Parallel CFD with Regent

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The goal of this project was to explore various new parallel programming strategies that were designed for current and emerging computer architectures. One new strategy is Regent, a research programming language which extracts implicit dataflow parallelism from code written with sequential semantics. Regent is designed to exploit both shared and distributed memory architectures. Here, one- and two-dimensional Godunov-type finite-volume methods were implemented to assess Regent's parallel scalability and ease of use.

Introduction to Regent

Regent is a high-productivity programming language for parallel computing that is based on the idea of **logical regions**.

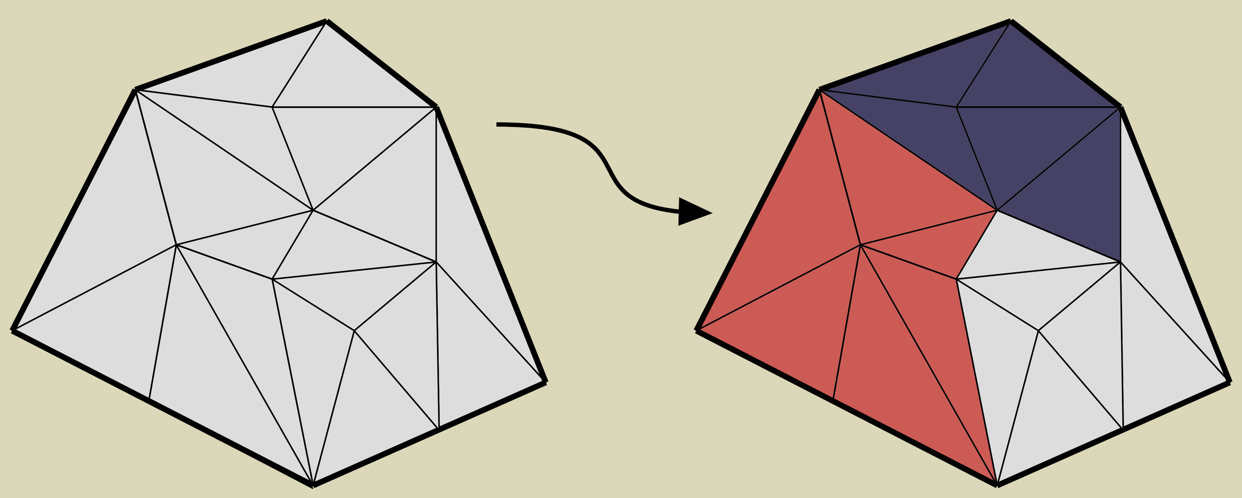
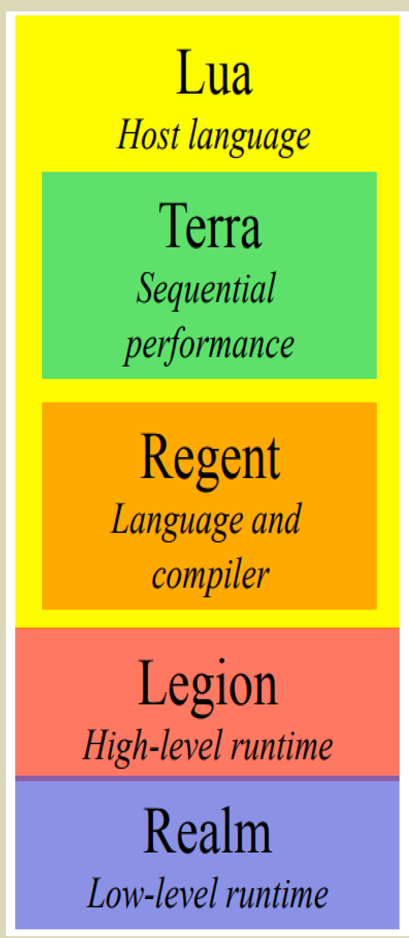


Figure: Region decomposed into different colors.

