A UPC++ Actor Library and its Evaluation on a Shallow Water Application

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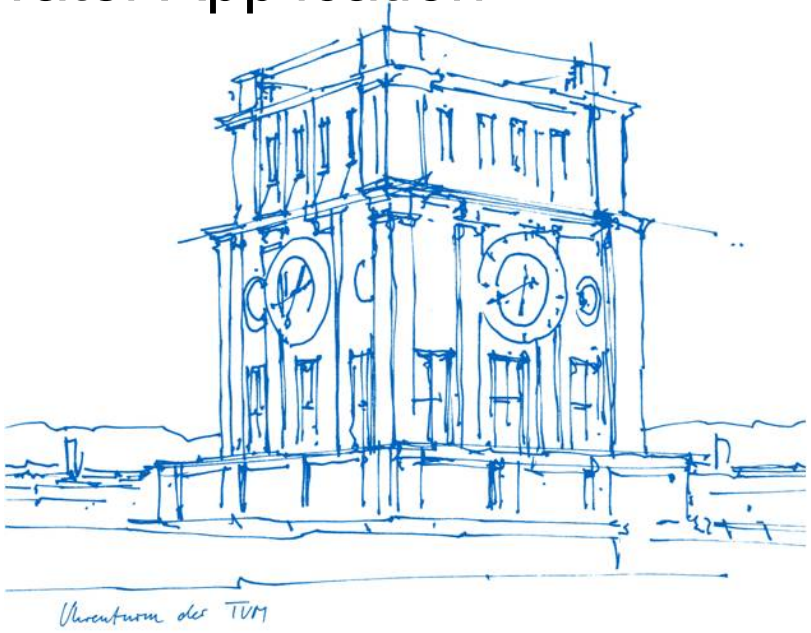


Parallel Applications Workshop, Alternatives To MPI+X
November 18th 2019
Denver, Colorado

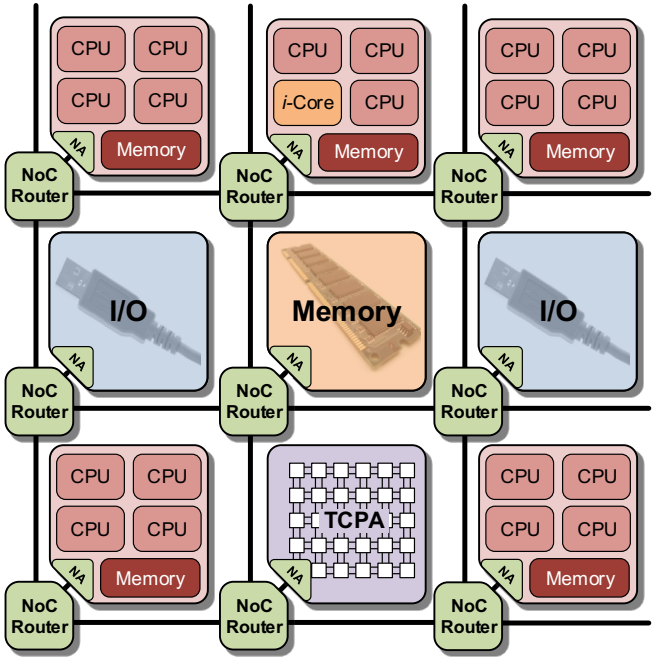
Motivation

Invasive Computing:

- Dynamic resource allocation
- Predictability through exclusive resource usage
- Heterogeneous compute tiles

Actor-based Modelling

- Good fit for architecture, enables exploration of different mappings of actors to compute tiles
- SWE-X10 as sample application



Transfer to larger-scale applications

Is it feasible to program an actor library using standard languages and frameworks?

If so, how does performance compare, both to our X10-based library, and BSP?

