The Chapel Runtime

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Greg Titus
Principal Engineer
Chapel Team, Cray Inc.

Outline

- Introduction
- Compilation Architecture
- Predefined Modules
- Runtime
- Example
- Future Work

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What is Chapel?

- **An emerging parallel programming language**
  - Design and development led by Cray Inc.
    - in collaboration with academia, labs, industry
  - Initiated under the DARPA HPCS program

- **Overall goal: Improve programmer productivity**
  - Improve the programmability of parallel computers
  - Match or beat the performance of current programming models
  - Support better portability than current programming models
  - Improve the robustness of parallel codes

- **A work-in-progress**
  - Just released v1.7

- **http://chapel.cray.com/**

Chapel's Implementation

- **Being developed as open source at SourceForge**
- **Licensed as BSD software**
- **Target Architectures:**
  - Cray architectures
  - multicore desktops and laptops
  - commodity clusters
  - systems from other vendors
  - *in-progress:* CPU+accelerator hybrids, many-core, …

Chapel Execution Model: Locality

- **Program launches on one or more *locales***
  - *Locale*: in Chapel, something that has memory and processors
    - So far, usually a system node
  - User main program executes on locale 0
  - Other locales wait for work, to be delivered by Active Messages

- **User code controls execution locality**

```
//
// Move execution to the locale associated with locale-expr
// for the duration of statement.
//
on locale-expr do statement
```

Chapel Execution Model: Parallelism

- **User code creates parallelism in the form of *tasks***

```
//
// Task-parallel style, no implicit synchronization.
//
begin statement                          // one new task

//
// Task-parallel style, implicit barrier at end.
//
cobegin block-statement                  // one new task per stmt

coforall idx-var in iter-expr do  // one new task per iter
  statement

//
// Data-parallel style, implicit barrier at end.
//
forall idx-var in iter-expr do  // #tasks <= #iterations,
  statement                     // #iterations and locality
                                // may differ for each task
```

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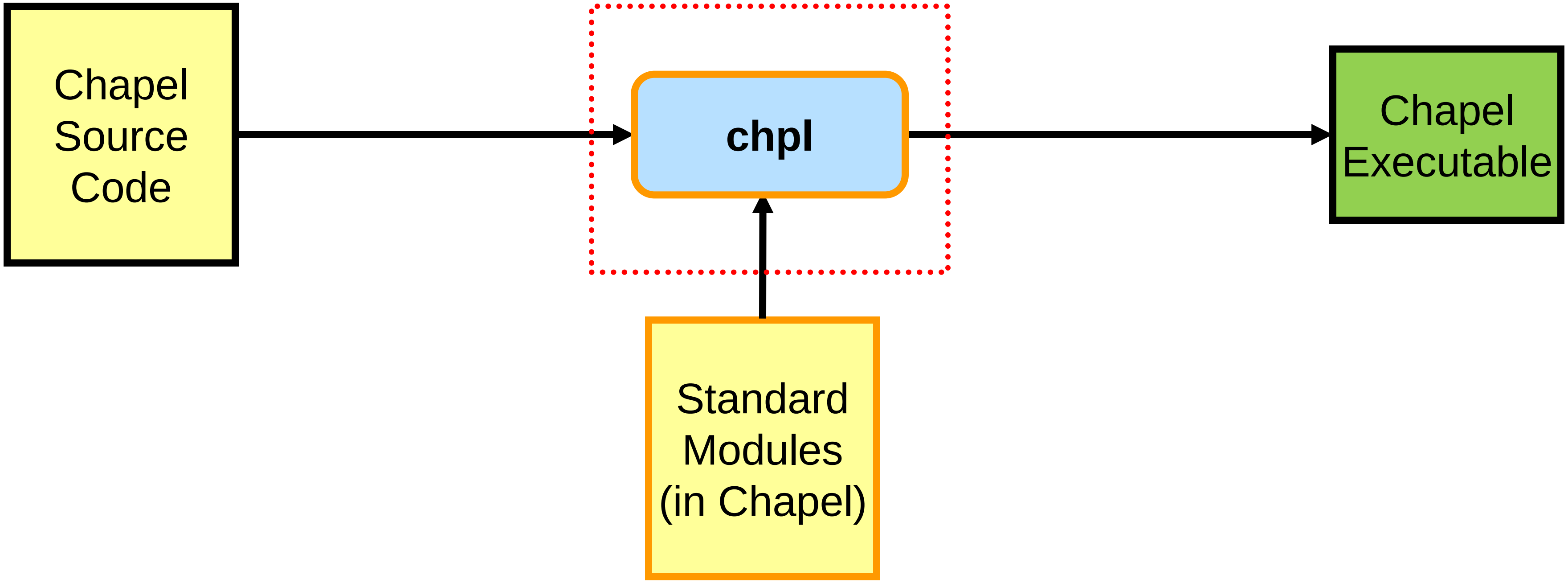
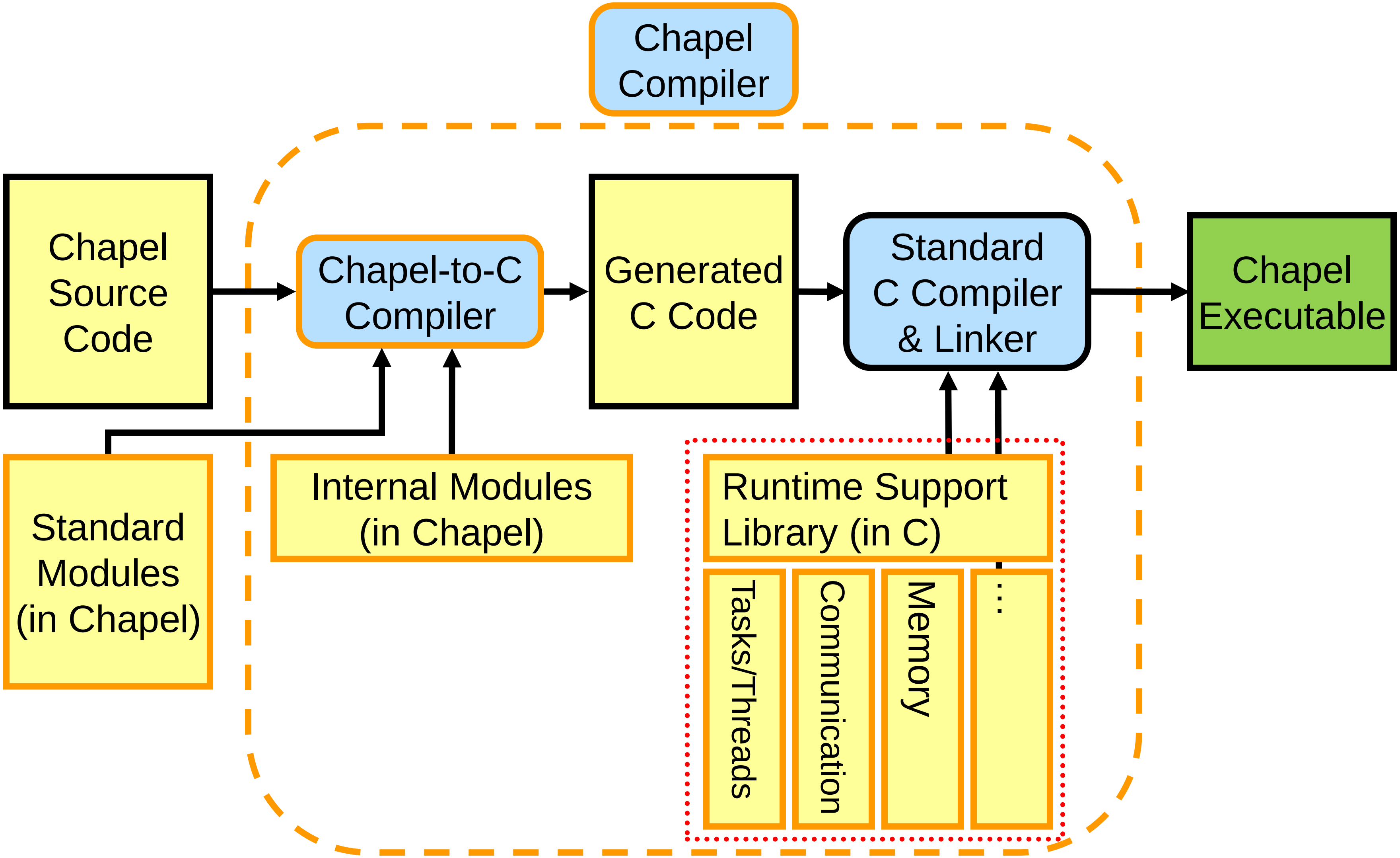
Compiling Chapel



