Locale Model Improvements

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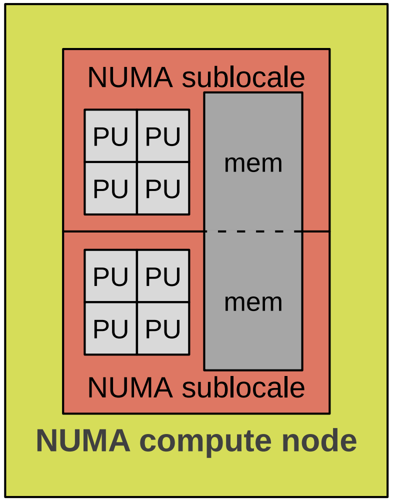
Outline

- NUMA Locale Model Improvements
- Chapel on KNL

NUMA Locale Model Improvements

NUMA: Background

- **‘numa’ locale model describes NUMA compute nodes**
  - NUMA: Non-Uniform Memory Access
  - a NUMA node has 2 or more *sublocales**
    - represented as child locales of network-level locales
    - each has processors and memory
  - access to own-sublocale memory is faster than access to other-sublocale memory



- **Performance with ‘numa’ locale model was poor**
  - DefaultRectangular arrays were not fully optimized for sublocales
  - parallel iterator placed tasks on sublocales as it wished
  - array data was not always similarly placed
  - thus: unreliable task/data affinity

* = these are typically called numa *domains*, but we’re avoiding that term here to avoid confusion with Chapel’s domains

NUMA: Background (DefRect Domain Iteration)

- **How DefaultRectangular domain parallel iteration works**
  - block one dimension of the domain, creating #sublocales subdomains

```
forall i in {1..2, 1..8, 1..N} { … }
```

example:
{1..2, 1..8, 1..N}

	1	2	3	4	5	6	7	8
1	1..N	1..N	1..N	1..N	1..N	1..N	1..N	1..N
2	1..N	1..N	1..N	1..N	1..N	1..N	1..N	1..N

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forall i in {1..2, 1..8, 1..N} { … }
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example:
{1..2, 1..8, 1..N}

on 4 sublocales:

	1	2	3	4	5	6	7	8
1	1..N	1..N	1..N	1..N	1..N	1..N	1..N	1..N
2	1..N	1..N	1..N	1..N	1..N	1..N	1..N	1..N

rewritten

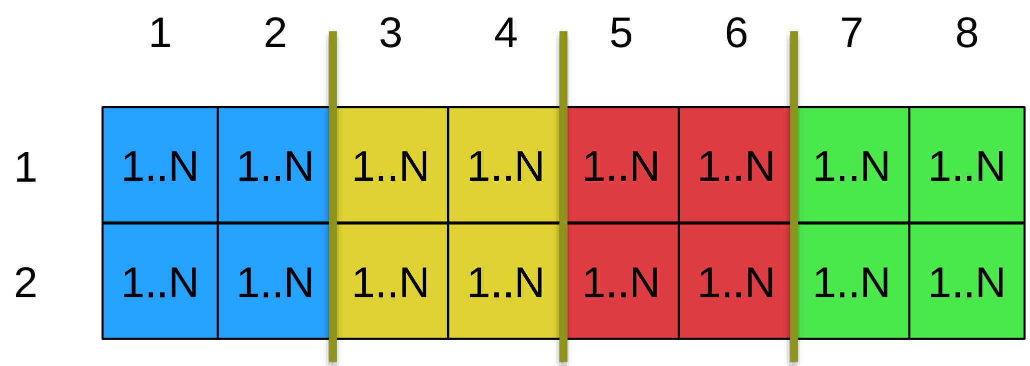
```
coforall subloc in 0..#here.getChildCount() {   // 0..3
  local on here.getChild(subloc) {   // 1 task runs on each sublocale
    forall i in {1..2, subloc*2+1..#2, 1..N} { … }
  }
}
```

NUMA: Background (DefRect Array Locality)

- **Goal: array memory locality matches index partitioning**
  - locality was set implicitly, via first-touch

