Managing the Memory Hierarchy

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Now Where Did I Put That Data?

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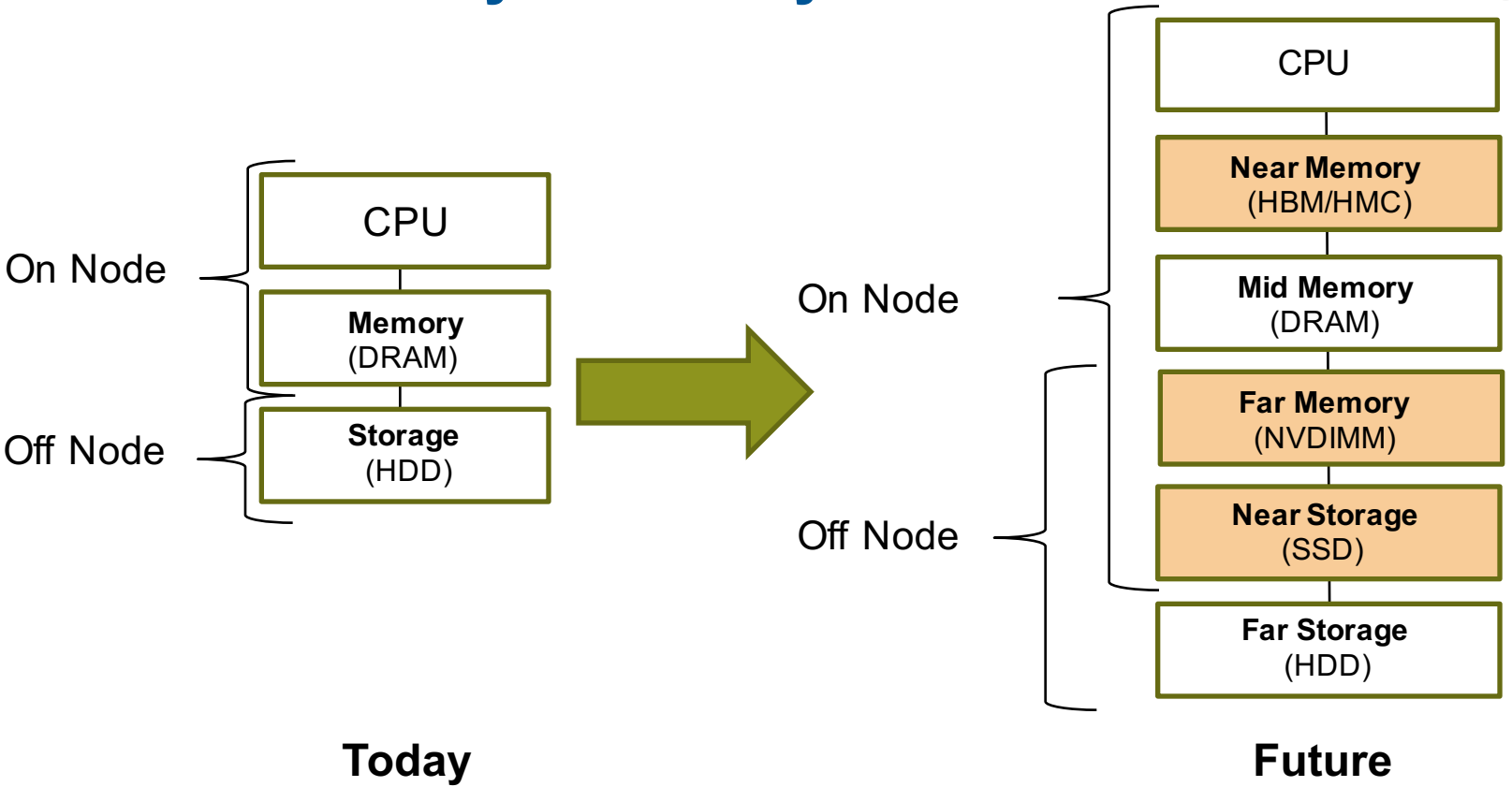
Abstract Memory Hierarchy

