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An Introduction to Wasatch

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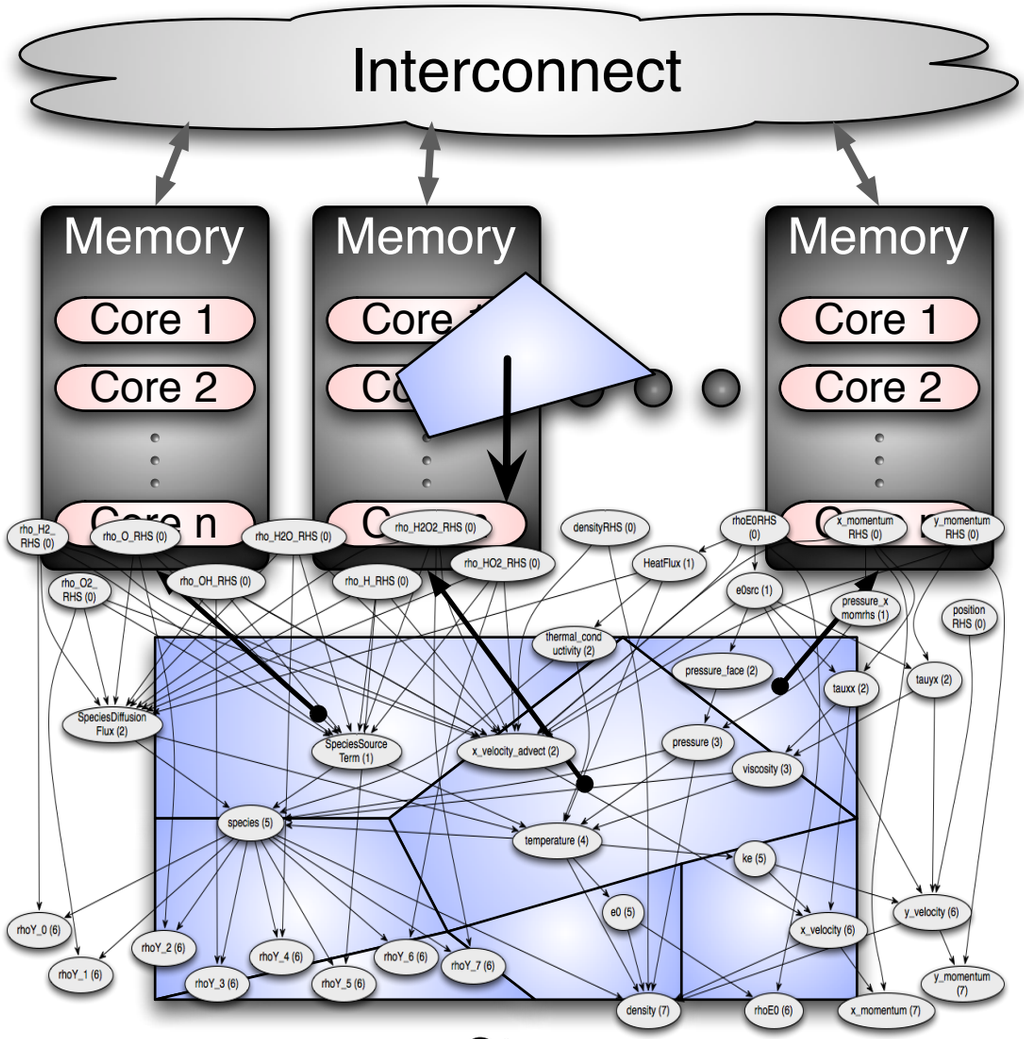
Levels of Parallelism

- Domain decomposition (data parallel)
  - subdivide the physical domain into patches/ worksets & distribute across nodes/cores
- Algorithm decomposition (task parallel)
  - Identify tasks on a patch/workset that can be evaluated concurrently
- Fine-grained (vector) parallelism
  - Perform operations independently on various grid points
  - Field operations (mesh loops)
  - Discrete calculus operations (sparse matvec)
  - Some can be hidden from the user
    - expression templates to collect series of mesh operations and dispatch them optimally in parallel...



