SciencesPo

Implementing the ForceAtlas 2 graph layout algorithm in Rust

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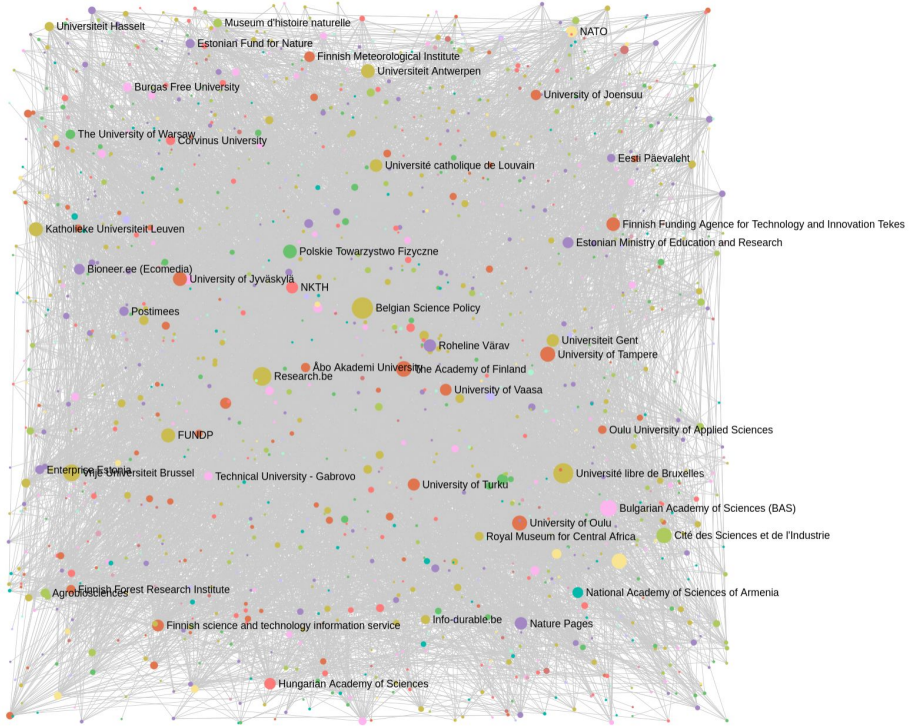
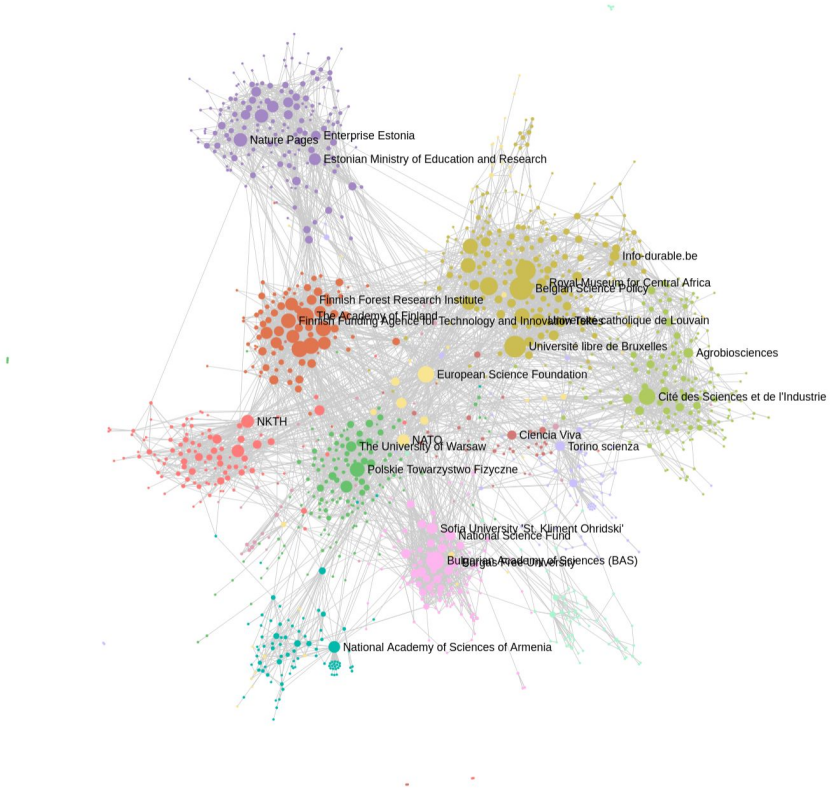
Graphs

