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Chapel Aggregation Library (CAL)

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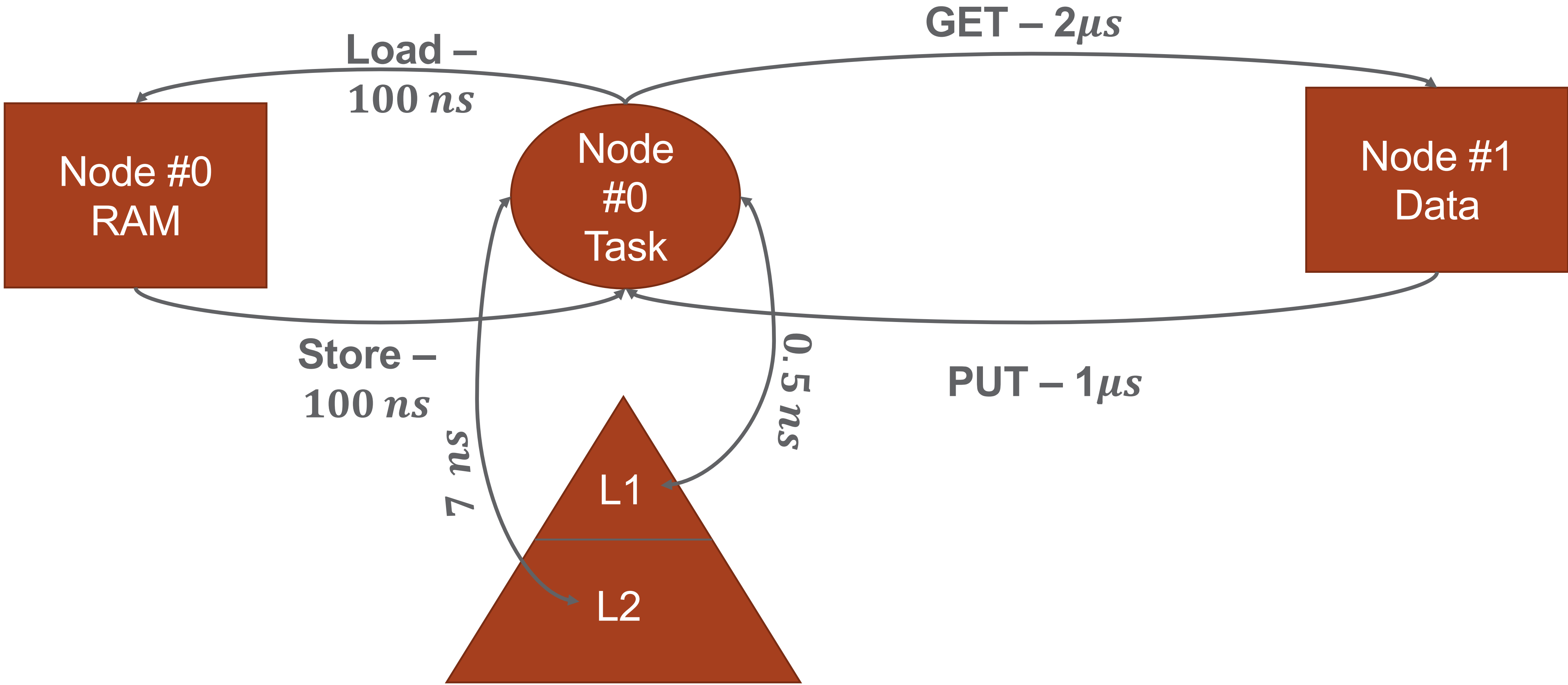
The Problem

- Accessing remote data is slow
    - Multiple orders of magnitude slower to access than local memory



Load –
$100\ ns$

GET – $2\mu s$

Node #0
RAM

Node
#0
Task

Node #1
Data

Store –
$100\ ns$

$0.5\ ns$

PUT – $1\mu s$

$7\ ns$

L1

L2

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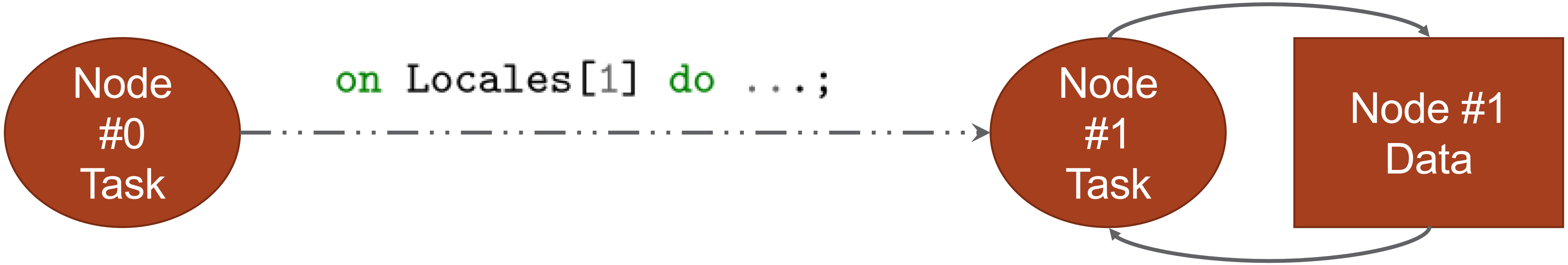
- "Moving the computation to the data" not always the best solution
  - Using an *on* statement requires migrating tasks to another locale