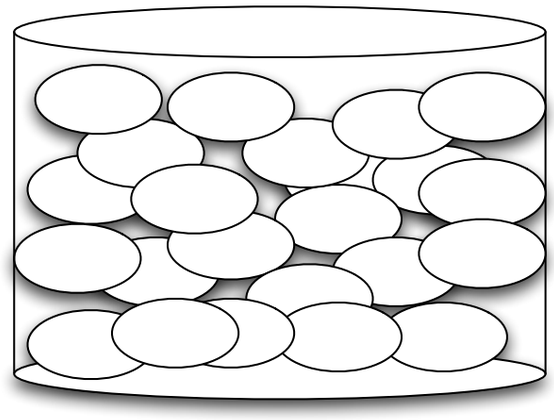
$$\nabla^2\phi + s$$

One expression
(calculated on a patch/workset)

Expression Library

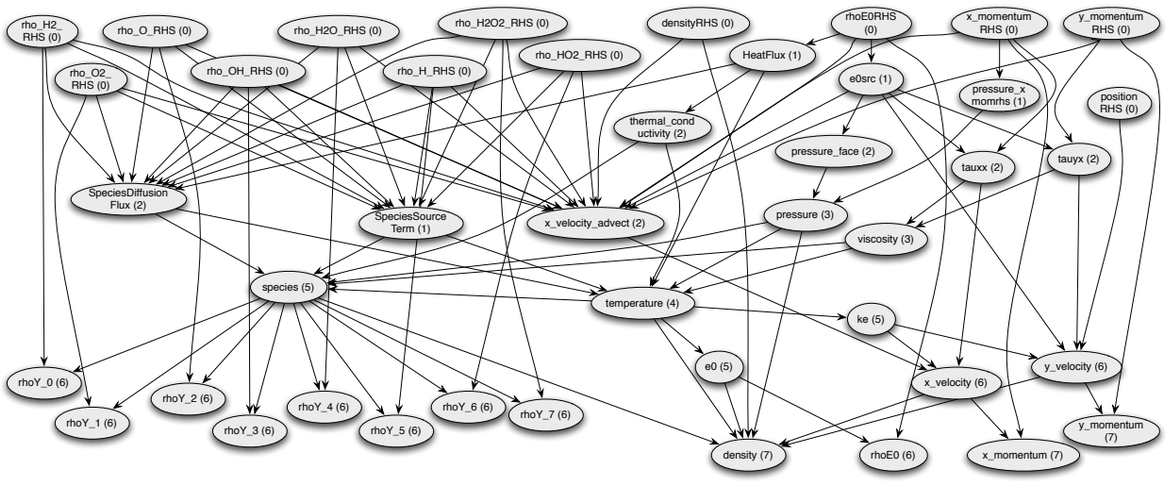
(Algorithm Decomposition)

- Uses graph theory to automatically construct algorithms from dependencies among expressions
- Thread-based parallelism via algorithm decomposition (exposing concurrency in the algorithm)
- Key classes:
  - *Expression*: a node in a graph. Calculates one or more fields of the same type.
  - *ExpressionTree*: a graph containing one or more nodes. Automatically constructed given a set of root nodes.
- Expressions are where the bulk of user code in Wasatch will be written.



Create individual expressions and register them.

Request calculation of any # of fields. The graph to accomplish this is automatically created!



https://software.crsim.utah.edu/trac/wiki/ExprLib/GettingStarted

SpatialOps Libray

(type-safe vectorized operations)

- Supports field & stencil operations directly - no more loops!
- Strongly typed fields ensure valid operations at compile time.
- Allows a variety of implementations to be tried without modifying application code.

an excerpt from:
`Wasatch/Expressions/DiffusiveFlux.h`

```
typedef typename GradT::DestFieldType FluxT;
typedef typename GradT::SrcFieldType  ScalarT;

const GradT* gradOp_;
const ScalarT* phi_;
const FluxT* coef_;
```

The "work" part of an expression to calculate a diffusive flux.