- Nodes
- Edges (potentially weighted)
- How to project them into an arbitrary 2D space so we can:
    1. Do visual network analysis
    2. Perform a kind of dimensionality reduction

We want to go from this



To that


Nature Pages
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Sofia University 'St. Kliment Ohridski'
National Science Fund
Bulgarian Academy of Sciences (BAS)
National Academy of Sciences of Armenia

Graph layout algorithms

- Most popular graph layout algorithms (at least for Visual Network Analysis) are “Force-Directed”
- They are a physics simulation:
  - nodes repulse each others as bodies in space
  - linked nodes attract each other as if bound by overstretched springs
  - a gravity force pulls everything to the center

Graph layout algorithms (cont'd)

- Most known algorithm is Fruchterman-Reingold

Fruchterman, Thomas M. J.; Reingold, Edward M. (1991), "Graph Drawing by Force-Directed Placement", *Software: Practice and Experience*, **21** (11), Wiley: 1129–1164, doi:10.1002/spe.4380211102, S2CID 31468174.

- State-of-the-art algorithm is ForceAtlas2

Jacomy M, Venturini T, Heymann S, Bastian M (2014) ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software. PLoS ONE 9(6): e98679. https://doi.org/10.1371/journal.pone.0098679

ForceAtlas2 canonical implementations

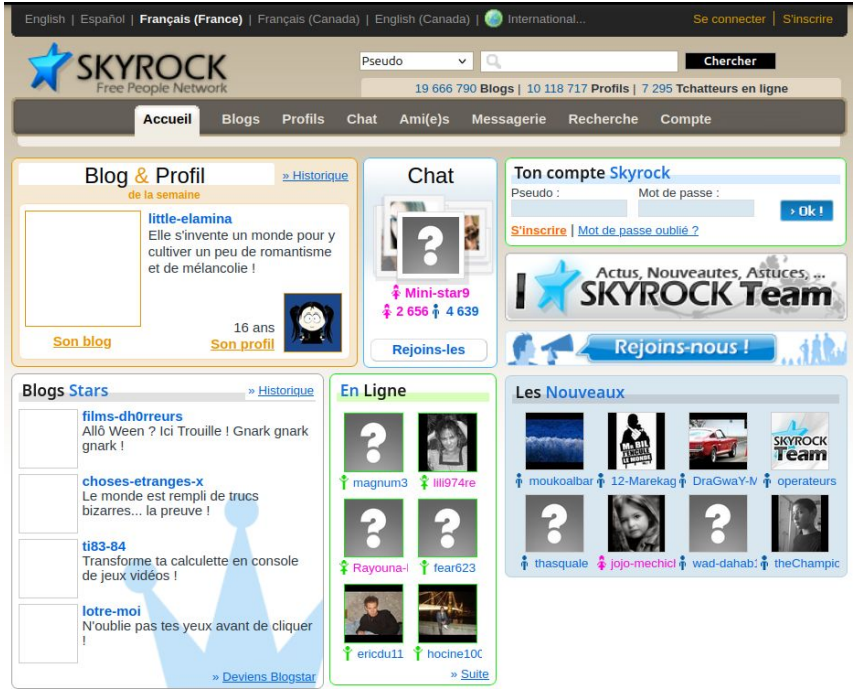
- In Java: Gephi (FA2 authors are actually behind Gephi) https://gephi.org/
- In JavaScript: graphology (mine) https://graphology.github.io/standard-library/layout-forceatlas2

They are too slow for some purposes

- JVM tweaking is pain
- JavaScript has structural issues (even if you can achieve very good single-threaded performance by relying on Typed Arrays and/or wasm):
    - floats everywhere
    - no efficient multithreading
    - Maps limited to ~24 bits addressing (lol)
    - etc.

