Locale Model Improvements

Chapel Team, Cray Inc.
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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
● How DefaultRectangular domain parallel iteration works
  ● block one dimension of the domain, creating #sublocales subdomains
    
    \[
    \text{forall } i \text{ in } \{1..2, 1..8, 1..N\} \{ \ldots \}
    \]

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

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NUMA: Background (DefRect Domain Iteration)

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

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

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

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<tr>
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</table>
```

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:

![Graph showing HPCC STREAM-EP Performance (GB/s)]
**NUMA: Background (DefRect Array Locality)**

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

  ![Bar Chart](image)

  - gasnet-mpi, flat
  - ugni, numa

  - 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:
  ```python
  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:
  ```python
  forall i in A.domain do A[i] = B[i] + alpha * C[i];
  ```
  - performance worse, often much much worse
NUMA: Impact (2-node Cray XC w/ ugni)
NUMA: Impact (2-node Cray XC ugni vs. gasnet)

![Graph showing performance comparison between gasnet-mpi, flat and ugni, numa.

- 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

```java
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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