Mini introduction to Rust

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What is Rust ?

Rust ("rouille" in French) is a programming language created in 2009, using only old (rusty), but robust ideas. Some features, compared to C, C++ and Python, are:

- no memory leak or segfault, generally guaranteed at compile time;
- no race conditions, generally guaranteed at compile time;
- strict ownership system, fast executable;
- Cargo, which replaces cmake, doxygen, ctest, anaconda, etc. in a single utility.
- "most loved programming language" in the Stack Overflow Developer Survey every year since 2016.

Installing Rust

Rust install with the command

```
curl -$\,$-proto '=https' -$\,$-tlsv1.2 -sSf https://sh.rustup.rs | sh
```

Create a new project

```
cargo new bonjour; cd bonjour
```

Compilation and execution

```
cargo run
```

- Cargo is the package and compilation manager of Rust. The compiler is rustc.
- The source code is in src. Here there is a single file main.rs.
- The file Cargo.toml is an important config file. It describes the list of external libs that will be automatically downloaded by Cargo.

Upwind transport solver

Transport equation at velocity $c < 0$, with unknown $u(x,t)$, $x \in \mathbb{R}$, $t \in]0, T[$,

$$\frac{\partial u}{\partial t} + c\frac{\partial u}{\partial x} = 0, \quad u(x,0) = u^0(x).$$

The exact solution is

$$u(x,t) = u^0(x - ct).$$

Upwind finite difference scheme,

$$u_i^n \simeq u(x_i, t_n), \quad x_i = i\Delta x, \quad t_n = n\Delta t,$$

$$\frac{u_i^{n+1} - u_i^n}{\Delta t} + c\frac{u_{i+1}^n - u_i^n}{\Delta x} = 0, \quad u_i^0 = u^0(x_i).$$

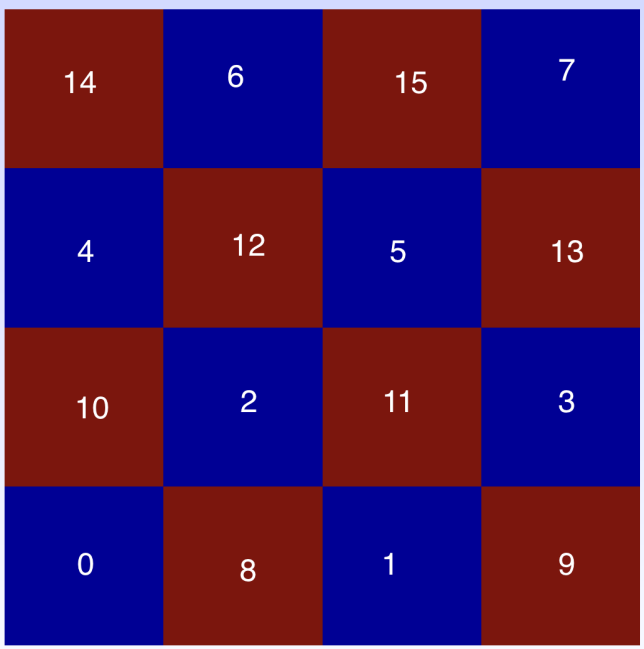
We store u_i^n at time n in the array `un[i]`, `0≤i<nx+1`.

Rust code

- Variables are immutable by default.
- An object passed to a function cannot be used anymore: use reference instead.
- Only one mutable reference or several immutable references allowed at a time.
- The compiler messages are generally helpful. Cargo clippy gives hints about what can be improved.
- It is recommended to use iterators for efficient and robust programs. Use of two different arrays for storing u_i^n and u_i^{n+1}.
- Automatic parallelism with the rayon library, without race condition.

A more complex example: lattice Boltzmann solver

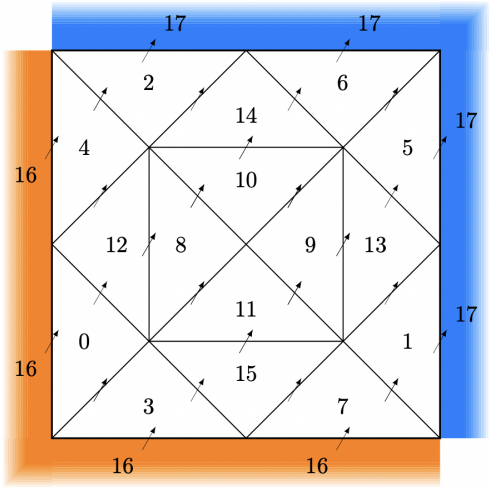
- Resolution of a PDE on a regular mesh split into "boxes". The computations on red boxes depend only on blue boxes and vice versa.
- Sort the array of boxes by color. Then "split at mut" the array: separate access to the blue and red boxes.
- Automatic parallelization, without race condition.

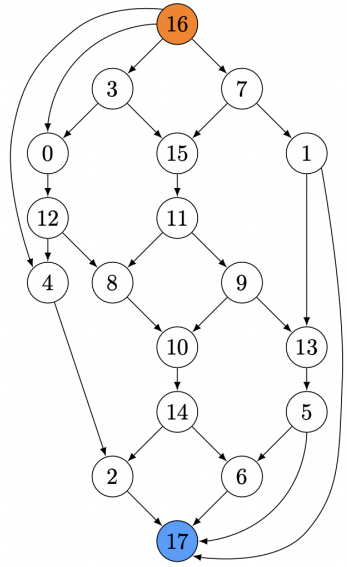


$$\left[\begin{array}{ll} 0 & \\ \vdots & \text{mutable} \\ 7 & \\ - & \leftarrow \text{split at mut here} \\ 8 & \\ \vdots & \text{immutable} \\ 15 & \end{array}\right]$$

Upwind scheme in 2D or 3D

Dependency graph of the computations





- The solution can be explicitly computed by following a topological ordering of a Direct Acyclic Graph (DAG), e.g. 3, 7, 0, 15, 1, etc.
- In addition there is parallelism: (3,7) can be computed in parallel, then (0,15,1) can be computed in parallel, etc.
- Low storage: the solution can be replaced in memory during the computations.