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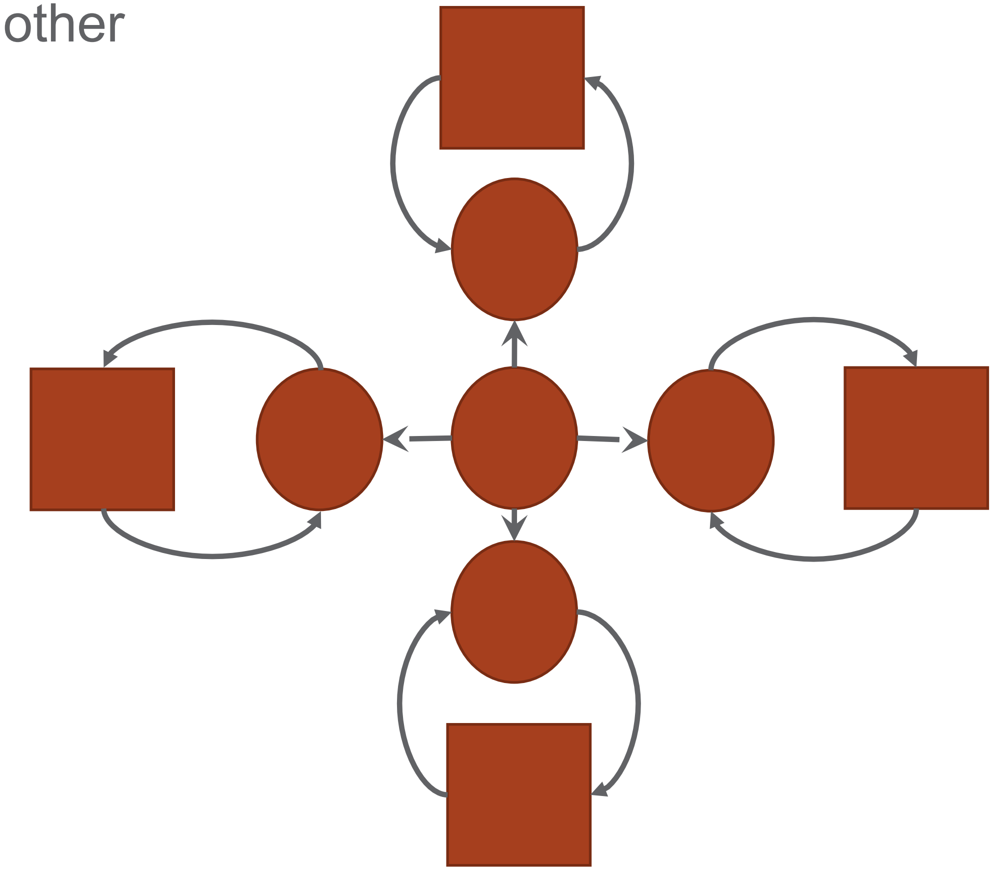
        - ✓ Can become bottleneck if fine-grained



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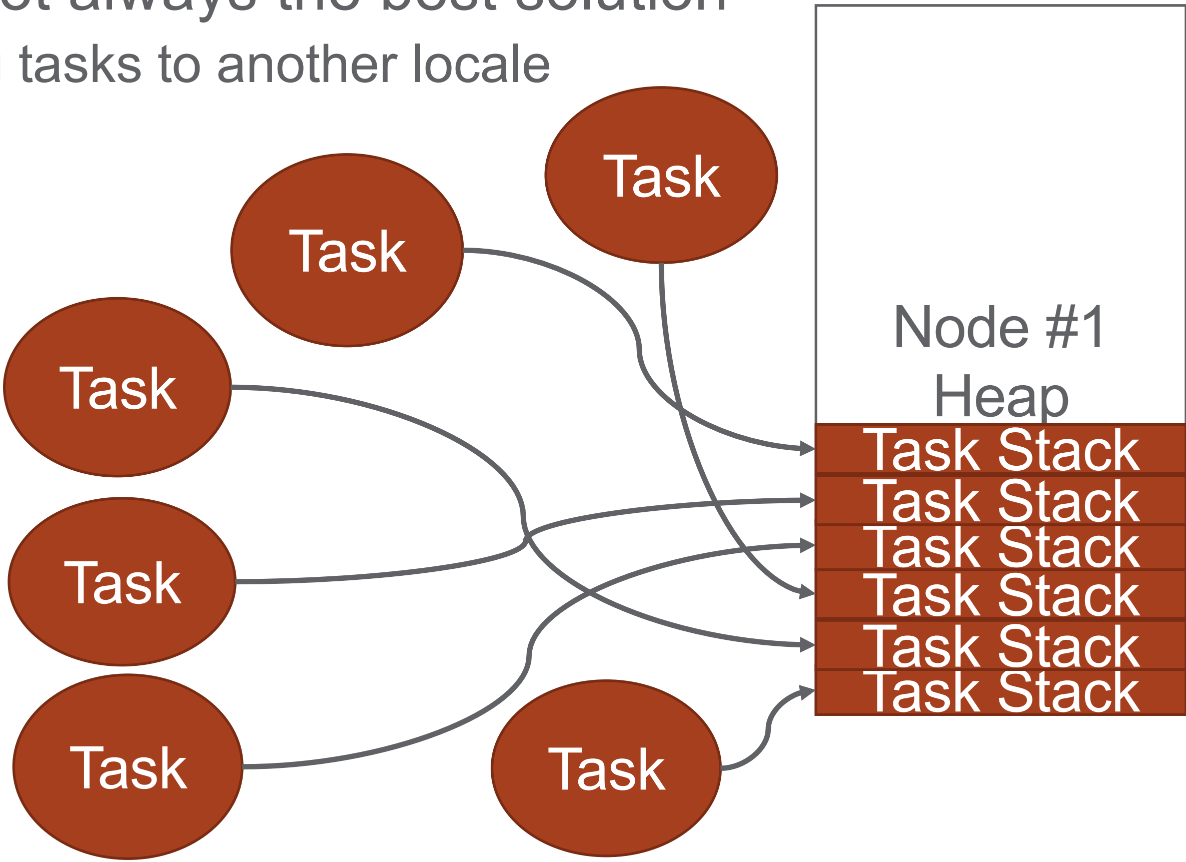
- “Moving the computation to the data” not always the best solution
  - Using an *on* statement requires migrating tasks to another locale
    - ✓ Can become bottleneck if fine-grained
    - ✓ Task creation is relatively expensive
      - Tasks are too large to spawn in a fire-and-forget manner (issue #9984)
      - Migrating tasks require individual active messages (issue #9727)



