Gravitational collapse in 2+1 dimensional anti-de Sitter space

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Motivation: To investigate the nature of gravitational collapse in 2+1D AdS spacetime, and see how far the already remarkable likeness between BTZ and higher dimensional black holes extends. In particular:

- Can we form BTZ black holes using more realistic forms of matter? (in this case a massless scalar field)

  Earlier studies of collapse considered pressureless dust (Mann & Ross, 1993), thin rings of matter (Peleg & Steif, 1995), null radiation (Husain, 1994) and colliding particles (Matschull, 1999). Husain and Olivier are currently also studying the massless scalar field.

- If we can form black holes, does the system exhibit critical behaviour at the threshold of formation?

  In other words is the critical solution universal, and do the masses of resulting black holes in the supercritical regime scale as $M \propto (p - p^{*})^{\gamma}$?

Theory: Einstein gravity with a negative cosmological constant $\Lambda = -1/\ell^2$, and a minimally-coupled massless scalar field ϕ:

$$\mathcal{L} = \int d^3x \sqrt{-g} \left(R - 2\Lambda - \frac{\kappa}{2} \phi_{,a} \phi_{,b} g^{ab} \right)$$

Numerics:

- We choose a unit light-speed gauge and a compactified radial coordinate r:

$$ds^2 = \frac{e^{2A}}{cos(r/\ell)^2} \left(dr^2 - dt^2 \right) + \ell^2 \tan(r/\ell)^2 e^{2B} d\theta^2$$

  Reason: we need to place boundary conditions at time-like infinity for a well-posed problem, as light signals travel to and from infinity in finite local time $\Delta t = \pi \ell / 2$.

- We place Dirichlet boundary conditions on ϕ at infinity. Apparently the equations of motion do not allow us to throw any outgoing radiation off the edge of the universe.

- To study the interior structure of the black holes we implement singularity excision – when variables start to diverge numerically we excise the grid to the causal future of the problem points.

- We solve the constraint equations at $t = 0$ to obtain the initial conditions for a given ϕ. Then using the evolution equations we evolve the system forwards in time with a 2-step Crank-Nicholson scheme (implemented for the most part in RNPL).