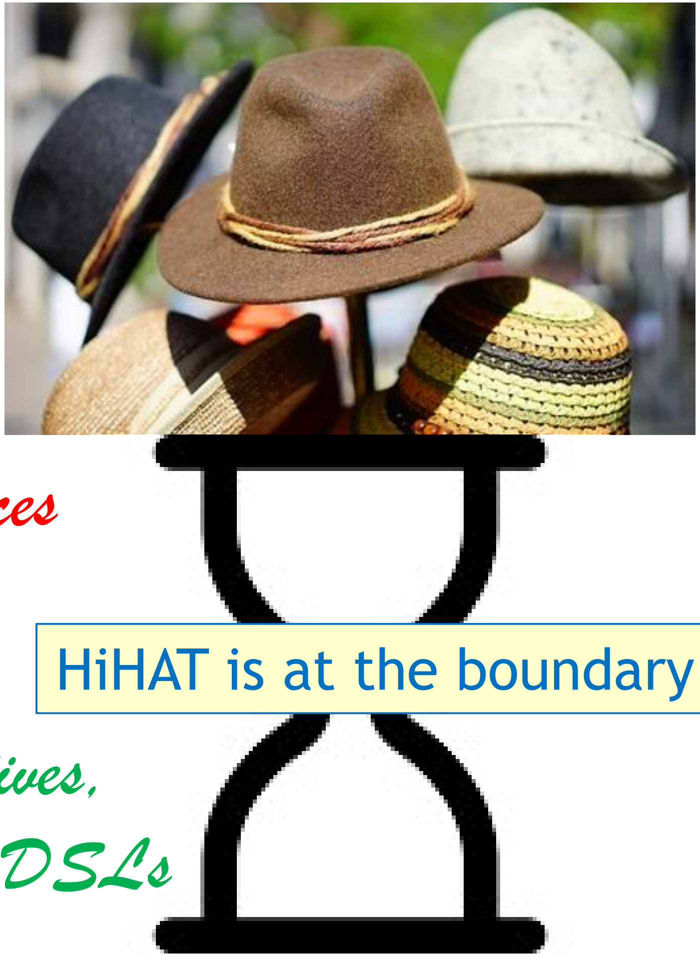
- Heterogeneity within a platform
  - Increasing specialization
  - Host, accelerators; kinds, layers and locations of memory; interconnect
- Retargetability across platforms
  - One software architecture, many targets
  - And of course we want…

PERFORMANCE PORTABILITY DEFINITION

- “Same code” + different architectures → efficient performance

PERFORMANCE PORTABILITY CONTRADICTIONS

- “Same code” + different architectures → efficient performance
- Contradictions – first set
  - But I like my language! The other guy’s language gives horrible performance!
  - But I need a special data layout for each target!
  - But I have a favorite user-level interface. Don’t take that away from me!



User interfaces

target agnostic

HiHAT is at the boundary

Target directives, languages, DSLs

target specific

PERFORMANCE PORTABILITY PARTIAL SOLUTIONS

- "Same code" + different architectures → efficient performance

- Potential solutions – first set
  - Language: Target-specific task implementations where needed
  - Data layout: Task implementations tailored for data layout, scheduler can choose to re-layout data off of the critical path
  - User-level interface: Layer client user-facing runtimes on top of retargetable interface

PORTABILITY IS IN THE EYE OF THE BEHOLDER

- Task: High-level language, with directives or DSL or even assembly instructions

PORTABILITY IS IN THE EYE OF THE BEHOLDER

- Pluggable implementations
  - Task: High-level language, with directives or DSL or even assembly instructions
  - Best way for a given platform: target-specific APIs and implementations