A Solution

- Coarsen the granularity of the data
    - Buffer units of data to be sent to a locale in *destination buffers*

From: Locale #0 To: Locale #1

A Solution

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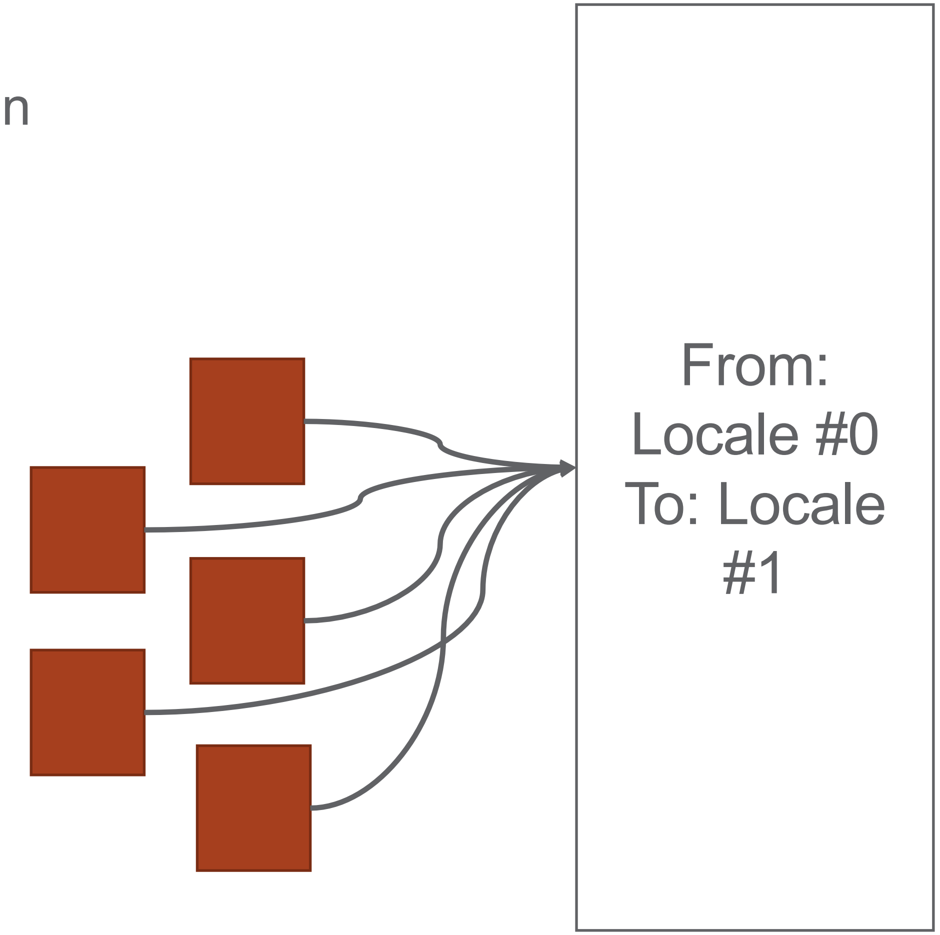

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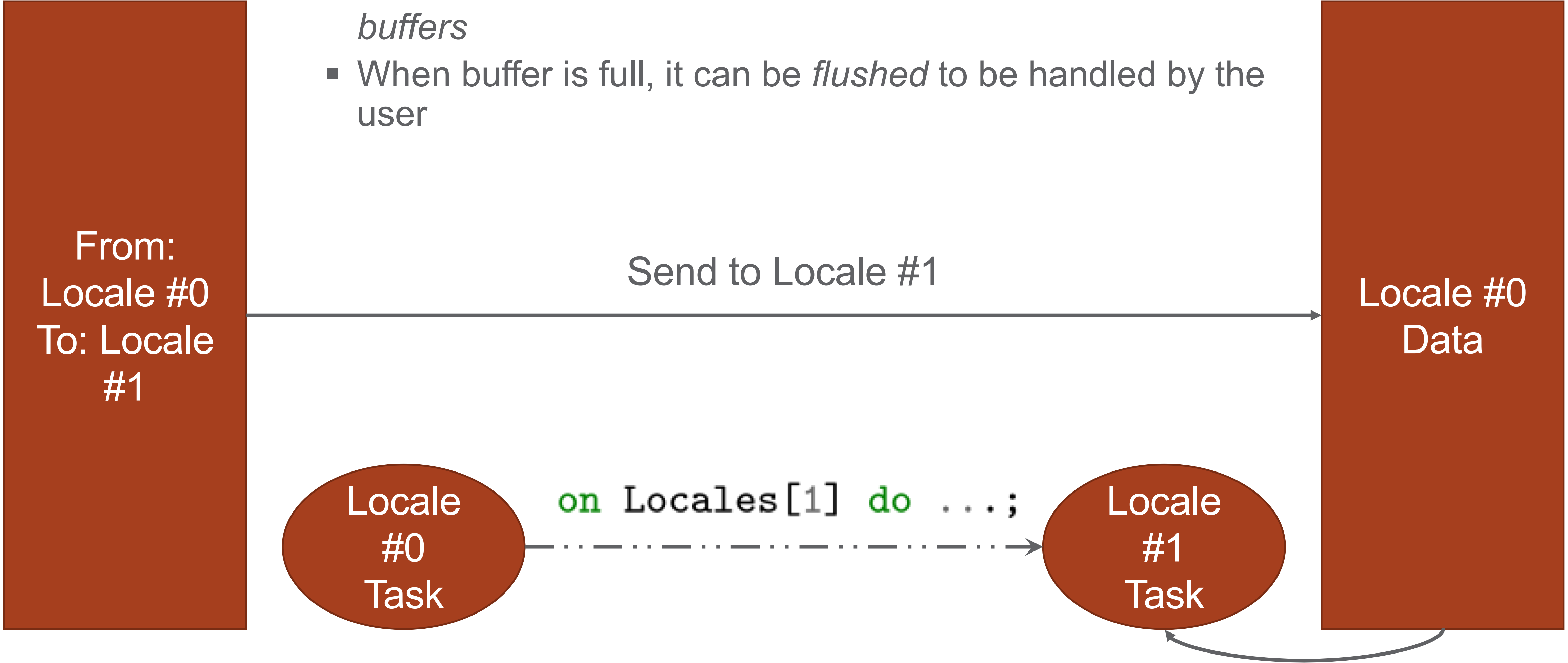