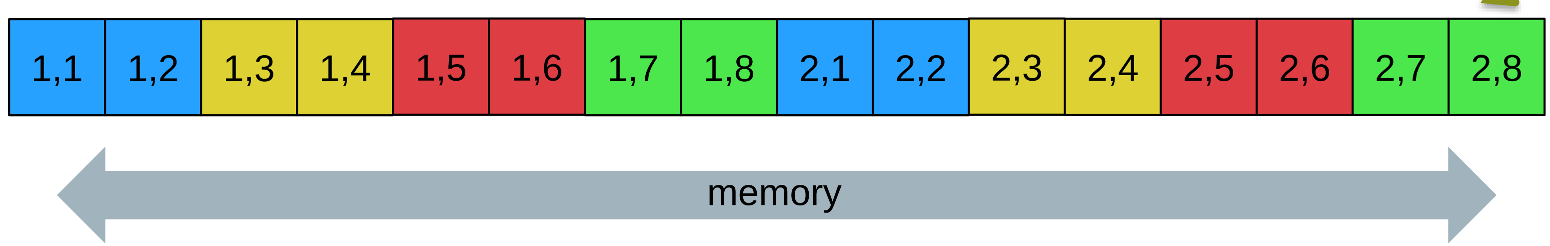
example:
{1..2, 1..8, 1..N}

on 4 sublocales:



memory locality follows domain partitioning

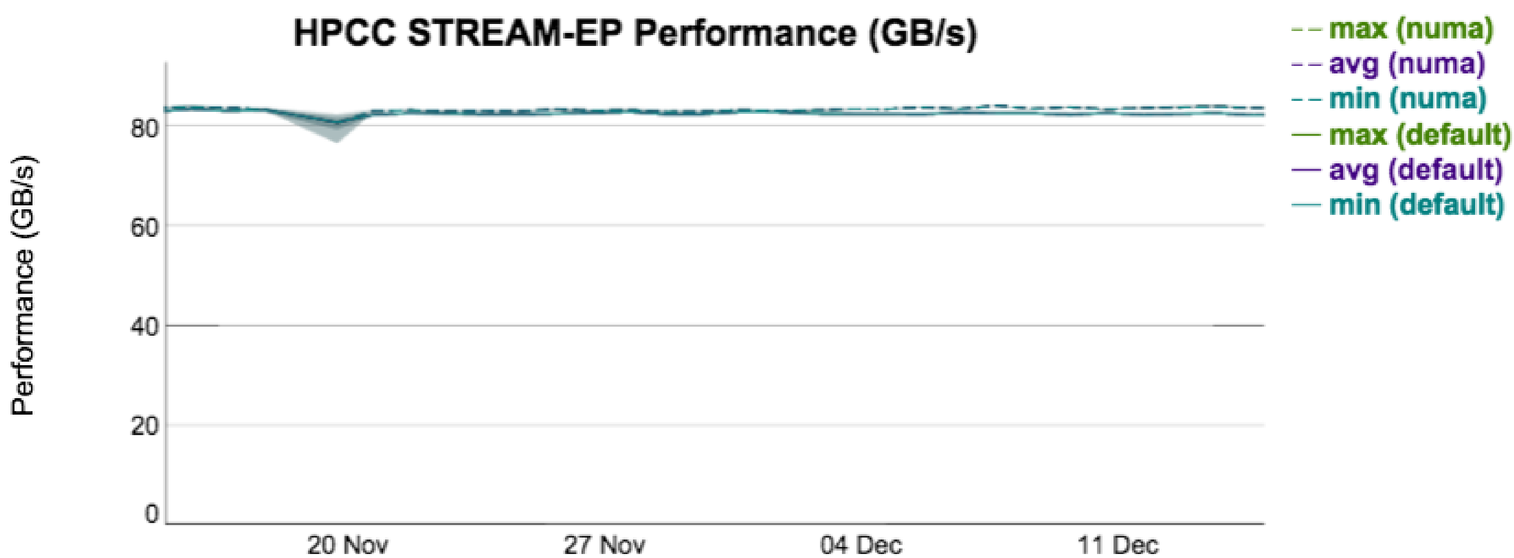
1..N array
elements
in each
box



NUMA: Background (DefRect Array Locality)

