Mini introduction to Rust

Philippe Helluy

IRMA Strasbourg, Inria Tonus

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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 [JJKD17];
- 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.

Tutorial objectives

If time permits:

- Simple Rust programs manipulations.
- Iterators and automatic parallelism.
- A very simple example of struct with generics and traits.
- A C wrapper for using OpenCL in Rust.
- An example of macro.
- Documentation and testing.

Not seen today, but important:

- Rust pointers: Box, Rc, RefCell, Arc.
- Thread safety.
- Standard library.

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.

1D solver

Wave equation with unknown $u(x,t)$, $x \in \mathbb{R}$, $t \in]0,T[$,

$$\frac{\partial^2 u}{\partial t^2} - \frac{\partial^2 u}{\partial x^2} = 0, \quad u(x,0) = u^0(x), \quad \frac{\partial u}{\partial t}(x,0) = 0.$$

Leapfrog ("saute-mouton") scheme

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

$$u_i^{n+1} = -u_i^{n-1} + 2(1-\beta^2)u_i^n + \beta^2\left(u_{i-1}^n + u_{i+1}^n\right), \qquad (1)$$

where $\beta = \Delta t/\Delta x$.

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 three different arrays for storing u_i^{n-1}, u_i^n and u_i^{n+1}.
- Automatic parallelism with the rayon library, without race condition.
- Source code at `https://github.com/phelluy/tutorust`

First transformation

- Improve the solver thanks to cargo clippy.
- Change all loops with iterators.
- Make the solver parallel thanks to rayon.
- Try to change some parts of the program.
- Simple lines can be tested at https://play.rust-lang.org/.

2D solver

We know consider the 2D case on a square. In 2D the leapfrog scheme reads:

$$p_{i,j}^{n+1} = -p_{i,j}^{n-1} + 2(1-2\beta^2)p_{i,j}^{n} + \beta^2\left(p_{i-1,j}^{n} + p_{i+1,j}^{n}p_{i,j-1}^{n} + p_{i,j+1}^{n}\right). \quad (2)$$

Boundary conditions:

$$p_{0,j}^{n} = p_{1,j}^{n}. \quad (3)$$

$$p_{N+1,j}^{n} = p_{N,j}^{n}. \quad (4)$$

$$p_{i,0}^{n} = p_{i,1}^{n}. \quad (5)$$

$$p_{i,N+1}^{n} = p_{i,N}^{n}. \quad (6)$$

Code description

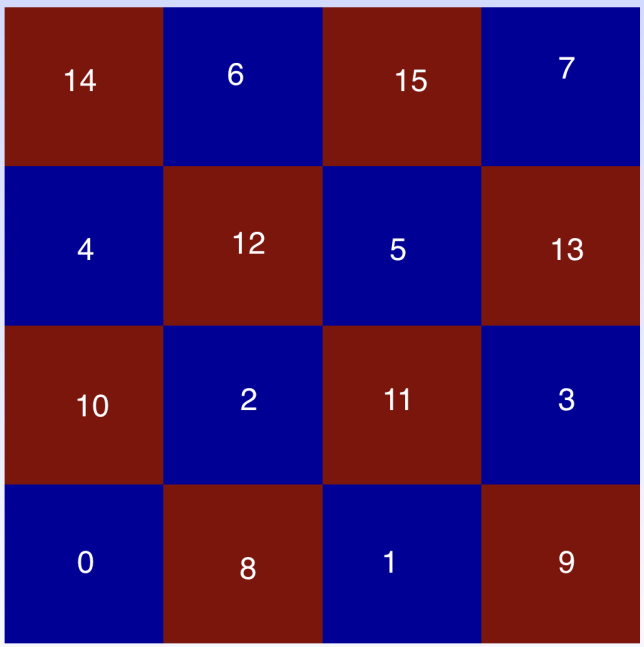
- We define a 2D array struct.
- Overloading of the [][] operator for immutable or mutable access.
- template <T>.
- 2D plot with Python.

OpenCL wrapper in Rust

- C bindings.
- Unsafe code.
- Memory management.
- One example of macro.
- Doc and testing with Cargo.
- Application to the wave equation on GPU.
- Source code at `https://github.com/phelluy/minicl`

A more complex example: lattice Boltzmann solver

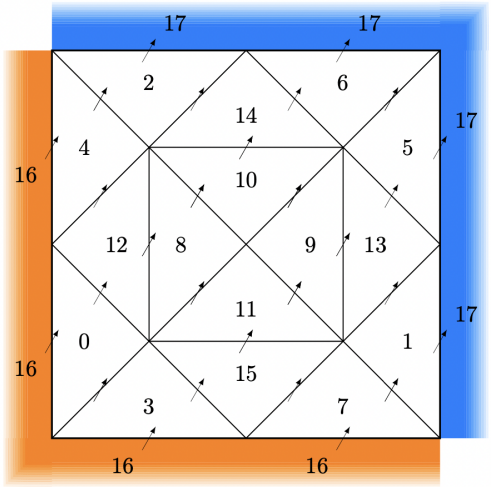
- Resolution of a PDE on a regular mesh split into "boxes". The computations on red boxes depend only on blue boxes and vice versa.
- Sort the array of boxes by color. Then "split at mut" the array: separate access to the blue and red boxes.
- Automatic parallelization, without race condition.