From: Locale #0 To: Locale #1

Send to Locale #1

Locale #0 Data

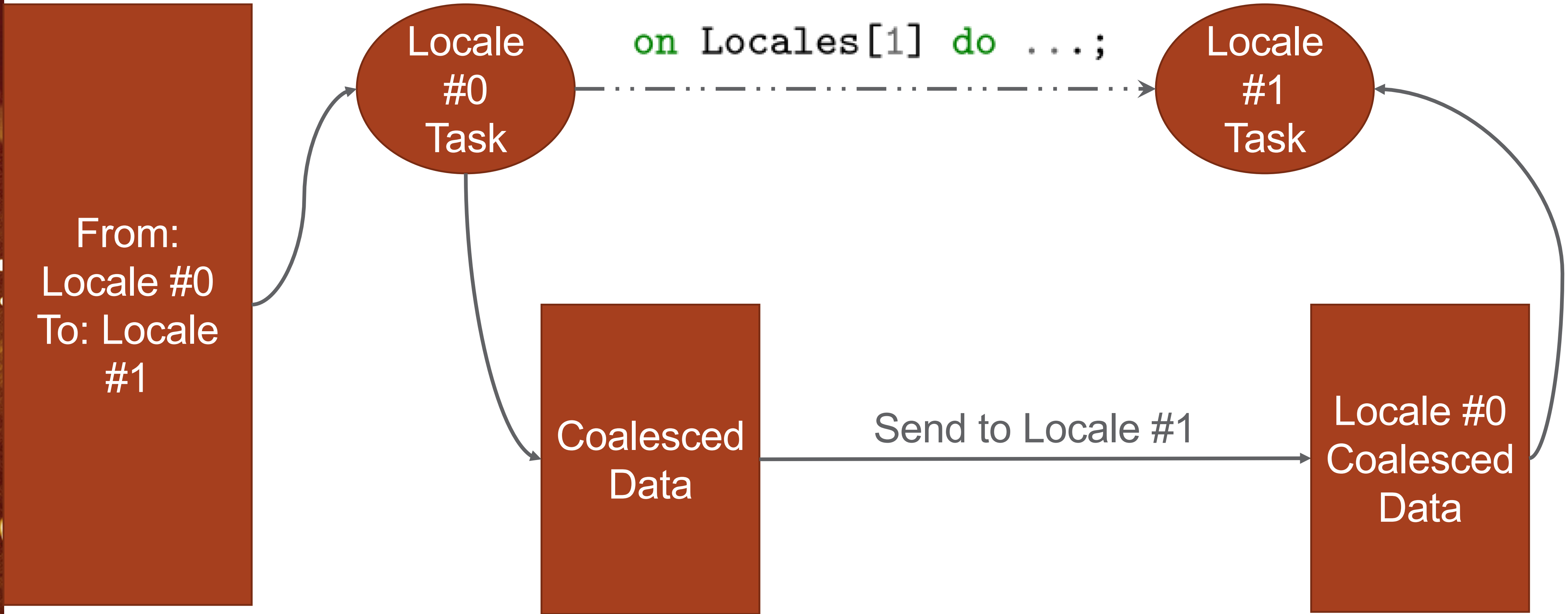
Locale #0 Task

`on Locales[1] do ...;`

Locale #1 Task

A Solution

- Coarsen the granularity of the data
  - Buffer units of data to be sent to a locale in *destination buffers*
  - When buffer is full, it can be *flushed* to be handled by the user
  - User can perform *coalescing* to combine aggregated data