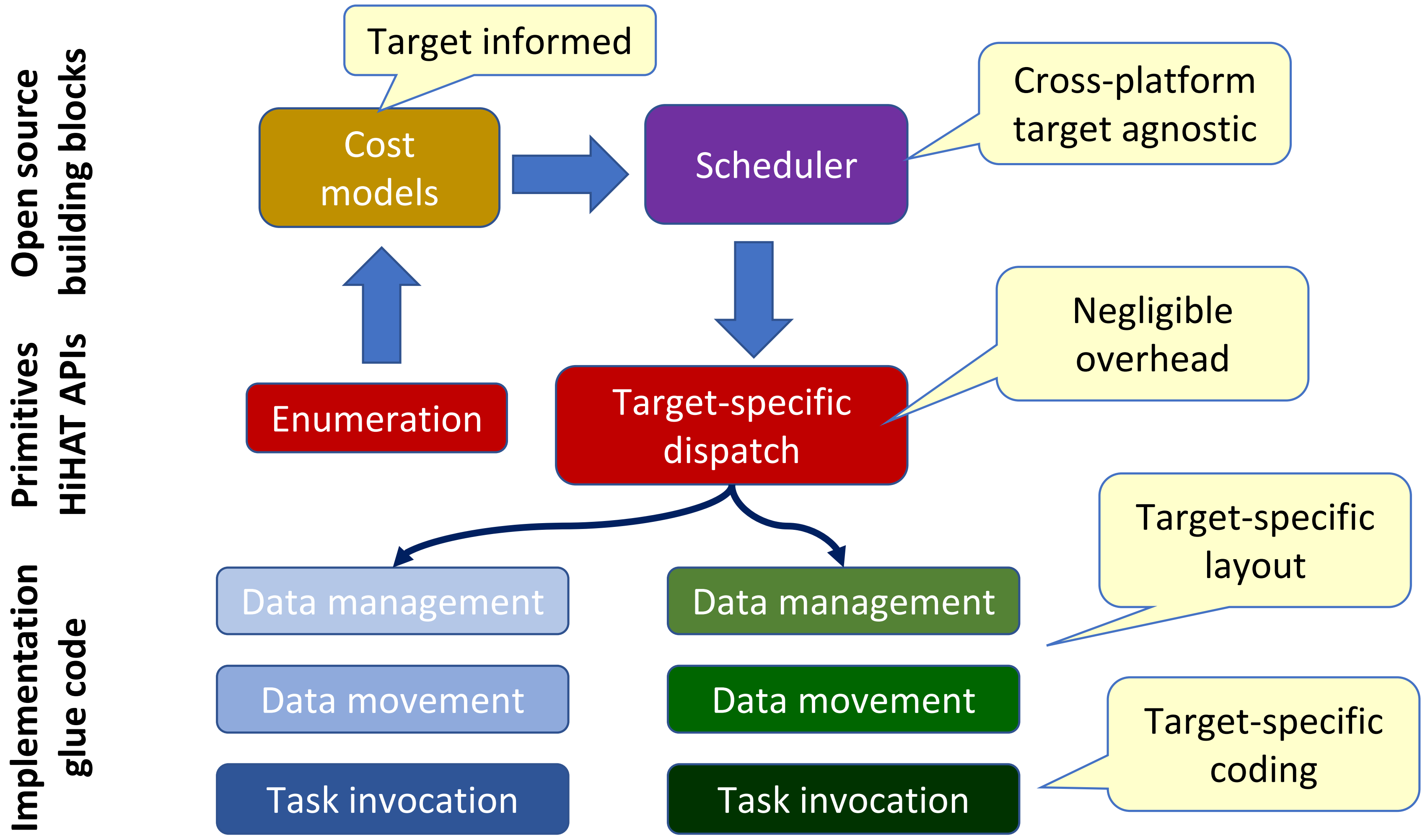
PORTABILITY IS IN THE EYE OF THE BEHOLDER

- Sequence of target-agnostic primitives
  - Invoke, manage data, move data, coordinate, enumerate
- Pluggable implementations
  - Task: High-level language, with directives or DSL or even assembly instructions
  - Best way for a given platform: target-specific APIs and implementations

PORTABILITY IS IN THE EYE OF THE BEHOLDER

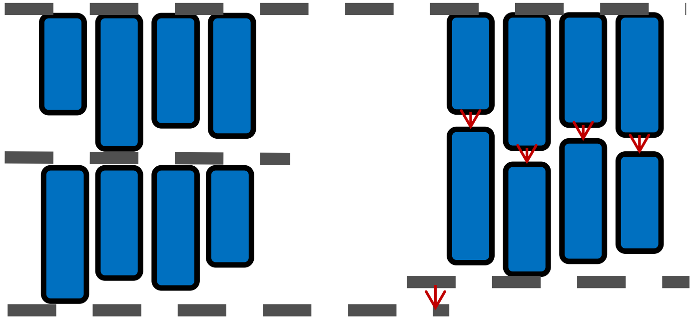
- Scheduler – binding and ordering, based on cost model
  - Select target, implementation, layout, add actions as needed
  - Invoke primitives where and when most appropriate
- Sequence of target-agnostic primitives
  - Invoke, manage data, move data, coordinate, enumerate
- Pluggable implementations
  - Task: High-level language, with directives or DSL or even assembly instructions
  - Best way for a given platform: target-specific APIs and implementations

