USING *openGR* FOR NUMERICAL RELATIVITY

P. WALTER*, J. ALLEN, R. A. MATZNER

Physics Department, University of Texas at Austin,
Austin, TX 78722, USA
**E-mail: pwalter@physics.utexas.edu*

M. ANDERSON

Math Department, Brigham Young University,
Provo, UT 84602, USA

A. NEROZZI

Centro Multidisciplinar de Astrofiísica - CENTRA, Dept. de Física, Instituto Superior Técnico,
Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

U. SPERHAKE

California Institute of Technology,
Pasadena, CA 91109, USA

This article focuses on the scaling performance of the evolution portion of *openGR*, a code for Numerical Relativity. As expected, *openGR* scales considerably better for unigrid domains than it does for domains using Fixed Mesh Refinement (FMR).

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1. Introduction

We discuss how *openGR*, a *SAMRAI*-based finite difference code for General Relativity, scales by investigating both strong and weak scaling.[1–4] A relation between the wall clock time t of a simulation and the number of processors n can be written as $t = an^b$, where b represents the slope on a log-log graph. When comparing two simulations gives

$$\frac{t_2}{t_1} = \left(\frac{n_2}{n_1}\right)^b,$$

providing the ratio of wall clock times for varying number of processors.

Strong scaling consists of measuring performance by running the same simulation on a varying number of processors. The ideal case corresponds to a slope b of -1 on a log-log plot, giving $t \sim \frac{1}{n}$. Eventually, a limit will be reached where the communication overhead per processor (ghostzone cells) will become comparable to the size of the job per processor (non-ghostzone cells), corresponding to a leveling off of the wall clock time.

Weak scaling consists of varying the overall size of the simulation such that each processor is running the same size of job. Deviations away from the ideal case of zero slope place a limit on the size of the job that can be run.

Since the majority of wall clock time of a simulation is spent evolving a given spacetime, we present scaling results of the wall clock time spent in PVODE (the

evolution portion of *openGR*). All of these examples were run on the TACC computer *Ranger*.

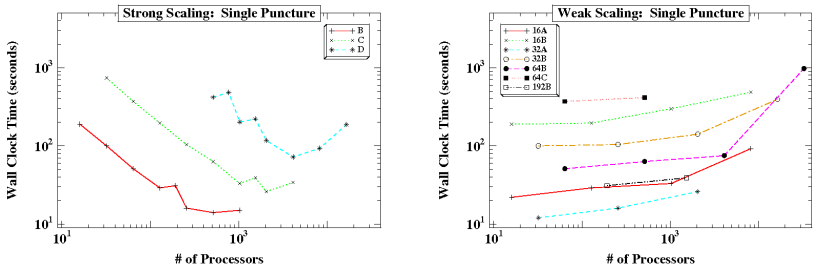
2. Single Puncture Scaling on Unigrid Domain

Figure 1a shows the strong scaling of simulations of a single puncture (a single black hole) at rest in a unigrid domain. Each simulation was carried out to a time $t = 4.5M$, where M is the mass of the puncture. Details are shown in Table 1.

Figure 1b shows the weak scaling of the simulations of a single puncture at rest. The average slope for all the curves combined is .23. For simulations of $1,536$ processors or less, the slope is .09. We conclude that unigrid simulations run with good scaling efficiency at least up to $4,096$ processors.

Table 1. Simulations of a single puncture at rest without mesh refinment (unigrid) evolved to $t = 4.5M$. The physical domain is $-100M$ to $100M$ in each spatial direction, where M is the mass of the puncture. Note that each subsequent job is a factor of two finer in resolution, and thus a factor of eight larger in total number of points.

