SWE-X10: Simulating shallow water waves with lazy activation of patches using ActorX10

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Motivation

- Challenge for scientific computing: Optimal utilization of heterogeneous and dynamically changing resources by dynamically changing work loads.
- Today: Many scientific applications are based on programming models targeting static and homogeneous resources (SPMD pattern)
- Different programming paradigms may open new perspectives to look at problems.

Our approach:

- APGAS programming paradigm (X10 programming language)
- Actor-based modelling (ActorX10 framework)
- Low-level optimization of compute kernel (Auto-Vectorizing C++ loops)

Motivation

Proxy-Application SWE-X10

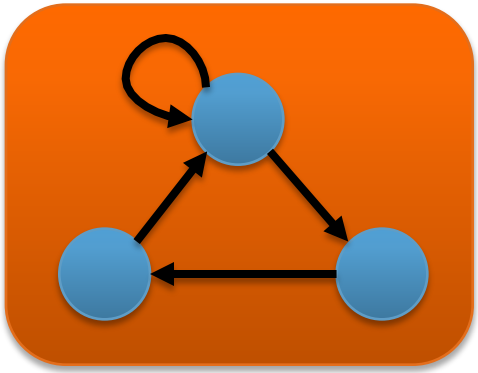
- Built on ActorX10
- Control based on finite state machines
- No global coordination scheme, actors schedule themselves
- Lazy activation of patches

Goal

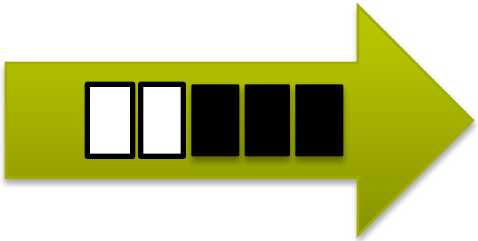
- Show flexibility of actor-based approach
- Provide base for further extensions

Actors and Channels

Actors
- “Threads + Objects”
- Semantics of Execution defined in terms of Functions and Finite State Machines
- State transitions triggered by changes in channels



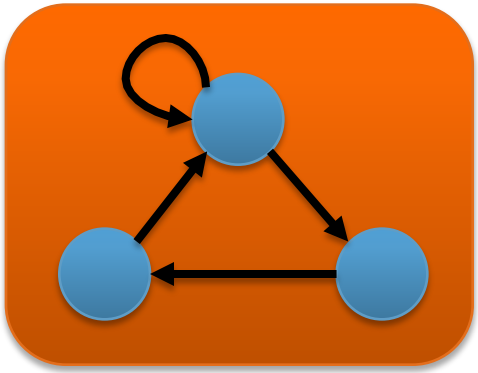
Channels
- Unidirectional connection between two actors
- FiFo semantics
- Operations: *Read():T, Write(T), Peek():T*
- Guards: *mayRead(Int):Boolean, mayWrite(Int):Boolean*