COMMON RETARGETABLE SW ARCHITECTURE



MOTIVATIONS FOR A SCHEDULER

- Lack of predictability
  - Where data comes from, in memory hierarchy or across network
  - When computation will finish: complex algorithms, load imbalance, DVFS
- Growing complexity
  - Too many factors at play to settle on a single portable static scheduler
  - Too much diversity in increasingly-heterogeneous platforms
- Going asynchronous
  - Break out of bulk synchronous, move to point-point
  - Dynamic management of resources



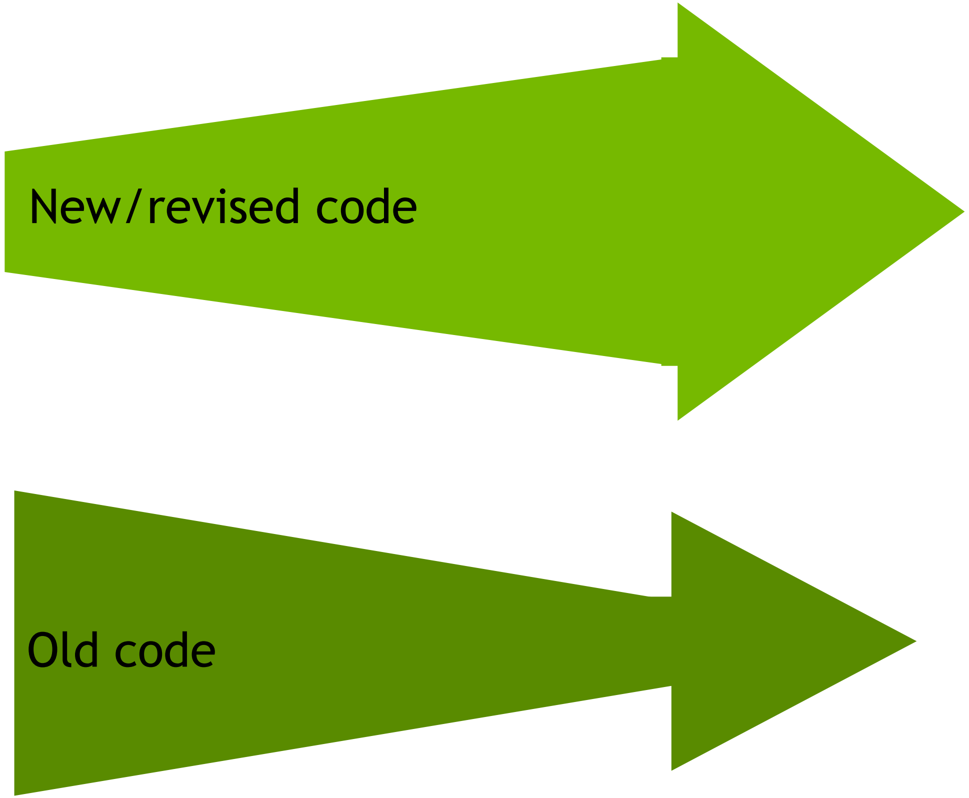
PROVIDING ACCESS TO PERFORMANCE

Meeting our customers where they are, offering a path forward

% lines of code — gains, ROI

- Exposing maximal parallelism
- Extreme scaling
- Tuning for the target platform
- Tailored abstractions