Design of Regent

- Based on the programming model of Legion
- The runtime handles parallel, asynchronous task scheduling
- Embeded in Lua (a Python-like scripting language)
- Has access to Terra for fast computation



Programming in Regent

- Programs appear to be written sequentially
- Regions of data are defined and decomposed
- Parallelism is extracted automatically from task-region dependency

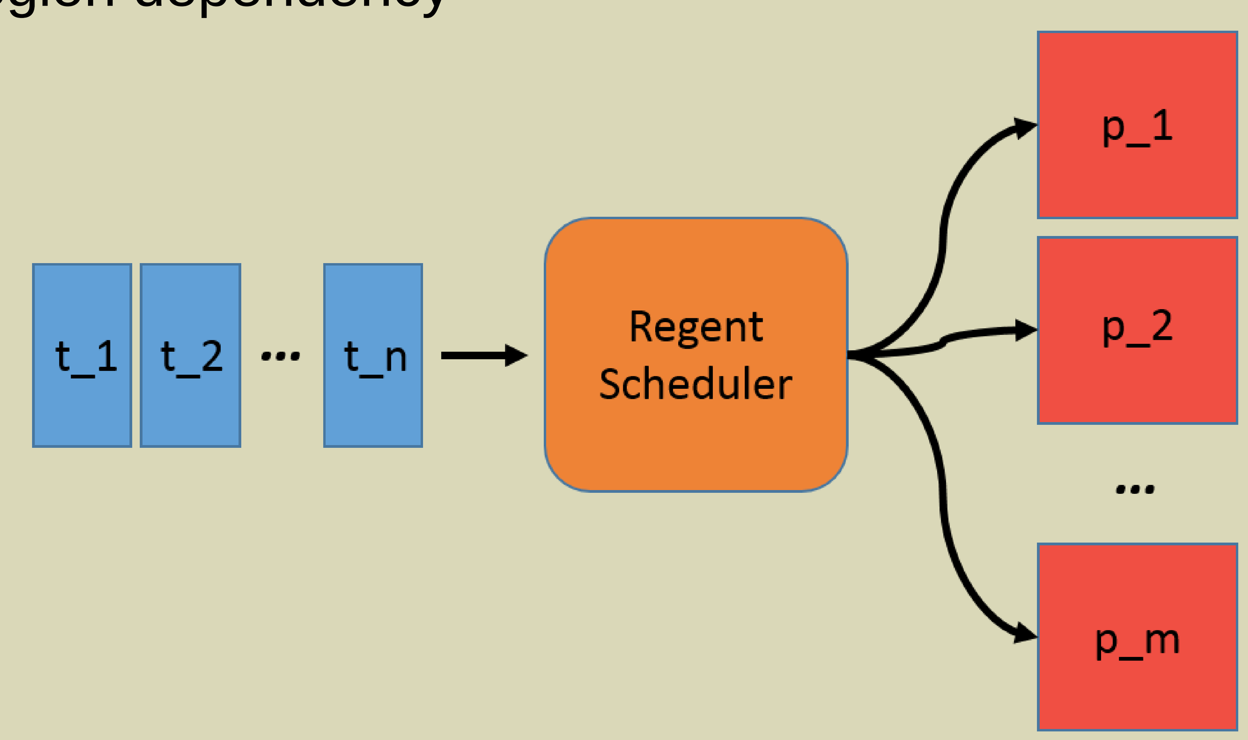


Figure: Regent runtime parallel asynchronous task scheduling.

2D Euler Equations

We solve numerically the 2D Euler equations for gas dynamics:

$$\frac{\partial U}{\partial t} + \nabla \cdot \vec{F} = 0$$

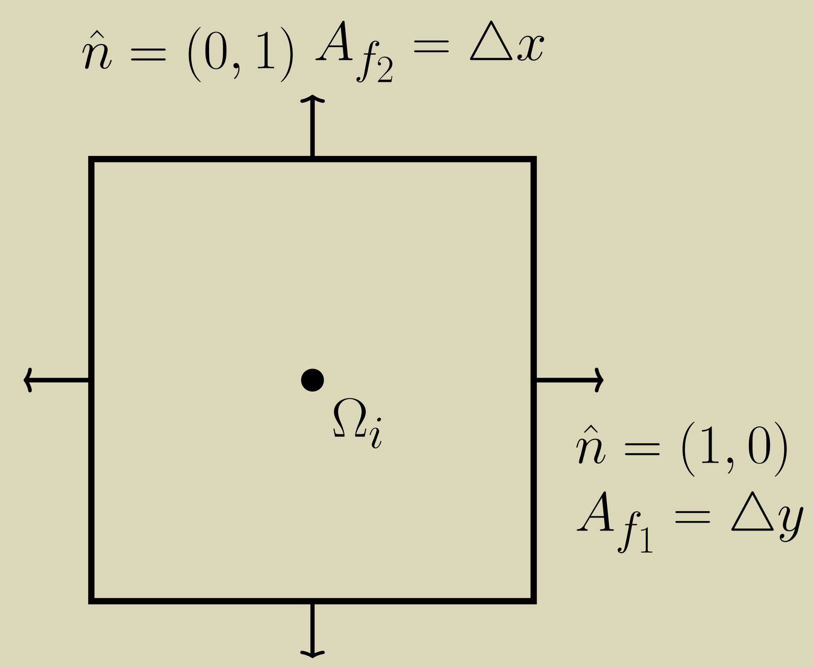
Where the vector U and tensor F are given by

$$U = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ \rho e_t \end{bmatrix} \quad \vec{F} = \left[\begin{bmatrix} \rho u \\ \rho u^2 + p \\ \rho uv \\ \rho e_t u + up \end{bmatrix} \begin{bmatrix} \rho v \\ \rho uv \\ \rho v^2 + p \\ \rho e_t v_+ vp \end{bmatrix} \right]$$

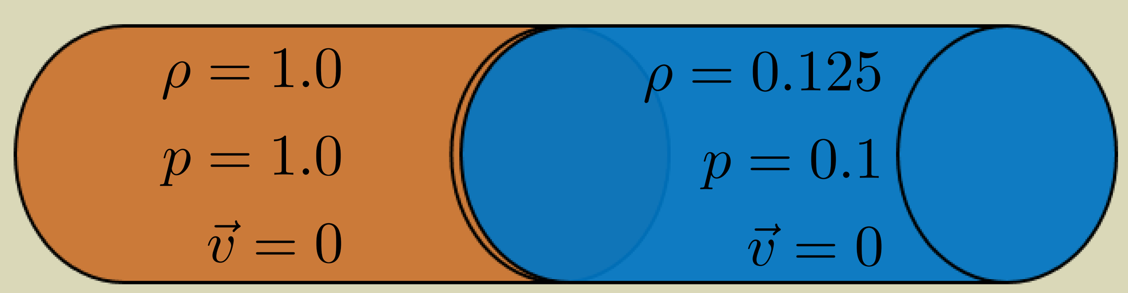
The Euler equations are discretized with Forward Euler in time and the **finite volume method** in space. Integrating the above equations over each control volume gives the following:

$$\frac{\partial \bar{U}}{\partial t} + \frac{1}{V_i} \sum_{f_j \in \Omega_i} (\bar{F} \cdot \vec{n}) = 0$$

Face fluxes are calculated using the Rusanov approximate flux function, and gradient limiters are employed to result in a stable, second order accurate scheme.



Sod Shock Tube Initial Conditions



Sedov Blast-type Problems

- A high specific internal energy is placed into a single computational cell, which translates into a high pressure:

$$p_0 = \frac{(\gamma - 1)\epsilon_0 \rho}{V}$$

Simulation Results

We simulated spatially 1st and 2nd order discretizations of the 1D and 2D Euler equations.