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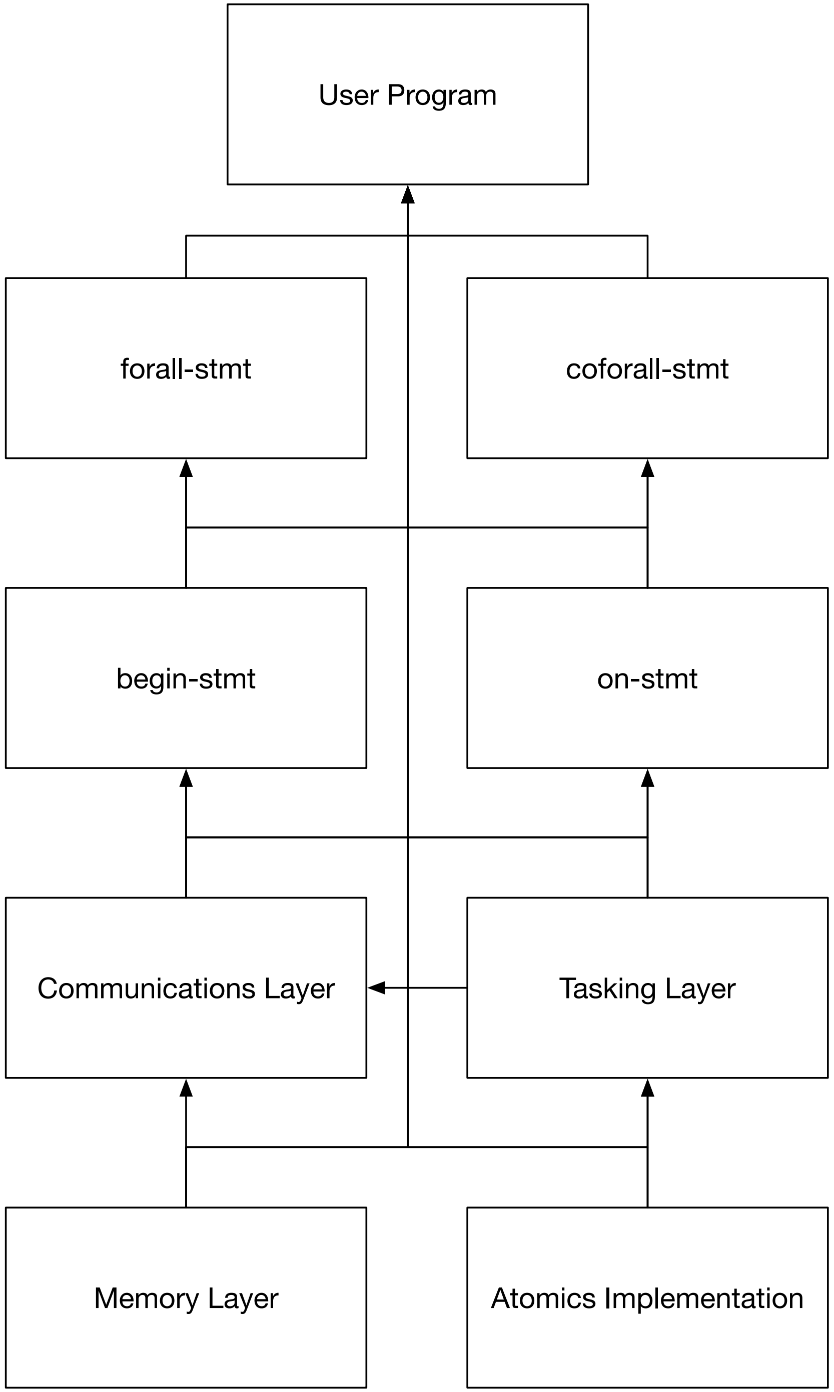
Chapel’s Multiresolution Design Philosophy

- Higher Level composed of Lower Level abstractions, features, and language constructs
    - Changes to lower level propagate up to higher level
    - User free to use either
        - ✓ High-Level for convenience
        - ✓ Low-Level for performance



Global-View Programming

- Abstracts locality for the user
  - No need to think: “What portion of the array does this task own?”
  - Array can be accessed from any locale, even if it is not distributed over that locale…
    - ✓ Remote references are resolved into remote PUT/GET *implicitly*

Chapel

```
var sum : float;
forall a in arr with (+ reduce sum) {
  sum += a;
}
```

MPI

```
float globalSum = 0;
float localSum = 0;
for (int i = localStart; i < localEnd; i++) {
  localSum += arr[i];
}
MPI_REDUCE(&localSum, &globalSum, ...);
```

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- Multiresolution: More Abstraction

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- Multiresolution: Less Abstraction

Chapel

```
var sum : float;
coforall loc in Locales with (+ reduce sum) do on loc {
  coforall tid in 0..#here.maxTaskPar with (+ reduce sum) {
    for i in computeRange(arr.domain.localSubdomain(), tid) {
      sum += arr[i];
    }
  }
}
```