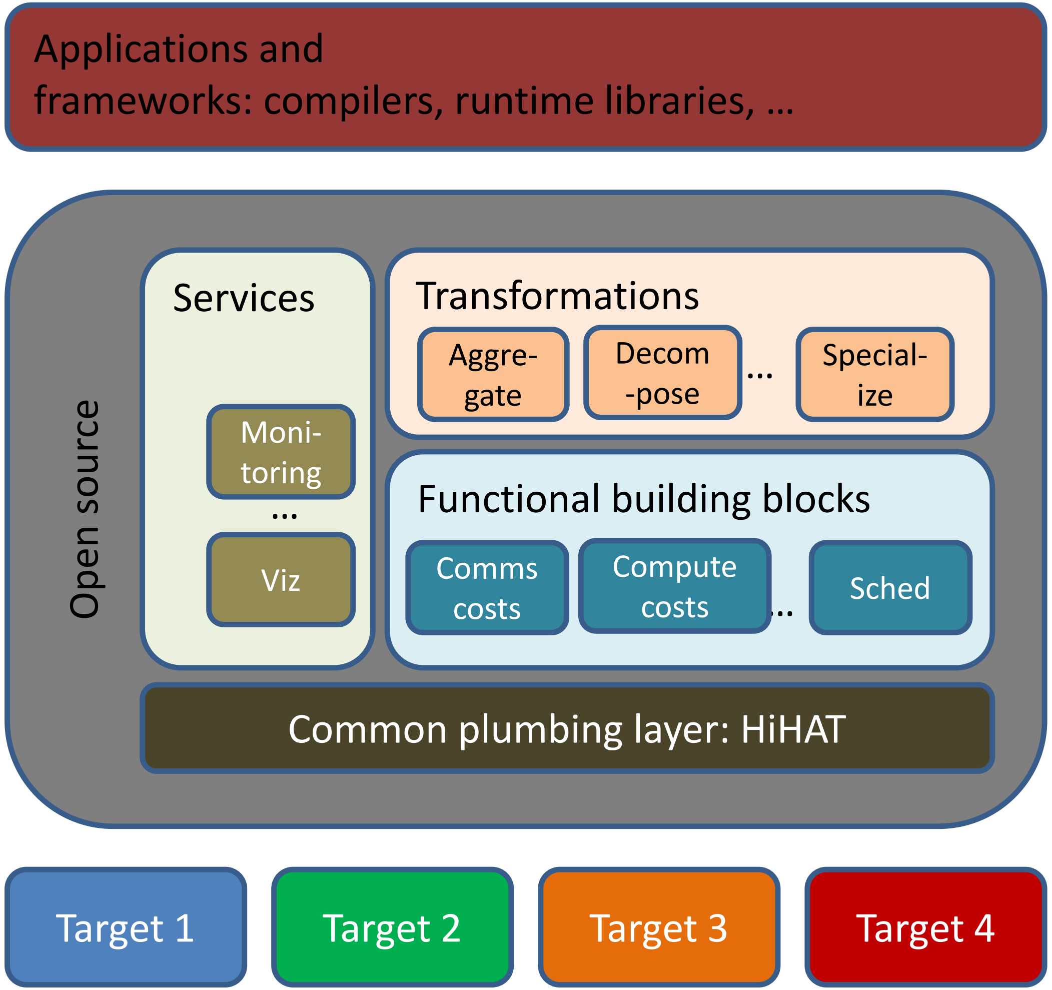
- Limited effort
- Traditional language interfaces



App developers code

Tuners configure

Experts implement



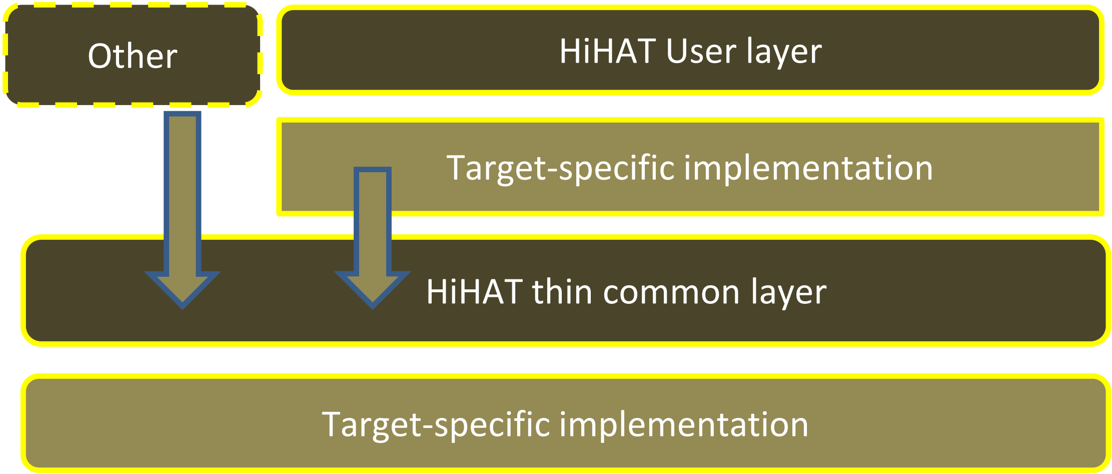
https://wiki.modelado.org/Heterogeneous_Hierarchical_Asynchronous_Tasking