Chapel Compilation Architecture



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- **Predefined Modules**
- Runtime
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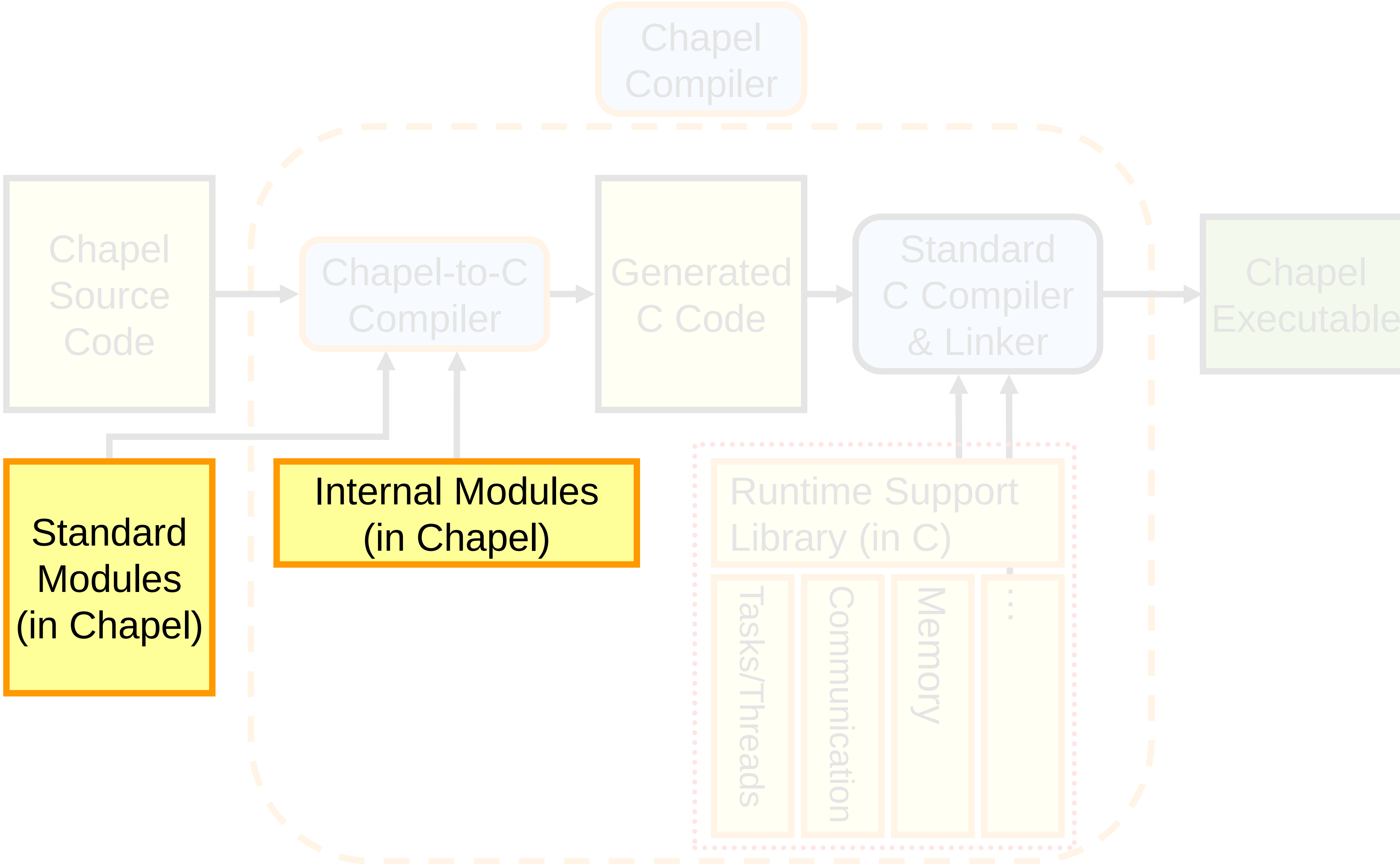
Chapel Compilation Architecture



Predefined Modules

- **A *module* in Chapel encapsulates types, variables, and functions**
  - To bring the definitions in a module into a program, you `use` it (with exception below)
  - Users can write modules
  - Some predefined modules come with Chapel
- **Predefined modules**
  - Internal
    - Support the language
    - Arrays, distribution maps, etc.
    - Implicitly brought in; no `use` needed
  - Standard
    - Support user code
    - Math, random numbers, time, etc.
    - Must be explicitly brought in with a `use` statement