MPI

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float globalSum = 0;
float localSum = 0;
for (int i = localStart; i < localEnd; i++) {
  localSum += arr[i];
}
MPI_REDUCE(&localSum, &globalSum, ...);
```

Chapel Aggregation Library (CAL)

- Written in Chapel, for Chapel
  - **Minimal** and User-Friendly
    - ✓ Unassuming of how data is handled
    - ✓ Designed specifically for Chapel
  - **Distributed**, Scalable, and Parallel-Safe
    - ✓ Supports Global-View Programming
    - ✓ Usable with Chapel’s parallel and locality constructs
  - **Modular**, Reusable, and Generic
    - ✓ Generic on user-defined type
    - ✓ Easy to use and ’plug in’

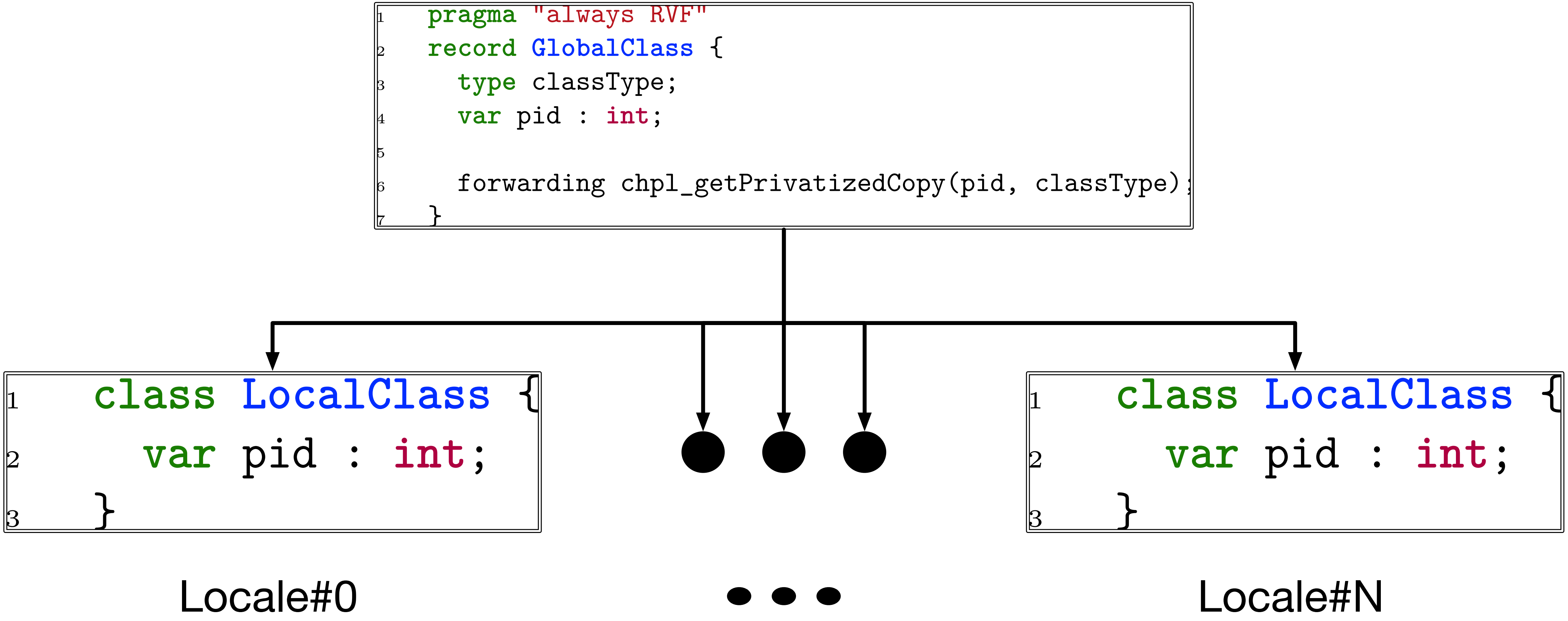
Minimalism

- CAL is an aggregation library
  - Processing of the aggregated data is deferred to the user
  - Buffer is returned to the last task that filled it

```
const msg = "From Locale#0 to Locale#1";
const loc = Locales[1];
var aggregator = new Aggregator(string);
var buffer = aggregator.aggregate(msg, loc);
if buffer != nil then handleBuffer(buffer);
[(buf, loc) in aggregator.flush()] on loc do handleBuffer(buf);
```

Distributed Object Pattern

- Use privatization to enable global-view programming
  - GlobalClass forwards access to per-locale LocalClass *privatized instances*
  - Each privatized instance can communicate and coordinate with others



```
pragma "always RVF"
record GlobalClass {
  type classType;
  var pid : int;

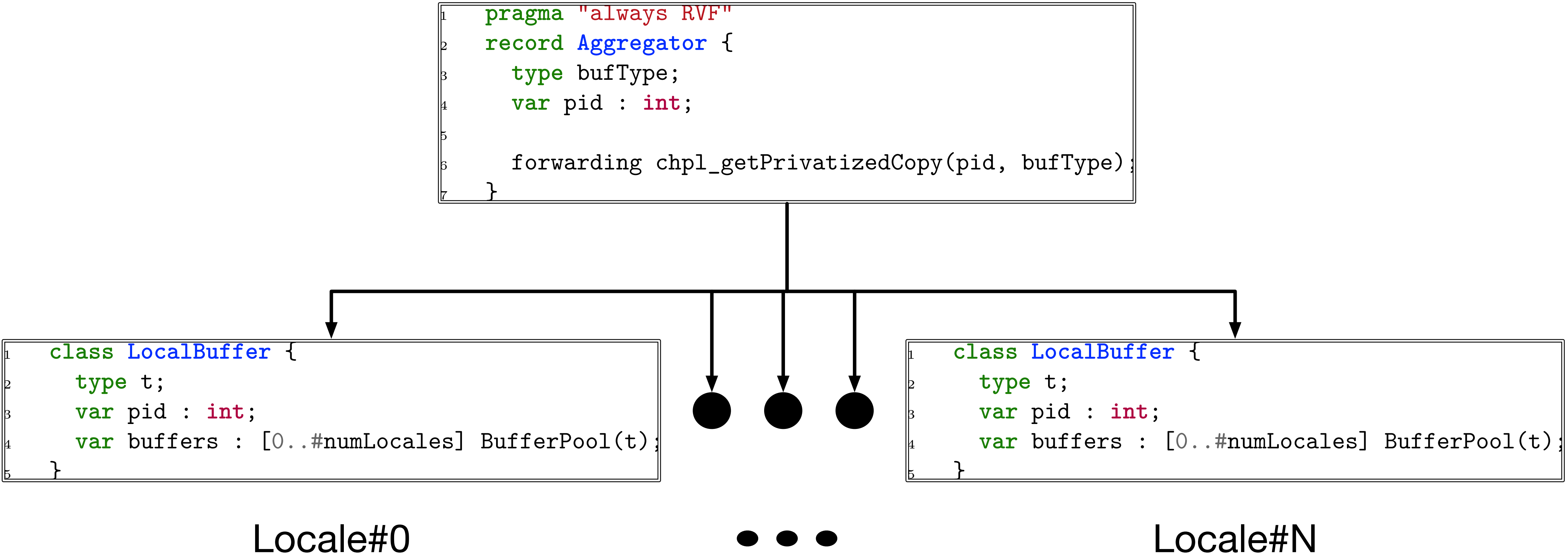
  forwarding chpl_getPrivatizedCopy(pid, classType);
}
```