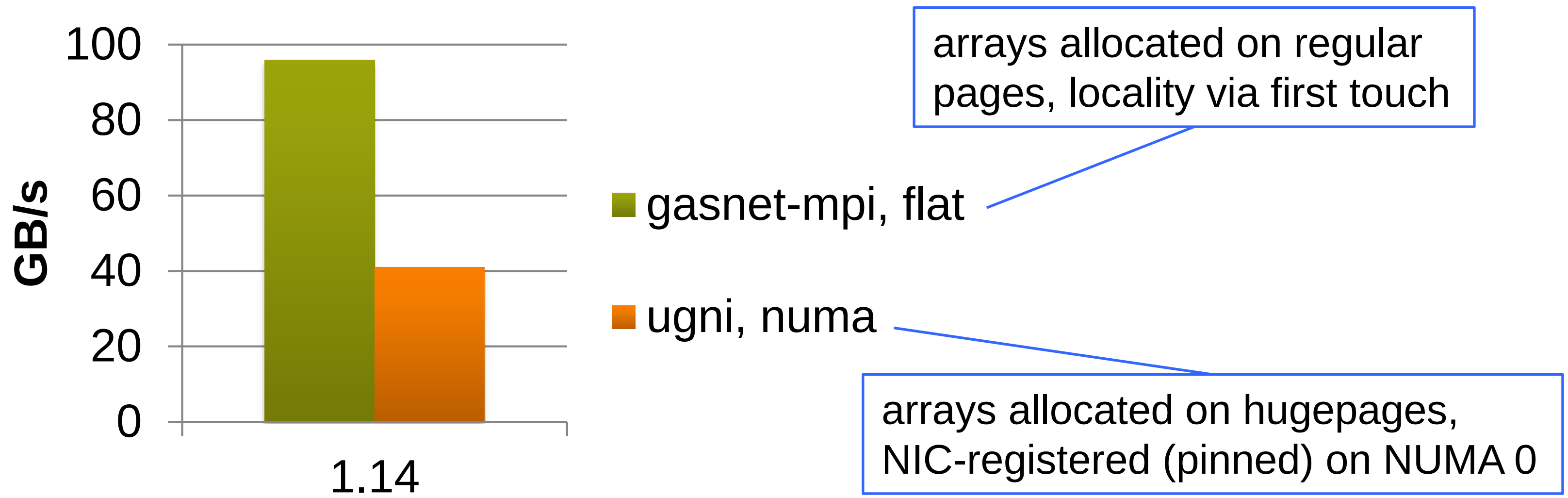
- **In many cases this technique resulted in good affinity**
  - unsurprising, since this is effectively what OpenMP does for NUMA

stream-ep on single-locale linux64:



NUMA: Background (DefRect Array Locality)

- **But pre-existing locality can thwart first-touch**
  - stream-ep on multi-locale Cray XC:

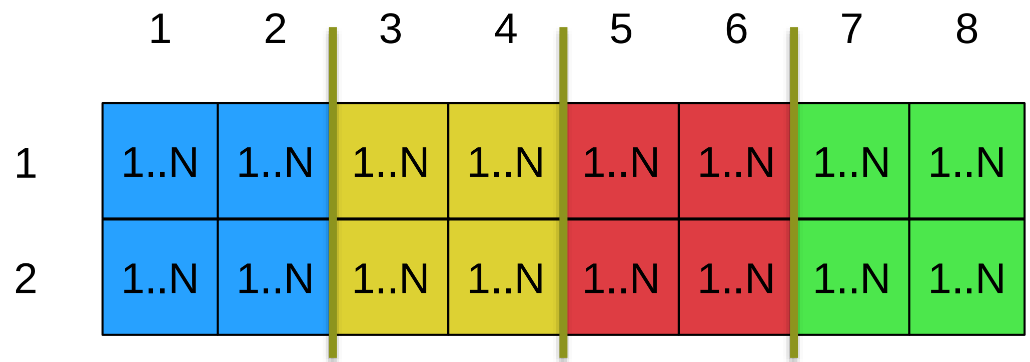


  - NIC registration of comm=ugni heap pins mem, setting NUMA locality
    - changing NUMA locality would mean re-registration, broadcast, etc.
  - any reused memory will also have pre-existing locality
    - changing NUMA locality will be expensive due to page migration

