Cactus support for Astrophysics

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Abstract

This talk outlines existing infrastructure for relativistic simulation in Cactus, listing a number of useful commonly used thorns

- the `CactusEinstein` arrangement
- Infrastructure thorns (Mol, Carpet)
- Utility thorns (elliptic solvers, etc.)
- Miscellaneous thorns

Einstein's equations

$$R_{ab} - \frac{1}{2} R g_{ab} = 8\pi T_{ab}$$

Have a geometric part and a physical part.

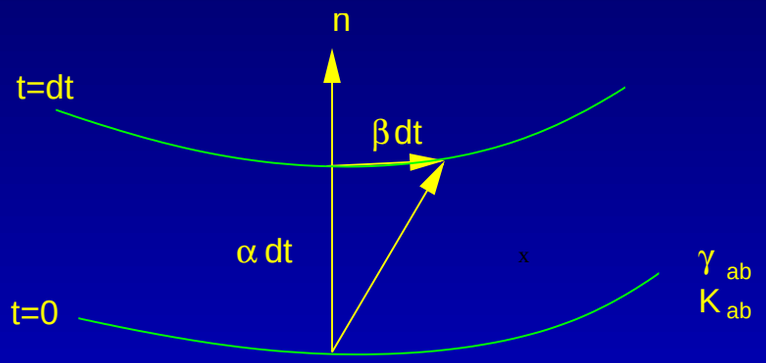
For numerical purposes, commonly expressed in terms of "ADM" variables:

γ_{ab} 3-metric on a spacelike slice

K_{ab} extrinsic curvature of a spacelike slice

α, β gauge variables, specify the slicing

T_{ab} the matter stress-energy tensor



The $3+1$ paradigm and ADM variables form a common denominator among various numerical relativity tools.

CactusEinstein/

A set of common thorns, data structures, and utilities for general relativity.

ADMBase: set up variables in the ADM formulation of Einstein equations

- each evolution variable is a cactus grid function
  `gxx, gxy, ..., kxx, kxy, ...`
- tacit assumption of 3d cartesian components

ADM: an implementation of the ADM formulation

- evolve Einstein equations using the ADM formulation
- matter terms can be included by externally computed $T_{\mu\nu}$

ADMConstraints, ADMMacros, ADMAnalysis: various computations using the variables defined in ADMBase

Maximal: implements the “maximal slicing” condition

SpaceMask: utilities for setting up a mask on the grid

...CactusEinstein

AHFinder: find apparent horizons using a minimisation or flow algorithm

Extract: Zerrilli extraction of gravitational waves

PsiKadelia: analysis thorn for Newman-Penrose quantitities, etc.

IDAnalyticBH, IDBrillData, IDAxiBrillBH: various initial data sets

Other useful thorns

MoL, Carpet: finite differencing, set up mesh refined grids

LocalInterp, AEILocalInterp: interpolation on grids, can be used with Carpet

Elliptic solvers

CactusElliptic, EllPETSc, EllSOR: solve linear elliptic equations

TATelliptic, TATJacobi, TATPETSc, TATCG, TATMG: alternate interface for general elliptic problems

Kranc

High level (mathematica) interface for turning complicated equations into evolution thorns using MoL.

AEIThorns, AEIDevelopment

ADM_BSSN: an implementation of BSSN formulation of Einstein equations

- BSSN variables are converted to ADM variables in order to make use of CactusEinstein infrastructure

BAM_Elliptic: a multigrid solver for PUGH

Exact: implements various exact solutions for testing or as initial data

AHFinderDirect: Thornburg's fast horizon finder

EHFinder: Diener's event horizon finder

IDPuncture: puncture initial data using the TAT elliptic solvers

Noise: initial data for the robust stability test

Summary

Many useful tools exist for doing relativistic astrophysics.

The CactusEinstein infrastructure forms a common denominator through which thorns can communicate.

There is no such thing as a cactus “user”:

- numerical *black holes* are not *black-box* – you need to invest time in learning these tools, and modifying them to suit your purpose
- time invested in developing common infrastructure is paid back through larger collection of available tools

Cactus is a community code – increasing the size of the developer community increase the usefulness to everybody.