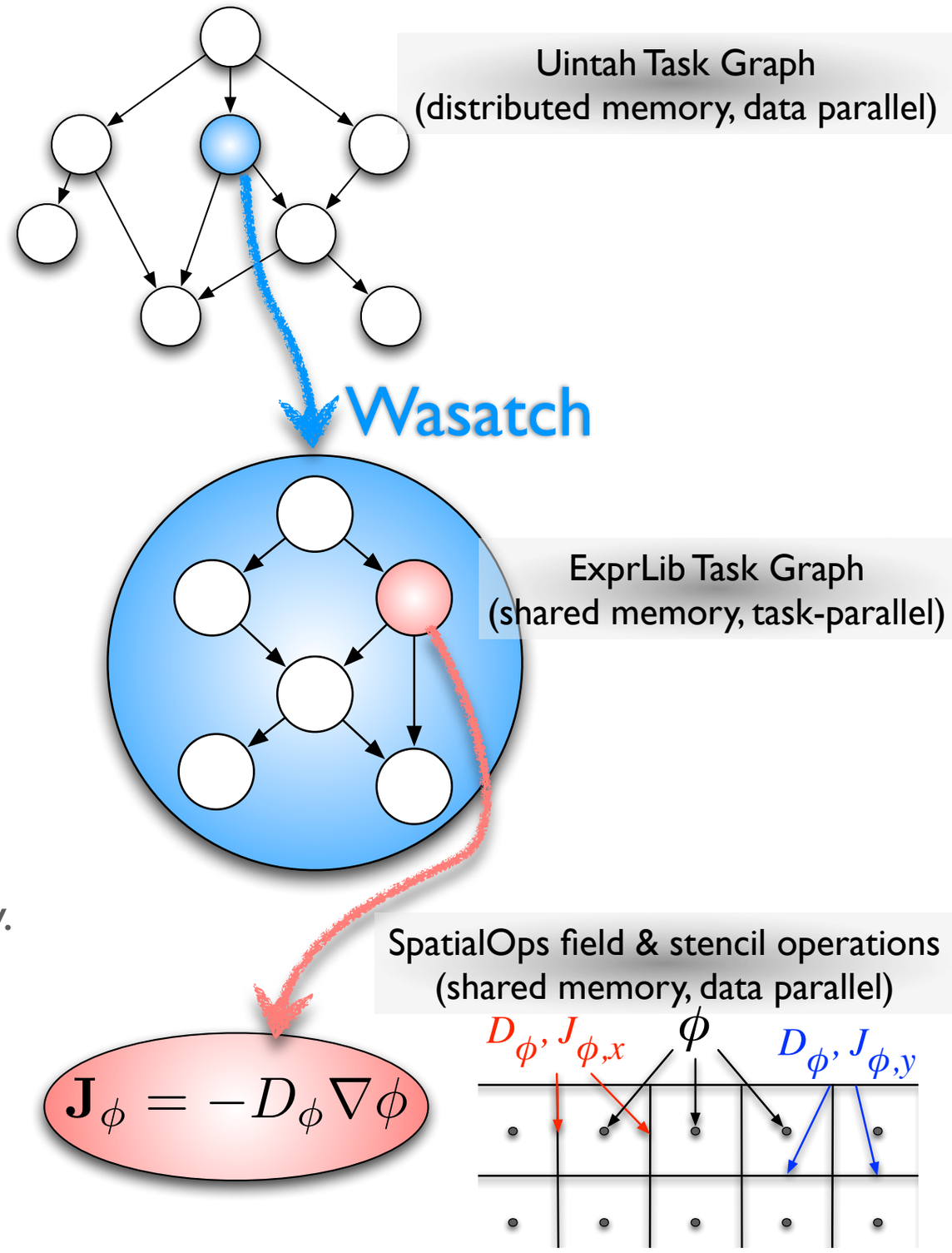
```
template< typename GradT >
void
DiffusiveFlux<GradT>::evaluate()
{
  FluxT& result = this->value();

  gradOp_->apply_to_field( *phi_, result ); // J = grad(phi)
  result <<= -result * (*coef_);            // J = -gamma * grad(phi)
}
```

https://software.crsim.utah.edu/trac/wiki/SpatialOps

Why Wasatch?

- Concept: interface the Expression and SpatialOps libraries with Uintah.
  - Expression Library provides a simple way of handling complexity in code and also gives thread parallelism.
  - SpatialOps library provides compact ways of dealing with discretization.
  - Uintah gives MPI parallelism
- Wasatch:
  - Parses input and turns this into transport equations, expressions, etc.
  - Generates expression graph(s) and exposes them to Uintah as task(s)
  - Allows code to be developed in a Uintah-agnostic way.
- Result: rapid development of robust code.
  - heavy usage of C++ templates.