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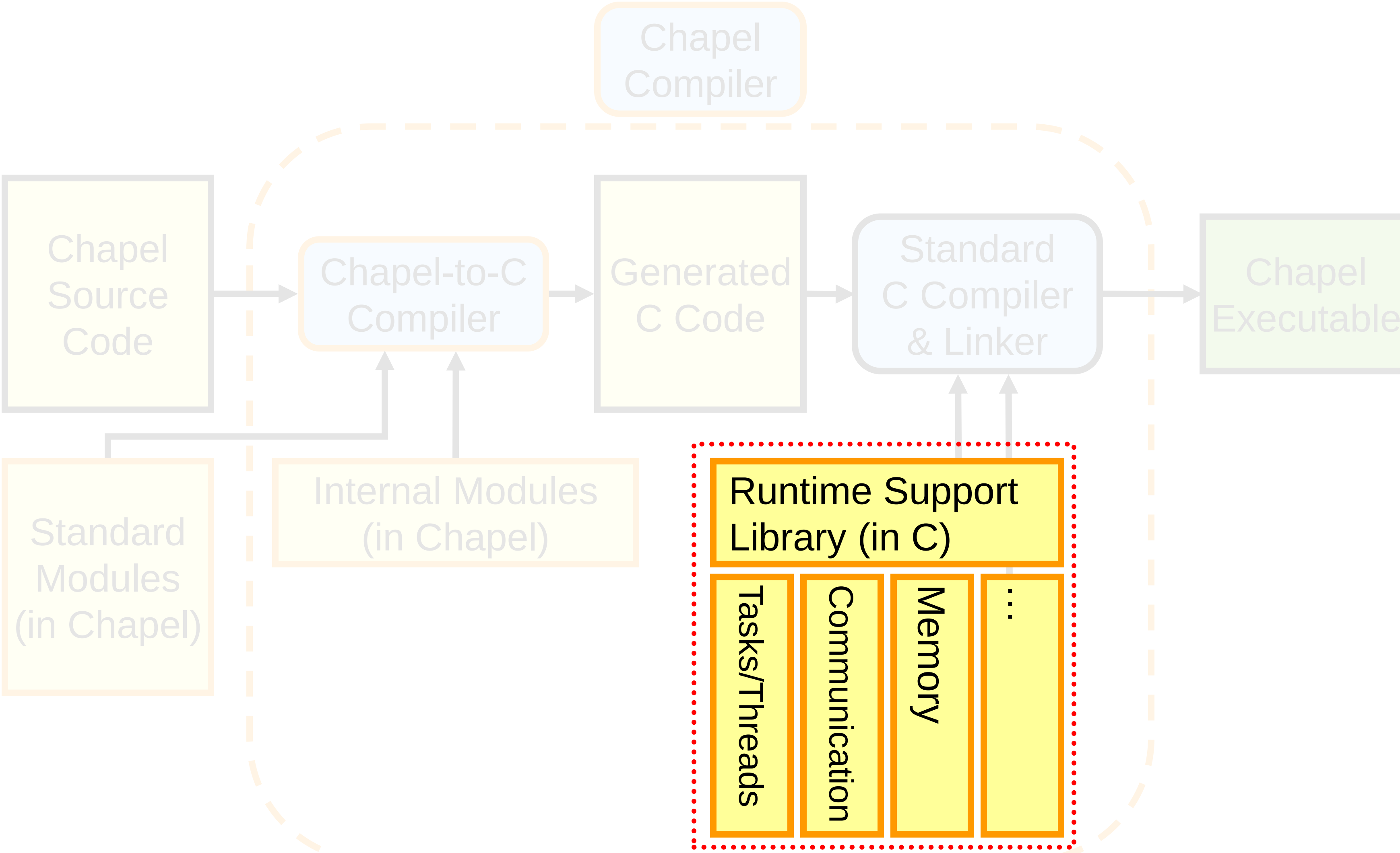
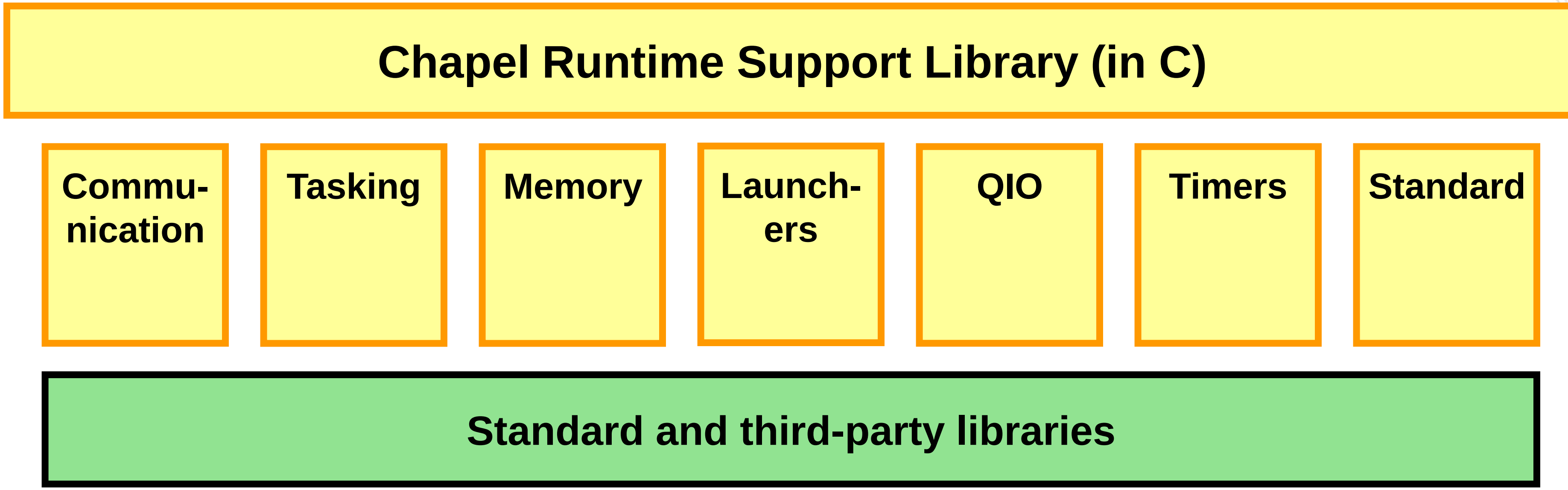
Chapel Compilation Architecture



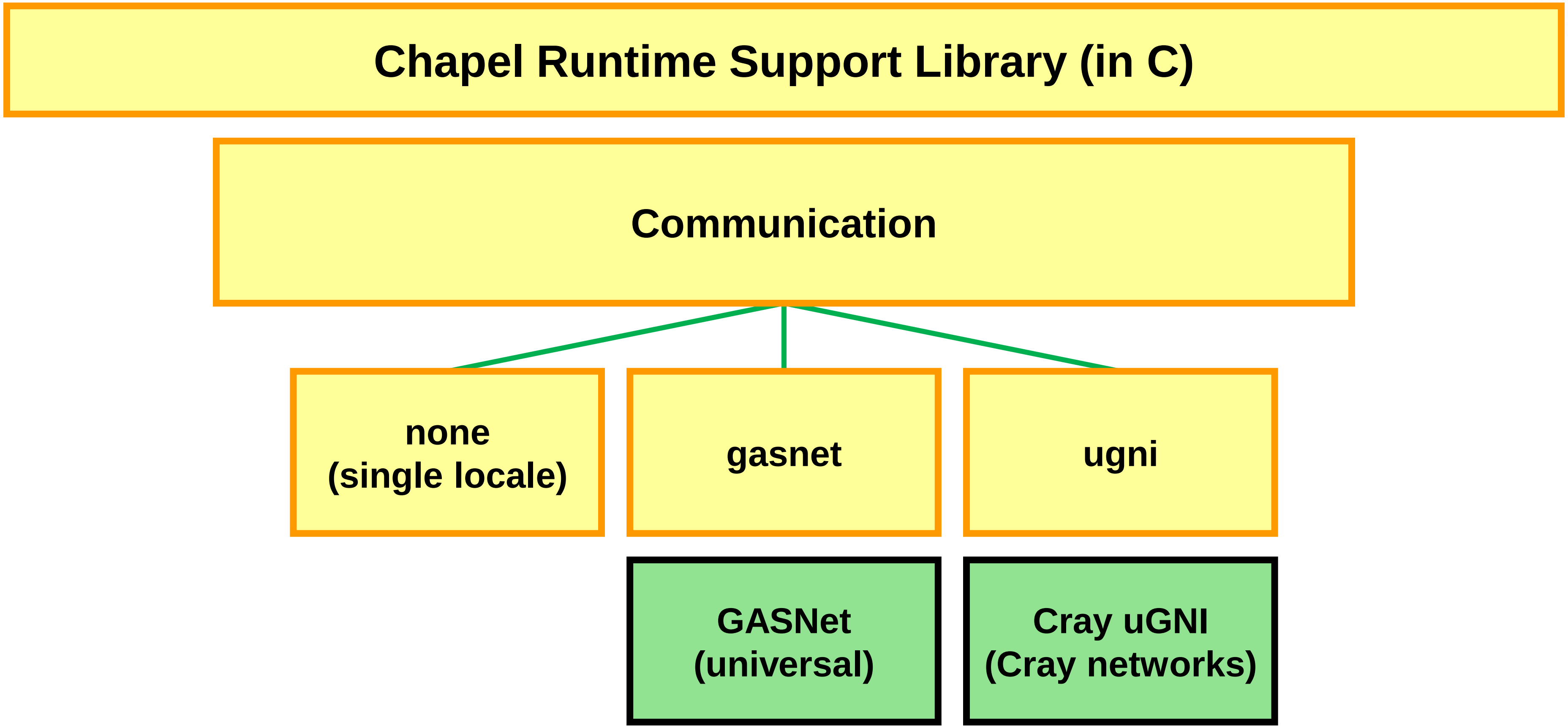
Chapel Runtime

- **Lowest level of Chapel software stack**
- **Supports language concepts and program activities**
- **Relies on system and third-party services**
- **Written in C**
- **Composed of *layers***
  - A misnomer – these are not layers in the sense of being stacked
  - More like *posts*, in that they work together to support a shared load
  - Standardized interfaces
  - Interchangeable implementations
- **Environment variables select layer implementations when building the runtime**
  - And when compiling a Chapel program, also select which already-built runtime is linked with it