HIHAT: APIS FOR RETARGETABILITY

- Plug in target-specific implementations from below
- Implement data management, data movement, invocation, coordination, querying

- User: ease of use via abstraction

- Common: minimal overhead



Bold = shared material on mapping to HiHAT

LANGUAGE OR TASKING FRAMEWORKS

Some part of each institution has expressed technical interest, not necessarily business commitment.

- C++ (**CodePlay**, IBM) Michael Wong
- Chapel (**Cray**), Brad Chamerlain
- Charm++ (**UIUC**) Ronak Buch, (**Charmworks**) Phil Miller
- Darma (**Sandia**) Janine Bennett
- Exa-Tensor (**ORNL**) Wayne Joubert
- Gridtools (**CSCS**, Titech) Mauro Bianco
- HAGGLE (**PNNL/HIVE**) Antonino Tomeo
- Kokkos, Task-DAG (**SNL**) Carter Edwards
- Legion (**Stanford/NV**) Mike Bauer
- OmpSs (BSC) Jesus Labarta
- Realm (**Stanford/NV**) Sean Treichler
- OCR (**Intel**, **Rice**, GA Tech) Vincent Cave
- PaRSEC (**UTK**) George Bosilca
- Raja (**LLNL**) Rich Hornung
- Rambutan, UPC++ (LBL) Cy Chan
- R-Stream **(Reservoir Labs)** Rich Lethin
- StarPU (**INRIA**) Samuel Thibault
- SyCL (**CodePlay**) Michael Wong
- SWIFT (**Durham**) Matthieu Schaller
- TensorRT (**NVIDIA**) Dilip Sequeira
- VMD (**UIUC**) John Stone