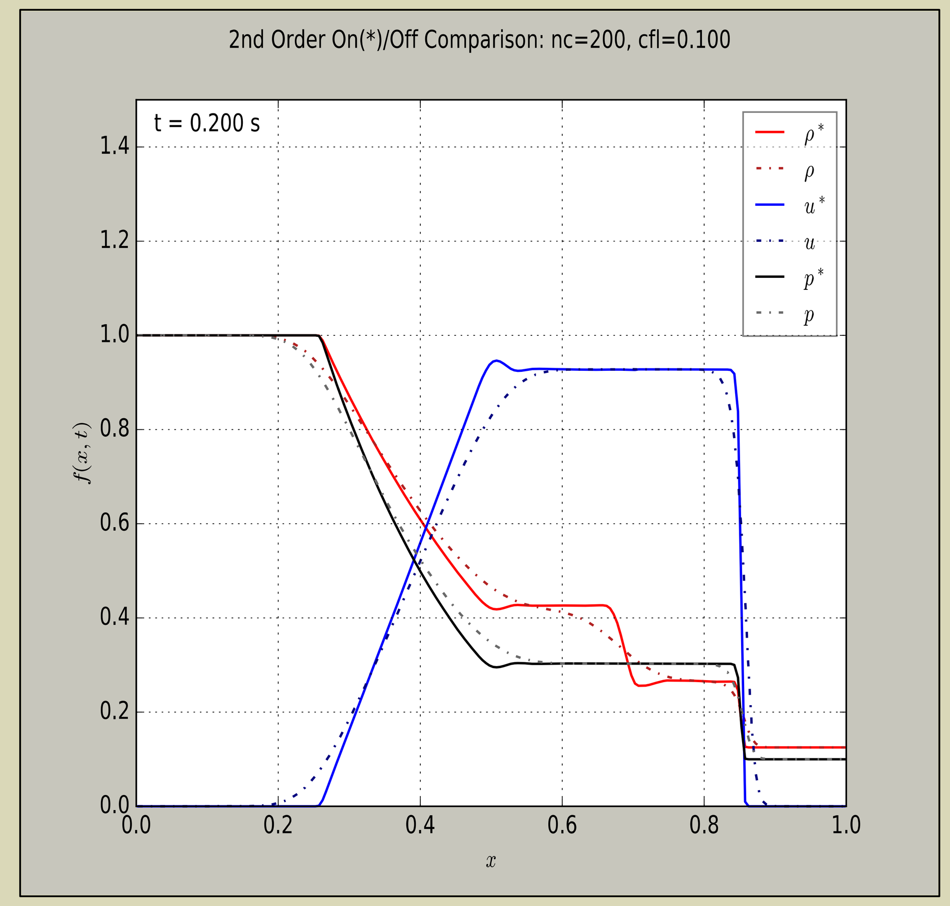


Figure: 2nd order results for the 1D Sod Shock Tube problem.