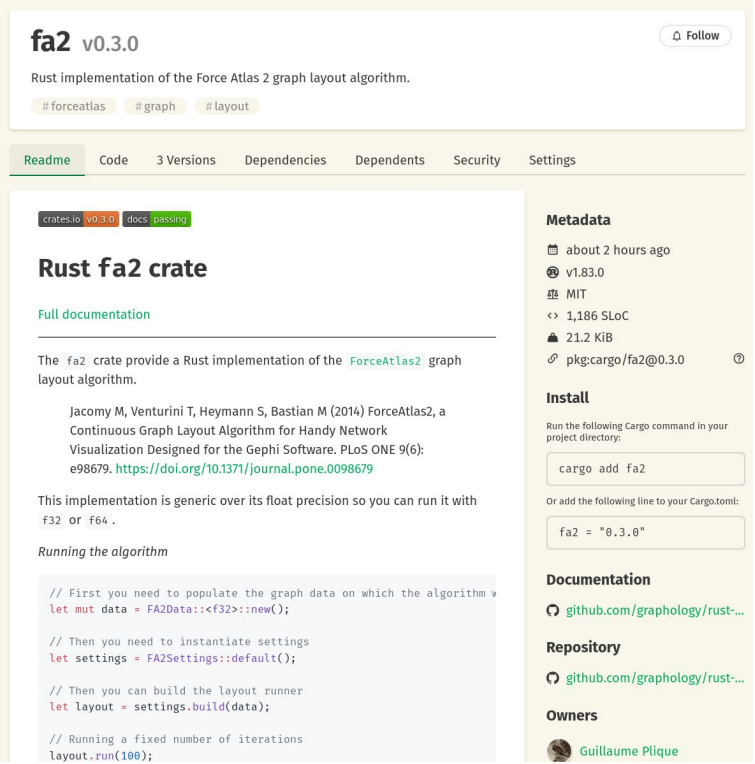
I have a big network

- the “French myspace”: skyblogs
- 12M nodes
- 400M edges



Let’s Rewrite it in Rust!

The fa2 crate



fa2 v0.3.0

Follow

Rust implementation of the Force Atlas 2 graph layout algorithm.

forceatlas # graph # layout

Readme | Code | 3 Versions | Dependencies | Dependents | Security | Settings

crates.io v0.3.0 docs passing

Rust fa2 crate

Full documentation

The `fa2` crate provide a Rust implementation of the `ForceAtlas2` graph layout algorithm.

> Jacomy M, Venturini T, Heymann S, Bastian M (2014) ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software. PLoS ONE 9(6): e98679. https://doi.org/10.1371/journal.pone.0098679

This implementation is generic over its float precision so you can run it with `f32` or `f64`.

Running the algorithm

```
// First you need to populate the graph data on which the algorithm w
let mut data = FA2Data::<f32>::new();

// Then you need to instantiate settings
let settings = FA2Settings::default();

// Then you can build the layout runner
let layout = settings.build(data);

// Running a fixed number of iterations
layout.run(100);
```

Metadata

about 2 hours ago
v1.83.0
MIT
1,186 SLoC
21.2 KiB
pkg:cargo/fa2@0.3.0

Install

Run the following Cargo command in your project directory:

```
cargo add fa2
```

Or add the following line to your Cargo.toml:

```
fa2 = "0.3.0"
```

Documentation

github.com/graphology/rust-...

Repository

github.com/graphology/rust-...

Owners

Guillaume Plique

Problem: generic over float precision

- Solved using the `num-traits` crate and the following shenanigans.

```rust
use std::iter::Sum;
use std::ops::{AddAssign, DivAssign, SubAssign};

use num_traits::{Float as NumFloat, FloatConst};

1 implementation
pub trait Float:
    NumFloat + FloatConst + SubAssign + AddAssign + DivAssign + Sum + Send + Sync
{
}
impl<T: NumFloat + FloatConst + SubAssign + AddAssign + DivAssign + Sum + Send + Sync> Float for T {}
```