Chapel Runtime Organization



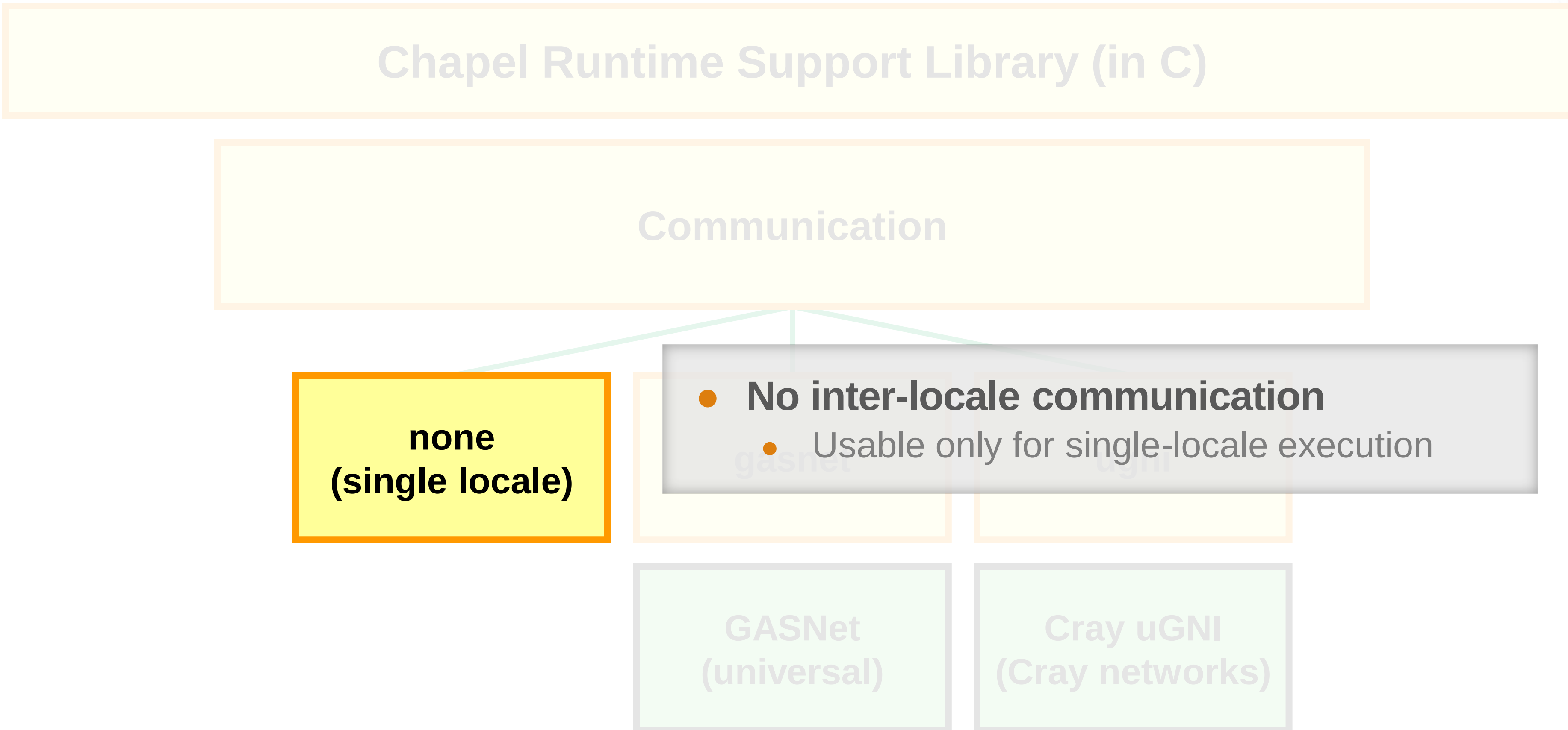
Runtime Communication Layer



Runtime Communication Layer

- **Supports inter-locale communication**
- **PUT operations**
  - Single value and multiple values (strided)
- **GET operations**
  - Single value and multiple values (strided)
  - Blocking and (non-strided, tentative) non-blocking
- **Remote fork operations**
  - Run a function on some other locale
  - Uses Active Message model; normally starts a task to do the function
  - Blocking
    - Local side waits for remote side to complete; used for Chapel `on`
  - Non-blocking
    - Local side proceeds in parallel with remote side; used internally
  - “Fast”
    - Target function runs directly in AM handler
    - Used for small target functions that will not communicate

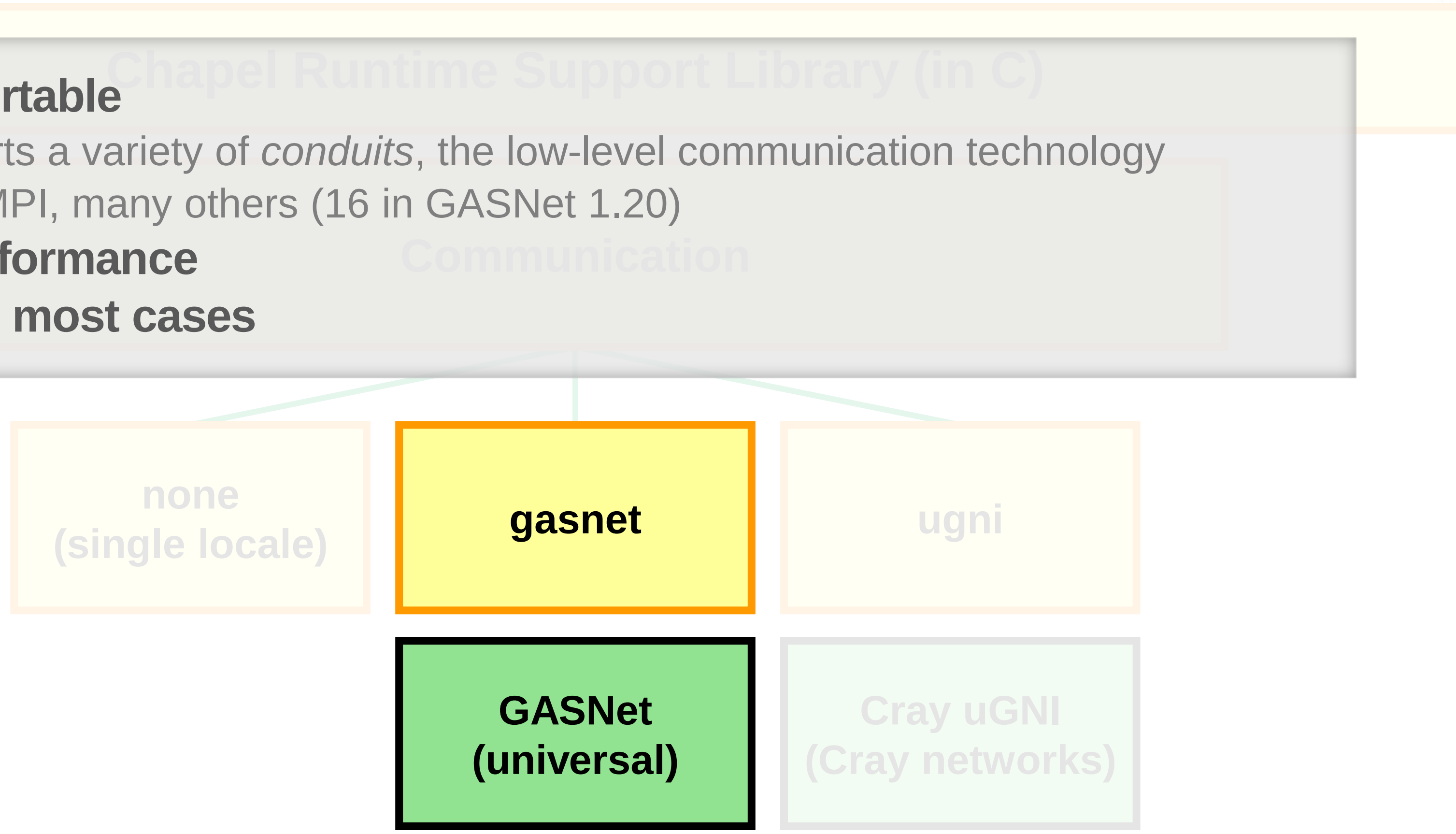
Runtime Communication Layer Instantiations



- **No inter-locale communication**
  - Usable only for single-locale execution

Runtime Communication Layer Instantiations

- **Highly portable**
  - Supports a variety of *conduits*, the low-level communication technology
  - UDP, MPI, many others (16 in GASNet 1.20)
- **Good performance**
- **Default in most cases**



Runtime Communication Layer Instantiations

Chapel Runtime Support Library (in C)

- **Very good performance on Cray hardware**
  - Especially for applications limited by remote communication latency
  - But could still be improved
- **Default with prebuilt Chapel module on Cray systems**