```
class LocalClass {
  var pid : int;
}
```

```
class LocalClass {
  var pid : int;
}
```

Aggregator

- Aggregator forwards all accesses to per-locale privatized instances
- Distributed and parallel access is abstracted
  - Supports global-view programming



```
pragma "always RVF"
record Aggregator {
  type bufType;
  var pid : int;

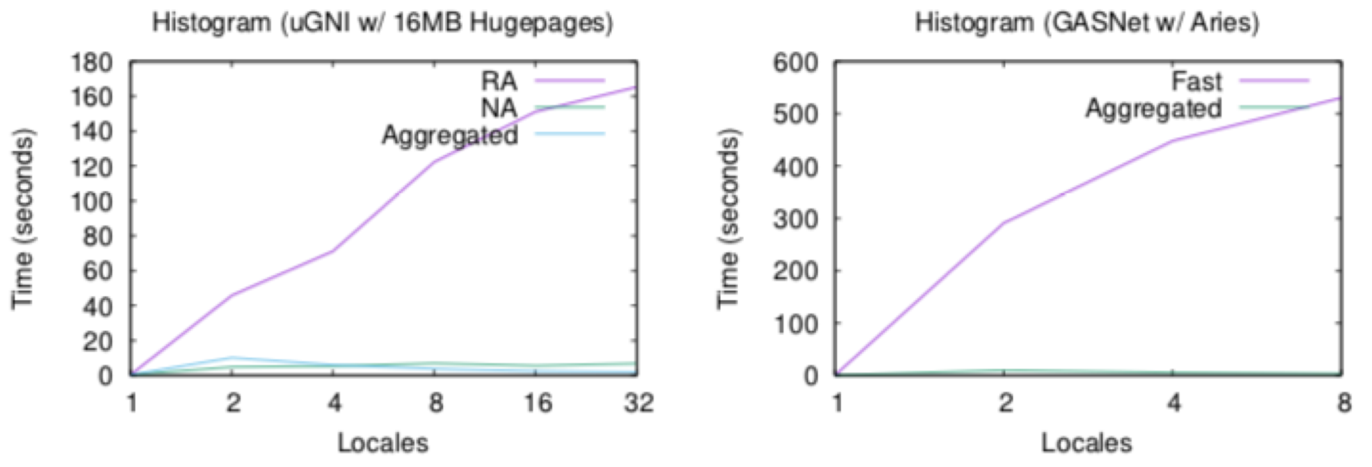
  forwarding chpl_getPrivatizedCopy(pid, bufType);
}
```

```
class LocalBuffer {
  type t;
  var pid : int;
  var buffers : [0..#numLocales] BufferPool(t);
}
```

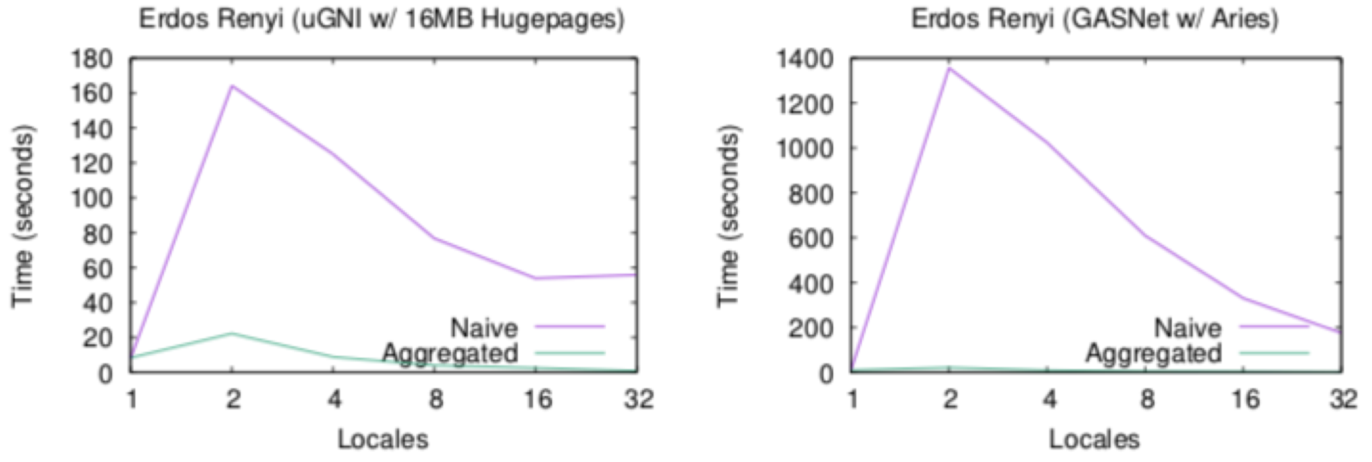
```
class LocalBuffer {
  type t;
  var pid : int;
  var buffers : [0..#numLocales] BufferPool(t);
}
```

Aggregator - Performance

- 10x – 100x speedup at 32 nodes
  - Histogram
  - Hypergraph Generation



(a) uGNI Histogram (b) GASNet Histogram



(a) uGNI Erdos Renyi (b) GASNet Erdos Renyi

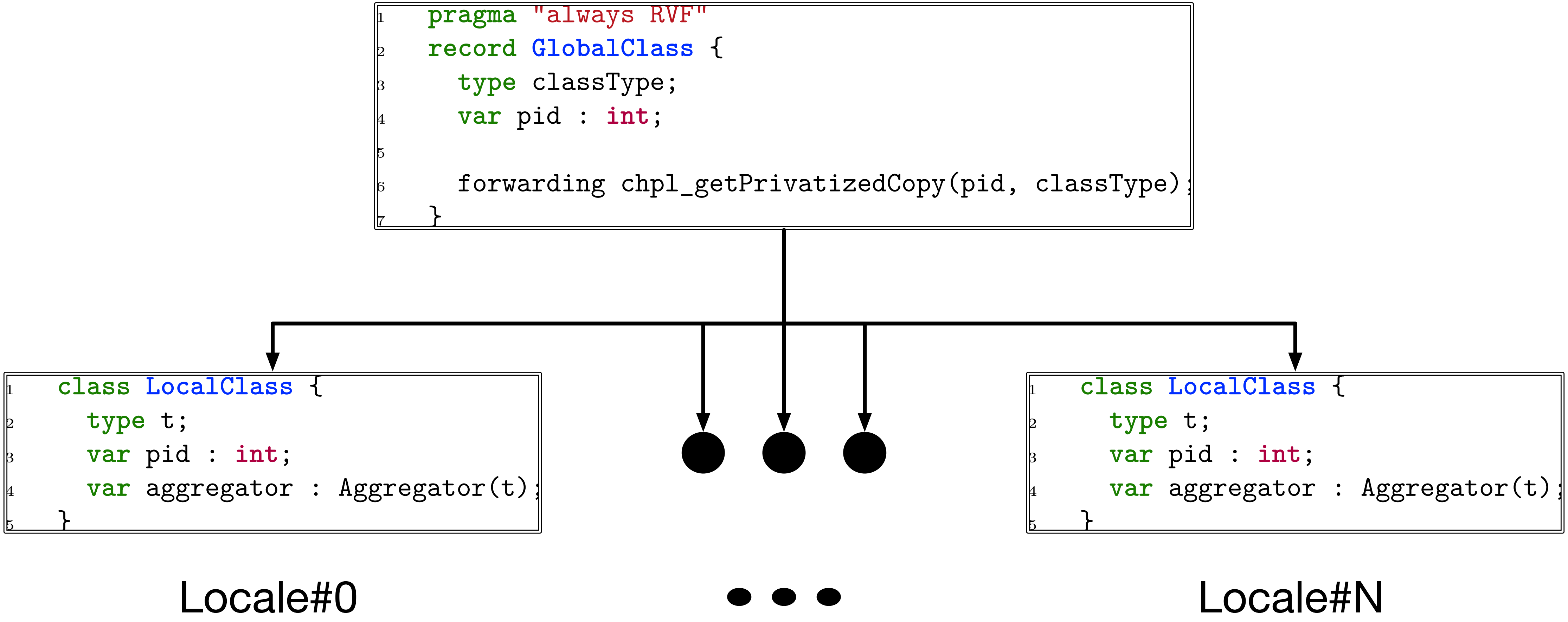
Distributed - Example

- Aggregator is allocated on Locale#0, but accessible from Locale#1
  - Accesses are forwarded to Locale#1’s privatized instance
  - Global-View Programming
- Implicit parallelism (line 9) vs Explicit parallelism (line 11)