✓ Tools: **C++, OpenMP, UPC++**

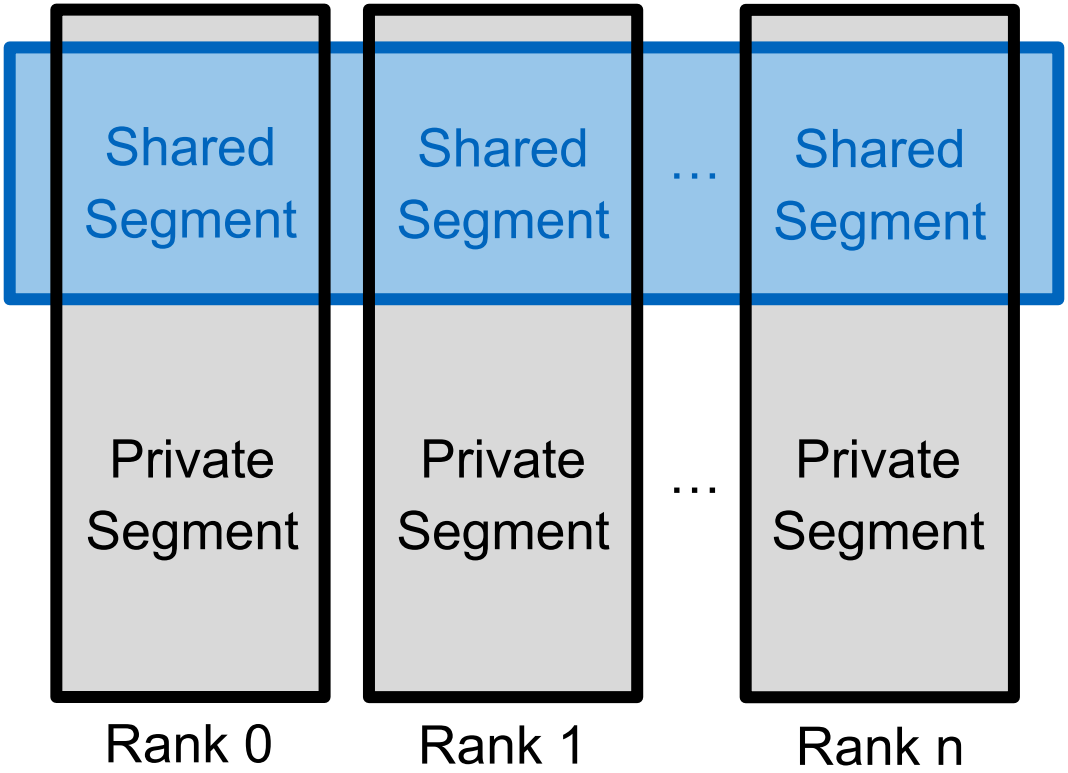
UPC++

Asynchronous **P**artitioned **G**lobal **A**ddress **S**pace (APGAS) Model

Reliance on one-sided communication

Asynchronous, continuation-based API

Based on GASNet-EX, makes direct use of InfiniBand and (some) Cray interconnects

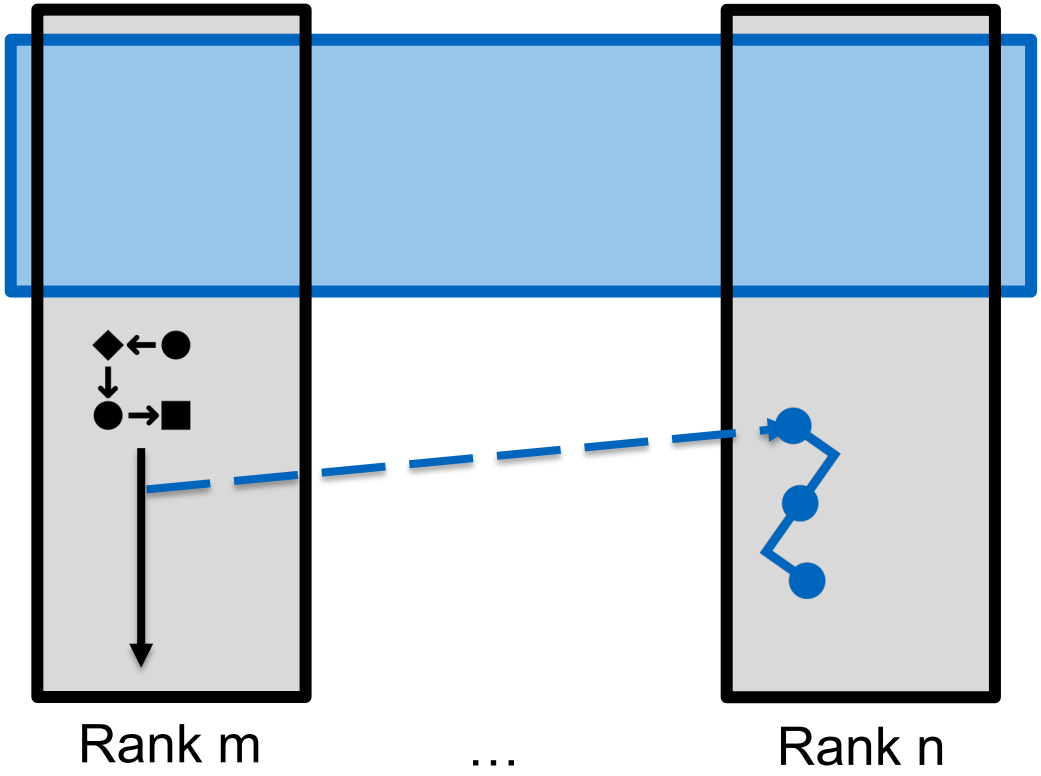


Adapted from: *UPC++ Specification v1.0 Draft 10, available at https://upcxx.lbl.gov*

UPC++

RPCs

- Executed asynchronously
- Serialization and transfer of parameters, return value
- Completion events available after the local part (or overall RPC execution) is finished



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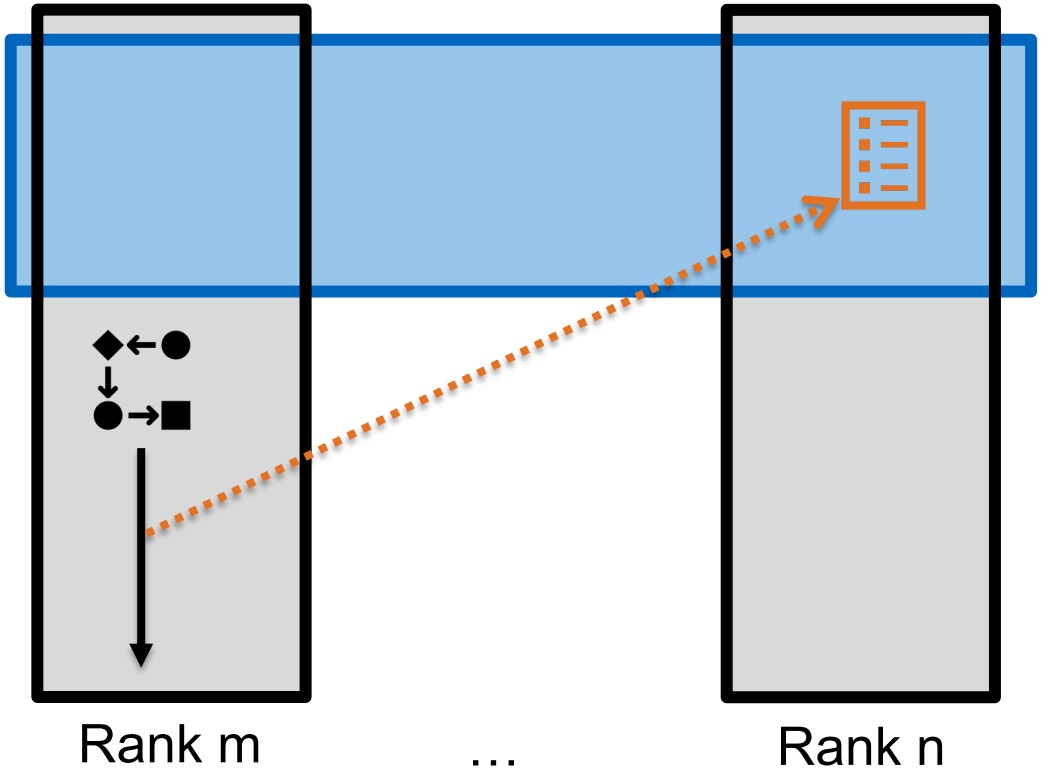
Global Pointers

- Point to data in Shared segment
- May be used as target for RMA operations



UPC++

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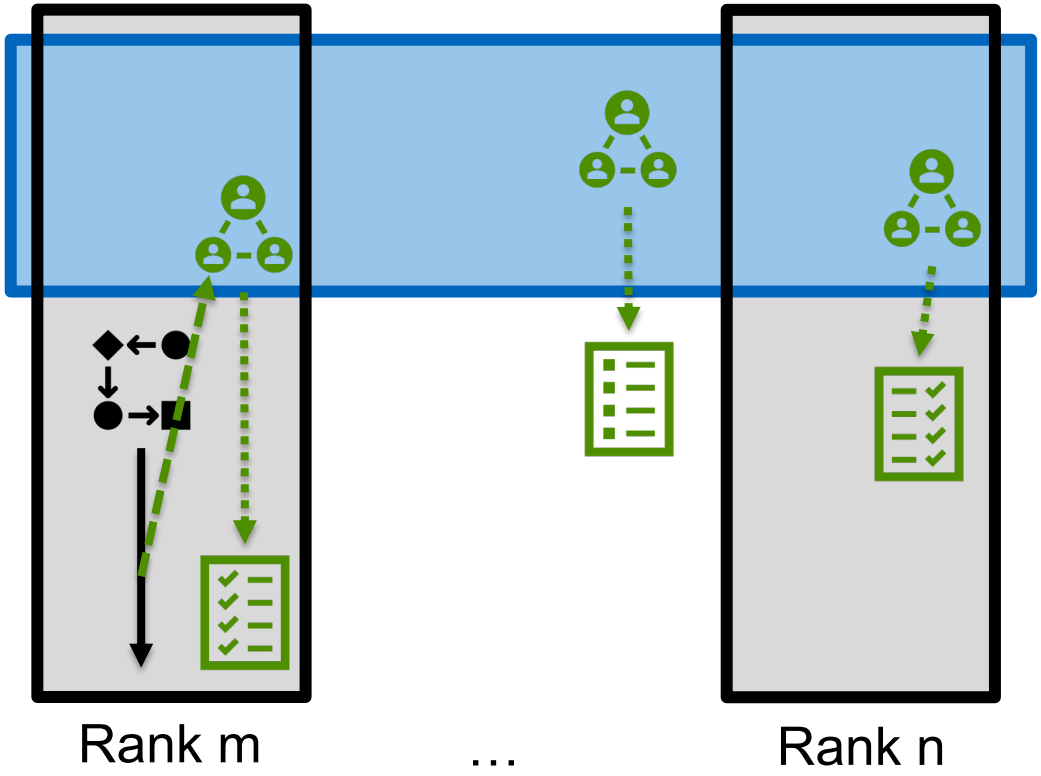
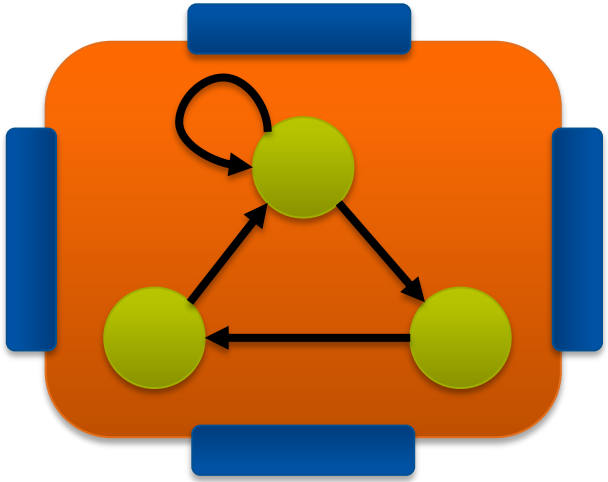
Distributed Objects
- Created collectively
- Same handle points to different objects on each rank