Communication

none (single locale)

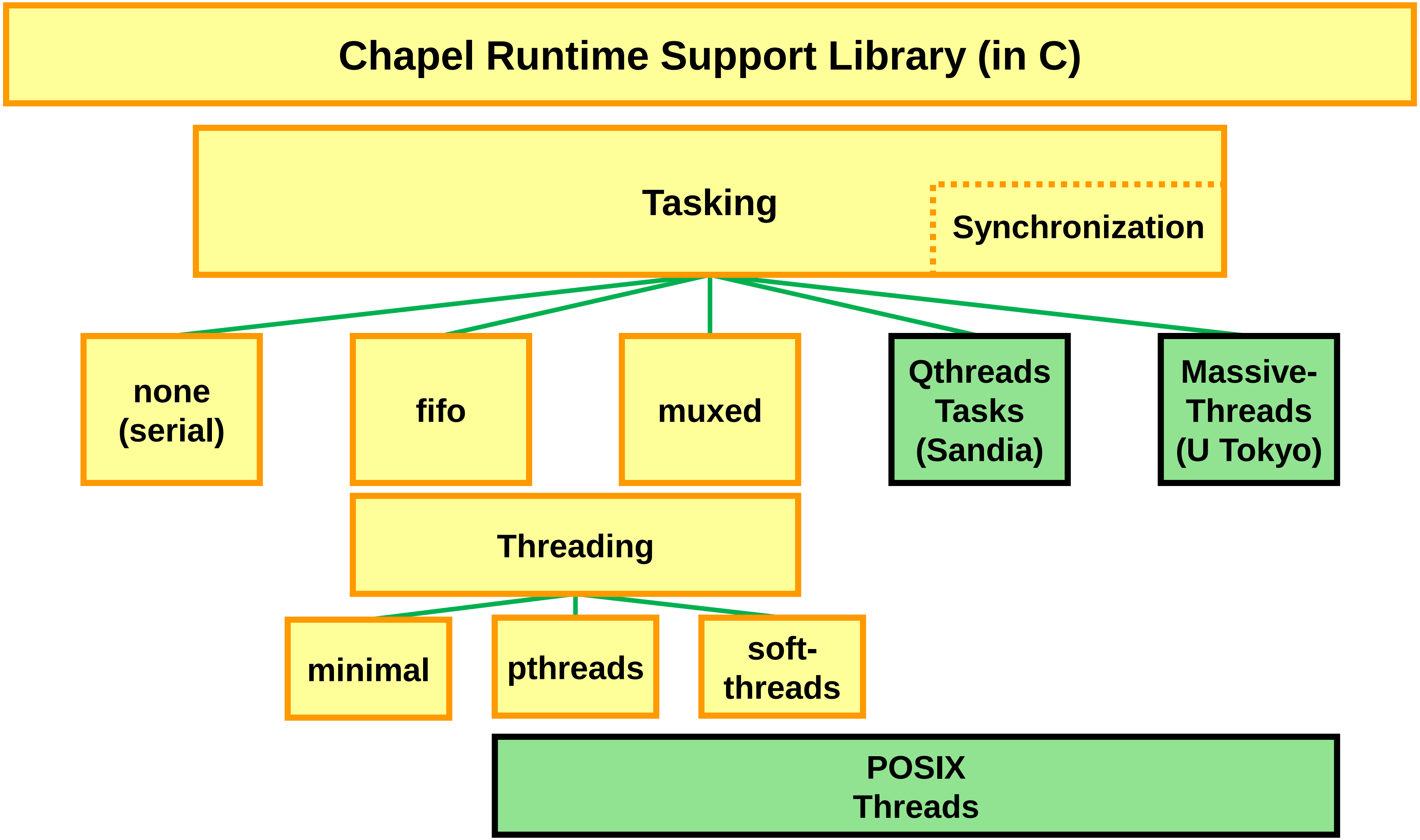
gasnet

ugni

GASNet (universal)

Cray uGNI (Cray networks)

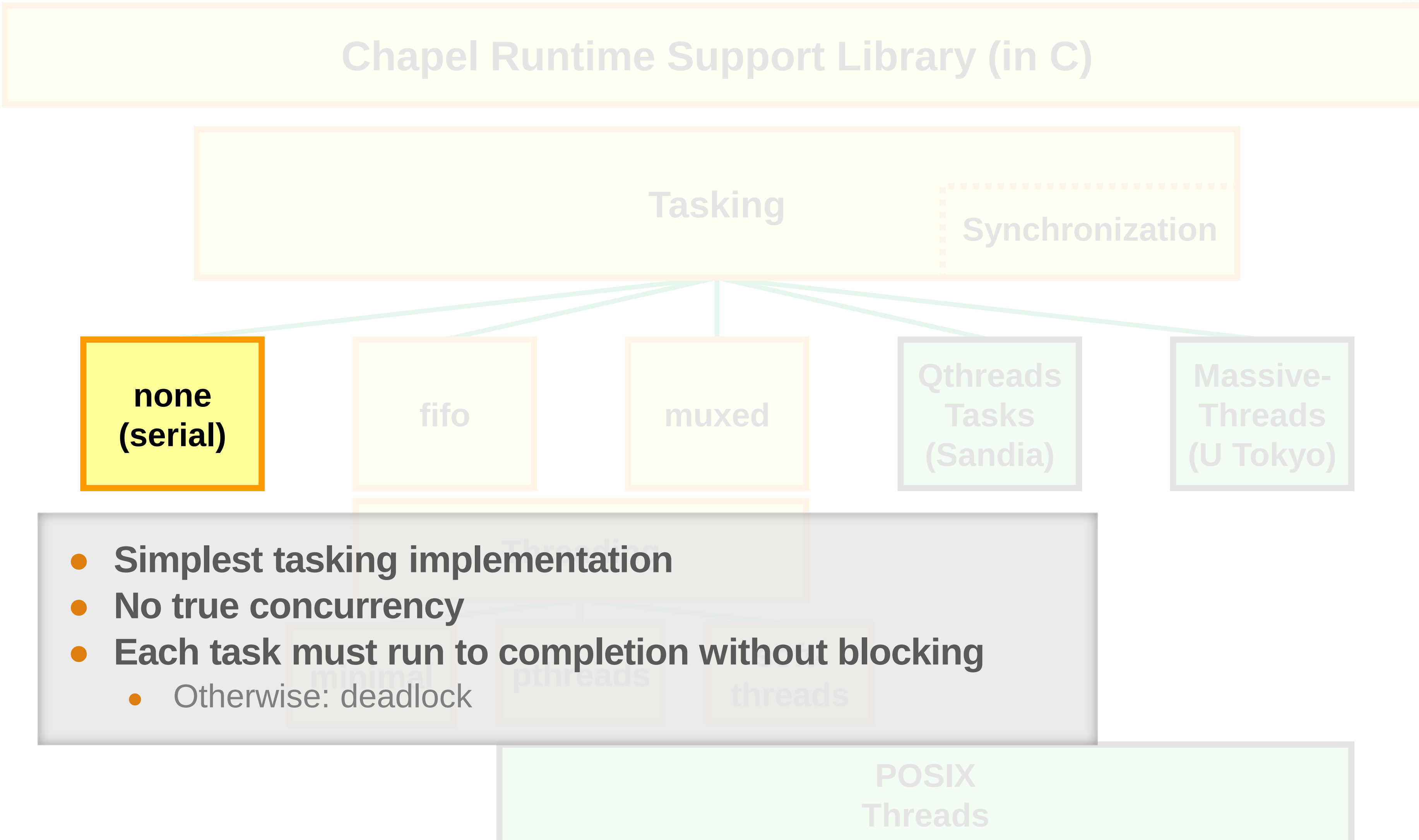
Runtime Tasking Layer



Runtime Tasking Layer

- **Supports parallelism**
- **Local to a single locale**
- **Operations**
  - Create a group of tasks
  - Start a group of tasks
  - Start a "moved" task
    - Used to run the body of a non-fast remote fork, for an `on`
  - Synchronization support (*sync* and *single* variables)
- **Threading layer**
  - Aimed to separate Chapel tasking from underlying threading
  - Built an interface and a few instantiations
    - Interface known only to the tasking and threading layers (fortunately)
  - Didn't turn out so well
    - Third-party tasking layers have internal threading interfaces already
    - Threading turned out to be hard to generalize, especially with performance
  - Leaning toward removing this as a separate interface

