Using Tpetra without CUDA UVM

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The Trilinos team has removed the requirement for UVM usage

- Motivation:
  - New platforms may or may not have reliable UVM-like capabilities
  - Debugging application and system issues with UVM is difficult
  - Explicit memory management should avoid performance surprises
- Trilinos still works with UVM enabled
  - And UVM enabled remains default for CUDA builds
  - But applications need to remove use of deprecated code and behavior
  - Build with
    -D Tpetra_ENABLE_DEPRECATED_CODE=OFF
    -D Kokkos_ENABLE_CUDA=ON
    -D Kokkos_ENABLE_CUDA_UVM=OFF

Biggest change: Tpetra manages sync / modify between host and device

- Tpetra has Kokkos::DualViews of matrix and vector data
- New Tpetra class WrappedDualView manages the sync / modify flags between host and device views
- Users no longer sync / modify explicitly
- Users cannot hold both host and device pointers concurrently
- Affects MultiVector, CrsMatrix, CrsGraph, and Block variants

Example: vector fill with UVM is straightforward

```
// Without UVM, this code will fail
multivector_t mv(…);
auto mvData =
     mv.getLocalViewHost();



for (j = 0; j < numData; j++)
   mvData(j,0) = rhs(j);


myDeviceFunction(mv);
```

Code worked with UVM
but failed without UVM

Without UVM, careful management of host and device views is needed

Without UVM, explicit modify/syncs were needed – messy and error-prone

```
multivector_t mv(…);
auto mvData =
     mv.getLocalViewHost();
mv.clear_sync_state();
mv.modify_host();
for (j = 0; j < numData; j++)
   mvData(j,0) = rhs(j);
mv.sync_device();
myDeviceFunction(mv);
```

Without UVM, careful management of host and device views is needed

Without UVM, explicit modify/syncs were needed – messy and error-prone

```
multivector_t mv(…);
auto mvData =
     mv.getLocalViewHost();
mv.clear_sync_state();
mv.modify_host();
for (j = 0; j < numData; j++)
   mvData(j,0) = rhs(j);
mv.sync_device();
myDeviceFunction(mv);
```

Tpetra now manages the sync/modify state for users

```
multivector_t mv(…);
{ auto mvData =
        mv.getLocalViewHost(
           Tpetra::Access::OverwriteAll);

  for (j = 0; j < numData; j++)
    mvData(j,0) = rhs(j);
}
myDeviceFunction(mv);
```

Key changes for Tpetra::MultiVector users (details to follow)

1. Capture host and device views in separate scopes
   - Don’t hold raw pointers to multivector’s data
   - Let views go out of scope as soon as you’re done working with them
2. Separate scope for local operations and Trilinos operations on an object
   - Trilinos operations can choose where to access data
3. Indicate intended usage of views
   - ReadOnly, ReadWrite, OverwriteAll
4. Reduce switching between host and device accesses
   - Be aware of data synchronization

Key changes for Tpetra::CrsGraph/CrsMatrix users (details to follow)

Same as MultiVector

1. Capture host and device views in separate scopes
   - Don't hold raw pointers to data
   - Let views go out of scope as soon as you're done working with them
2. Separate scope for local operations and Trilinos operations on an object
   - Trilinos operations can choose where to access data
3. Indicate intended usage of views
   - ReadOnly, ReadWrite, OverwriteAll
4. Reduce switching between host and device accesses
   - Be aware of data synchronization
5. getLocalMatrix*() and getLocalGraph*() build Kokkos' matrix and graph ON DEMAND now (rather than returning stored data structures); use wisely
6. Functions returning Teuchos::ArrayView of CrsMatrix/CrsGraph data are dangerous and deprecated
7. Functions returning raw pointers to CrsMatrix/CrsGraph data are dangerous and deprecated

#1: Capture host and device views in separate scopes

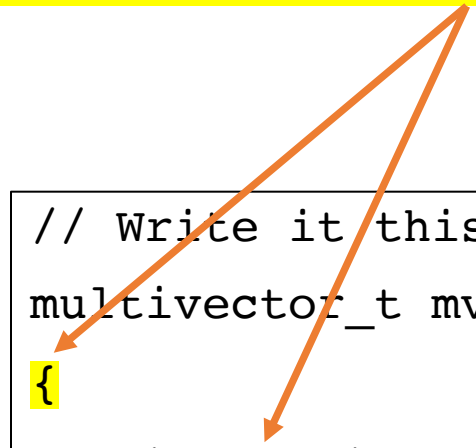
```
// NOT OK

auto v_h = mv.getLocalViewHost(tag);


auto v_d = mv.getLocalViewDevice(tag);
```

```
// OK
{
  auto v_h = mv.getLocalViewHost(tag);
}
{
  auto v_d = mv.getLocalViewDevice(tag);
}
```

Tpetra will track reference counts, including for subviews, on host and device to prevent simultaneous access

Example: Correct scoping in vector fill

Let mvData go out of scope when you're done working with it



```
// Write it this way
multivector_t mv(…);
{
  auto mvData =
       mv.getLocalViewHost(
          Tpetra::Access::OverwriteAll);
  for (j = 0; j < numData; j++)
    mvData(j,0) = rhs(j);
}
myDeviceFunction(mv);
```

Scoping rules apply to existing ArrayRCP interfaces, too

Let mvData go out of scope when you're done working with it.