UPC++ Actor Library

Actors

- Encapsulate specific functionality, data and behavior
- Behavior defined through finite state machines
- No data sharing between actors
- Defined communication endpoints (Ports)
- Have the ability compute whenever data in their ports (InPorts or OutPorts) changes
  - ➢ Actors are being **triggered**



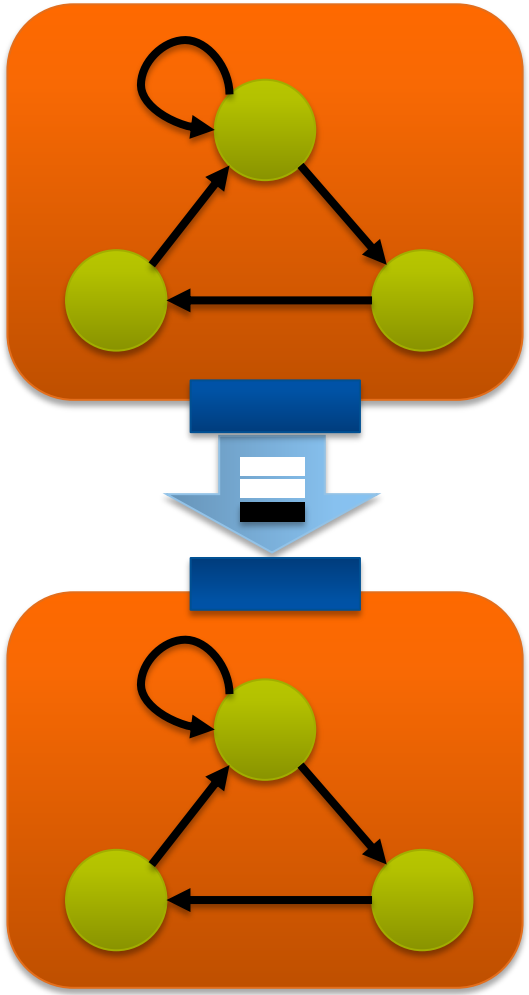
Application Developers…

- …subclass and implement **act()** method (actor FSM)
- …use ports as communication endpoints
- …specify which ports are connected