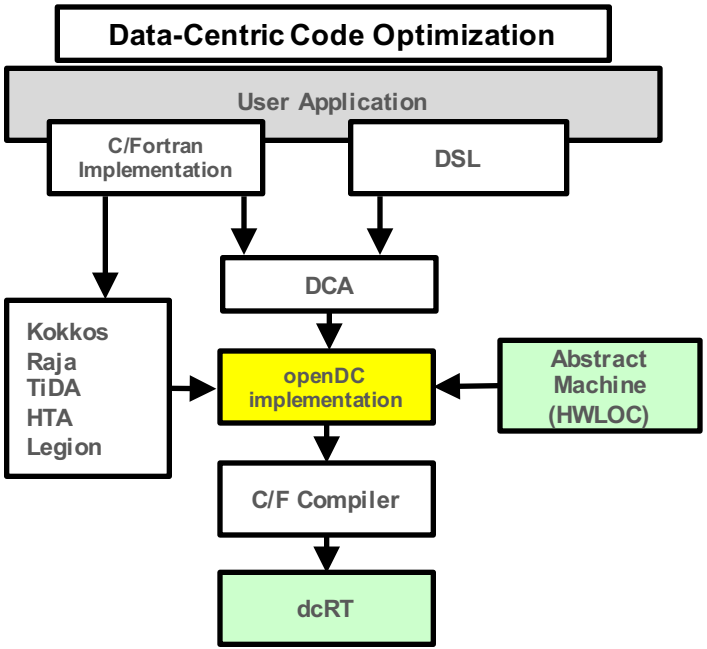


Data Management

- **Providing initial functionality today, developing more**
- **Will incorporate new technologies as they mature**
  - E.g. It's possible we'll have multiple levels of NVM in the hierarchy
- **Three levels of interest:**
  - On-node memory (on package, local bulk memory)
  - Network-attached NVM that is accessed as memory
  - Network attached NVM that is accessed via file system
- **At each level, want a dual approach**
  - APIs for users to manage and access data
    - APIs, directives, and tools for on-node memory management
    - Distributed object storage in NVM
    - DataWarp APIs
  - System software to automate placement and usage of the memory

Data Management in the Memory Hierarchy

- **Investigating programming model support for the various memories**
  - Largely concerned with placement and layout of data plus related work scheduling
- **Includes existing and future elements of memory hierarchy**
  - Caches, near/fast memory, bulk memory, remote memory, NVM
- **Community efforts making some progress**
  - Legion, Kokkos, RAJA, etc.
- **Cray is also investigating some proprietary techniques**
  - Expect synergy across efforts, potential for integration



Overall Hierarchy Management Strategy

- **OS provides the infrastructure**
  - Not well placed for decision making
  - Should expose detailed attributes to runtime
- **Programming model runtime aids or makes the decisions**
  - Has detailed application knowledge
  - Opportunity to hide details from programmer
- **Tools analyze usage to help with placement**
  - Especially for data not easily placed by application usage

Near Term Memory Hierarchy Plans

- **Developed initial set of directives for memory placement**
  - Agreement to work with Intel on standardization in OpenMP
- **Developing tools to advise programmer on placement**
  - Use performance counters and compiler instrumentation
- **Considering extensions to existing "placement" libraries**
- **NVRAM considerations are next**

CCE Support for High Bandwidth Memory

- **Support base Intel mechanisms**
  - Treat "memkind" API as a third-party library
  - Recognize "FASTMEM" attribute

- **Add directive (pragma) to support data allocation in HBM**
  - Support Fortran, C, and C++ and cover more use cases
  - The directive can be used on **both local and global variables**
  - The directive **can also be used on a statement**
    - Changes allocation routines (allocate, malloc, etc.) to use HBM
  - **If Clause** for dynamic control of directive
  - **Fallback Clause** to control behavior if allocation fails
  - Ideally will become part of a standard, possibly OpenMP

Directive for Existing Heap Allocations

```
!dir$ memory(attributes)
#pragma memory(attributes)
```

- **Appears prior to an allocation/deallocation statement**
  - Fortran: allocate
  - C/C++: malloc, calloc, realloc, posix_memalign, free
  - C++: new, delete, new[], delete[]
- **Directive on deallocation must match (C/C++ only)**
- **Converts normal allocation to high-bandwidth memory**
- **Initially "bandwidth" is the only allowed attribute**
  - Other attributes may be added in the future

Directive for Variable Declarations

```
!dir$ memory(attributes) list-of-vars
#pragma memory(attributes) list-of-vars
```

- **Specified at declaration of variable**
  - For global variables, directive must be visible for every use of global
  - Within type for allocatable members
- **Allowed on:**
  - Local and global variables
  - Scalars, structs, and arrays (fixed size and variable length)
  - Fortran allocatables (including members of derived types)
    - Memory allocated will use high bandwidth memory
- **Not allowed on:**
  - Dummy arguments, Fortran pointers, variables involved in equivalences, Coarray or UPC shared variables
  - Common blocks or variables within a common block

If Clause

```
!dir$ memory(attributes) if(expression)
#pragma memory(attributes) if(expression)
```

- **Dynamic control of directive**
- **For declarations**
  - Expression is evaluated when variable goes into scope
- **For heap allocations**
  - Expression is evaluated when directive is encountered
  - The expression must match on the deallocation (C/C++ only)

Fallback Clause

```
!dir$ memory(attributes) fallback
#pragma memory(attributes) fallback
```

- Controls behavior if allocation fails
- Default behavior: allocation fails
- Fallback behavior: allocation returns normal memory

Tool Support Plans for HBM

- **HBM summary info**
  - Memory use mode info (was cache or managed memory used?)
- **Program memory high water mark for sampling and tracing**
  - Break this down into DDR and HBM memory
- **Report active allocations at samples or during tracing at the function level**
- **Report overall program wallclock time, top time consuming routines, etc.**
- **Provide information on candidates for HBM placement**

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