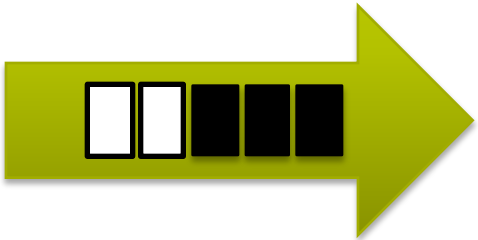


Actors and Channels

Implemented in **ActorX10** framework

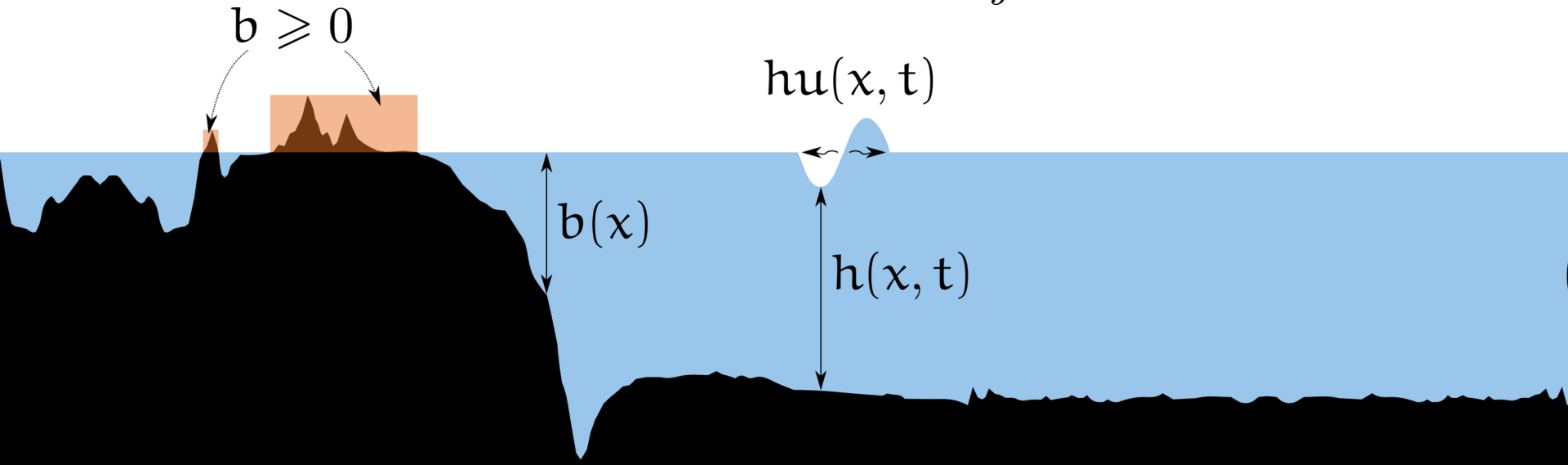
S. Roloff, A. Pöppl, T. Schwarzer, S. Wildermann, M. Bader, M. Glaß, F. Hannig, and J. Teich. **ActorX10: An actor library for X10**. In *Proceedings of the Sixth ACM SIGPLAN X10 Workshop (X10)*. ACM, 2016.





The Shallow Water Equations

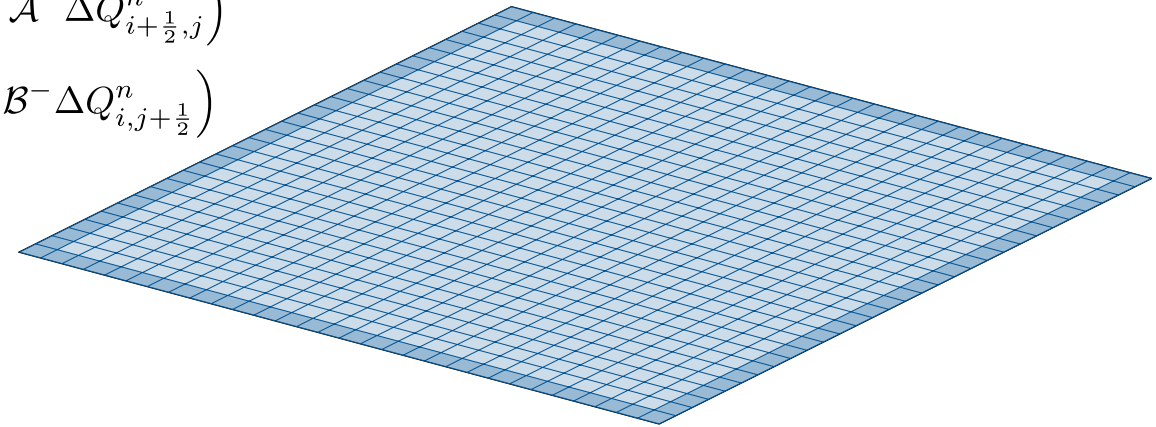
$$\begin{bmatrix} h \\ hu \\ hv \end{bmatrix}_t + \begin{bmatrix} hu \\ hu^2 + \frac{1}{2}gh^2 \\ huv \end{bmatrix}_x + \begin{bmatrix} hv \\ huv \\ hv^2 + \frac{1}{2}gh^2 \end{bmatrix}_y = S(t, x, y)$$