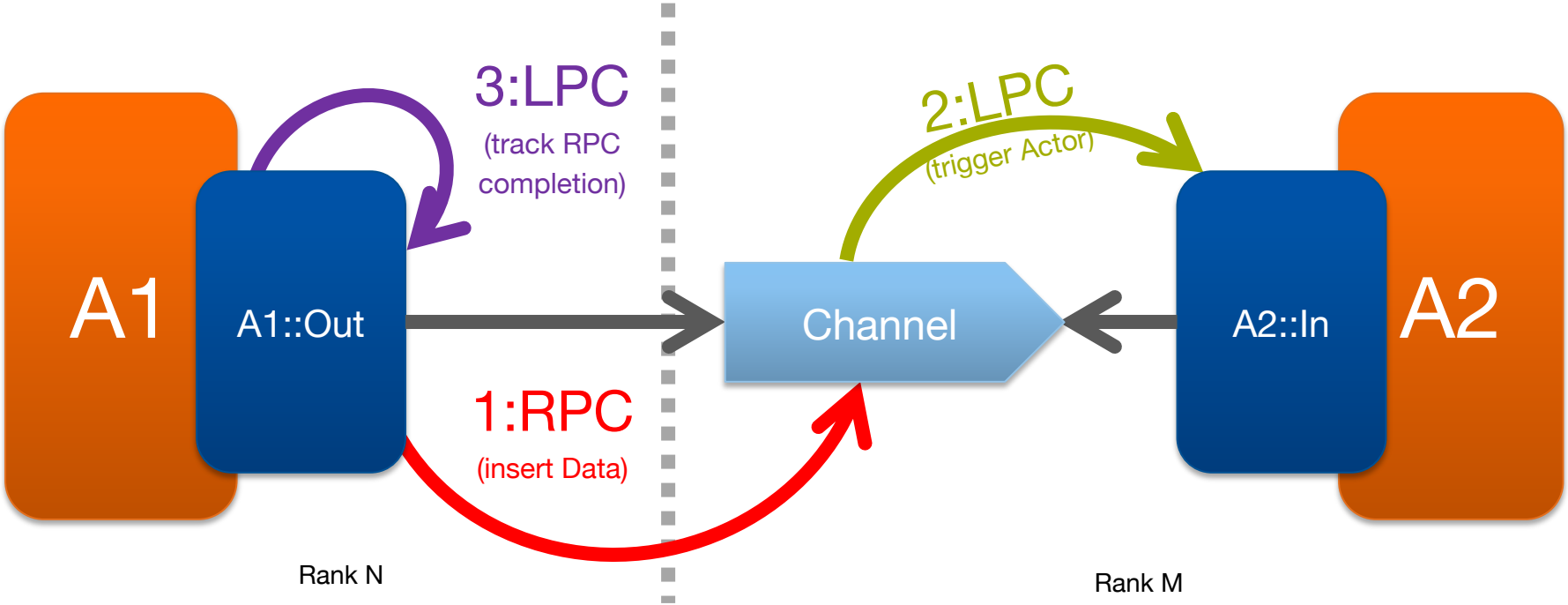
UPC++ Actor Library

Channels

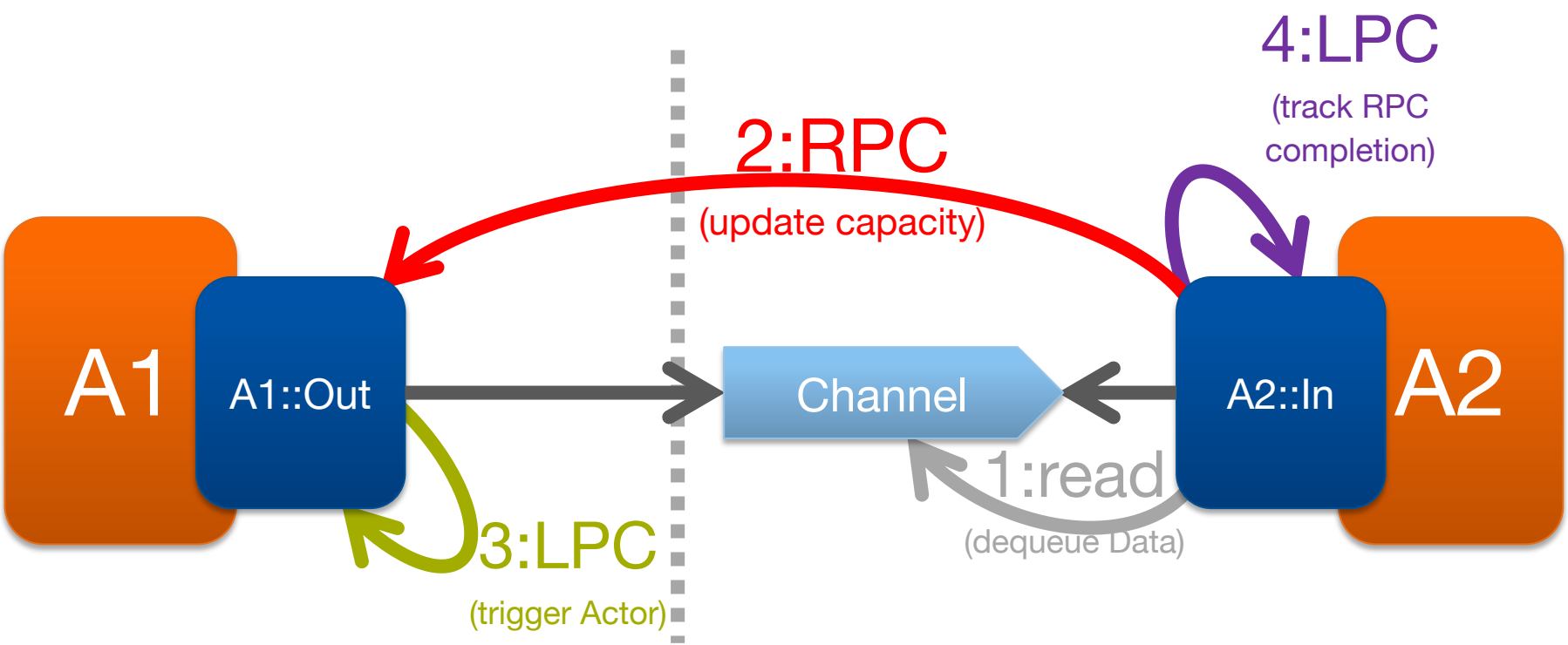
- Unidirectional connection between two ports
- FiFo semantics
- Operations: *read()*, *write(T)*, *peek()*
- Guards: *available()*, *freeCapacity()*



UPC++ Actor Library – Write



UPC++ Actor Library – Read



UPC++ Actor Library – Actor Execution Strategies

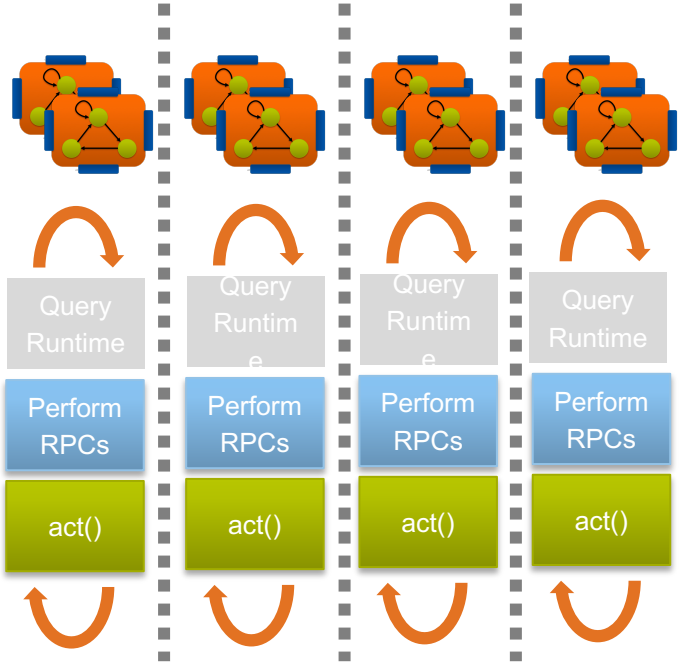
Rank-based Execution Strategy

One thread per UPC++ rank, one rank per (logical) core

One event loop:
- Query runtime for progress
- Execute RPCs, mark affected actors
- Execute act() on affected actors

May use sequential UPC++ code mode

Low number of actors per rank



UPC++ Actor Library – Actor Execution Strategies

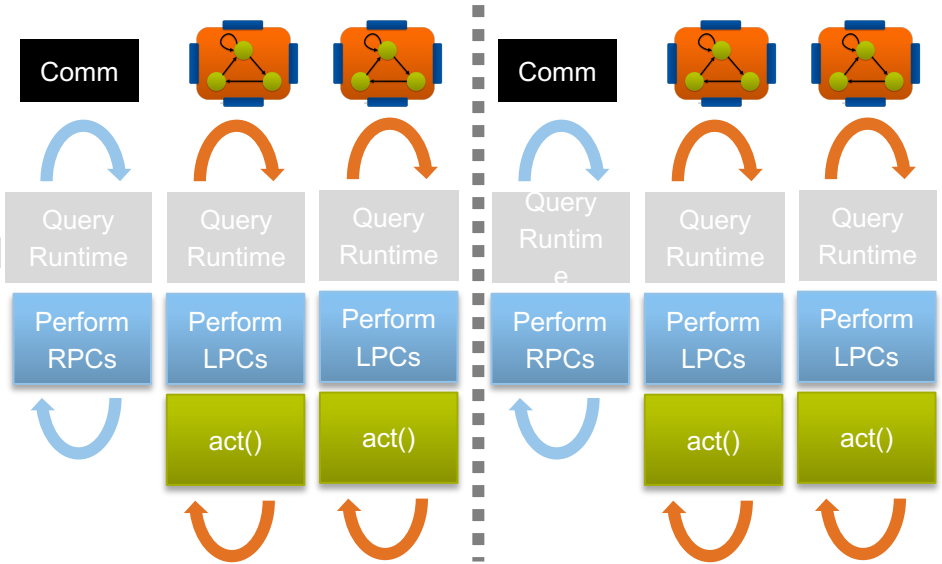
Thread-based Execution Strategy

One thread per actor, and one communication thread, low number of ranks per node

Two event loops:

- Communication thread queries runtime and executes RPCs
- Actor threads query runtime for progress and execute LPCs, execute act