TABULATED RESULTS

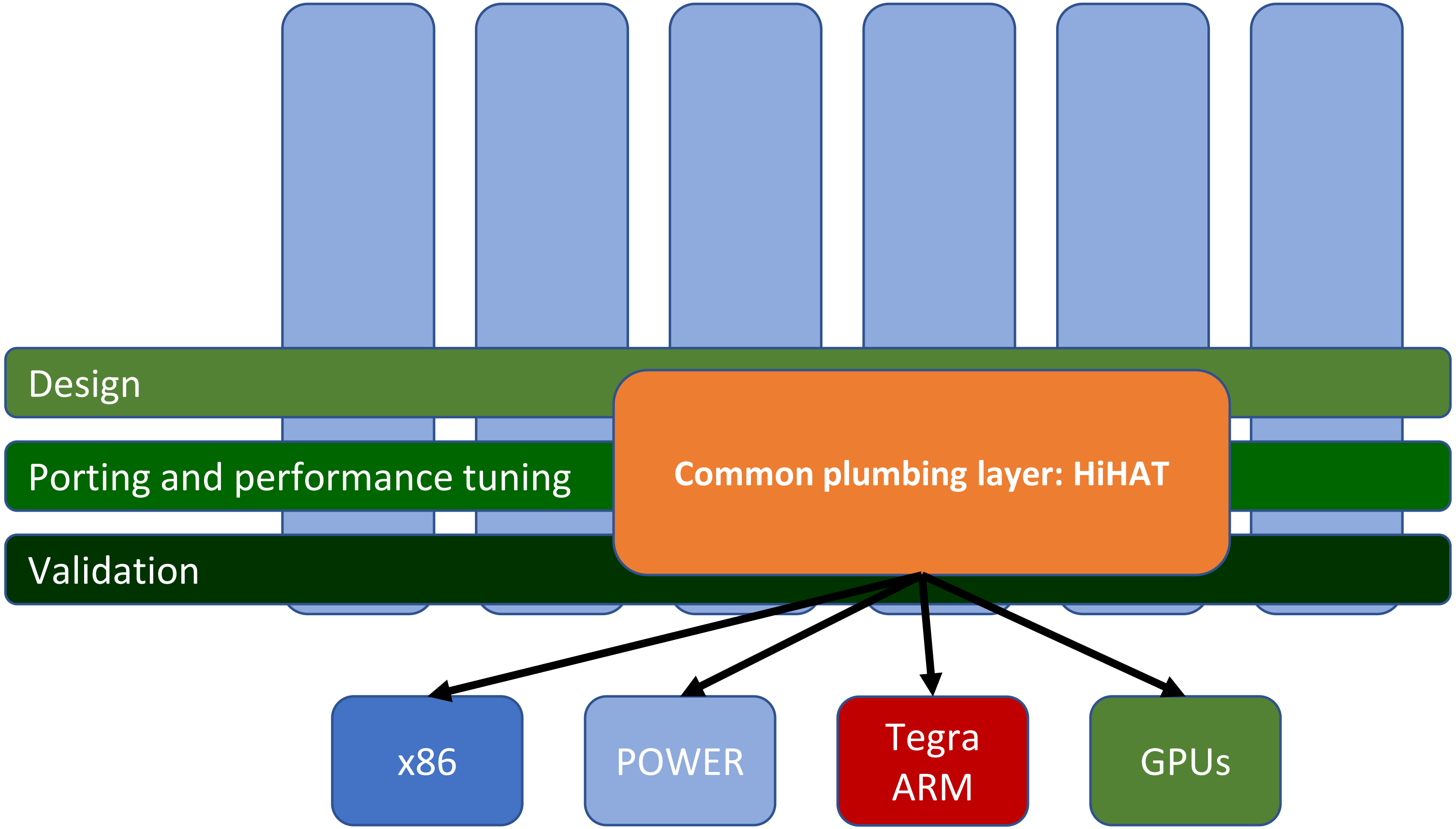
Strong interest, modestly amenable; progress; next

Type of functionality	Level of interest			Amenability to refactoring		
	H	M	L	H	M	L
Data movement – target-optimized copies, DMA, networking	15	1	1	7	5	1
Data management – kinds and layers of memory, specialized pools	11	4	2	7	4	2
Coordination – completion events, locks, queues, collectives, iteration	9	8	0	6	5	1
Compute – local or remote invocation	7	3	4	4	5	4
Enumeration – kinds/# of resources, topologies	11	5	1	4	4	3
Feedback – profiling, utilization	6	7	2	4	7	1
Tools – tracing, callbacks, pausing, debugging	3	12	2	2	7	2

ADOPTION

- Meet requirements
  - Provisioning: C ABI, library, interoperable, profiling
  - Performance: enables access to perf features, low overhead → supports fine granularity
  - Incremental, easy on ramp
- Open architecture
  - Be a provider for tasking and language runtimes and frameworks
  - Plug in implementations from below, from vendors or third parties
  - Share building blocks, e.g. cost models, schedulers
- Easiest and best solution

SO MANY FRAMEWORKS, SO LITTLE TIME

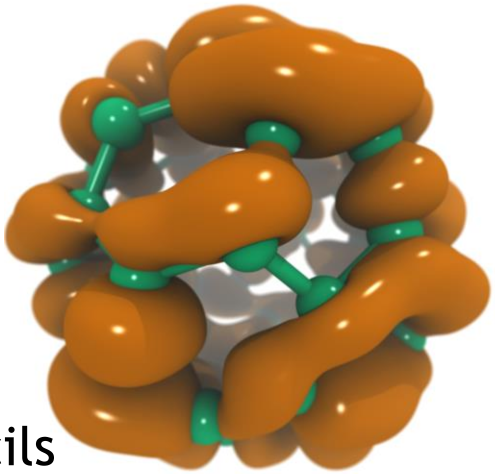


PROTOTYPE INFRASTRUCTURE CAPABILITIES

The basics are already working

- Current test platform: 2 CPU sockets + 2 GPUs in one node
- Data movement
  - User Layer: <dst, src, size> using logical handles for addressing
  - Common Layer: use specialized flavors
  - Set up comms, establish visibility as needed
- Data management
  - User Layer: Allocate or register, and create address-memory resource association
    - Also support tagging to clean up a set of allocations/wraps at once
  - Common Layer: No tagging
- Invocation
  - Register target-specific implementations, invocation with closure
- Microbenchmarks show overheads are within measurement noise