Get an ArrayRCP (1D or 2D):
getData, getDataNonConst
get1dView, get1dViewNonConst
get2dView, get2dViewNonConst

```
// Write it this way
multivector_t mv(…);
{
  auto mvData =
       mv.getDataNonConst(0);

  for (j = 0; j < numData; j++)
    mvData(j) = rhs(j);
}
myDeviceFunction(mv);
```

Don’t hold/grab/hand-out pointers to raw data

```
// DANGER DANGER DANGER

typename
  AbstractConcreteMatrixAdapter<
    Tpetra::RowMatrix<Scalar, LocalOrdinal, GlobalOrdinal, Node>, DerivedMat>
    ::super_t::spmtx_vals_t
  AbstractConcreteMatrixAdapter<
    Tpetra::RowMatrix<Scalar,
                      LocalOrdinal,
                      GlobalOrdinal,
                      Node>,
    DerivedMat>::getSparseValues() const
  {
    typename super_t::local_matrix_t lm = this->mat_->getLocalMatrixHost();
    return lm.values.data();
  }
```

Tpetra can not track use of raw data() pointer; cannot sync appropriately

Applies to CrsGraph, CrsMatrix, MultiVector

#2: Separate scope for local operations and Tpetra operations on an object

```
// NOT OK

auto v_h = mv.getLocalViewHost(tag);
doStuffOnHost(v_h);


mv.doExport(…);
```

```
// OK
{
  auto v_h = mv.getLocalViewHost(tag);
  doStuffOnHost(v_h);
}

mv.doExport(…);
```

Trilinos operations (e.g., doExport) may choose to use host or device

#3: Indicate intended usage of views

Tpetra syncs as needed for type of access

- Tpetra::Access::ReadOnly
  - Tpetra syncs if needed
- Tpetra::Access::ReadWrite
  - Tpetra syncs if needed
  - Tpetra marks modified
- Tpetra::Access::OverwriteAll
  - Tpetra syncs only if view is a subview
  - Tpetra marks modified
  - Use only if writing ALL entries of view

```
// Use access tags to indicate intent
{
  auto read_h =
       mv.getLocalViewHost(
            Tpetra::Access::ReadOnly);
  auto readwrite_h =
       mv.getLocalViewHost(
            Tpetra::Access::ReadWrite);
  auto write_h =
       mv.getLocalViewHost(
            Tpetra::Access::OverwriteAll);

}
```

Access tags allow Tpetra to manage sync/modify status for users

Subview OverwriteAll may sync anyway

- Kokkos DualViews share modify flags with their subviews
- When sync'ing a subview, need to sync the entire view
- Subview with OverwriteAll access will behave as if ReadWrite to prevent corruption of other subviews

```
// Write it this way
multivector_t mv(map, 3);
auto mySubVec =
       mv.getVectorNonConst(2);
{
  auto mySubData =
       mySubVec.getLocalViewHost(
         Tpetra::Access::OverwriteAll);

  for (j = 0; j < numData; j++)
    mySubData(j) = rhs(j);
}
myDeviceFunction(mv);
```

Will behave as if ReadWrite

#4: Reduce switching between host and device accesses

Syncs mv to host in EVERY iteration

```
// Lots of data transfer
multivector_t mv(map, 3);

for (int v = 0; v < 3; v++) {
  // Fill vector on host; use it on device
  {
   auto mySubVec =
       mv.getDataNonConst(v);

   for (j = 0; j < numData; j++)
      mySubVec(j) = rhs(j);
  }
  myDeviceFunction(mySubVec);
}
```

Syncs mv to device in EVERY iteration

Syncs mv to host in FIRST iteration

```
// Write it this way
multivector_t mv(map, 3);

for (int v = 0; v < 3; v++) {
  // Fill all vectors on host
  auto mySubVec =
       mv.getDataNonConst(v);

  for (j = 0; j < numData; j++)
    mySubVec(j) = rhs(j);
}
// Use all vectors on device
myDeviceFunction(mv);
```

Syncs mv to device once

#5: Use CrsGraph::getLocalGraph() conservatively

```
// NOT Efficient

auto numrows =
  g.getLocalGraph().row_map.extent(0)-1;
auto nnz =
  g.getLocalGraph().entries.extent(0);


auto rowptr = g.getLocalGraph().row_map;
auto colidx = g.getLocalGraph().entries;
```

```
// Better


auto numrows = g.getNodeNumRows();
auto nnz = g.getNodeNumEntries();



auto lclGraph = g.getLocalGraphDevice();
auto rowptr = lclGraph.row_map;
auto colidx = lclGraph.entries;
```

getLocalGraphHost/Device() builds graph ON DEMAND now, rather than returning a stored pointer