Requires balancing of communication thread against number of actors



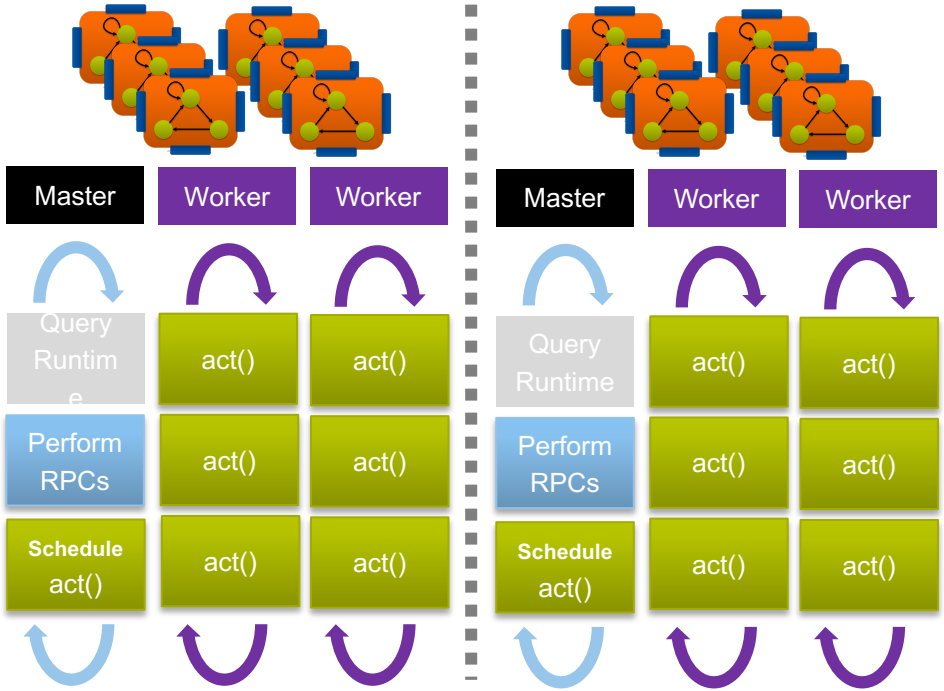
UPC++ Actor Library – Actor Execution Strategies

Task-based Execution Strategy

Map act() executions on OpenMP tasks

One event loop:
- Master thread queries Runtime
- Performs any incoming RPCs and triggers affected actors
- Schedules OpenMP task for each invocation of **act**. Dependencies between act invocations of same actor

Large number of actors per rank possible



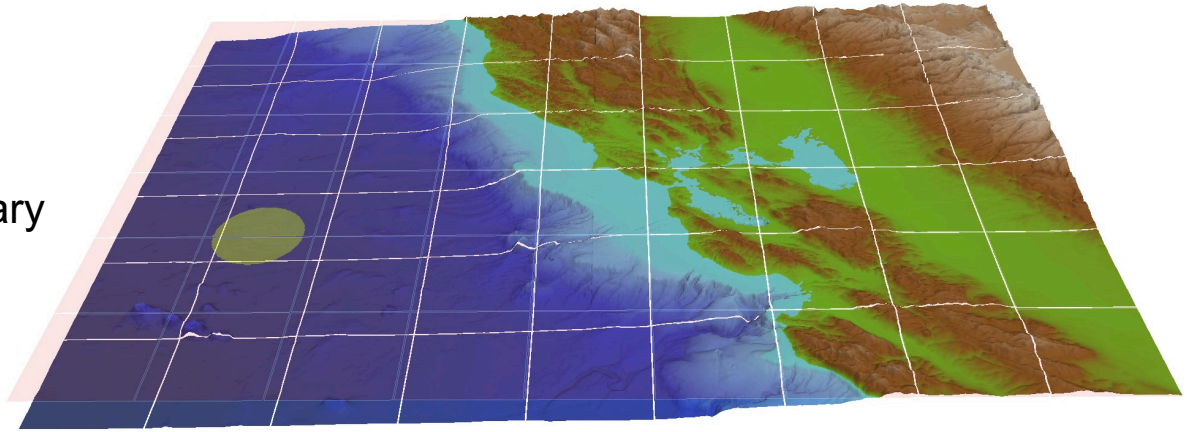
Pond – A Shallow Water Proxy Application

Based on prior applications

- **SWE**, a BSP-based code written using MPI and OpenMP
- **SWE-X10**, an actor-based X10 application written using the actorX10 library

Parallelized using our actor library

Possible to auto-vectorize with AVX512 with Intel Compiler (v18.0)



Pond – A Shallow Water Proxy Application

$$\begin{bmatrix} h \\ hu \\ hv \end{bmatrix}_t + \begin{bmatrix} hu \\ hu^2 + \frac{1}{2}gh^2 \\ huv \end{bmatrix}_x + \begin{bmatrix} hv \\ huv \\ hv^2 + \frac{1}{2}gh^2 \end{bmatrix}_y = S(t, x, y)$$