Problem: parallel computing

- The algorithm is usually framed in steps: repulsion, attraction, gravity & force application (with swing, traction adjustments etc.)
- When running in parallel, the algorithm must be reframed to apply each step nodewise
- This means that repulsion now needs some CSR-adjacent structure to hold the sparse adjacency matrix
- All plumbing is done with *rayon*

```rust
/// A romantic name for a variant of CSR matrix.
#[derive(Debug)]
3 implementations
pub(crate) struct NeighborhoodIndex<F: Float> {
    node_offsets: Vec<usize>,
    edge_stubs: Vec<(usize, F)>,
}
```

Problem: Amdahl's law

- Pairwise repulsion is obviously quadratic
- People use the Barnes-Hut method, using an adaptive quadtree to scale repulsion to O(n log(n))
- Repulsion through Barnes-Hut **can** be parallelized
- But Barnes-Hut tree construction **cannot** (at least not easily)
- On my graph, using 64 CPUs: 1 iteration = 10s, tree construction = 7s

Problem: SoA vs. AoS, cache lines, SIMD etc.

- Struct of Arrays is usually better for cache alignment and was proven better to hold the graph's data for FA2 in my implementation
- The case of the Barnes-Hut tree is different and is a compromise between Struct of Arrays and Array of Structs.
- Explicit SIMD usage did not yield improvements. Some auto-vectorization by the compiler is already happening in some parts of the algorithm.
- Barnes-Hut repulsion is actually branching-bound

Niche optimization & memory layout

```rust
/// A struct holding the data necessary to represent a graph that will be
/// spatialized by the FA2 algorithm.
#[derive(Debug)]
3 implementations
pub struct FA2Data<F: Float> {
    pub(crate) xs: Vec<F>,
    pub(crate) ys: Vec<F>,
    pub(crate) ms: Vec<F>,
    pub(crate) delta_xs: Vec<F>,
    pub(crate) delta_ys: Vec<F>,
    pub(crate) old_delta_xs: Vec<F>,
    pub(crate) old_delta_ys: Vec<F>,
    pub(crate) convergences: Vec<F>,
    pub(crate) edges: Vec<(usize, usize, F)>,
}
```

```rust
#[derive(Debug, PartialEq)]
2 implementations
enum RegionKind<F: Float> {
    Empty,
    Leaf {
        node: usize,
    },
    Internal {
        first_child: usize,
        mass: F,
        mass_center_x: F,
        mass_center_y: F,
    },
}

#[derive(Debug, PartialEq)]
4 implementations
pub struct BarnesHutTree<F: Float> {
    kinds: Vec<RegionKind<F>>,
    center_xs: Vec<F>,
    center_ys: Vec<F>,
    sizes: Vec<F>,
    next_siblings: Vec<Option<NonZeroUsize>>,
}
```

Problem: animating the layout to debug it

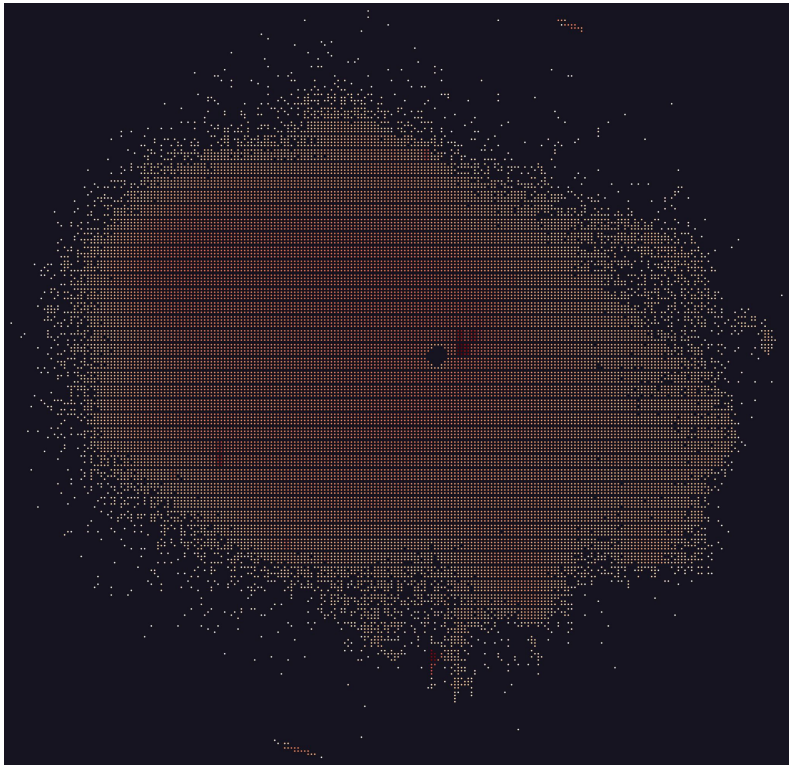
- Force-directed graph layout algorithms are **non-deterministic** and their results are dependent on nodes' starting positions
- They don't have trivial stopping conditions
- People usually rely on animating the layout to debug it and/or know when to stop it
- Demo