#5: Use CrsMatrix::getLocalMatrix() conservatively

```
// NOT Efficient



rowptr = m.getLocalMatrix().graph.row_map;
colidx = m.getLocalMatrix().graph.entries;
values = m.getLocalMatrix().values;
```

```
// Better


auto mlocal = m.getLocalMatrixDevice();
rowptr = mlocal.graph.row_map;
colidx = mlocal.graph.entries;
values = mlocal.values;
```

getLocalMatrixHost/Device() builds KokkosSparse::CrsMatrix ON DEMAND now, rather than returning a stored pointer

#6: Returned Teuchos::ArrayViews are dangerous and deprecated

```
// Deprecated

m.getLocalRowView(row, indices_AV,
                  values_AV);
m.getGlobalRowView(row, indices_AV,
                   values_AV);

m.getLocalRowCopy(row, indices_AV,
                  values_AV);
m.getGlobalRowCopy(row, indices_AV,
                   values_AV);
```

```
// New interface returns Kokkos::Views


m.getLocalRowView(row, indices_KV,
                  values_KV);
m.getLocalRowCopy(row, indices_KV,
                  values_KV);
m.getGlobalRowView(row, indices_KV,
                   values_KV);
m.getGlobalRowCopy(row, indices_KV,
                   values_KV);
```

Tpetra cannot track usage of data in Teuchos::ArrayView for sync/modify; use Kokkos::Views instead

#7: Returned raw pointers are dangerous and deprecated

```
// Deprecated

m.getLocalRowView(row, indices_raw,
                  values_raw, nentries);
```

```
// New interface returns Kokkos::Views


m.getLocalRowView(row, indices_KV,
                       values_KV);
```

Tpetra cannot track usage of data in raw pointers for sync/modify; use Kokkos::Views instead

Other deprecations will follow, but will be less disruptive

Deprecations:

- Fewer Teuchos::ArrayRCPs, ArrayViews in interfaces; more Kokkos Views
- Greater reliance on access tags (e.g., Tpetra::Access::ReadWrite) instead of function naming conventions (e.g., getDataNonConst and getData)
- More consistent naming (unambiguous Host/Device in function names, ”Local” vs “Node”, etc.)

Impact on applications / packages:

- Changes easily adopted by applications and packages (name changes rather than logic changes)
- Will be deprecated as time/staff permits
- Will be summarized and documented on wiki

For more info

- Email
  - tpetra-developers@software.sandia.gov
  - kddevin@sandia.gov
- Wiki
  - Tpetra info: https://github.com/trilinos/Trilinos/wiki/Tpetra-Information-Page
  - UVM removal info: https://snl-wiki.sandia.gov/display/TRIL/UVM+Removal

Update code to remove use of deprecated interfaces

For now, most interfaces remain

- Get an ArrayRCP (1D or 2D):
  - `getData, getDataNonConst`
  - `get1dView, get1dViewNonConst`
  - `get2dView, get2dViewNonConst`
- Get a single column as Vector:
  - `getVector, getVectorNonConst`

Removed without deprecation

- `Tpetra::withLocalAccess`
- `Tpetra::for_each`
- `Tpetra::transform`

Deprecated interfaces

- Accessors without Access tags
  - `getLocalViewHost()`
  - `getLocalViewDevice()`
  - `getLocalView<>()`
  - `getLocalBlock()`
- Sync/modify now handled by MultiVector
  - `mv.sync_host(), mv.sync_device(), mv.sync<>()`
  - `mv.modify_host(), mv.modify_device(), mv.modify<>()`
  - `mv.clear_sync_state()`

Designate Host/Device for local graph/matrix

Scoping rules apply – cannot hold both device and host pointers in same scope

```
// Deprecated – device option

auto graphDevice = g.getLocalGraph();
auto matrixDevice = m.getLocalMatrix();
```

```
// New interfaces
{
auto graphDevice =
     g.getLocalGraphDevice();
auto matrixDevice =
     m.getLocalMatrixDevice();

}
{
auto graphHost =
     g.getLocalGraphHost();
auto matrixHost =
     m.getLocalMatrixHost();

}
```

New functions identify host or device use of Kokkos::CrsGraph and KokkosSparse::CrsMatrix. Scoping rules apply!

Use new getLocalGraphHost, getLocalMatrixHost where appropriate

```
// Deprecated (from Ifpack2)

auto Alocal = A.getLocalMatrix();
Arowmap =
  Kokkos::create_mirror_view(Alocal.graph.row_map);
Aentries =
  Kokkos::create_mirror_view(Alocal.graph.entries);
Avalues =
  Kokkos::create_mirror_view(Alocal.values);
Kokkos::deep_copy(Arowmap, Alocal.graph.row_map);
Kokkos::deep_copy(Aentries, Alocal.graph.entries);
Kokkos::deep_copy(Avalues, Alocal.values);

… Use Arowmap, Aentries, Avalues as input …
```

```
// New interfaces

auto Alocal =
     m.getLocalMatrixHost();
Arowmap = Alocal.graph.row_map;
Aentries = Alocal.graph.entries;
Avalues = Alocal.graph.values;


… Use Arowmap, Aentries, Avalues
as input …
```

New functions identify host or device use of Kokkos::CrsGraph and KokkosSparse::CrsMatrix. Scoping rules apply!