Discretization

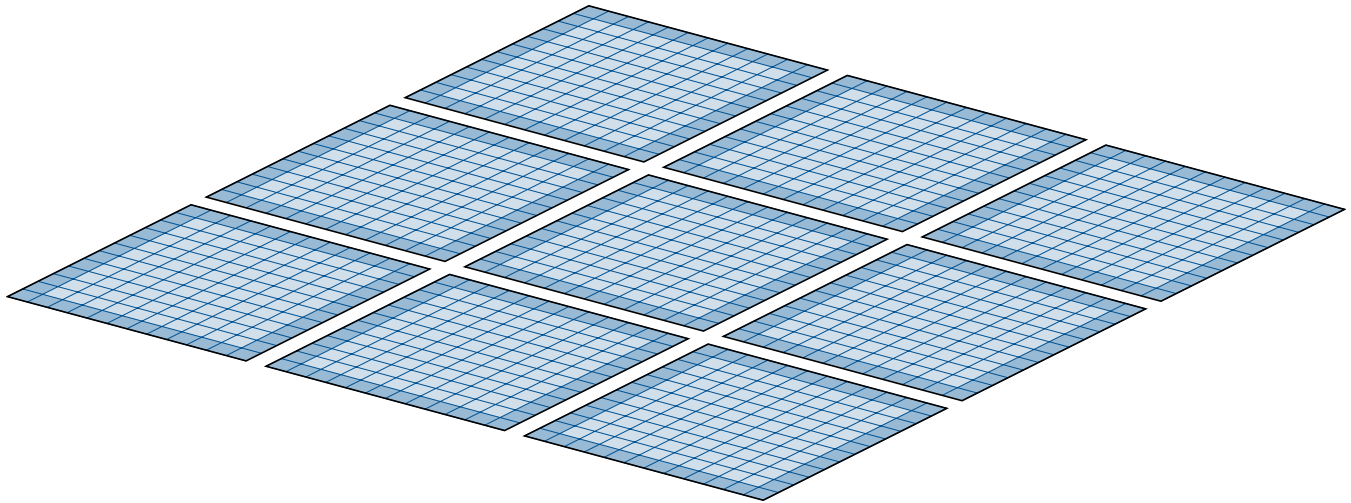
- Continuous simulation domain is discretized onto regular, cartesian grid
- Numerical approach based on LeVeque (R. J. LeVeque, D. L. George, and M. J. Berger. **Tsunami modelling with adaptively refined finite volume methods**. *Acta Numerica*, 20:211–289, 2011)
- Update Scheme:

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



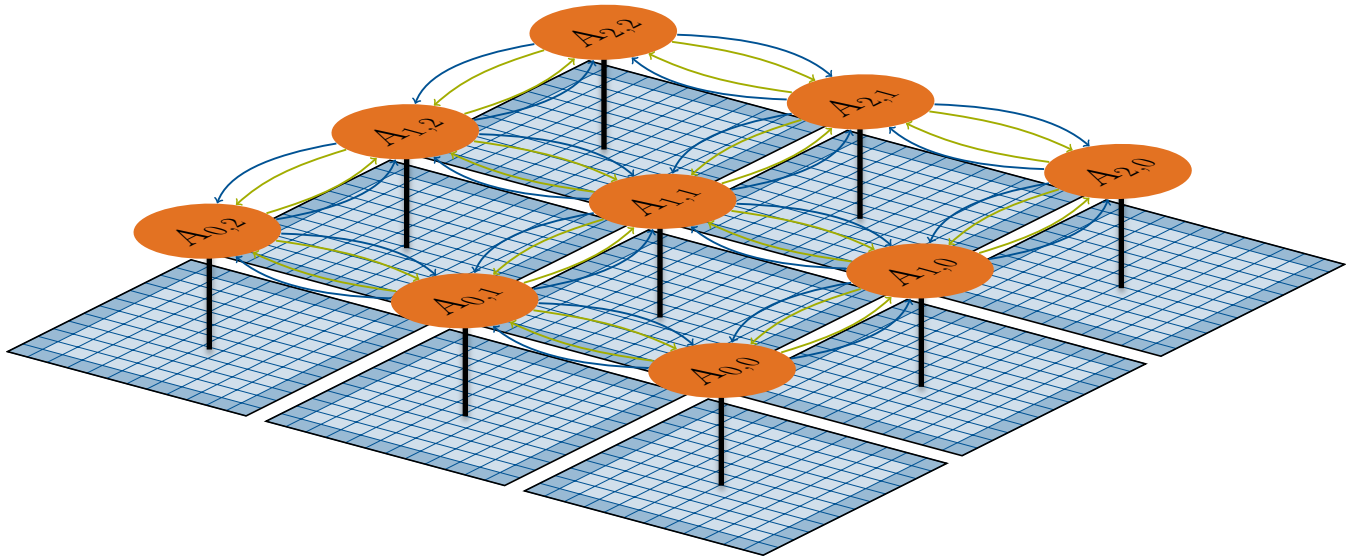
Distribution

Subdivision into rectangular, equally-sized patches with Halo regions



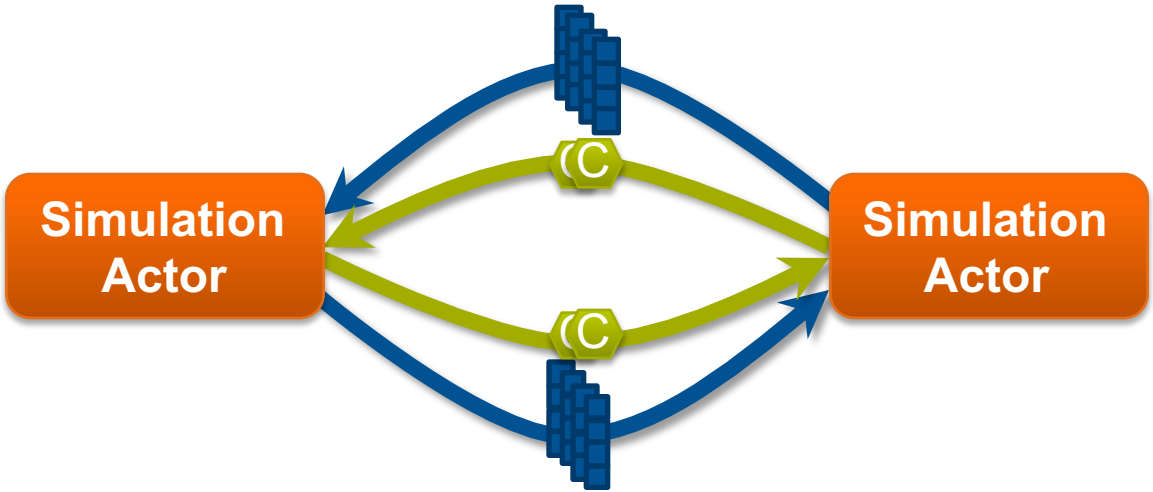
Actor-Based Modelling

- One actor per patch
- Actors connected with direct neighbors



Actor-Based Modelling

Four channels between each actor, one for Simulation Data and one for Control Data in each direction



Actor-Based Modelling – Local Coordination

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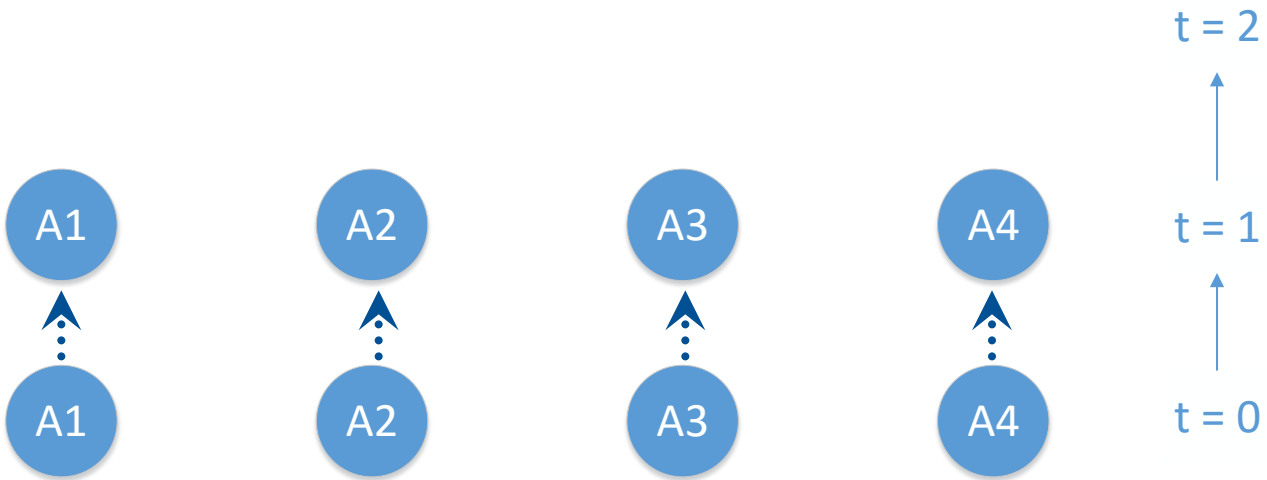