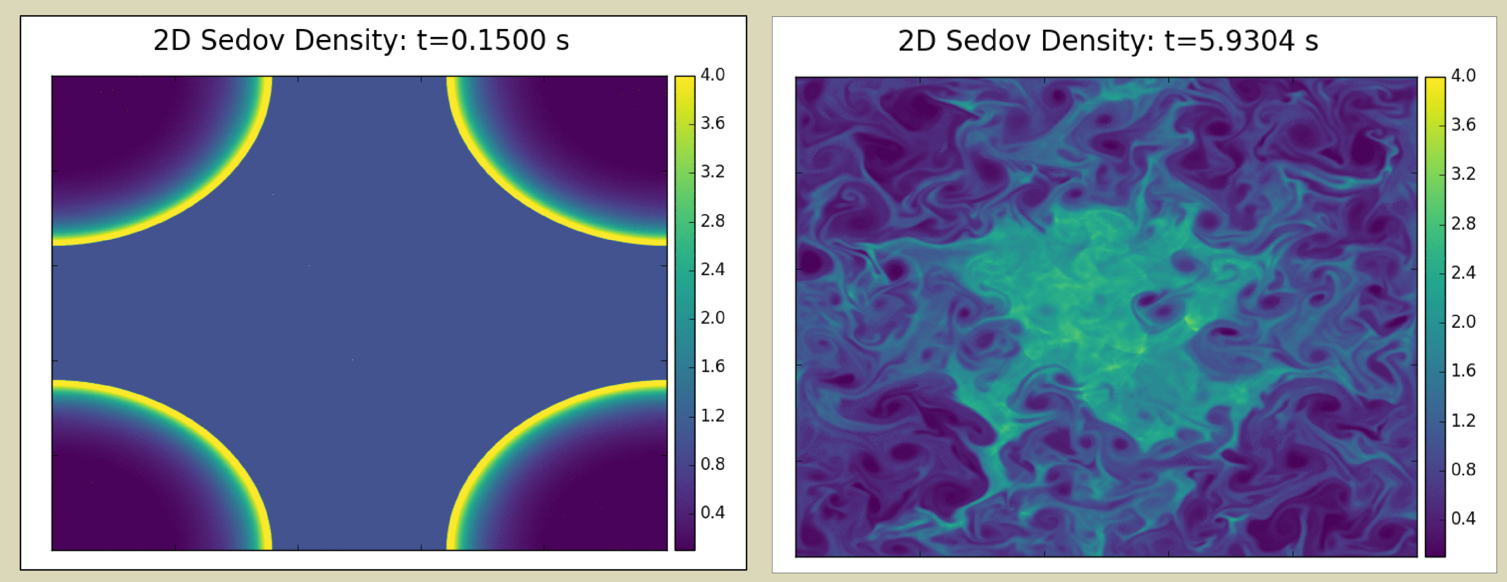
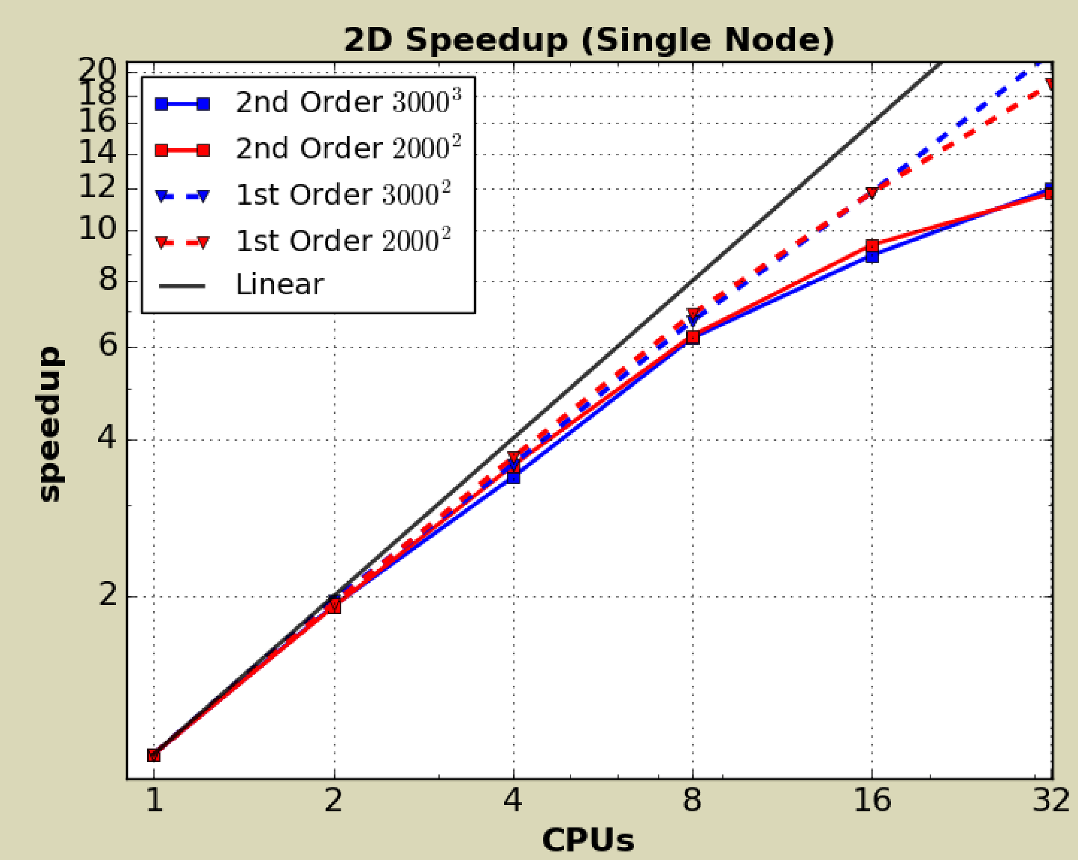


Figure: Time evolution of a multi-blast wave problem.

Strong Scaling Results



Conclusions

- Regent scales well on a single node, although large problem sizes are required.
- Regent provides relatively low-cost parallelism.