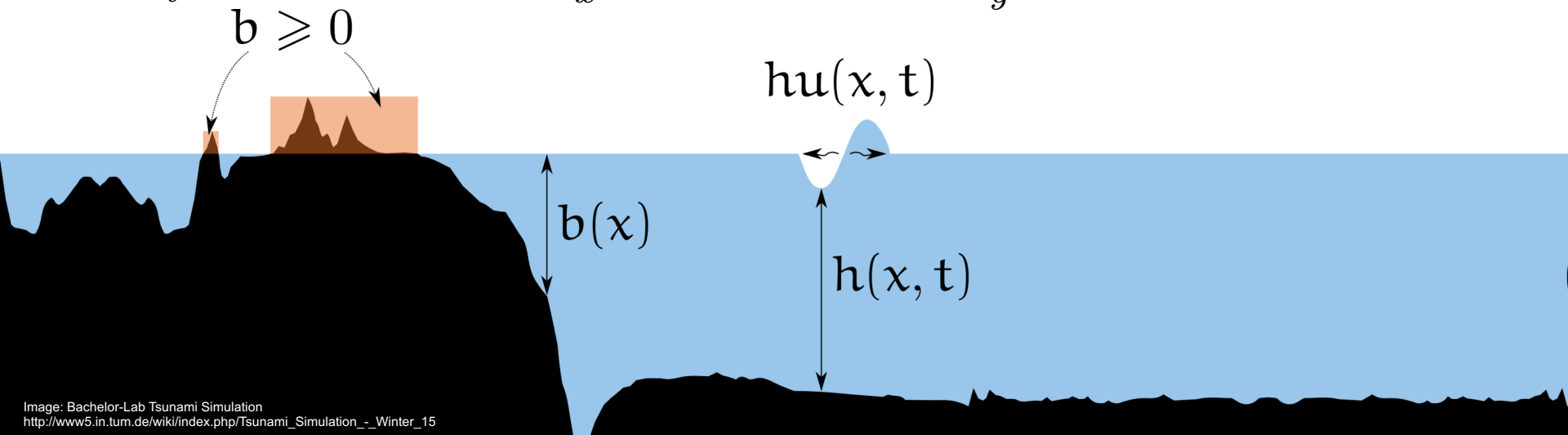


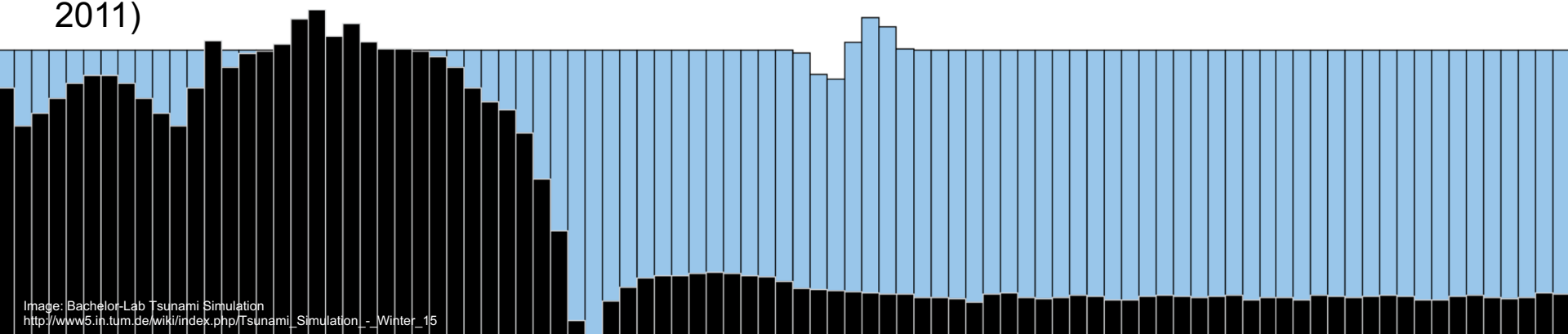
Image: Bachelor-Lab Tsunami Simulation
http://www5.in.tum.de/wiki/index.php/Tsunami_Simulation_-_Winter_15

Pond – A Shallow Water Proxy Application

Finite volume scheme on a Cartesian grid with piecewise constant unknown quantities and Euler time step

$$Q_{i,j}^{n+1} = Q_{i,j}^{n} - \frac{\Delta t}{\Delta x}\left(\mathcal{A}^{+}\Delta Q_{i-\frac{1}{2},j} + \mathcal{A}^{-}\Delta Q_{i+\frac{1}{2},j}^{n}\right) - \frac{\Delta t}{\Delta y}\left(\mathcal{B}^{+}\Delta Q_{i,j-\frac{1}{2}} + \mathcal{B}^{-}\Delta Q_{i,j+\frac{1}{2}}^{n}\right)$$

Numerical approach based on LeVeque (R. J. LeVeque, D. L. George, and M. J. Berger. Tsunami modelling with adaptively refined finite volume methods. Acta Numerica, 20:211–289, 2011)



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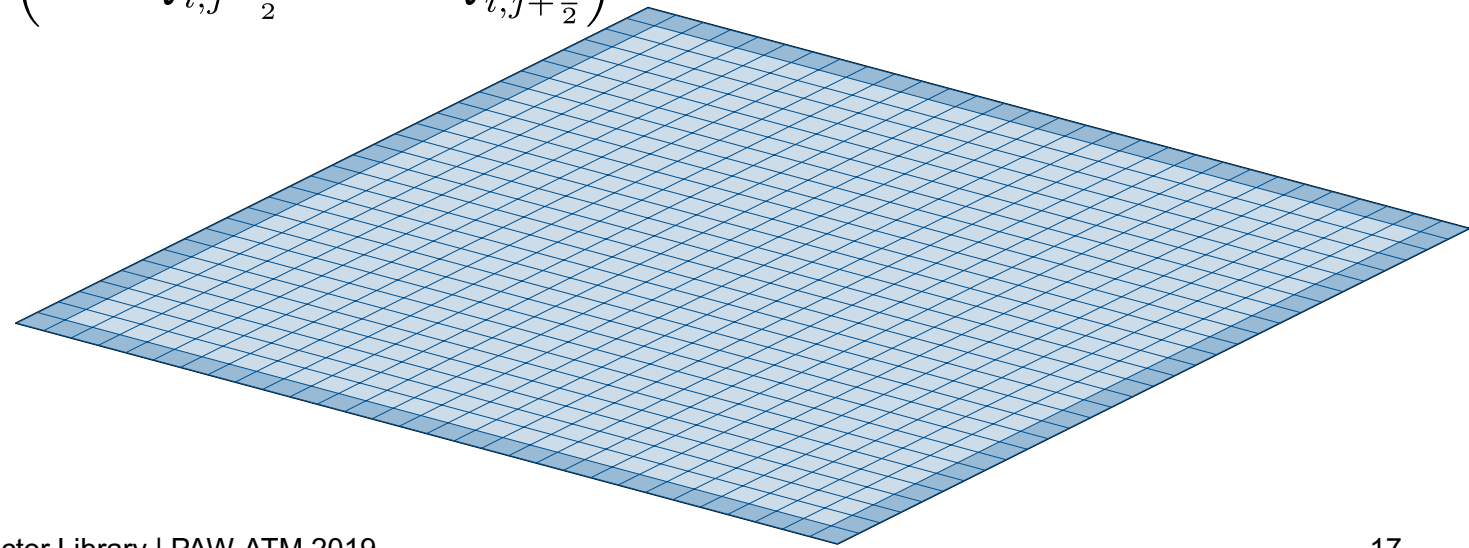
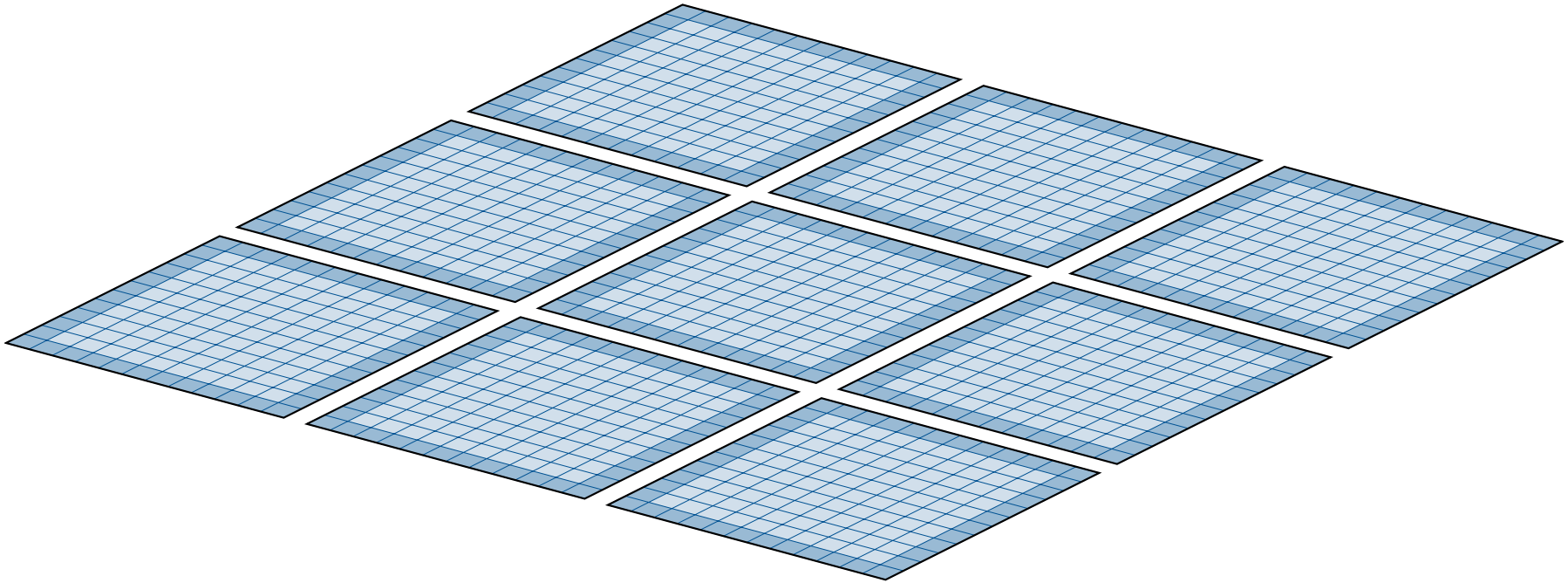