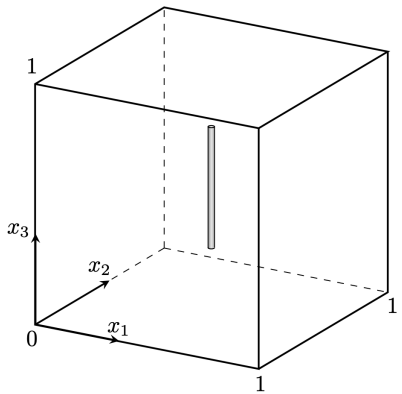
Rust implementation

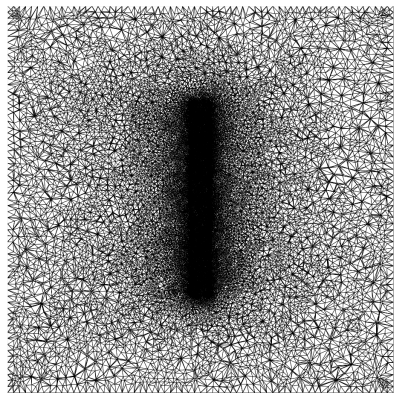
We have implemented the upwind algorithm in Rust with the "split at mut" trick. More details in [GHMD21].

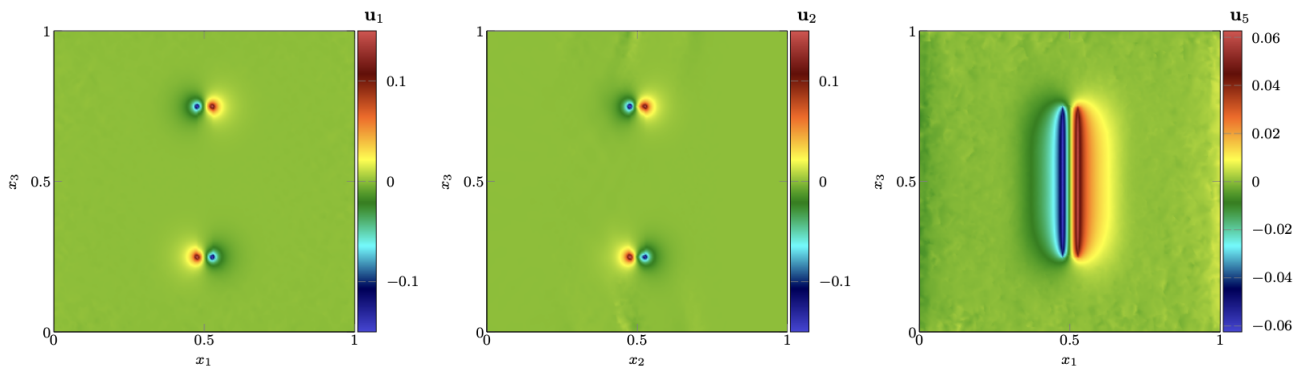
			Error e_r		CPU (s)	
Method	CFL β	Δt	$\nu = 2$	$\nu = 5$	1 thread	24 threads
RK3DG	0.37	0.00009	0.00070	0.01238	4,607.95	785.28
D3Q4P	0.37	0.00009	0.00103	0.01467	1,524.45	234.48
RK3DG	0.93	0.00023	0.00070	0.01238	2,189.76	384.79
D3Q4P	0.93	0.00023	0.00103	0.01467	613.44	90.84
RK3DG	1.85	0.00046	0.00070	0.01238	1,121.96	212.60
D3Q4P	1.85	0.00046	0.00103	0.01467	304.41	45.14
D3Q4P	3.70	0.00091	0.00103	0.01468	153.09	22.40
D3Q4P	9.25	0.00228	0.00104	0.01479	61.60	8.96
D3Q4P	18.50	0.00456	0.00115	0.01619	30.76	4.53
D3Q4P	37.00	0.00912	0.00210	0.02992	15.34	2.46
D3Q4P	92.50	0.02281	0.01107	0.16589	6.17	0.92
D3Q4P	185.00	0.04562	0.04509	0.40344	3.10	0.48

Application to an electromagnetic solver

- The transport solver is the building block of our CFL-less scheme for conservation laws.
- Unstructured mesh of the unit cube made of large and small cells. A small electric wire at the middle of the mesh.
- Resolution of the Maxwell equations.







(a) Solution at time $t = 0.75$; left panel: $E_1\big|_{x_2=0.5}$; middle panel: $E_2\big|_{x_1=0.5}$; right panel: $H_2\big|_{x_2=0.5}$.

Conclusion

- Practical use of Rust in a scientific computing context.
- Less bugs, which was the objective.
- Automatic, fast and robust parallelism.
- Friendly environment.
- Many other features, which we have not yet explored.

Bibliography I

Pierre Gerhard, Philippe Helluy, and Victor Michel-Dansac.
CFL-less Discontinuous Galerkin solver.
https://hal.archives-ouvertes.fr/hal-03218086, May 2021.