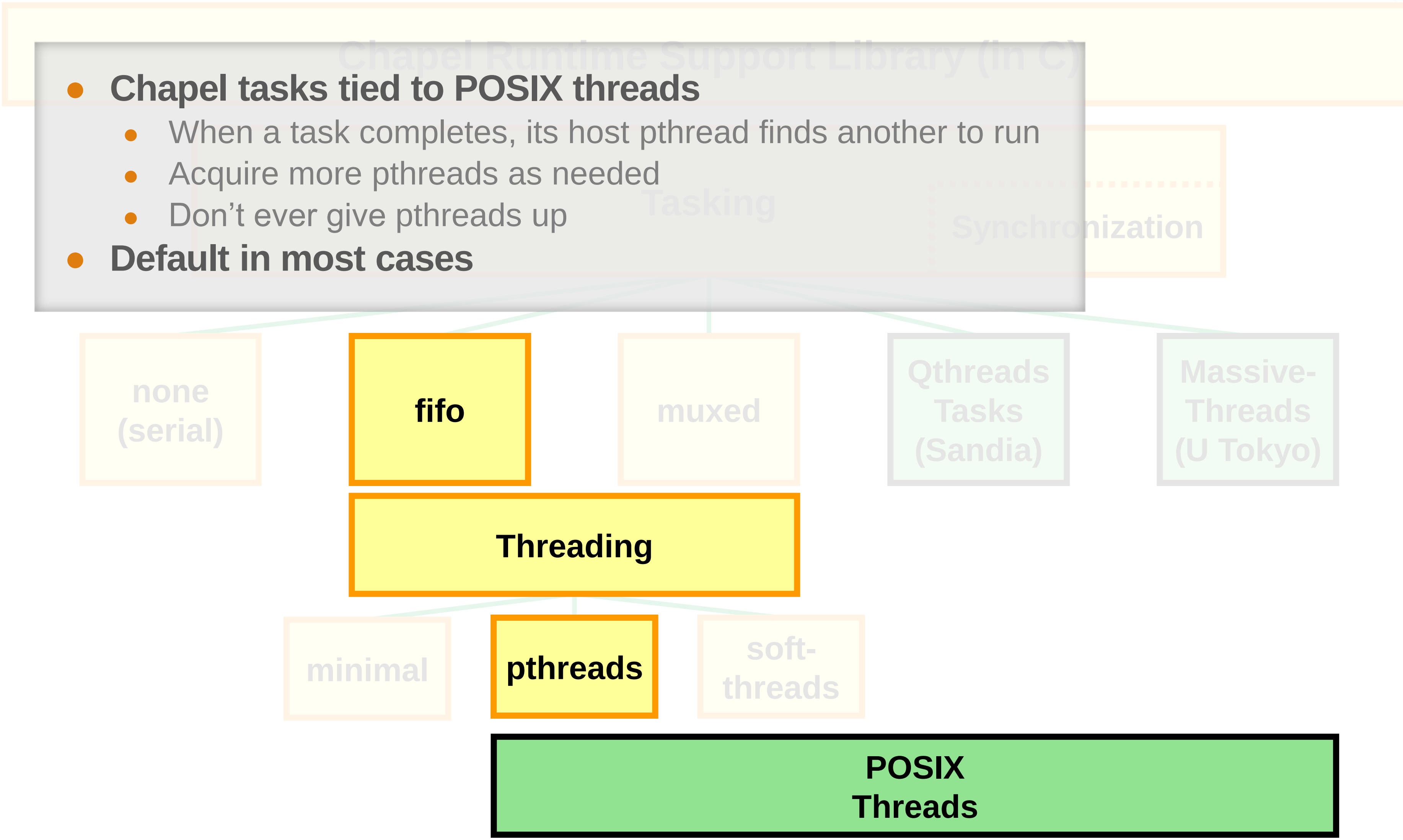
Runtime Tasking Layer Instantiations



- **Simplest tasking implementation**
- **No true concurrency**
- **Each task must run to completion without blocking**
  - Otherwise: deadlock

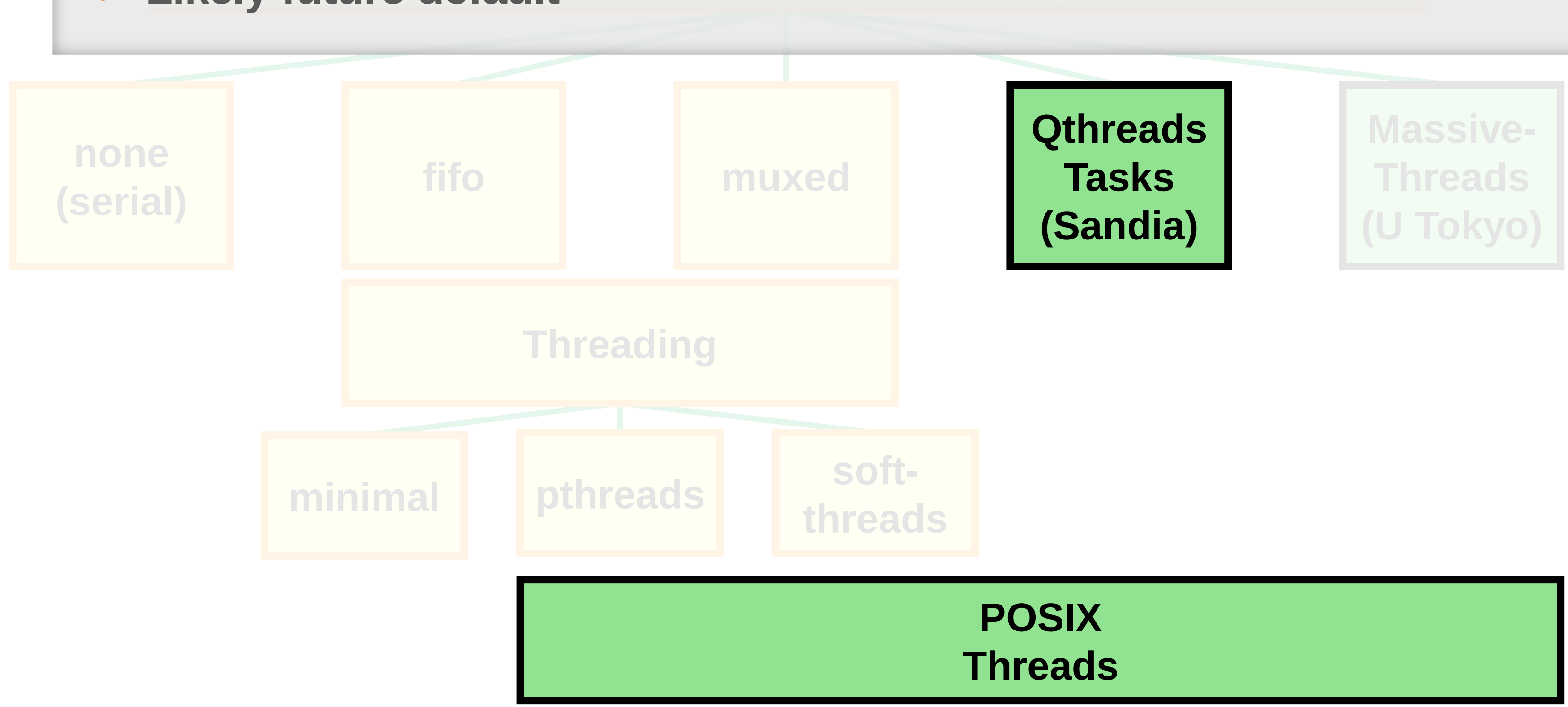
Runtime Tasking Layer Instantiations

- **Chapel tasks tied to POSIX threads**
  - When a task completes, its host pthread finds another to run
  - Acquire more pthreads as needed
  - Don’t ever give pthreads up
- **Default in most cases**