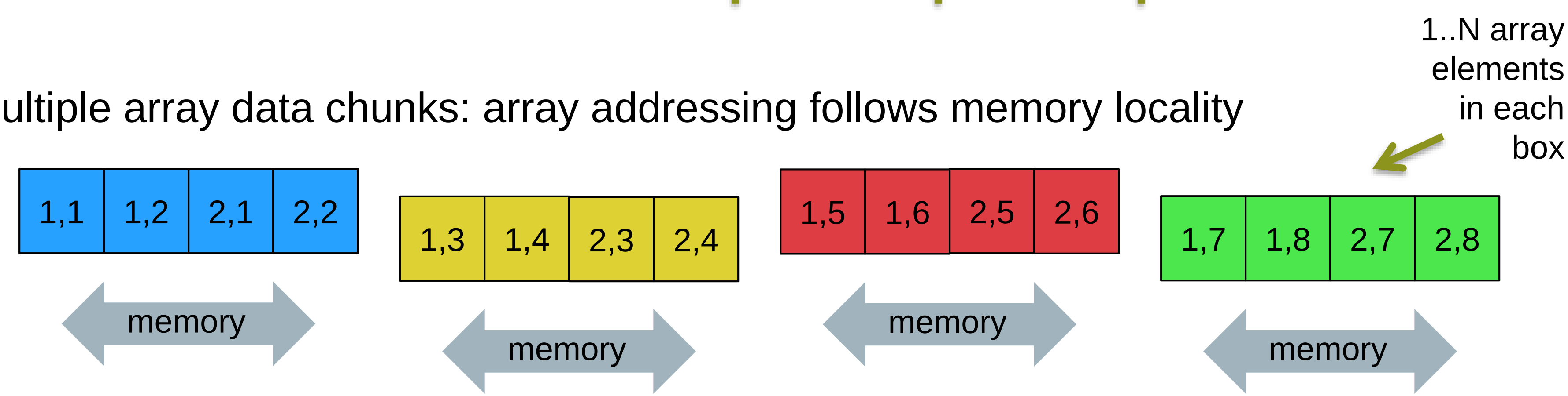
NUMA: This Effort

- **Split array data just like DefRect iterator splits domain**
- **Set NUMA locality of each array data chunk separately**

example:
{1..2, 1..8, 1..N}
on 4 sublocales



multiple array data chunks: array addressing follows memory locality



NUMA: This Effort (Multi-chunk Array Alloc)

- **Multi-chunk array allocation is also known as *multi-ddata***
- **Partition array data as DefRect iterator partitions domain**
  - Currently only done for arrays >= 1 MiB
- **Reworked array implementation extensively**
  - rewrote array addressing and iterators
  - updated other code that assumed a single array data block

NUMA: This Effort (NUMA-Aware Mem Alloc)

- **In some cases, just force locality after allocation**
  - configurations: single-locale, any memory layer
  - only for array data allocation
- **In other cases, do real NUMA-aware allocation**
  - configuration: Cray XC, comm=ugni, registered heap, mem=jemalloc
  - affects all memory allocation, not just array data
  - implemented using new comm/mem layer cooperation:

comm:	allocate heap space on hugepages
mem:	logically partition heap into #sublocs blocks; set each block's locality to corresponding NUMA sublocale
comm:	register heap with the NIC
mem:	manage each block as a separate heap: allocation by task on *subloc* always comes from *subloc*'s heap

NUMA: Impact

- **Performance depends on style of array access**

- **Array iteration, implicit element access:**

```
forall (a,b,c) in zip(A,B,C) do a = b + alpha * c;
```

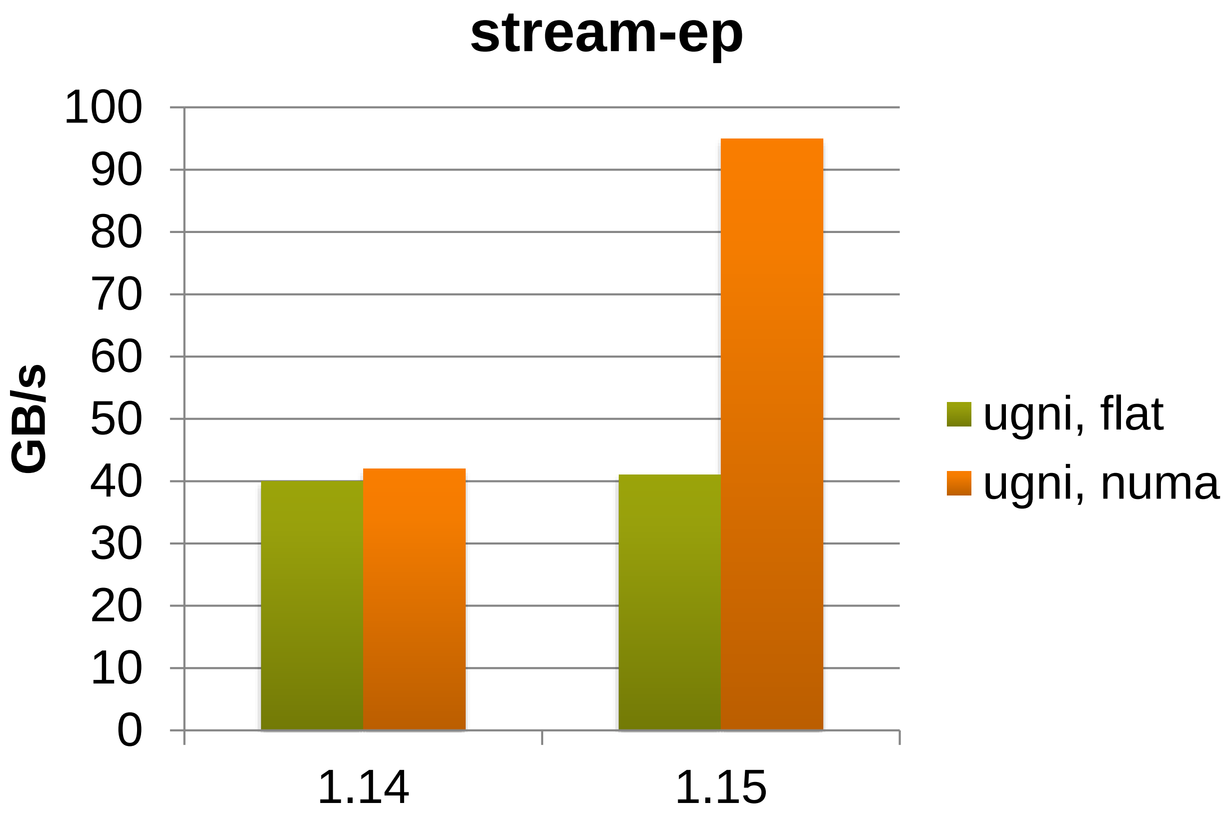
  - single-node: performance largely unchanged
    - locality was good based on first-touch, though now is more principled
    - a memory reuse test case should show improvement, but is difficult to code
  - multi-node with registered heap: performance better, often much better

