Evolving Black Holes with FMR

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AMR Overview

- Many problems in physics solvable via finite different approx's to PDEs of interest. Divide the computational domain into a mesh, and in the limit where the mesh spacing goes to zero we expect to recover the exact solutions to the PDEs.

- For a given degree of numerical accuracy, it is often the case that the minimum required mesh spacing may not be known a priori, so it may be desirable for the finite difference algorithm to adaptively refine the mesh in various parts of the domain.

- The development of "adaptive mesh refinement" (AMR) computer codes poses difficulties for many researchers because the codes tend to be quite complicated. This complexity is intensified when one considers that, to take advantage of modern "high-performance" computing machinery, a simulation code should be able to run efficiently in a distributed computing environment.

- Thus it is desirable to have a publicly-available system in which parallelism and AMR are provided "automatically".

- Even without a truly ‘adaptive’ mesh code, it may still be desirable to have a fixed mesh refinement (FMR) code, with which to concentrate computational resources where they are most needed (and, e.g. to allow one to push the outer boundaries further out.)

Other AMR/FMR Work To Date

- Choptuik; Steve Liebling
- Grand Challenge/GrACE
- Lee Wild
- Gerd Lanfermann
- Centrella's Group
- Diener (Khohklov)

Recent Work among AEI/KDI

- Codes:
  - Erik Schnetter's Carpet (FMR package) works with Cactus.
  - Manish Parashar's GrACE (AMR package)...does not yet work with Cactus.
- Earlier this summer:
  - Revamp of Einstein thorn allowed for timelevels
  - Revamp of CartGrid3D thorn allowed Carpet to work with our thorns
  - MoL does not yet work with FMR/AMR. Awaiting change to Flesh
  - Still needed timelevels in ADM_BSSN, but Ian & I added those..

Our Method

- The MR Method
  - FMR; Can do “progressive” MR
  - Vertex Centered
  - Interpolation: Cubic in space (2 ghost zones), Parabolic in time (3 time levels)
  - Initial Data Scheme: http://www.aei.mpg.de/ shawley/CarpetWork/initdata/threelev_initdata.ps
- The Code itself
  - Carpet is a Cactus Driver
  - “Black box”
  - Performance?
  - Thorns Must... (see next slide)
- The GR Stuff
  - BSSN
  - 1+log slicing

- Gamma-freezing shift

Aside: Preparing Your Thorns for the Advent of FMR/AMR in Cactus

In general: **Make sure your thorn is 'suitably ignorant'** about what's happening in time & space.

For anything 'clever', don't do it in the C or Fortran code!
Instead, use Cactus infrastructure:

- Use Cactus timelevels
- Use CCTK_DELTA_SPACE(?) macros for Δx, Δy, Δz
- Do all your Sync's in the Scheduler
- Use "grid variables" for all your data, i.e. don't store static data (e.g. temporary arrays) which you think is data for the whole grid
- Use thorn Time if you're going to be doing funny things to the time (e.g. May-White codes)

Tests

- Wave Equation
  - Periodic waves: Convergence movie: http://www.aei-potsdam.mpg.de/ shawley/CarpetWork/CarpetWork.html
  - 1/r data: Convergence movie: http://www.aei-potsdam.mpg.de/ shawley/CarpetWork/CarpetWork.html
- Schwarzschild: Lapse movie: http://www.aei-potsdam.mpg.de/ shawley/CarpetWork/alp.mpg
- FMR vs unigrid
  - Sometimes FMR crashes, depending on grid
  - FMR Needs puncture between grid points; Unigrid doesn't care
  - Need to figure out why

Future Work

- Teukolsky waves
- Misner BBH
- “Putting boundaries far out”: Repeat a unigrid run, but with a coarser grid around it, extending outer boundary.
- Need to write MR elliptic solver to handle more general initial data