MOLECULAR ORBITALS (MO) APPLICATION



- Compute wavefunction amplitudes on a grid for visualization
  - Evaluate linear combination of Gaussian contractions (polynomials) at each grid point, function of distance from atoms
- Algorithm made arithmetic bound via fast on-chip memory systems
- Three different algorithms for different memory structures:
  - GPU constant memory
  - Shared memory tiling
  - L1 global memory cache
- Representative of a variety of other grid-oriented algorithms, stencils
- Use of special GPU hardware features, APIs helped drive completeness of HiHAT proof-of-concept implementation already at an early stage

MOLECULAR ORBITALS PERFORMANCE

- Performance of MO algorithm on HiHAT User Layer PoC implementation closely tracks CUDA performance.
- Spans x86, POWER and Tegra ARM CPUs

HIHAT API GAINS FOR MOLECULAR ORBITALS APPLICATION

Molecular Orbital Algorithm, Mem Kind		Speedup vs. ShMem	HiHAT API gain
x86 + GPU	SharedMem HiHAT	1.000x	1.028x
	L1CachedGlblMem HiHAT	1.088x	1.025x
	ConstMem HiHAT	1.472x	1.031x
PWR + GPU	SharedMem HiHAT	1.000x	0.999x
	L1CachedGlblMem HiHAT	1.116x	1.001x
	ConstMem HiHAT	1.534x	0.983x
ARM + GPU	SharedMem HiHAT	1.000x	-
	L1CachedGlblMem HiHAT	1.094x	-
	ConstMem HiHAT	1.059x	-
	NoPin-SharedMem HiHAT	2.349x	0.995x
	NoPin-L1CachedGlblMem HiHAT	2.561x	0.984x
	NoPin-ConstMem HiHAT	2.562x	0.998x

PORTABILITY ON MO

Mapping between CUDA and HiHAT

- Time to port MO: 90 minutes
- HiHAT has fewer unique APIS (6 vs. 10)
- HiHAT has fewer static API calls (30 vs. 38)

- **Accelerate optimization space exploration**
- Also enhance coding productivity

TARGET-SPECIFIC API USAGE IN MOLECULAR ORBITALS APPLICATION

Category	Original CUDA		Ported to HiHAT	
Invoke	<<<>>>	3	hhuInvoke()	3
Data mvt	cudaMemcpy()	7	hhuCopy()	7
	cudaMemcpyToSymbol()	7	hhuCopy()	2
Configuration	cudaSetDeviceFlags()	1	(config)	0
	cudaFuncSetCacheConfig()	2	(config)	0
Data mgt, minimal	cudaMalloc()	7	hhuAlloc()	7
	cudaMallocHost()	1	hhuAlloc()	1
	cudaHostAlloc()	1	hhuAlloc()	1
	[free]		hhuClean()	[1]
	[symbols]	-	hhuRegMem()	7
Data mgt, eliminatable	cudaFree()	7	hhuFree()	(7)
	cudaFreeHost()	2	hhuFree()	(2)
	[symbols]	-	hhuDeregMem()	(7)
Coordination	-	0	hhuSyncAll()	1
Totals				
static	14+3+3+9+9+0	38	9+3+0+16+16+1	43
static min'l	14+3+3+9+9+0	38	9+3+0+17+0 +1	30
unique	2+1+2+5+0+0	10	1+1+0+2 +2 +1	7
unique min'l	2+1+2+5+0+0	10	1+1+0+3 +0 +1	6

TAKE-AWAYS

- Portability comes at the scheduling layer, on top of target-agnostic primitives
- Dynamic scheduling may have the most promising path to portability and scaling
- Necessary conditions: meet requirements; be pluggable; open source approach; be the easiest path to performance, generality and robustness
- HiHAT prototype looks promising as a retargetable infrastructure