Pond – A Shallow Water Proxy Application

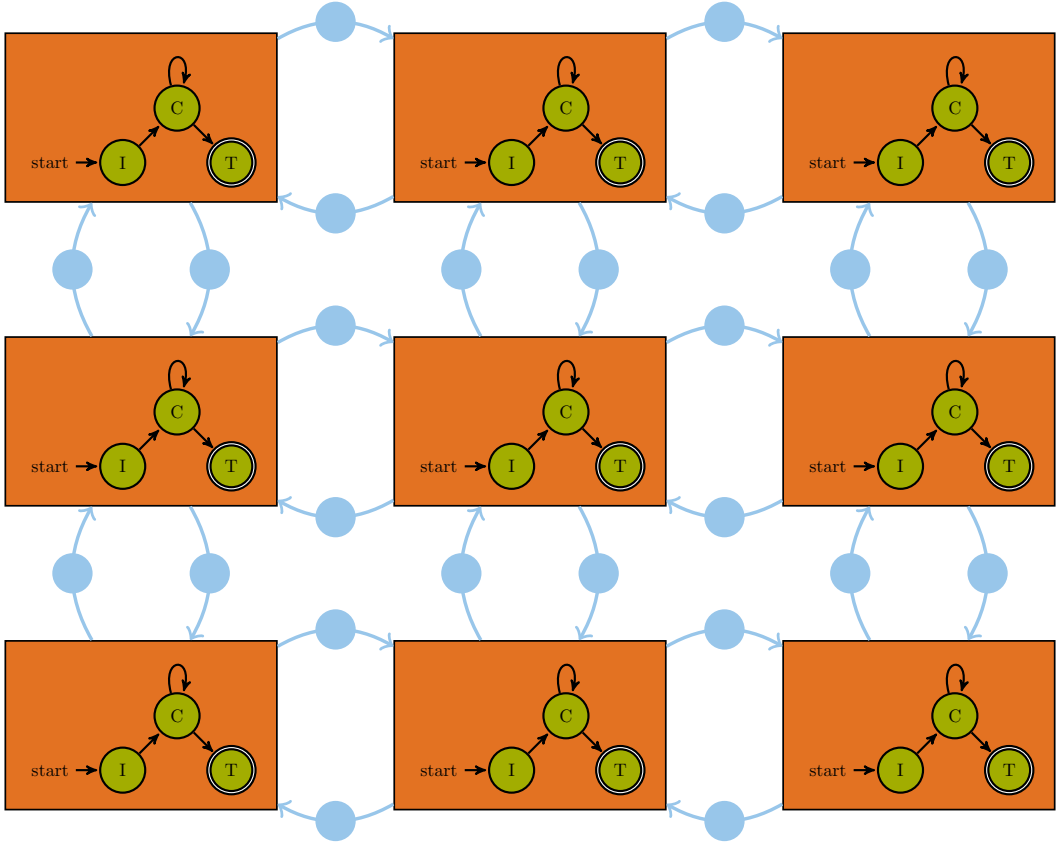
Subdivision into rectangular, equally-sized patches with Halo regions



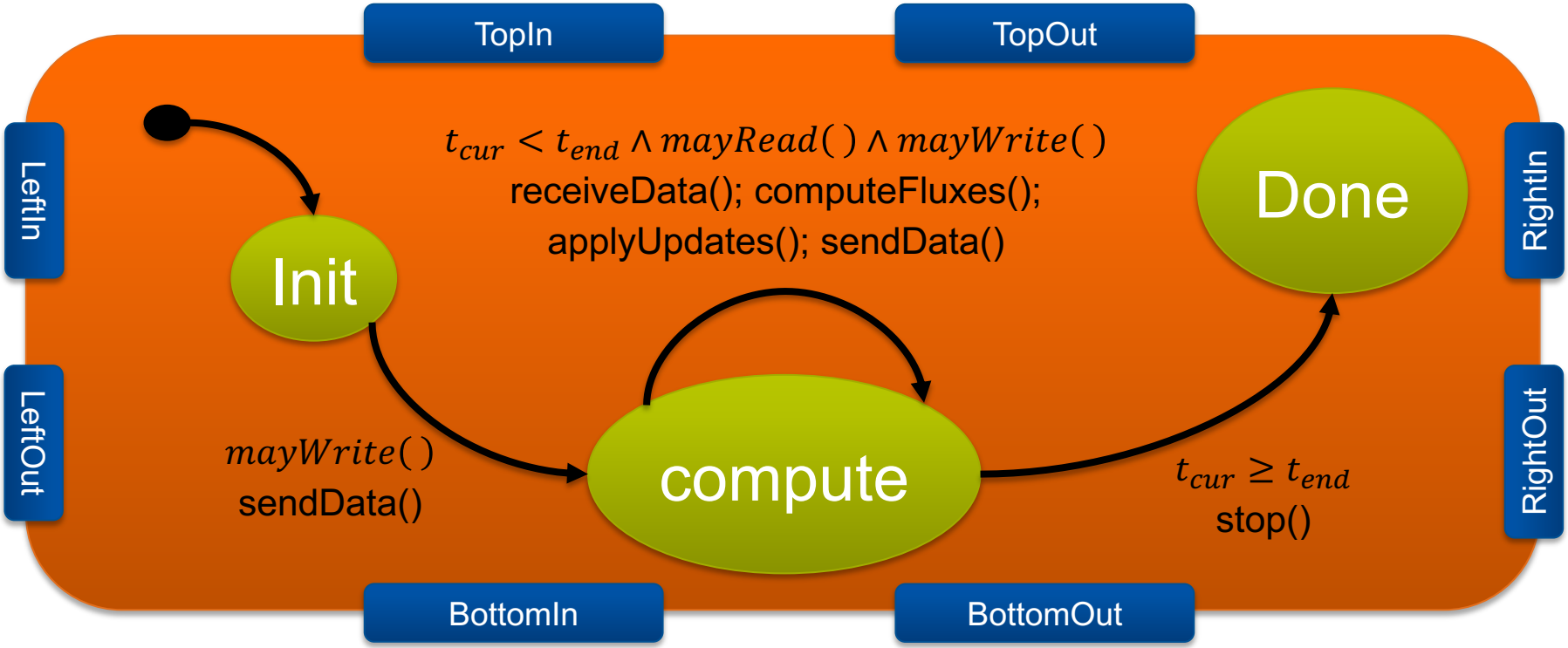
Pond – A Shallow Water Proxy Application

One actor per patch

Actors connected with direct neighbors



Pond – Simulation Actor



Evaluation

Performed on NERSC **Cori**

- Single socket Intel Xeon Phi (Knights Landing) nodes
- 68 cores (272 hyperthreads) per node
- 16GB MCDRAM
- 6TFlop/s (SP)
- Intel Compiler 18, Vectorization using AVX512