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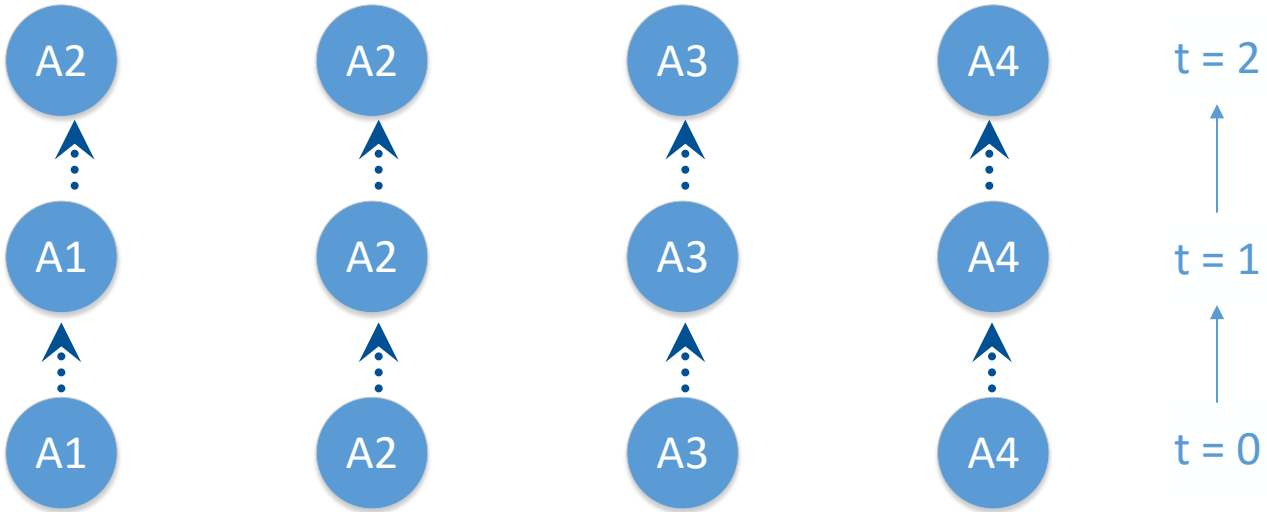
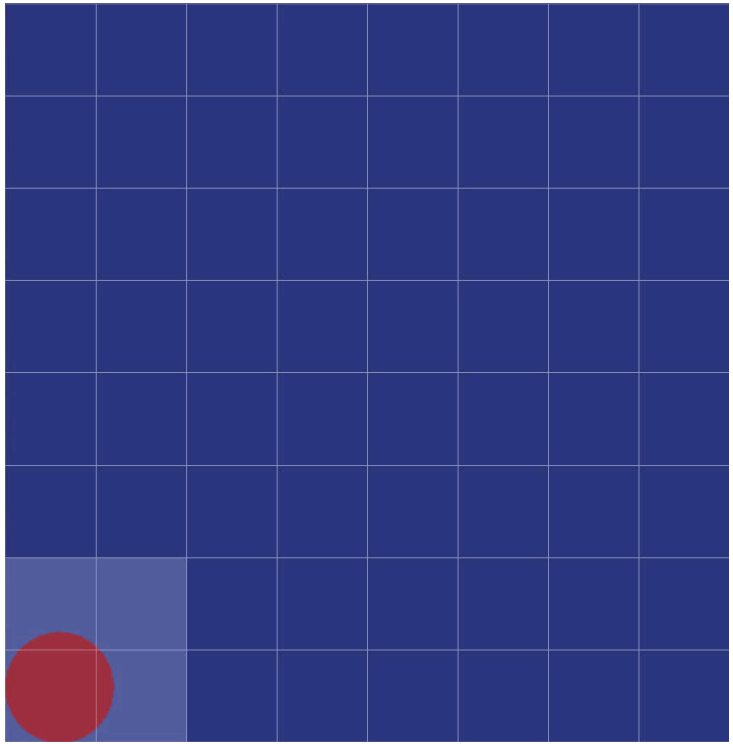