- **Domain/range iteration, explicit element access:**

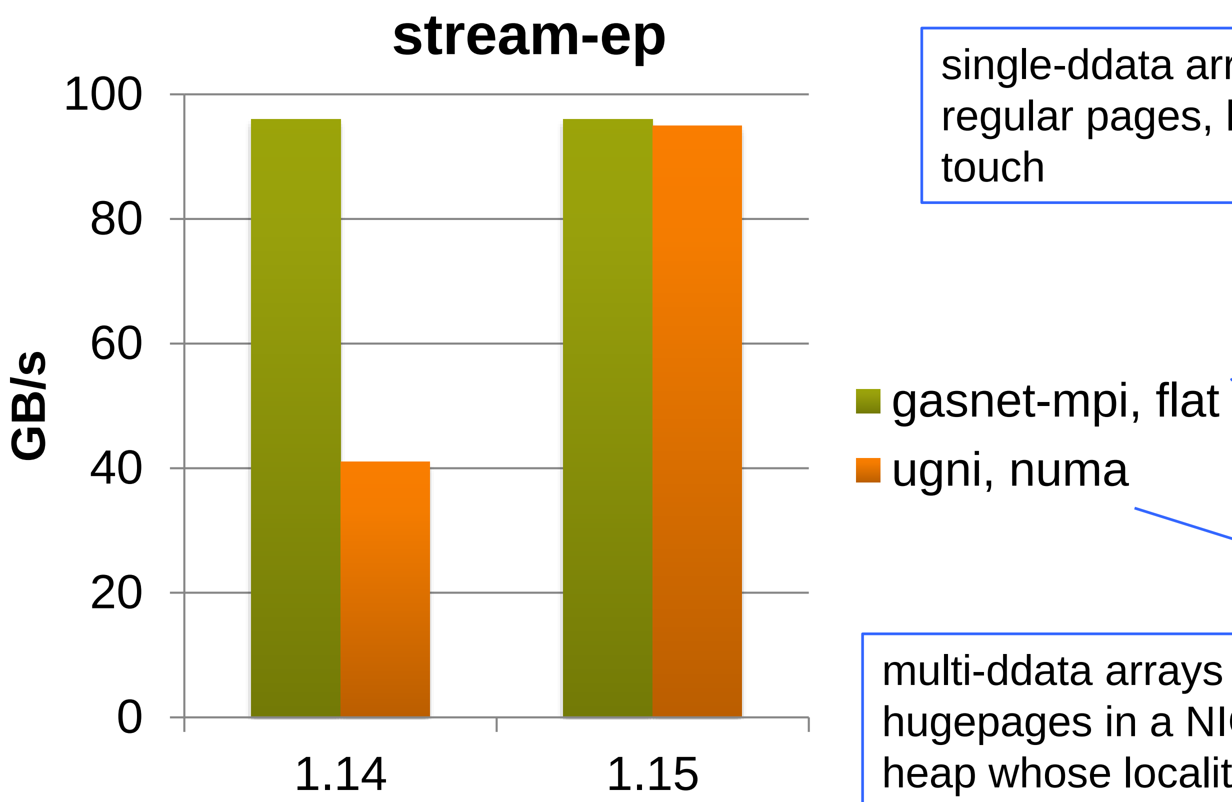
```
forall i in A.domain do A[i] = B[i] + alpha * C[i];
```