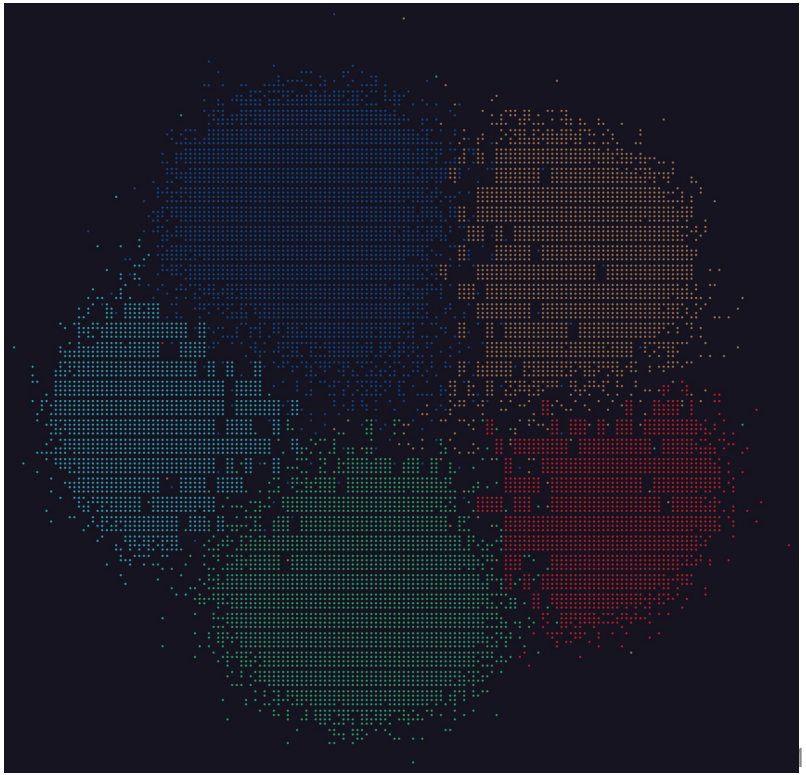
Animating the layout in the shell

- 12M nodes is a hassle to raster
- Doing so in a terminal using braille characters is actually fast enough
- We'll add a density gradient on top for better precision
- Using xan (in Rust) plotting capabilities and a bash loop (more)

```
ls dump/*.csv | sort | while read positions;
do
    xan plot x y -Q --hide-all -D or_rd $positions
done
```