Actor-Based Modelling – Lazy Activation

No initial activity in large parts of the simulation domain

- “Lake-at-Rest” is being computed
- Unnecessary use of resources

➢ Just don’t do it!



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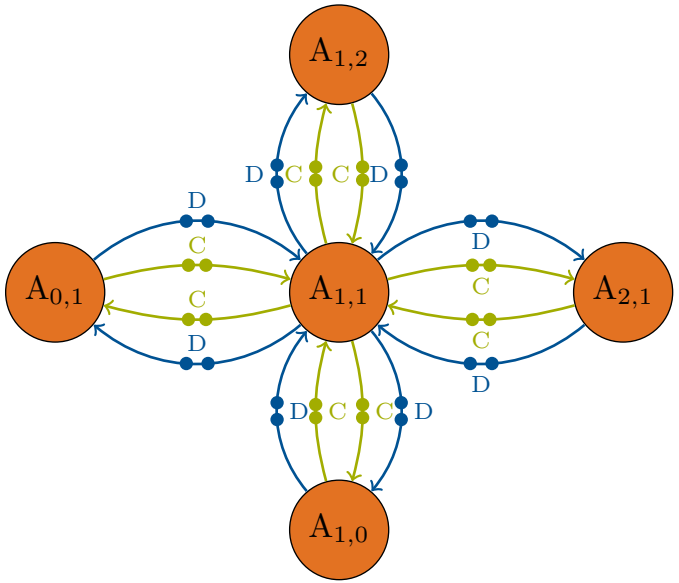
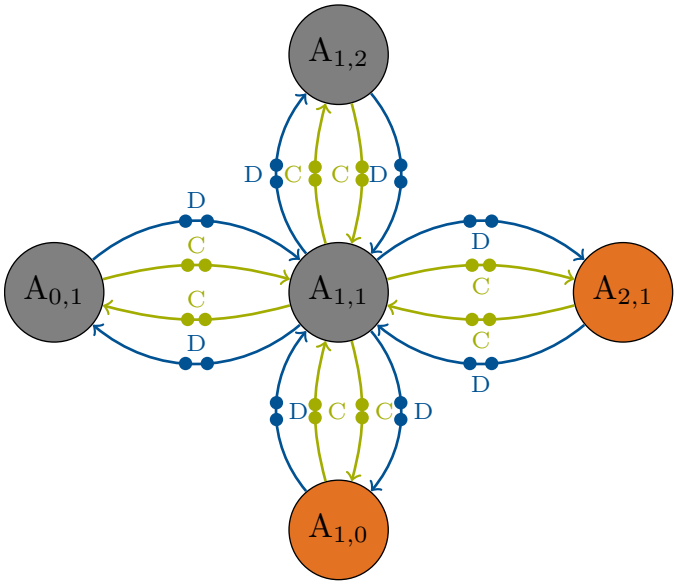


Actor-Based Modelling – Lazy Activation

Example: $A_{1,0}$ and $A_{2,1}$ initially active, rest inactive.

- $A_{1,0}$ just generated first non-zero update to be sent to $A_{1,1}$
- Messages from $A_{1,0}$ to $A_{1,1}$
  - Control Message: “Activate.”
  - Data: Containing the non-zero ghost layer
- $A_{1,1}$ is triggered, sets itself to active
  - Control messages to all neighbors: “I have been activated and will send and receive updates now.”
  - Other active neighbors ($A_{2,1}$) will depend on updates from and send updates to $A_{1,1}$
  - Inactive neighbors are aware of activity of $A_{1,1}$