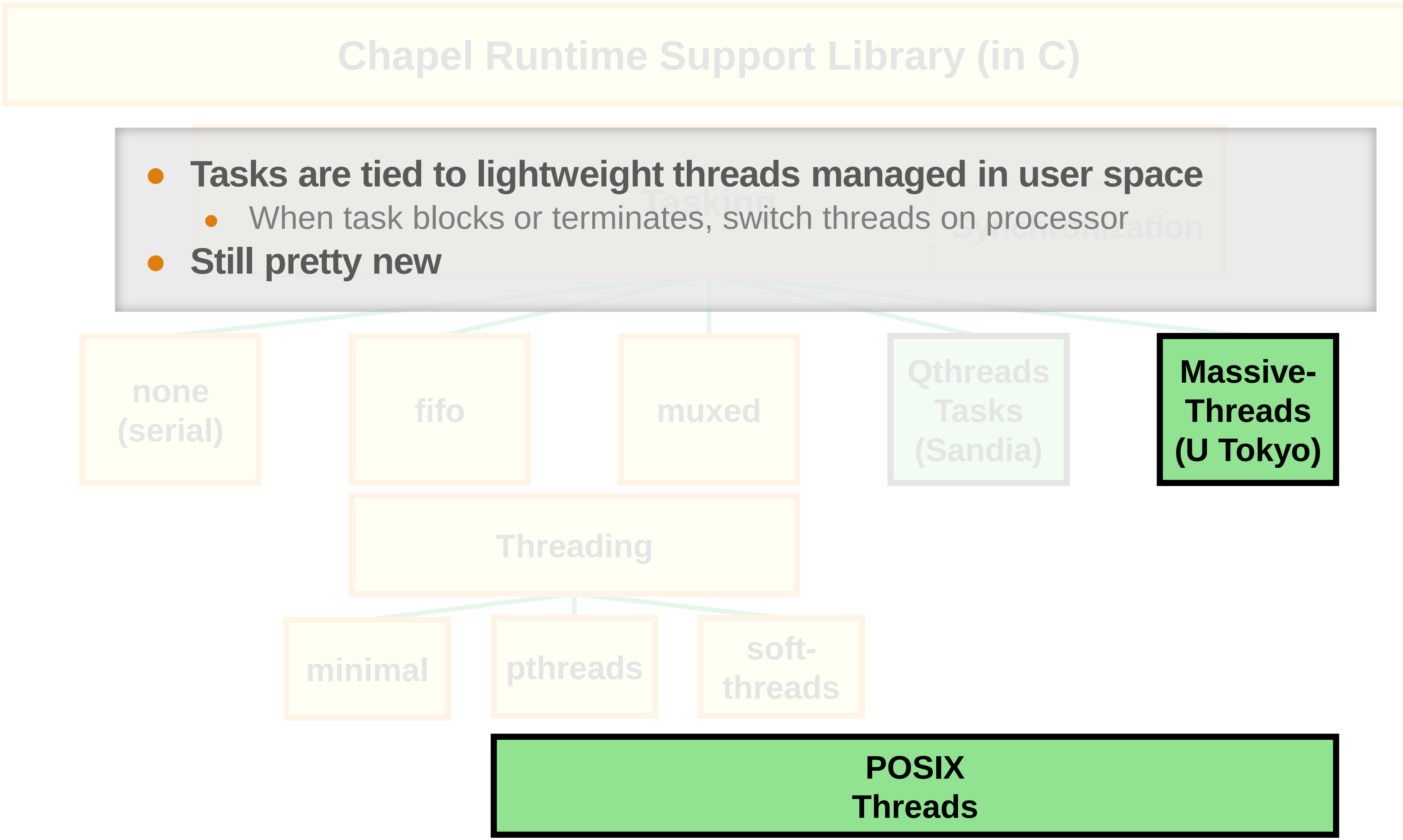
Runtime Tasking Layer Instantiations

- **Tasks are tied to lightweight threads managed in user space**
  - When task blocks or terminates, switch threads on processor
- **Good performance**
- **Likely future default**



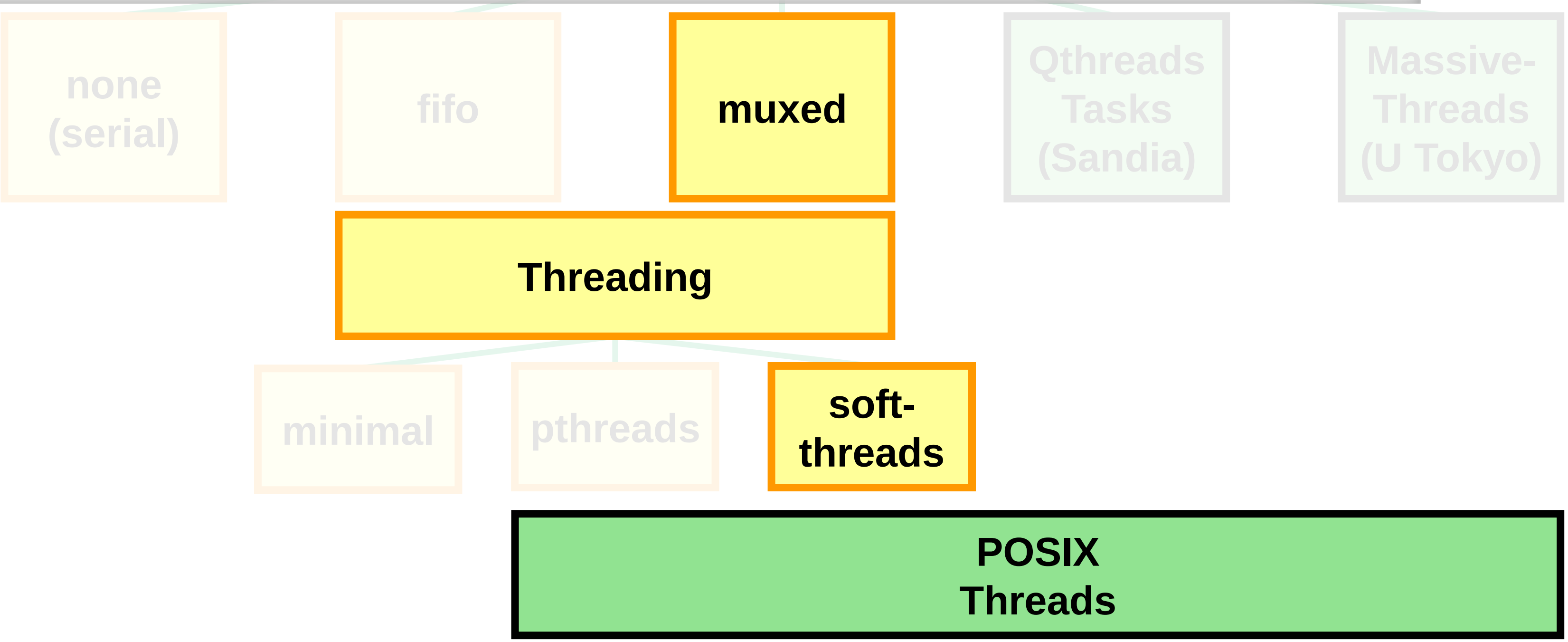
Runtime Tasking Layer Instantiations

- **Tasks are tied to lightweight threads managed in user space**
  - When task blocks or terminates, switch threads on processor
- **Still pretty new**