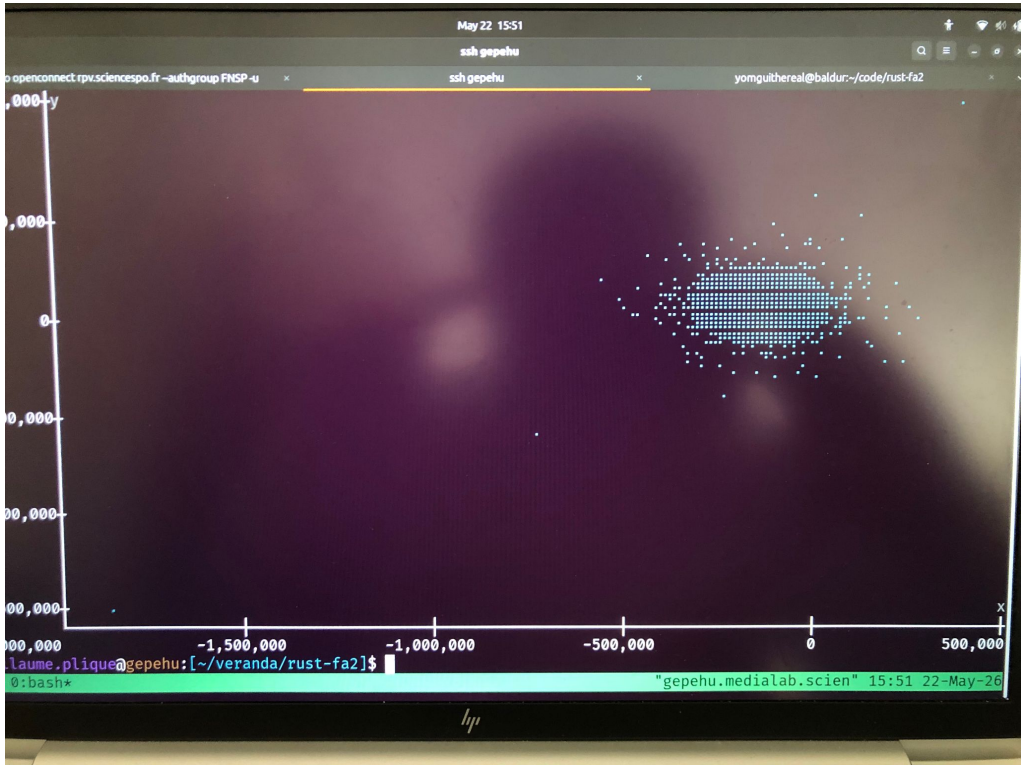
Rendering a graph in the terminal



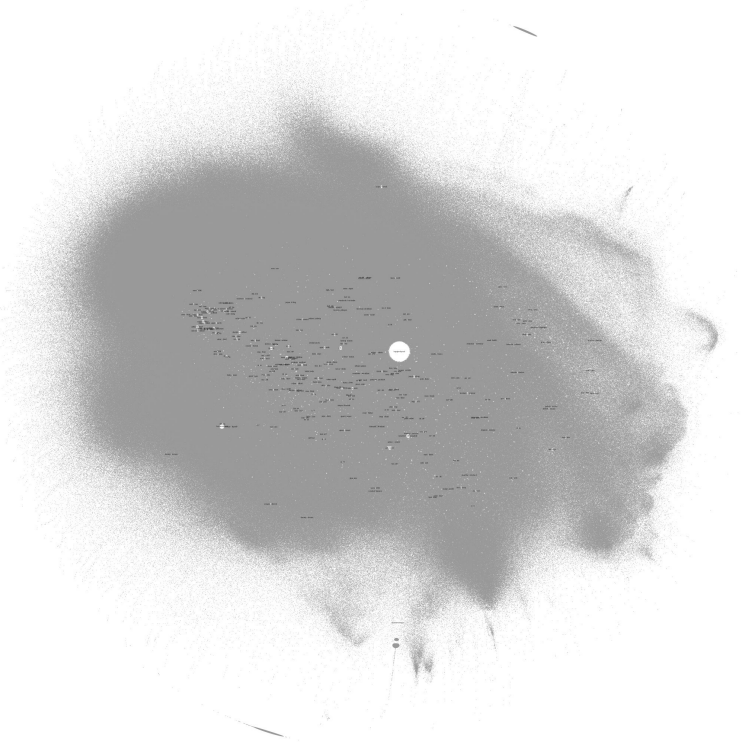


Animating the layout in the terminal

Debugging offshoots



My social network is now spatialized (albeit still ugly)!



The Future

- Parallel Barnes-Hut forest
- K-means repulsion
- N-dimensional layout (> 4 dims, which is novel)
- Bench wasm vs. JS low-level implementation

Rust is perfect to my eyes

- Very fine control over performance and memory usage
- Parallelization is so easy
- I don’t want to use C or C++
- Julia is 1-based

Thank you for listening!

Crate: https://crates.io/crates/fa2
Docs: https://docs.rs/fa2/latest/fa2/

Barnes-Hut artifacts art –>