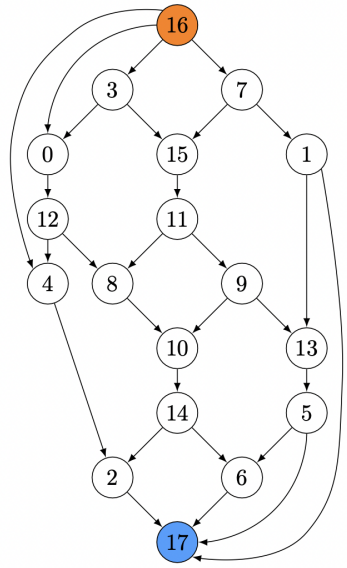


$$\left[\begin{array}{ll} 0 & \\ \vdots & \text{mutable} \\ 7 & \\ - & \leftarrow \text{split at mut here} \\ 8 & \\ \vdots & \text{immutable} \\ 15 & \end{array}\right]$$

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.

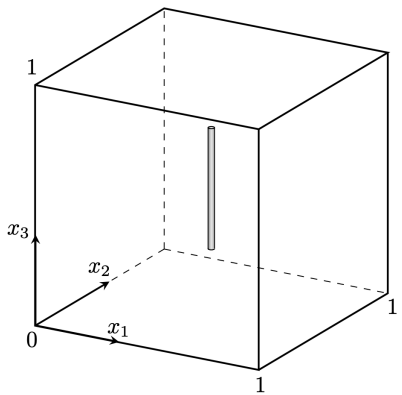
Rust implementation

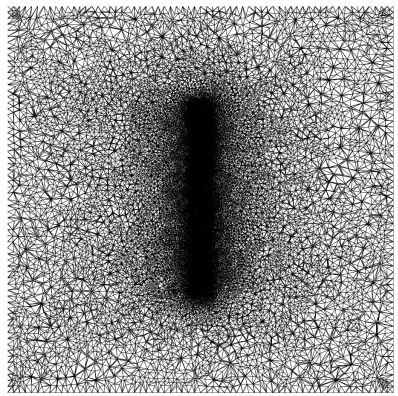
We have implemented the upwind algorithm in Rust with the "split at mut" trick. More details in [GHMD21].

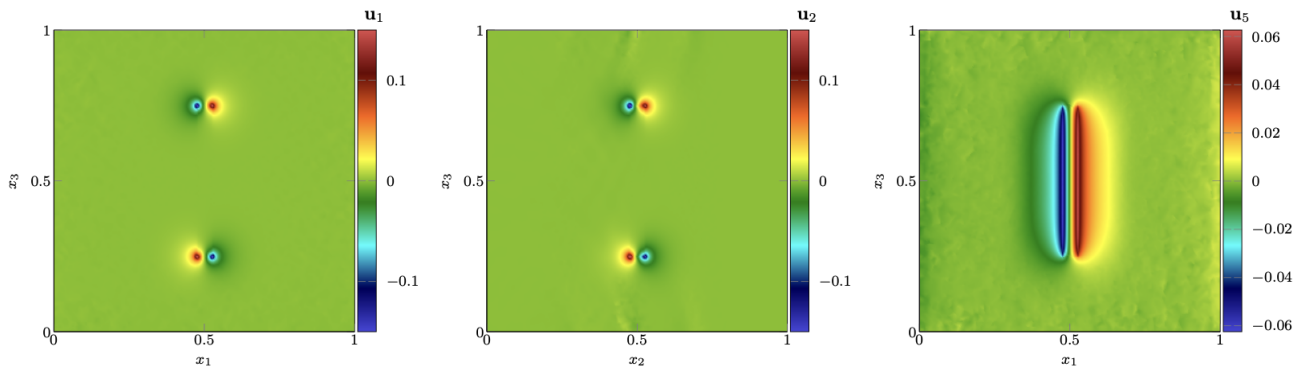
			Error e_r		CPU (s)	
Method	CFL β	Δt	$\nu = 2$	$\nu = 5$	1 thread	24 threads
RK3DG	0.37	0.00009	0.00070	0.01238	4,607.95	785.28
D3Q4P	0.37	0.00009	0.00103	0.01467	1,524.45	234.48
RK3DG	0.93	0.00023	0.00070	0.01238	2,189.76	384.79
D3Q4P	0.93	0.00023	0.00103	0.01467	613.44	90.84
RK3DG	1.85	0.00046	0.00070	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.

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