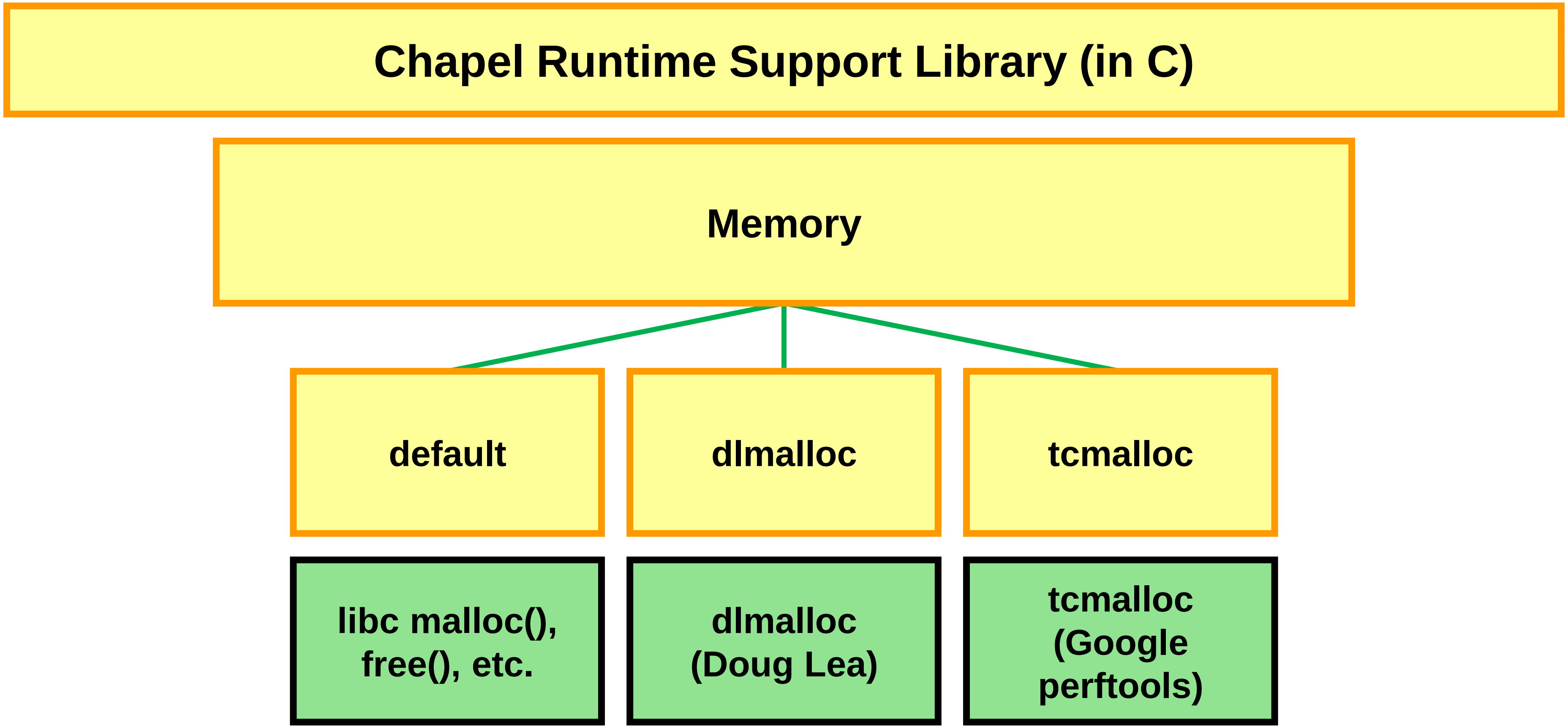


Runtime Tasking Layer Instantiations

- **Tasks are multiplexed on threads**
  - When task blocks or terminates, switch tasks on thread
- **Threading layer manages lightweight threads in user space**
  - Small fixed number of threads per system node
- **Very good performance**
- **Default with prebuilt Chapel module on Cray systems**



Runtime Memory Layer Instantiations



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Example (from HPCC RemoteAccess)

```
var T: [TableSpace] atomic elemType;
…
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
```

Do atomic `xor` updates to random elements of an array that spans locales. `Updates` is a *distributed domain*, representing iterations and where they should run. `RAStream()` is a stream of random numbers. *Zippered iteration* combines these, pairwise, into a *tuple* per iteration. (Then: toss the iteration; use the random number.)

Example (distribute the work)

```
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
```

(effectively)

```
coforall loc in Locales do on loc do              // across locales
  forall (_, r) in localUpdates, RAStream()) do  // single locale
    T[r & indexMask].xor(r);
```

Assume in general #updates >> #locales, and thus we can run several tasks per locale and still do many updates per task.

Example (distribute the work globally)

```
coforall loc in Locales do on loc do                // across locales
  forall (_, r) in localUpdates, RAStream()) do  // single locale
    T[r & indexMask].xor(r);
```

(corresponding runtime calls)

```
for (int i = 0; i < numLocales; i++)
  if (i != myLocale)
    chpl_comm_fork_nb(i, onWrapper, forkArgs);
onFn1TaskBody(taskArgs);
```

originating locale

target locale

```
void onWrapper(forkArgs) {  // called by AM handler
  chpl_task_startMovedTask(onFn1TaskBody, taskArgs);
}
void onFn1TaskBody(taskArgs) {
  forall (_, r) in localUpdates, RAStream()) do T[…].xor(r);
  barrier;
}
```

This is such a common code idiom that we don't actually create local tasks to do the on statements; we just launch remote tasks directly.

Example (distribute the work locally)

```
coforall loc in Locales do on loc do                 // across locales
  forall (_, r) in localUpdates, RAStream()) do    // single locale
    T[r & indexMask].xor(r);
```

(corresponding runtime calls)

```
  for (int t = 0; t < nLocalTasks; t++)
    chpl_task_addToTaskList(taskBodyFn, taskList,   // make descriptors
                            taskArgs);
  chpl_task_processTaskList(taskList);              // initiate tasks
  chpl_task_executeTasksInList(taskList);           // ensure started
  barrierAfterCoforall;
  chpl_task_freeTaskList(taskList);                 // cleanup
  …

void taskBodyFn(taskArgs) {
  for (int i = 0; i < nTaskIters; i++) T[r & indexMask].xor(r);
}
```

Here we are creating the tasks that will do all the local iterations.

Example (do the updates)

```
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
```

Compiler must find a definition in the internal modules for an `xor()` method on atomic data. As it turns out, there are more than one.

Example (do updates, no network atomics)

```
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
```

```
inline proc xor(value:int(64),…):int(64) {
  on this do atomic_fetch_xor_explicit_int_least64_t(_v, value, …);
}
```

modules/internal/Atomics.chpl

If we don't have network atomic support, then we do an `on` to move execution to the locale that owns the data, and do the update using a processor atomic operation.

Example (do updates, no network atomics)

```
inline proc xor(value:int(64),…):int(64) {
  on this do atomic_fetch_xor_explicit_int_least64_t(_v, value, …);
}
```

modules/internal/Atomics.chpl

```
chpl_comm_fork(localeOf(this), onWrapper, forkArgs);
```

originating locale

target locale

```
void onWrapper(forkArgs) {  // called by AM handler
  chpl_task_startMovedTask(onFn2TaskBody, taskArgs);
}
void onFn2TaskBody(taskArgs) {
  atomic_fetch_xor_explicit_int_least64_t(_v, value, …);
  chpl_comm_put(originatingLocale, fork_ack_addr, 1);
}
```

The originating locale uses the comm layer to do a blocking remote fork. The remote locale's Active Message handler creates a task to run the body of the `on`. That task does the user's work, then sends a completion acknowledgement to let the fork on the originating locale proceed. (Note: we might actually use a "fast" fork here.)

Example (do updates, with network atomics)

```
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
```

```
inline proc xor(value:int(64)):int(64) {
  var v = value;
  chpl_comm_atomic_xor_int64(v, this.locale.id:int(32), this._v, …);
}
```

modules/internal/comm/ugni/NetworkAtomics.chpl

If the network can do atomics (and the communication layer supports them), then it's simpler. Just call the communication layer directly to do the `xor` in the network, given the operand and the atomic datum's remote locale and address there.

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Future Work

- **Currently working on hierarchical locales**
  - To support hierarchical, heterogeneous architectures such as NUMA nodes, traditional CPUs with attached GPUs, many-core CPUs
    - Adds (sub)locale-aware memory management
    - Sublocale task placement
  - New architecture internal module will read an architectural description
  - Compiler-emitted memory and tasking calls will go to module code.
    - Though for some architectures will effectively collapse to direct runtime calls at user program compile time.
- **Other things we hope to get to soon**
  - Task teams (for collectives, etc.)
  - Eurekas (for short-circuiting searches, etc.)
  - Task private data

Questions?