  - performance worse, often much worse

NUMA: Impact (2-node Cray XC w/ ugni)



NUMA: Impact (2-node Cray XC ugni vs. gasnet)

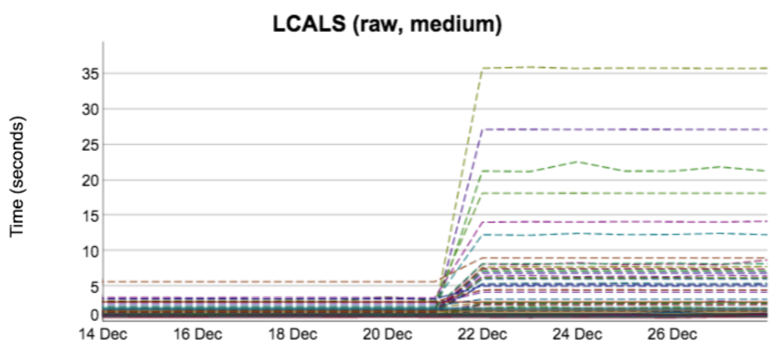


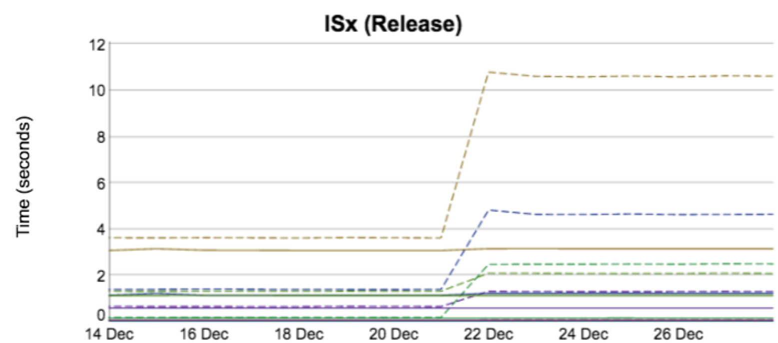
single-ddata arrays allocated on regular pages, locality via first touch

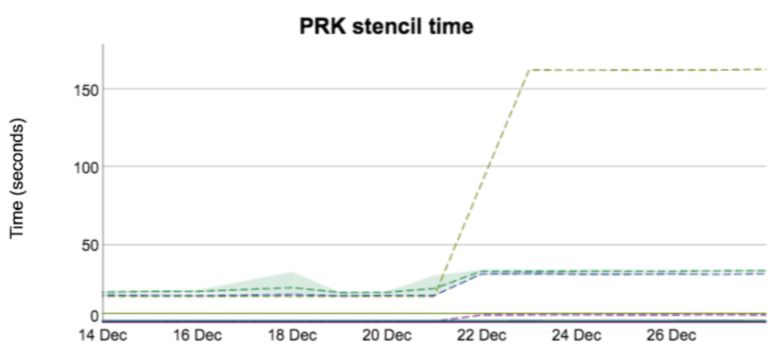
multi-ddata arrays allocated on hugepages in a NIC-registered heap whose locality is blocked across NUMA sublocales

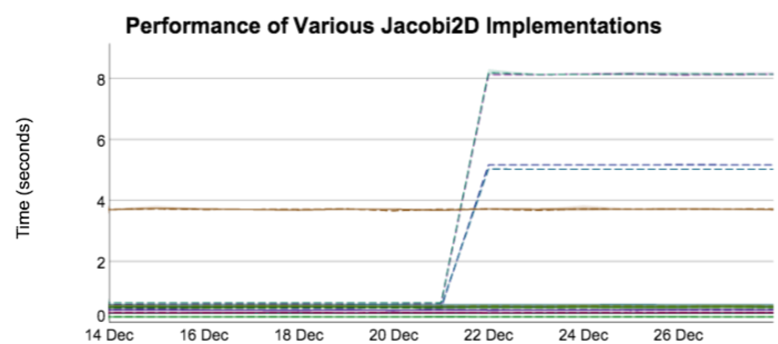
NUMA: Impact (Performance Regressions)