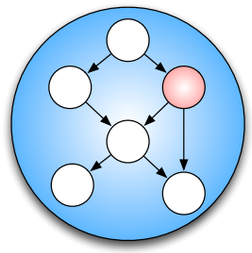


A Few Key Uintah Concepts

- Patch: a sub-region in space where we are solving PDEs
- Task: some work to do on a patch to calculate the value of one or more fields.
- A few required tasks
  - Initialization
  - Setting the value of the time step
  - Advance solution over time step increment.

Key Wasatch Abstractions

"Core" Wasatch Developers will need to understand these.



- *TaskInterface*: wraps ExpressionTree objects as Uintah tasks
  - This happens largely behind the scenes.
  - All field requirements are gathered from the ExpressionTree and advertised to Uintah, and the Uintah task is automatically created.
- *TransportEquation*: a class to support formation of PDE solvers
  - Register expressions required to set initial conditions for this equation.
  - Register expressions required to calculate the RHS of this equation.
  - Set BCs for this equation.
- *TimeStepper*: a class to support advancing PDEs in time (Runge-Kutta)
  - creates an ExpressionTree (graph) and wraps it to expose it to Uintah as a (heavy-weight) Task.
    - Plug in an expression to calculate the RHS of an equation and it does the rest!
  - Easily add new transport equations to the TimeStepper, resulting in automatic generation of new algorithms with appropriate coupling/ordering.
  - When TransportEquations are parsed from the input file, an "adaptor" is created that plugs them into a TimeStepper.

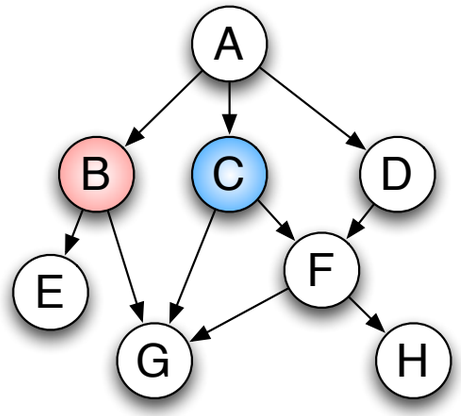
Wasatch Skeleton

- Wasatch::problemSetup
  - Registers the material(s) for use in solving this problem.
  - Creates any expressions triggered directly from the input file. These are typically associated with calculating initial conditions.
  - Sets up property evaluation expressions (may be required by any transport equation).
  - Creates a time integrator for solving the set of PDEs.
  - Parses and constructs transport equations. This, in turn, registers relevant expressions required to solve each transport equation and also plugs them into the time integrator.
- Wasatch::scheduleInitialize
  - Set up spatial operators associated with each patch.
  - Set up the ExpressionTree (and then the Uintah::Task(s)) that will set the initial conditions.
- Wasatch::scheduleComputeStableTimestep
- Wasatch::scheduleTimeAdvance
  - Plug each transport equation that has been set up into the time stepper and generate the full ExpressionTree that will calculate the RHS for all of the equations.
  - Create the Uintah::Task(s) associated with the ExpressionTree to advance the solution for the PDE system forward one time step.

Graph/Algorithm Cleaving

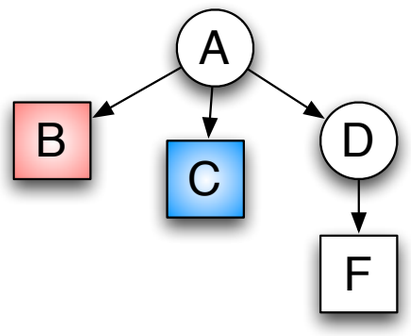
Programmer "tags" expressions that require ghost updates.
Graphs are automatically cleaved.

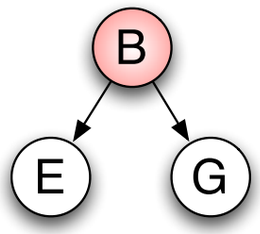
Original "full" graph
(translated into a Uintah Task):

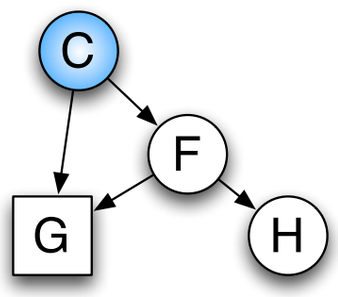


"B" and "C" require ghost updates prior to execution of "A"

Modified to three Uintah Tasks:







Order of execution:

1. "B" tree
2. "C" tree
3. "A" tree

Three separate graphs (Uintah Tasks).
Uintah manages ghost updates.