```
1   var aggregator = new Aggregator(int);
2   // Migrate to Locale #1 from Locale #0
3   on Locales[1] {
4     // Aggregate single value to Locale #0
5     var buffer = aggregator.aggregate(0, Locales[0]);
6     // If non-nil, then handle buffer.
7     if buffer != nil then handleBuffer(buffer);
8     // Aggregate multiple units of data via Chapel's implicit parallelism
9     var buffers = aggregator.aggregate(1..1024, Locales[0]);
10    // Check if any of the buffers are nil
11    [buf in buffers] if buf != nil then handleBuffer(buf);
12  }
```

Modularity

- Composition of Distributed Objects
  - Aggregator can be used within other global-view data structures
  - Future of Distributed Object Oriented Programming (?)



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```

```
class LocalClass {
  type t;
  var pid : int;
  var aggregator : Aggregator(t);
}
```

```
class LocalClass {
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}
```

Future Works

- Software release of CAL
  - Currently only available as module under Chapel HyperGraph Library (CHGL)
    - ✓ github.com/pnnl/chgl
  - Independent release coming soon (?)
- Integration into Chapel
  - Mason package or Standard Module (?)
  - Run-time integration
- Aggregation handlers as first-class functions
  - Once Chapel has better first-class function support

Potential Application
Light Weight Tasks (LWT)

- Chapel Tasks are infeasible to use in fire-and-forget manner
  - Stack size of tasks in Chapel are static and large (8MB default)
  - Task migration can be made asynchronous but is not aggregated
- Solution – Make a library for LWT
  - Use Distributed Object pattern for Global-View programming
  - Use *Aggregator* for aggregation
  - Use First-Class Functions (once improved) to represent a lightweight task

```
var lwt = new LWT(visit);
proc visit(v : Vertex) {
  for vv in neighbors(v) {
    if hasProperty(vv) {
      lwt.spawn(vv, vv.locale);
    }
  }
}
forall v in vertices {
  if hasProperty(v) {
    lwt.spawn(v);
  }
}
```

Vertex Degree Distribution

```
// Find largest degree of all vertices in distributed graph
var N = max reduce [v in graph.getVertices()] graph.degree(v);
// Histogram is cyclically distributed over all locales
var histogramDomain = {1..N} dmapped Cyclic(startIdx=1);
var histogram : [histogramDomain] atomic int;

// Aggregate increments to histogram
var aggregator = new Aggregator(int);
forall v in graph.getVertices() {
  const deg = graph.degree(v);
  const loc = histogram[deg].locale;
  var buffer = aggregator.aggregate(deg, loc);
  if buffer != nil {
    on loc do [deg in buffer] histogram[deg].add(1);
    buffer.done();
  }
}

// Flush
forall (buf, loc) in aggregator.flush() {
  on loc do [deg in buf] histogram[deg].add(1);
  buffer.done();
}
```