- **Big locModel=numa performance losses for many tests**
  - array access is much slower when iterating over domain or range
  - due to added overhead of index calculation for multi-chunk arrays





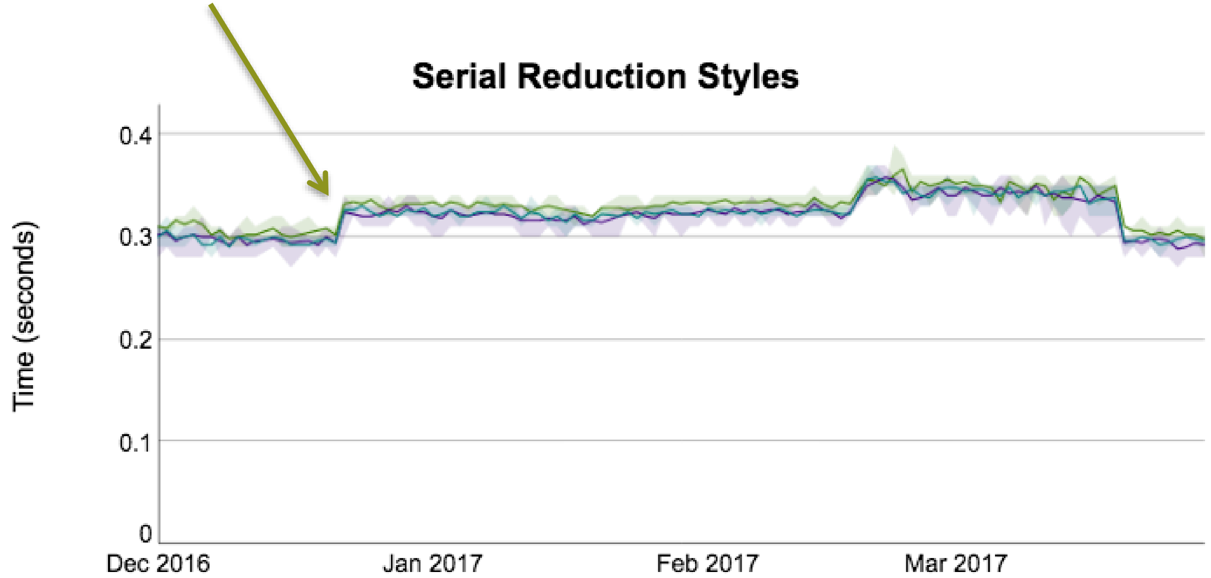




NUMA: Impact ('flat' Perf Regressions)

- **New array metadata fields even impacted locModel=flat**
  - they weren't used, but initializing them wasn't free
  - and mere presence changed cache line sharing in array descriptor

added metadata fields in array
descriptor reduce performance

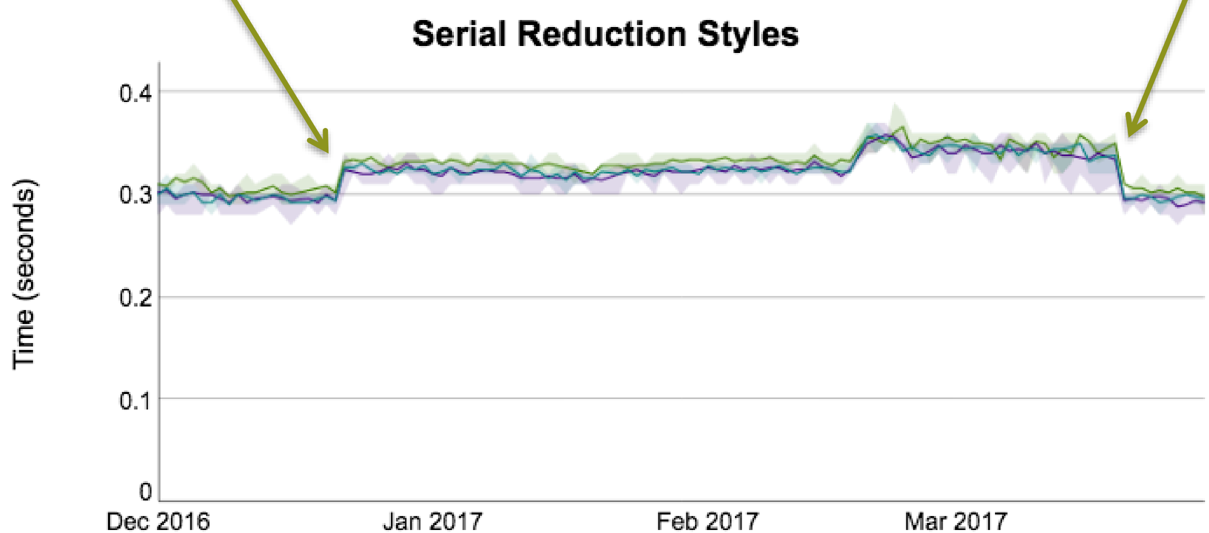


NUMA: Impact ('flat' Perf Regressions)