Comparison of

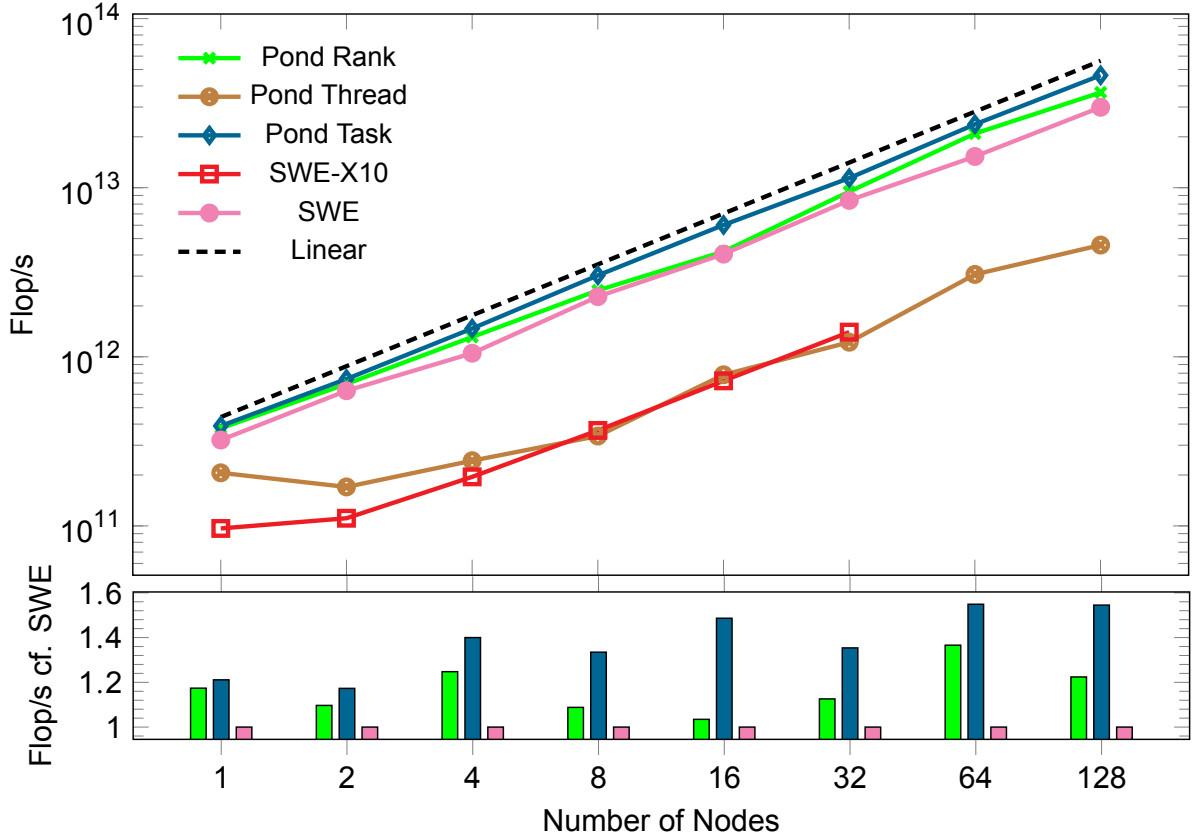
- SWE-X10, prior X10 application, based on actorX10, an X10 actor library
- SWE, prior MPI+OpenMP application, follows the BSP model
- Pond using our actor library (using the three available execution strategies, Rank, Thread and Task)

All subjects follow same numerical approach, same Riemann solver used in all cases

Evaluation – Weak Scaling

Radial Dam Break Scenario

4096^2 grid cells per node

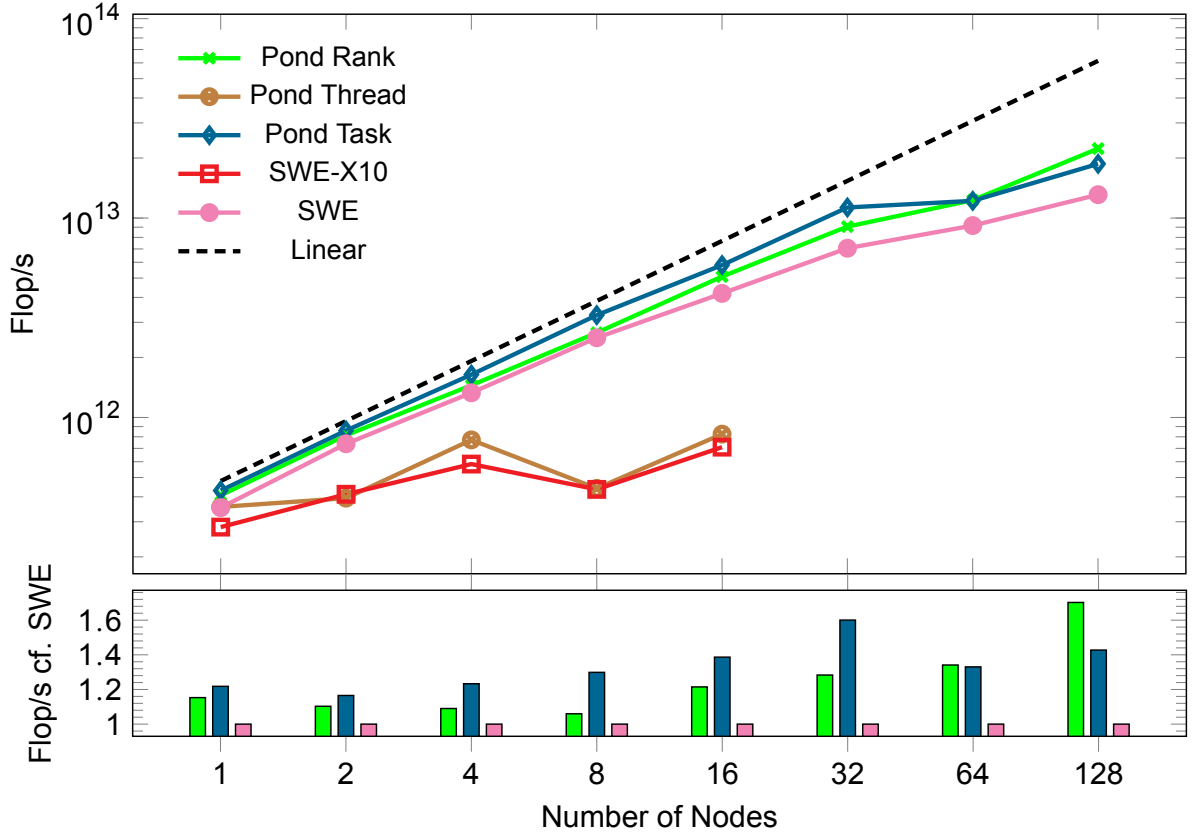


Evaluation – Weak Scaling

Radial Dam Break Scenario

16384^2 grid cells per node

Patch sizes from 512x512 down to 64x64 grid cells



Conclusion

Competitive with OpenMP and MPI

UPC++ enables overlap of communication and computation

Higher abstraction level for application programmer

Flexibility regarding backend

Questions + Acknowledgements

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UPC++ Tutorial at LBL

- December 16th
- At NERSC or Online

More Info at:

https://www.exascaleproject.org/event/upcpp

https://upcxx.lbl.gov ▶ News