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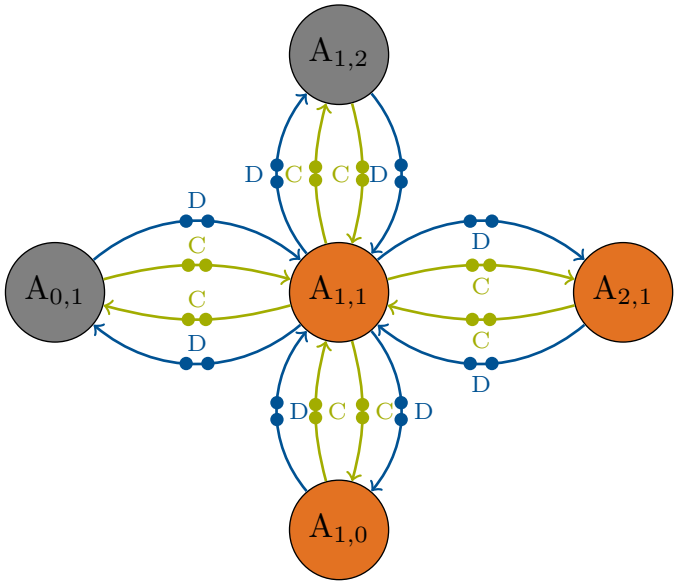
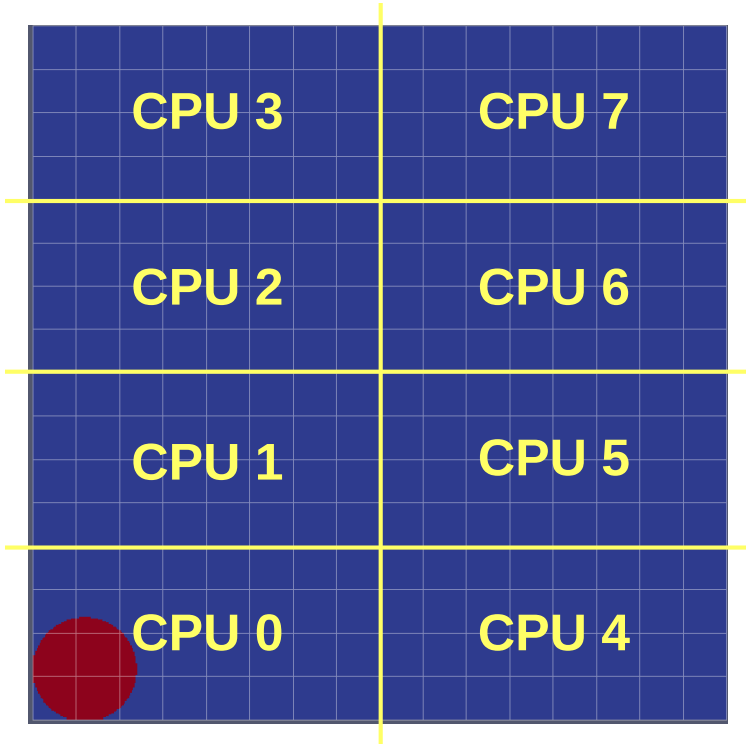


Lazy Activation – Evaluation

- Radial Dam break with initial disturbance in lower left corner of the simulation domain
- 8192×8192 grid cells, divided into patches of size 512×512
- Cluster with 28 dual-socket nodes
  - Intel Xeon E5-2670 CPUs (332.8GFlop/s SP per node)
  - 128GB memory per node (Stream Triad: 108.9GB/s per node)
  - Infiniband QDR interconnect
- 4 patches per CPU core
  - 4 nodes with 2 sockets, 8-core CPUs
  - One X10 Place per socket



Lazy Activation – Evaluation

Evaluation Criterion: CPU time

Without lazy activation:
- Simulation time: 1433s
- CPU time: 12264s (3.41h)

With lazy activation:
- Simulation time: 1203s
- CPU time: 6741s (1.87h)

Simulation-dependent!

Conclusion and Future Work

- Actor-based solver for the shallow water equations
- Initial demonstration of flexibility gained through actor-based modelling
- Expansion of SWE-X10 towards
  - Block-adaptive mesh refinement
  - Local time stepping scheme
  - Load-balancing
- Extend code towards heterogeneous environments
  - Explore resource combinations
  - Find optimal allocations for certain scenarios

Thank You for Your Attention

Acknowledgements

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