- **New array metadata fields even impacted locModel=flat**
  - they weren't used, but initializing them wasn't free
  - and mere presence changed cache line sharing in array descriptor

added metadata fields in array descriptor reduce performance

new 'void' type allows effectively removing numa-oriented array descriptor fields for locModel=flat



NUMA: Next Steps

- **Major 1.16 decision: stay with multi-ddata?**
- **If retaining multi-ddata:**
  - reduce array access overhead; how much can we achieve?
  - provide for programmer specification re: single- vs. multi-ddata
- **If reverting to single-ddata:**
  - how (whether) to handle pre-existing locality?
  - how to handle multi-node NIC-registered heaps?
- **Improve NUMA-aware memory allocation**
  - do more sublocale-aware allocation (task stacks, etc.)
  - reduce migration by allocating memory with proper locality

Chapel on Intel Xeon Phi “Knights Landing” (KNL)

Chapel on KNL: Background (KNL)

- **KNL is a many-core platform (60+ cores)**

- **Cores can access two kinds of memory**
  - external memory (DDR)
  - on-package high-bandwidth multichannel DRAM (MCDRAM)

- **Different from other processors supported by Chapel**
  - helps us think forward to more complex emerging architectures
  - leads us to exercise and expand NUMA support
  - will also benefit from future vectorization efforts

Chapel on KNL: Background (KNL Configs)

- **KNL can be used in several different configurations**
  - cluster modes
    - cores can appear as grouped into one, two, or four NUMA nodes
  - memory modes
    - MCDRAM used as memory
    - MCDRAM used as direct-mapped level-3 cache
    - a combination of the two
  - configuration is controlled by BIOS
    - a change requires ~15 minutes to reboot the affected processor

- **MCDRAM is seen as core-less NUMA nodes**
  - when accessed via the Linux NUMA interface

Chapel on KNL: This Effort

- **Create 'knl' locale model**
  - NUMA-oriented, based on 'numa' locale model with modifications
  - benefits from the multi-ddata improvements

- **Provide a mechanism to use MCDRAM**
  - in a portable way

- **Use a newer release of hwloc**
  - required updates to handle core-less NUMA nodes (MCDRAM)

Chapel on KNL: This Effort

- **New methods on 'locale'**

```
locale.highBandwidthMemory()  // MCDRAM if 'locale' is KNL in mem. mode
locale.lowLatencyMemory()     // DDR on KNL
locale.largeMemory()          // DDR on KNL
locale.defaultMemory()        // DDR on KNL
```

  - implemented across all locale models for portability
  - use the Intel memkind library when CHPL_LOCALE_MODEL=knl
  - yield regular memory, otherwise

- **A basic structure for accessing different kinds of memory**
  - long term, possibly could be used by domain map authors

Chapel on KNL: Impact

- **Chapel programs can target KNL's MCDRAM**

```
on here.highBandwidthMemory() {
  x = new myClass();        // placed in MCDRAM
  ...
  on here.defaultMemory() {
    y = new myClass();      // placed in DDR
    ...
  }
}

on y.locale.highBandwidthMemory() {
  z = new myClass();        // same locale as y, but using MCDRAM
  ...
}
```

Chapel on KNL: Impact

- **Programs work whether MCDRAM is available or not**
  - uses default memory if MCDRAM is unavailable

- **Each locale figures this out for itself**
  - can use heterogeneous configuration of KNL processors
  - avoids the need to reboot if configuration choice is not critical

Chapel on KNL: Status and Next Steps

Status:

- 'knl' locale model and locale methods are available in Chapel 1.15
  - included in Chapel module on Crays

Next Steps:

- Experiment with using MCDRAM in various benchmarks
- Work on vectorization improvements/optimizations
  - also explore potential KNL-specific optimizations
- Enhance the interface to specify multiple conditions
  - "Give me high bandwidth memory, but only if at least 1GB exists"
- Architecture queries
  - "Is high bandwidth memory available on this locale?"

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