Thesis Review

Faculty of Mathematics and Physics
Charles University in Prague

❑ Supervisor's Review ☑ Referee's Review **
❑ BSc. Thesis ☑ MSc. Thesis

Author:	Anton Khirnov
Thesis title:	Numerical evolution of black-hole spacetimes
Study program:	Physics
Submitted:	2013

Supervisor/Referee:	Dr. Carlos Palenzuela
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Thesis quality (technical field and expertise):
❑ excellent X very good ❑ standard ❑ substandard ❑ nonconforming

Objective accuracy (error appearance):
X nearly perfect ❑ standard ❑ frequent, but minor ❑ serious errors

Thesis results:
❑ original X both original and compiled ❑ productive compilation ❑ copied

Thesis size:
❑ large X standard ❑ just acceptable ❑ insufficient

Thesis quality (style and grammar, and graphic arrangement):
X excellent ❑ very good ❑ standard ❑ substandard ❑ nonconforming

Misprints:
X negligible ❑ acceptable number ❑ very frequent

Overall thesis quality:
❑ excellent X very good ❑ standard ❑ substandard ❑ nonconforming

Supervisor's/Referee's Comments:

The author performs a methodical numerical study of the BSSN system, probably the most widely-used formulation in Numerical Relativity to study sources of gravitational radiation. Several issues are tested, which involve not only a fair knowledge of General Relativity but also of different concepts arising in Partial Differential Equations: gauge conditions, well posedness and hyperbolicity, boundary conditions and numerical methods for hyperbolic systems. Additionally, the author also had to learn how to use a community code called "Einstein Toolkit", which he used for this study. He implemented in this code a routine with the Lorentz-boosted maximal trumpet initial data, as well as some quantities for further analysis.

The extensive numerical simulations within this spacetime are novel and allow to reach some conclusions which agree with those found already in the literature; the trumpet solution is an attractor with either maximal or 1+log slicing condition. The latter seems to behave better in numerical simulations, leading to more accurate solutions, while the damping term in the coordinate condition (Gamma driver) leads to a deformation of the coordinates.

The author seems to have a reasonably good insight on the different advanced topics and the extense literature. Although the main idea of the thesis is modest, it is novel and the analysis has been performed careful and methodically. The thesis is well written with only few small mistakes. If the author gives satisfactory replies to the following questions then I would recommend to give him the excellent qualification.

Questions raised (and to be answered by the author during the Thesis Defence):

1) page 6, after eq. (1.7) : "normal observers do not stay on constant spatial coordinates as time t progresses". Although this is correct, the logic is the other way around (i.e., the congruence of time lines do not stay constant along the normal to the hypersurfaces) since the synchronization is performed before the time lines are chosen.
2) page 8 : Bianchi identities are mentioned but neither defined nor referenced.
3) page 9, second paragraph: "With a specific choice of the slicing condition they can be made strongly hyperbolic, but only if the momentum constrains are identically satisfied[17]". What does the author exactly mean? How is this condition enforced?
4) page 9, last paragraph before section 1.3: it is claimed that conformal decomposition is an essential part of a stable evolution system. This can not be true, since there are many formulations (i.e., like the Generalized Harmonic) which can evolve successfully binary black holes. Actually, the first inspiral-merger-ringdown was performed by using one of these formulations.
Then, why the conformal decomposition is necessary for the evolution of punctures with BSSN? And what are the strongest advantages of the GH formulations?
5) page 16, first paragraph: it is mentioned that the initial data of binary black hole will contain some spurios junk radiation. Where is it coming from?
6) page 20: although it is discussed later, this is the place to mention that the correspondence between strong hyperbolicity and well-posedness has only been proved for systems in the linearized regime.
7) page 49, caption of figure 3.8 : It is written "Scaled for 4th order convergence", which is not correct for this plot.
8) page 50, end of the 5th paragraph: the author states that the solution does not converge to the desired order because the radiative boundary conditions use lower order discretizations. At later times, will the solution in all the domain be contaminated by this effect? What will be the convergence rate of the solution at this late times?
9) page 61: why did the author use a CFL=1/8, a value which is much lower than the stability limit?

10) page 90: section 4.3 studies the propagation of waves and the velocity of the different modes. From these simulations, is there any preferred choice for the gauge parameters, such that the solution satisfy some desirable properties (i.e.,like stability and/or accuracy)?

Supervisor's/Reviewer's recommendation on Thesis rating:

X excellent ❑ very good ❑ standard ❑ reject

Done in Toronto, Canada
Date August 25, 2013

Name Carlos Palenzuela

Signature .....