Job	A	B	C	D	E
Resolution	$5M$	$2.5M$	$1.25M$	$\frac{5M}{8} = .625M$	$\frac{5M}{16} = .3125M$
# of Points	40^3	80^3	160^3	320^3	640^3
Strong Scaling:	Proc. Range		$16 - 256$	$32 - 1024$	$512 - 4096$
	Slope		$-.95$	$-.89$	$-.85$
Weak Scaling:	Average	Slope	.23		



(a) (b)

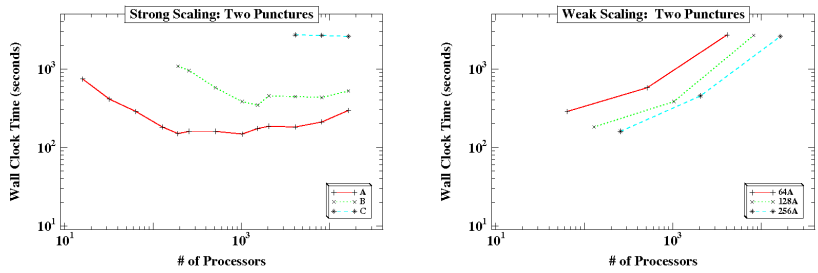
Fig. 1. Strong and weak scaling runs for single puncture evolutions in a unigrid domain (see Table 1). (a) Strong scaling for runs of jobs B, C, and D, where each curve represents the same job being carried out on varying numbers of processors. (b) Weak scaling simulations where each subsequent data point on curve represents a job containing eight times the number of points carried out on eight times the number of processors. The labels for the curves given in the key define the number of processors and the job being run for the leftmost data point on the curve. For instance, on the curve 64B, the leftmost data point is 64 processors running job B. The next point on the curve is 512 processors running job C. The next two points on the curve are 4,096 processors running job D and 32,768 processors running job E, respectfully.

3. Scaling of Two Punctures with FMR

Figure 2a shows the strong scaling of simulations of two punctures, initially at rest, which then infall. All simulations were carried out to $t = .2M$. Here, M is the sum of the masses of both punctures. Details are given in Table 2. Results show consistent behavior up to $\sim 1.5k$ processors, reflecting the lack of ideal but acceptable scaling. For those jobs, runs greater than $4k$ processors clearly have no scaling advantage. Figure 2b shows weak scaling where the average slope of all three curves combined is .62. We are investigating the reason for the poorer scaling in the FMR case.

Table 2. Simulations of two equal-mass punctures initally at rest with nine levels of mesh refinement, the two finest of which are moving boxes that track the punctures. M is the total mass of the two punctures. Note that the three jobs (A,B,C) are not quite factors of eight larger than each other in regards to the total number of points. Each subsequent job does, however, have twice the resolution everywhere throughout the domain. Each level is refined by a factor of two. Simulations evolved to $t = .2M$.

Physical Domain	$[-100M, 100M]$ in x,y,z		
Puncture Locations	$(-\frac{3M}{2}$,0,0) and $(\frac{3M}{2}$,0,0)		
Job	A	B	C
Resolution of Coarsest Grid	$4M$	$2M$	M
Resolution of Finest Grid	$\frac{M}{64}$	$\frac{M}{128}$	$\frac{M}{256}$
Strong Scaling: Proc. Range	$16 - 192$	$192 - 1536$	$4096 - 16384$
Slope	-.63	-.5	-.03
Weak Scaling: Avg. Slope	.62		



(a) (b)

Fig. 2. Strong and weak scaling runs for evolutions of two punctures with 9 levels of fixed mesh refinement. The two finest levels are moving boxes that track and stay centered on each puncture (see Table 2). (a) Strong scaling for runs A, B and C, where points on a given curve represent the same job for a varying number of processors. (b) Weak scaling simulations where each subsequent data point on curve represents a job containing roughly eight times the number of points carried out on eight times the number of processors. The labels for the curves given in the key define the number of processors and the job being run for the leftmost data point on the curve. For instance, on the curve 256A, the leftmost data point is 256 processors running job A. The next point on the curve is 2048 processors running job B, followed by 16,384 processors running job C.

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