Modelling Nuclear Reactors with Julia

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My objective

To see how well Julia fits my use cases

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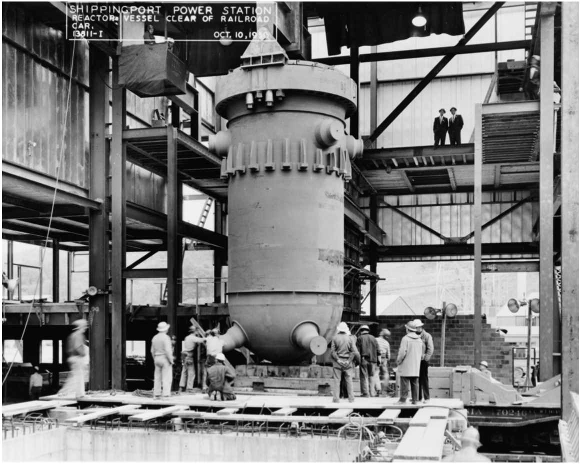
Benchmark problem: a nuclear reactor simulator (specifically method of charactersitics)

What a nuclear reactor looks like

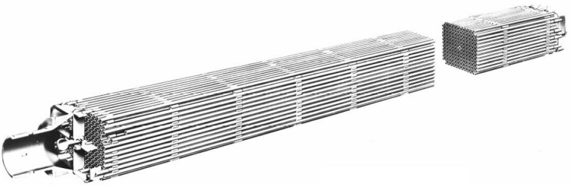
The heart of a typical nuclear powerplant is a pressure vessel where water is heated



Credit: US DOE

What a nuclear reactor looks like

Inside that vessel are about 200 fuel assemblies—bundles of rods containing uranium



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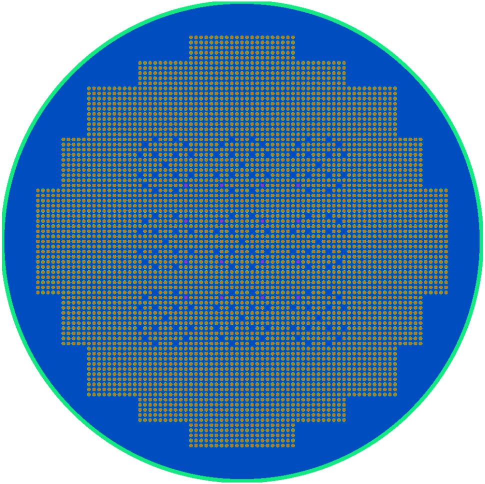
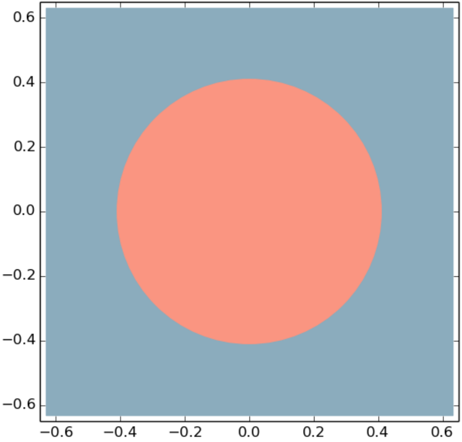
What a nuclear reactor looks like

Reactors have a lot of axial symmetry which usually allows us to model them in 2D



What my geometry looks like

For this project, I further simplified down the model to a single "pin cell" with reflective boundaries



The problem

Goal: neutron interaction rate

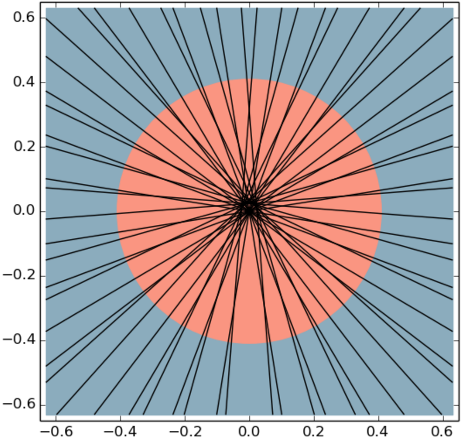
Complication: strong anisotropy

Diffusion can't solve this problem!

Solution: integrate over characterstic paths

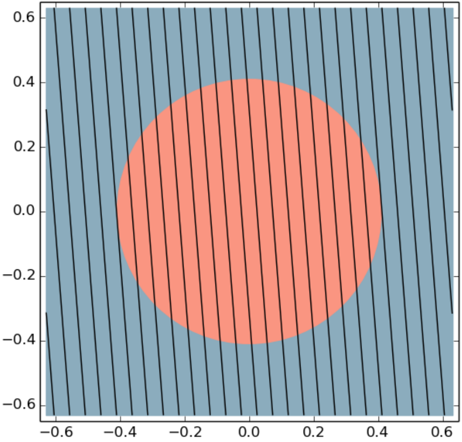
Neutron characteristics

Select a set of azimuthal angles (32 in this case)



Neutron characteristics

Repeat each azimuthal ray with a regular spacing (0.5 mm in this case)



The algorithm

Algorithm 2 Transport Sweep Algorithm

$\Phi_{i,g} \leftarrow 0 \quad \forall\, i, g \in \{I, G\}$ # Initialize FSR scalar fluxes to zero
while $\Phi_{i,g}\ \forall\, i$ not converged **do**
  for all $m \in M$ **do** # Loop over azimuthal angles
    for all $k \in K(m)$ **do** # Loop over tracks
      for all $s \in S(k)$ **do** # Loop over segments
        for all $g \in G$ **do** # Loop over energy groups
          for all $p \in P$ **do** # Loop over polar angles
            $i \leftarrow I(s)$ # Get FSR for this segment
            $\Delta\Psi_{k,i,g,p} \leftarrow \left(\Psi_{k,g,p} - \frac{Q_{i,g}}{\Sigma^T_{i,g}}\right)\left(1 - e^{-\tau_{k,i,g,p}}\right)$ # Compute angular flux change along segment
            $\Phi_{i,g} \leftarrow \Phi_{i,g} + \frac{4\pi}{A_i}\omega_m\omega_p\omega_k \sin\theta_p \Delta\Psi_{k,i,g,p}$ # Increment FSR scalar flux
            $\Psi_{k,g,p} \leftarrow \Psi_{k,g,p} - \Delta\Psi_{k,g,p}$ # Update track outgoing flux
          end for
        end for
      end for
    end for

Credit: Will Boyd

The codes: a three-way face-off

C++

Well developed parallel research code with many features

Python

My own homework code, slow

Julia

Similar to the Python code, but fast

	C++	Python	Julia
Baseline	2.8 s (1×)	117.0 s (41×)	14.4 s (5×)
Serial opt	-	-	-
2 Procs	-	-	-

Direct translation Python → Julia gives 8× speed up. Awesome!

	C++	Python	Julia
Baseline	2.8 s (1×)	117.0 s (41×)	14.4 s (5×)
Serial opt	-	-	9.4 s (3×)
2 Procs	-	-	-

Direct translation Python → Julia gives 8× speed up. Awesome!

A little serial optimization gets us close the C++ reference

	C++	Python	Julia
Baseline	2.8 s (1×)	117.0 s (41×)	14.4 s (5×)
Serial opt	-	-	9.4 s (3×)
2 Procs	-	-	46.1 s (16×)

Direct translation Python → Julia gives 8× speed up. Awesome!

A little serial optimization gets us close the C++ reference

Sadly my parallel efforts didn't turn out